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SCENE SIMULATION FOR PASSIVE IR SYSTEMS*

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ABSTRACT

The development of large mosaic detector arrays will allow for the construction of staring LWIR sensors which can observe large fields-of-view instantaneously and continuously. In order to evaluate and exercise these new systems it will be necessary to provide simulated scenes of many moving targets against an infrared clutter background. At the AEDC as part of our ongoing efforts to provide a test capability in this area of sensor evaluation, we are monitoring the development of a number of simulator technologies which have the potential for providing a multiple target test capability. However, since at this time there is not a system available for use within a cryo-cooled vacuum environment, we are currently developing a projector/screen system for use at the AEDC in an attempt to provide the needed test capability.

This system is comprised of a mechanical scanner, a diffuse screen, and a miniature blackbody. A prototype of the mechanical scanner, which is comprised of four independently driven scanners, has been designed, fabricated, and evaluated under room and cryogenic vacuum conditions. A large diffuse screen has been constructed and tested for structural integrity under cryogenic/vacuum thermal cycling. Constructional techniques have been developed for the fabrication of miniature high-temperature blackbody sources. Finally, a concept has been developed to use this miniature blackbody to produce a spectrally tailorable source.

INTRODUCTION

The role of satellite-borne long wavelength infrared (LWIR) systems is rapidly changing from passive early warning of an offensive missile launch to that of a major segment of an active defense-in-depth (DID) network. Projected satellite systems will perform many tasks including early-warning, destruction of boost-phase vehicle, tracking of those rockets which leak through, mid-phase discrimination of active reentry vehicles (RVs), and subsequent destruction and handover to ground-based systems for the final defense leg.

No one type of sensor system can be expected to perform all of the detecting, tracking, and discriminating functions which will be required. At the present time it is not known which of the various systems may be located on common satellite

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platforms or which may be on multiple smaller satellites. It is obvious, however, that the future test facilities needed to evaluate and test these systems prior to deployment must provide infrared targets and scenes which can reproduce scenarios typical of the most stressing offensive attack which can be envisioned.

It is the purpose of the present report to give a brief summary of multiple target simulation requirements and describe the status of a source projection target system.

REQUIREMENTS FOR TESTING IR SENSORS

The field-of-view (FOV) of infrared (IR) sensor systems can be divided into three types: the space background, the earth limb, and the earth surface. Each of these fields-of-view consists of a background contribution and a set of targets, and in each case the targets move relative to the background. In some instances the targets may be colder than the background, thus producing a negative contrast target.

Sensors confined to looking above the earth limb will see targets against a background of stars. These stars, along with the targets, will appear as point sources at the focal plane of the sensor and will be the least complex scene required. The types of objects could range from reentry vehicles (RV), decoys and spent rocket casings to plumes from final deployment and dispersion thrusters. Such plumes and intentionally deployed particle clouds could reach sufficient size as to appear as extended sources--illuminating several adjacent pixels on the mosaic array in the detector focal planes.

A simulated target scenario for sensor systems will thus require an overall background at 20 K to simulate the space environment. It should include a pattern of stars which can be swept across the field-of-view. The rate at which the stars move across the background will depend on the particular orbit and viewing attitude of the sensor. Superimposed on this scene will be the targets and objects of the simulated attack force. While these objects all move in the same general direction some allowance must be made for individually tailored trajectories. Discrimination between targets and decoys in this exoatmospheric phase of the trajectory will most likely rely on target signatures. Therefore, a test simulator should have the capability of producing targets and objects with sufficient spectral structure for the sensor to exercise its discrimination algorithms. The possibility of a blooming target to simulate plumes and particle clouds would also be desirable.

The earth limb field-of-view requires all of the previously noted simulations plus a superimposed extended source over an extensive portion of the imaged scene. This extended source could have significant structure depending on the atmospheric conditions. Periods of intense solar activity can result in auroral events with significant radiation in wavelengths to which the IR systems are sensitive. This structure can last from seconds to several minutes; thus an additional simulation requirement is a superimposed IR background which has a structured intensity that can be varied with time.

The requirements for an earth-looking FOV simulator are so different from those previously described that it is probable that completely different concepts and technologies will be needed to produce it. The emitted and reflected radiation from the earth surface and clouds will provide a complex, structured background.

Exoatmospheric objects such as satellites, RVs, and decoys can be cooler than this background and can present a negative contrast. Objects reentering the atmosphere will experience aerothermal heating, and thus their radiant energy can be expected to increase by several orders of magnitude as they are being tracked. Objects within the atmosphere, such as aircraft, cruise missiles, and ships, will have positive signatures; however, these will be modified by atmospheric absorption. This absorption will vary depending on the pathlength of the radiation through the atmosphere which will be a function of the viewing angle of the satellite system.

The ability to test surveillance sensor systems hinges on the development of new target simulation techniques. It is unlikely that a single scene generator will be able to provide the variety of scenarios required for the evaluation of the various types of sensors which are being proposed for future surveillance and defense systems.

TEST METHODOLOGY

Surveillance systems using staring mosaic arrays are expected to have large aperture optical telescopes with a wide field-of-view. This presents a particular problem for a ground test facility which must provide a simulated IR scene at an effective infinite distance. The prime technology barrier is the large mirrors needed to provide the collimated radiation. A test methodology has been proposed which circumvents the problems associated with the large chamber optics.

In this evaluation sequence, the mission/scenario testing is accomplished on the sensor focal plane before assembly in the telescope system. The test must provide an IR scene generator and a set of optical mirrors to focus this scene on the mosaic array. This testing can provide an evaluation of the optical performance of the focal plane and the data processing capability of the associated computer system and its algorithms.

