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Technical Memorandum 33-608

Image Dissector Development

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PREFACE

The work described in this report was performed by the Guidance and Control Division of the Jet Propulsion Laboratory.

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ABSTRACT

A second-generation electrostatically focused image dissector tube for use in spacecraft attitude control star trackers is being developed with the support of an industrial contractor. Significant improvements are being made in functional characteristics, as well as in package dimensional control, tolerance of a wide variety of environmental conditions, and expected reliability over long operational lifetimes.

I. BACKGROUND

Image dissectors, or scanning photomultipliers, are used as the direction sensing and star brightness measuring element in the Mariner spacecraft attitude control star tracker. The image dissector is, in essence, a photomultiplier which has electron optics to re-form the image from the photo-cathode at a sampling aperture plate located at the entrance to the electron multiplier structure. A means of deflecting the electron image is provided by transverse electrostatic fields in order to scan the electron image across the aperture for signal modulation purposes, and to provide field of view gimballing.

Incorporation of all of these functions -- field of view gimballing, signal modulation, detection, and pre-amplification -- within a single functionally simple electron device provides substantial benefits in terms of a relatively simple star tracker package, optimum signal processing, low weight, and potentially unlimited lifetime due to the no-moving-parts design. Either electrostatic or magnetic field effects may be used for focusing the electron image and for deflection. The magnetic technique has the advantages of providing a very uniform resolution over the field and of having deflection coils external to the vacuum envelope. This leads to a simpler image dissector tube structure; however, substantial penalties must be paid in terms of the weight and size of the magnetic shielding required to prevent interference with spacecraft science experiments and the weight and power requirements associated with the magnetic coils. The Mariner spacecraft star sensor uses an electrostatically focused and deflected image dissector. Resolution has been adequate for all requirements, and the power drain is very small -- typically 0.1 W to operate all functions of the image dissector. The gimballed field of view limits have been typically 11 × 41 deg, with a null pointing accuracy of 0.05 deg.

Image dissectors have been used for a variety of tasks since 1934, when they were first used in an early form of television (Ref. 1). Ruggedized units suitable for a space-borne application were not available until 1963, when development of the Mariner image dissector was successfully completed by industry under contract to JPL (see Fig. 1). The photo-cathode of the early Mariner image dissector is an S-11, shown in Fig. 1 deposited on the inner surface of a sealed fiber-optics faceplate. A clear glass faceplate has been used more recently for Mariner 1969 and 1971. The two-axis deflection structure used is the Schlesinger Deflectron (Ref. 2), an interleaved set of four conducting patterns mounted to the inner surface of a cone. The envelope is principally a glass and Kovar structure. The 12-stage electron multiplier is capable of providing essentially noise-free signal amplifications of 10^7. Automatic gain control can be provided by controlling the multiplier driving voltage.

This dissector has been successfully used on the Mariner 4 spacecraft for the flyby of Mars in 1964, Mariner 5 to Venus in 1967, Mariner 6 and 7 to Mars in 1969, and most recently, the Mariner 9 spacecraft, which in 1972 photographed the entire surface of Mars from a planetary orbit.

The potential for a long and trouble-free lifetime provided by the no-moving-parts design philosophy was first demonstrated by the Mariner 4 unit, which operated in space throughout the full 3-year lifetime of the spacecraft.

However, a number of problem areas in the Mariner image dissector have been apparent since its earliest use. The Kovar and glass envelope structure is relatively fragile, has a high magnetic retentivity (which can lead to null pointing errors), and cannot be fabricated to close dimensional tolerances. In addition, many of the tubes have exhibited an anomalously large and noisy dark current, which has often exceeded the signal current. The Mariner 6 spacecraft at one point executed an unscheduled reverse direction roll search as a result of a lengthy burst of excess dark current. Excess dark current is believed to be due to the use of cesium in the formation of both the photo-cathode and the electron multiplier secondary emitting surfaces. Deposition on other surfaces is thought to create relatively large areas having thermionic electron emission and possibly to allow direct surface conduction.

