

ML1 Use case tutorial

07/16/2025



1 Introduction

The ML1 is a calibrated, frequency stabilized, laser source. This stabilization is accomplished through the balancing of intensities of orthogonality polarized modes within a HeNe laser. The gain profile of a HeNe laser in the 632nm regime can be imagined as a gaussian curve with a central peak that is primarily determined by the mixture of Helium and Neon within the laser tube with a full width half maximum of approximately 1.5 GHz as illustrated in Fig. 1. It is reasonable to consider that peak as stable as long as the gas mixture is in a stable state. At MGL, we usually estimate a drift of the ML1 source of approximately 2MHz per year, and recommend a recalibration every two years.

To control the location of the laser modes, the laser tube length is controlled. This is achieved by either applying heat or cooling down the tube. The tube is constructed out of glass, which easily expands and contracts with heat, and the allowed laser mode frequencies are proportional to the laser cavity length as $\text{Laser Frequency} = \frac{\text{Speed of Light}}{2 \times \text{Cavity Length}} \times \text{Mode Number}$. This means that by wrapping a resistive heater around the laser tube and monitoring the two output intensities of the two laser modes, it is possible to keep them at a location where they are equidistant from the more stable central frequency. The current tubes in the ML1 are designed to have approximately 750MHz separation between modes and the coating of the mirrors are birefringent which forces adjacent modes to be orthogonally polarized. Therefore when two modes are found to have equal intensity, they will be located equally on either side of the HeNe peak. Any modes aside from the two highest intensity will have so little gain that they are negligible, and because the modes are orthogonal, they are easily separable and comparable. The schematic of the ML1 is shown in Fig. 2.

At this point it is important to reiterate that the frequency that is calibrated in the ML1 source is the peak frequency of the HeNe gain, and not the output laser modes themselves. These output frequencies are highly dependent on the ambient temperature, as well as other noise sources. That being said, when the two modes are equal, they are equidistant from the calibrated frequency and thus the mean frequency of the two modes can be used to approximate the stable frequency. This

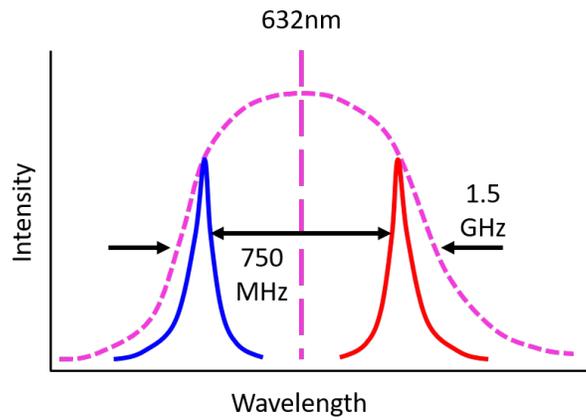


Figure 1: This plot shows the laser modes in a typical ML1 under a standard HeNe gain profile at the 632nm center line.

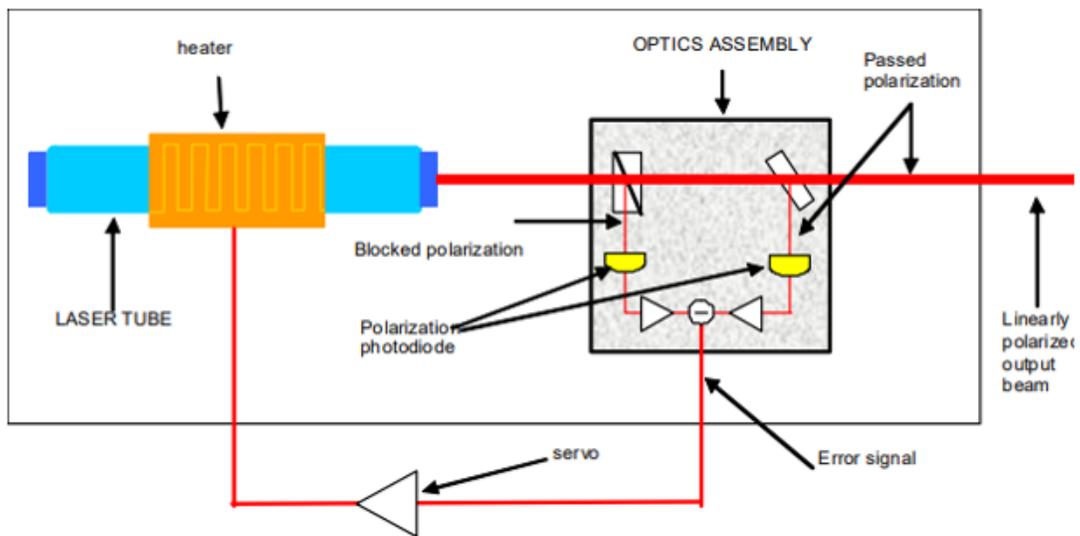


Figure 2: This is the ML1 schematic provided in the associated MGL manual. It is included here as a visual reference. It depicts the heater wrapped around the laser tube and the tube emitting laser light into the passed/blocked detector system that is used to generate the feedback necessary to lock the laser.

