SECTION I, ENGINEERING SCIENCE

A Solar Aspect Sensor For Spinning Rockets

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The altitude-time trajectory of a rocket may be obtained by double integration of the longitudinal acceleration. The acceleration data is obtained from longitudinal accelerometers and telemetered to ground based recording stations. (Cooper, 1963). If the true attitude of the rocket is known at the time corresponding to the longitudinal acceleration, a more accurate trajectory analysis can be made. This is based on the assumption that the acceleration is in the direction of the rocket axis and that there is zero angle of attack.

The knowledge of the attitude of a rocket or satellite is also useful for many scientific investigations when the vehicle is in the higher regions of the atmosphere where data are being taken. There are various types of aspect sensing systems being used currently in work with rockets, satellites, and space probes. Among the systems presently being used are magnetic and solar aspect sensors, magnetic and horizon sensors, earth sensors and combinations of these devices. The gyroscope or stable platform is a well known attitude determining device but in many cases its cost makes its prohibitive. Within certain limitations the attitude of a rocket can be determined by measuring the angle between the rocket axis and a line to the sun and the angle between the rocket axis and a line parallel to the earth's magnetic field. The attitude of the vehicle may most readily be obtained by the use of the direction cosines of these solar and magnet vector angles. (Cooper, 1964).

Solar and magnetic aspect devices are commercially available. Many of the solar instruments are structurally complicated and cost prohibits their use in many cases. This paper describes a solar aspect angle measuring device that is simple, inexpensive, and reasonably accurate.

If a vertical slit were cut through the skin surface of a rocket and a photo-electric optical sensor placed behind the slit, the sensor would receive an impulse of light from the sun each time the sensor and the slot were in alignment with the sun as the rocket spins on its axis. All rockets are fired with a certain amount of roll to improve stability and the roll rate may be determined by such an optical slit system. If another light impulse can be made to follow the impulse from the vertical slot by an amount of angular rotation, which is a function of the angle between the rocket axis and the sun, the solar aspect angle can be obtained. This may be done by cutting another slit diagonally with the rocket axis on the skin surface of the rocket. The sun light will energize the same sensor that it energizes through the vertical slit, or it may energize another sensor. The point along the diagonal slit at which the sensor and the sun are in alignment will represent an angle of rotation which is a function of the solar vector angle. If the roll rate of the rocket is assumed to be constant, the ratio of the time between the two impulses from the sun received by the sensors to the time required for a complete roll of the rocket can be used as solar aspect data. This principle is used for the design of the solar aspect sensor described here.

The photosensors used are Philco L4412 silicon junction devices which are encapsulated in small glass envelopes. They are designed primarily for use in punched card reading machines and other optical sensing devices. The response curve of the sensors favors the infra-red region of the

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optical spectrum. The Philco L4412 sensor is actually a photo-voltaic device which generates a voltage when receiving electromagnetic radiation in the form of light. The devices will supply 0.050 milliamperes of current into a 1000 ohm load when illuminated from a 600 foot-candle source. Since the sun provides an intensity of illumination of some 10,000 foot candles, there is adequate intensity for the sensor even when the light beam is not normal to the sensitive area of the photosensor.

The solar aspect sensor described here uses two slits, a vertical slit called the reference slit, and a diagonal slit used for measuring the solar vector angle. Located in back of these slits are three silicon junction photosensors. Each of the three sensors is in view of the sun over a specified range of solar vector angles, and only the upper and lower sensors can view the sun through the reference slit. The design of the prototype aspect sensor unit is such that the total included angle of the solar vector that can be measured ranges between seven and 117 degrees off the rocket axis.

Figure 1 shows sketches of an aspect sensor unit and how each photosensor is used to receive impulses from the sun. The total range of angles is shared by the three sensors as shown. As the rocket rotates and the solar impulses are detected by the photosensing devices, a transistor amplifier circuit is used to condition these signals so that they can be fed to the telemetry system. These signals appear on the telemetry in the form of pulses, one pulse being the reference pulse and the following pulse being the delayed pulse representing the solar vector angle. The electronic circuit was devised so that the signal from the lower or the upper sensors, which are the same ones used for the reference pulse, have a lower voltage amplitude than the signal from the middle sensor. This makes it easy to identify the signals in order to know what range of solar angles is being presented.

Since the first models of the solar aspect sensors were to be flown on Aerobee rockets they were tailored for these rockets. Also since the first units were going through a feasibility phase of their development they were designed to occupy space which was readily available and which would require no structural modifications of the rocket. The solar aspect sensors were designed to occupy the space behind doors which are used for access to fuel valves and other motor adjustments. The slits were cut in the surface of the doors as illustrated in Figure 2. The locations of the photosensors within the box-type enclosure behind the curved access door were arranged so that the viewing angle to the sun would not be obscured by the tail fin which is adjacent to one side of the door. This causes the useful rotation angle of the aspect sensor to be nonsymmetrical with respect to the aspect sensor center line. This does not harm the design nor performance of the device, however.

