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THE LIQUID METAL SLIP RING EXPERIMENT FOR THE COMMUNICATIONS TECHNOLOGY SATELLITE

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SUMMARY

The Liquid Metal Slip Ring (LMSR) experiment for the Communications Technology Satellite (CTS) is described. The experiment is designed to demonstrate liquid metal slip ring performance in a space environment. The experiment will also allow evaluation of those features of a LMSR where improvement in performance over conventional slip rings is expected.

The experiment will be based on the LMSR technology currently under development by the NASA Lewis Research Center (LeRC). The primary measurements to be made in the experiment will allow a determination of the slip ring electrical resistance, between ring insulation resistance and ring cleanliness. The experiment package will weigh an estimated five pounds and occupy approximately 170 cubic inches. It will require approximately 12 watts of power and 14 data channels and nine commands from the telemetry and command system. All power and signal conditioning will be performed within the experiment package.

BACKGROUND

The next generation of High Power Communication Satellites will utilize large, deployable, sun tracking solar arrays as a primary power source. Further, it is likely that the conditioning of the raw power will be done directly on the solar arrays. The conditioned power will be transferred across a continuously rotating interface between the sun tracking solar arrays and the earth tracking satellite center body. The electrical loads will use the power transferred directly from the solar arrays across slip rings. Current through the rings may be as high as 30 amperes and voltage between rings may be as high as 16,000 volts. A typical mission will require between 100 and 200 slip ring circuits. Mission life times will be five years or more.

Conventional slip rings employ brushes sliding on cylindrical rings to transfer electrical signals and power across rotating interfaces. They are classified as either dry lubricated or wet lubricated depending on the method used to minimize wearout of the sliding contacts. Typical dry lubricated systems employ polished coin silver rings and brushes made of a self lubricating composition material such as $Ag/MoS_2/Cu$. Typical wet lubricated systems employ gold rings and gold leaf spring brushes lubricated with a low vapor pressure oil. Both types have been successful on a variety of missions to date. However, for the class of missions described above, liquid metal slip rings have several advantages over conventional slip rings. A few of the more important advantages are listed below:

1. Lower electrical noise - The electrode interface resistance of a wetted electrode is less than one micro ohm-cm^2. Measured electrical noise has proven negligible.

2. Higher current capability - The conductive area of the contacts is greatly increased compared to the asperity contacts of conventional rings. The high contact area allows for high current without power loss and associated heating problems.

3. Higher voltage capability - The brush-wear residue of conventional rings which is the primary source of electrical breakdown between conventional ring circuits is eliminated in LMSRs.

4. Longer life - Brush wearout is eliminated.

5. Small variation in friction torque - The viscous shear of the liquid metal between electrodes is many orders of magnitude lower than the sliding friction of conventional slip rings. The absence of stick-slip friction greatly eases the control requirements for the spacecraft attitude stabilization system.

Liquid metal slip rings employing gallium as the liquid metal have been used in high vacuum research apparatus since 1967. Przybyzewski reported such a device in the NASA Tech Brief of reference 1.

Reference 2, a 1966 journal article, hints of liquid metal slip ring work being performed in Russia. European and American companies are currently working with gallium liquid metal slip rings for use in high power generating equipment. The development effort leading up to this flight experiment began at the LeRC in 1969.

SUMMARY OF DEVELOPMENT WORK

A summary of the development effort related to the flight experiment is given in the following paragraphs. References 3 through 6 provide greater detail.

Concepts

Figure 1 illustrates the basic concept of the LMSR and shows a few of the many electrode geometries studied to date. The electrodes can be continuous cylindrical sections or brushes or probes. In all cases the liquid metal, which is held in position by capillary forces, is designed to wet the electrodes. The cavity containing the liquid metal can be formed by a single electrode or between electrodes, depending on the electrode configuration.

Material Studies

Gallium was chosen as the liquid metal for LMSRs primarily because of its low vapor pressure. An examination of the literature (see reference 7) produced very little useful information on the engineering properties of gallium at the temperatures of interest for LMSRs (100° C and below). In an effort to supplement the existing literature, much of the work in references 3 and 4 was directed at determining gallium properties and defining gallium compatible materials. The important physical properties of gallium are given in Table I.

The primary results of the material studies are given below:

1. Nickel is an excellent electrode material.

2. Aluminum and copper are attacked by gallium.

3. Kapton, Teflon, alumina and epoxy filled fiberglas make excellent insulators.

Surface Film

The most difficult problem encountered in the development of the LMSR was the build up and ejection of debris from the liquid metal cavities. The slip ring assemblies described in references 3, 4, 5, and 6 all experienced debris ejection to some extent.