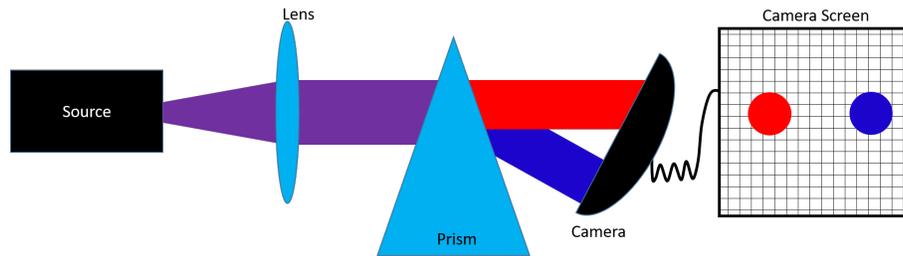


Figure 3: This basic outline of a spectrometer shows a laser source emitting light into a collimating lens, which in turn directs the light into a basic prism. Prisms send different frequencies of light in different directions. In this case, the prism is located in front of a camera which can be calibrated using an ML1 laser source.

mean frequency is what is calibrated at the MGL facility.

While this is the basic principal behind the use of the ML1 in MGL absolute gravity devices, this principal can be used in a variety of applications. In the remainder of this document, we will describe a few basic examples of situations where the ML1 source can be utilized and how.

2 Spectrometer Calibration

Spectrometer calibration is the most obvious and easiest to understand application of the ML1 source. A spectrometer is a device that is used determine the frequency or frequencies of a particular source. There are a wide variety of methods to achieve this, but for simplicity, take the scheme in Fig. 3 using just a prism, which separates light spatially by frequency, and a camera. By looking at where the light hits the camera, you can determine the frequency of the light but only if you know which location on the camera corresponds to which frequency and how far apart two frequencies should be. The ML1 is an ideal source for calibrating this device. We know that our two laser modes are going to be approximately 750MHz apart (This exact separation can vary, but is provided in the data sheet for every MGL produced source). This means that we can shine one mode at a time on the camera and calculate the difference in distance and correlate that back to a difference in frequency. Once we have this measurement, we can also use the mean position between those two locations and assign it the value of the calibrated central frequency. While this method is susceptible to errors arising from nonlinear treatment of frequencies in various spectrometers, these frequencies are close enough to provide calibration on the MHz level.

3 Interferometric Measurements

Interferometric measurements are an obvious use case for the ML1 since this is the basis of an absolute gravity meter. Rather than re-explaining the typical absolute gravity meter, which can be found in their respective manuals, we will instead look at a basic interferometer. In the most



basic Michelson Interferometer there are two equal arms. Light enters the interferometer and is split equally between the two arms. Light travels those two paths and is then recombined and compared. This comparison is known as interference. Light has a property known as phase that records every interaction light undergoes. When one beam is split in two, both new beams have the same phase. If one of these two beams encounters something its twin does not (this can be as simple as traveling a slightly longer or shorter distance), then it will have a different phase than its twin (so now they are no longer twins). When the two beams are then compared (interfered), this difference in phase shows up as light and dark bands known as fringes. In the case of moving a simple distance, a full fringe cycle will be observed every time the distance is changed by one half of a wavelength (the speed of light divided by the frequency). The exact size of a fringe is directly related to light frequency (as are some light interactions). This means that when an ML1 is utilized in one of these types of applications, the experiment should be conducted twice, once per mode, and the results averaged and compared against the calibrated ML1 value. MGL is confident that this will give results similar to those of an atomically stabilized source as we have demonstrated this with our own meters, namely running an FG5x on a WEO-100 and an ML1. The data from the WEO-100 is quieter and you do not have to change modes meaning the data taking process is significantly faster; however, it is possible to achieve similar accuracy by increasing the amount of data taken with the ML1. So while an ML1 has a higher rms value, and thus takes longer to get to the end result, the final accuracy can be similar. This is good news for any customers looking for a more robust and lighter source who can also take a little more time in data collection.

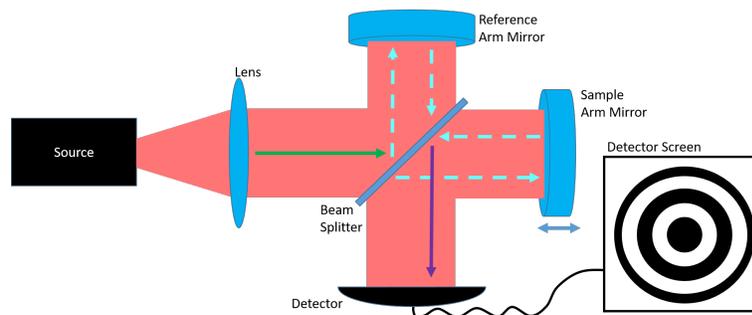


Figure 4: The standard layout of a Michelson interferometer involves a single source emitting light that is collimated and sent into a dual arm system. The beam splitter in the middle splits the initial beam equally into the two arms. The reference arm is kept stable, while the sample arm includes some property to be measured. In the case presented, the small blue arrow next to the reference mirror indicates that the sample mirror is being moved back and forth. The two arms are then recombined at the beam splitter and sent into a detector. Finally, the fringes observed by this detector are depicted for the case where both mirrors are aligned directly along the beam path. If you were to angle one of the mirrors, the fringes would be linear.



