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PROPOSAL - 68 - 3835 - 2

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TECHNICAL PROPOSAL

**IMAGE VELOCITY SENSOR
WITH IMAGE INTENSIFIED VIDICON**

29 JULY 1968

Itek

OPTICAL SYSTEMS DIVISION

ITEK CORPORATION • 10 MAGUIRE ROAD • LEXINGTON, MASSACHUSETTS 02173

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BIF-059-0002-68

CONTENTS

1.	Introduction and Summary	1-1
2.	Requirements Analysis	2-1
2.1	Light Level Considerations	2-1
2.2	Gradient, Null	2-1
2.3	Reliability	2-2
2.4	Environmental and Test Requirements	2-2
3.	Sensor Design Approach	3-1
3.1	Origin and Background of Proposed Design	3-1
3.2	Theory and Elementary Description	3-1
3.3	Detailed Sensor Description	3-13
3.4	Sensor Characteristics	3-28
4.	Test Support Equipment	4-1
4.1	IVS Special Test Setup	4-1
4.2	Environmental Chamber	4-3
5.	Design and Development Program	5-1
5.1	Electronics Assembly	5-1
5.2	Sensor Head Assembly	5-2
6.	Self Test	6-1
6.1	Optics	6-1
6.2	Target Drive	6-1
6.3	Summary	6-1

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CONTROL SYSTEM

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BIF-059-0002-68

FIGURES

3-1	Rudimentary Sensor	3-4
3-2	Variation of Rectified High Frequency Video Signal With Velocity	3-4
3-3	Single-Axis Sensor	3-5
3-4	Sensor With Modulation	3-6
3-5	Sensor Operating Principle	3-7
3-6	Two-Axis Configuration Using Two Independent, Orthogonal Sensors	3-8
3-7	Sensor Configuration Using Displaced Image Technique	3-8
3-8	One Camera With Off-Axis Image	3-10
3-9	One Camera With On-Axis Image	3-10
3-10	Sensor Head Layout	3-15
3-11	Schematic of IVS Sensor Head	3-17
3-12	Spectral Sensitivity of Intensifier Input Surface (S-20)	3-18
3-13	Image Modulation Configuration	3-20
3-14	Modulation Technique Using Oscillating Refractor Plate	3-21
3-15	Sensor Electronics Block Diagram	3-24
3-16	IVS Power Requirements	3-30
4-1	Target Drive Schematic	4-5
4-2	Target Drive Optical Path	4-6
4-3	Sensor Format Referenced to 2.8-Inch Diameter Circle and Table of Velocities for Roll: 40 Degrees, and Pitch: 30 Degrees	4-7
4-4	Target Drive Controls	4-8
4-5	Useful Ranges of Table and Refractor Plate for Frequency Response Tests	4-9
4-6	Target Drive Servo Block Diagram	4-10
4-7	Closed Loop Frequency Response	4-11
4-8	Target Source With Environmental Test Chamber	4-12
6-1	Schematic Arrangement of Self Test System	6-2
6-2	Projection System	6-2
6-3	Target Drive	6-3

~~D/SECRET~~

HANDLE via BYEMAN
CONTROL SYSTEM

~~D/SECRET~~

BIF-059-0002-68

TABLES

3-1	Total Block Failure Rate per 10 ⁶ Hours	3-12
3-2	IVS Weight Summary	3-29
3-3	Sensor Head Weight Estimate	3-29
4-1	Target Drive Characteristics	4-4

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CONTROL SYSTEM

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BIF-059-0002-68

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1. INTRODUCTION AND SUMMARY

This proposal is submitted in response to General Electric Company's Request for Proposal No. 159 dated 3 June 1968 for the design, development, and production of Image Velocity Sensors (IVS) for use in the MOL-Dorian system.

This, the technical volume of the proposal, presents an analysis of specification requirements, describes the technical approach and experience, and relates anticipated performance to design requirements.

The Image Velocity Sensor, a component of the MOL-Dorian camera system, senses motion in the optical image and feeds correction signals to the tracking mirror servo systems to provide fine tracking. Since the IVS is a feedback device in a sophisticated control system, important design requirements which have to be considered are sensor dynamics, output gradient, noise level, and null stability. These requirements must be met over wide ranges of target contrast, scene illumination, and scene content.

The proposed Itek IVS consists of a sensor head and an electronic assembly. The sensor head includes an input prism assembly, relay optics, and an image intensified vidicon. The electronic assembly includes processing electronics, camera circuitry, and special power supplies.

The proposed sensor is based on a design concept originated in an Itek IR&D program and further developed under a recent Government contract. Sensing is accomplished by observing the variation of the high-frequency video content in the output of the vidicon. Image modulation is used to provide polarity sensing and to produce a null signal for zero velocity. Automatic gain control is employed to normalize the sensor output for a wide range of illumination and scene conditions.

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2. REQUIREMENTS ANALYSIS

The importance of the Image Velocity Sensor to the Dorian mission is appreciated by Itek technical and management personnel. The sensor is essential in order that the image rates of about 0.25 inch per second, achievable on the basis of the tracking computer output, may be reduced to below 0.020 inch per second. Since the sensor acts as a transducer in the tracking mirror servo system, there are important interface and performance requirements.

In selecting the design proposed herein, a number of configurations were considered in an effort to choose the design that would best satisfy the mission requirements. However, the design, as specifically identified in a later section, will likely not meet all of the requirements of the specification. In this section, general sensor requirements and some of the more significant considerations and constraints are discussed.

It is recognized that when utilizing a tracking mirror for image motion compensation as is done in the Dorian mission, only one point in the format has zero velocity. All other points have radial and/or tangential velocities which are functions of roll and pitch gimbal angles and distance from the zero velocity point on the format. The graded IMC mechanism at the camera back is designed to compensate for these "off-axis rates" on the basis that the tracking mirror nulls the velocity at the center of format. Thus, it is a requirement of the IVS that it be immune to off-axis rates and provide a true measure of center-of-format velocity.

2.1 LIGHT LEVEL CONSIDERATIONS

Only a small percentage of the input scene illumination is available at the sensor aerial image. It is well known, from work and accomplishments in the prior development phase of this program, that the resulting low-light level illumination has a major impact on the design configuration. It is assumed that smear rate-exposure time-light level tradeoff optimization has dictated the selected transmission/reflection ratio of the pellicle, and that system transmission otherwise has been made as high as practical.

Although the possibility of replacing the second beam splitter with a flippable mirror has been noted, we have attempted to avoid this relaxation of system objectives. Our resulting design will operate to low sun angles without depriving the astronaut of a simultaneous view of the image.

In the proposed design, two images are necessary to provide inputs to the two-axis sensor channels. These images are provided by beam splitting an on-axis patch.

2.2 GRADIENT, NULL

The approximate plus and minus 35 percent allowable tolerance on sensor gradient appears to be a reasonable compromise between tolerable tracking servo gain variation and

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BIF-059-0002-68

AGC requirements in the sensor to accommodate wide ranges of illumination, contrast, and scene content.

One of the approaches to increasing illumination level at the sensing element is to employ optical minification between the optical interface and the sensing tube. This scale factor change is limited to about 2:1 since the allowable null velocity at the sensing tube is reduced by an equal ratio.

In addition a small field of view prohibits erroneous velocity indications due to scene content changes which may occur even in the perfect tracking situation. The optimum may be slightly greater than 2:1 based on studies not yet completed in the current contract phase.

2.3 RELIABILITY

The specified MTBF of 10,000 hours is a very stringent requirement for a system which includes as many series elements as the IVS. It is recognized, however, that overall mission success necessitates an allocation of failure rate to a number of essential systems and that each system must have a high probability of survival. With the stated 1,112-hour mission life, and MTBF of 10,000 hours, the probability of survival is $e^{-1,112/10,000} = 0.89$.

According to some of our preliminary estimates, on-orbit operation for a 30-day mission would be about 100 hours. If an equal number of hours is utilized in checkout and ground handling, actual operation would not exceed 200 hours. With an MTBF of 15,000 hours, the probability of survival would be 0.987 for this lower operating life condition.

2.4 ENVIRONMENTAL AND TEST REQUIREMENTS

With few exceptions the environmental requirements are similar to those of previous Itek programs. Vibration, shock, and acceleration requirements are typical.

Design for the normal expected operating thermal environment presents no problems. However, it is expected that degraded performance will be obtained at the 10 and 140 °F temperatures required in the thermal cycling test. The thermal altitude test calls for operation and performance observation at temperature extremes in vacuum. Since operation is not required in the mission profile during the two brief periods of vacuum, this test imposes an unrealistic requirement for which we are not designing.

Helium presents special problems because of its ability to migrate through glass. A special design is required to attenuate the leakage rate through the vidicon.

The pure oxygen test requirement necessitates extreme care in the choice of materials from a combustibility and outgassing viewpoint. All possible sources of arcing such as motor brushes, relay contacts, and switches must be eliminated.

A special test chamber is required for use in conjunction with the target simulator for performing temperature, vacuum, helium, and oxygen environmental tests.

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3. SENSOR DESIGN APPROACH

3.1 ORIGIN AND BACKGROUND OF PROPOSED DESIGN

The technique employed in the Itek IVS originated in an internal research and development program which was started in the fall of 1962. A single-axis breadboard unit consisting of an electrostatic deflection vidicon camera and suitable signal processing circuitry for the detection of image motion and direction was developed. Tests were performed on moving scenes on film that demonstrated the feasibility of the Itek concept.

As part of an earlier contract, Preliminary Design Study for Satellite Reconnaissance, further tests were conducted to demonstrate applicability of the Itek sensing technique to the image velocity sensing requirement of the Dorian mission. This demonstration included testing of the single-axis sensor with a target simulator at the Lockheed Missile and Space Division. In preparation for the tests, the breadboard unit was modified in some respects, both in order to package the sensor in a more suitable form for the tests and to incorporate some necessary revisions. Modifications at this time included a new wedge-type modulator and modulator drive system which synchronized the image modulation to the frame rate, incorporation of the RCA PK-301 Vidicon Camera and use of the 50-millimeter Xenon Schneider lens.

The results of the test program were reported in Itek document no. 9600-66-047, Image Velocity Sensor, dated 27 April 1966.

Following this effort, Itek entered into a development phase in which the main objectives were to design a two-axis sensor and to perform analyses, tradeoffs, and tests leading to a completely integrated sensor meeting the Dorian requirements. The two-axis technique was developed, and tests were conducted with a breadboard model. A unit called the brassboard, compatible with the space, weight, and interface specified for the sensor, was then designed and built. The electronics assembly was not built in compact form, although a good design layout for the flight package exists.

This latest effort covered the period from 15 August 1966 to 15 August 1967 and is summarized in Itek document no. 9415-67-148, Image Velocity Sensor.

