High Stability ITU Grid References

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1. Introduction

DWDM evolution has placed increasing importance on the availability of precise wavelength standards in the 1480nm to 1620nm region. Presently DWDM channels are defined on an exact 100 Ghz frequency grid with future systems on a 50 or even 25Ghz grid. A reliable grid at 25Ghz would require the network lasers to maintain accuracy over time and environment of at least ±0.02nm or better. Transmission lasers with this accuracy are not normally available. Measurement devices would also benefit. Most precision wavelength measurement devices use a HeNe laser at 632nm as a reference and measure the wavelength ratio in an interferometric configuration. This technique relies on significant correction factors to correct for the index of refraction difference between 632nm and 1550nm [1]. Optical spectrum analyzers would also benefit from precise in band wavelengths for calibration. The need for precision frequency references in the 1.5 micron band with increasing accuracy is evident.

There are few fundamental frequency references in the 1550nm band. The only gas laser line is the 1523nm HeNe line. This laser line is difficult to fabricate in a stabilized configuration and typically outputs multilongitudinal modes. DFB laser stabilization offers an attractive alternative but needs a stable transition to probe as a reference. Atomic transitions in this region are between excited states and produce a low locking signal typically with high noise. Some researchers have investigated locking a DFB by frequency doubling to a Rubidium transition at 780nm[2]. Several previous papers have reported on research in stabilizing external cavity laser diodes to molecular absorption lines of acetylene, hydrogen cyanide, and ammonia[3,4]. These materials are known to have highly stable transitions some of which have been measured to an absolute accuracy of 1 part in 10^9 and which are very insensitive to environmental effects[5]. These studies have resulted in laser output with the emission wavelength stabilized long term to within a few MHz. All these results, however, have drawbacks:

- The studies generally used high frequency modulation of the laser frequency to achieve an error signal using the Pound-Drever technique. This results in an undesirable frequency and amplitude modulation on the laser output.
- The apparatus used was typically complicated and not subject to use as a practical portable low cost standard
- The emission wavelengths available did not include an ITU grid wavelength.

In this paper we report on a simple, robust laser locked to molecular absorption lines that can produce an emission wavelength with no modulation that can be stabilized to within 0.1 picometers long term. In addition the techniques described allow stabilization to at least a few selected ITU grid wavelengths.

2. Locked Laser Configuration

A block diagram of the locked laser is shown in Fig 1. The laser is a standard telecommunication grade DFB laser commonly used for 2.5Gbit DWDM applications. All laser wavelength tuning is derived from temperature tuning the DFB chip. The laser is mounted on a large heat sink and shielded from any room air currents to achieve an environment with a thermal inertia. The laser output is split with part of the output available for application and part sent through a gas absorption cell. The output of the gas cell is detected in a photodiode, amplified, and digitized. The digitized signal is processed in a microprocessor and the results used to control the TE cooler/heater circuit. The TE cooler circuit is designed for superior low frequency noise characteristic. We achieve a noise level of <0.0001ºC. The detected transmission characteristics of the gas cell are used to control the emission wavelength of the laser. A low noise laser drive circuit is included which allows for accurate and stable output power to be achieved. The use of a microprocessor to control the locking and the highly digital architecture allows for optimal tailoring of acquisition and locking behavior.

