Analysis of Laser Linewidth Measurements Based on Fabry Perot Interferometer System

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Abstract-- The linewidth of a tunable laser source TLS with both narrow and wide modes settings are measured directly using scanning Fabry-Perot interferometer.. This system consists of a confocal resonator that contains two high reflectivity mirrors; by varying the resonator length by the piezoelectric transducer, the system acts as a very narrow band-pass filter. The operation of interferometer is controlled by a controller and the linewidth is measured using detection oscilloscope. With narrow mode setting, the linewidths are measured to be around 12 MHz, 14 MHz and 16.5 MHz for signal wavelengths of 1520 nm, 1540 nm and 1560 nm, respectively. While the linewidth is slightly fluctuated with the wide mode setting, and a value varies from 104 to 195 MHz are obtained.

Index Term-- Fabry Perot Interferometer; Tunable laser source TLS; Laser linewidth

I. INTRODUCTION
The spectral bandwidth (linewidth) of lasers can be as broad as several hundreds of gigahertz and down to as narrow as several hundreds of hertz. This wide range of parameters offers enormous potential in fields of engineering, applied science and pure scientific research. The linewidth of a single frequency laser is the full width at half maximum (FWHM) of the optical spectrum. More precisely, it is the width of the power spectral density of the emitted electric field in terms of frequency, wavenumber or wavelength. Typical linewidths of stable free-running single-frequency solid-state lasers are a few kilohertz range, whereas the linewidths of semiconductor lasers are often in the megarhertz range. Much smaller linewidths, sometimes even below 1 Hz, can be reached by stabilization of lasers, which can be achieved using ultra-stable reference cavity.[1] [2] [3].

The linewidth of a laser is strongly related to the temporal coherence. Lasers with very narrow linewidth (high degree of monochromaticity) are required for various applications, e.g. as light sources for various kinds of fiber-optic sensors, for spectroscopy (e.g. LIDAR), in coherent optical fiber communications, and for test and measurement purposes.[4][5].

The tunable laser source TLS has a high output power with high side mode suppression ratio and can accurately set wavelength range to accommodate various aspects of dense wavelength division multiplexing (DWDM) use. These characteristics are excellent for evaluating optical fiber amplifiers and components, DWDM systems, etc. The gain medium of the TLS is a conventional laser diode but the internal Fabry Perot resonator is disabled by an antirefection coating on one of the facets. An external cavity is created by adding an external diffraction grating which acts both as a mirror and a wavelength-selective element [6]. The output power, single-mode operation and wavelength stability strongly depend on temperature stability compared with Diode-pumped single-frequency solid-state lasers (including fiber lasers) which are the best-known low-noise coherent laser sources with a spectral linewidth ranging from hundreds of kilohertz to as narrow as a few kilohertz [7]. These lasers have also the potential to produce near-quantum-limited intensity noise by combining the use of an amplitude squeezed pump diode and an electronic feedback loop [8].

Many different technologies can be used for spectral analysis, but the preferred method for highest-resolution spectral analysis is the scanning Fabry-Perot interferometer technique. As the Fabry-Perot interferometer is a very simple device that relies on the interference of multiple beams, it is ideal for measuring laser linewidth, longitudinal mode structure and frequency stability of a laser source.

II. CONCEPT AND THEORY
A spherical mirror Fabry-Perot interferometer in the confocal configuration has many advantages over plano-plano interferometers, such as easier construction and alignment. These interferometers are used in a variety of spectroscopic applications, including laser spectrum analysis and generating frequency markers for laser frequency scans[9]. The device consists of two partially transmitting mirrors that are precisely aligned to form a reflective cavity as shown in fig 1. Incident light enters the Fabry-Perot cavity and undergoes multiple reflections between the mirrors so that the light can interfere with itself many times, by varying the mirror separation with a piezoelectric transducer the cavity acts as a very narrow band-pass filter.
Knowing the free spectral range of the interferometer allows the time-base of an oscilloscope to be calibrated to facilitate quantitative measurements of a laser line shape. If the frequency of the incident light is such that constructive interference occurs within the Fabry-Perot cavity, the light will be transmitted. Otherwise, destructive interference will not allow any light through the Fabry-Perot interferometer.

III. EXPERIMENTAL SETUP
The linewidth measurement on TLS is carried out by a scanning Fabry-Perot interferometer approach using high finesse spectrum analyzer, which can be used to examine the fine structures of the spectral characteristics of CW lasers. The spectrum analyzer consists of a confocal cavity that contains two high reflectivity mirrors; by varying the mirror separation with a piezoelectric transducer the cavity acts as a very narrow band-pass filter. The design of the Fabry-Perot interferometer cavity is comprised of an Invar cavity with internal piezo stacks. This design utilizes the negative thermal coefficient of the piezo stacks to create the nearly a thermal cavity that is necessary for the stability of these high resolution spectrometers. Knowing the free spectral range of the spectrum analyzer allows the time-base of an oscilloscope to be calibrated to facilitate quantitative measurements of a laser line shape.

