Purpose:

To use the Doppler shift of a returned radar echo from Mercury to determine the velocity at which its surface is rotating, and thus to determine its rotation period.

Introduction:

Since Mercury is a small planet whose surface features have low contrast, and because it is so close to the Sun that it is rarely visible against a dark sky, it is difficult to determine how fast it is rotating merely by looking at it from Earth. In recent years, however, radar techniques have proven most effective in measuring its speed of rotation. The method you will employ here actually has wider applications than just the measuring of the rotation of Mercury. It can be used to study the behavior of other planets as well, from cloud covered Venus, to the rings of the major planets, to the smallest asteroids.

The basic idea is to use a radio telescope to send a short pulse of electromagnetic radiation of known frequency towards the planet Mercury and then to record the spectrum (frequency vs. intensity) of the returning echo. Depending on the relative position of the Earth and Mercury, the pulse will take between 10 minutes and half an hour to travel to Mercury, bounce off, and return.

By the time the pulse has reached Mercury, it has spread out to cover the entire planet. Because the planet's surface is a sphere, the pulse hits different parts of the planet at different times. The pulse first hits the surface at a point directly on a line between the centers of the Earth and Mercury (the "sub-radar point"), and a few microseconds later on points further back, toward the edges of the planet. Thus we wait for the first echo, from the sub-radar point, and then by looking at the returning echoes at succeeding times, each a few microseconds later than the next, we get information about different parts of Mercury's surface.

The frequencies of the returning echoes are different from the frequency of the pulse sent out because the echoes have bounced off the moving surface of Mercury. Any time a source of radiation is moving radially (directly towards or away from the observer) there will be a Doppler shift in the received frequency that is proportional to the velocity along the line of sight.

There are two motions of Mercury that can produce such a shift. One is its orbital velocity as a whole around the Sun, and the other is its rotation around its axis. The first echo, from the sub-radar point, is shifted in frequency only by the orbital velocity of the planet as a whole. We can calculate how fast the planet is moving with respect to the Earth from the amount of the shift, but we can't tell how fast it is rotating (spinning) because the component of the rotational velocity of the surface of Mercury is perpendicular to our line of sight at this point (Figure 1), and so there is no additional frequency shift. The echoes that come in after the sub-radar echo, however, show additional shifts because they come from further back where the rotational velocity is more directly along our line of sight. Because of the rotation of Mercury, one edge of the planet is moving towards us a little
faster than the planet as a whole, and the other edge is moving away from us a little slower. So due to the Doppler effect, part of the returning echo (from the faster moving edge of Mercury) is at a slightly higher frequency, and part of the returning echo (from the slower moving edge) is at a slightly lower frequency (Figure 2).

We measure the amount of this frequency shift and apply our knowledge of the Doppler effect to calculate the velocity of the surface of Mercury, and from this, its period of rotation.