Application Note AN-2095

Controlling the S7500 CW Tunable Laser

1 Introduction

This document explains the general principles of operation of Finisar's S7500 tunable laser. It provides a high-level description of the circuitry needed to control the S7500, as well as the control algorithms running on that circuitry.

2 How to use this Application Note

The audience for this application note is hardware and firmware engineers who want to design circuitry and the associated firmware for controlling the Finisar S7500 CW tunable laser.

3 General Principles of Operation of the S7500 Laser

3.1 Modulated Grating Y-Branch Laser

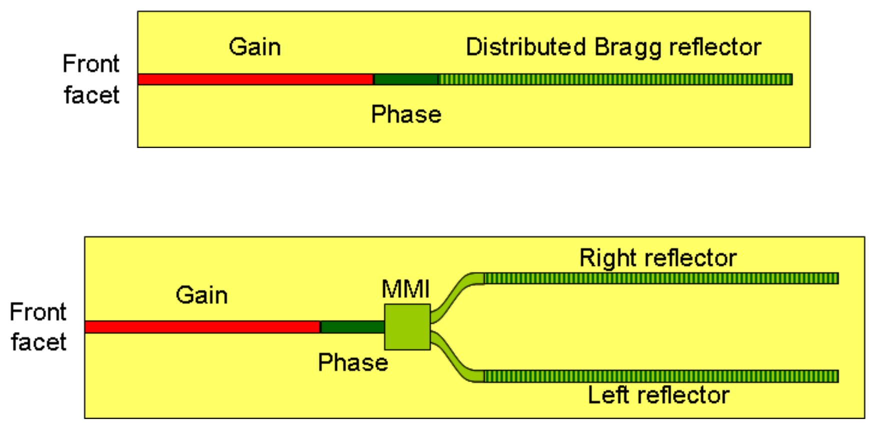


Figure 1 Schematic top view of a conventional distributed Bragg reflector laser and Finisar's modulated grating Y-branch (MG-Y) laser

Finisar's patented tunable laser, the Modulated Grating Y-branch (MG-Y) laser, is based on a conventional distributed Bragg reflector (DBR) laser (Figure 1). The tuning range of a DBR laser is however limited to ~1 THz (~8 nm), which means a single DBR laser can not cover the full C- or L-band. In order to extend the tuning range, the single grating reflector of the DBR laser is replaced by a combination of two modulated grating (MG) reflectors.

The operation of the MG-Y laser is based on the Vernier effect. The two modulated grating reflectors have a comb-shaped reflectivity spectrum, as is illustrated in Figure 2. The combs have slightly different peak separations, such that only one pair of peaks overlap at any time. Both reflections are combined using a multi-mode interference (MMI) coupler (Figure 1).

The aggregate reflection seen from the input port of the MMI coupler is plotted in the lower half of Figure 2. A large reflection only occurs at the frequency where a reflectivity peak from the left reflector is aligned with a reflectivity peak from the right reflector. The laser will thus emit light at the frequency of the longitudinal cavity mode that is closest to the peak of the aggregate reflection. By tuning one of the reflectors by an amount equal to the difference in peak separation, an adjacent pair of peaks can be aligned, i.e. a large tuning of the emission frequency (wavelength) is obtained for a relatively small tuning of a single reflector.

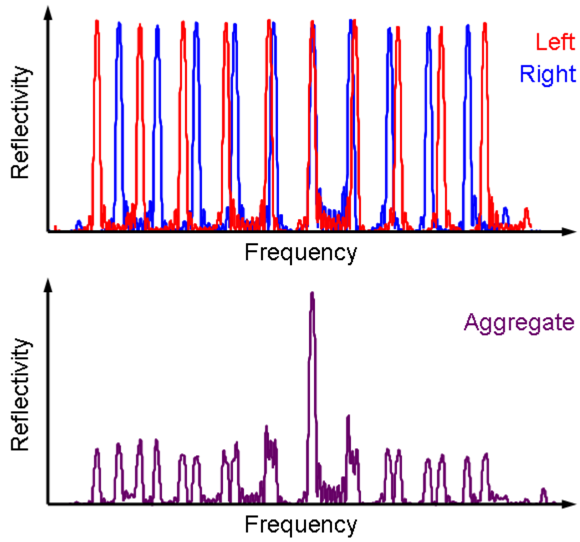


Figure 2 Reflectivity spectra of the left and right modulated grating reflector (top) and the aggregate reflectivity spectrum as seen from the input of the MMI splitter (bottom).

