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KU BAND DEPLOYED ASSEMBLY AND GIMBAL*

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SUMMARY

Requirements for Shuttle Orbiter missions to locate satellites for servicing and to communicate when out of touch with a direct ground link are satisfied by a Ku Band deployed antenna system providing an integrated radar and communications function.

The deployed assembly comprises that portion of the system that stows in the limited space between the Shuttle door radiators and the payload volume for launch and landing, and is deployed out from the Shuttle during orbit to provide near spherical coverage by a 91.44 cm (36 inch) diameter antenna. Unique features of the gimbal assembly are:

- Edge mounted antenna to minimize stowage volume in Shuttle and maximize gain
- Unique two-axis housing and shaft arrangement to accommodate two runs of waveguide and 55 electrical conductors without requiring slip rings
- Maximum use of aluminum in gimbal structure to reduce costs
- Lubricant chosen to survive earth and space environments.

BACKGROUND

Obtaining a good RF gain margin without using parametric amplifiers led to the selection of a 91.44 cm (36 inch) diameter antenna reflector for the Ku Band system. With this baseline antenna size, an edge mounted gimbal configuration was selected from a tradeoff study of the three configurations shown in Figure 1. The edge mount was the clear winner when weight, trunnion obscuration, peak power, and stowage considerations were compared. Disturbance torques due to Shuttle accelerations are negligible; therefore, a centered load is not an operational constraint. To test the antenna in a 1 g field, a counterbalance or offloading device would be required for any of the three configurations. This testing is simplified with the edge mount.

*This task was performed under contract to Rockwell International, Space Systems Division.

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ANGULAR COVERAGE. The angular coverage requirements call for maximum field of view for TDRS communication and unrestricted coverage of all points within 60 degrees of Shuttle zenith for radar rendezvous. Obscuration caused by the gimbal trunnion is minimized by locating the primary axis so that the obscuration cone falls within the Shuttle body area. The antenna is deployed as far from the Shuttle body and as high and far forward as possible to decrease overall obscuration presented by the Shuttle.

Ability to deploy the antenna is dependent upon the amount of volume available for stowage and the Shuttle hardware that the deployed assembly must clear. The allocated volume is in the forward part of the payload bay between the cabin bulkhead and the Remote Manipulator Boom. A 7.62 cm (3 inch) static clearance between the door radiators and the payload envelope is required. A full scale mockup, shown in Figure 2, was constructed to verify fit.

Ideally, the deployment hinge would be canted so that the antenna is swung up and out into an optimum location. However, stowage considerations and interference problems involving the boom and the integral Deployed Electronics Assembly (DEA) prevent the use of a canted hinge. With the vertical hinge, optimization with respect to angular coverage and obscuration was accomplished by canting the gimbal mount on the structure. A beneficial byproduct of the edge mounted antenna is that the location of the antenna beam center varies as a function of the line of sight. The antenna literally looks around the corner from the fixed gimbal axis intercept coordinate position, thus increasing total coverage. With the pole axis pointed outboard, more favorable coverage is attained and ample clearance between the antenna sweep volume and the vehicle is provided. Figure 3 shows the coverage achieved by the selected design.

DEPLOYMENT AND STRUCTURE. The deployed assembly shown in Figure 4 consists of a structural frame that attaches to the Rockwell hinge, together with the DEA and gimbal antenna assembly that attach to the frame.

Figure 5 shows details of the structural frame and the DEA mounting. Originally, a simple tubular boom to connect the gimbal to the hinge, with the DEA strapped alongside, was considered. However, it was difficult to keep the boom and box within the prescribed stowage envelope without resorting to a less than optimum boom diameter with undesirable sharp bends. The selected open frame configuration takes advantage of the structural properties of the 0.635 cm (one-fourth inch) thick thermal radiator that is part of the DEA.

ENVIRONMENTS. In addition to standard environments associated with space vehicles, the Ku Band Deployed Assembly (DA) must also be designed to withstand the unusual environment of multiple re-entry as well as aircraft type ground environments. Also, since the Shuttle is a manned space vehicle, the constraints on flammability and toxicity apply.