A subsequent test program is conducted with the telescope assembled. In this test a collimating mirror is required; however, it can be limited in size to the entrance aperture of the test system. This test becomes one of integration, optical alignment, telescope throughput, off-axis rejection, and radiometric calibration, all of which can be accomplished by mapping the field-of-view with calibrated IR sources.

Two types of test facilities are required. The first is a focal plane array (FPA) facility that provides radiometric calibration and also produces dynamic IR scenes to test the detector system's ability to detect, sort, and track objects. The second facility requires a collimation system that can illuminate the full aperture of the sensor telescope. The mirrors required for such a facility need to be approximately 20-percent larger than the entrance aperture of the test article. Full-aperture illumination would preserve the diffraction-limited resolution of the sensor telescope and would also permit total FOV tests by using a scanning and focal plane mapping technique.

In the present paper our concern is with the development of a system to produce dynamic IR scenes for the FPA facility.

REVIEW OF TARGET SIMULATOR CONCEPTS

Multiple target simulator concepts fall into two general categories. Those systems in the first category compose the scene from a mosaic of discrete elements and can be further grouped as IR emitters or IR modulators, figs. 1a, 1b, and figs. 1c-1e, respectively. Illumination by a wide-beam IR source is required for all of these systems, i.e., figs. 1a-1e. The second category is comprised of what are classed as analog systems, c.f., figs. 1f and 1g.

Some examples of the concepts that have been, or are currently being evaluated are listed in table I. Our assessment of the state-of-the-art with regard to the scene simulators that are being developed for use with warm backgrounds has indicated that some of these may be capable of adaptation for use in a cryogenically cooled vacuum environment. However, the unavailability of a multiple target simulator to provide a mix of spectrally differing targets with independent control of intensity in a cryo-cooled vacuum environment provided the impetus for the cryogenic projector system currently being developed at the AEDC.

CRYOGENIC MULTIPLE TARGET SYSTEM

Components for the projection screen multiple target system are shown in fig. 2. The sources are miniature IR emitters which in the prototype will be designed as blackbody cavities. In future versions the spectral output of the sources will be tailored to simulate specific target signatures. The projection optics are duplicated for each source and consist of a set of cryogenically cooled (20-K) mirrors driven by mechanical actuators. The choice of mirror driver is determined by the type of target motion to be simulated. The mechanical scanner currently under development is geared toward slow-moving targets at large distances. The screen is a cryogenically cooled reflective surface which is diffuse to IR radiation. The number of moving targets which might be projected simultaneously with this system is limited by the degree of miniaturization which can be accomplished in the sources and scanners. The clutter background can be projected from a single still-frame projector. Recent development efforts have been directed toward constructing and testing the projection screen, developing and testing the scanner system, and developing the technology required to produce a high-temperature miniaturized blackbody source.

MINIATURE BLACKBODY SOURCE

It was recognized early in the development process that currently available blackbody sources were too large for use in a multiple target system. These conventional blackbody sources are composed of an isothermal cavity whose walls have an emissivity close to unity and an area much larger than the emitting orifice. The requirement to operate the source within a vacuum/cryogenic environment complicates the design of a miniature blackbody (MBB) since: (1) The need to operate within a 20-K enclosure results in strong thermal gradients between the MBB and its support structure. This complicates the problem of providing an isothermal cavity and results in an increased design effort to minimize heat loss from the cavity; (2) Outgassing from components used in the manufacture of conventional blackbody sources can contaminate sensitive optical components located within the cryogenic/vacuum environment. As a result of the need to minimize these heat loss and contamination effects it is not appropriate to use construction techniques that have been used successfully for blackbody sources operating at ambient conditions. It has been determined that the multiple target system will require a contamination-free MBB operating at temperatures up to 600 K. This operational requirement places severe restrictions upon the materials used for construction and necessitates improved thermal isolation.

A schematic of an AEDC MBB is presented in fig. 3. The core of the blackbody is made of aluminum. A dual acme thread is cut in the outer surface to accommodate the heater wire (fig. 4). The dual thread permits both ends of the heater wire to exit at the rear of the core. Prior to winding the insulated heater wire on the core, the ends of the constantan heater which are to be used as the electrical supply leads are stripped and electroplated with copper. This adds power leads to the heater without any welded or soldered connections. The insulated section of the heater wire is wound on the threaded portion of the heater core and attached to it in such a manner that good thermal contact is established between the heater wire and the core. The heated core is mounted in the MBB assembly via a ceramic tube (fig. 3), and the heater leads pass through two passageways down the length of this tube.

Work continues in the area of embedding temperature sensors in the body of the core. The current technique under investigation is potting the ceramic-coated platinum sensors into the core using a curable ceramic cement. Initial work has indicated reasonably successful bonding to the anodized core holes.

SPECTRAL SOURCES

One method for discriminating between RVs and decoys is by comparing the spectral signatures of the objects in the FOV of the sensor. This can be accomplished by using bandpass filters at the detectors. Some systems use two color bands and others three. A simplified example of discrimination between an RV and an identically shaped decoy might consist of determining the temperature difference between them. One would expect that during the mid-course flight that the massive RV would retain its basic temperature while the low mass decoy would drop in temperature as they both radiated heat. The absolute radiant energy received by a sensor could not be relied on to distinguish the difference since the view angle and aspect angle of each object could be quite different. However, the ratio of the energy received in two appropriately chosen bands could be used to identify the RV as the warmer object. Evaluation of the ability of dual- and tri-color sensors to discriminate between targets and decoys in a ground test facility requires spectrally tailored sources. This can be accomplished with blackbody sources using spectral filters.