The spectrum analyzer is control by a controller box. This scanning Fabry-Perot controller box is specifically designed to control the Fabry-Perot Interferometers by generating a high-stability, low noise voltage ramp. This ramp signal is used to scan the separation between the two cavity mirrors. The controller adjusts the ramp voltage and scan time, allowing the user to choose the scan range and speed, while an offset control allows the spectrum displayed on an oscilloscope to be shifted right or left. A TTL output allows the user to externally trigger an oscilloscope on either the beginning or midpoint of the ramp waveform. The controller also has a calibrated zoom capability that provides a 1X, 2X, 5X, 10X, 20X, 50X, or 100X increase in the period of the ramp signal, which allows for an extremely wide range of scan times.

The controller box also includes a high-precision photodetector amplifier circuit used to monitor the transmission of the cavity. Using the output sync signal from the controller, an oscilloscope can be used to display the spectrum of the input laser. The detector circuitry incorporates a blanking circuit that disables the photodiode response during the falling edge of the sawtooth waveform. The blanking circuit can be disabled by switching a circuit board jumper [10].

IV. RESULTS AND DISCUSSION
Fig 2 shows the experimental set, which consists of Fabry Perot interferometer, controller box, oscilloscope, laser source (TLS), and grin lens to align the laser beam inside the cavity. The beam from TLS is focus on the input iris opening using the grin lens. At first, the beam is centered on the iris opening when the input iris is closed. Visible red laser is used to help us to do good alignment of laser beam inside the cavity of interferometer. Then, the back iris is opened to scan the unit. The adjustment is carried out until the beam is pointed at center of the cavity of the spectrum analyzer. The scope gain is adjusted to maximum sensitivity and the detector is positioned close to the rear opening. Then the back iris is slowly closed so that the measurement can be started. The linewidth measurement is carried out for various wavelength and spectral width modes settings of the TLS.

The linewidth of the laser beam is first measured for the TLS’s signal with narrow mode setting at input signal power of 0 dBm. The wavelength of the TLS is varied from 1520 nm to 1560 nm. Fig. 3 shows the plot of a free spectral range (FSR), which is obtained using a TLS operating at 1550 nm. It is observed that the distance between the two peaks, ΔT is measured to be around 11.5 ns. Fig.4 shows the time domain spectrum of the output spectrum at three different wavelengths, which were obtained from an oscilloscope. This spectrum is observed due to the convolution of the laser linewidth and finesse of the TLS signal with narrow mode setting.
As shown in the figure, the FWHM ($\Delta \tau$) of the spectra are determined to be 92 μs, 107 μs and 127 μs for signal wavelengths of 1520 nm, 1540 nm and 1560 nm, respectively. The linewidth of the TLS in frequency domain can be calculated using the following formula:

$$\text{Linewidth (Hz)} = \frac{\Delta \tau}{\tau} \times 1.5 \text{ GHz} \quad (1)$$

Based on Equation 1, the linewidths are calculated to be around 12 MHz, 14 MHz and 16.5 MHz for signal wavelengths of 1520 nm, 1540 nm and 1560 nm, respectively. This result shows that the linewidth of the TLS increases with the operating wavelength. This linewidth values obtained is comparable with other measurement using other techniques such as heterodyne technique. This technique is expected to be more accurate due to the resolution of this technique, which is so much smaller compared to the other techniques.

The linewidth of the TLS against its operating wavelength for different spectral settings at input signal of 0 dBm can be shown in Fig. 5. From this graph it is clearly shown that the linewidth increases as the operating wavelength increases especially for narrow mode setting. At narrow setting, the value of linewidth obtained varies from 12.2 MHz to 17.9 MHz within C-band wavelength region. However, the linewidth is slightly fluctuated with the wide mode setting. The linewidth value obtained varies from 104 to 195 MHz with this setting as shown in Fig. 6.

The linewidth on a TLS with both narrow and wide modes settings are measured using scanning Fabry-Perot interferometer for comparison purpose. This technique does not require expensive equipments such as Radio frequency spectrum analyzer RFSA. The interferometer consists of a confocal cavity that contains two high reflectivity mirrors; by varying the mirror separation with a piezoelectric

V. CONCLUSIONS

The linewidth on a TLS with both narrow and wide modes settings are measured using scanning Fabry-Perot interferometer for comparison purpose. This technique does not require expensive equipments such as Radio frequency spectrum analyzer RFSA. The interferometer consists of a confocal cavity that contains two high reflectivity mirrors; by varying the mirror separation with a piezoelectric
transducer the cavity acts as a very narrow band-pass filter. The operation of interferometer is controlled by a controller and the linewidth is measured using oscilloscope. The linewidths are calculated to be around 12 MHz, 14 MHz and 16.5 MHz for signal wavelengths of 1520 nm, 1540 nm and 1560 nm, respectively. This result shows that the linewidth of the TLS increases with the operating wavelength. This linewidth values obtained is comparable with other measurement using heterodyne technique.

REFERENCES