

would enable measurement of distances to more than 50 targets at an update rate >10 Hz, without a requirement for *a priori* knowledge of target geometry.

The apparatus (see figure) includes a laser ranging unit (LRU) that includes an electronic camera (photo receiver), the field of view of which contains all relevant targets. Each target, mounted at a fiducial position on an object of interest, consists of a small lens at the output end of an optical fiber that extends from the object of interest back to the LRU. For each target and its optical fiber, there is a dedicated laser that is used to illuminate the target via the optical fiber. The targets are illuminated, one at a time, with laser light that is modulated at a frequency of 10.01 MHz. The modulated laser light is emitted by the target, from where it returns to the camera (photodetector), where it is detected.

Both the outgoing and incoming 10.01-MHz laser signals are mixed with

a 10-MHz local-oscillator to obtain beat notes at 10 kHz, and the difference between the phases of the beat notes is measured by a phase meter. This phase difference serves as a measure of the total length of the path traveled by light going out through the optical fiber and returning to the camera (photodetector) through free space.

Because the portion of the path length inside the optical fiber is not ordinarily known and can change with temperature, it is also necessary to measure the phase difference associated with this portion and subtract it from the aforementioned overall phase difference to obtain the phase difference proportional to only the free-space path length, which is the distance that one seeks to measure. Therefore, the apparatus includes a photodiode and a circulator that enable measurement of the phase difference associated with propagation from the LRU inside the fiber to the target, reflection from the fiber end,

and propagation back inside the fiber to the LRU. Because this phase difference represents twice the optical path length of the fiber, this phase difference is divided in two before subtraction from the aforementioned total-path-length phase difference.

Radiation-induced changes in the photodetectors in this apparatus can affect the measurements. To enable calibration for the purpose of compensation for these changes, the apparatus includes an additional target at a known short distance, located inside the camera. If the measured distance to this target changes, then the change is applied to the other targets.

This work was done by Carl Christian Liebe, Alexander Abramovici, Randall Bartman, Jacob Chapsky, John Schmalz, Keith Coste, Edward Litty, Raymond Lam, and Sergei Jerebets of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-43240

Tachometers Derived From a Brushless DC Motor

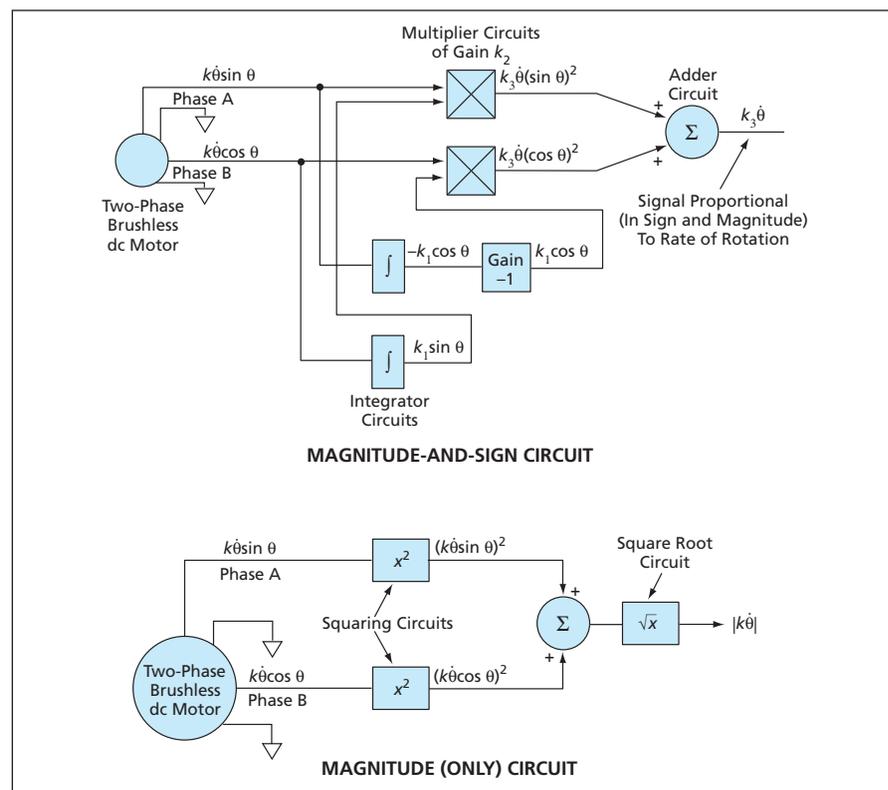
Neither excitation of the motor nor mechanical brushes is necessary.