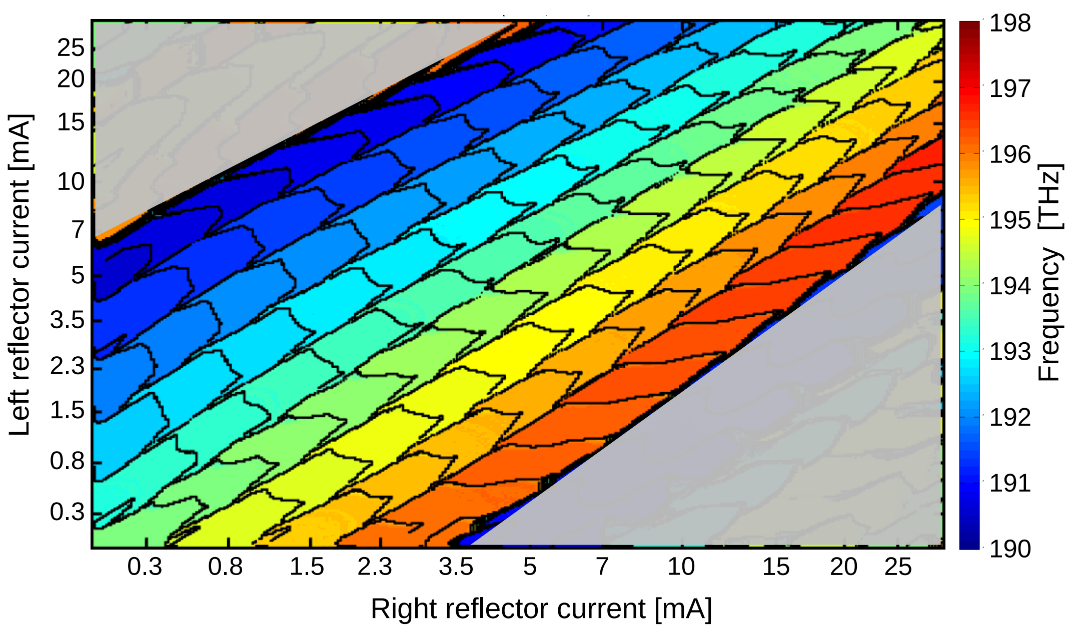


Figure 3 Emission frequency of an MG-Y laser plotted as a function of the left and right reflector currents. A discontinuous frequency change occurs at the boundaries indicated by the black contours.

Figure 3 shows a map of the emission frequency as a function of the left and right reflector currents. Each of the diagonal bands in the figure corresponds to a particular pair of reflectivity peaks from either reflector being aligned. When a different pair of reflectivity peaks is aligned, e.g. by changing just one of the reflector currents, a relatively large frequency change occurs (approximately 0.7 THz).

As is apparent from the frequency map, each of the diagonal bands is in turn subdivided into many similarly shaped regions. Within such a region the main peak in the laser emission spectrum is associated with one particular cavity mode. Picking an operation point centrally within the region will result in single mode laser operation with high side-mode suppression ratio (SMSR). The SMSR will be >40 dB in most of the region, and will only drop close to the boundaries.

If the laser is tuned along the center line of a particular band in Figure 3, both reflectors are tuned simultaneously, keeping a particular pair of reflectivity peaks aligned. At the boundary between two adjacent mode regions, the laser will jump from one cavity mode to the adjacent cavity mode (the cavity mode spacing is approximately 50 GHz). Within each of the regions, the frequency changes continuously.

In order to achieve full frequency coverage, a third dimension of tuning needs to be added: phase. By injecting current into the phase section (cf. Figure 1), the roundtrip phase of the cavity is changed. How this affects the mode map of Figure 3 is illustrated in Figure 4.

As the phase current is increased, all the mode regions in the map of Figure 3 will shift outward (towards higher reflector currents), with the midpoint of each region moving along the center line of the corresponding band. At the same time, the emission frequency for that midpoint will increase continuously. The original mode pattern is repeated when the phase current is increased so much that a phase shift of 2π (or 4π, …) is obtained. In 3 dimensions the mode regions from Figure 3 thus turn into mode tubes.

When the tuning currents (left reflector, right reflector, and phase) are adjusted such that the operation point tracks the center of a single mode tube, the laser is tuned continuously while keeping the same distance to the mode boundaries and therefore maintaining a high SMSR (Figure 5). By stitching together the tuning ranges covered by each of the tubes, full coverage over the entire C-band is obtained.

