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Mechanical Design of the Spin-Scan Cloud Camera

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The development and design of two Spin-Scan Cloud Cameras, successfully operating at a 23,000-statute-mile synchronous altitude, are described. The first, a single-color camera (black and white pictures), was launched from Cape Kennedy on December 6, 1966. This camera is still in daily use and has provided many thousands of high-resolution pictures. The second, a multicolor camera, was launched on November 6, 1967. Use of the satellite spin, combined with a precision step mechanism to obtain pictures of the earth's cloud cover, is described in detail.

I. Introduction

Early in 1965, personnel from the University of Wisconsin, Hughes Aircraft's Space Systems Division, and the Santa Barbara Research Center investigated concepts to provide high-resolution pictures of the earth's cloud cover from synchronous altitude. The result was the Spin-Scan Cloud Cameras, which are carried on *Applications Technology Satellites* (ATS) and have provided thousands of such pictures (Fig. 1).

The *Application Technology Satellites* B and C, designed and built by Hughes Aircraft's Space Systems Division for the NASA Goddard Space Flight Center, are spin-stabilized spacecraft which rotate with their spin axes parallel to the earth's rotational axis. The concept was to capitalize on this feature and use the 100-rpm spin of the spacecraft to provide the horizontal, or longitudinal, sweep as one component of a scan raster. The second component, the vertical step, would be incorporated in the camera mechanism. By utilizing the spinning spacecraft and a stepping camera, a picture would be generated much in the same manner as a television picture.

II. Functional Description

The black and white camera, Fig. 2, consists of a high-resolution telescope and a light detector or detectors coupled with a step mechanism. The latitudinal, or vertical, step mechanism advances one step for each spacecraft revolution. When the step mechanism has completed