As a result of the LMSR development effort to date, an understanding of the problem has been achieved. The debris problem may be overcome by:

1. Prohibiting ring rotation if the slip rings are exposed to atmospheric pressures of greater than 10^{-6} torr.

2. Employing an electrode geometry that is tolerant of some surface film.

THE FLIGHT EXPERIMENT

The measurement to be made on the flight experiment will demonstrate that LMSRs can function in a spacecraft environment. They will also allow evaluation of those features of the LMSR where improvement in performance over conventional rings is expected.

Experiment Description

The flight experiment will be a self contained package. It will contain the following:

1. Six liquid metal slip ring circuits.

2. A drive mechanism capable of rotating the slip rings at 1 and 10 revolutions per day.

3. High voltage and high current power supplies.

4. A temperature control circuit capable of maintaining the temperature of the liquid metal above 30° C.

5. Measurement instrumentation and associated signal conditioning electronics.

The experiment is shown schematically in figure 2.

Spacecraft Interface

The experiment/spacecraft interface will consist of the following:

1. Mechanical (5 lb box, 6-3/4 x 6-3/4 x 6-3/4 inches).

2. Electrical (28v regulated bus; 12 watts).

3. Telemetry (14 data channels).

4. Command (9 commands).

5. Handling (maintain temperature below 30° C prior to and throughout launch).

Electrode Configuration

The behavior of the surface film discussed earlier has been found to be very dependent on the geometry of the electrodes. The electrode geometry selected for the flight experiment is shown in figure 3. It represents the most successful design evaluated to date.

The slip ring assembly consists of an axial stack of ring rotor electrodes with tangential cup cavities. Dielectric washers separate the ring electrodes which are mounted on a hollow shaft. The stator electrodes are cylindrical probes with hemispherical ends. The probes are supported by the housing which is made of dielectric material. Table II gives typical dimensions and material specifications.

The ring electrode cavities are underfilled 3 percent by volume with gallium. Both the probes and cavities are wetted with the liquid metal.

MEASUREMENTS AND EXPECTED RESULTS

On the basis of the ground experiments performed to date, a small amount of film is likely to form on the surface of the liquid metal prior to obtaining a space environment. The success of the LMSRs will depend on the quantity and behavior of the film. The primary measurements to be made on this flight experiment will be related to the existence and behavior of surface film.

Slip Ring Insulation Resistance Measurements

Two slip rings of a very high voltage design will be contained in the experiment package. The insulation surrounding the high voltage circuits will be designed such that the leakage current due to the surface resistance of the insulation material is greater than the leakage current due to the bulk resistance and gas or plasma resistance surrounding the high voltage circuit. If the slip rings generate debris and it is not contained in the ring cavity, then it is expected that the debris will be deposited on the surface of the insulating material with a resulting decrease in surface resistance. The leakage current can be expected to increase quantitatively as the quantity of debris deposited increases. A surface breakdown would be the eventual result.

A schematic of this measurement is shown in figure 4. A 2 kilovolt dc supply (current limited to 100 μ amps) will be connected to one of the high voltage electrodes. It is planned to apply the high voltage continuously for the duration of the mission and measure the long term variations in the leakage current. The average leakage current between the rings and between the rings and chassis ground will be measured with electrometers.

Slip Ring Electrical Resistance Measurement

Two slip rings of a power slip ring design will be included in the experiment package. The two rings will be connected in series by connecting the rotor electrodes together on the rotor shaft. Direct current will be continuously passed through the rings for the duration of the mission and the long term variation in the resistance through the rings will be measured.

Two amperes of direct current will be supplied by either a DC-DC converter or another source specifically designed for this experiment.

The current through the rings will be measured by sensing the voltage drop across a known resistance. The voltage drop across both rings in series will also be measured. The schematic for this measurement is shown in figure 5.

The electrical resistance of a slip ring employing wetted electrodes is very small, essentially that of the bulk resistance of the liquid metal and electrodes. If excessive debris forms, however, the resistance can increase by 2 or 3 orders of magnitude and become variable. Thus, measurement of the electrical resistance of a slip ring circuit will provide information about the formation and control of debris.

Optical Debris Sensing

Changes in surface optical properties associated with the formation of surface film will be detected in one of the power rings.

A light emitting diode will transmit light to the surface of the liquid metal via fiber optics. Reflected or scattered light will be sensed by a phototransistor via another fiber optics bundle. A schematic for the measurement technique is shown in figure 6.