3.2 THEORY AND ELEMENTARY DESCRIPTION

3.2.1 Single-Axis Sensor Theory

The basic principle of operation of this sensor is that smear—due to image velocity for a finite exposure time on a light storage surface—results in a stored image with less high spatial frequency content than would be the case for zero image velocity. This applies not only for a photograph, but also for storage type television camera tubes such as the iconoscope, orthicon, image orthicon, and vidicon. The instantaneous signal from these tubes is not proportional to the

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instantaneous illumination at the position being scanned, but is rather proportional to the time integral of the illumination at that position since the previous scan of the same point, or one frame period. A frame period for a TV tube is analogous to exposure time for a photograph. A moving image on a vidicon produces a smeared stored image with reduced high spatial frequency content. This results in a reduced amount of high temporal frequency signal at the output of the tube. A rudimentary sensor based on this operating principle is shown in Fig. 3-1. The nature of the variation of rectified high frequency video signal with velocity is shown in Fig. 3-2.

To make use of the above principle, the video signal is fed into a high pass filter (see Fig. 3-3) which removes the low frequency portions of the signal which are not significantly affected by image motion. This is followed by a video amplifier and a full-wave rectifier. The rectifier output, shown as "rectified high frequency video signal," is a dc level indicative of the high frequency content of the stored image.

The ability of the basic sensing mechanism to sense the direction of image motion is incorporated by superimposing a cyclic velocity on the input velocity by means of a modulator. The image can be modulated in a variety of ways; a flat glass wobbleplate modulator is used in the brassboard. During one half cycle, the modulation velocity adds to the component of image velocity parallel to the modulation direction; during the other half cycle, the velocities subtract. By comparing the video high frequency content of the two half cycles, an output indication of magnitude and direction is obtained for the component of image motion parallel to the modulation direction.

Fig. 3-4 shows the effect on the rectified video signal resulting from sinusoidal modulation. When there is no steady component of image velocity, the video output modulation for the first and second halves of the modulation cycle is identical. This symmetry is reflected in video modulation at twice the modulation frequency. The lower portion of Fig. 3-4 illustrates the case for a positive steady component of image velocity parallel to the modulation direction. Total velocity (scene plus modulation) is now higher in the first half cycle than in the second half. Therefore, the output is more positive during the second half cycle than during the first. Notice that the video output modulation is no longer purely second harmonic, but includes a fundamental modulation frequency component. In the case of a negative steady component of image velocity, it would be seen that the phase of this fundamental frequency component was shifted 180 degrees. A phase-sensitive detector operating at the modulation frequency, can, therefore, discern the existence and direction of an input image velocity. Zero scene velocity is now sensed as a null, and not as a peak as occurred in the basic sensor. Both analysis and test show that the phase-sensitive detector output is quite linear with velocity.

If the input image velocity is perpendicular to the modulation direction, there is no fundamental frequency component. In this case, the net image velocity magnitude is the same during the negative modulation half cycle as it is for the positive half cycle, unlike the situation where the input velocity is parallel to the modulation direction.

The above discussion treated the modulation and velocity sensing as an instantaneous process; however, since the vidicon is a storage and sampling device, image smear that is sensed is representative of the integrated velocity-time history for the last 1/30 second. The effective integration period depends on the phase relationship of the modulation cycle with respect to each raster line. Fig. 3-5 indicates an integration time related to scan line number in the vidicon raster (assume a zero scene velocity). Qualitatively, it can be seen that scan line no. 1, which is smeared during the 180- to 360-degree portion of the modulation cycle is smeared less than scan line no. 511 which is smeared from the 270- to 90-degree portion of the modulation cycle. The rectified high frequency video shows an inverse relationship. Notice that the smear factor

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and the high frequency video modulation occur at twice the modulation frequency. This is due to the symmetrical character of each half of the modulation cycle.

In the presence of image motion, the smear history is different for each half cycle, and a fundamental component of the modulation frequency then exists in the rectified high frequency video.

Without some sort of automatic gain control (AGC), the phase-sensitive detector output for a given input image velocity would vary appreciably for different scenes and illuminations. The second harmonic component of the rectified video signal is an AGC function. This component exists whether or not an input image velocity is present and its amplitude is a measure of the change in rectified video as a function of a known velocity. This second harmonic component can be detected and used as a normalizing or AGC function as shown in Fig 3-3. The AGC circuitry tends to keep the magnitude of the second harmonic signal at the output of the gain control element constant. This tends to make the sensitivity of the sensor output constant, i.e., independent of scene and illumination over a wide dynamic range.

The above presents the basic theory of the single-axis sensor to a first order approximation. There are second order effects which modify the above. For instance, it was stated that there was no fundamental signal component without image velocity. Actually there is a small fundamental component, the amplitude and phase of which are dependent on the particular scene. Upon demodulation, the in-phase component of this fundamental produces a bias error. Another second order effect is the fact that the second harmonic signal does not remain constant, independent of velocity. Continuing sensor development is aimed at minimizing the effect of these second order characteristics on sensor performance.

A quantitative analytical treatment of the above described operation has been developed and is presented in the Appendix.

3.2.2 Two-Axis Techniques

There are a number of basic approaches possible to adapt the Itek single-axis Image Velocity Sensor for two-axis operation. The first and most obvious approach, shown in Fig. 3-6, is the utilization of two independent but orthogonal sensors, each measuring an image velocity component. A basic requirement for satisfactory operation of such a system is that image velocity components, perpendicular to the direction of modulation and scan, do not appear as outputs in that sensor. Prior tests have demonstrated that this independence does, in fact, exist and that this technique can be used.

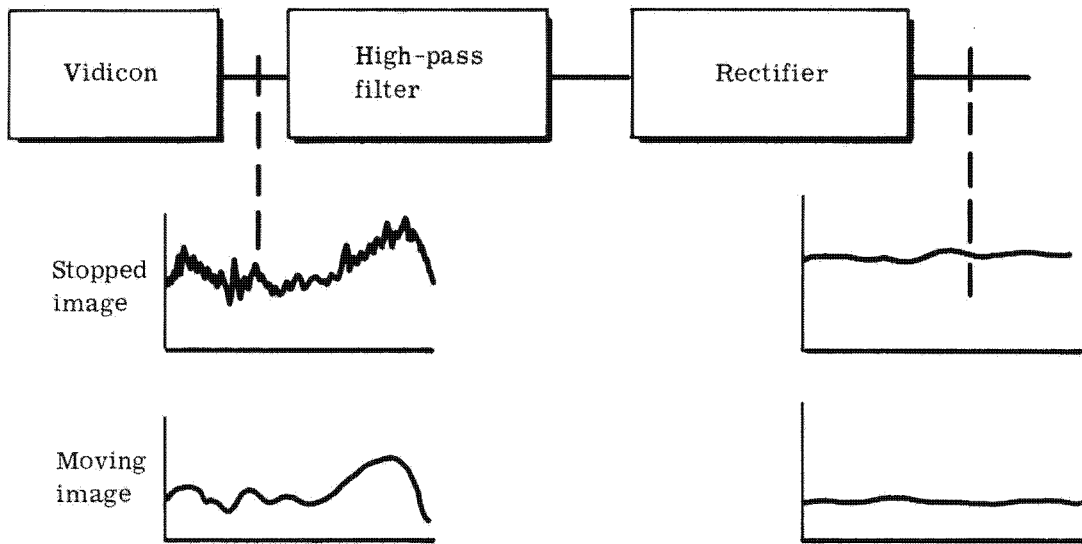
While the above described technique represents the minimum extrapolation from proven performance of the single-axis sensor, size, weight, power, and space considerations necessitate investigation of smaller but possibly more complex systems. A further consideration, and one common to most of the considered approaches, is that of light level.

A beam splitter is shown in Fig. 3-6 for separating the image for two-axis sensing on separate vidicons. Use of the beam splitter results in a 60-percent illumination level reduction for each channel.

An alternate approach to the use of a beam splitter is shown on Fig. 3-7. In this approach (the displaced image technique), each camera system looks at separate patches. The primary problem with this approach, for the present application, is that only one of the patches can be located at the desired point in the aerial image (i.e., center of format). The "off-axis" patch must be located such that its average velocity is equal to the center-of-format velocity in the direction sensed.