A schematic of a method for producing a spectrally tailored source is shown in fig. 5. The concept is shown for a two-color system although it can be extended for a tri-color source. The radiation is produced by two blackbody sources. In front of each blackbody is a bandpass filter corresponding to the bandpass filters of the sensor to be tested. The relative intensity of the radiation to be included in each band is set by adjusting either the blackbody temperature or the orifice size to the mixing integrating sphere. The total intensity of the radiation is set by choice of orifice size between the mixing sphere and the attenuating sphere.

PROJECTION SCREENS

Earlier studies have indicated that gold-coated grit-epoxy surfaces hold promise as being capable of operating at cryogenic temperatures with acceptable diffuse reflecting characteristics. Recent studies have shown that such surfaces can survive repeated cycling from 20 to 300 K. However, some bidirectional reflectivity distribution function (BRDF) measurements with a grit screen have shown that for small illuminated areas of the screen it does not diffuse tightly focused coherent radiation. For larger areas of illumination, acceptable diffuse reflection characteristics were obtained. From considerations of these data and BRDF measurements obtained with other materials, there are indications that acceptable diffuse characteristics can be obtained with materials that diffuse focused IR radiation with internal body-reflection properties. The gold-coated grit-epoxy surfaces are surface diffusers, i.e., the incident radiation does not penetrate into the body of the material. Surface diffusers were chosen because they had a better chance of surviving the vacuum cryogenic conditions. Examples of body diffusers are compressed salt powders in which radiation actually enters the material, undergoes multiple reflections in the crystalline structure, and is reemitted in a diffuse manner. However, compressed salt powders have obvious limitations when considered for use in a cryogenic/vacuum contamination-free environment. A suitable body diffuser target projection screen could possibly be made of a thin sheet of germanium, a crystalline, IR transmitting material used frequently as a vacuum chamber window. Radiation incident upon the rough face of the germanium would be partially scattered and reflected in a random distribution pattern while the remainder of the radiation would be transmitted into the material where it would undergo multiple scattering from the internal crystalline structure, reflect off the plated back surface, and be reemitted at the rough surface. Some inherent blooming of the target will occur in this (and any) body diffuser.

MECHANICAL ACTUATOR

A mechanically scanned mirror system can provide a state-of-the-art dynamic target generator for objects which move across the FOV of the sensor at slow angular rates. A typical scenario might suppose a sensor viewing a target traveling at 17,000 nmi/hr at a distance of 5,000 nmi. The angular velocity (assuming the object traveling normal to the line-of-sight) is approximately 1 mrad/sec. These rates can be provided by standard micrometer drives operating pivoted mirrors.

A gimbal system for pivoting a mirror flat both in the X and Y directions about a single point on its surface is shown in fig. 6. The friction-free X and Y pivots consist of Bendix flexures. The Bendix flexure has the advantage of rigid conductive paths through the device and thus provides for direct cooling of the mirror from the mounting block.

A prototype system using four such gimbaled mirrors assembled in a common unit is shown in fig. 7. The focused beam from four independent sources housed between the micrometer drives is folded onto the gimbaled mirrors via mirror flats on the underside of the cruciform central mounting block.

The Newport Research Corp. (NRC) micrometer drives (modified for vacuum use) have a 0.1-μm resolution which, when coupled to the 75-mm moment arm of the gimbal, provides a resolution of 1.3 μrad of the mirror or 2.6 μrad of the steered beam. The minimum and maximum micrometer drive speeds using the standard controller will provide beam slew rates from 1 to 10 mrad/sec.

A prototype of this actuator (fig. 8) has been constructed, and its performance has been evaluated at ambient conditions using an He/Ne laser as a radiation source. This evaluation has shown that multiple targets can be projected onto the screen and moved independently of each other in a controlled repeatable manner. A gimbaled mirror driven by an NRC micrometer drive has been tested under cryogenic/vacuum conditions and has been found to operate in a controlled, repeatable manner.

CONCLUSION

An infrared multiple target/complex scene generator is a requirement for evaluation of sensor systems prior to deployment. Test facilities must provide the sensors with a range of realistic mission simulations to effectively determine the operating characteristics. Due to the diversity of mission requirements, no one simulation system can meet all the needs of the sensor testing community; therefore, a wide variety of approaches are currently under development. Most of the prototype multiple target simulators stress the ability to create a large number of discrete, precisely located sources with fixed spectral content and limited dynamic range. The AEDC simulation system emphasizes spectrally tailored, analog target images having wide dynamic range in a cryogenic environment. These attributes are definite requirements for testing space-viewing sensors. The system can produce a small number of targets, it is mechanically complex, and a diagnostic capability must coexist with it to determine the positional accuracy of the individual targets. All of these limitations can be dealt with in a manner which will not detrimentally affect the usefulness of the concept.

Table 1.
Evaluation of potential concepts for IR scene generators

Concept	Vacuum	Cryogenic	Independent Spectral Sources	Intensity & Spectral Independence	Number of Targets
Mosaic modulator	Yes	No	No	No	each pixel
Liquid crystal modulator	Yes	No	No	No	each pixel
Magneto-optic modulator	probably	No	No	No	each pixel
Deformable mirror	probably	No	No	No	each pixel
Thermal element array	Yes	Yes	Yes	No	each pixel
Laser Scanner	probably	probably	Yes	No	Scan limited
Membrane Converter	Yes	No	Yes	No	Source limited
Analog Projector	Yes	Yes	Yes	Yes	4 → 40