The output of the optical debris sensor will provide a "signature" of the surface of the liquid metal. Calibration of the signature against ground test data will allow a direct evaluation of the ring cleanliness.

Other Measurements

In order to provide information on the state of the experiment, the following housekeeping parameters will be monitored:

1. Temperature measurements on the rotor and stator.
2. Drive motor current.
3. Heater current.

The rotor electrode temperature will be sensed by mounting a thermistor on the rotor. Two slip ring circuits will be provided in the experiment package to connect to the rotor mounted thermistor leads.

APPLICATION

Preliminary design studies indicate that an operational slip ring assembly using the electrode configuration of this experiment would have the following characteristics:

1. Stack length (excluding bearings) - 14-20 rings per inch.
2. Maximum outside diameter - 3 inches.
3. Inside shaft diameter - 3/4 inches.
4. Specific weight (includes rings, spacers, probes, shaft and housing material) - 0.03 pounds per ring.
5. Current capability - 2 amps per probe; 10 amps per ring.
6. Voltage capability - 2kv between adjacent circuits.
7. Electrical noise - negligible.
8. Electrical power loss - negligible.
9. Friction torque - negligible.
10. Special handling - temperature constraint during pre-launch handling.
11. Life - no recognized wearout mode.

CONCLUDING REMARKS

The Liquid Metal Slip Ring flight experiment will demonstrate a new approach to power and signal transfer across a rotating interface. Spacecraft designers will be able to use this concept to improve the overall performance of the next generation of high power communication satellites.

REFERENCES

1. Przybyzewski, John S.: Liquid Gallium Rotary Electric Contact. NASA Tech Brief 69-10138, 1969.

2. Yatsenko, S. P.; Loshkin, D. V.; and Perelshteyn, G. N.: The Application of Gallium Alloys in Liquid Sliding Contacts. Academy of Sciences of the USSR. Ural Branch. Institute of Chemistry. Transactions, No. 12, 1966, pp. 132-134.

3. Clark, R. B.: Experimental Liquid Metal Slip Ring Project. NASA CR-72780, 1970.

4. Weinberger, S. M.: An Experimental Liquid Metal Slip Ring to Transfer Power Between Rotating Satellite Parts. NASA CR-72790, 1970.

5. Clark, R. B.: Design Study for a Liquid Metal Slip Ring Solar Array Orientation Mechanism. NASA CR-120954, 1972.

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7. Lyon, Richard N., ed.: Liquid-Metals Handbook. Second ed., U.S. Government Printing Office, 1952.

TABLE I

PROPERTIES OF GALLIUM

Density, g/cm^3	6.1
Surface tension, dyne/cm at 30° C	735
Viscosity, poise at 100° C	0.016
Vapor pressure, torr at 80° C	10^{-33}
Melting point, °C	30
Freezing point	Supercools
Boiling point, °C	1983
Resistivity, μΩ cm at 30° C	28
Toxicity	Not Toxic
Corrosivity	Variable

TABLE II

TYPICAL DIMENSIONS AND MATERIAL SPECIFICATIONS

(a) Dimensions

Element		Dimension
Slip ring:	cup width	0.064 cm (0.025 in)
	cup depth	0.064 (0.025)
	diameter	5.08 (2.00)
Probe:	diameter	0.038 (0.015)
	depth	0.051 (0.020)
	trailing angle	90°

(b) Materials

Element	Material
Slip Ring	Nickel 200
Probe	Nickel 200
Mounting dielectric	Delrin
Labyrinth/spacer dielectric	Kapton