The electronic circuit used in conjunction with the solar aspect sensors is illustrated schematically in Figure 3. Three silicon type 2N338 high-beta transistors are used. One is an input amplifier for the upper and lower photosensors. Another is an amplifier for the middle sensor, while a third transistor is a mixer-buffer which provides a signal to the input of the FM/FM telemetry channel.

Since the 2N338 transistors are high current-gain devices, the collector circuit of transistor, Q101, is almost saturated with current, established by the small amount of base current provided from the six-volt source through resistor, R101. The transistor input resistance is small compared to R101, therefore the base current through the 470 kilohm resistor is 11.5 microamperes. Referring to the characteristic curves of the transistor, it can be seen that 220 microamperes of current will flow in the collector circuit of Q101 through R102. This will place the collector of the transistor at a voltage slightly above zero as shown by the intercept of the 27 kilohm load line with the saturation characteristic. The forward base-to-emitter voltage, V_{BE}, for a silicon transistor is in the order of 0.6 volts. This voltage is appled across the photosensor in reverse direction, and when dark, the photosensor represents a high impedance. When photosensor, CR101 or CR102, receives light it generates a voltage which

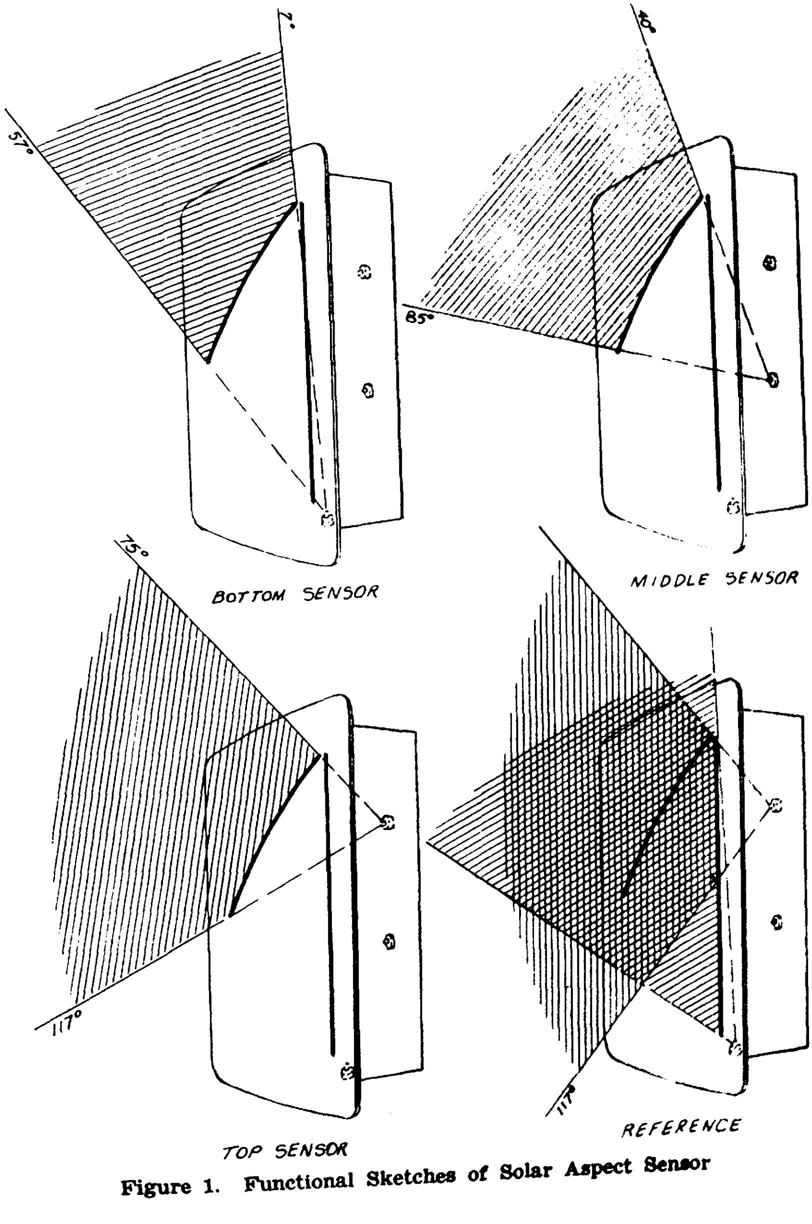

Figure 1. Functional Sketches of Solar Aspect Sensor

aids the current through R101, and since the voltage drop across the photosensor is much less than V_{BE} of Q101, the transistor loses base current while CR101 conducts, and the collector current of Q101 approaches zero. This causes the voltage at the collector of Q101 to approach the six-volt power source level representing the condition when the photosensor receives a signal from the sun through the optical slits in the solar aspect sensor.