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3-3



Limitations: (1) scene sensitive, (2) no directional information

Fig. 3-1 — Rudimentary sensor

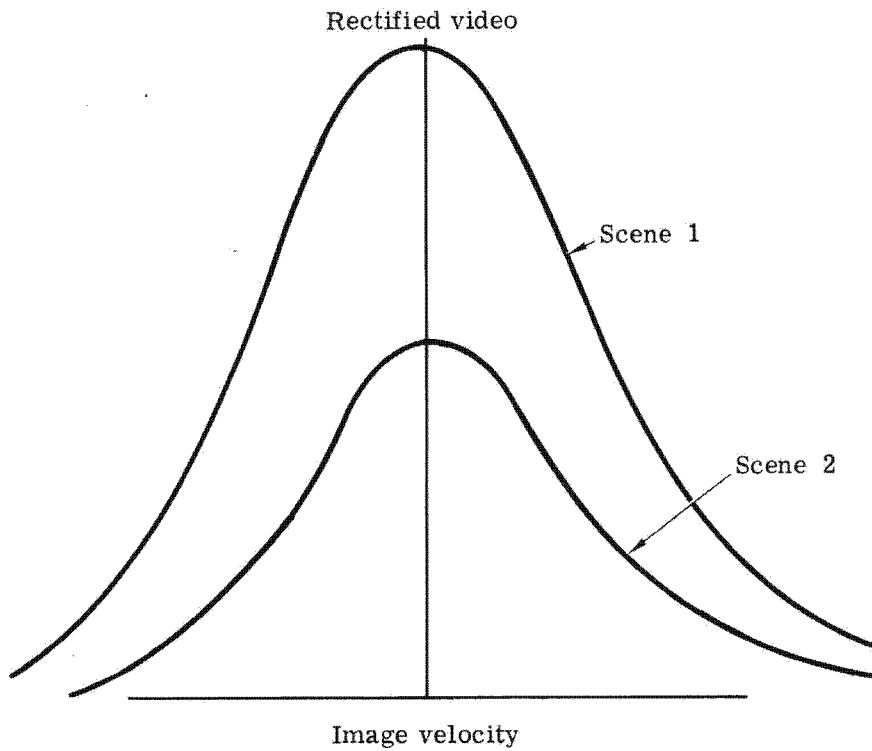


Fig. 3-2 — Variation of rectified high frequency video signal with velocity

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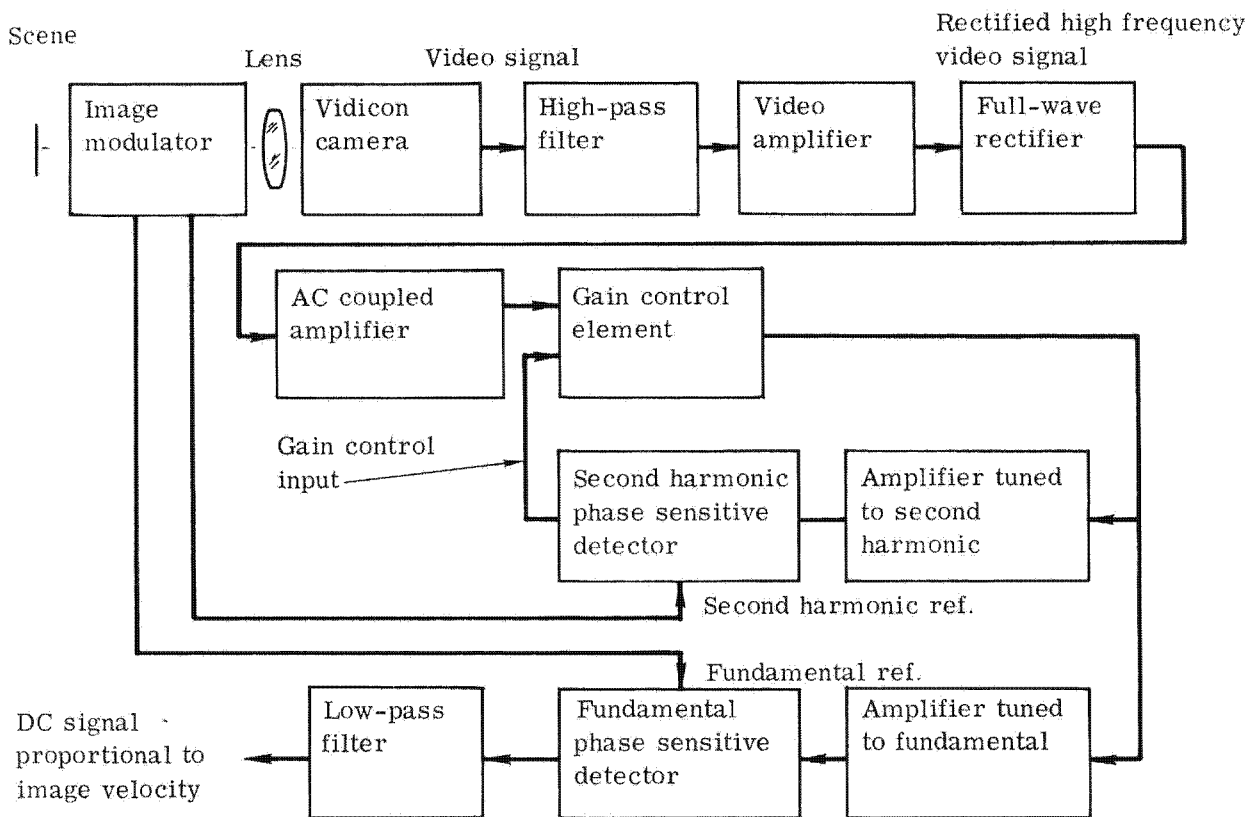


Fig. 3-3 — Single-axis sensor

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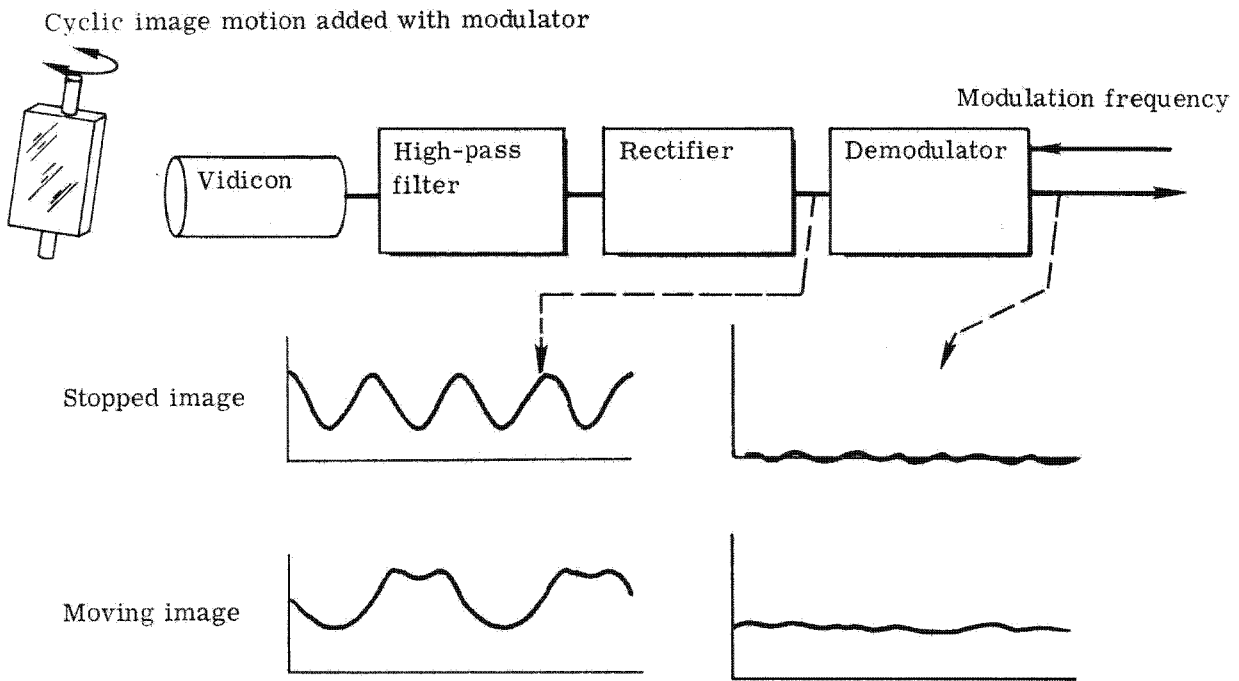


Fig. 3-4 — Sensor with modulation

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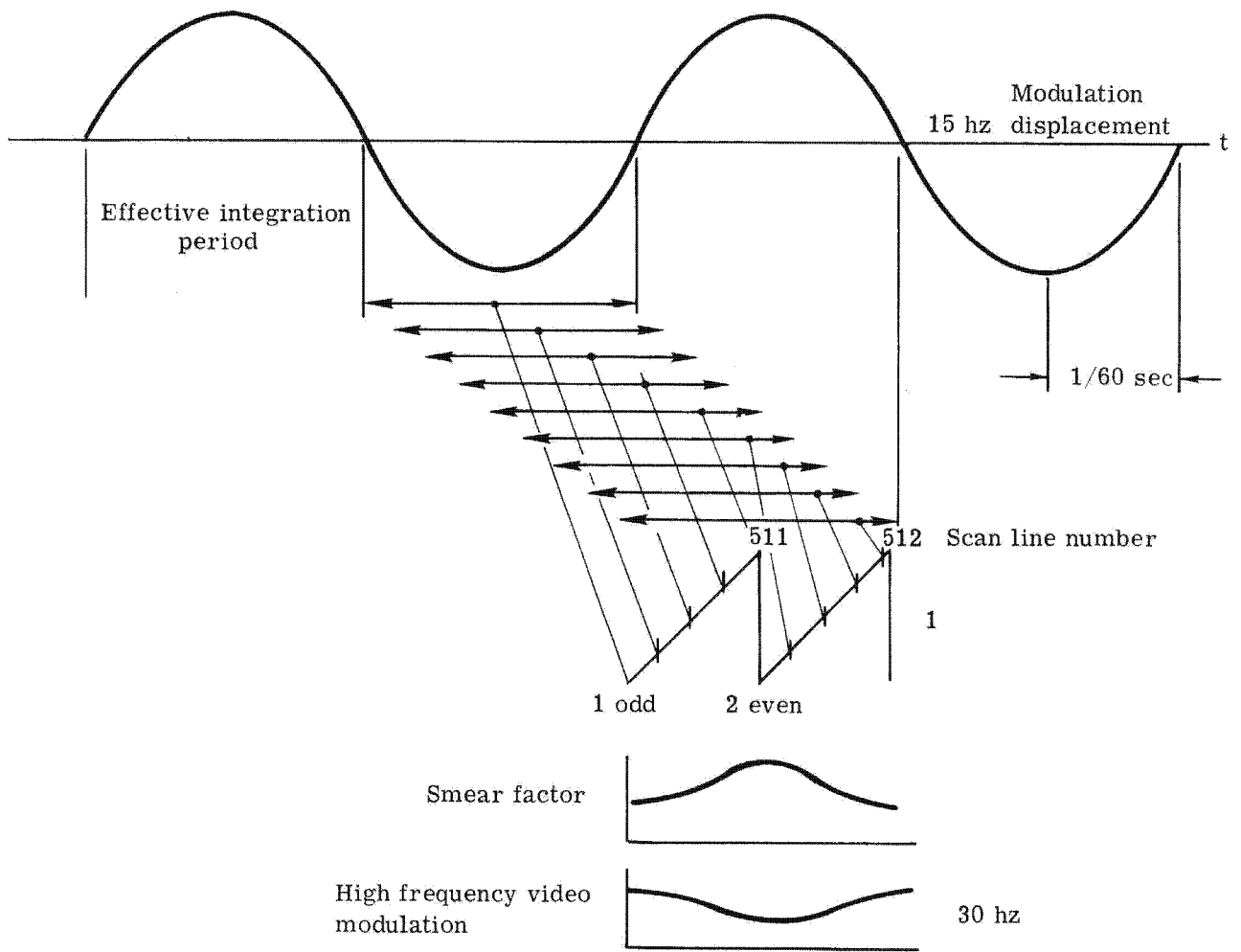


Fig. 3-5 — Sensor operating principle

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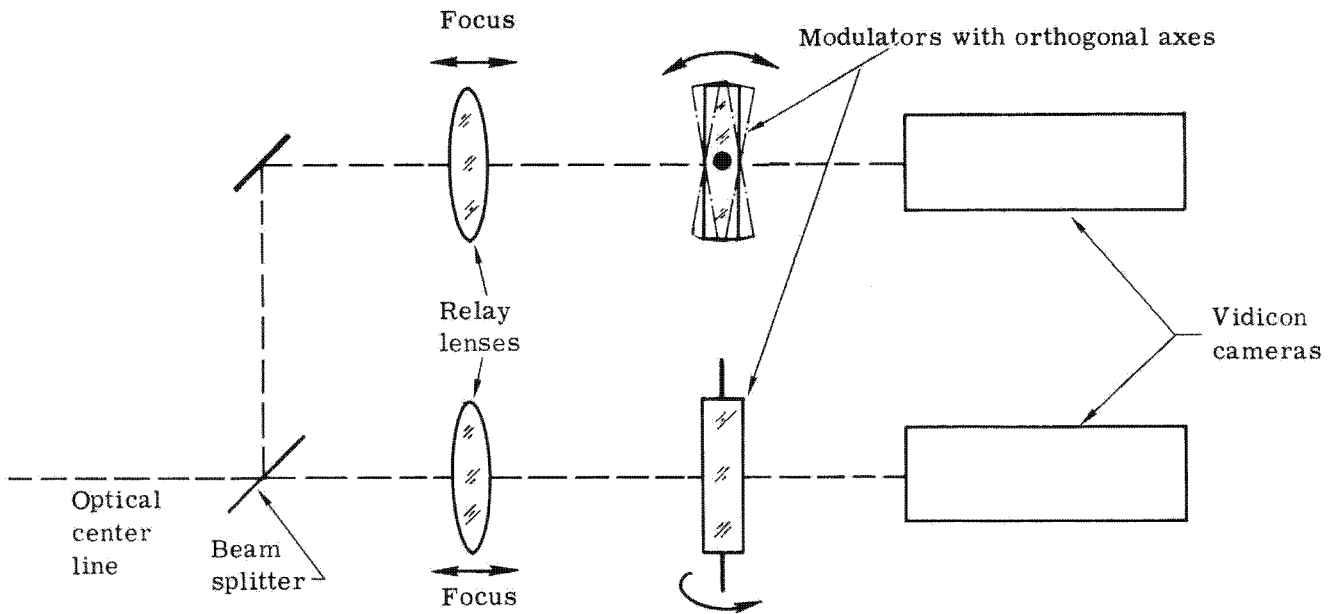