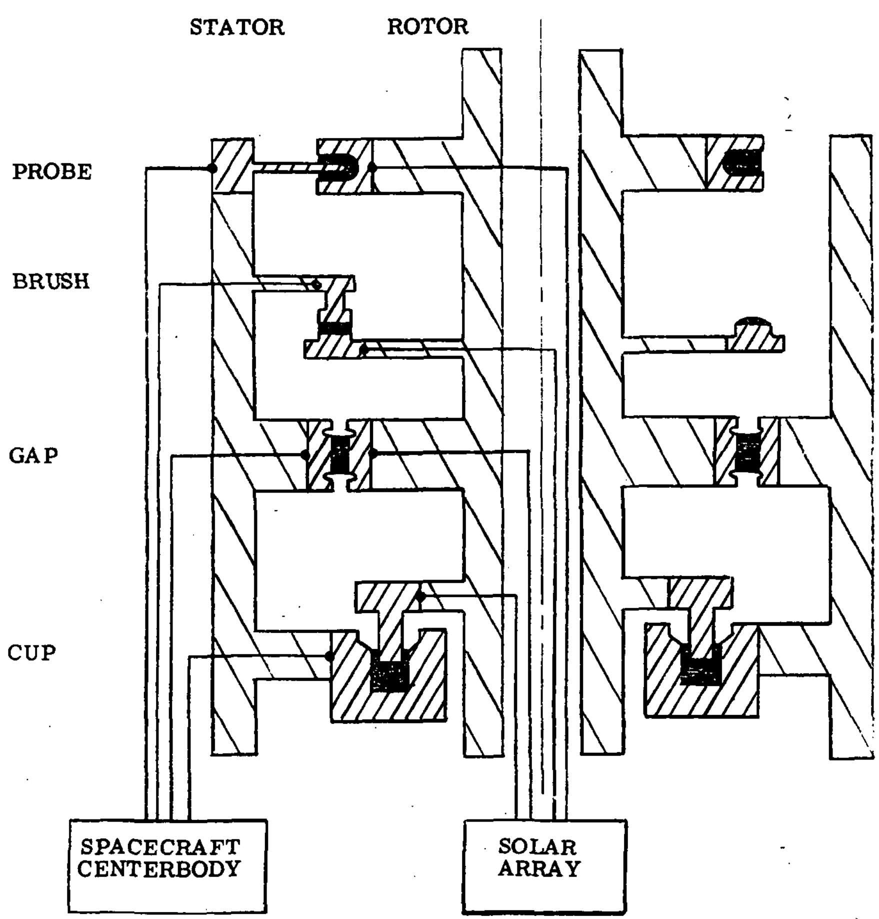

FIGURE 1. - LMSR ELECTRODE CONFIGURATION.

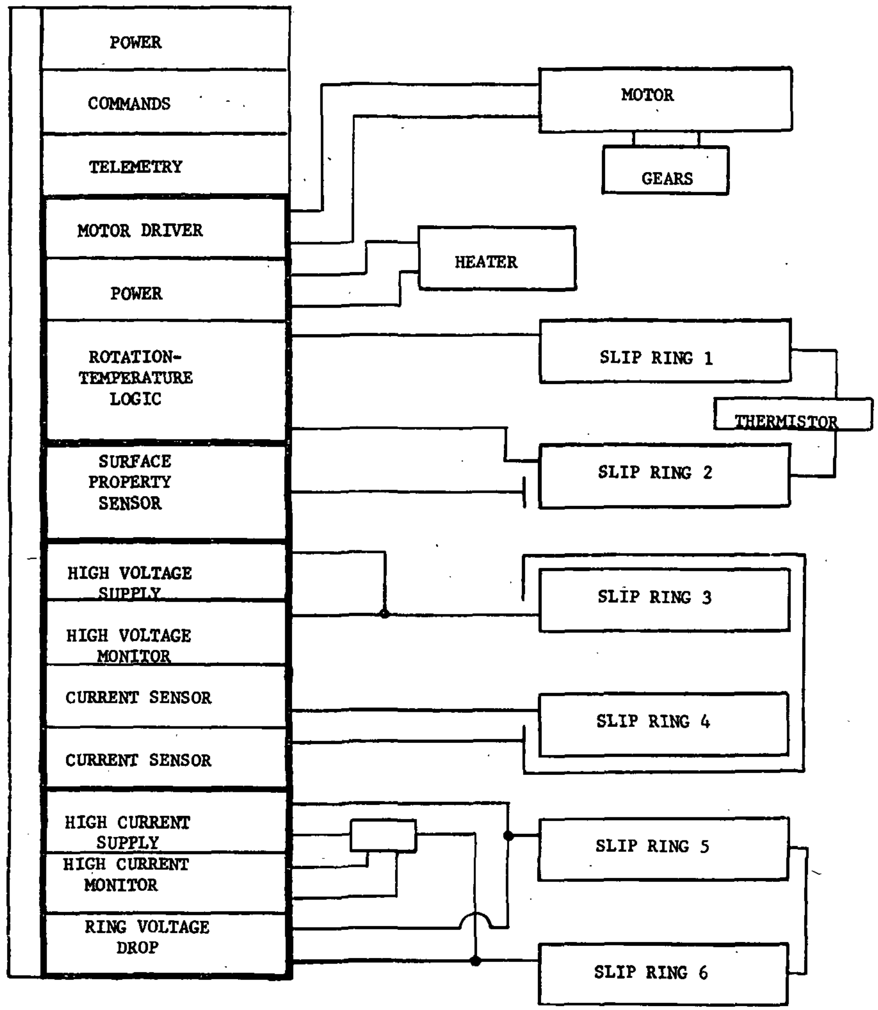

FIGURE 2. - LMSR EXPERIMENT.

