definitive determination of the gravity field and do not necessarily span the useful operating life of the satellite. The count of the anomalistic revolution number N, however, still begins with the first perigee passage.

One word of caution is needed about the use of these elements. The elements describe a precessing ellipse which has the best rms fit to an accurately computed orbit over a time span of 24 hr. The epoch of each set of elements is the last perigee passage before the beginning of the time span. In the fitting process, the elements are assumed constant except for the argument of perigee ω and the longitude of the node Ω, which are assigned constant time derivatives (the precession rates). As a consequence, the semimajor axis a, the eccentricity e, and the inclination i are the averages of these quantities over the time span and to high approximation are the values of these quantities at the center of the time span. Thus they belong to an epoch different from the epoch given in the tables. Further, the derivatives of perigee ω, the node Ω, and the time of perigee t_p themselves belong to the later epoch. If one intends to use these elements for the purpose of studying their variations, the values for ω, Ω, and t_p should be carried forward in time, using their theoretical time derivatives, by an amount equal to 12 hr plus one-half of a period. Since the beginning of a fitting span occurs at random with respect to perigee, this process leaves "noise" in the elements equivalent to the changes in the elements during one-half of a period. It is regretted that we did not realize how significant the changes in the elements within 12 hr can be when we fixed the procedure for fitting the elements.

References

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Design of a Total Radiation Thermopile Detector

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EFFECTIVE thermal balance testing in a space simulation chamber requires the measurement and control of irradiance (the total radiant power per unit area incident upon the test object). Requirements for a detector to measure irradiance are determined by the spectral content, collimation, and physical arrangement of the radiation sources to be measured. Additional stability requirements are necessary if the detector is to serve also as a feedback transducer in closed-loop control of the radiation sources.

A detector suitable for both measuring and control purposes should possess the following features:

1) It should be small in size so that the shadows produced will not measurably affect test results.

2) Response should be independent of spectral content and angle of incidence of the radiation, and its output should be linear with respect to the magnitude of irradiance. With these characteristics, irradiance measurements can be made of both high- and low-temperature sources with a single calibration constant and without the need for calibration curves.

3) A hemispherical field of view is necessary when measing the irradiance produced by distributed sources.

4) Zero drift in the detector should be negligible. If appreciable zero drift were present, use of the detector as a feedback transducer would be seriously impaired.

5) Design should be such that detectors can be readily produced with similar sensitivity factors and response times. This is particularly important if several detectors are to be integrated into a multiple-channel radiation control system.

A detector has been developed which incorporates a thermopile with a blackened receiver to achieve a spectrally uniform and linear output signal. Zero drift is made negligible by electrically maintaining the thermopile reference junctions at a constant temperature.

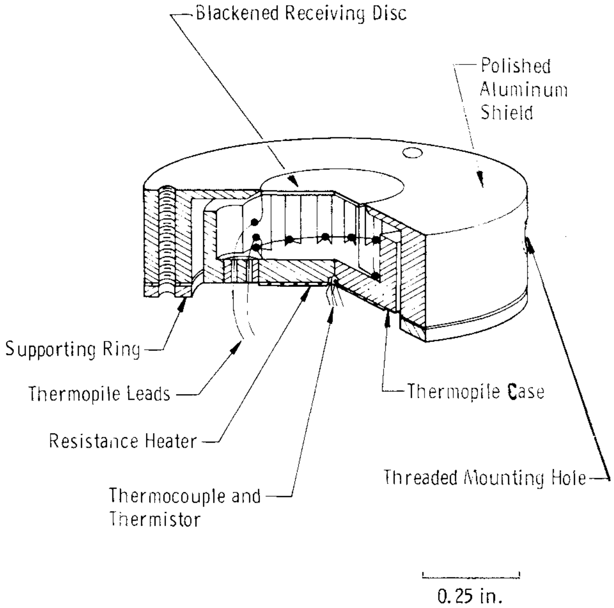

Fig. 1 Assembled detector.

Description of Detector and Case Temperature Controller

Cutaway and exploded views of the detector are shown in Figs. 1 and 2. The receiving disk is coated with optical black lacquer and absorbs approximately 0.98 of all incident radia-

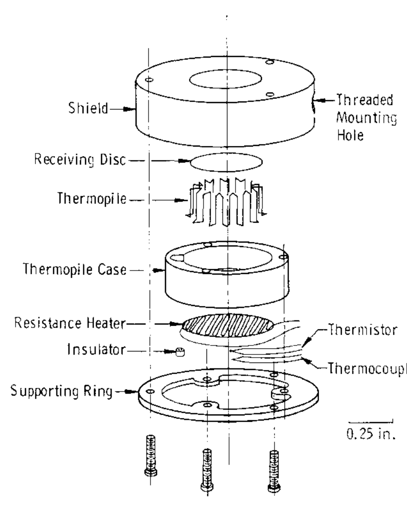

Fig. 2 Thermopile radiation detector with heated reference junctions.

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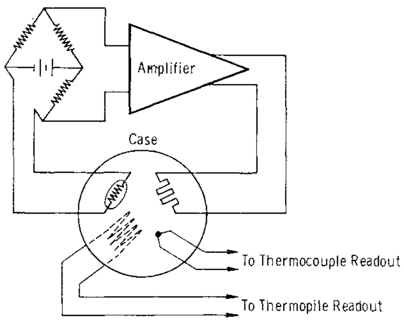

Fig. 3 Detector thermopile case temperature controller.

tion at normal incidence.[1] A portion of this absorbed energy is re-radiated from the receiver; the remainder is transferred to the thermopile case primarily by conduction through the thermopile wires, resulting in a thermopile signal that is linearly related to irradiance. The receiver and shield have no physical contact.