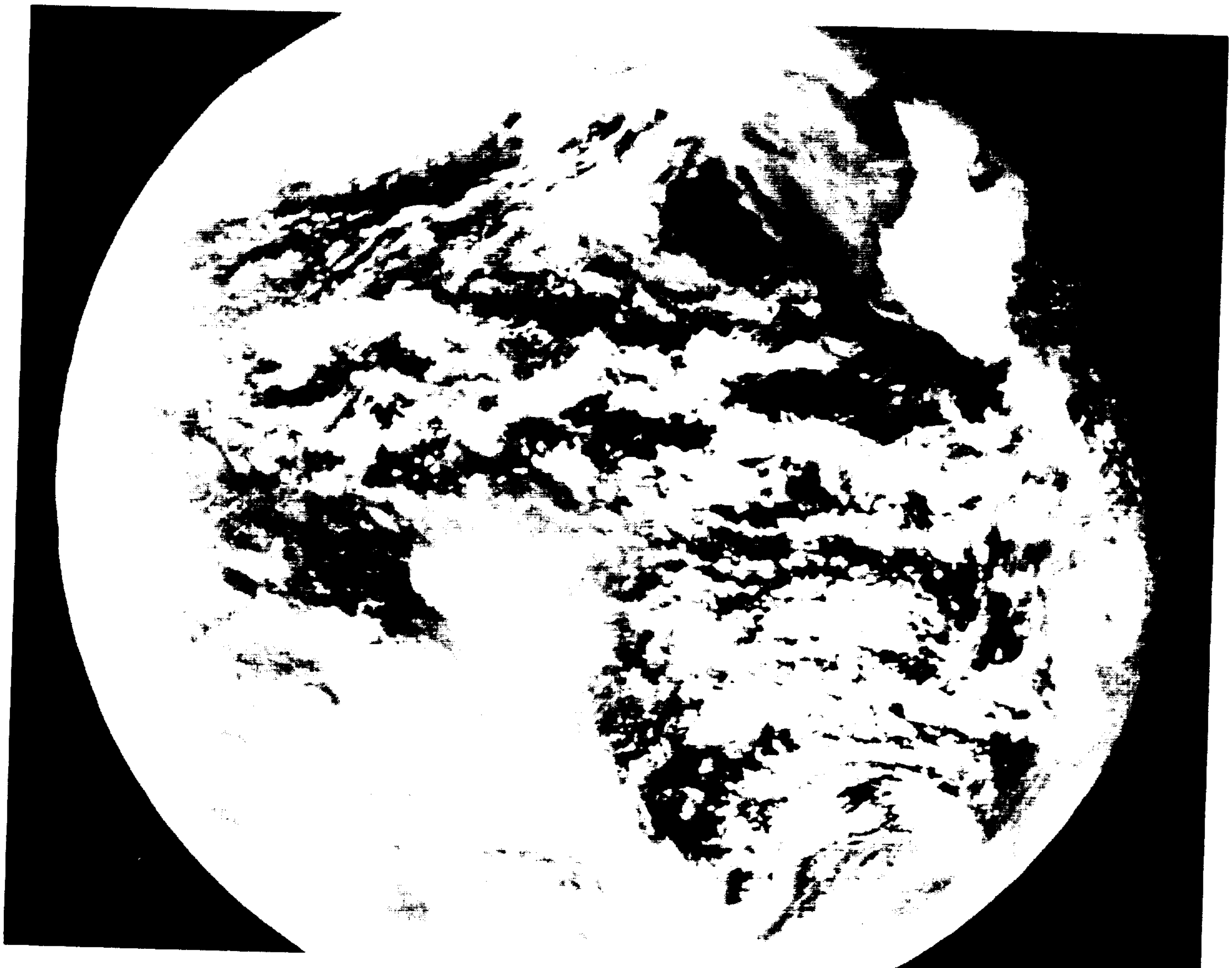

Fig. 1. View of the earth taken from ATS-1 spacecraft in a synchronous equatorial orbit, 19,300 nautical miles altitude