Materials and processes were carefully screened, therefore, to assure survival and continued operation. To avoid galvanic corrosion, sealing against humidity was required at each interface where steel screws contacted aluminum parts. Sliding closures were employed together with dessicant filled filter ports. Humidity tests were conducted to evaluate operational characteristics of bearing dry film lubricant.

Thermal environment carried one unique aspect. The location of the DA on the Shuttle places it just above and ahead of the Shuttle door radiators. These radiators are concave and covered with highly specular silvered teflon. In orbit, with the sun 30 degrees behind and 30 degrees to the right of Shuttle zenith, the DA is placed in the focus of fairly efficient collectors. Therefore, the DA is covered with silvered teflon which not only radiates heat from the DA itself, but also rejects the intense heat load from the Shuttle door radiators. Relief was granted by NASA to assure that this sun angle would not be maintained for a long period of time.

GIMBAL PACKAGE

The gimbal packaging arrangement is shown in Figure 6. The primary axis gimbal housing is fixed relative to the supporting structure, and its motor and bearing system rotates the inner T-shaped shaft through a full 360 degrees stop-to-stop. The secondary axis gimbal motor and bearing system rotates its housing, to which the antenna supports are attached, around the upper branch of the T shaft a minimum of 165 degrees stop-to-stop. Gimbal limits on this secondary axis are set simply by sizing the housing cutout which must clear the T shaft. For the primary axis, assuring the full 360 degree range without a blind spot at the end of travel required the incorporation of a toggle stop to allow a 1 degree minimum overlap.

Selection of the more conventional fixed housing rotating shaft configuration for the inner axis would involve the complexity of exiting the waveguide run between the axes and routing the waveguide to a juncture with the inner gimbal rotary joint. Further, the service cables that must cross the axes would have to make a similar exit and have their service loops mounted externally with several special guides, restraints, and supports to provide proper gimbal freedom. The T shaft configuration allows a much simpler waveguide, rotary joint, and cable packaging to be used by allowing the whole arrangement to move together across the axis junction. Internal cable breakouts are also avoided. Cabling which passes through the gimbal, shown in Figure 7, is a printed circuit flat ribbon that carries 55 conductors (20 shielded groupings) and two RG 178 coaxial leads. The T shaft configuration also allows a stiffer and simpler antenna attachment than would be achievable with widely separated shaft ends. Since the shaft ends are not exposed in this arrangement, the housing ends are closed off to provide environmental protection. The only open space through which contamination could enter is the area at the shaft juncture where the inner axis housing is cut away to allow gimbal freedom. In this area, a seal is provided around the bearings, and all other axis equipment is placed in enclosures beyond the bearings. The enclosures are equipped with dessicant filled filtered openings to allow the inflow of air to bypass the bearings during Shuttle descent and thus protect the overall cleanliness level of the mechanism interior.

Two precision angular contact bearings, lubricated by dry film lubricant, support the gimbal axes. One of the bearings in each set has the outer race mounted onto a diaphragm spring to provide axial compensation with temperature. This arrangement is a proven Hughes design used on several despin assemblies built for long life communications satellites. The spring mounted bearing is located at the opposite end of the shaft from the rotary joint and encoder, precluding dimensional change of these critical gaps.

Bearing lubrication for this application has been selected from the standpoint of successful operation in a space mission over the temperature range and also from the standpoint of the ground environment to which the gimbals will be subjected. An evaluation test conducted in July 1977 showed that bearings ion plated with 1500 Å of 99 percent pure commercial grade lead provided the best and most uniform performance when tested between several cycles of humidity exposure.

The gimbal motors are 17.78 cm (7 inch) diameter, full rotation, permanent magnet brush dc motors. High torque motors are required to achieve the 400 degree/sec^2 accelerations associated with the radar search spiral scan. The incremental shaft angle encoders, 4096 counts per revolution together with an index pulse, use light emitting diode sources and photo transistor sensors. The basis for selection of these components is given in Table 1.