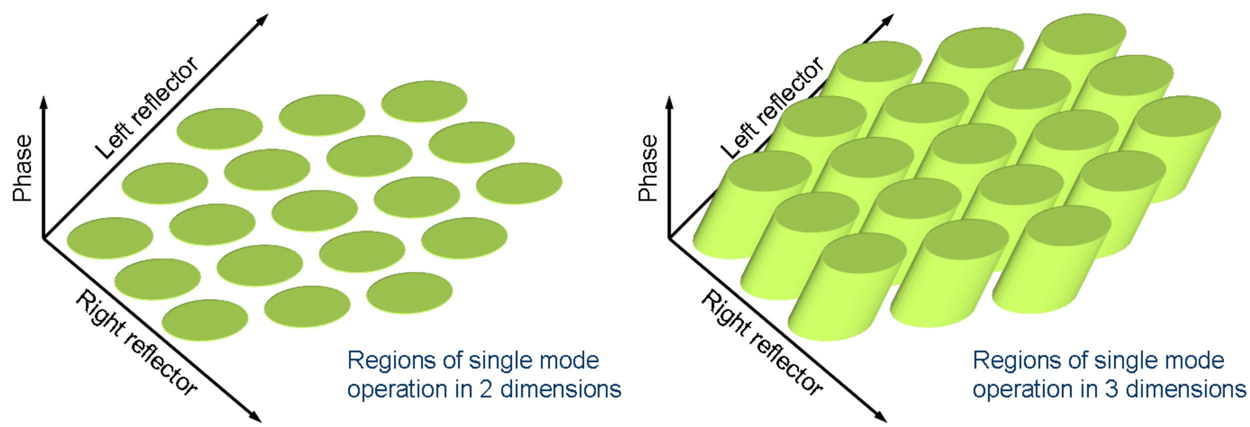


Figure 4 Mode maps in 2 and 3 dimensions.

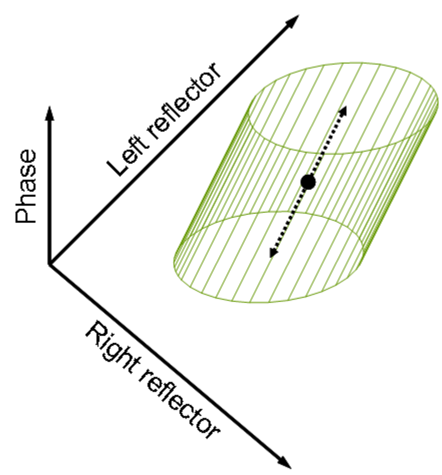


Figure 5 Continuous tuning along a single mode tube.

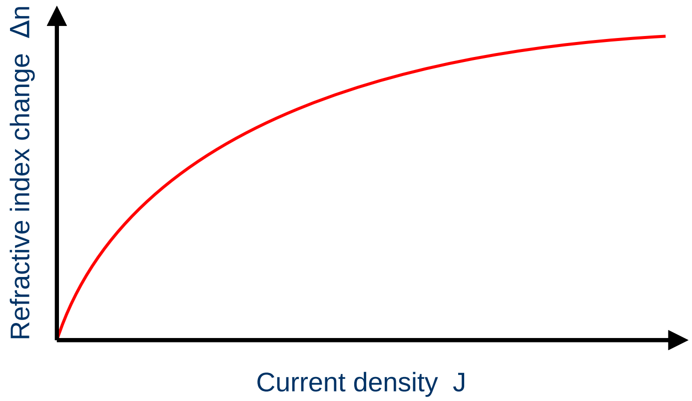


Figure 6 Sub-linear relation between the current density J injected in a particular tuning section (phase, left reflector or right reflector) and the change in the refractive index n of the waveguide in that section, which is proportional to the change in emission frequency.

By characterizing the centerlines of the different single mode tubes, the beginning-of-life (BOL) operation points for the ITU channel frequencies can be located. At the same time, these centerlines provide a path for fine-tuning of the emission frequency around the nominal operation point, which can be used to stabilize the frequency in a feedback loop (cf. §5).

Note that the pictures in Figure 4 and Figure 5 are somewhat simplified. The relationship between frequency and current is non-linear, as can be seen from the horizontal and vertical scales in Figure 3. This means that the single mode tubes above will be curved when they are plotted on linear current scales.

3.2 MG-Y Laser with Integrated Semiconductor Optical Amplifier

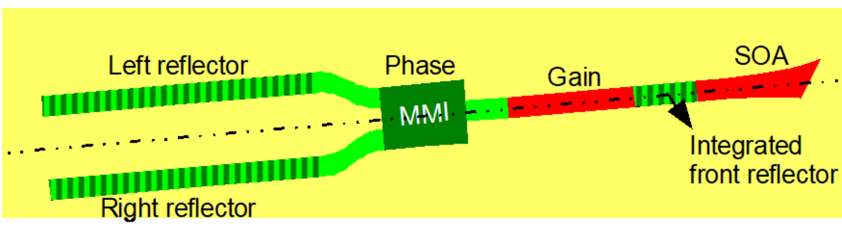


Figure 7 MG-Y laser with integrated semiconductor optical amplifier.