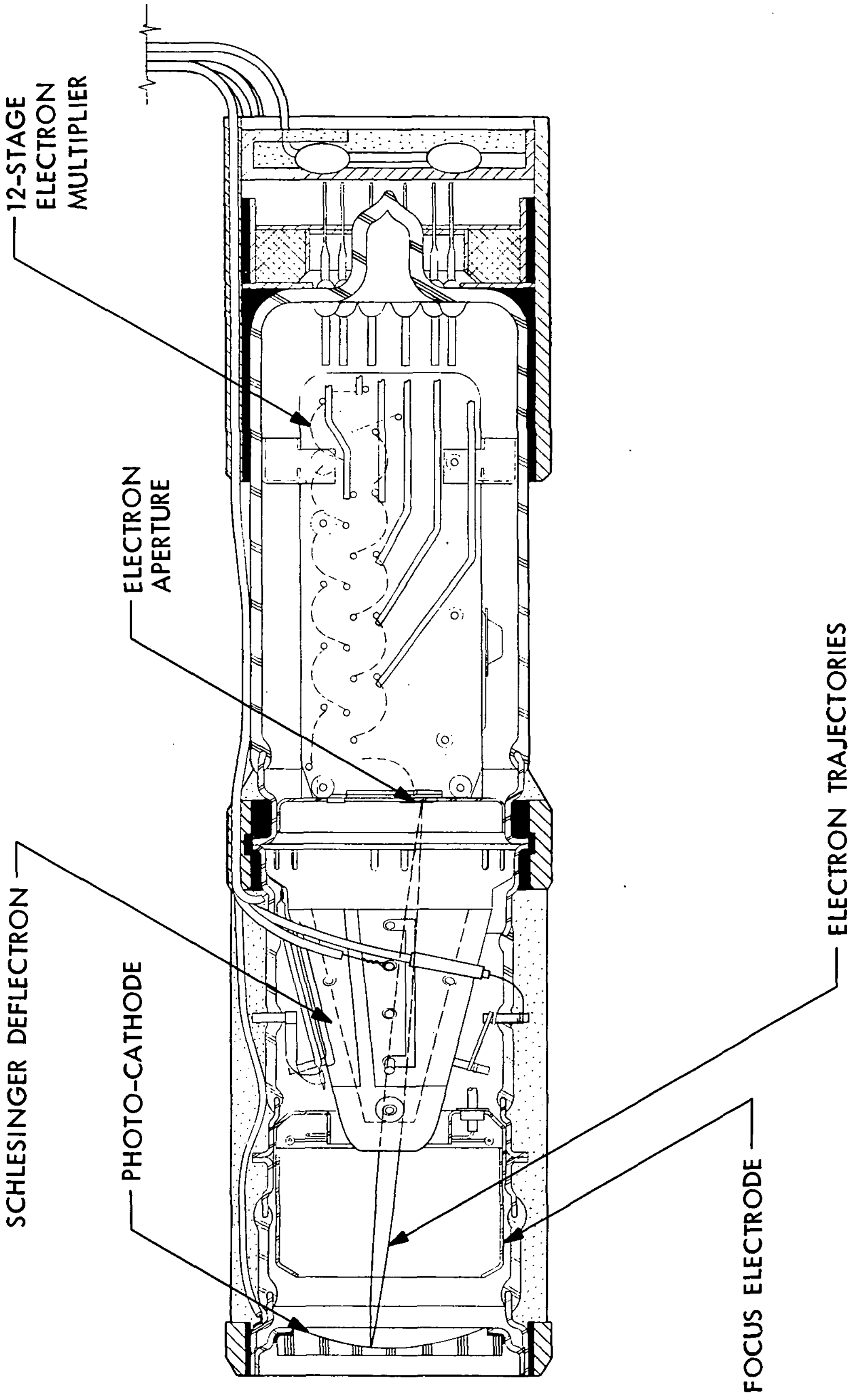

Fig. 1. The Mariner electrostatic image dissector

A number of long-duration outer planet missions are now planned that will use the Mariner star tracker. In order to meet the need for high reliability and low-noise operation for long periods of time, as well as for the purpose of improving the producibility and reproducibility of the image dissector, a contract has been let to upgrade the design. The design has been completed, and the first units have been tested and delivered.