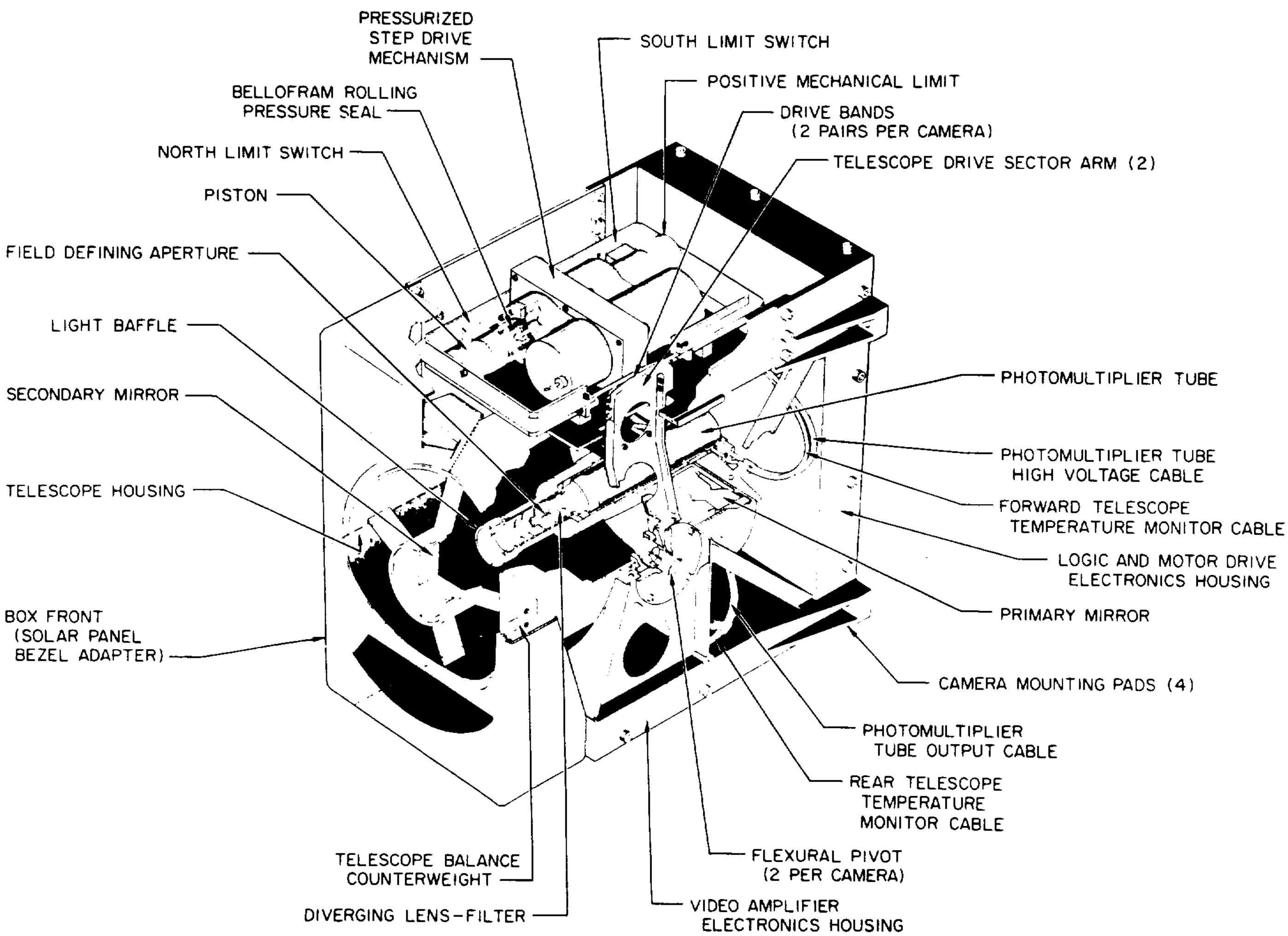

Fig. 2. Cutaway drawing of the single-color Spin-Scan Cloud Camera (SSCC)