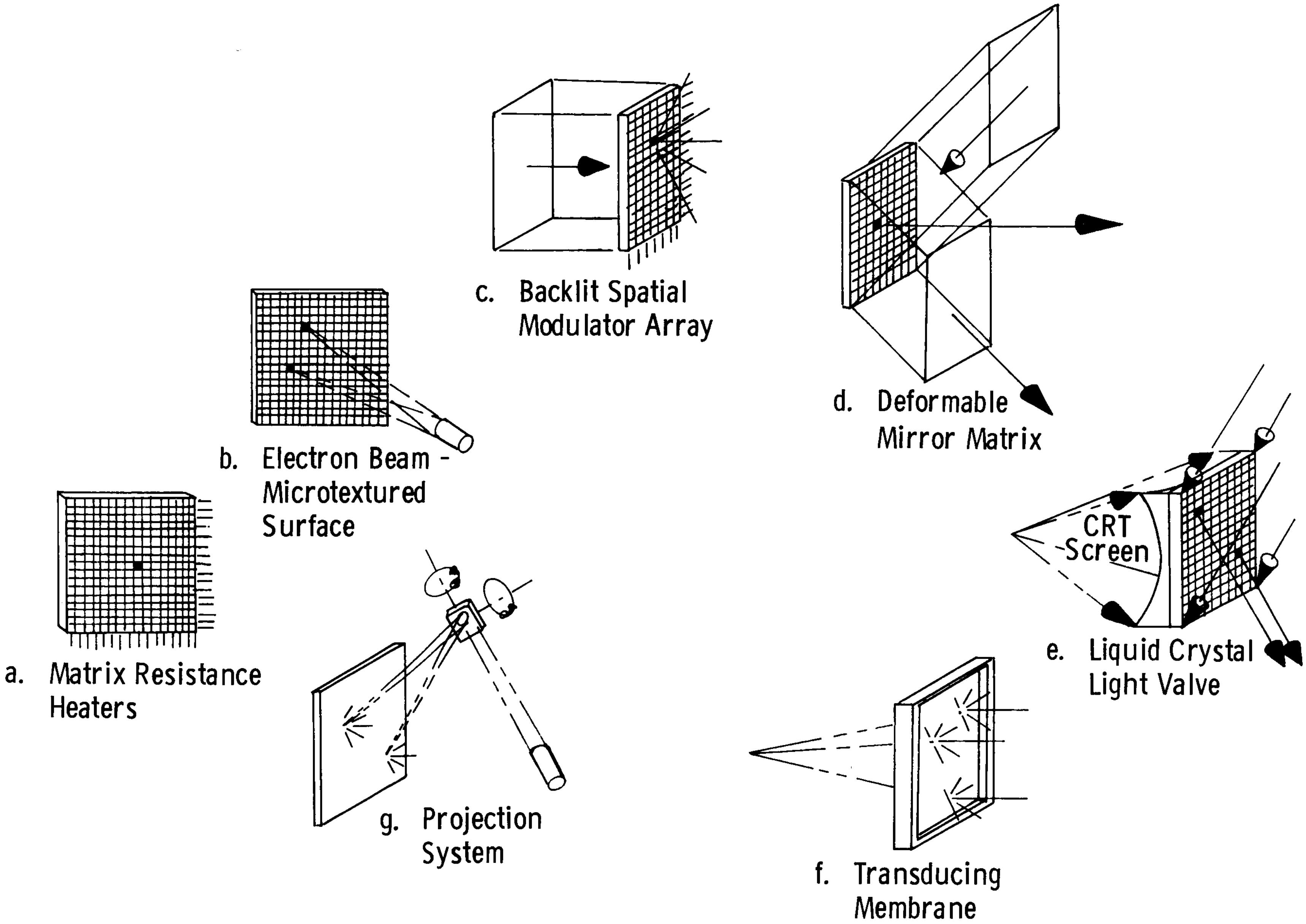

Figure 1. Organization of multiple target simulators

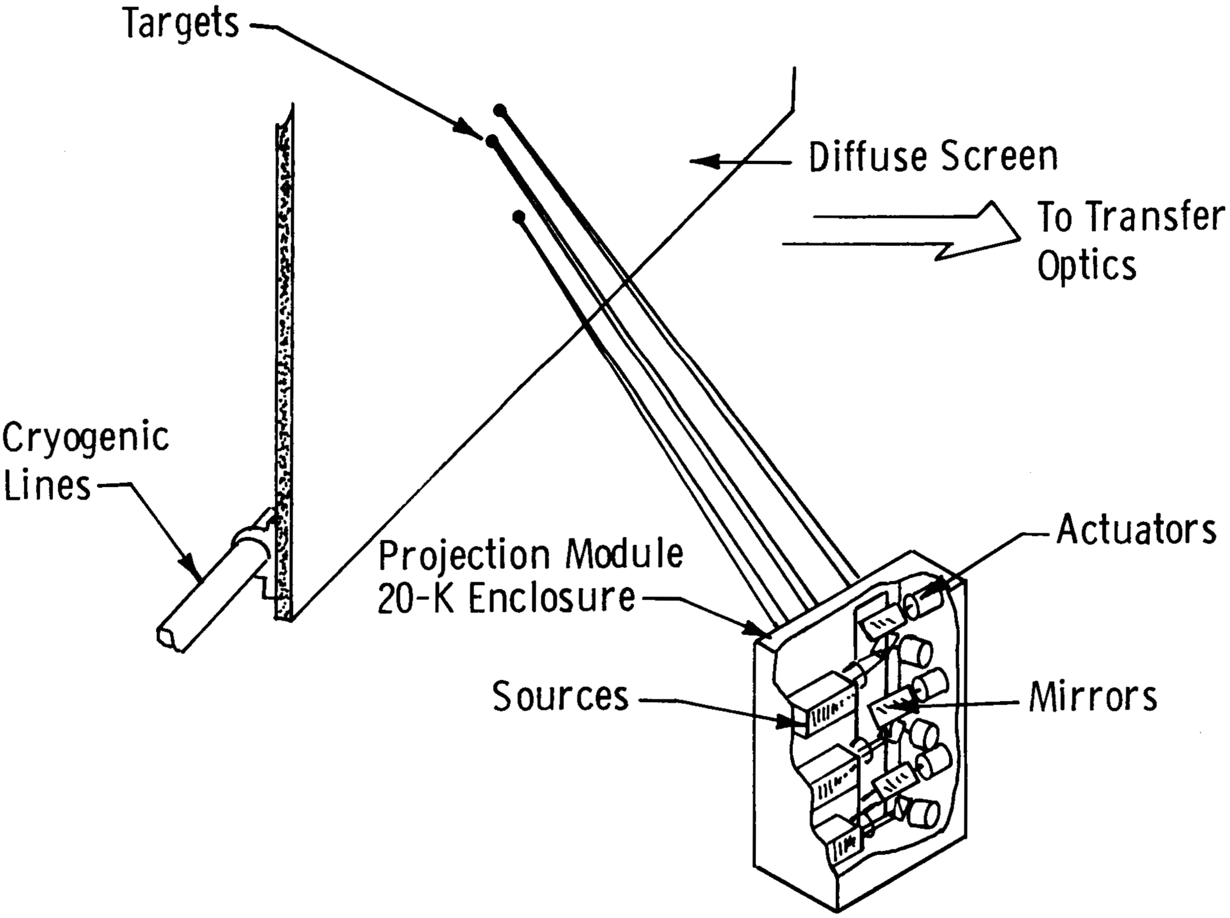