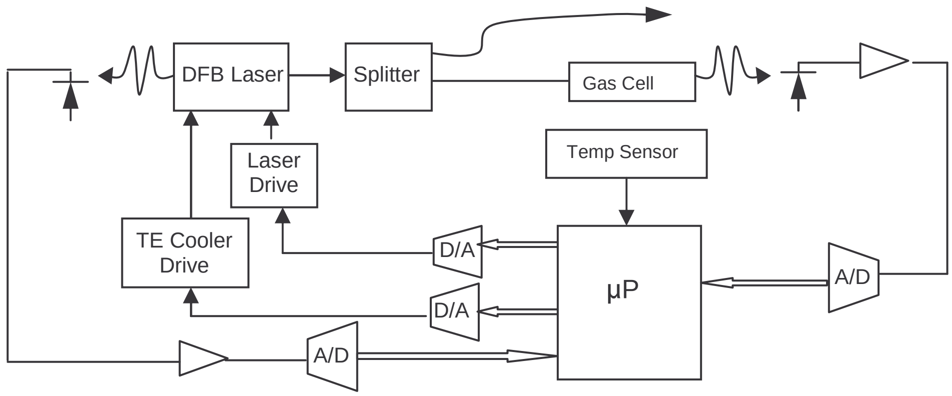

Fig. 1. Block diagram of locked laser

3. Locked laser operation

When the laser is first turned on a calibration scan is initiated, where the wavelength of the laser is tuned over about a 0.4nm span. Since the absorption transitions are at least 0.4nm apart this span will include the transition of interest and no others. The laser tuning characteristics are typically 0.09nm/ºC. The initial scan is done with a resolution of 12 bits (0.01pm/bit) and takes about 25 seconds. In the actual lock routine the laser wavelength is tuned at a 15-bit resolution (.002pm/bit), which for all intents is continuous. The position of the absorption peak within this span is determined along with the net minimum and maximum transmissions of the cell. These values are used to create normalized targets for a specific wavelength that is tolerant of temperature changes and to any change in alignment or throughput that the cell has experienced.

The pressure of the gas in the absorption cell has a significant impact on the width and steepness of the absorption line transmission. For acetylene at 20 Torr the FWHM of the absorption line is about 6.4pm and the slope at the 50% point is about 0.03pm for a 1% change in transmission. Higher pressures will broaden the line. For example an acetylene cell at 200Torr has a FWHM of 25pm, a hydrogen cyanide cell at 100Torr has a FWHM of 50pm[6,7]. Larger width maybe useful if the desire is to stabilize to a wavelength some distance from the center wavelength of the transition. Most often a low-pressure cell is used. The absorption lines are all Doppler broadened. The minimum width at low pressures, as determined by the Doppler width, is about 5pm. Since the transmission is digitized to 12 bits a resolution of <0.001pm/bit with a noise level of about ±1 bit is available at the 50% point. Some researches have advocated the use of subdoppler spectroscopy to stabilize the laser wavelength [8]. This technique gives a very steep error signal and the line probed can be very narrow indeed. For acetylene this linewidth is estimated at <1Mhz. One might think that this would result in performance several orders of magnitude superior to the results shown in this talk. This is not the case, however, due to our superior signal to noise level and the influence of short-term fluctuations of the laser itself on the results. In our case it would also be far too easy for the laser to lose lock and the technique requires very high laser power. Since our laser wavelength stabilization is achieved only by varying the laser chip temperature we depend on the short-term stability of the laser itself. The Allen variance of commercial DFB lasers has been measured at on the order of 10^-8 (0.015pm) at time scales of 1Hz. This level of stability is sufficient for DWDM applications in the foreseeable future. We cannot track out variations in the temperature any greater than about 1Hz. Careful but not heroic isolation of the laser from room temperature variations can easily reduce fluctuations to below this bandwidth.

Three lock modes have been studied. A lock to one side or the other of the absorption line defines two of these modes. In this case the circuit just maintains the cell transmission at the value determined to give the correct output wavelength. In this mode there is no modulation of the laser wavelength. The actual wavelength that the device locks to will depend on the line width of the transition. Unless adjustments are made temperature changes will affect the laser wavelength at a rate of about 0.005pm/ºC. If this is not negligible this can be compensated by changing the locking threshold as the temperature varies. Even in the case where the threshold is not compensated accurately or at all, the average of the two side locks is still a very accurate representation of the line center. This can be applied quite usefully wavemeter verification. In the third mode the device locks to the minimum transmission which corresponds to the center of the absorption line. In this case a low frequency low amplitude dither is applied to the thermal circuit at a frequency of 1Hz and a P-P amplitude of 0.05pm to provide the locking signal. In general it is found that side locking gives superior short term stability due to the steepness of the absorption line transmittance and the lack of dither and the center lock gives superior long term stability due to the stability of the line center wavelength. The average of the side locks reflects both advantages. The environmental stability of molecular absorption lines is well documented. For example the line center of the acetylene transitions have been measured to have a temperature drift of <2Khz/ºC [9].

4. Discussion

The wavelength of the laser is measured in side lock by using another gas cell as a frequency discriminator. Results are shown in Fig2. We have found that backrefelection can have a significant effect on the laser wavelength. Shown in Fig 2a is the case where the backreflection is <-40dB. In Fig2b an intentional backreflection level of about –14dB is introduced. The laser has a built in isolator of about 30db. This shows that low-level backreflections below –40dB can significantly affect laser wavelength fluctuations. As can be seen the short-term stability is ±0.02pm if reflections are controlled. Long term stability of the laser is better then 0.1pm for all lock modes. Recent tests using a verified wavemeter traceable back to the cesium standard have confirmed this accuracy. The use of side locking can allow for a limited laser wavelength tuning by adjustment of the locking threshold. This technique can result in a lock wavelength that is an exact ITU grid location. For example the P14 line of carbon 12 acetylene has a line center of 195.5005106Thz, easily allowing a side lock to an exact 195.5Thz. Higher-pressure cells would allow for larger tuning range but eventually accuracy would suffer.