4 Wavemeter Calibration

A wavemeter is a method of measuring the wavelength (the speed of light divided by the frequency) by measuring the number of fringes observed by an interferometer as one arm is moved a known distance. The device must move a well characterized distance and must move that same distance every time the device is used, where the laser frequency is determined by Eq. 1.

$$N = \frac{2 \times L}{\lambda} = \frac{2 \times L \times \nu}{c} \quad (1)$$

Here, N is the number of fringes, L is the change in distance, λ is the wavelength, ν is the laser frequency, and c is the speed of light. Another way to operate a wavemeter is to send a known(calibrated) source through the device at the same time as an unknown source and measure the difference in fringes. The basic scheme for this method is shown in Fig. 5. This mode of operation means that the need for a tightly-controlled test arm movement is reduced since it is measured by both the calibrated and uncalibrated laser. The laser frequency is determined by Eq. 2.

$$\nu_{unknown} = \nu_{known} - \frac{(N_{known} - N_{unknown}) \times c}{2 \times L} \quad (2)$$

In both cases, the ML1 can be used as the calibrating source. In the first instance, the ML1 can be used for first one mode and then the other and the two results can be averaged and attributed to the calibrated frequency. In the second instance, the ML1 can be compared against the unknown source twice, once for each ML1 mode. Again the result would be averaged and the result set to the calibrated frequency.

It is worth pointing out that the wavemeter and the ML1 have another mutually beneficial relationship. The exact separation of the two modes of the ML1 are highly sensitive to many factors. One way to get a quick measure of this separation in a given environment would be to measure the modes on a wavemeter and directly measure the frequency separation by counting the observed fringes. Half of this observed frequency difference is the exact offset of one of these modes from the calibrated frequency for that environment at that time. This effectively calibrates the ML1 source to itself for a short period of time.

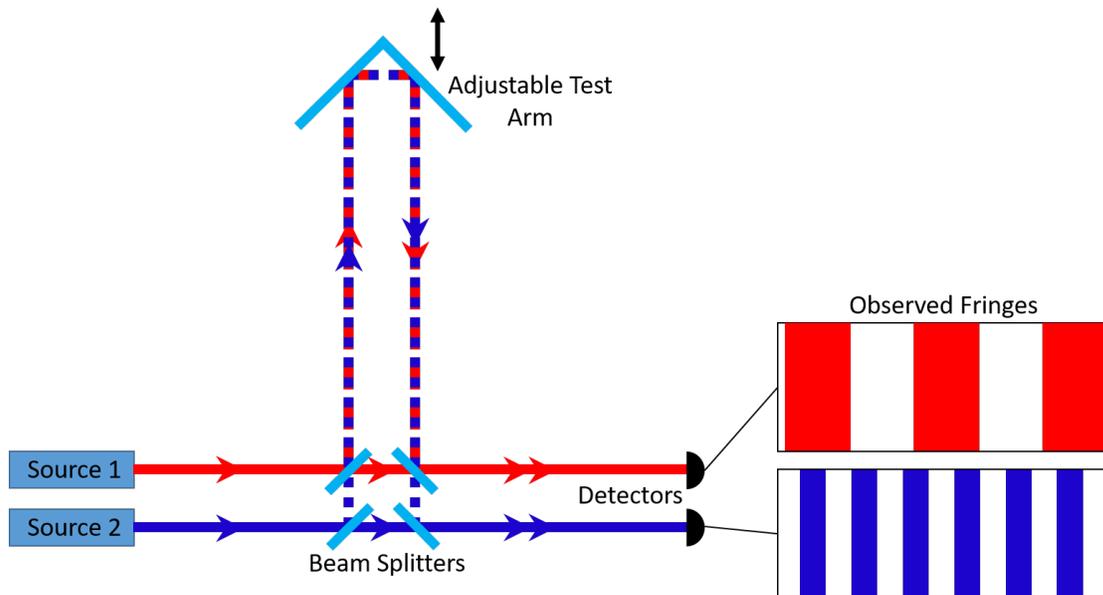


Figure 5: The wavemeter shown here is a dual color system. This simply means that two laser sources used at the same time, one with a known wavelength and one that is unknown. Both lasers are sent into a Mach-Zehnder interferometer. Essentially this means that, at the beam splitter, part of the beam is sent directly along its initial path, and part is sent down a sample path whose length can be changed. Afterwards, the two beams are recombined and the fringes are observed on a detector. As the experiment is performed on two lasers at the same time, by looking at the number of fringes for each laser, the frequency of the unknown source can be determined from the other.