II. DEVELOPMENT

Figure 2 is a section view of the new tube. The electron-optical configuration has remained the same; otherwise, the tube has been completely redesigned. The entire structure is ceramic and metal, excepting the sapphire faceplate; it is jigged and hydrogen furnace brazed into three subassemblies, which are then heliarc welded at assembly. The tube is potted at final assembly into a cylindrical shield with the same mounting dimensions as the mounting rings of the present Mariner image dissector. The shield is a composite structure, having a fiberglass shell for electrical insulation nested inside an aluminum shell. For subsequent procurements, the aluminum will be replaced with a magnetic shielding material.

The photocathode is the EMR Photoelectric Type "U" -- a cesium-free material having unusually stable characteristics. This cathode has performed successfully under an earlier JPL contract to demonstrate stability at temperatures of 145°C. Figure 3 shows the spectral energy density of the attitude control reference star Canopus and typical radiant sensitivity characteristics of the "U" photocathode and current Mariner image dissector S-11 photo-cathode as negotiated in contracts with the respective suppliers. One new image dissector has been delivered having 50% greater sensitivity than illustrated, and several of the Mariner dissectors have had twice the illustrated sensitivity.

A significant change has been made in the construction of the electrostatic deflection cone assembly. The earlier model uses a ceramic cone base with Monel deflection structures stud-mounted to the ceramic cone. Null pointing direction drifts having stabilization times of up to several hours have been observed with this earlier model and are thought to be due to electrostatic charging of several dielectric surfaces, including the ceramic