In the S7500 tunable laser, a semiconductor optical amplifier (SOA) is monolithically integrated on the laser chip (Figure 7). By adjusting the current through the SOA, the output power can be adjusted independently from the emission frequency. Moreover, reverse biasing the SOA will block all light coming from the laser (>40 dB suppression), which is used when tuning from one channel to another to avoid spurious emission at other wavelengths.

4 S7500 Tunable Laser Package

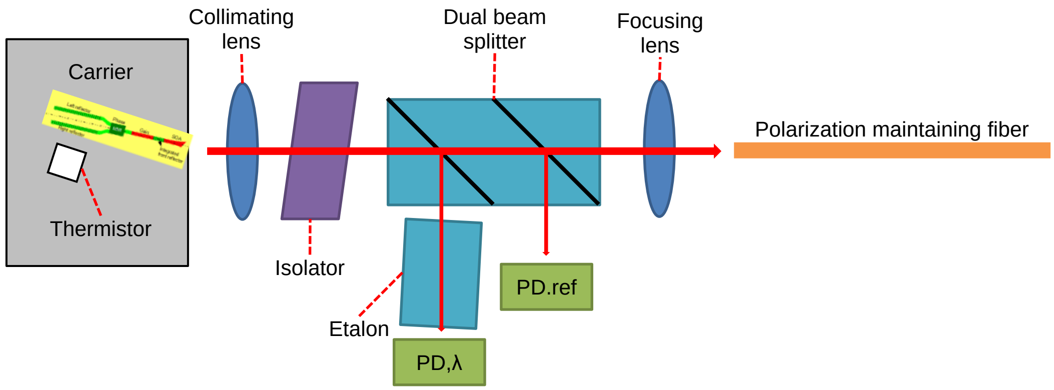


Figure 8 Block diagram of the S7500 tunable laser package.

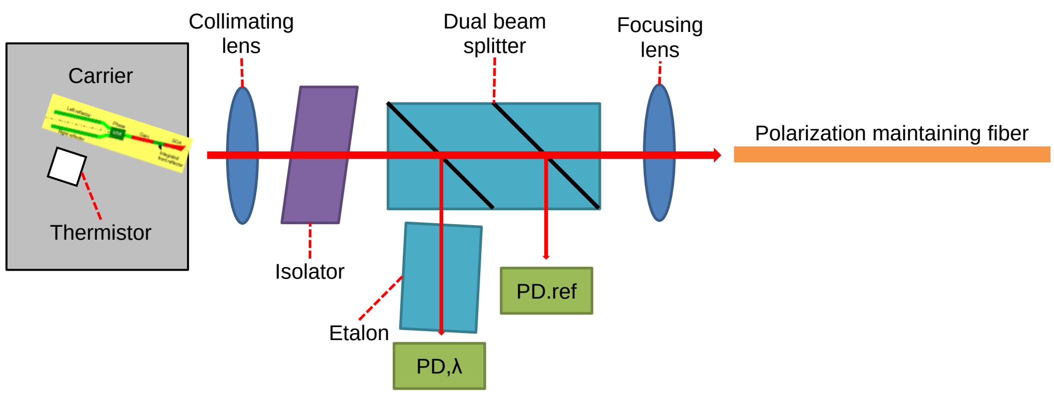


Figure 8 shows a block diagram details of the S7500 tunable laser package. The MG-Y + SOA chip is mounted on a carrier together with a thermistor. The chip on carrier is in turn placed on a second carrier that holds the entire internal optical sub-assembly (OSA), which is temperature controlled using a thermo-electric cooler (TEC).

The output beam from the laser chip is collimated using a first lens. The light then passes through an optical isolator and two beam splitters, each of which deflects a small fraction of the beam. One deflects light directly onto a photodiode for power monitoring (reference PD), while the other routes the light through a glass etalon on to a wavelength monitoring photodiode (etalon PD). A second lens focuses the collimated beam into the polarization maintaining fiber pigtail.

The assembly of beam splitters, etalon, and photodiodes constitutes the wavelength locker. Figure 9 plots the normalized ratio of the etalon PD current to the reference PD current as a function of the detuning from a given nominal frequency. By monitoring this ratio, any deviation from the nominal frequency can be detected.

The free spectral range of the etalon is 50 GHz. During assembly, the etalon is rotated such that the ITU grid frequencies (50 GHz grid) all line up on the positive slope of the locker response curve. Additional fine tuning is performed during calibration by adjusting the operating temperature of the OSA.