Fig. 3-6 — Two-axis configuration using two independent, orthogonal sensors

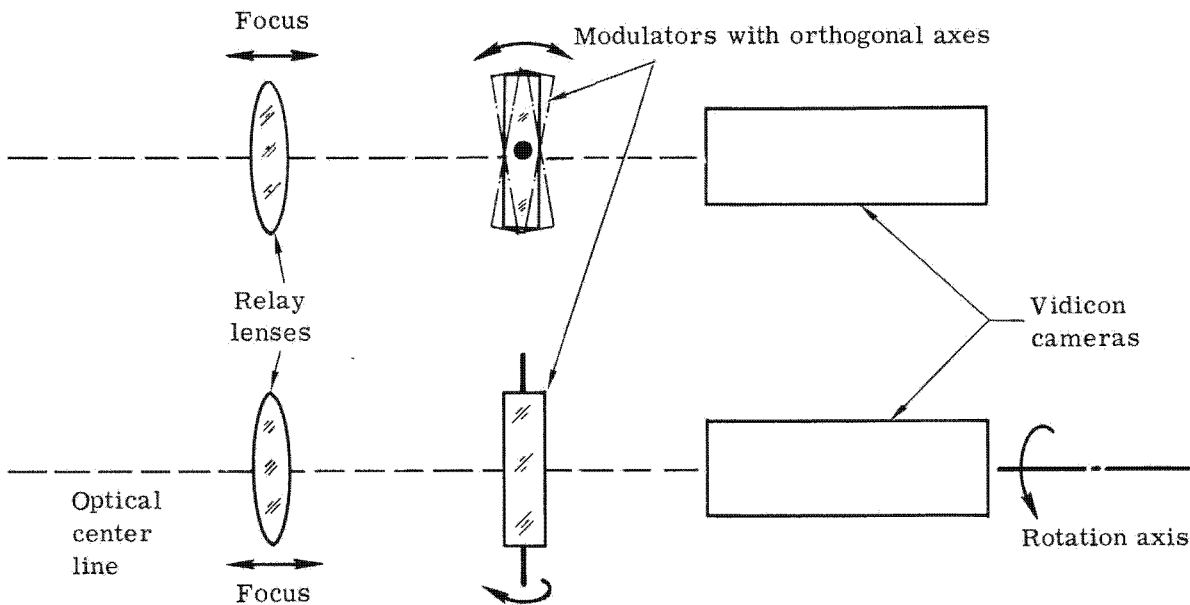


Fig. 3-7 — Sensor configuration using displaced image technique

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Although the approach shown in Fig. 3-7 does substantially increase camera illumination, as compared with the technique used in Fig. 3-6, serious problems due to the weight, size, and power aspects of a two-camera system are introduced. The two-patch approach necessitates a complex roll servo slaved to the main tracking mirror. The current brassboard is based on this design principle. However, addition of the intensified vidicon removes the light level component and allows the use of two on-axis patches. This arrangement permits the elimination of the roll servo in the proposed design.

Single camera techniques must be considered in an effort to reduce the above parameters.

A logical approach to single camera operation is to have some form of image space sharing. Two images are placed side by side on the face of the vidicon and one image would be rotated 90 degrees to represent the second image velocity axis. These images could be produced from one scene (reproduced by use of a beam splitter and rotated), or they could be produced from different portions of the scene.

The approaches evolving from the above discussion are: (1) the displaced image technique (see Fig. 3-8), which, while requiring roll servo, provides higher illumination; and (2) the on-axis beam splitter technique (see Fig. 3-9) which does not require a roll servo but lessens illumination at the vidicon. However, the low illumination can be compensated for through the use of an image intensifier block. Testing has indicated that linearity and overall performance are greatly improved with higher and constant illumination on the face of the vidicon. The image intensifier with controlled gain accomplishes both of these functions.

An important design decision in the electronics system, for image sharing, is the determination of whether the raster will be shared on a split-line or split-field basis. Either form of gating and steering of the video signal is easy to achieve. Tests of a single-axis sensor, on both a split-field and a split-line basis, have been conducted. In both cases, the signal level was reduced because less than half a raster of information was being processed. Recent tests have indicated null accuracy is more readily achieved through field splitting as opposed to line splitting.

For these reasons, the single camera conventional TV raster scan, linear sinusoidal modulation, and dual image-split field systemology has been selected.

3.2.3 Technical Considerations

This section presents a discussion of technical parameters pertaining to operation of the IVS in the overall system. The proposed design is a best compromise of these parameters in an attempt to optimize overall performance.

3.2.3.1 Focus

The aerial image plane presented to the IVS by the main optical system varies dynamically in focus by ± 0.050 inch. This magnitude of focus variation degrades sensor performance, but, based upon existing analysis, not to the extent of requiring focus compensation.

In addition, the sensor must be designed to accommodate an additional static focus variation of ± 0.250 inch. This can be done by shimming the IVS mounting adapter during initial installation.

3.2.3.2 Reliability

The reliability analysis of the proposed sensor system was accomplished following the procedures of the "part failure" method described in paragraphs 4.2 and 5.2 of MIL-HDBK-756A, assuming constant part failure rates.

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3-9

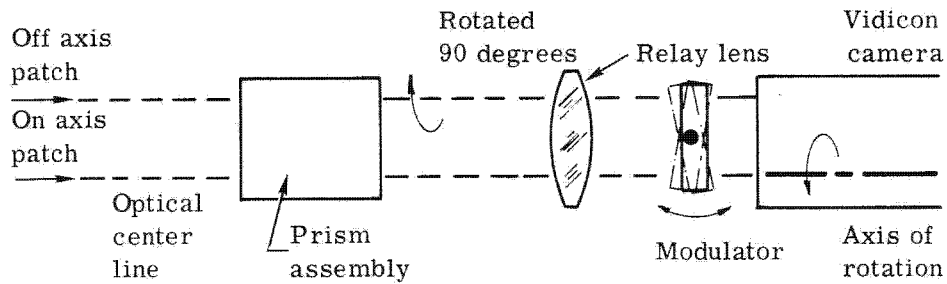


Fig. 3-8 — One camera with off-axis image

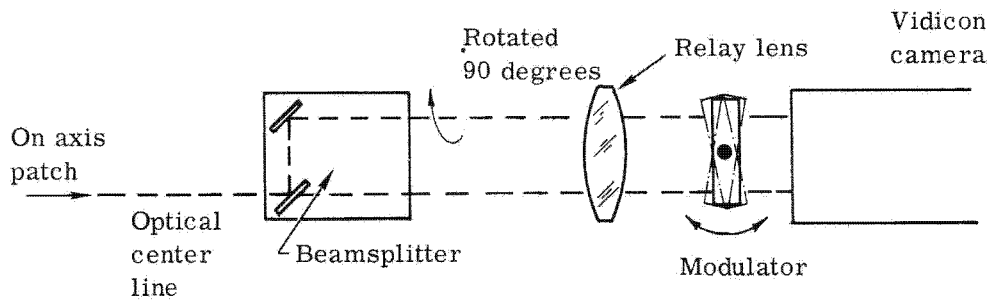


Fig. 3-9 — One camera with on-axis image

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The following sources of failure rate (λ) data were utilized for the failure rate prediction of the Itek designed equipment:

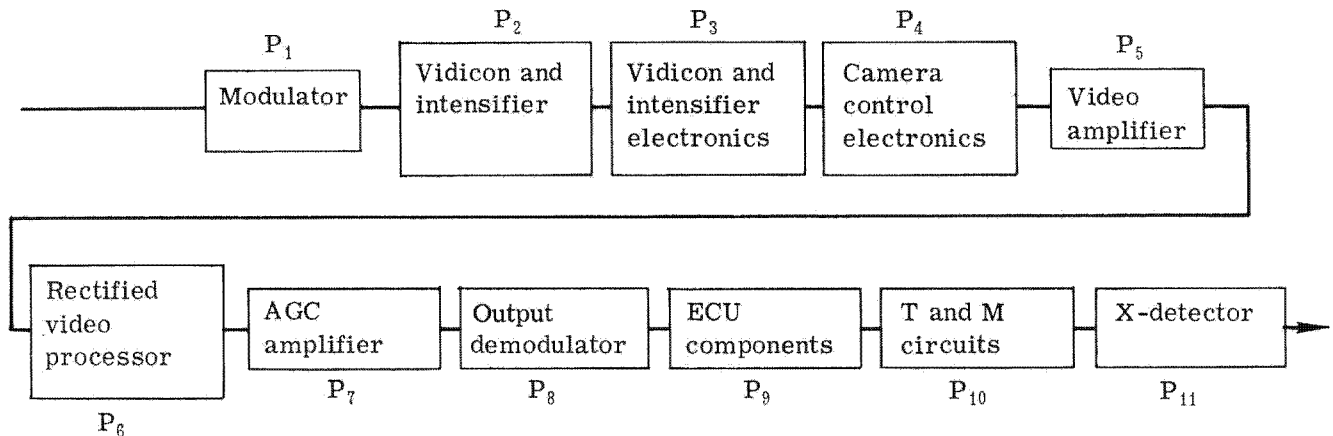
1. MIL-HDBK-217A
2. D2-113572-1, Boeing Company (Voyager Program)
3. Vendor supplied part data
4. IRE proceedings, Seventh National Symposium on Reliability and Quality Control

An experience factor of 0.1 has been applied to the basic MIL-HDBK-217A semiconductor failure rates to represent the improvement expected with use of TX (extra test requirements) parts.

Failure rates for purchased equipment have been supplied to Itek by the equipment vendors.

The proposed sensor system may be represented by a series model as indicated below.

The total block failure rate per 10^6 hours is shown in Table 3-1.



Probability of Survival

$$P_S = P_1 \cdot P_2 \cdot P_3 \cdot P_4 \cdot \dots \cdot P_{11}$$

$$P_S = e^{-(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 \cdot \dots \cdot \lambda_{11})t}$$

Where $\lambda = \lambda_2 + \lambda_3 + \lambda_4 \cdot \dots \cdot \lambda_{11} = 126$ failures per 10^6 hours

When the λ values are substituted in the above expression, the result is as follows:

$$P_S = e^{-0.000126t}$$

The probability of survival for 1,112 hours mission life is 96 percent.

3.2.3.3 Camera Image Illumination

Because of the relatively low illumination level of the aerial image, it is important that the optical relay system have a high transmission even with the image intensifier. This leads to a

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Table 3-1 — Total Block Failure Rate per 10^6 Hours

Modulator	2.4
Vidicon and intensifier	90.0
Vidicon and intensifier electronics	4.6
Camera control electronics	12.9
Video amplifier	2.6
Rectified video processor	2.2
AGC amplifier	2.3
Output demodulator	3.1
ECU components	1.3
T and M circuitry	2.2
X-detector	<u>2.4</u>
Total	126.0
MTBF	8,000 hours

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design consistent with a minimum number of air-glass surfaces and the use of internal reflection, where required.

