Application Note 2

Using the Winters Electro-Optics Laser Heterodyne System

OVERVIEW OF THE OPTICAL SETUP

The optical setup (see Figure 1) is designed to compare a primary optical frequency standard (Reference Laser) with another primary standard or a secondary optical frequency standard (Laser Under Test). A heterodyne signal is generated when the output beams of the reference laser and the laser under test are combined on the active area of a fast Avalanche Photodetector. The overlapping and combining of the output beams is accomplished with a high-reflectance mirror (Mirror #1) and a Beamsplitter mounted on kinematic mirror mounts. The combined beams are focused onto the photodetector with a 25 mm focal-length lens (Lens #2) mounted on a 3-axis stage. Optical isolation for the lasers is provided by an Acousto-Optic Modulator (AOM). Alignment and focusing of the laser beams into the AOM is accomplished with Lens #1 and Mirror #2, and an adjustable Iris Aperture selects the desired Bragg order from the AOM output.

Two waveplates ($\lambda/4$, $\lambda/2$) and a linear polarizer can be used in various combinations to reject unwanted modes of multi-mode (e. g. Zeeman- or polarization-stabilized) lasers, and to maximize the amplitude of the heterodyne signal. They can be placed in any of three mounts (labeled Waveplate #1, Waveplate #2, or Polarizer) depending upon the type of laser under test.

ALIGNING THE OPTICAL SETUP

The purpose of aligning the optical setup is to ensure that the resulting heterodyne signal is of sufficient amplitude and signal-to-noise ratio to produce reliable frequency counting. This is primarily realized via a good overlap of the output beams of the lasers. A secondary goal of aligning the optical setup is to provide optical isolation for the lasers. An Acousto-Optic Modulator (AOM) prevents reflections from the photodetector from causing instabilities in the lasers, which could otherwise corrupt the measurement of the heterodyne signal.

From a practical point of view, it is easier to first align the AOM using only the output beam of reference laser. Later, the output beam of the laser under test will be aligned to overlap the output beam of the reference laser, thereby aligning it to the AOM as well.