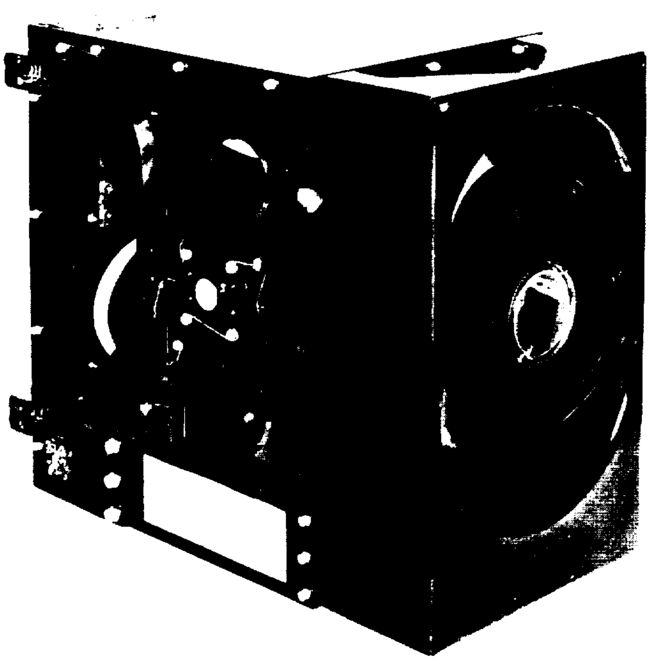

Fig. 3. Single-color Spin-Scan Cloud Camera

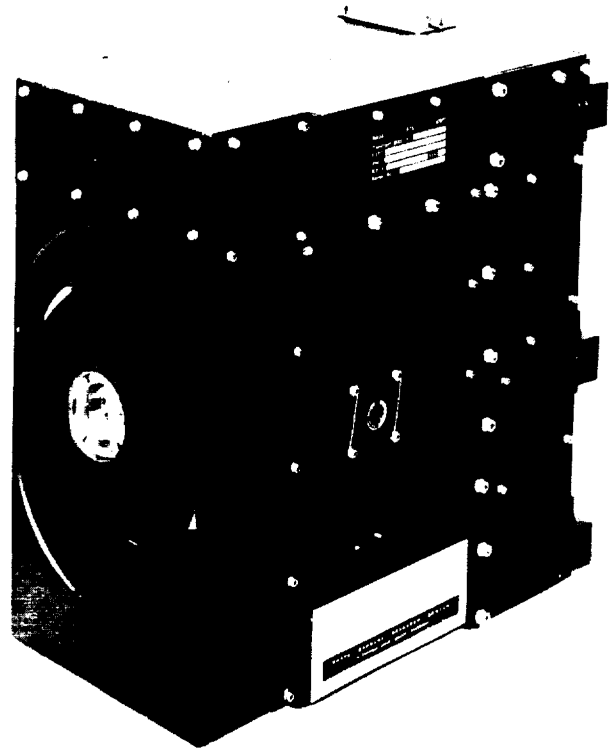

Fig. 4. Multicolor Spin-Scan Cloud Camera (MSSCC)

2000 steps in approximately 20 min, a limit switch initiates retrace and the telescope returns to the top or north latitude position. At this point, another limit switch starts the normal north–south stepping in synchronism with spacecraft rotation. Figure 3 shows the assembled black and white camera. The multicolor camera, Fig. 4, scans the full earth disk and requires 2400 steps, approximately 24 min, to complete one picture.

III. Mechanical Description

The mechanical design requires a high degree of precision in only two areas: (1) the spacing and mounting of the optical elements into the telescope housing and (2) certain parts of the precision step mechanism.

The two cameras are identical in every major respect except in the number of photomultiplier tubes required. Figure 5 shows the relationship between the telescope and the single photomultiplier tube required for the black and white camera, and Fig. 6 shows the photomultiplier tube housing, located aft of the telescope, supporting the three photomultipliers required on the color camera. Figure 6 also shows the block closing the end of the tube housing and forming one end of the fiber optics bundle which relays the energy to each photomultiplier tube. The fiber optics bundle (Fig. 7) consists of three 0.005-in.-diameter glass fibers. These are terminated in the telescope behind an aperture plate (Fig. 8) containing three 0.0015-in.-diameter holes spaced 0.010 in. apart. The apertures lie in a plane normal to the spacecraft's spin axis. The fiber optics permit relative motion between telescope and photomultiplier tubes.

A. Telescope

The telescope is the only component in each camera that is sensitive to the temperature extremes likely to be encountered in the hostile environment of space. To maintain the 0.1-mrad optical resolution, the telescope housing assembly is fabricated from Invar 36 steel alloy. The longitudinal shift permitted is on the order of 0.0003 in. The thermal characteristics of this material closely match those of the quartz optical elements. The telescope assembly consists of a tube, a secondary mirror housing with support legs brazed into the forward end of the telescope tube, and a primary mirror support plate bolted to the aft end.