SERVO CONTROL. A Rate Sensor Assembly (RSA) containing two rate integrating gyros (RIGs) is mounted on the gimbal output. With the primary axis gyro mounted on the secondary axis output, this gyro measures the true line of sight rather than the primary axis gimbal rate. This causes a scale factor change as a function of secondary look angle that must be compensated for to achieve servo stability. Loop closure electronics for the two RIGs are located within the RSA package. This location minimizes noise in the high bandwidth loop that might be picked up on the 9.6 meter long cable between the electronics and the DA. The RSA package is also temperature controlled to assure stable operation.

A feature of the design worth noting is the absence of tachometers. By using the RIGs to provide rate damping signals, adequate servo performance can be achieved without the cost and weight penalty of tachometers.

Another prominent feature of the servo design is the coordinate conversion requirement. Since the trunnion axis is not aligned with the Shuttle X-axis, commanded designate angles are generated in Shuttle pitch and roll and must be transformed into gimbal coordinates for execution. Conversely, the gimbal angles and LOS rates must be transformed into Shuttle pitch and roll equivalents for astronaut readout. It is also necessary to transform slew commands, since a nominal pitch slew actually requires the combined motion of both gimbal axes. The coordinate conversions are performed by the control logic microprocessor, thus eliminating the need for bulky resolver chains.

GIMBAL LOCK SYSTEM. Multiple launch and re-entry use of the DA calls for a reuseable gimbal lock system. The system consists of two DC gearhead servo motors mounted on the stationary housing of the primary axis that rotate V wedges into blocks located under the two structural members extending below the secondary axis housing. This configuration is shown in Figure 8.

A single motor-driven lock was originally planned; however, attempting to lock both axes at a single point was not workable. The restricted volume around the gimbal due to the antenna size and angular coverage requirements did not allow a pinning or grasping type of lock.

CONCLUSION

The Shuttle DA gimbal hardware was selected from proven technology, packaged to accommodate Shuttle stowage and use. Other mechanisms with the assembly--an RF polarization switch and waveguide switch--were also designed to use state of the art components.

TABLE 1. Ku-BAND ANTENNA POSITIONER

Item	Options	Advantages	Disadvantages
Axis location	Edge mount*	• Lighter weight • Better stowage fit • Better deployed pole location • Lowest cost • Lowest trunnion obscuration	• Unbalance in 1 g field • Load inertia variation
	Yoke mount	• Less 1 g unbalance • More conventional approach	• Complex structure • Difficult stowage • Higher system weight • Higher cost
Motor type	DC brush torquer*	• Simpler electronics • Well proven • Self commutating	• Brush friction • Ripple torques
	DC brushless torquer	• Less friction than ~~dc~~ brush torquer	• Requires resolver
	Stepper motor	• Lowest power • Lightest weight	• Speed limitation in raster • Gear train wear • Stepping dynamics in track
Position readout	Resolver	• Absolute position indication • Long life elements	• Complex electronics • >360° ambiguity • Complex wiring
	Incremental encoder*	• Digital output compatibility • No >360° ambiguity • Small cable bundle	• LED degradation • Requires initial setting
	Absolute encoder	• Interrogation capability reduces LED use	• Multiple parallel bits requires large wire bundle • >360° ambiguity
Rate feedback	Separate tachometer	• Conventional	• Additional component • Additional cabling
	Use position readout rate of change*	• Eliminates component	• None