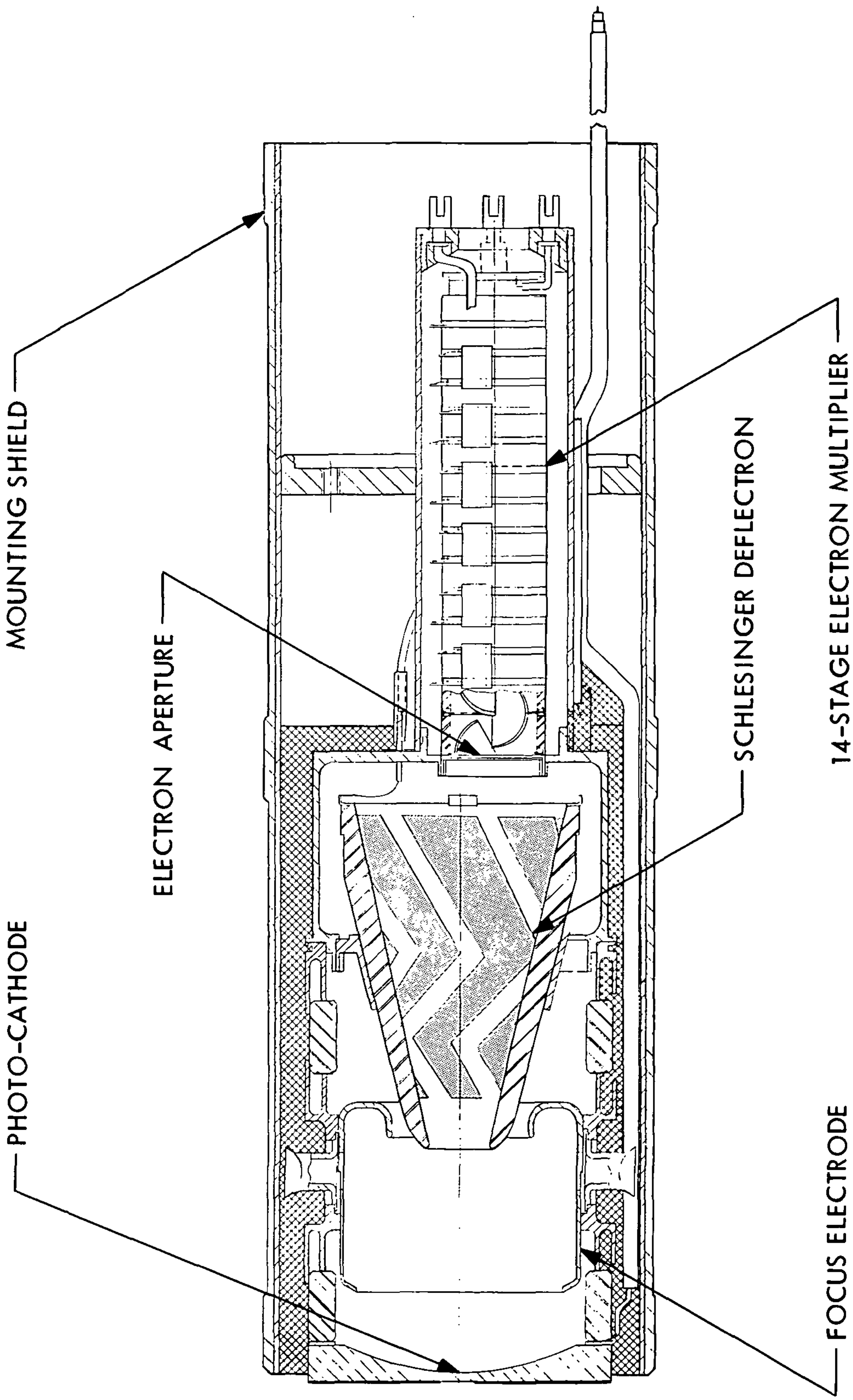

Fig. 2. Advanced development image dissector

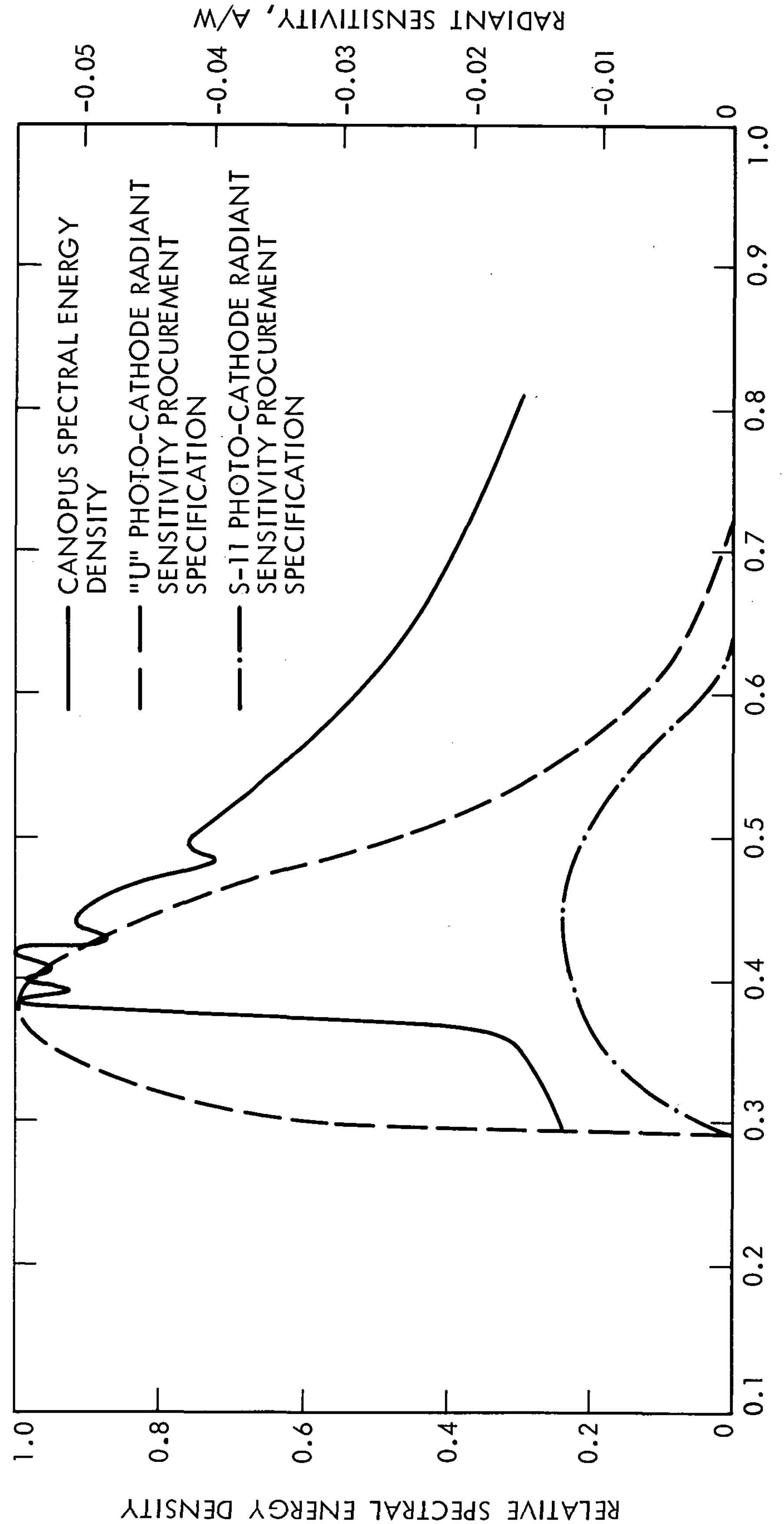

Fig. 3. Star source and photo-cathode spectral characteristics

cone. The ceramic cone in the new image dissector is metallized and grounded on the exterior and has a thin, slightly conducting chromium oxide layer on the inside. The deflectron pattern is photoresist deposited directly on the chromium oxide surface. For the same reason, the ceramic ring which contacts the faceplate is aluminized over the exposed portion of its inner surface and electrically connected to the photo-cathode.

The electron multiplier is a standard product line item. It consists of 14 stages of beryllium-copper dynodes mounted in a jigged and brazed ceramic stack. This structure is known to be stable and to contribute very little to the dark current. A dark current of 5×10^{-12} A measured at the anode for a multiplier gain of 10^7 is typical. Gain characteristics are usable up to 10^8. Typical use in this application will be at 10^6, a figure which is usually reached at 1300 V. Stability in the presence of extreme environments is very good. The multiplier is rated for operation up to a maximum of 125°C and for very high levels of vibration.

The pinched-off tubulations shown in Fig. 2 outboard of the focus electrode are the processing channels through which the tube is evacuated and metal vapors are introduced to form the photo-cathode. After processing, the sources are withdrawn and the tubulations pinched off. No bulk reactive materials are left within the assembly after processing.

Table 1 lists the materials used in the new tube. Material selections were guided largely by concerns for compatibility with high vacuum, limiting of thermally induced stresses to safe levels, ease and reliability of fabrication, and low magnetic permeability and retentivity. Sapphire was chosen to replace glass for the faceplate because of its ruggedness, brazeability, and close thermal expansion match to the 96% aluminum oxide ceramic. Monel 404 was selected for the major structures because of its excellent brazeability, weldability, and low magnetic permeability (1.10). Although the material has a large thermal expansion coefficient compared to that of the ceramic (18×10^{-6}/°C vs. 7×10^{-6}/°C), it is very ductile and, in addition, stress-relieves above 300°C. Reliable Monel 404-ceramic seals have been developed and proven in the course of this contract.