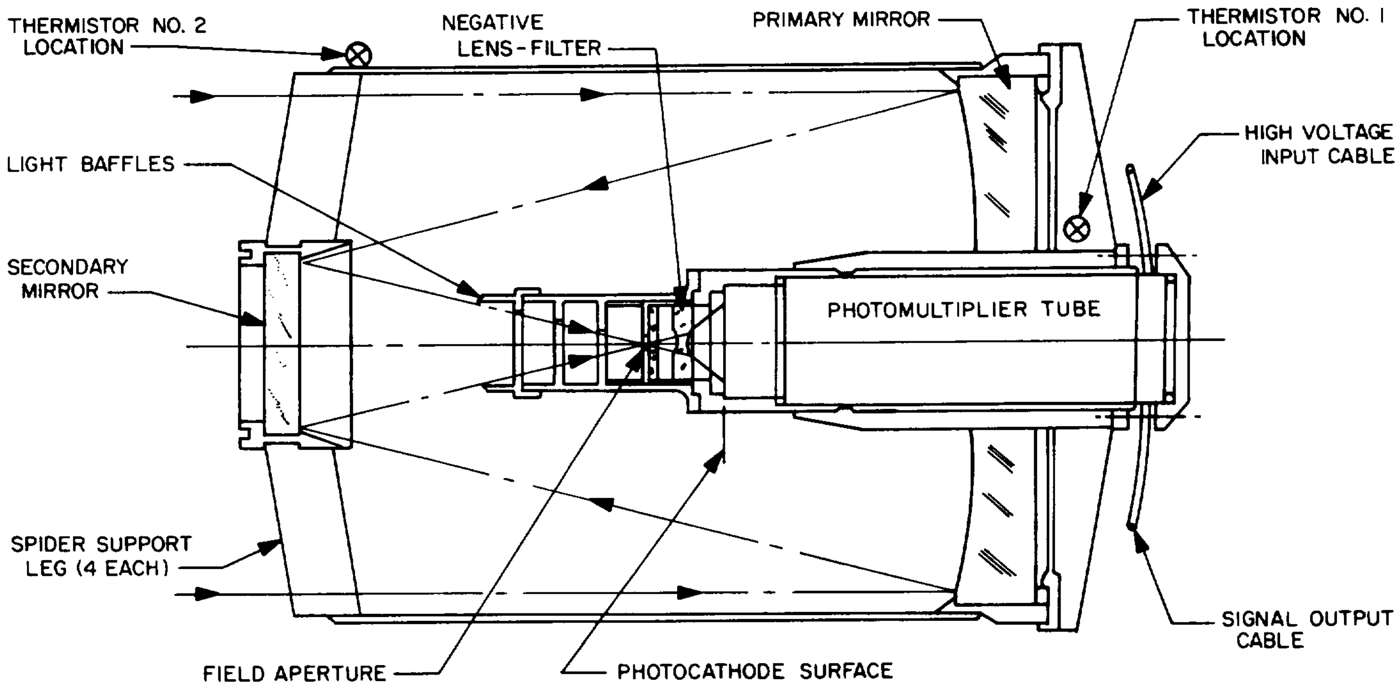

Fig. 5. Cross section of telescope assembly, SSCC

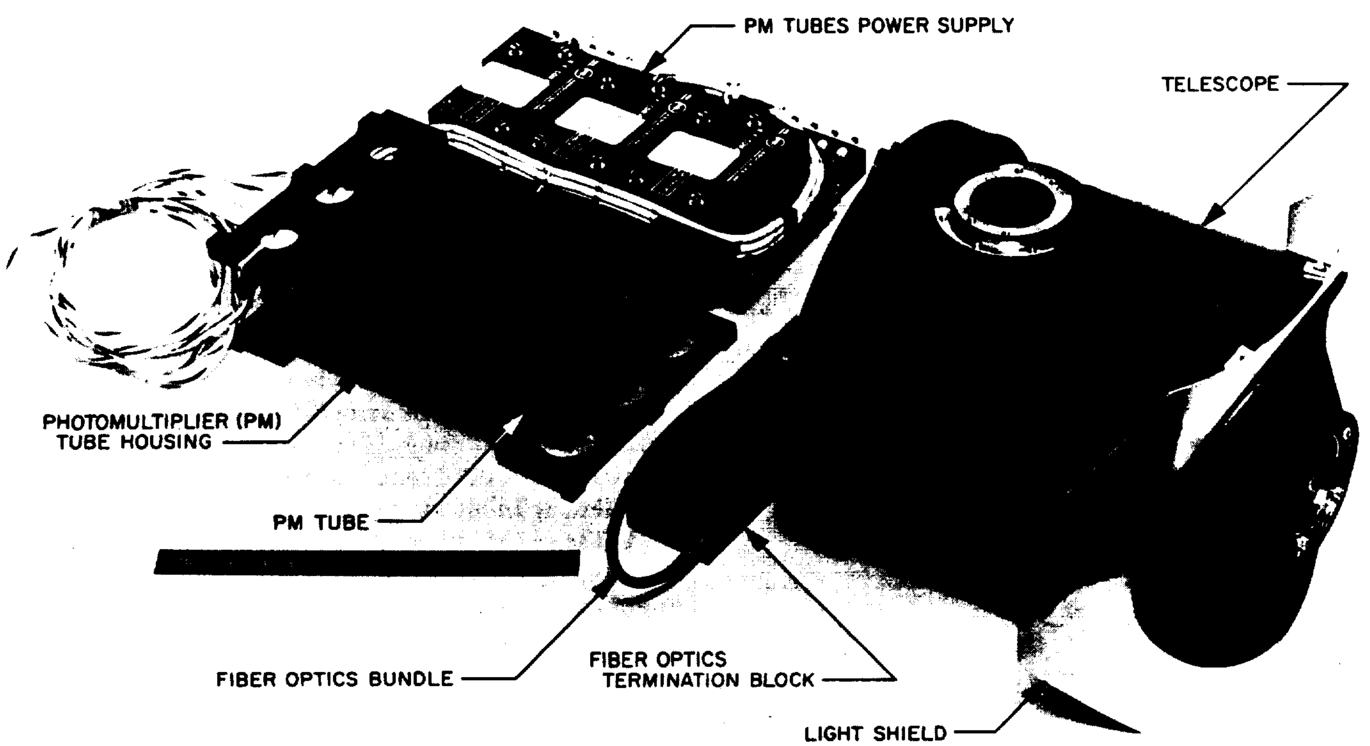

Fig. 6. Multicolor camera telescope and photomultiplier tube housing

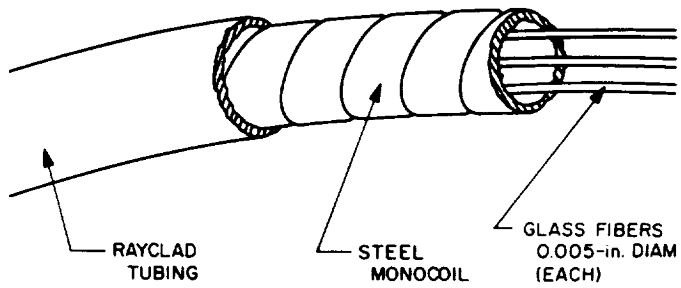

Fig. 7. Fiber optics housing, MSSCC

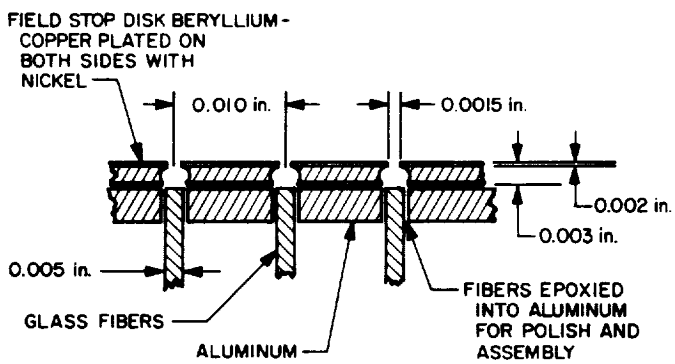

Fig. 8. Field stop, MSSCC

The telescope assembly is supported at its center of gravity by two double-ended, flexural pivots (Fig. 9). Two sector arms are attached and registered to the telescope at these pivot points. The sector arms roll on the drive frame, which is part of the step mechanism, and are attached to the drive frame by drive bands. These