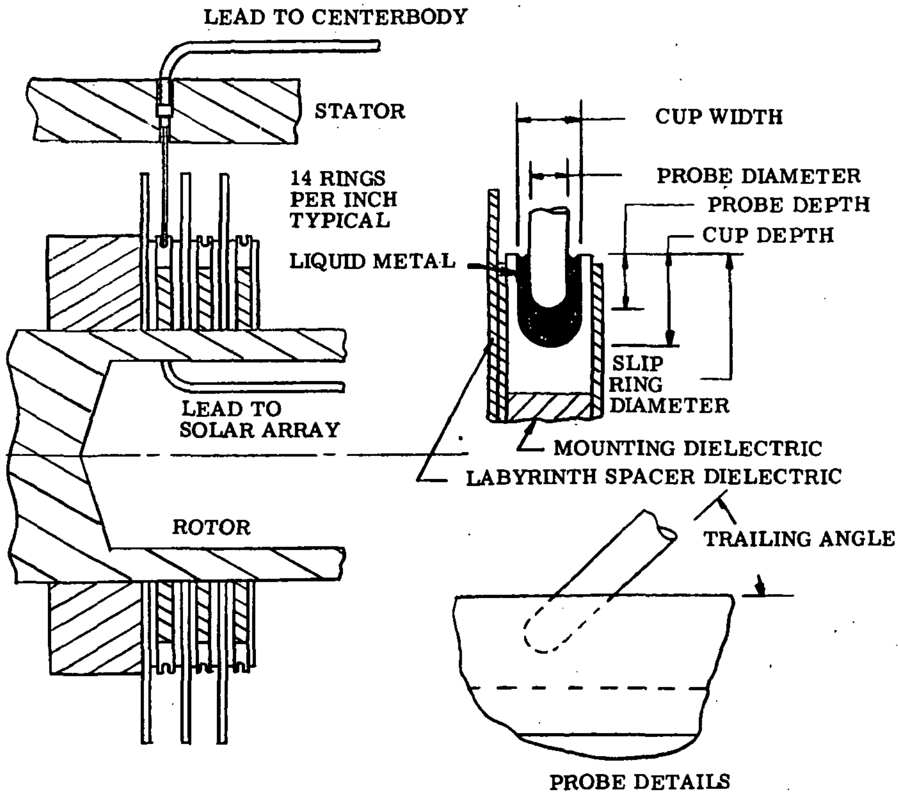

FIGURE 3. - TYPICAL LMSR ASSEMBLY

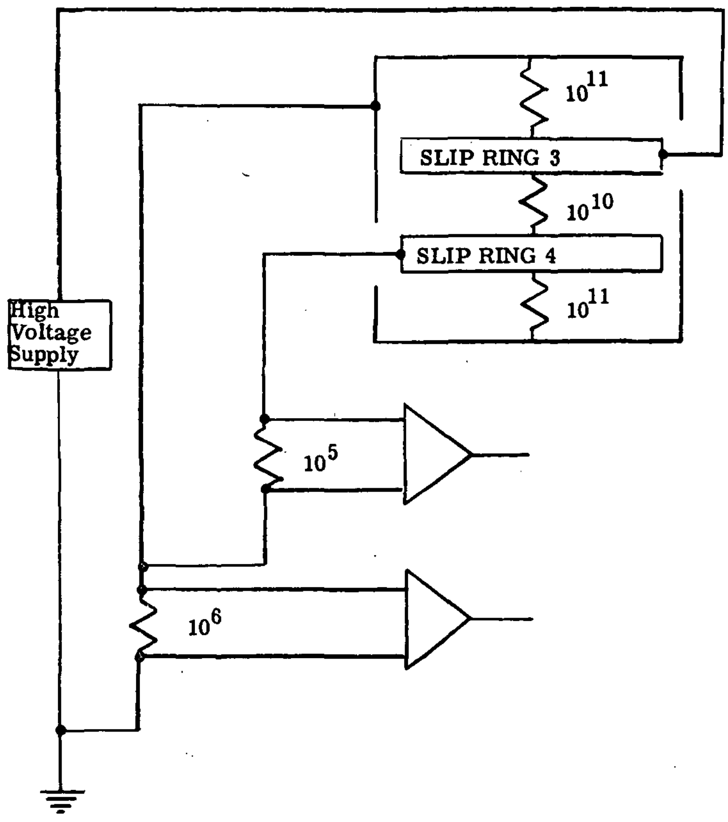

FIGURE 4. - SCHEMATIC OF SLIP RING LEAKAGE CURRENT MEASUREMENT.