Figure 2. Multiple target projection system

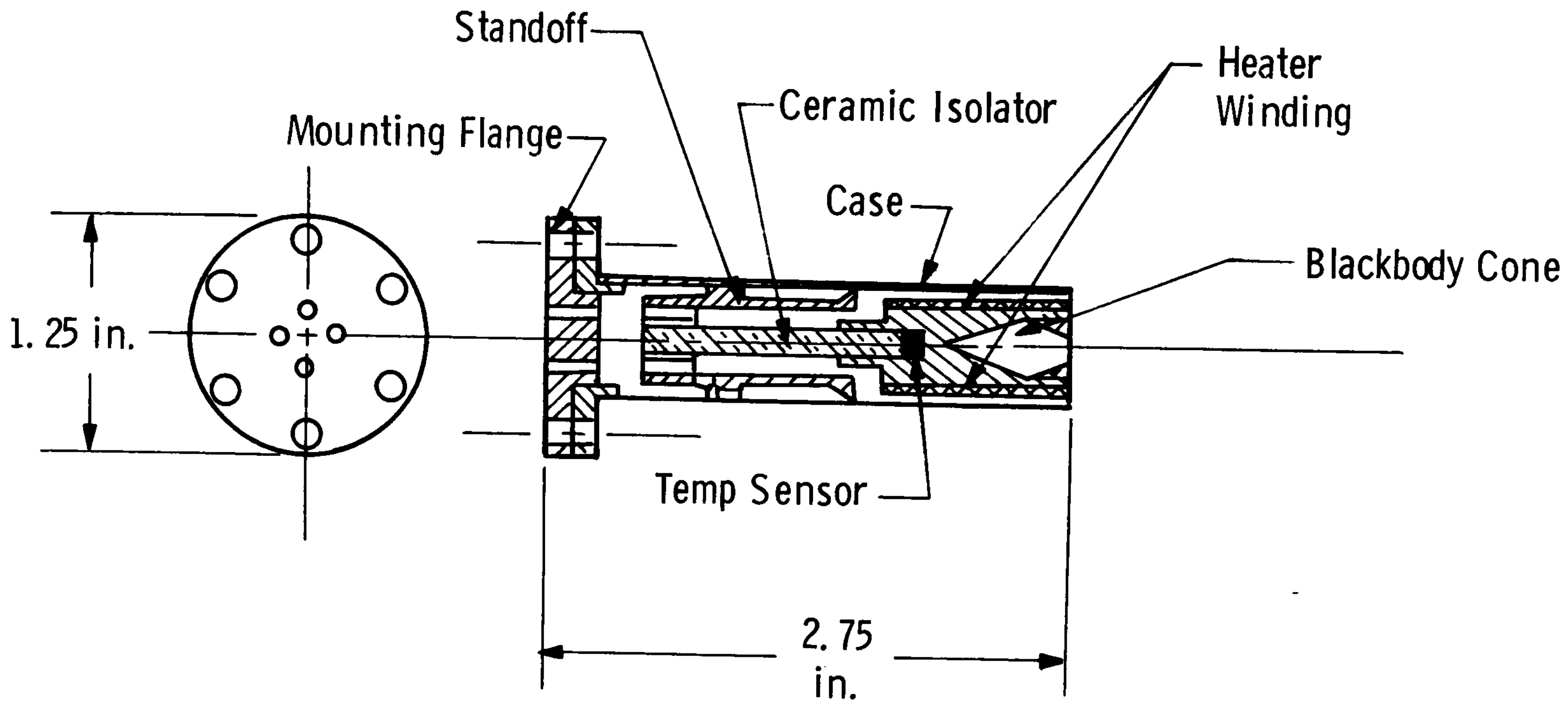

Figure 3. Miniature blackbody schematic

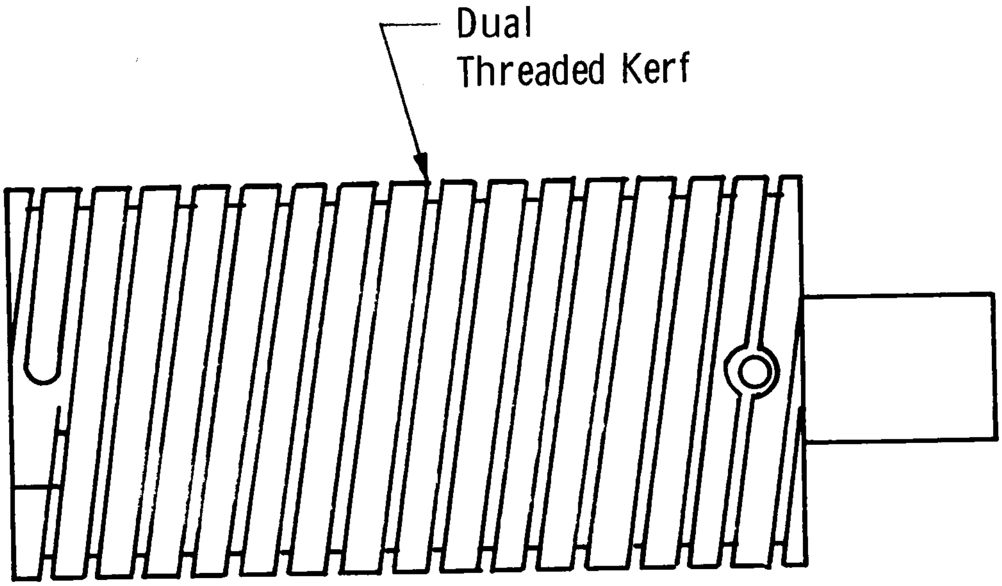