*Selected design

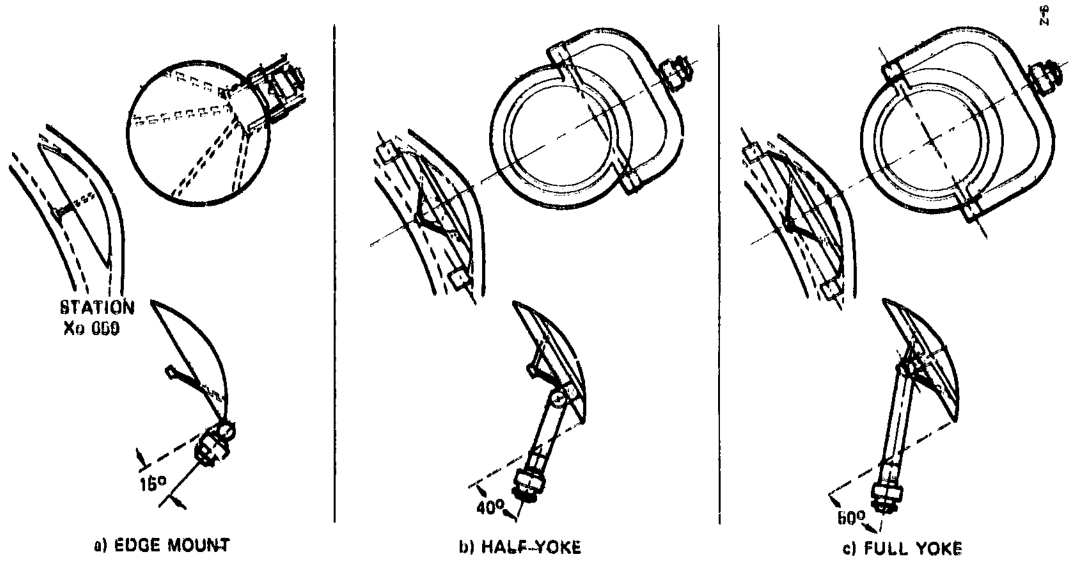

Figure 1.- Gimbal configurations considered, showing trunnion half-angle obscuration.

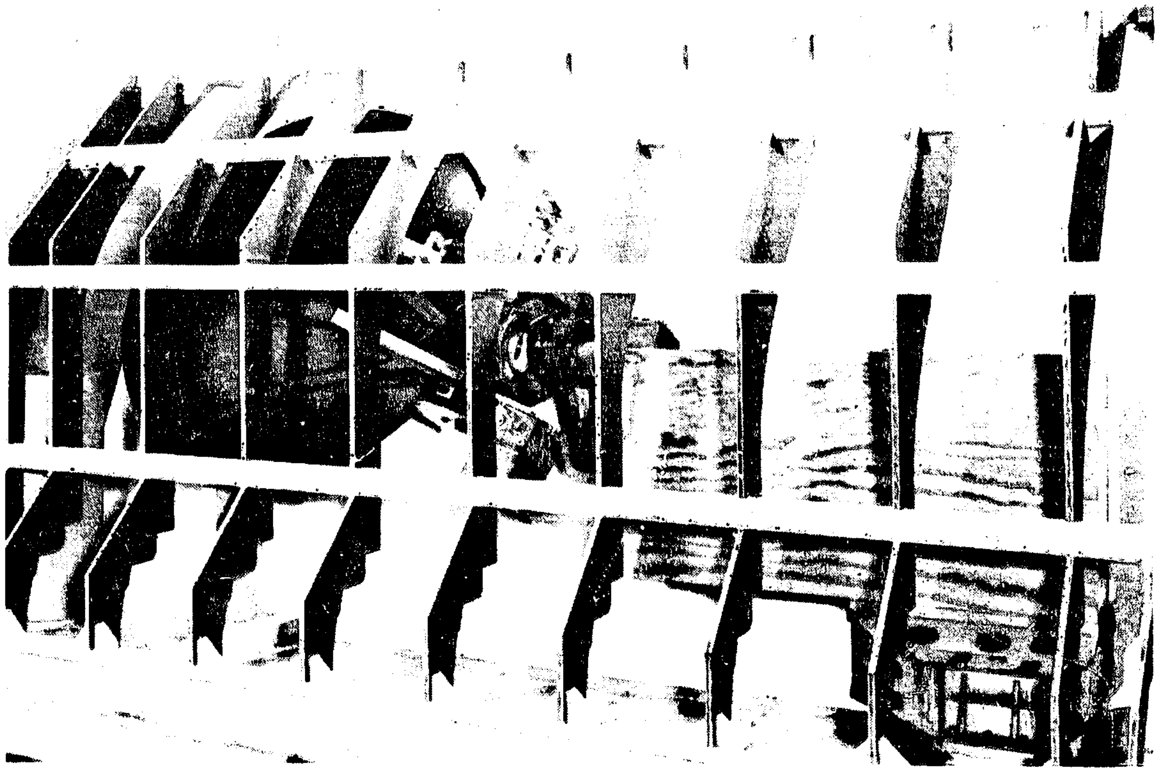

Figure 2.- Deployed assembly mockup.