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The upper part of the figure illustrates the major functional blocks of a direction-sensitive analog tachometer circuit based on the use of an unexcited two-phase brushless dc motor as a rotation transducer. The primary advantages of this circuit over many older tachometer circuits include the following:

- Its output inherently varies linearly with the rate of rotation of the shaft.
- Unlike some tachometer circuits that rely on differentiation of voltages with respect to time, this circuit relies on integration, which results in signals that are less noisy.
- There is no need for an additional shaft-angle sensor, nor is there any need to supply electrical excitation to a shaft-angle sensor.
- There is no need for mechanical brushes (which tend to act as sources of electrical noise).
- The underlying concept and electrical design are relatively simple.

This circuit processes the back-electromagnetic force (back-emf) outputs of the two motor phases into a voltage directly proportional to the instantaneous rate (sign · magnitude) of rota-



These Analog Tachometer Circuits perform straightforward operations on the back-emf outputs of a brushless dc motor to generate voltages proportional to the rate of rotation of the shaft.

tion of the shaft. The processing in this circuit effects a straightforward combination of mathematical operations leading to a final operation based on the well-known trigonometric identity $(\sin x)^2 + (\cos x)^2 = 1$ for any value of x . The principle of operation of this circuit is closely related to that of the tachometer circuit described in "Tachometer Derived From Brushless Shaft-Angle Resolver" (MFS-28845), *NASA Tech Briefs*, Vol. 19, No. 3 (March 1995), page 39. However, the present circuit is simpler in some respects because there is no need for sinusoidal excitation of shaft-angle-resolver windings.

The two back-emf signals are $k \dot{\theta} \sin \theta$ for phase A and $k \dot{\theta} \cos \theta$ for phase B, where k is a constant that depends on the electromagnetic characteristics of the motor, θ is the instantaneous shaft angle, and the overdot signifies differentiation with respect to time. Note that $\dot{\theta}$ is the quantity that one seeks to measure.

Each back-emf signal is fed to one of two inputs of a multiplier circuit of gain k_2 dedicated to its respective phase. Each of these signals is also integrated with a suitable time constant and gain to obtain a voltage of $k_1 \sin \theta$ for phase A and $-k_1 \cos \theta$ for phase B (where k_1 is a constant that incorpo-

rates the combined effects of the gain and the time constant). The output of the integrator for phase B is inverted to obtain a voltage $k_1 \cos \theta$. Each of these signals is fed to the other input terminal of the multiplier circuit for its respective phase.

The multiplier circuit for phase A thus generates an output signal proportional to both of its inputs; namely $k_3 \theta (\sin \theta)^2$, where $k_3 = k_1 k_2$. In a similar manner, the multiplier circuit for phase B generates an output signal of $k_3 \theta (\cos \theta)^2$. These signals are fed to an adder circuit. By virtue of the identity $(\sin \theta)^2 + (\cos \theta)^2 = 1$, the output of the adder is simply $k_3 \theta$.

The lower part of the figure illustrates the major functional blocks of a direction-insensitive analog tachometer that, except for its lack of directionality, offers the same advantages as does the analog tachometer described above. However, this circuit is conceptually simpler in that it does not contain integrators.

This circuit processes the back-emf outputs of the two motor phases into a voltage directly proportional to magnitude of the instantaneous rate of rotation of the shaft. As in the circuit described above, the processing in this circuit effects a straightforward combination of mathematical operations

leading to a final operation based on the identity $(\sin x)^2 + (\cos x)^2 = 1$ for any value of x .

Further as in the circuit described above, the two back-emf signals are $k \dot{\theta} \sin \theta$ for phase A and $k \dot{\theta} \cos \theta$ for phase B, where k is a constant that depends on the electromagnetic characteristics of the motor. In the present case, the quantity that one seeks to measure is $|\dot{\theta}|$.

Each back-emf signal is fed to a dedicated squaring circuit. The outputs of the squaring circuits for phases A and B are thus proportional to $(\dot{\theta} \sin \theta)^2$ and $(\dot{\theta} \cos \theta)^2$. The outputs of the squaring circuits are fed to an adder. By virtue of the identity $(\sin \theta)^2 + (\cos \theta)^2 = 1$ the output of the adder is proportional to $\dot{\theta}^2$; this output is fed to a square-root circuit to obtain a final output proportional to $|\dot{\theta}|$.

This work was done by David E. Howard and Dennis A. Smith of Marshall Space Flight Center. Further information is contained in a TSP (see page 1).

This invention has been patented by NASA (U.S. Patent No. 6,084,398). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-31142/3.