Minification of the relayed image provides a camera illumination gain proportional to the square of the minification factor. However, the allowable scale change is limited by the increasingly stringent null sensing requirement at the vidicon.

3.2.3.4 Interface Alignment

In order to provide velocity signals which are representative of center of format, it is necessary that the vidicon raster scan the proper areas of the aerial image. Failure to conform to the ideal geometry (i.e., center of along- and cross-track patches on optical center) will cause null errors. Representative magnitudes of error are as follows:

Patch	Dimensional Error, inches	Resultant Velocity Error, inches per second
Along- or cross-track	0.020	0.00026

There are two sources of geometrical error: (1) alignment of the sensor to the aerial image, and (2) relative alignment of the sensor subassemblies. An error budget must be established to determine the relative allowable magnitude of the two sources.

The present design approach is to mount the IVS to fixed dowel pins. Therefore, the location of the aerial image optical axis with respect to the dowel pins must be accurately maintained.

3.3 DETAILED SENSOR DESCRIPTION

The proposed Image Velocity Sensor (Fig. 1-1) is based on the above described principles of operation. It consists of two units—the sensor head and the electronics assembly.

3.3.1 Sensor Head

The sensor head layout is shown in Fig. 3-10 and its optical/mechanical schematic is seen in Fig. 3-11. The cylindrically shaped sensor head is designed for flange mounting to the image column. The major functions to be performed by this unit are as follows:

1. Provide beam splitting and image half rotation
2. Relay the aerial image
3. Velocity modulate the image.

The unit consists of the following major subassemblies:

1. Beam splitter image half-rotation prism assembly
2. Field lens
3. Modulator assembly
4. Relay lens
5. Intensified vidicon camera (IV) with high voltage power supply
6. Field flattener lens and sealing window.

The beam splitter/prism assembly is inserted into and beyond the aerial image. Within the prism assembly, the on-axis patch is split into two paths, one path is rotated 90 degrees.

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3-13

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The optical path lengths of both elements of the split patch are maintained equal by suitable adjustment of air-glass distances.

A relay lens assembly relays the split patch aerial image onto the intensifier tube's photo-sensitive surface.

A single oscillating refraction plate is located between the image half-rotation prism and the field lens to provide velocity modulation.

3.3.1.1 Optical System

The optical system shown in Fig. 3-11 will be used to transmit the image to the vidicon. This system consists of a field lens and a relay lens, a singlet and an airspaced triplet, respectively. A field flattener will provide further correction. Lenses will be designed by the optical design section to satisfy the design goals presented here:

- | | |
|-------------------------|--------------------------------|
| 1. Minimum weight | 4. Maximum modulation transfer |
| 2. Minimum size | 5. Environmental conditions. |
| 3. Maximum transmission | |

These goals conflict to some extent insasmuch as goals 1, 2, and 3 have optimum solutions using a minimum number of elements, while optimum solutions for goal 4 may require increasing the number of elements. In addition, the prism assembly and windows introduce astigmatism, spherical, lateral-chromatic, and axial-chromatic aberration into the image. This would restrict the use of "off the shelf" lenses, since all commercially available lenses which would meet the first order specifications were designed for use without a prism which adversely affects image quality when added.

In addition to adhering to the above requirements, the system must meet the following specific requirements:

1. Minification: 2×
2. Image size: 0.375 × 0.500 inch
3. Spectral range: S-20 (see Fig. 3-12).

These considerations suggest adding elements to the design to increase the number of variables which could be used to correct the aberration to a minimum value, but this would be in conflict with goals 1, 2, and 3.

Interface

Fig. 3-10 shows the mechanical/optical interface for the IVS. The design is compatible with all the requirements of "IVS Installation Interface," GE drawing no. 711-03013.

The proposed configuration requires alignment of an adapter section (not Itek-supplied) with respect to the aerial image prior to installation of the IVS. This alignment would include location of the dowel pins with respect to the aerial image and shimming of the adapter to compensate for focus variation from system to system and image plane tilt.

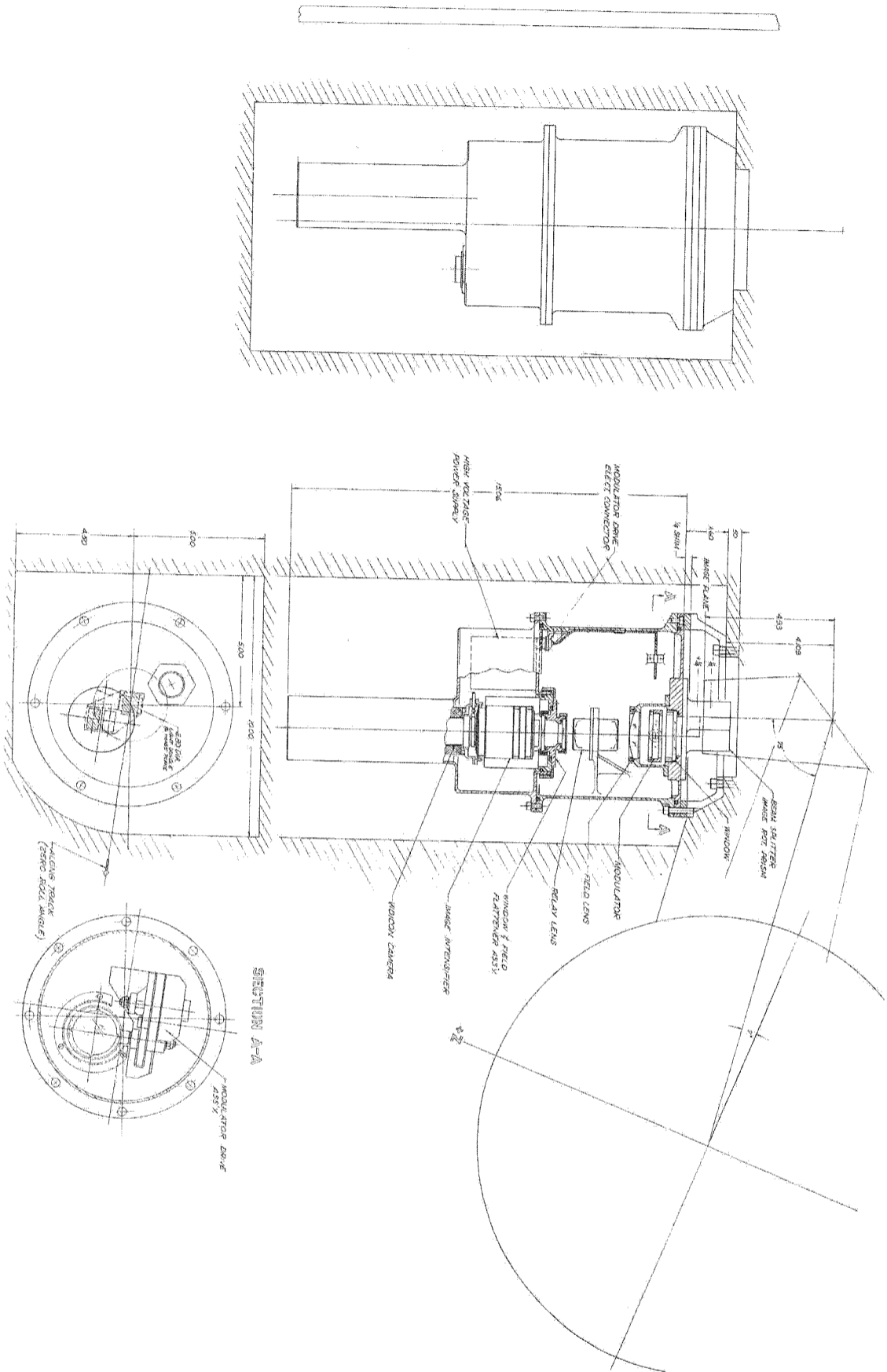
This approach will provide a mechanical-optical interface which will allow complete interchangeability of sensors without adjustment inside the vehicle. Additionally, it will be much simpler to adjust the small, lightweight adapter piece rather than the entire sensor.

The interface surface between the sensor head assembly and the mounting adapter will be flat to within 0.001-inch TIR to prevent transmission of stray light and dust particles.

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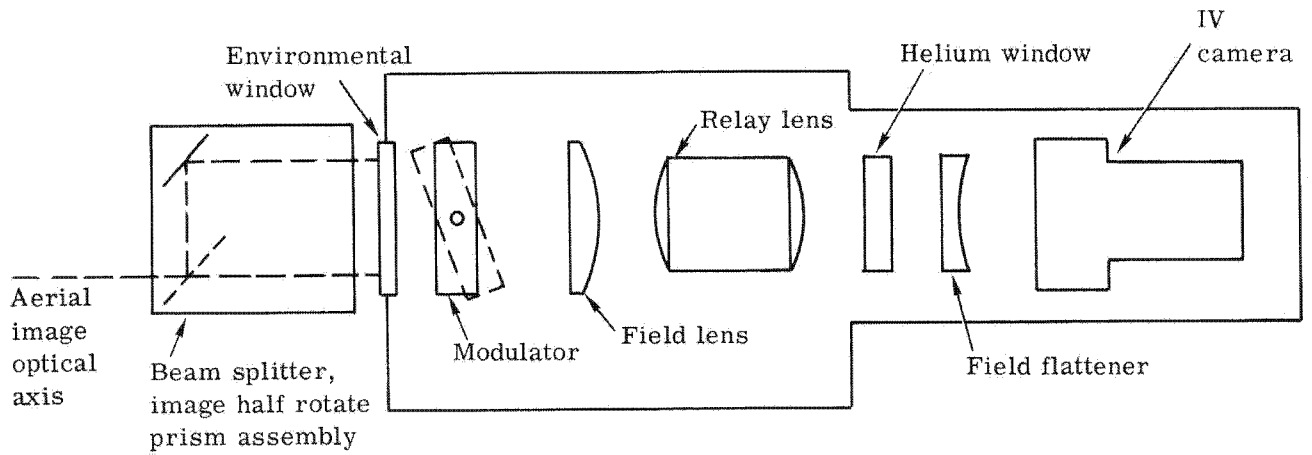