Figure 4. Heater core

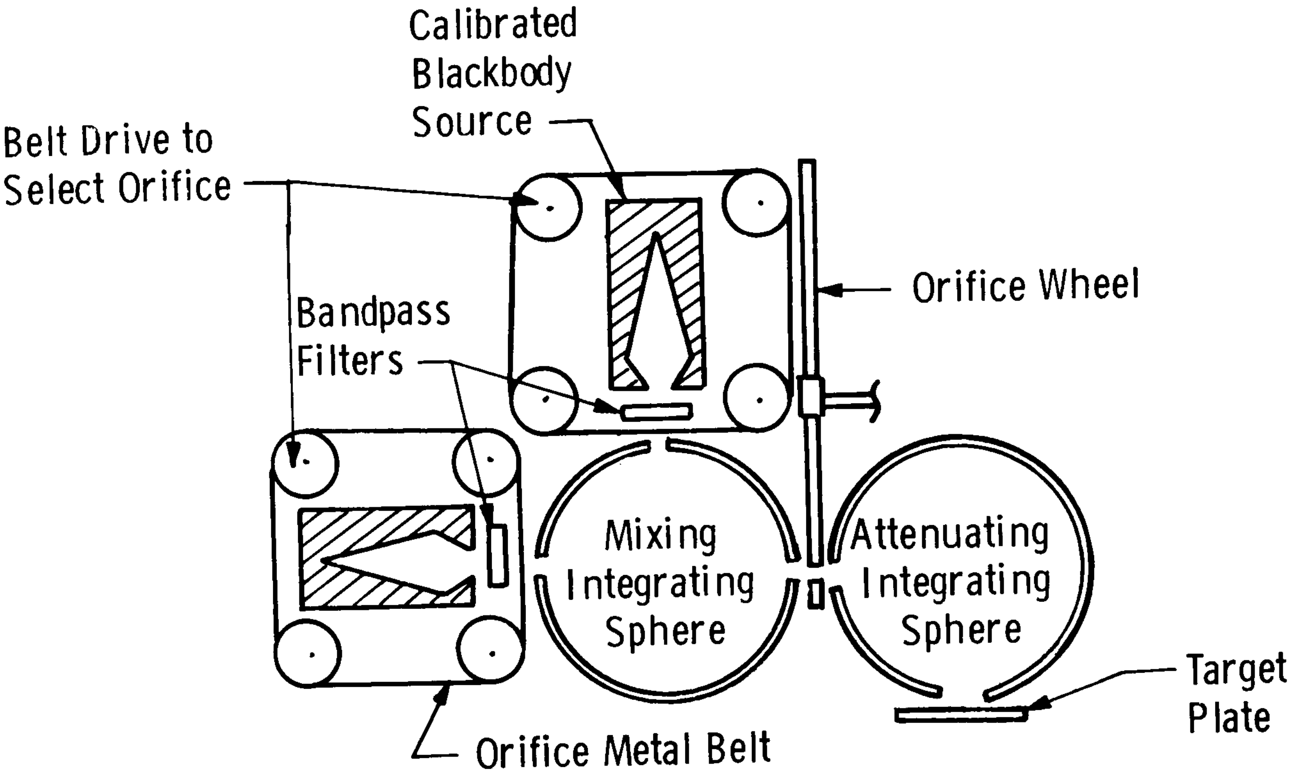

Figure 5. Spectrally tailored IR source

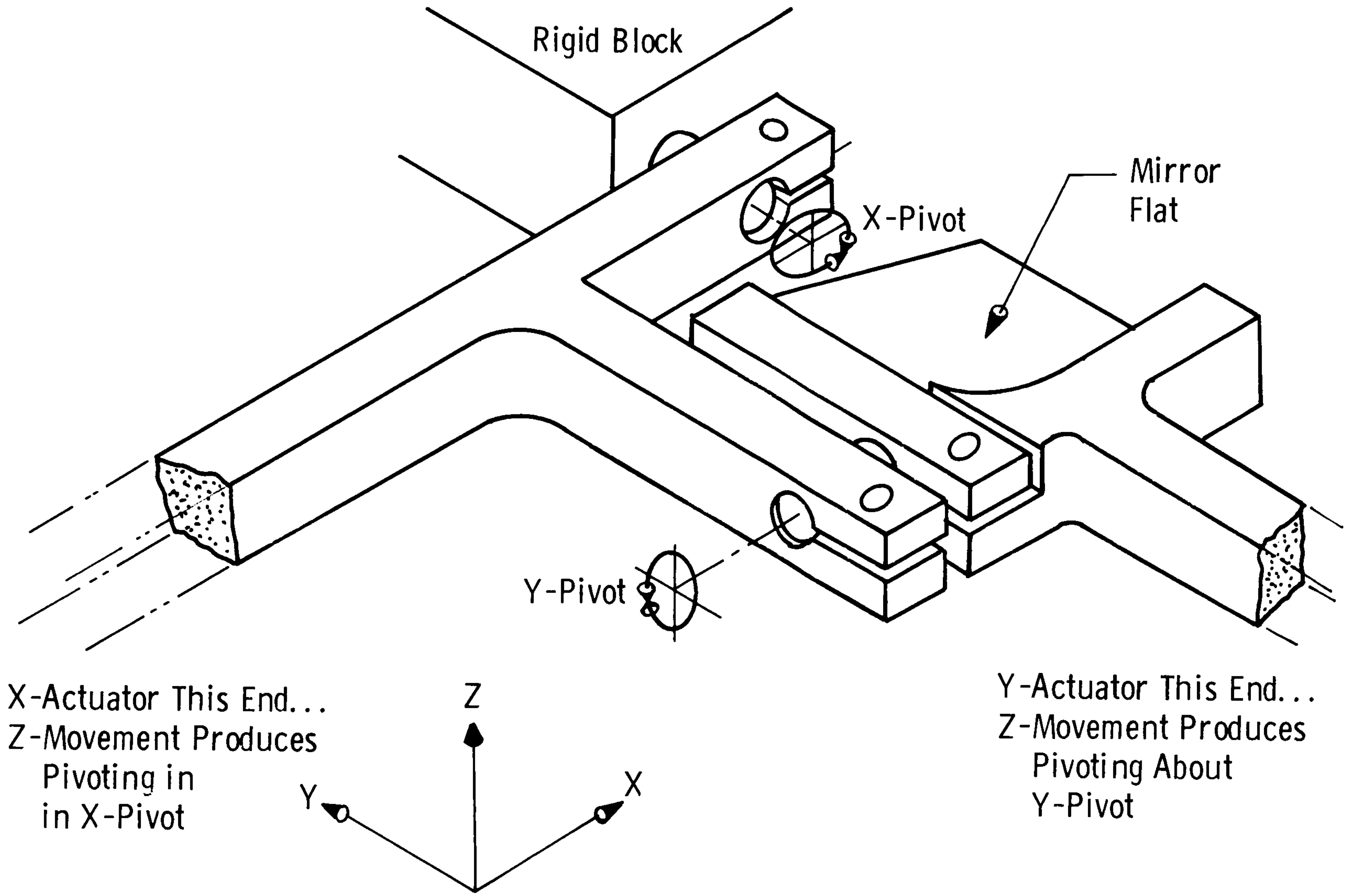