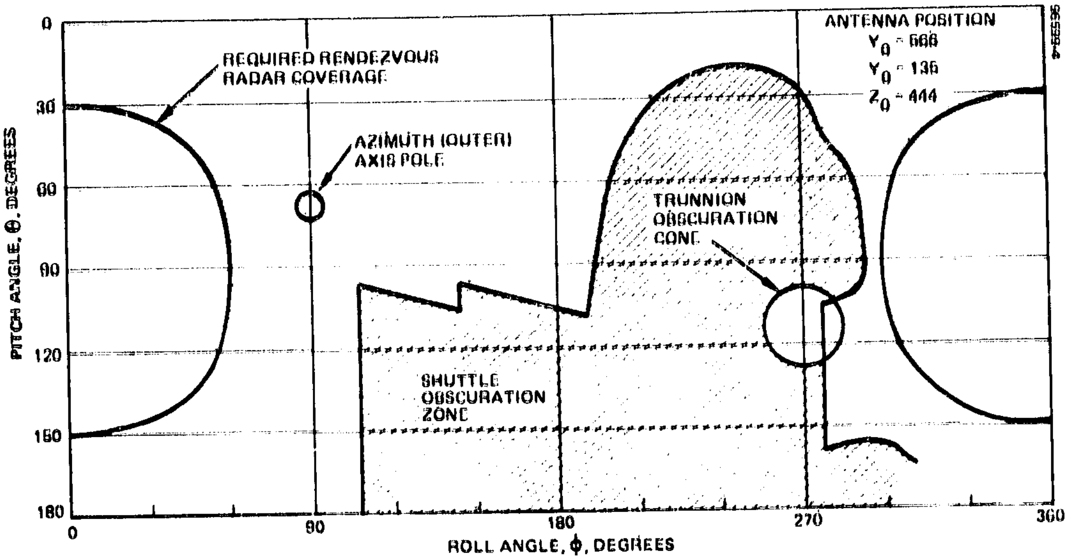

Figure 3.- Right antenna obscuration and gimbal characteristics based on 91.44 cm (36 inch) diameter antenna beam.