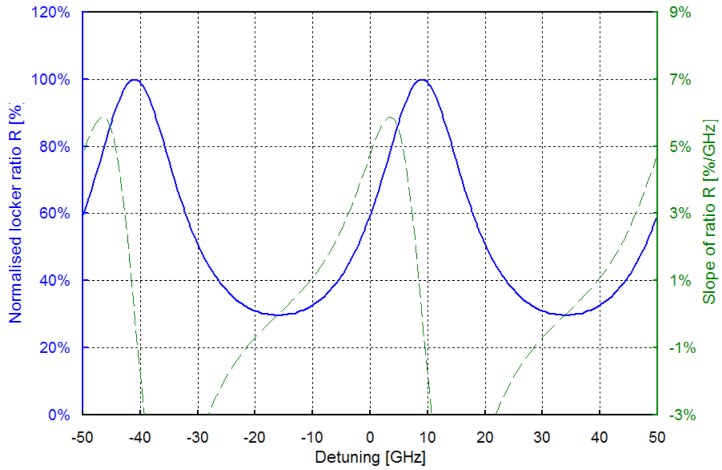


Figure 9 Wavelength locker response as a function of the detuning from the nominal channel frequency.

5 Control Electronics

5.1 Hardware

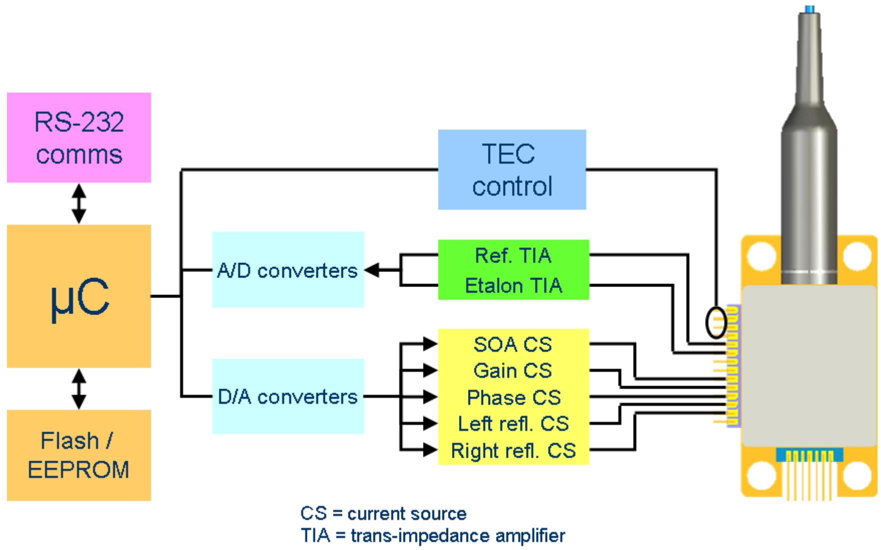


Figure 10 Block diagram of the control electronics for the S7500 tunable laser.

Figure 10 shows a block diagram of the electronic circuitry required to control the S7500. The control is typically coordinated by a microcontroller. The application code in the microcontroller runs the control algorithms for frequency and power control and handles communications with the outside world (e.g. over an RS-232 serial connection). The temperature of the optical sub-assembly inside the package is controlled by an integrated TEC controller.

For each of the laser sections, and the SOA, there is a current source controlled by the microcontroller through a digital to analog (D/A) converter. The currents generated by the reference and etalon photodiodes are converted to voltages using trans-impedance amplifiers and subsequently measured using analog to digital (A/D) converters.

In order to keep the output power constant, the microcontroller reads the reference PD value and adjusts the SOA current accordingly. The frequency is stabilized by adjusting the tuning currents (left reflector, right reflector, and phase) along the centerline of a single mode tube (cf. §3.1), such that the locker ratio (ratio of the etalon PD value to the reference PD value) remains constant.

More detail on the control algorithms is provided below. These algorithms require certain parameters, most of which need to be calibrated on a channel by channel basis. Those parameters are stored in a non-volatile memory.

5.2 Control Algorithms

5.2.1 Frequency Control Loop

As described in section 3.1 above, the laser can be fine-tuned by moving along the centerline of a single mode tube in the three-dimensional space of tuning currents (left reflector, right reflector, and phase). During calibration of the S7500, the loci of all of these lines are determined. On these lines operating points are identified that yield emission frequencies on the desired frequency grid. If the shape of the centerline around each of these operating points is also stored, then a control loop can correct for any frequency error (detected using the wavelength locker) by moving the operating point up or down along this centerline until the error is eliminated. Moving along the centerline assures that a high SMSR is maintained.