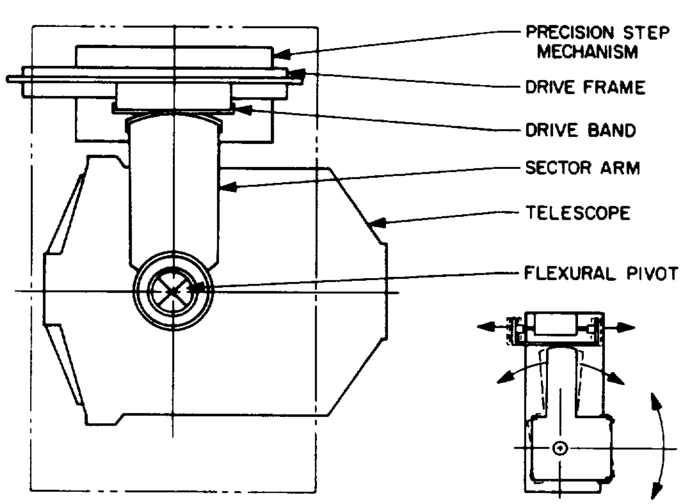

Fig. 9. Schematic showing sector arms, drive bands, and flexural pivots, MSSCC

bands, two on each sector arm, permit roll action but are pulled tight to eliminate backlash. The radius of the sector arms is governed in part by the large reduction ratio required in the step mechanism and in part by the physical clearance needed between telescope and drive.

In synchronous orbit, the camera is constantly subjected to a centrifugal force approximately six times gravity due to the 100-rpm spin of the spacecraft. To obtain full earth coverage, the telescope requires ±9 deg of angular motion. Flexural pivots, properly oriented, are ideal for this application. They permit the required angular motion and yet provide adequate radial support with no radial play. Any radial play in the telescope pivot bearings would introduce error in the step linearity and step position repeatability. The flexural pivots and the drive bands are ideally suited to the hostile environment of space.

B. Precision Step Mechanism

The basic step drive consists of a stepper motor, 90 deg per step, 2000 steps required, coupled to a precision rotating nut through a 10.1:1 gear reduction. The rotating nut drives a precision lead screw having 40 threads/in. To obtain a complete earth scan by the multicolor camera, these values were extended to ratios of 10:1, with 50 threads/in. and 2400 steps required. The lead screw causes the drive frame to move linearly 0.0006 in. (black and white camera) and 0.0005 in. (color camera) per step. This linear travel, coupled to the telescope through the sector arms, translates this straight-line motion into rotary motion to provide the required 27 seconds of arc per step at the telescope. The average repeatability of the drive is better than one step in 2000 steps.

The overall reduction from the 90 deg/step of the motor to the 27 seconds of arc required at the telescope is 12,000:1. To obtain maximum life from the precision lead screw, nut, bearings, gears and motor, the drive is lubricated, pressurized to two atmospheres with nitrogen, and sealed. To allow the linear motion to be transmitted from the sealed drive, two rolling diaphragms are used. To each end of the lead screw is attached an aluminum piston which travels inside a stainless steel cylinder. The diaphragm rolls between these two surfaces. The piston supports the diaphragm on the inside and the cylinder provides support on the outside so that only the curved portion between the piston and cylinder is subjected to the pressure differential. The calculated leak rate of the diaphragms is 4×10^{-6} cm^3/s, or an operating life of approximately 3 years.