A small quantity of magnetic materials has been retained in the construction of the electron multiplier for reasons of compatibility with the commercial product. Nickel, with a permeability of up to 600, and Kovar,

Table 1. Material selections

Part	Material
Faceplate	Sapphire, 60-deg orientation, U. V. grade
Multiplier envelope	Ceramic, 96% alumina
Vacuum envelope	Ceramic, 96% alumina
	Monel 404
Focusing electrode	Monel 404
Deflection cone	Ceramic, 96% alumina
Deflection cone mounting ring	Monel 404
Deflection cone pattern	Copper
Dynodes	Beryllium copper
Dynode cups	Nickel, electronic Grade A
Mounting cylinder	Aluminum 6061 T-6
Mounting cylinder sleeve	Epoxy fiberglass, G-11
Multiplier support bulkhead	Epoxy fiberglass, G-11
Anode	Stainless steel 304
Anode mounting flange	Kovar
Multiplier coupling ring	Kovar
Braze material	Silver 72%, copper 28%, eutectic
Encapsulation	Sylgard 185

with a permeability of up to 3700, are utilized in the dynode mounting cups and in two mounting rings. The total magnetic moment is small and well removed from the free-electron trajectories.

These material selections have been reviewed from the standpoint of interplanetary space and radioisotope thermoelectric generator (RTG) power supply radiation effects. No lifetime problems due to these radiation environments are foreseen.

Some interactions of radiation fields with the photo-cathode and dynodes will result from collisional and Cerenkov processes but are expected to be very small. Signal processing at the modulation frequency of the image dissector provides a very high level of discrimination against signals originating uniformly from the surface of the photo-cathode, or anywhere within the dynode structure. Recent tests have shown that photo-electron flux densities released from the photo-cathode must approach $10^6/cm^2$ s in order to appreciably alter star tracker characteristics. An early test of sapphire fluorescence was made in neutron and gamma fields at ten times the then-anticipated TOPS RTG levels. No measurable levels of fluorescence were found.

III. TEST RESULTS

To date, two tubes have been tested and delivered under the contract. The first was constructed using a stainless-steel and ceramic structure, which was later abandoned because of the difficulty of performing welding and brazing operations. However, the functional characteristics are expected to be representative. The second tube has been built to the design described in this report.

Table 2 summarizes the results of preliminary tests which were performed by the contractor prior to delivery. Test results are listed in the first two tabular columns, the contract specification in the third, and current specifications for the Mariner image dissector are shown in the fourth column. The data shows that very significant improvements have been made in the photo-cathode sensitivity, tube stabilization times, and dark current levels. Modest improvements in photo-cathode and photomultiplier uniformities appear to have been achieved. Both deflection stabilization and gain

Table 2. Functional test results

Test parameter	Tube 1	Tube 2	Design specification	Mariner dissector specification
Photocathode sensitivity at 0.41 μm, A/W	0.077	0.053	≥.055	~0.014 at 0.45 μm
Photocathode sensitivity uniformity	0.89	0.75	≥.75	0.75
Electron multiplier gain uniformity	0.75	0.82	≥.70	0.70
Gain stabilization time, to 90%, s	90	96	≤60	≤2 h until $dG/dT \leq 0.2\%/\text{min}$
Deflection stability after 60 s, μm	2.5	5.3	≤2.5	25
Dark current at 2×10^6 gain, 22°C, A	3×10^{-12}	9.8×10^{-11}	$\leq 2.5 \times 10^{-10}$	$\sim 10^{-7}$
Dark current at 2×10^6 gain, 75°C, A	1.5×10^{-10}	Not measured	$\leq 1 \times 10^{-9}$	Not applicable

