Q: What is an *autocollimator*?

A: This FAQ discusses the principles of operation of an autocollimator.

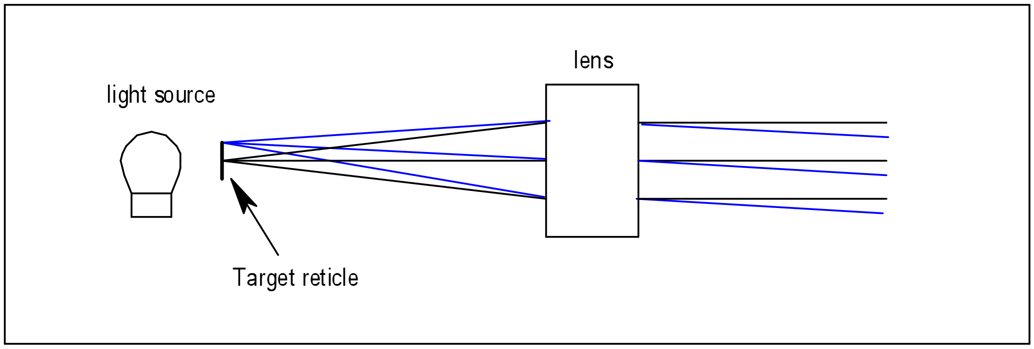

Figure 1: start with a simple collimator

Let's start with a simple collimator. (If you are not familiar with the operation of a collimator it may be helpful to refer to the FAQ titled "tutorial on collimator"). In this FAQ we'll only consider the case where the reticle consists of a single pinhole.

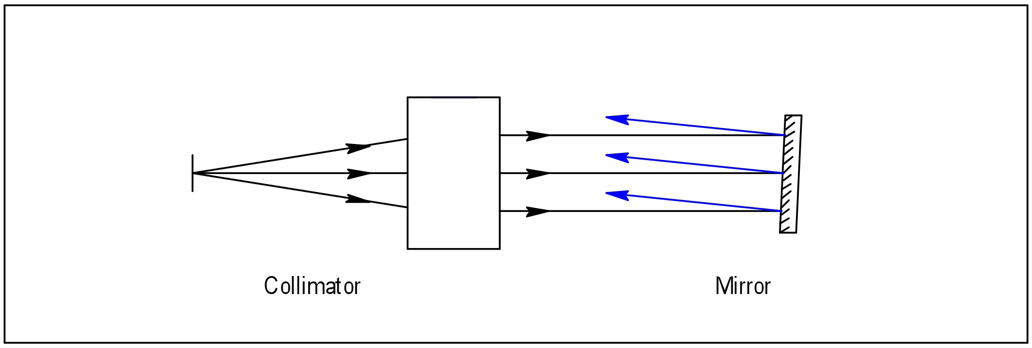

Figure 2: Add a mirror

Now consider what happens to the beam after it is reflected:

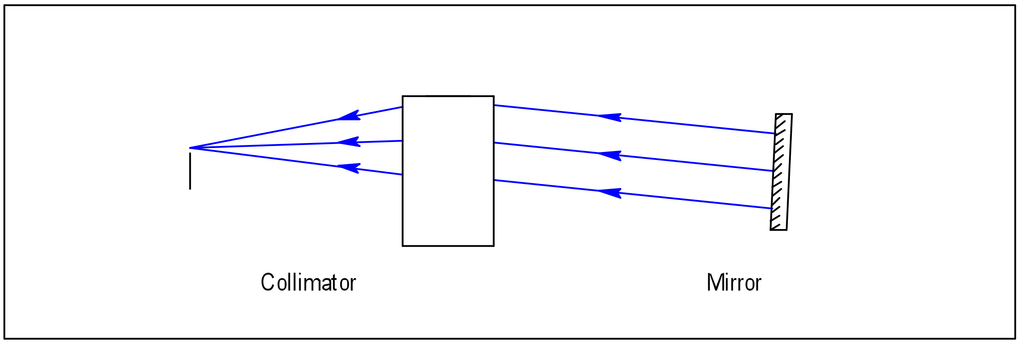

Figure 3: reflected beam

For simplicity, lets concentrate on the reflected beam only. The beam passes back through the lens and forms an image on the reticle. If the mirror is tipped, the reflected beam will not return to the center of the reticle.

We still have a few steps to go to turn the example into an autocollimator, but we can already note some important points:

- If the mirror is tipped by an angle **A**, the return beam is deviated by an angle **2A**
- If the collimator focal length is **F**, the image of the return beam is displaced by **2AF**
- If the mirror is tipped by too large an angle, part (or all) of the reflected beam will miss the lens.