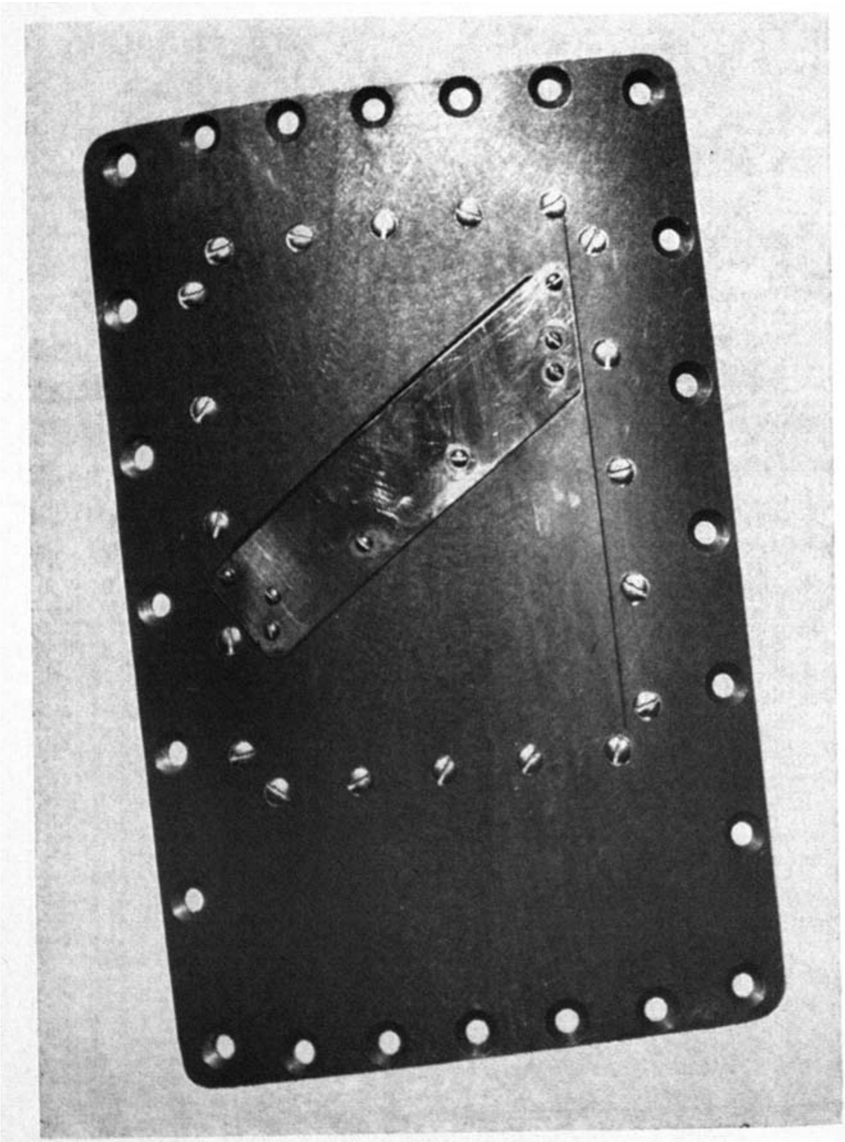

Figure 2. Outside Surface of Solar Aspect Sensor

The input circuit for the middle photosensor, CR103, functions in a manner similar to that for CR101 and CR102 using transistor, Q102. The output signal voltages from the collectors of Q101 and Q102 are mixed at the input of transistor, Q103, by means of mixing resistors, R105 and R107. The values of R105 and R107 are chosen so that the output voltage from the emitter of Q103 will be approximately 0.5 volts for the upper and lower photosensors and 1.5 volts for the middle sensor.