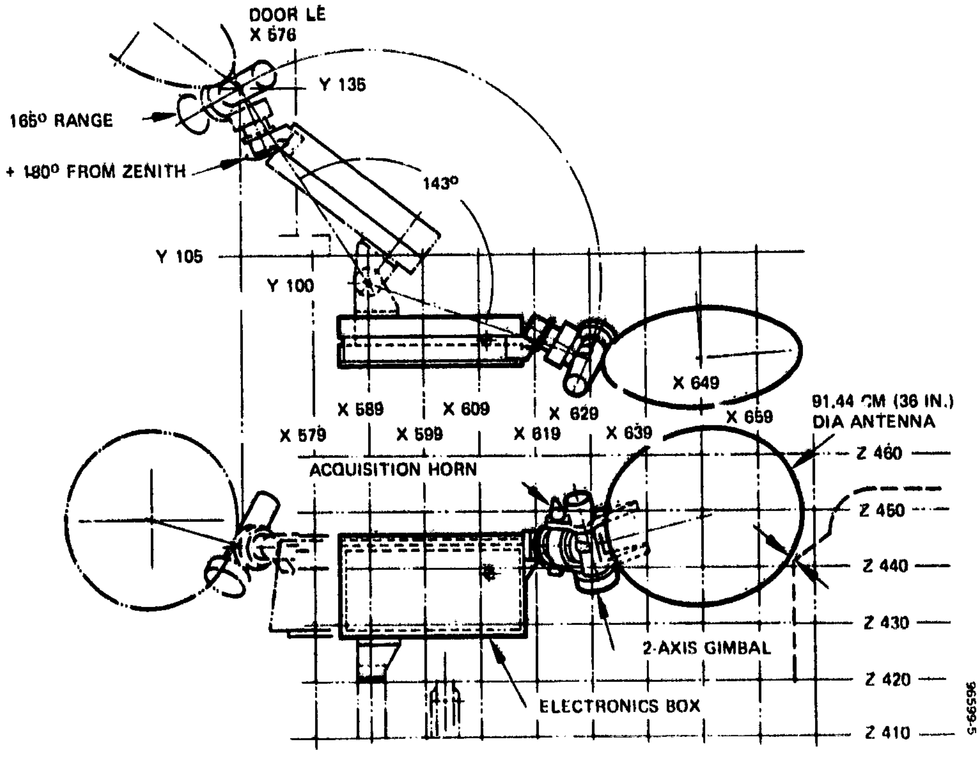

Figure 4.- Deployed mechanism assembly.

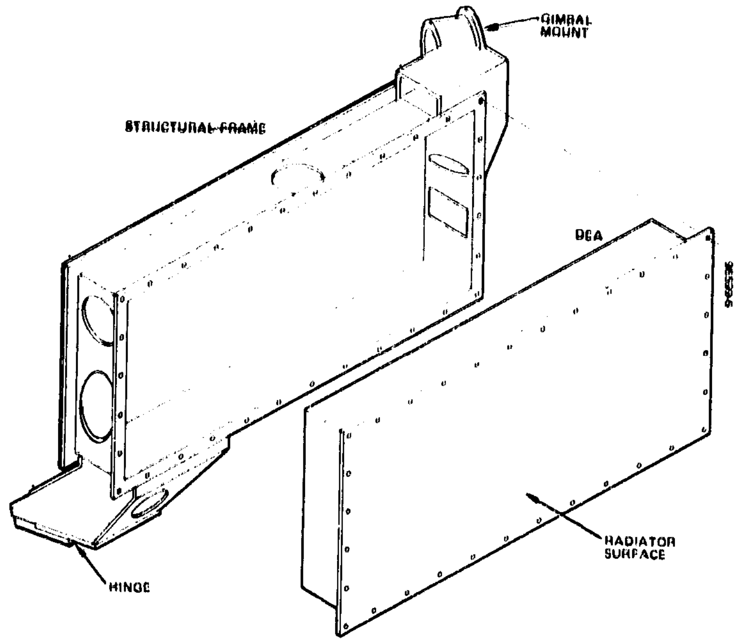

Figure 5.- Structural frame and DEA mounting.

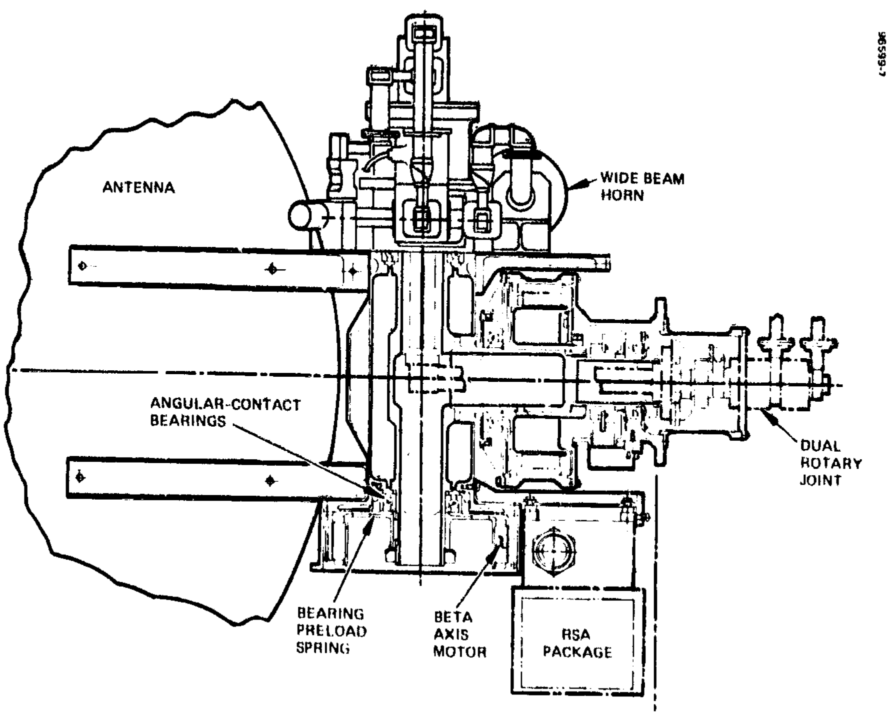

Figure 6.- Antenna gimbal.