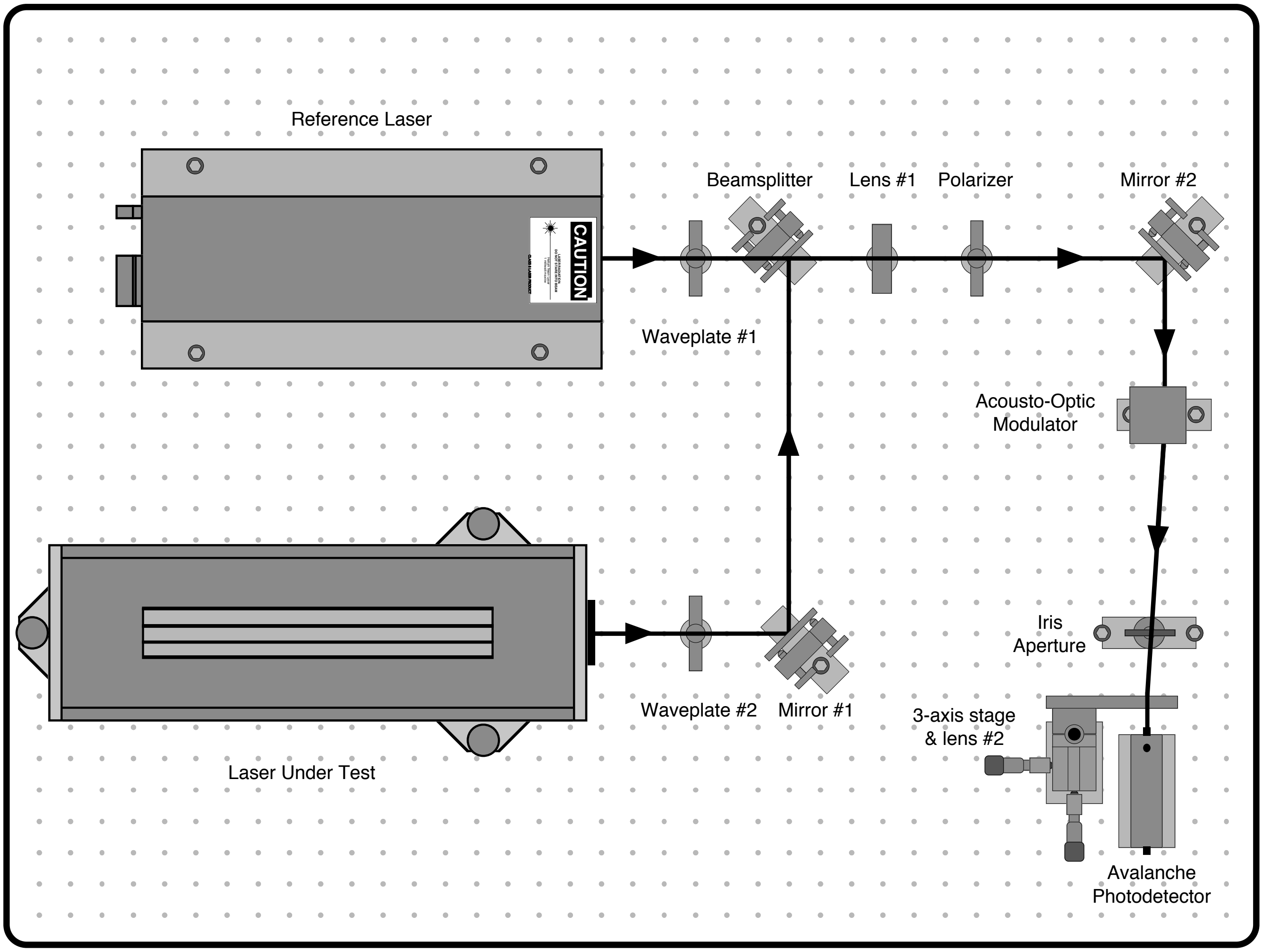


Figure 1: Optical Heterodyne Setup

Aligning the Acousto-Optic Modulator

The Acousto-Optic Modulator (AOM) provides optical isolation for the reference laser and the laser under test. The AOM contains a crystal which is driven by an rf acoustic wave. The acoustic wave generates an index grating, and laser light traversing the crystal undergoes Bragg diffraction from this grating. The diffracted laser beam experiences a frequency shift and a change of direction. The frequency shift is equal to a multiple of the frequency of the acoustic wave, and can be either positive or negative depending upon which Bragg order is selected. Since the best efficiency (~ 80%) is generally attained using the ±1 Bragg orders, one of these is used in most optical setups.

The procedure for aligning the AOM is as follows:

1. Block the output beam of the laser under test by either closing its output shutter or by placing a suitable beam block in its path.

2. Open the output shutter of the reference laser.

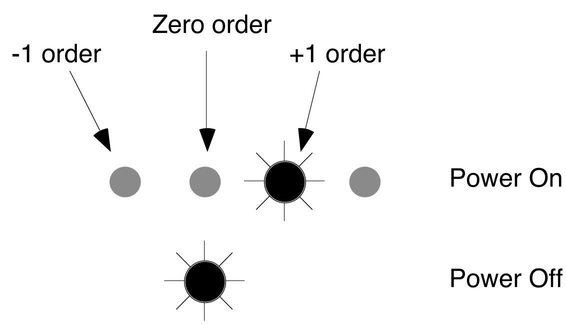
3. Adjust the height of Lens #1 to produce a horizontal beam at Mirror #2.

4. Remove the AOM from its mount. Adjust the vertical angle of Mirror #2 to produce a horizontal beam at the Iris Aperture.

5. Place the AOM back in its mount. Adjust the height of the AOM to match the height of the laser beam.

6. Adjust the horizontal angle of Mirror #2 to steer the beam into the entrance aperture of the AOM.

7. Turn on the APD Bias Supply to supply +15 V power to the AOM. Rotate the AOM to maximize the optical power in the +1 Bragg order. Note: the non-diffracted (zero order) beam can be identified by turning off the APD Bias Voltage Supply & GPIB Controller.



8. Adjust the Iris Aperture to transmit only the +1 Bragg order.

Aligning the Avalanche Photodetector

1. Place the METER SELECT switch on the APD Bias Supply in the VOLTAGE position. Adjust the bias voltage to 150 V using the BIAS ADJUST knob.

2. Place the METER SELECT switch on the APD Bias Supply in the CURRENT position. The current displayed on the digital meter should be less than 10 μA with the laser beam blocked. If the current exceeds 10 μA, reduce the bias voltage until the current drops below 10 μA.

3. Adjust the 3-axis stage to focus the laser beam on the photodiode of the avalanche photodetector. Optimize the focus adjustment by maximizing the detector bias current. If the bias current exceeds its current-limited value of ~200 μA, reduce the bias voltage and continue with optimizing the focus.

Aligning the Laser Under Test

1. Unblock the output beam of the laser under test (LUT) by opening the output shutter or removing the beam block.

2. Adjust Mirror #1 so that the output beam of the LUT overlaps the output beam of the reference laser on the front surface of the Beamsplitter.

3. Adjust the Beamsplitter so that the output beam of the LUT overlaps the output beam of the reference laser at the entrance aperture of the AOM.

4. While monitoring the heterodyne signal on a spectrum analyzer or oscilloscope, fine tune Mirror #1 to maximize the heterodyne signal amplitude.