Thermopile measuring junctions are attached to the anodized aluminum receiver with epoxy cement and are in good thermal contact with the receiver. The junctions are electrically insulated from each other by the anodized aluminum case that is maintained at a constant temperature. A 20-ohm resistance heater, a thermistor, and a thermocouple are also cemented to the case to control and monitor case temperature. In operation, the case temperature is maintained above that temperature that would be established by radiative and conductive heat transfer inside a vacuum chamber under the condition of maximum anticipated irradiance. The detector shield is made of polished aluminum to restrict radiation heat transfer except through the receiver and case rear surface. The shield contains a threaded hole for mounting the detector which is normally mounted at the end of a $\frac{1}{8}$-in.-diam rod. A supporting ring holds the detector together and thermally insulates the case and shield. The detector is 1 in. in diameter and $\frac{3}{8}$-in. deep. Copper and constantan wire of 0.002-in. diam is used to make the 22-junction thermopile. The receiver is stamped from 0.0005-in.-thick aluminum foil and is 1 cm in diameter.

A block diagram of the case temperature controller is shown in Fig. 3. Power is supplied to the resistance heater on the detector case by a direct-coupled amplifier containing four low-power, switching-type transistors and one-power transistor. The amplifier input error signal is derived from a thermistor that is physically located on the detector case and forms one leg of a resistance bridge. To control case temperature within ±0.1°K, the amplifier has a voltage gain of approximately 1000.

Installation of one detector in a vacuum chamber requires at least seven electrical feedthroughs, including two for a copper-constantan thermocouple. If N detectors are installed, it is possible to make three connections common to all detectors, reducing the total number of feedthroughs to $4N + 3$.

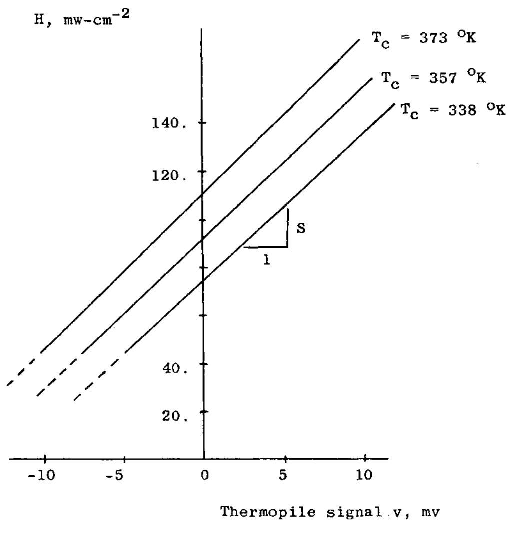

Fig. 4 Typical detector calibration curves for three case temperatures.

Performance

Typical detector calibration curves are shown in Fig. 4. These curves indicate that increasing irradiance from all sources within the detector's hemispherical field of view causes the thermopile output signal v to pass through zero and reverse polarity. The irradiance H_0 corresponding to zero thermopile signal is determined by case temperature T_c (Fig. 4) and is the H intercept of the calibration curve. When the thermopile signal is zero, all radiant power absorbed by the receiver is re-radiated. Then $H_0 = (\epsilon/\alpha)T_c^4$, where ϵ/α, the ratio of emittance to absorptance, is taken as unity. Detector sensitivity factor S mw-cm^{-2} mv^{-1} is the slope of the calibration curve and is a function of receiver temperature. In practice, the calibration curve is defined by the mean sensitivity factor, corresponding to a particular case temperature, and the appropriate value of H_0. A typical calibration for a case temperature of 357°K is: $H = Sv + H_0 = 6.60v + 92$ mw-cm^{-2}, where the measured thermopile signal v is in millivolts.

The maximum case temperature allowable is 400°K and is limited by the epoxy cement used in construction. With an irradiance of one solar constant, equilibrium case temperature is less than 400°K even though adjacent vehicle surfaces have low values of absorptance. It is possible that high-temperature surfaces in the vicinity of propulsion units could cause equilibrium case temperatures in excess of 400°K. Thermopile signals attain 98% of their final values in approximately 11 sec after a step change in irradiance.

All significant detector errors introduced into the measurement of irradiance result from thermopile signal nonlinearity, case temperature variation from the desired value, and the error in setting the case temperature. Additional errors result from calibration to obtain the sensitivity factor or incorrect measurement of thermopile and thermocouple signals.

The error produced by nonlinearity is not greater than 0.7% of one solar constant and results in an indicated irradiance that is always low. The error associated with case temperature variation from the desired value is not greater than ±0.09% of one solar constant provided case temperature variation is less than 0.10°K. The maximum error resulting from incorrect measurement of case temperature initially is not greater than ±0.7% of one solar constant if measured with a regular grade, uncalibrated, copper-constantan thermocouple. The error in measured irradiance introduced by the detector is then not larger than the sum of the three separate errors or approximately ±1.5% of one solar constant.

Conclusion

This radiation detector possesses features that make it suitable for measuring and/or controlling irradiance up to one solar constant in vacuum. It is applicable in any vacuum environment that results in an equilibrium case temperature less than 400°K. Detector error, including zero drift and nonlinearity, is not greater than ±1.5% of one solar constant. Response is uniform with respect to wavelength.

Reference

[1] "Parsons' optical black lacquer," The Eppley Lab., Inc. Bulletin (July 1963).