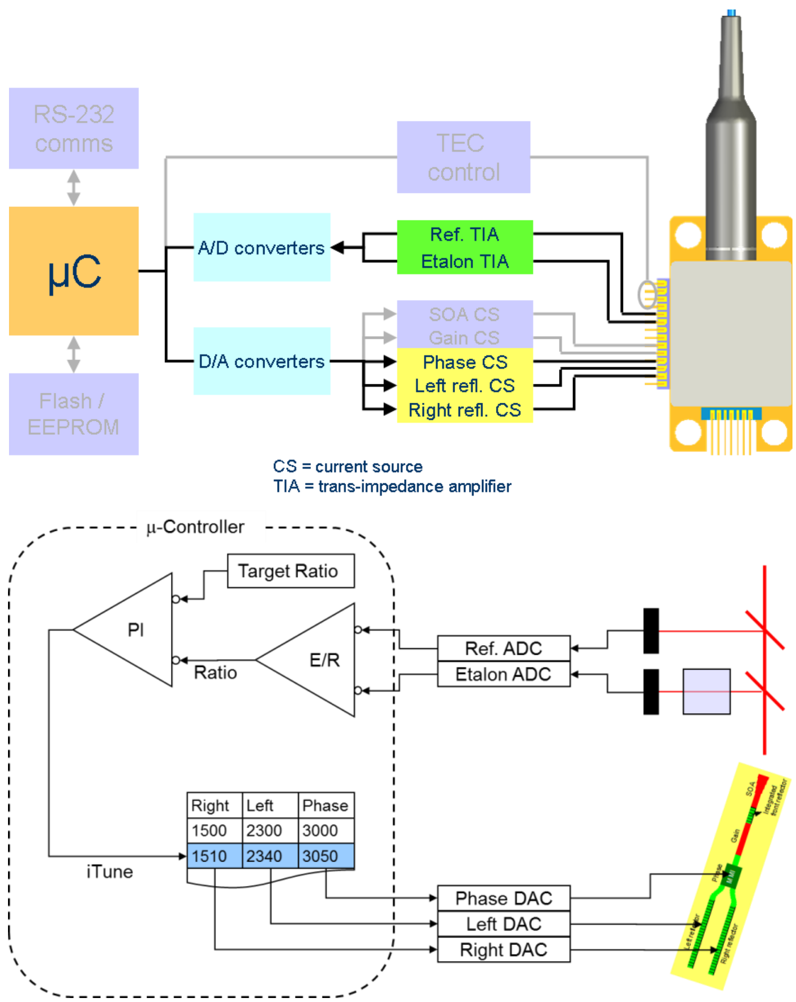


Figure 11 Block diagram of the frequency control loop.

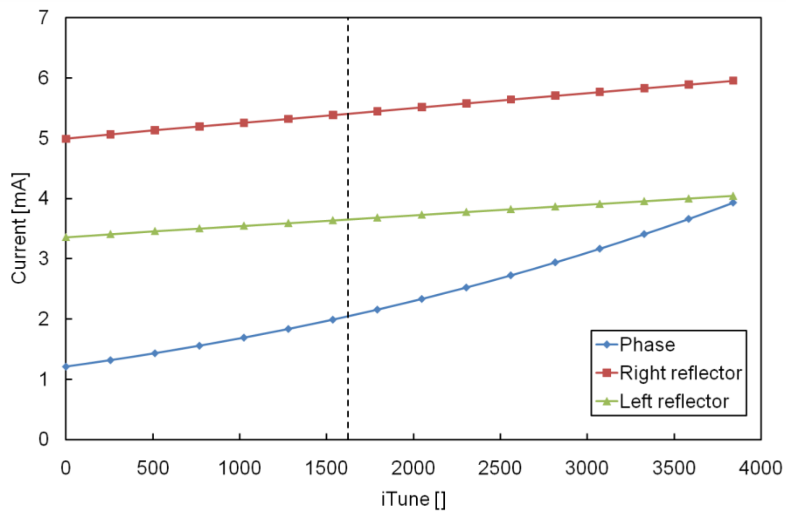


Figure 12 Example of a fine tune table, describing a piecewise linear approximation of the centerline of a single mode tube around a given nominal operating point.

In a practical implementation, a piecewise linear approximation of the centerline is generated around the nominal operating point for each channel (with frequency $\nu_{Channel}$). A fine tune table is constructed consisting of 16 operating points, approximately equidistant in frequency, spanning approximately 40 GHz around the nominal channel frequency $\nu_{Channel}$. An example is shown in Figure 12.

