Using Doppler Shifts of GPS Signals To Measure Angular Speed

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A method has been proposed for extracting information on the rate of rotation of an aircraft, spacecraft, or other body from differential Doppler shifts of Global Positioning System (GPS) signals received by antennas mounted on the body. In principle, the method should be capable of yielding low-noise estimates of rates of rotation. The method could eliminate the need for gyroscopes to measure rates of rotation.

The method is based on the fact that for a given signal of frequency \( f \) transmitted by a given GPS satellite, the differential Doppler shift is attributable to the difference between those components of the instantaneous translational velocities of the antennas that lie along the line of sight from the antennas to the GPS satellite. On the basis of straightforward geometric considerations (see figure), it can be readily shown that the differential Doppler shift is related to the angular velocity \( \omega \) of the rotating body by

\[
f_1 - f_2 = 2f_s (\omega \times \mathbf{r}) \cdot \mathbf{a} / c,
\]

where \( f_1 \) and \( f_2 \) are the instantaneous Doppler-shifted frequencies of the replicas of the ft signal received by the two antennas, \( \mathbf{r} \) is half of the baseline vector between the two antennas, \( \mathbf{a} \) is a unit vector along the line of sight from the antennas to the GPS satellite, and \( c \) is the speed of light.

It must be noted that the equation above can be solved to obtain only partial information about \( \omega \). However, if there are three or more antennas and if signals can be received from two or more GPS satellites, then one can form simultaneous independent equations for different pairs of antennas and different unit vectors that can be solved to obtain all of the components of \( \omega \).
It is assumed that the received $f_{r1}$ and $f_{r2}$ signals would be subjected to the usual GPS processing, including phase-shifting and cross-correlation with the applicable GPS pseudorandom-noise code for acquisition and tracking. To obtain the differential Doppler frequency $f_{r1} - f_{r2}$ for a given antenna pair and a given GPS satellite, the $f_{r1}$ and $f_{r2}$ signals would be fed to a multiplier. By virtue of the trigonometric identity for the product of sines of different arguments, the low-frequency multiplier output would be a sinusoidal waveform of frequency $f_{r1} - f_{r2}$. For high accuracy, the multiplier output could be fed to a subsystem containing a zero-crossing detector coupled with a counter driven by a quartz-crystal clock circuit. Such a subsystem could accumulate counts over times long enough to enable estimation of periods of rotation to within microseconds.

This work was done by Charles E. Campbell, Jr., of Goddard Space Flight Center. Further information is contained in a TSP (see page 1).

This invention has been patented by NASA (U.S. Patent No. 6,593,879). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center, (301) 286-7351. Refer to GSC-14087-1.

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**Monitoring Temperatures of Tires Using Luminescent Materials**

Hot spots are detected and monitored as indications of local damage.

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A method of noncontact, optical monitoring of the surface temperature of a tire has been devised to enable the use of local temperature rise as an indication of potential or impending failures. The method involves the use of temperature-sensitive paint (or filler): Temperature-sensitive luminescent dye molecules or other luminescent particles are incorporated into a thin, flexible material coating the tire surface of interest. (Alternatively, in principle, the luminescent material could be incorporated directly into the tire rubber, though this approach has not yet been tested.) The coated surface is illuminated with shorter-wavelength light to excite longer-wavelength luminescence, which is observed by use of a charge-coupled-device camera or a photodetector (see Figure 1).

If temporally constant illumination is used, then the temperature can be deduced from the known temperature dependence of the intensity response of the luminescence. If pulsed illumination is used, then the temperature can be deduced from the known temperature dependence of the time or frequency response of the luminescence. If sinusoidally varying illumination is used, then the temperature can be deduced from the known temperature dependence of the phase response of the luminescence.

Unlike a prior method of monitoring the temperature at a fixed spot on a tire by use of a thermocouple, this method is not restricted to one spot and can, therefore, yield information on the spatial distribution of temperature: in particular, it enables the discovery of newly forming hot spots where damage may be starting. Also unlike in the thermocouple method, the measurements in this method are not vulnerable to breakage of wires in repeated flexing of the tire. Moreover, unlike in another method in which infrared radiation is monitored as an indication of surface temperature, the luminescence measurements in this method are not significantly affected by changes in infrared emissivity.

This method has been demonstrated in application to the outside surface of

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**Two Antennas on a Rotating Body** would have different components of velocity along the line of sight to a GPS satellite, giving rise to different Doppler shifts of the two received GPS signals.