Fig. 3-11 — Schematic of IVS sensor head

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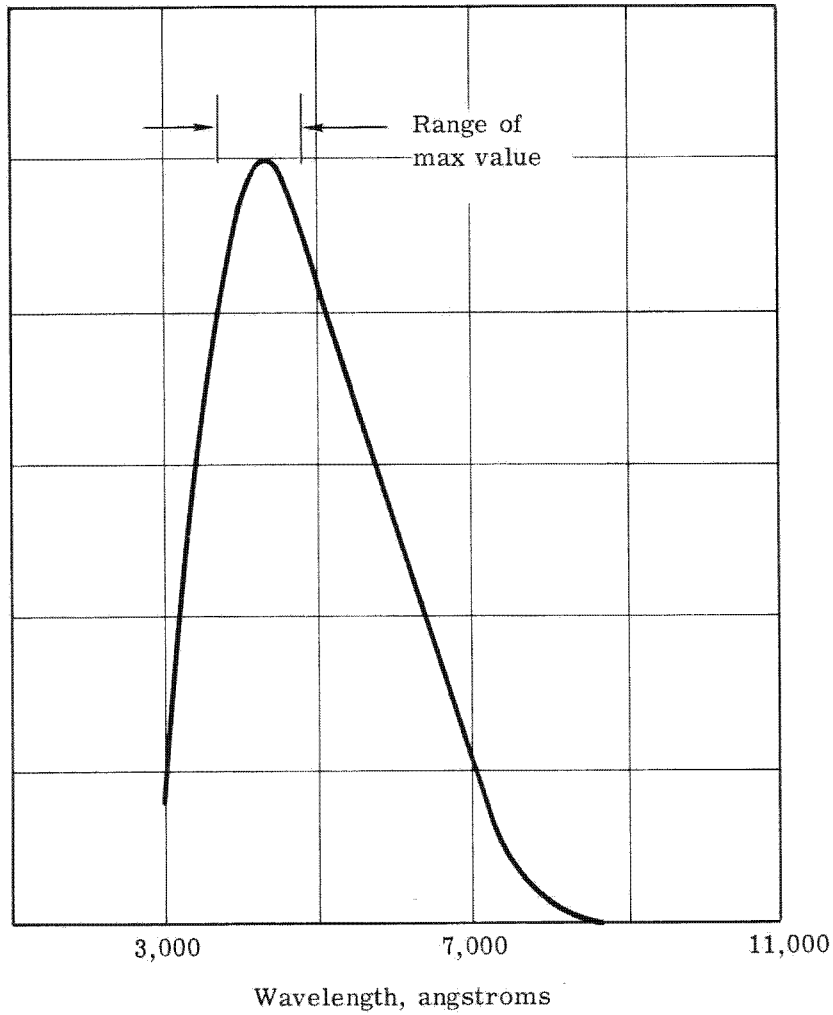


Fig. 3-12 — Spectral sensitivity of intensifier input surface (S-20)

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3.3.1.2 Mechanical Description

Modulator

An oscillating flat glass refractor plate is used for image modulation (see Fig. 3-13). The design has the additional feature of $I\omega$ (inertia-velocity) balance.

The unit has two equal inertias (one being the refractor plate) which are coupled at a 1:1 ratio with an arm and cam follower bearing and a torsional spring load. Both inertia loads are first moment balanced.

The torsional springs and inertias are designed to cause the system to have a natural frequency equal to the desired modulation frequency. The springs also provide a spring load (by preloading) at the arm-follower bearing to prevent separation and prevent displacement drift of the velocity-controlled refractor plate.

The modulator mechanism is driven with a combination brushless torque motor-tachometer. The velocity magnitude and frequency are servo-controlled by a sinusoidal signal derived from camera pulses.

This arrangement provides a modulator system with the following advantages:

1. Extremely low power requirement because of the match of natural and command frequencies
2. No output disturbance because of $I\omega$ balance
3. Insensitivity to external disturbance because of first moment plus $I\omega$ balance
4. Simple position drift control for the velocity servo.

This technique has been used in the existing Itek brassboard sensor with satisfactory results. Motor power consumption has been experimentally determined to be less than 0.1 watt.

The magnitude of image modulation is proportional to the glass thickness and index and the oscillation rate. Fig. 3-14 shows the equations which determine modulation velocity with an oscillating refractor plate.

3.3.1.3 Structural

The support structure, image rotation prism holder, and camera case are the primary structural elements of the sensor. Preliminary studies, based on a 50-g static load applied in three orthogonal directions, revealed no highly stressed elements. The equivalent static loading was derived for a lumped mass, single-degree-of-freedom system, subjected to the specified random motion (see GE specification no. DR1100). Fragility limits for components such as motors, vidicon tube, camera assembly, and prisms were not exceeded. Because stress is not a major consideration, element thickness, as now shown, would remain essentially unchanged if the structure were fabricated from either magnesium or aluminum; the random acceleration response should decrease because of improved material damping characteristics. Provisions for soft-mounting the prism to the holder are contemplated to reduce thermal distortion.

3.3.2 Sensor Electronics Assembly

The sensor electronics is a machined magnesium piece. Ribs are employed to maximize strength while minimizing weight. This box would be bolted to the cold plate in order to dissipate the power generated within it. Gasketing to provide both pressure and EMI sealing is utilized between the cover and the box assembly. It is estimated that the electronics assembly size will be approximately 6 by 9 by 6 inches, and its weight will be approximately 12 pounds.

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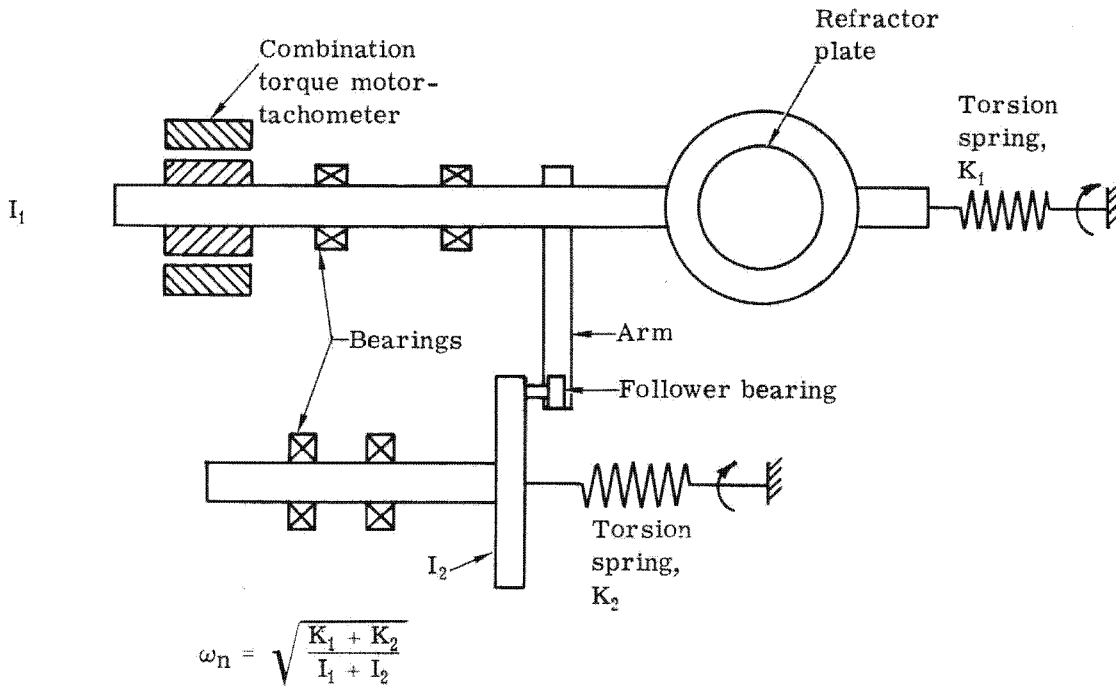
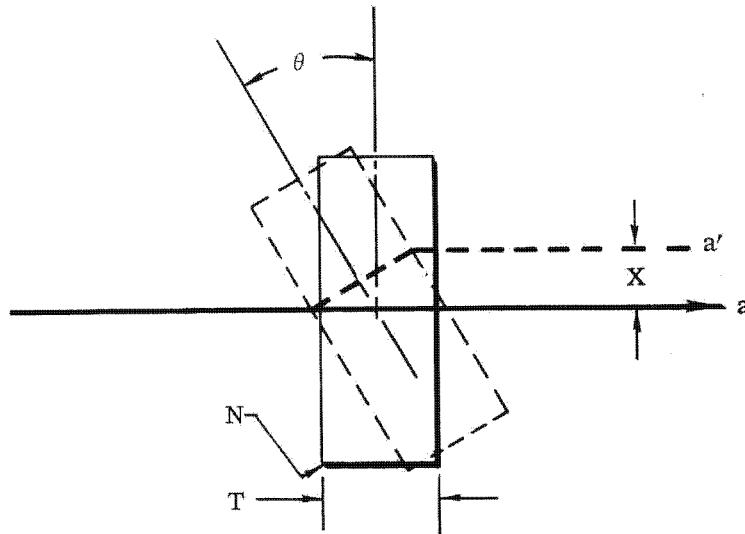


Fig. 3-13 — Image modulation configuration

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$$X = T \sin \theta \left(1 - \frac{\cos \theta}{\sqrt{N^2 - \sin^2 \theta}} \right)$$

$$\dot{X} = T \cdot \dot{\theta} \left[\cos \theta - \frac{\cos^2 \theta - \sin^2 \theta}{\sqrt{N^2 - \sin^2 \theta}} - \frac{\sin^2 \theta \cdot \cos^2 \theta}{(N^2 - \sin^2 \theta)^{3/2}} \right]$$

for small angles.

$$X = T \cdot \theta \left(\frac{N - 1}{N} \right)$$

$$\dot{X} = T \cdot \dot{\theta} \left(\frac{N - 1}{N} \right) = T \left(\frac{N - 1}{N} \right) \theta \omega \cos \omega t$$

Fig. 3-14 — Modulation technique using oscillating refractor plate

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The signal processor electronics system consists of modular circuit cards. The nature of the electronics lends itself to this type of construction since discrete circuit functions can be assigned to each module. This means that each module can be fabricated and tested as a working entity in itself. In order to minimize weight while providing adequate thermal conduction, potting depth will be limited to that required to adequately conduct heat and provide a protective coating.

A multilayer printed circuit board with connectors attached will be used to interconnect the modules. This board will also provide the connections between the signal processor and the TV camera and other systems.

The major portion of the power or heat dissipation for the entire system will be in the electronics assembly. There are two sides to the problem of maintaining the electronics at an acceptable temperature level. First, the heat generated by the individual components must be transmitted to the housing, and second, this energy must be transferred from the housing to the surroundings in an efficient manner. The second item does not really constitute a problem since the electronic assembly is mounted on a fluid-controlled cold plate. Therefore, the major design consideration is the first problem.

In an electronic assembly such as that proposed here, the heat-generating items are small components mounted on printed circuit boards which are in turn mounted within a metal box. Good design practice requires that all possible paths for transmitting heat from the components to the enclosure be maximized. The major mode of heat transfer is conduction; since the boards mostly "see each other" rather than the enclosure, radiation plays a minor role, and convection is not present because of the zero-g environment. The path which must be utilized then is from the components to the board, from the point of contact to the board edge, from the edge to slides or ribs attached to the walls of the enclosure, and then to the cold plate.

Features have been included in the proposed design which maximize the above mentioned paths, thereby minimizing the temperature rise from the cold plate to the components. Conduction from the components to the boards is facilitated by encapsulating the components in a thermally conductive potting compound. Conduction from the center to the edge of the board is enhanced by bonding a copper thermal ground plane to the upper board surface. The contact resistance between the board and the slides will be minimized by a clamping arrangement.

