Application Note 3

Testing Various Laser Frequency Standards

COMPARING TWO IODINE-STABILIZED LASERS

Comparing two iodine-stabilized lasers may be the simplest measurement to make with a heterodyne system. The output beam parameters of iodine lasers are usually similar so wavefront curvatures at the photodetector are also similar. Iodine-stabilized lasers have linearly polarized outputs, so matching polarizations requires rotating the polarization angle of the laser under test to match that of the reference laser. This is accomplished by inserting a $\lambda/2$ waveplate in its beam path and rotating it to maximize the amplitude of the heterodyne signal.

CALIBRATING A POLARIZATION-STABILIZED LASER

Polarization-stabilized lasers are secondary optical frequency standards that operate by maintaining a fixed relative amplitude between two modes oscillating simultaneously in the laser. The two modes differ in frequency by one free spectral range of the laser cavity – typically 400 - 500 MHz – and (usually) have orthogonal linear polarizations. The output beam may contain one or both of the modes.

If the output beam of the polarization-stabilized laser contains only one of the two laser modes, the optical setup is the same as when comparing two iodine-stabilized lasers. The polarization angle of the polarization-stabilized laser is rotated to match the polarization angle of the iodine-stabilized laser. This is accomplished by inserting a $\lambda/2$ waveplate in its beam path and rotating it to maximize the amplitude of the heterodyne signal.

If the output beam of the polarization-stabilized laser contains both laser modes, three distinct frequencies will (generally) appear in the heterodyne signal. A strong, narrow peak will be displayed at a frequency corresponding to the free spectral range of the cavity of the polarization-stabilized laser. This peak is the heterodyne signal arising from the two modes of the polarization-stabilized laser. Two smaller, broader peaks will (usually) appear at lower frequencies. These peaks are the heterodyne signals arising from the combining of each mode of the polarization-stabilized laser with the iodine-stabilized laser. The sum frequency of these two peaks will equal the frequency of the strong, narrow peak. The presence of three frequencies can lead to frequency counting problems, therefore, one of the lasers modes should be removed before making any measurements.

One method for selecting the desired mode is to place an electrical filter in the signal line before the frequency counter. The choice of filter depends upon the values of the three frequencies present in the heterodyne signal. In practice, it is usually possible to isolate one of the frequencies with a low-pass filter by selecting an appropriate hyperfine component for the reference laser.

The desired laser mode can also be selected optically. In this method, a λ/2 waveplate is placed in the beam path of the polarization-stabilized laser to select which mode passes through a linear polarizer. Rotating the λ/2 waveplate will cause the smaller, broader heterodyne peaks to alternately shrink and grow as each is blocked or passed by the linear polarizer. At the same time, the strong narrow heterodyne peak will pass through minimums as each of the modes is blocked by the linear polarizer.

CALIBRATING A ZEEMAN-STABILIZED LASER

Zeeman-stabilized lasers are secondary optical frequency standards that operate by maintaining a fixed frequency difference between two modes oscillating simultaneously in the laser. The two modes are produced by applying a strong dc magnetic field to the laser gain medium. The magnetic field splits a single longitudinal mode of the laser into two modes, usually with orthogonal circular polarizations. The frequency splitting of the two modes varies slightly as a function of the average frequency of the modes, and it is usually less than 1 or 2 MHz. The output beam may contain one or both of the modes.

If the output of the Zeeman-stabilized laser contains only one of the laser modes, the heterodyne signal can be generated without the use of any waveplates or polarizers. This is because the circular polarization of the Zeeman-stabilized laser will always have an electric field component in the same direction as the linear polarized electric field of the iodine-stabilized laser. A λ/4 waveplate can be placed in the beam path of the Zeeman-stabilized laser to convert the circular polarization to linear polarization if desired, however, the transmission loss introduced by the λ/4 waveplate may offset any gain obtained from matching the polarizations.

If the output of the Zeeman-stabilized laser contains both laser modes, two or three distinct frequencies will appear in the heterodyne signal. A strong, narrow peak may be displayed at the mode-splitting frequency of the Zeeman-stabilized laser. This peak is the heterodyne signal arising from the two modes of the Zeeman-stabilized laser, but it will only be visible if the orthogonality of the two modes is removed with a linear polarizer. Two smaller, broader peaks will appear at higher frequencies. These peaks are the heterodyne signals arising from the combination of each mode of the Zeeman-stabilized laser with the iodine-stabilized laser. These peaks will appear relatively close together, as their frequency difference will equal the mode splitting of the Zeeman-stabilized laser.

Unfortunately, the presence of two closely-spaced frequencies in the heterodyne signal can cause severe frequency counting problems. The small frequency splitting also makes the selection of one of the peaks with electrical filters impractical. For this reason, a λ/4 waveplate should be placed in the beam path of the Zeeman-stabilized laser to prevent one of the laser modes from passing through the linear polarizer and reaching the photodetector.