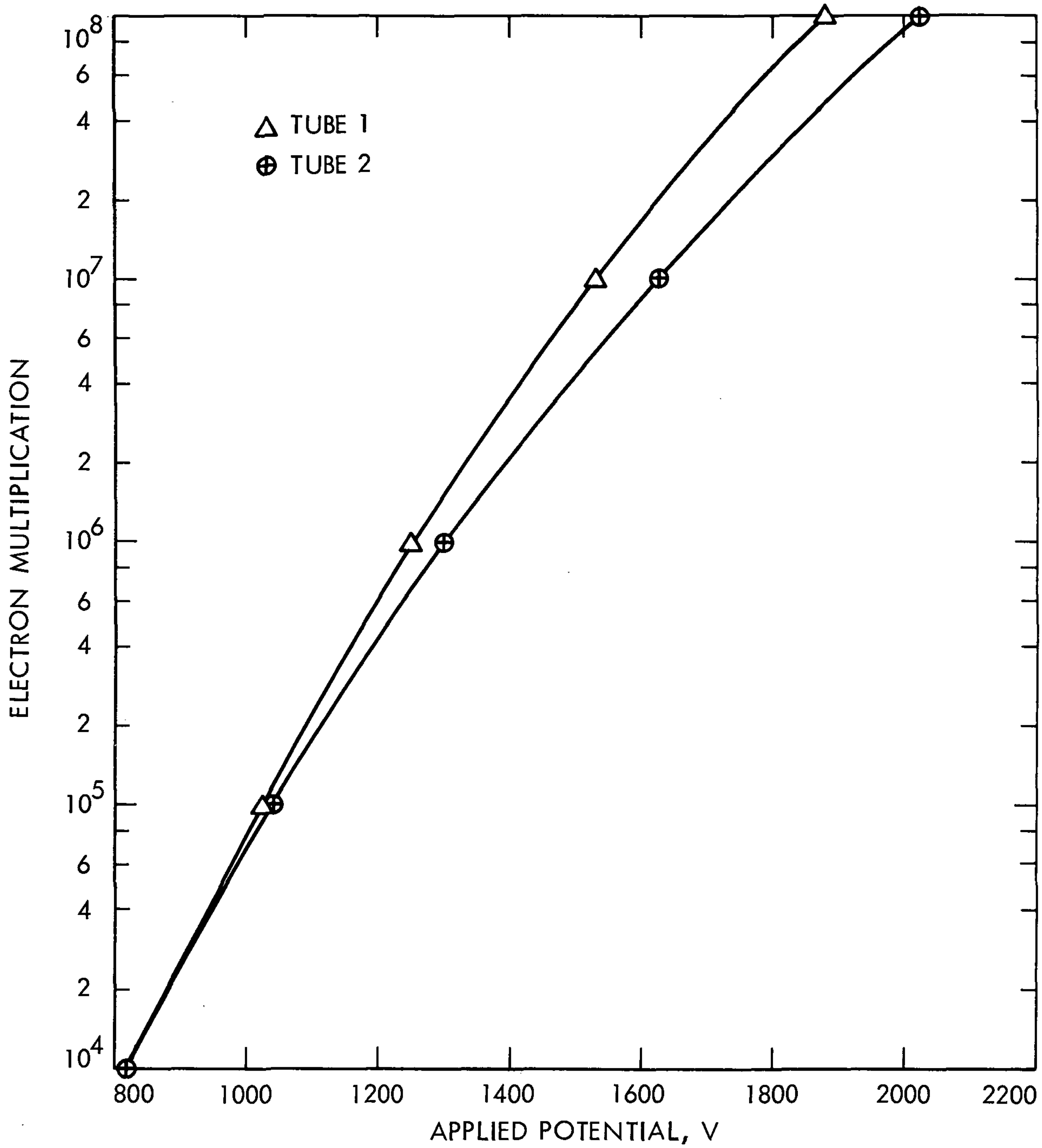

Fig. 4. Measured electron multiplier gain vs. voltage

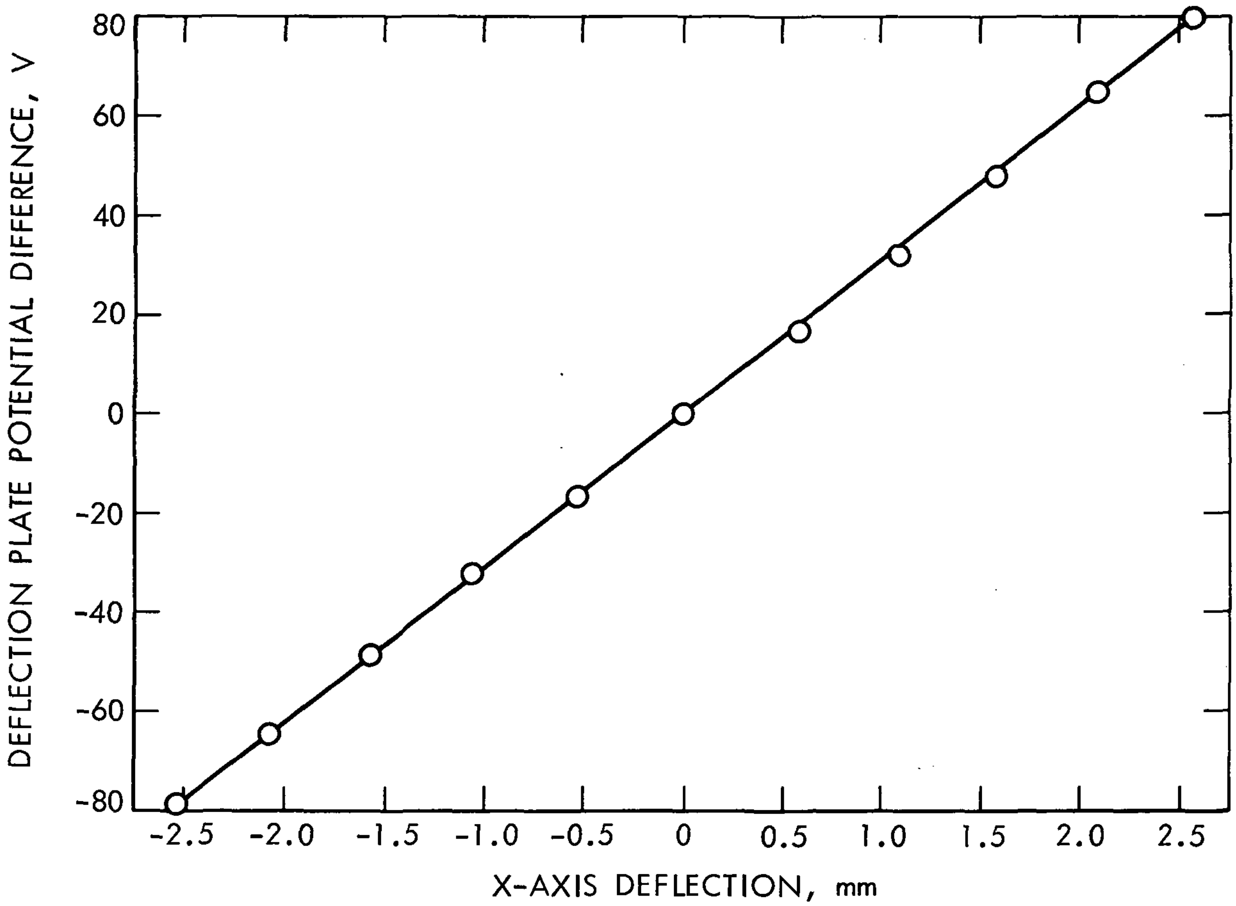

Fig. 5. Deflectron scanning characteristics, tube 1

stabilization are occurring over somewhat longer periods than had been estimated to be necessary.

Figures 4 and 5 depict measured multiplier gain values and deflection scanning characteristics over the central 1/2-cm field. It should be emphasized that these tests are only preliminary. A very thorough set of functional and environmental tests still remain to be performed to verify continued and stable performance under conditions of shock, vibration, magnetic and radiation fields, temperature extremes, and long-term operation.

IV. SUMMARY

Design and development of a second-generation image dissector appears to be reaching a satisfactory conclusion. An extremely rugged and essentially nonmagnetic structure meeting tight dimensional controls has resulted. Functional performance of delivered units has shown very significant improvements over that of the present Mariner image dissector. The excellent high-temperature stability and extremely low dark current values are good indicators of a long, stable, and highly reliable lifetime.

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