The maximum dissipation in an individual printed circuit board is approximately 1 watt. In order to get a preliminary value for the temperature difference between the components and the enclosure, the various thermal resistances were estimated for the proposed design. With an approximate total resistance of approximately 8- to 9-hr-°R/Btu and 1-watt dissipation, the temperature difference is about 30 °F.

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3.3.3 Electronics Description

3.3.3.1 Camera

A standard Lear Siegler Corporation model no. 0791 camera has been used in the breadboard tests and was also used in the brassboard. This camera model has been qualified for space application. Lear Siegler cameras which are predecessors of the 0791 model have been successfully employed in a number of military and space applications including Echo, Saturn I, Syncom Gravity Gradient Satellite (NASA-Hughes-General Electric Co.), and Gemini MA-9. LSI is presently under contract for TV cameras for space-borne cameras for the Centaur Program and Saturn V.

The TV camera used in the proposed system would basically be this 0791 camera modified to accept image intensified vidicon. Additional modification will provide output signals of the type and in the form required to optimize the system. The mixed blank is subtracted or removed from the composite video by an external circuit in the brassboard. This operation achieves certain desired results, but will be better performed within the camera video amplifier by utilizing a different means for applying the mixed blank to the video signal.

The image-sharing technique utilized in the sensor requires additional timing pulses to be supplied by the sync generator. Also, the modulator drive is generated by a pulse train at one quarter of the vertical field rate. The camera would provide these signals in the proposed system; in addition, it would provide the ± 15 -volt power required by the sensor electronics.

Additional improvements can be made in the camera to tailor gain, bandwidth, impedance levels, and S/N characteristics to the particular requirements of the sensor. These modifications will be included in the camera. Circuitry will be provided to control the gain of the image intensifier.

The vidicon tube used in the brassboard camera is a standard off-the-shelf 8567 ruggedized vidicon. Selection of an 8567 vidicon for low dark current, high gain, and uniform dark current at high target voltage (minimum flaring) may be desirable for best performance of the final design. A single stage, 25-millimeter image intensifier has been coupled to the 8567 to form an intensified vidicon (C23001F) for the system.

The 8567 tube was developed to meet a NASA specification for use in early earth-orbit Apollo missions. There is a considerable amount of life/reliability data available on the non-ruggedized version of this tube (8134) from studio use. In conference with RCA engineers, it was stated that because of tighter manufacturing controls and general ruggedization, the 8567 is even more reliable than the commercial version.

3.3.3.2 Signal Processor

Fig. 3-15 is a block diagram of the signal processor electronics subsystem of the two-axis image velocity sensor. As can be seen, an image input is presented to the TV camera, in this case a modified Lear Siegler Corporation, model no. 0791. A number of outputs are provided by the camera to aid in the signal processing operation.

The video amplifier provides a number of functions in addition to amplifying the TV camera output. The composite video, as it comes from the TV camera, is periodically clamped to ground from approximately a 1-volt level during the horizontal and vertical retrace periods. When this signal is ac-coupled, this level change results in large differentiation spikes which

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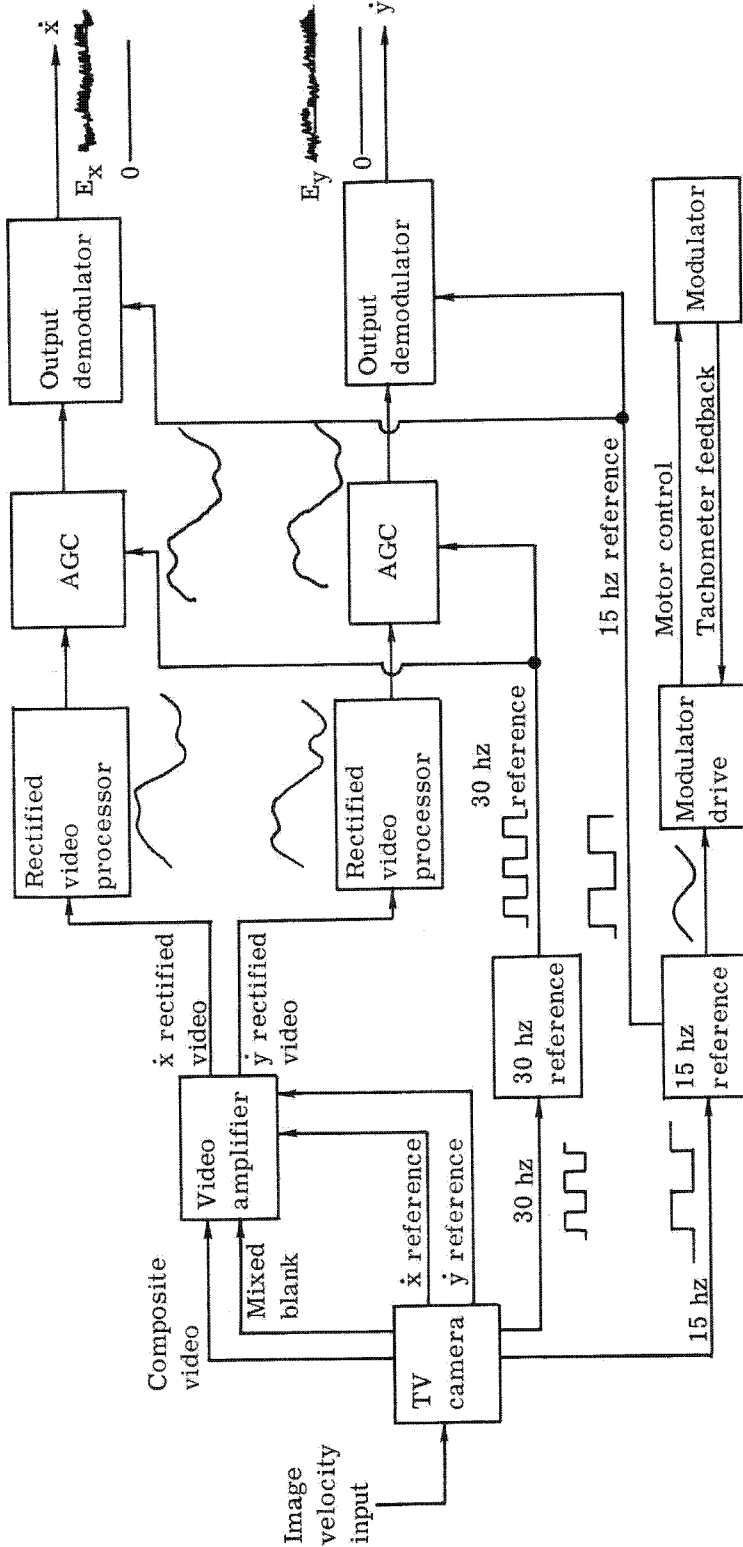


Fig. 3-15 — Sensor electronics block diagram

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in turn are noise signals large enough to saturate the video amplifier. As this level change is introduced in the camera by means of the mixed blank signal developed in the sync generator, it can be removed by "subtracting" or applying the mixed blank in a different manner. The camera has been modified to provide the ac video signal without a level change during the blank interval.

Tests and analysis have shown that the low frequency video signal components are undesirable. Therefore, the subtracted video signal is passed through a four-pole, high-pass filter with its break frequency at approximately 100 khz. Gain stages are followed by a full-wave video detector circuit. In order to ensure that the video signal will remain constant over as wide a range as possible, an AGC loop is provided. In addition, current bias is provided for the detector diodes to overcome the energy barrier of the diode forward voltage drop.

Because each field contains information for both the along- and cross-track image velocity channels, these field halves must be separated and directed into the appropriate channels. This is accomplished by gating FET switches into output buffer amplifiers and presenting the two outputs for further processing.

The modulator derives its reference from the TV camera also. In this way it is frequency-locked to the camera field rate, and, thus, beat frequencies in the sensor outputs are avoided. The 60-hz field rate is counted down to 30- and 15-hz pulse trains which are filtered to produce sinusoidal signals. The 15-hz sinusoid commands the modulator drive servo and is phase-shifted and squared to provide the output demodulator synchronous reference. The 30-hz pulse train is processed in a similar manner to provide the AGC synchronous reference.

The outputs of the field-sampling circuits contain many signals and frequencies in addition to the fundamental and second harmonic signals required by the system. In general, these unwanted signals are of considerably greater magnitude than the 15- and 30-hz signals. The requirement that these undesirable signals be removed without attenuating or phase-shifting 15- and 30-hz signals in addition to not limiting the sensor bandwidth results in a complex network. The 60- and 120-hz harmonics of the field rate are selected by high Q amplifiers, inverted, and reinserted into the rectified video signal. This results in the removal of these frequencies by subtraction. The 180- and 240-hz harmonics are blocked by transmission zeros created by series twin tee notches in the signal path. The rectified video processor is then made bandpass by placing a single high-pass break at 1.5 hz and three low-pass poles at 150 hz. In this way, adequate gain can be provided for 15- and 30-hz signals without fear of other frequencies causing amplifier saturation and other noise problems.

Further sensor gain normalization is required in addition to that provided by AGC in the video amplifier of the signal processor. This gain control is related to the video signal and not precisely to image velocity-sensitive signals. The amplitude of the signal at the second harmonic of the modulation frequency is related to velocity smear effects on video information. This signal can be selected and used for AGC purposes. In addition, its amplitude is affected by object velocity as well as by modulation frequency and amplitude. However, in spite of these limitations, the second harmonic can be used for AGC.

The 30-hz, second harmonic signal is selected by a $Q = 5$ bandpass amplifier and full-wave synchronous detector whose reference signal has been described above. The full-wave rectified 30-hz signal is filtered by a low-pass amplifier to dc. A set point reference is also provided by this amplifier. The dc output voltage controls the gate of an FET operating in its ohmic region as a voltage-controlled variable resistor. The drain-source resistance of the FET determines the feedback ratio and consequently the gain of the forward path amplifier, thus

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achieving an AGC function within the limitation discussed above. If certain tests require a fixed rather than a variable gain, a manual mode of gain adjustment is provided. The manual or fixed gain mode will also be selected during the slew mode of the system.

Finally, since the sensitivity has been normalized, the object velocity along each axis may be measured. First a $Q = 5$ bandpass amplifier selects the 15-hz fundamental signal so that it may then be synchronously detected. The synchronous reference signal has been discussed above. The means of making a final gain trimming adjustment is provided in the bandpass amplifier. The synchronous detector is followed by a low-pass ripple and noise filter. The frequency response, i.e., bandwidth of the sensor, is determined by the location of the output low-pass filter pole and the equivalent low-pass filter pole of the bandpass amplifier, in addition to a transport lag term.

3.3.3.3 Power and Control

Power is drawn from the prime vehicle +28-vdc power supply. A power supply within the TV camera control unit is driven from this source and supplies all of the image velocity sensor subsystems. This power supply generates the voltages required by the camera and provides 12 watts of ± 15 vdc for use in sensor circuits. Special reference voltages required in specific sensor modules are generated within these modules as needed. The only exception to the utilization of the camera power supply exists in the modulator servo. The power amplifier is driven directly from the +28-vdc source.