Of course the problem with the simple example is that we have no way to "see" the return spot on the reticle. To remedy this problem, let's add a beamsplitter (a partially reflective mirror.) This will change our collimator into an ***autocollimator*.**

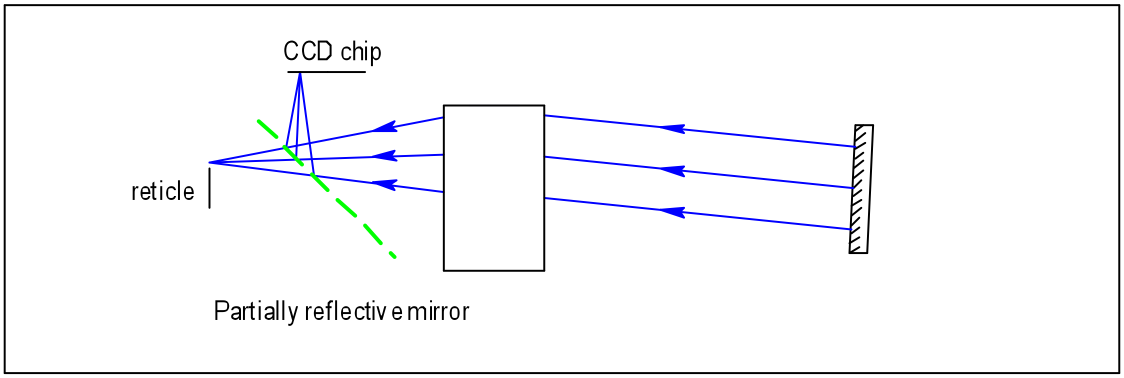

Figure 4: Add a partially reflective mirror

Figure 4 shows a CCD chip, but we could just as well use an eyepiece or a PSD (position-sensitive photodiode). The essential point is that the image is displaced by an amount proportional to the tilt of the mirror.

Numerical example:

- Assume the collimator focal length is 200 mm
- Assume the mirror is tipped by 1 milli-radian (about 1/16 degree)
- Assume the CCD pixels are 7.4 microns square
- The return beam is tipped by an angle of 2A, or 2 milli-radians
- The image at the CCD is displaced by 2AF or 400 microns

400 microns corresponds to 54 pixels on the CCD chip. This will be easily visible!

Another numerical example

- Same setup but with <u>1 arc-second</u> tilt of the mirror (about 5 micro-radians)
- The *return* beam is tipped by an angle of **2A**, or 2 arc-seconds
- The image at the CCD is displaced by **2AF** or about 2 microns.

This is about 0.3 pixel. Such a small displacement would be hard to see on the computer screen, but can easily be measured with PixelScope image processing software.

Field-of-view

As the examples suggest, the autocollimator is able to measure extremely small tip angles.

However, nothing comes for free, and there is a price to this sensitivity: the autocollimator field-of-view is quite small. It is not particularly useful for measuring an angle of 20 degrees[1]!

If the angle of the return beam is too great the image will simply miss the CCD chip entirely. The CCD chip used in the WRD autocollimators is 3.6 mm high and 4.8 mm wide. This suggests that under normal circumstances we should keep the beam within about 1.75 mm of the center of the chip.

With a 200 mm collimator, this corresponds to an angle of 0.5 degrees for the return beam.

Working distance

If the mirror is located too far away, the return beam may miss the autocollimator entirely. At intermediate distances only part of the beam may be lost. Whether this is a problem depends on the application. Let's look at a numerical example:

Practical example:

Consider the situation where the autocollimator is used as a null-measuring instrument: we will use the autocollimator to adjust the tip of a mirror. We want to adjust the mirror until the return beam is exactly centered on the CCD. We are not particularly interested in measuring large angles. As long as *some* of the return beam reaches the CCD we will know which way to tip the mirror. Then we'll adjust the mirror to center the return beam.

However, when we begin the process, the mirror may be tipped by an arbitrary amount. If the tip is too large then we won't be able to see the return beam. Let's say we believe the initial tip will be 0.5 degree or less. How far away can we place the mirror?

The 200 mm WRD collimator has a clear aperture of 0.90 inch. If the beam were displaced by 0.4 inches then somewhat less than half of the returning light would be captured. For the sake of the example let's assume we are willing to tolerate this much loss. If we know the angle of the return beam will be less than 0.5 degrees, then we'll need to keep the working distance to 60 inches or less[2].

[1] The autocollimator cannot measure large angles directly. However, if you have a sine-bar or some other angular reference, the autocollimator can be used to measure the *difference* between the known standard and another surface.

[2] The examples given so far suggest that the autocollimator can measure very small angles at rather large distances. This is true, but in some cases the <u>useful</u> working distance will be smaller because of air-path noise.

We are all familiar with the way the image of an asphalt highway can shimmer on a hot day. Such "mirage" effects occur on a smaller scale whenever the air-path is not perfectly uniform. A full discussion is beyond the scope of this FAQ, but a caution is in order: merely placing one's hand near the beam may be all that is needed to spoil a sensitive measurement.