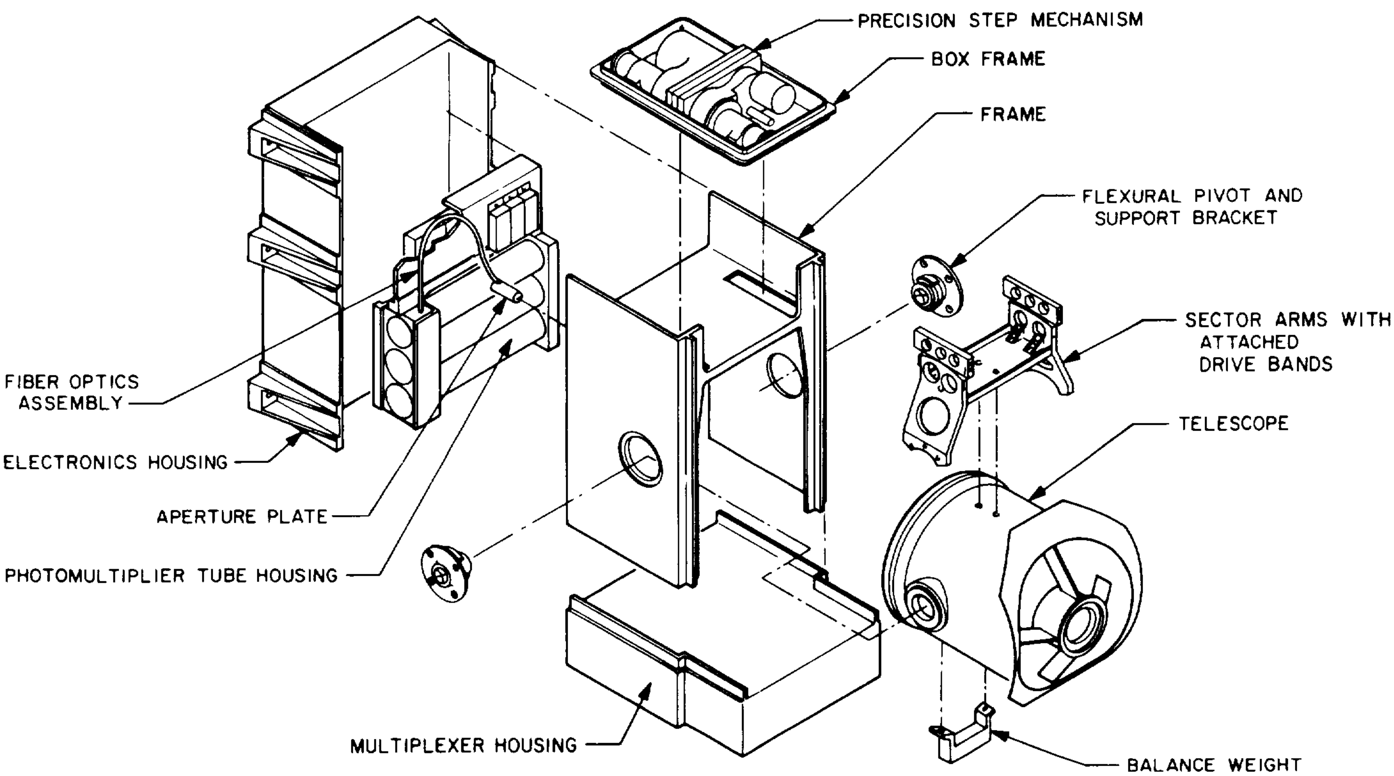

Fig. 10. Exploded view, major mechanical components, MSSCC

C. Frame and Electronics Housing of Color Camera

Figure 10 shows the major components of the color camera. The outside dimensions are 12 in. in height, 7 in. in width and 11 in. in depth. The camera weighs 23.5 lb. (The black and white camera is only 10 in. high and weighs 20 lb.)

Aluminum plates, dip brazed to form a structure, support the step drive mechanism and provide a housing for the electronics.

IV. Conclusion

Simplicity was the keynote of the total program. A straightforward design approach, standard fabricating techniques, high precision only where required, and reasonable tolerances wherever possible produced an excellent instrument of high reliability. More than a year's operation for the black and white camera, which is still operating, proves the adequacy of the lubrication sealing technique. Examination of both color and black and white pictures indicates that focus was indeed held.