5. Applications

The clearest use of a high stability laser reference is as a calibration source for calibrating the wavelength scale of an optical spectrum analyzer or the accuracy of a wavemeter. The techniques outlined have allowed us to demonstrate a laser with absolute accuracy superior to the most accurate wavemeters available on the commercial market. This points to an obvious extension, why not use the laser as a substitute to the more common HeNe laser as the reference within the wavemeter? We are investigating lasers stabilized to methane or hydrogen fluoride lines in the 1300nm band for just such a purpose. These lasers can be cost competitive due to their long life and solid state ruggedness. Another, perhaps even more exciting application, would be as a reference for locking the wavelength of actual network lasers. Normally network lasers are locked to grid locations using wavelength lockers. These lockers are typically etalons with a precise 50 or 100Ghz FSR. They are not really that precise, however. The typical specification for a high performance locker is ±0.02nm and this number is subject to environmental and lifetime degradation. If the lockers were referenced to either a single locked laser for offset or two locked lasers for offset and gain this specification could be considerably improved.

6. Conclusion

We have designed a relatively simple and robust locked laser that can achieve a long-term stability of better then 0.1 picometer using temperature tuning of commercial DFB lasers. This laser can also be configured to give an output on an exact ITU grid location. The use of molecular transitions of carbon 12 and carbon 13 acetylene, hydrogen cyanide and carbon monoxide allows for several hundred transitions from 1510nm to 1630nm to be utilized for high stability locking purposes. Other species such as methane or hydrogen fluoride can extend this range to the 1300nm band as well.

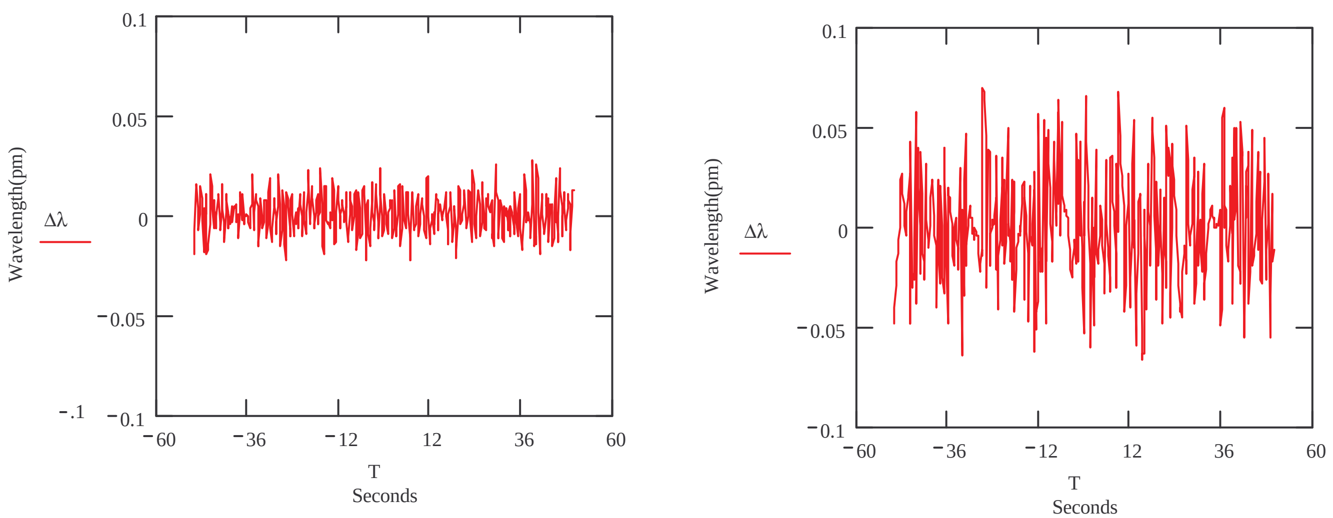

Fig 2a and Fig 2b: Laser locked wavelength in the case of low level reflections and in the case of reflection of –14dB

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