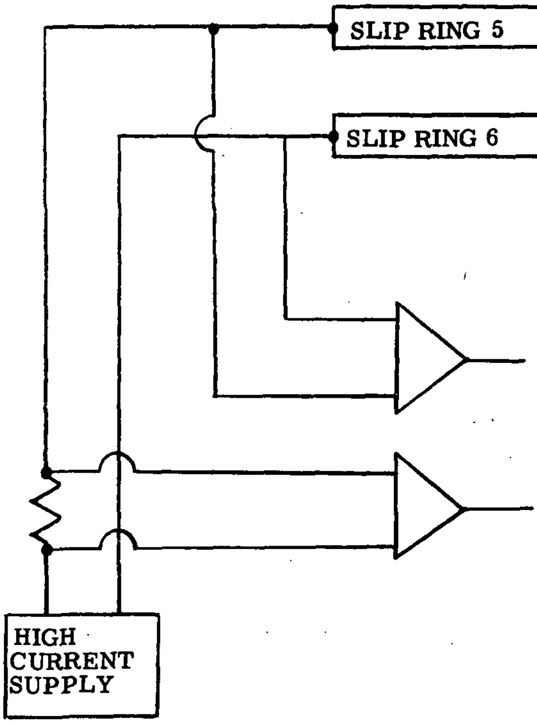

FIGURE 5. - SCHEMATIC OF RING ELECTRICAL RESISTANCE MEASUREMENT.

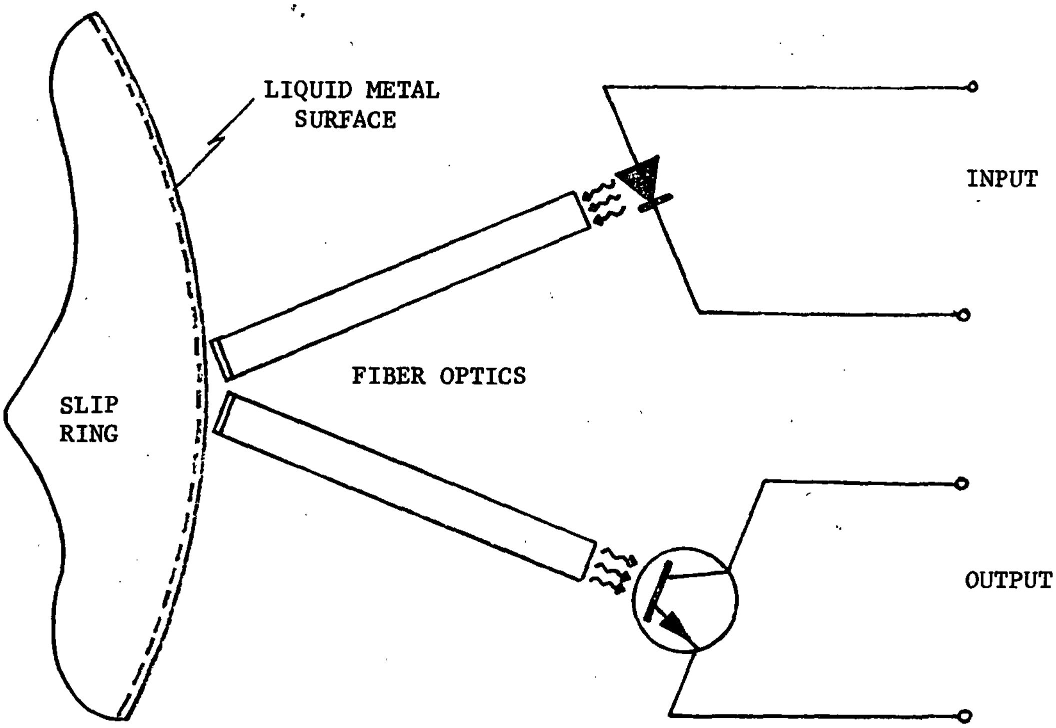

FIGURE 6. - SCHEMATIC OF SURFACE DEBRIS OPTICAL SENSOR.