OPTIMIZING THE HETERODYNE SIGNAL

The heterodyne signal must have a sufficient amplitude and signal-to-noise ratio for the frequency counter to reliably count the signal. While proper alignment of the optical system is a major part of attaining this goal, a proper choice of Avalanche Photodetector gain is also necessary.

The gain of the Avalanche Photodetector is the product of the gain of the rf amplifier (52 dB) and the avalanche electron multiplication of the photodiode. The avalanche multiplication factor can be varied from unity (0 dB) to approximately x1000 (60 dB) by increasing the bias voltage on the photodiode. Bias voltages below approximately 50 V produce no avalanche multiplication, while a voltage of approximately 150 V produces maximum multiplication.

The main advantage of using an avalanche photodetector is the availability of a very high gain-bandwidth product. The disadvantage of using an avalanche photodetector is the excess noise generated by the avalanche multiplication process. For this reason, it is desirable to operate the detector at the lowest possible avalanche multiplication factor that still produces adequate signal amplitude.

Figure 2 shows a typical heterodyne signal with a sufficient amplitude and signal-to-noise ratio to produce reliable counting. The large peak centered at approximately 40 MHz is the main heterodyne signal. The width and shape of this peak is a result of the frequency modulation present in the iodine-stabilized lasers. Both lasers are frequency modulated at a rate of approximately 1.2 kHz with a peak-to-peak amplitude of 6 MHz. Because the modulation rates of the lasers are different, the resulting heterodyne signal shows a peak-to-peak amplitude of 12 MHz. (Note: the width of the heterodyne peak may appear to pulsate or "breathe" – this is an aliasing effect arising from the non-degenerate modulation rates of the lasers and the sweep rate of the spectrum analyzer.)

The smaller peak centered at approximately 80 MHz is the second harmonic of the heterodyne signal. This peak is generated by non-linearities in the photodetector rf amplifier. A small amount (< -30 dBc) of the second harmonic is normal and will not affect the reliability of the frequency counting. An excessive second harmonic level indicates excessive photodetector gain, and will usually be accompanied by increased avalanche multiplication noise.

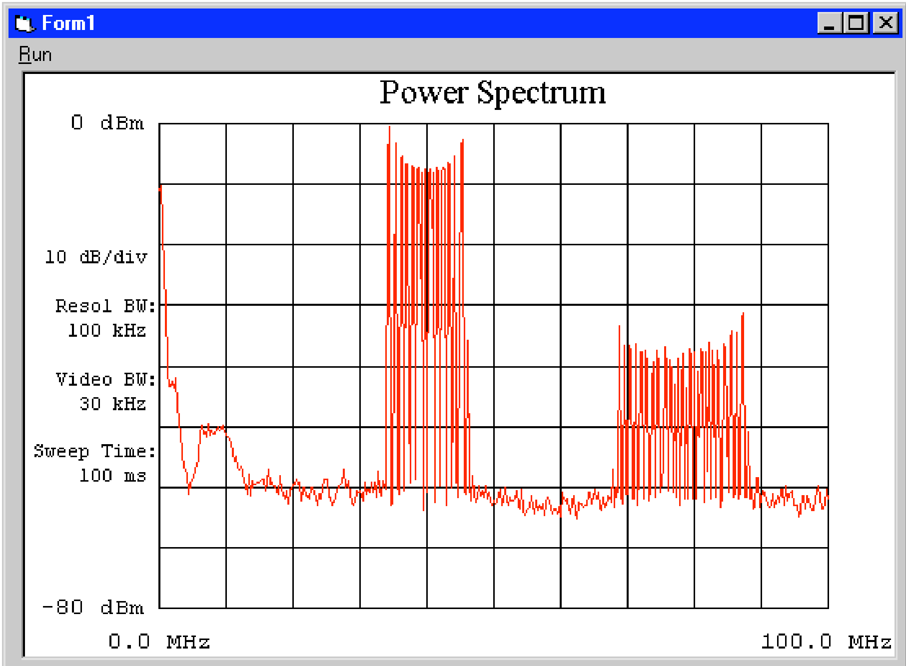


Figure 2: Typical heterodyne signal

Measuring the Heterodyne Signal Amplitude

The minimum signal amplitude required by the frequency counter is listed in the Specifications Chapter of the Agilent 53181A Operating Guide. These specifications generally apply to very clean input signals, however, so they should only be considered a starting point. Modulation and noise in the heterodyne signal can lead to counting errors at amplitudes above the specified sensitivity levels. For this reason, it is important to check experimentally that the frequency counter is counting reliably. Nevertheless, it is still prudent to check the heterodyne signal amplitude with a spectrum analyzer or oscilloscope prior to data acquisition.