Figure 6. Pivoting flexure mount

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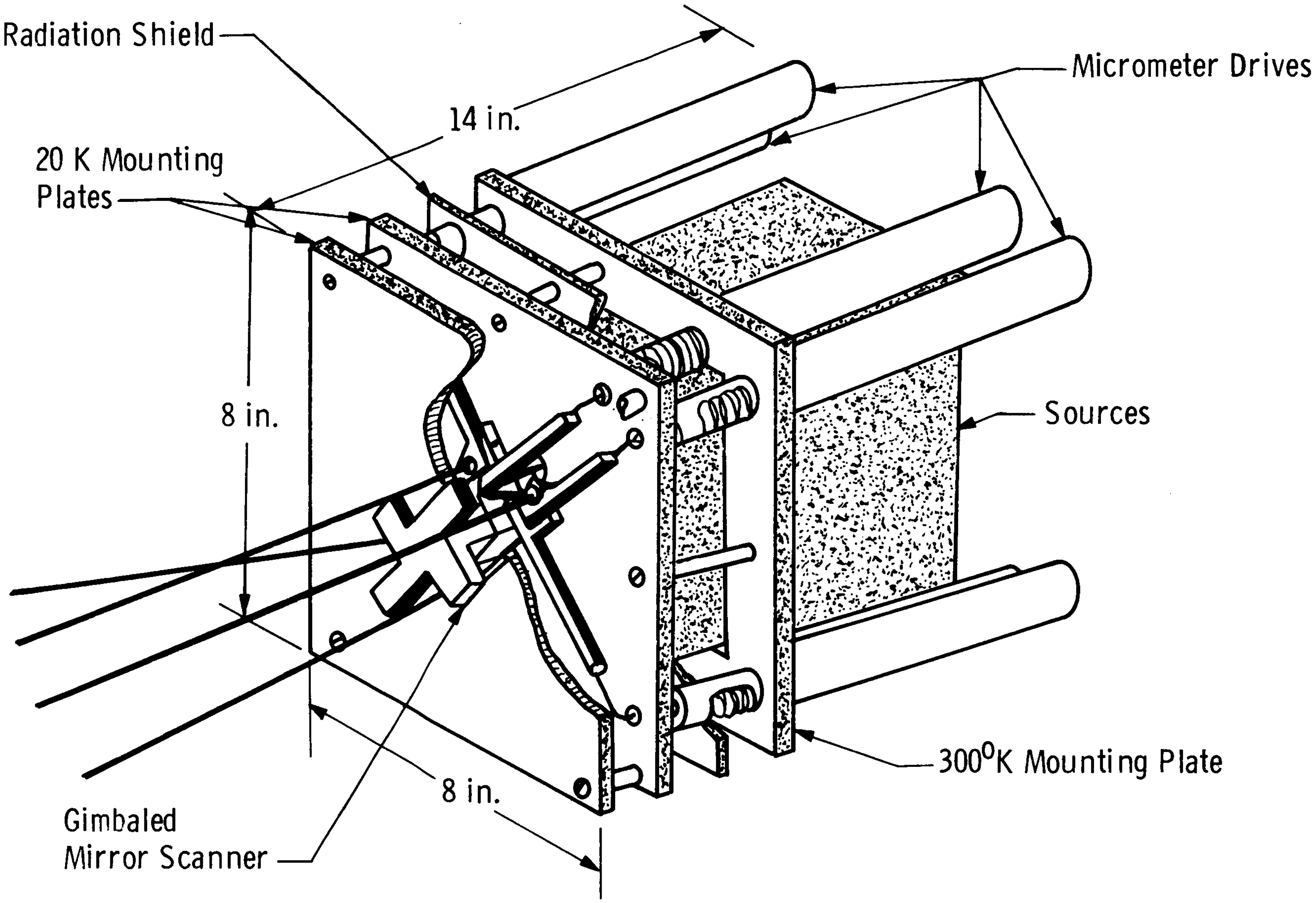