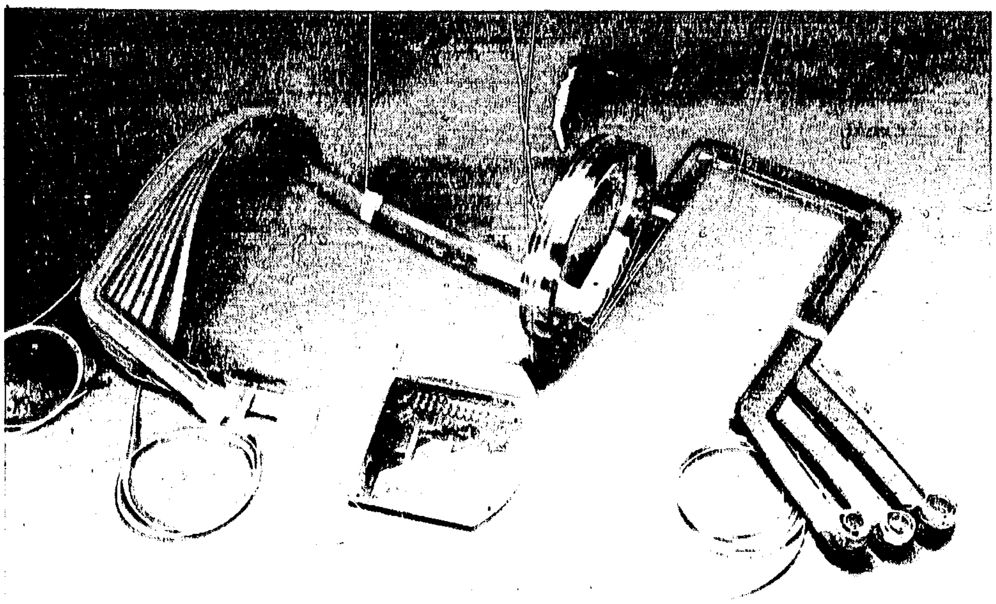

Figure 7.- Flat ribbon cable.

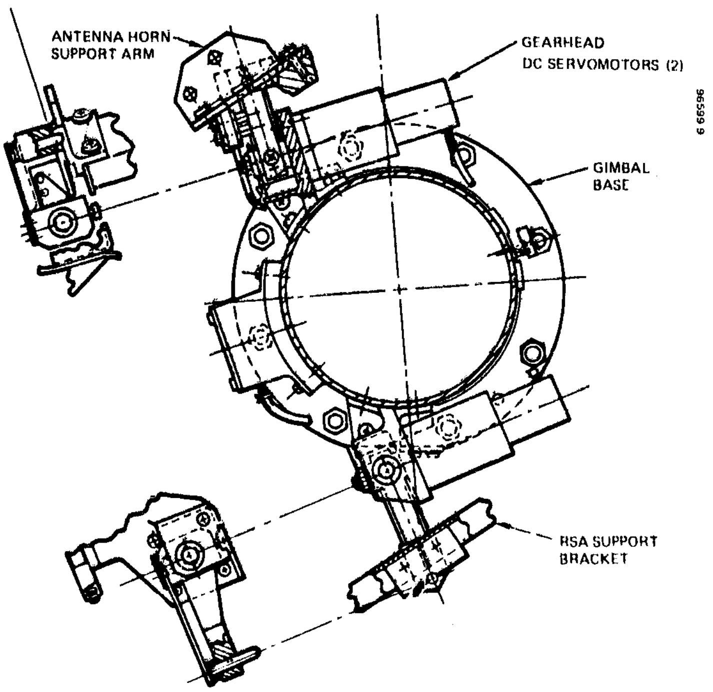

Figure 8.- Dual gimbal lock.