The position on the centerline is described by the parameter iTune, which ranges from 0x0000 to 0x0F00 (0 to 3840). The nominal operating point is located at iTune0, typically around 0x0600 (1536). The frequency control loop in the firmware continuously adjusts iTune to keep the locker ratio at the appropriate value. At each iteration of the control loop, the tuning currents are calculated by linear interpolation in the fine tune table as follows.

- The integer part of iTune / 0x0100 yields the index of the first interpolation point i;
- The fractional part of iTune / 0x0100 is used to interpolate between points i and i+1 in the table;

Since iTune is approximately a linear function of frequency, the gain of the frequency control loop will be the same for all channels, even though tuning efficiencies of the sections (in GHz/mA) can vary by more than an order of magnitude. The scale factors used were chosen such that all calculations can be done in an efficient way, e.g. using bit shift operations instead of divisions.

5.2.2 Locker Ratio

The laser emission frequency is monitored by measuring the ratio of the etalon PD current to the reference PD current. In order to avoid floating point calculations, the etalon PD value is pre-multiplied with 2^{12}.

$$\text{Ratio} = 2^{12} \cdot \frac{\text{etalon PD value}}{\text{reference PD value}}$$

As part of the calibration of the S7500, this ratio is measured as a function of frequency around the center frequency of the tuning range. A curve fit is applied and the resulting curve is stored as a table consisting of 200 points in steps of 128 MHz, centered on the nominal lock point (located 9000 MHz from the peak of the response, on the positive slope). Figure 13 shows an example.

Since the free spectral range of the etalon in most cases deviates slightly from 50 GHz, the actual lock point varies from channel to channel. Therefore, for each channel a value iRatio is stored in the look-up table (0x0000 ≤ iRatio ≤ 0x6380), which serves as an index in the stored locker ratio table. The locker ratio value for a particular channel is then calculated by linear interpolation in this table as follows.

- The integer part of iRatio / 0x0080 yields the index of the first interpolation point i;
- The fractional part of iRatio / 0x0080 is used to interpolate between points i and i+1 in the table;

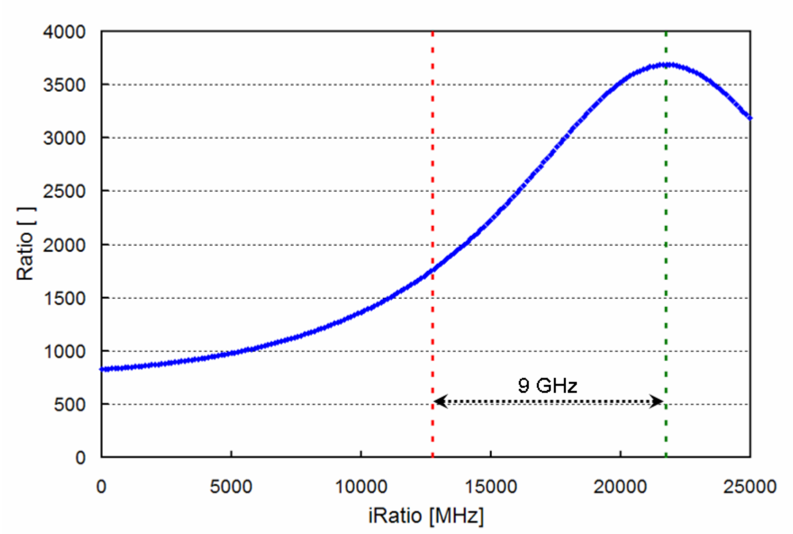


Figure 13 Example of a locker ratio table.

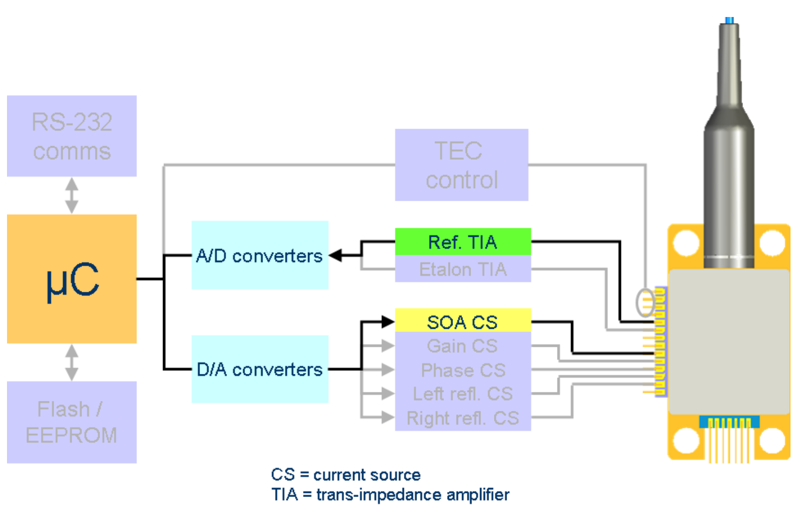
In principle, it would be sufficient to store Ratio for each channel directly in stead of iRatio. The above approach has several advantages though. Since iRatio is nominally scaled in MHz, fine tuning of the frequency with a certain amount can easily be done by adjusting iRatio by that amount and recalculating the locker ratio. This will for example facilitate the implementation of the LsTWEAK functionality in the 300-pin transponder MSA. Moreover, alarm thresholds in terms of frequency can easily be converted to equivalent thresholds in terms of the measured locker ratio.