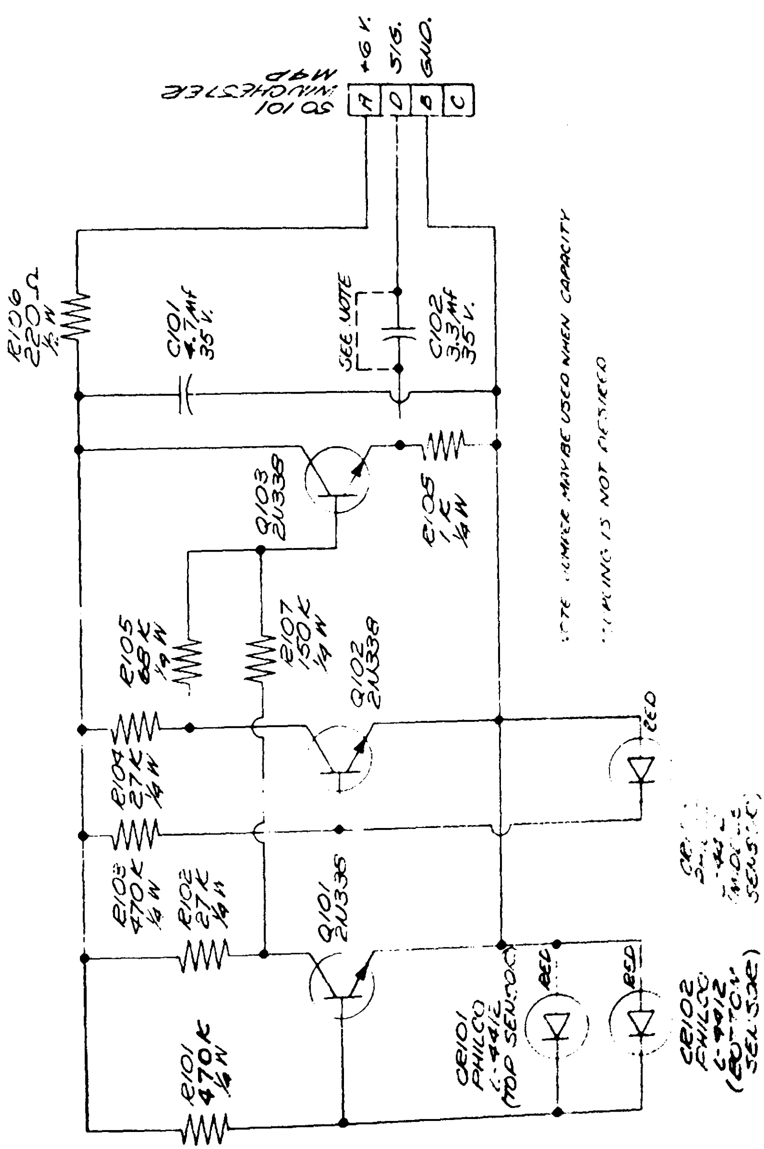

Figure 3. Schematic Diagram. Electronic Circuit

The total amount of current normally required to operate the electronic circuit for the solar aspect sensor unit is approximately 1.5 milliamperes. If a one-thousand milliampere-hour mercury battery is used as a power source, some seven hundred hours of operation are available before the battery is exhausted. A 5.4 volt mercury battery was used for two of the Aerobee rocket flights used in testing the feasibility of this solar aspect device at White Sands Missile Range, New Mexico.

Silicon transistors were used in this circuit so that it would be more stable over a wide range of temperatures. It was not expected that the circuit would be subjected to a rigid temperature environment, but tests were made to determine the range of operating temperature. No problems were encountered at temperatures as high as 65°C. At low temperatures the output voltage levels were decreased as a result of the decreased current amplification factor, beta, of the transistors. Resistors, R101 and R103, in the base circuits of the input transistors, Q101 and Q102, were chosen so that the transistors were not normally too heavily saturated. This was done to preserve the circuit sensitivity to light signals to the photosensor. At low temperatures where beta is reduced, the voltage drop, V_{CE}, is greater than at higher temperatures, and this reduces the output signal deflection. The signals are further reduced at the output of the emitter follower, Q103, because of the reduced current gain of that transistor. The circuit performs well at temperatures as low as -40 degrees, and it was not expected that this low temperature would be encountered during the useful portion of a rocket flight.

Since the output data from the solar aspect sensors are in the form of pulses, it is desirable that the center frequency of the subcarrier oscillator for the FM/FM telemetry be as high as possible. By using a high center frequency with a wide bandwidth, one can more faithfully preserve the rise-time characteristics of the signal pulses so that data can be read from the telemetry records more accurately. If a signal pulse from the solar aspect sensor unit represents one degree of rocket roll and the roll rate is two revolutions per second, then the pulse would be approximately 1.4 milliseconds of duration. In order to reproduce accurately the leading edge of this pulse, the subcarrier frequency should be at least as high as 14.5 KC. There are other limitations in reading out data from the telemetry, such as the response of the galvanometers being used in the recorder and the recorder paper speed.

To calibrate the solar aspect sensors in terms of solar vector angles, a calibration set-up was constructed which could be used to duplicate the roll of a rocket. The calibration device can be tilted in the presence of the sun to vary the solar vector angles.

No telemetry circuits are necessary in taking calibration data. Instead, a dc voltmeter is used to locate the leading edges of the solar impulses as the device is slowly rotated in the presence of the sun.

The sun may be used as an accurately positioned source of light for use in calibrating the aspect sensor. The physical location of the sun can be calculated from spherical trigonometry by knowing the latitude and the longitude at the observing point and the Greenwich hour angle and declination of the sun as obtained from a nautical almanac.

Literature Cited

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