Frequency and Amplitude Fluctuations

The output of a freely oscillating laser will fluctuate in both amplitude and frequency. Fluctuations of less than 0.1 Hz are commonly referred to as "drift"; faster fluctuations are termed "noise" or, when talking about sudden frequency shifts, "jitter."

The major sources of noise in a laser are fluctuations in the pumping source and changes in length or alignment caused by vibration, stress, and changes in temperature. For example, unfiltered line ripple can cause output fluctuations of 5 to 10 percent or more.

Likewise, a 10-μrad change in alignment can cause a 10-percent variation in output power, and, depending upon the laser, a 1-μm change in length can cause amplitude fluctuations of up to 50 percent (or more) and frequency fluctuations of several gigahertz.

High-frequency noise (>1 MHz) is caused primarily by "mode beating." Transverse Laguerre-Gaussian modes of adjacent order are separated by a calculable fraction of the longitudinal mode spacing, typically ~17 MHz in a 1-m resonator with long radius mirrors. If multiple transverse modes oscillate simultaneously, heterodyne interference effects, or "beats," will be observed at the difference frequencies. Likewise, mode beating can occur between longitudinal modes at frequencies of

$$\Delta\nu_{\text{longitudinal}} = \frac{c}{2L} = \frac{c}{2P} \; . \qquad (10.24)$$

Mode beating can cause peak-to-peak power fluctuations of several percent. The only way to eliminate this noise component is to limit the laser output to a single transverse and single longitudinal mode.

Finally, when all other sources of noise have been eliminated, we are left with quantum noise, the noise generated by the spontaneous emission of photons from the upper laser level in the lasing medium. In most applications, this is inconsequential.

METHODS FOR SUPPRESSING AMPLITUDE NOISE AND DRIFT

Two primary methods are used to stabilize amplitude fluctuations in commercial lasers: automatic current control (ACC), also known as current regulation, and automatic power control (APC), also known as light regulation. In ACC, the current driving the pumping process passes through a stable sensing resistor, as shown in figure 10.13, and the voltage across this resistor is monitored. If the current through the resistor increases, the voltage drop across the resistor increases proportionately. Sensing circuitry compares this voltage to a reference and generates an error signal that causes the power supply to reduce the output current appropriately. If the current decreases, the inverse process occurs. ACC is an effective way to reduce noise generated by the power supply, including line ripple and fluctuations.

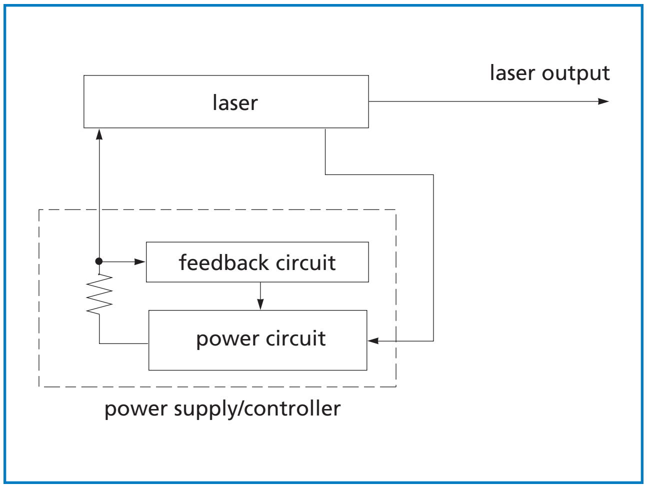


Figure 10.13 **Automatic current control schematic**

With APC, instead of monitoring the voltage across a sensing resistor, a small portion of the output power in the beam is diverted to a photodetector, as shown in figure 10.14, and the voltage generated by the detector circuitry is compared to a reference. As output power fluctuates, the sensing circuitry generates an error signal that is used to make the appropriate corrections to maintain constant output.

Automatic current control effectively reduces amplitude fluctuations caused by the driving electronics, but it has no effect on amplitude fluctuations caused by vibration or misalignment. Automatic power control can effectively reduce power fluctuations from all sources. Neither of these control mechanisms has a large impact on frequency stability.

Not all continuous-wave lasers are amenable to APC as described above. For the technique to be effective, there must be a monotonic relationship between output power and a controllable parameter (typically current or voltage). For example, throughout the typical operating range of a gas-ion laser, an increase in current will increase the output power and vice versa. This is not the case for some lasers. The output of a helium neon laser is very insensitive to discharge current, and an increase in current may increase or decrease laser output. In a helium cadmium laser, where electrophoresis determines the density and uniformity of cadmium ions throughout the discharge, a slight change in discharge current in either direction can effectively kill lasing action.

If traditional means of APC are not suitable, the same result can be obtained by placing an acousto-optic modulator inside the laser cavity and using the error signal to control the amount of circulating power ejected from the cavity.