5.2.3 Power Control Loop

The reference PD value is converted to a power reading (in mW·0x0080) using the output power scale factor K, which is calibrated for each channel.

$$P\,[\mathrm{mW}]\cdot 128 = K\cdot\frac{\text{reference PD value}}{2^{12}}$$

Any deviation from the nominal output power is compensated by adjusting the SOA current.



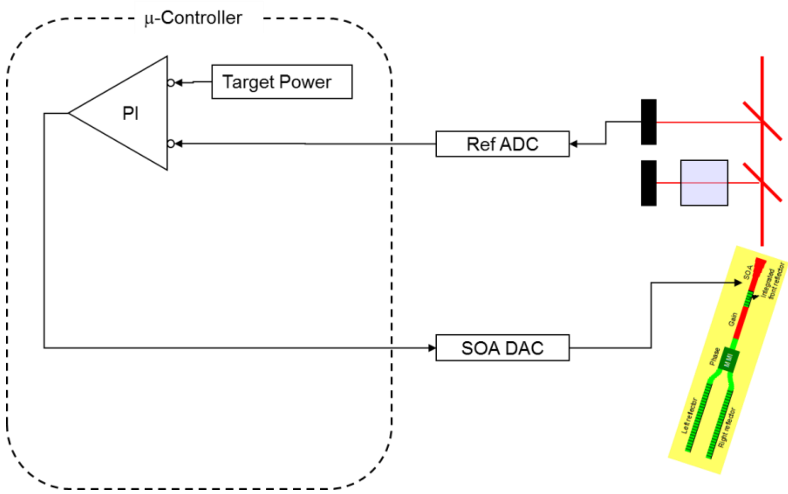


Figure 14 Block diagram of the power control loop.

In order to allow rapid adjustment of the output power within the specified range of 9 to 13 dBm, the look-up table contains values for the SOA current corresponding to the minimum and maximum output power settings at the beginning of life (individually for each channel). The SOA current for any given output power level between those limits can then easily be calculated by linear interpolation. The final fine adjustment of the SOA current is handled by the control loop as described above.

5.3 Tuning Procedure

The procedure for tuning from one channel to another is as follows. To begin with, the optical output is disabled by reverse biasing the SOA, which typically reduces the output power by more than 50 dB.

The microcontroller then calculates the tuning currents from the fine tune table for the new channel (cf. §5.2.1). Since the frequency at any given operating point (constant currents) will almost always decrease somewhat over life, an offset is applied to the nominal fine tune parameter iTune0, corresponding to a detuning of approximately +5 GHz, i.e. iTuneOffset = 0x01C9. With this offset, the frequency of the light that is transmitted once the SOA is turned on again, but before the frequency control loop has stabilized, is guaranteed to lie within ±10 GHz from the nominal channel frequency, even after many years of use. The new SOA current is calculated based on the current output power setting as described in §5.2.3.

5.4 Look-up Table

All calibration data needed for the control loops described above is stored in a channel look-up table. The table consists of a header with general calibration parameters, followed by rows with channel specific data. The header amongst others contains the following:

- Laser temperature set point;
- Minimum and maximum output power setting;
- Frequency of the first and last channel, as well as the grid spacing;
- Gain section current;

For each individual channel, the data consists of:

- SOA current for the minimum and maximum output power setting (cf. §5.2.3);
- Phase current fine tune table (16 values, cf §5.2.1);
- Left reflector current fine tune table (16 values, cf §5.2.1);
- Right reflector current fine tune table (16 values, cf §5.2.1);
- Index of nominal lock point in locker ratio table (iRatio0, cf. §5.2.2);
- Output power scale factor K (cf. §5.2.3);

6 Finisar Contact Information

Finisar Corporation

1389 Moffett Park Drive

Sunnyvale, CA 94089-1134

Tel: +1-408-548-1000

www.finisar.com

sales@finisar.com