The presence of frequency modulation complicates the determination of the amplitude of the heterodyne signal. Figure 3 shows a simulated heterodyne signal generated by an arbitrary waveform synthesizer. This signal consists of a 10 MHz, 0 dBm sinewave, modulated at a rate of 1 kHz with a peak-to-peak amplitude of 6 MHz. At first glance the signal amplitude appears to be far below the 0 dBm level. Recovering the true 0 dBm amplitude requires integrating the signal over its 6 MHz width. Real heterodyne signals can be integrated in the same way, but obtaining the correct signal amplitude also requires integrating the power in the signal harmonics.

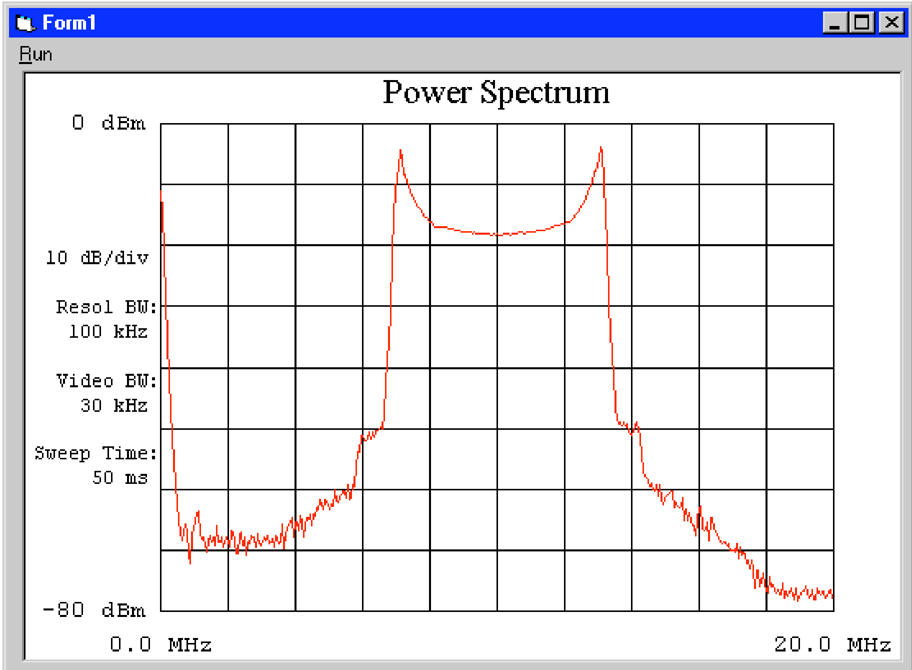


Figure 3: Simulated heterodyne signal

Setting the Avalanche Detector Gain

Reliable counting should be confirmed by changing the signal amplitude (via the BIAS VOLTAGE) and observing changes in the frequency counter values. The frequency counter should produce stable readings for a wide range of signal amplitudes. In general, a decrease in the displayed frequency will be observed when the signal amplitude drops below some critical level. Above this critical level, the displayed frequency should be stable over a 10 – 30 dB range of signal amplitudes. Far above the critical level the displayed frequency may increase. The optimum signal amplitude should be chosen within the stable region, far enough above the critical level so that small amplitude changes do not change the counter values.

Overlapping Wavefronts

Good heterodyne efficiency requires that the two laser beams have similar wavefront curvatures when they strike the active area of the photodetector. This will be the case if the output beams emerging from the two lasers have similar diameters and wavefront curvatures. If not, the beams will evolve differently through the optical system, and the wavefronts may differ greatly at the photodetector. The differing wavefronts then lead to poor heterodyne efficiency.

The optics of the heterodyne system have been designed to properly focus the output beam of a Model 100 Iodine-Stabilized Laser onto the Avalanche Photodetector. Any laser with similar output beam characteristics will also be focused properly onto the photodetector. Lasers with significantly different output beam characteristics may require additional optics, however, to attain proper focus at the photodetector.

Wavefront matching is most easily accomplished by modifying the output beam of the laser under test with one or more lenses before it strikes Mirror #1. Please refer to the Operator's Manual of the reference laser and that of the laser under test for more details about their output beam parameters. More information about modifying beam wavefronts can be found in *Lasers* by A. E. Siegman (University Science Books, 1986), *Quantum Electronics* by A. Yariv (John Wiley & Sons, 1975), or other books which discuss the propagation of Gaussian beams.

Matching Polarizations

Good beam overlap and wavefront matching may still not produce sufficient heterodyne signals if the polarizations of the two lasers do not match. For example, if the reference laser and the laser under test have orthogonal linear polarizations, the resulting heterodyne signal will have a very small amplitude. Polarization matching is easily accomplished using a combination of waveplates and a polarizer.