One consideration that is often overlooked in an APC system is the geometry of the light pickoff mechanism itself. One's first instinct is to insert the pickoff optic into the main beam at a 45-degree angle, so that the reference beam exits at a 90-degree angle. However, as shown in figure 10.15, for uncoated glass, there is almost a 10-percent difference in reflectivity for s and p polarization.

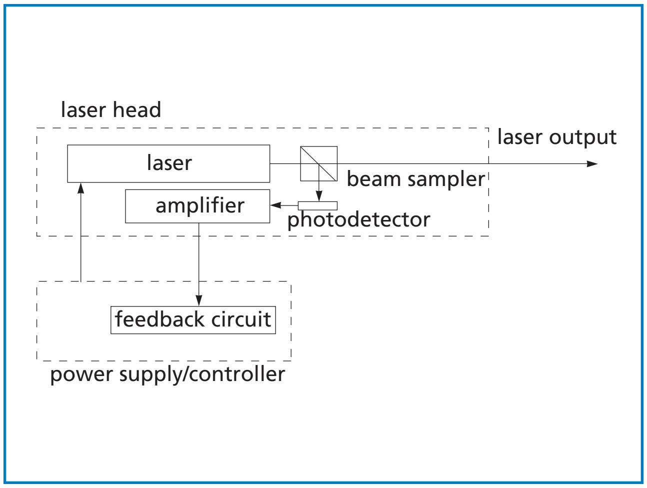


Figure 10.14 **Automatic power control schematic**

In a randomly polarized laser, the ratio of the *s* and *p* components is not necessarily stable, and using a 90-degree reference beam can actually increase amplitude fluctuations. This is of much less concern in a laser with a high degree of linear polarization (e.g., 500:1 or better), but even then there is a slight presence of the orthogonal polarization. Good practice dictates that the pickoff element be inserted at an angle of 25 degrees or less.

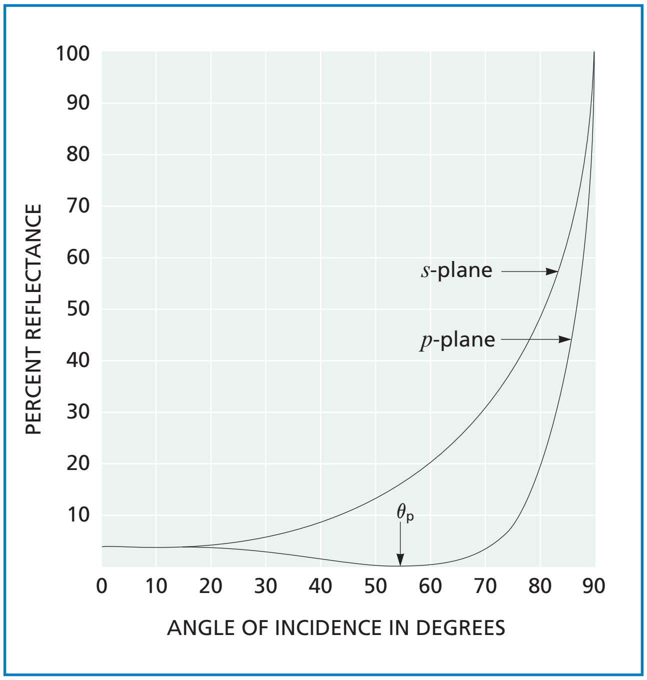


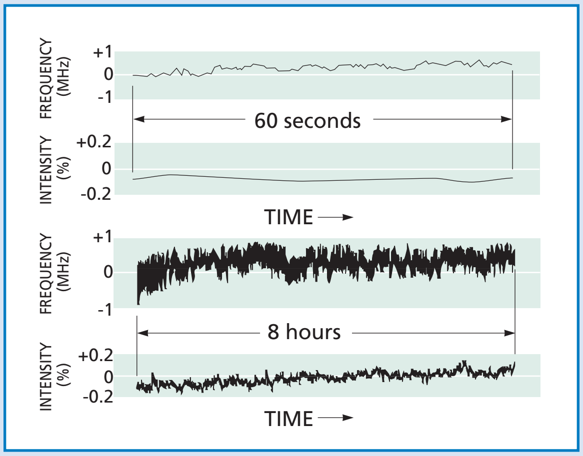
Figure 10.15 **Reflectivity of a glass surface vs. incidence angle for *s* and *p* polarization**

APPLICATION NOTE

Measuring Frequency Stability

The accepted method of measuring long-term frequency stability is to heterodyne the laser to be tested with another laser of equal or greater stability. By observing the variation of the resulting beat frequencies, the combined drift of the two lasers can be measured. The results will be no better than the sum of the two instabilities and will, therefore, provide a conservative measure of frequency drift.

In the charts below, a frequency-stabilized HeNe was hetrodyned with the output from a Zeeman-stabilized laser. The charts show the performance over one minute and over an eight-hour typical workday. The laser can be cycled over a 20°C temperature range without mode hopping.



Short- and long-term frequency stability of a frequency stabilized helium neon laser