Figure 7. Mechanical mirror scanning system

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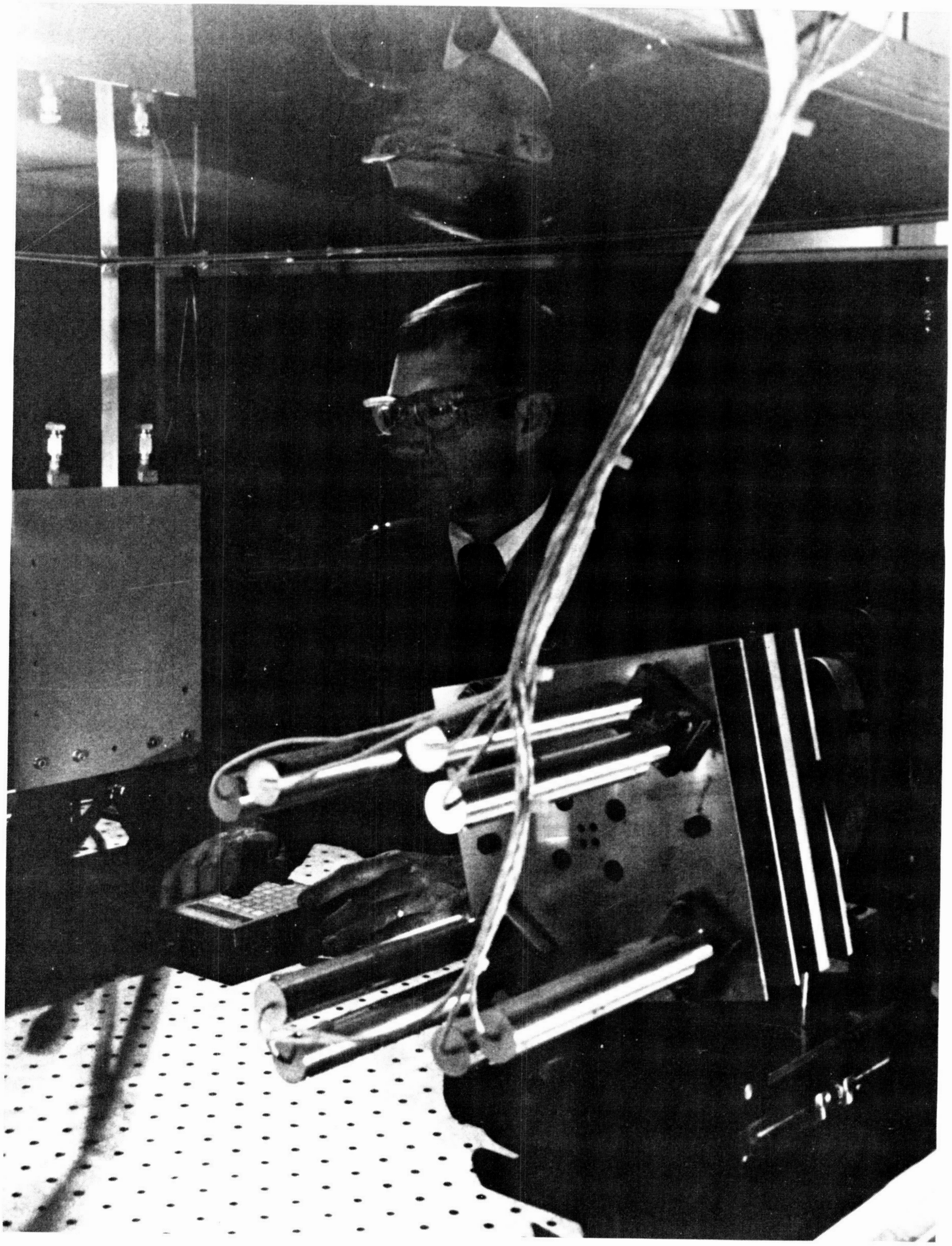

Figure 8. Photograph of mechanical mirror scanning system