It is assumed that the +28-volt power switching is done external to the sensor. Then the presence of +28 volts across the input power lines energizes the image velocity sensor, and it remains energized until the +28-vdc power is removed. This permits a smaller, lighter box for the electronics assembly, reduces the sensor EMI problem, and improves system reliability in comparison to power switching with a relay within the electronic assembly.

3.3.3.4 System Interface

The EMI protection required will be provided by the packaging technique utilized. The degree of protection will be determined through tests. The entire sensor (electronics assembly, cable, and head) can be considered an EMI tight enclosure. Therefore, appropriate sealing, gasketing, and shielding will be employed throughout. Line filters, as required, will be provided at the signal and power interface to minimize the effects of conducted EMI.

3.3.4 Maintainability

The principal approach to meeting the maintainability requirements will be to direct the IVS design toward modularization of subassemblies so as to simplify component replacement. Design for accessibility for facilitating such module and component replacement will also be stressed. These techniques and others will be investigated, and the design guidelines derived from them will be implemented through a maintainability program using MIL-STD-470 as a guide.

3.3.5 Safety and Hazard Minimization

The principal technique for ensuring safety and minimizing hazards to personnel and equipment in the design and implementation of the IVS Program is as follows:

1. Adherence to specified (GE specification no. DR1100A) safety factors as regarding the IVS basic structure and components.

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2. Adherence to GE specification no. DR1115 to ensure compatibility of all IVS equipment, materials, and processes with specified cabin atmospheres. In particular, this relates to odor, toxicity, flammability, outgassing, and contamination. While significant portions of the IVS will be contained within qualifiable hermetically sealed packages, it will, nevertheless, be a design goal to select all materials and processes on the basis of full compatibility with the life environment requirements of the laboratory module.

These techniques and others will be pursued through the implementation of a safety engineering program following the plan as outlined in MSM-S-131.

3.3.6 General Considerations Relating to Environmental Requirements

3.3.6.1 IVS Camera Package Subassembly

In order to ensure satisfactory operation of the IVS camera package within the helium environment, the camera case will be sealed as in Fig. 3-10. This configuration makes use of a three-compartment technique in which the camera tube itself forms the third compartment. This method will be used to attenuate anticipated helium permeation through the quartz elements of the package. Mounting and sealing at the glass-to-metal interface will be by appropriate sealing techniques, with due consideration to possible outgassing problems, or by metallic static face seals. The objective, of course, is to construct a hermetically sealed camera package which minimizes helium permeation through either the quartz optical elements or the sealing elements themselves.

As an additional barrier to helium permeation into the TV, it is planned to add a window at the beam splitter/prism assembly. This arrangement will make it feasible to seal the main sensor head assembly from helium, in turn reducing the helium partial pressure seen by the IV window.

3.3.6.2 IVS Sensor Head Assembly

As shown in Fig. 3-10, sensor head components are contained within an integral hermetically sealed package whose aft closure is formed by the camera package subassembly. This arrangement is utilized in order to prevent optical element contamination and to provide component protection during various phases of environmental testing. In its final assembly stage, this package will be purged with dry nitrogen and hermetically sealed off. The only exposed optical element in this arrangement will be a window for the entrance prism leading edge.

3.3.6.3 Interface of Sensor Head Assembly and Mounting Surface

The interface between the sensor head assembly and the mounting adaptor will be flat to within 0.001 TIR to prevent transmission of stray light and dust particles.

3.3.6.4 Sensor Electronics Package

The IVS sensor electronics package will be a totally enclosed unit employing hermetic-type connectors. In final assembly stages, it will be dry nitrogen-purged and hermetically sealed using conventional elastomeric seals.

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3.3.6.5 Corona

No problem with corona is anticipated for the following reasons:

1. The highest voltage that exists outside the pressurized TV camera head is +250 volts which goes to the electronics assembly for TV camera electronic focus control
2. This lead comes directly from the TV camera head, to the interconnecting cable, and thence into the pressurized electronics assembly. It does not enter any area where the pressure does not rapidly equalize during subjection to a low pressure environment.

According to W. T. Starr's article, "High-Altitude Flashover and Corona Problems," which appeared in the May-June 1962 issue of Electro-Technology: "Nor has there been any report as yet of corona occurring below a peak voltage of 270 volts."

Should corona be found to be a problem in spite of the above, it would be relatively simple to keep this voltage within the pressurized TV camera head and control focus from the electronics assembly by a suitable low voltage means, or to set the focus within the TV camera head before it is pressurized and sealed.

3.4 SENSOR CHARACTERISTICS

3.4.1 Size and Weight

The sensor head is a cylindrically shaped unit with a basic overall diameter of 7.75 inches and an overall length (from mounting flange to end) of 15.06 inches. The image half rotator prism extends 1.85 inches forward from the mounting flange. Fig. 3-10 shows the above overall dimensions.

The electronics package is a rectangular shaped ribbed box. Its overall dimensions are 6 inches long by 9 inches wide by 6 inches high.

Table 3-2 gives a weight summary for the IVS system and compares these weights with specification requirements.

Table 3-3 presents a detailed weight breakdown for the sensor head.

3.4.2 Power

Fig. 3-16 is a profile of the power required from the prime 28-vdc supply. The required power has been broken down functionally so that each operation within the sensor has a power budget. The power distribution has been further broken down to illustrate the requirements of the two modes of operation. During the slew mode, the sensor is being positioned so that it can perform a tracking function. During the tracking mode, the sensor is providing image velocity tracking information.

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Table 3-2 — IVS Weight Summary

Item Description	Present Design, pounds	Specification Requirements, pounds
Sensor head assembly	10.76	10.76 (14.00 maximum)
Electronic control package	12.00	12.24 (if sensor head assembly is 10.76 pounds)
Total Weight (One IVS System)	22.76	23.00

Table 3-3 — Sensor Head Weight Estimate

Front window assembly	0.10
End plate	0.50
Image rotator assembly	0.70
Field lens assembly	0.23
Modulator assembly	1.08
Relay lens assembly	.50
Camera assembly	5.50
Field flattener and window	.20
Housing	<u>1.95</u>
	10.76 pounds

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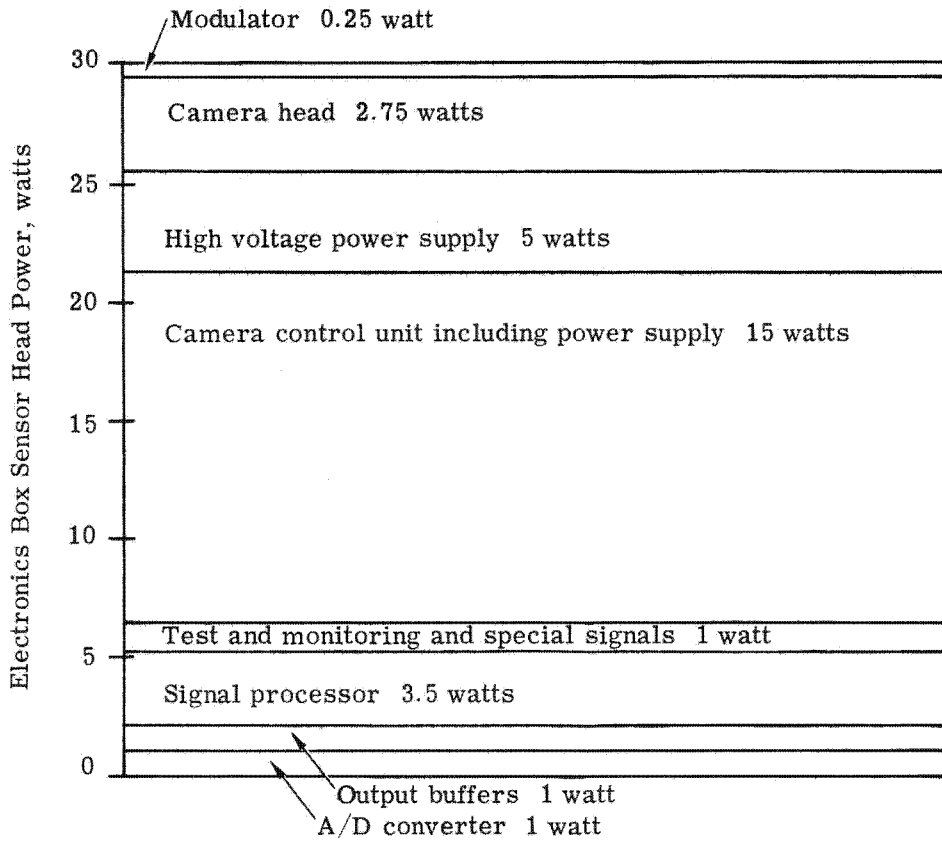


Fig. 3-16 — IVS power requirements

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4. TEST SUPPORT EQUIPMENT

4.1 IVS SPECIAL TEST SETUP

The IVS special test setup will be similar to the target simulator built on the Air Force prime contract with certain modifications. It will supply power to the IVS, provide the various input commands, and present a moving image to the pickup head.

The special test setup is made up of a target drive and a test console. The target drive contains the x-y target drives, light source, filters, and optics necessary to present the image to the IVS. It also provides the mounting interface for the sensor head. The test console contains all the circuitry and test equipment necessary to control and monitor the IVS and target drive. Table 4-1 is a summary of the target drive characteristics.

4.1.1 Target Drive

Fig. 4-1 is a schematic representation of the target drive. The IVS views the target normally through a folding mirror and a pair of lenses which produce a telecentric f/7 image at an overall target-to-image ratio of 1.9:1. The target, a 15-inch square glass plate, and the light box which illuminates it, are carried on an x-y table which is driven by velocity servos. The x-y table is mounted on a second table which rotates at a constant velocity.

The illumination of the target is continuously variable over a range of 3:1, and illumination at the image plane is reduced by inserting appropriate neutral density filters in the optical path. The illumination of the target is measured by a Spectra Milli-Candella foot-candle meter which views the same area of the target seen by the IVS.

Fig. 4-2 illustrates how the optical system produces an f/7 telecentric image at 1.9:1 conjugate ratio. For simplicity, the folding mirror has been removed and only the light bundle producing an image at the edge of the field has been shown. Consider point A in the target plane, 2.66 inches from the optical axis. In the absence of the 16-inch lens, this point would be imaged at point B. When the 16-inch lens is inserted one focal length behind the 14-inch lens, the central ray is deflected and becomes parallel to the optical axis. The bottom ray appears to be coming from point C and is deflected to intersect the optical axis at point D. The intersection of the two deflected rays at point E is the new image position. Thus, an image is formed by a light bundle whose central ray is parallel to the optical axis; therefore, the image is telecentric. By stopping the 14-inch lens down to approximately f/6, an f/7 cone is produced at the image plane. Resolution in the image plane is approximately 150 lines per millimeter.

Fig. 4-3 is a representation of the image with the areas used for the along- and cross-track image motion sensing in the Itek sensor indicated. Point A is the intersection of the optical axis with the image plane and is the image of the target's axis of rotation. X and Y are the along- and cross-track directions, and x and y are the directions of target motion.

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For the moment, let $\dot{x} = \dot{y} = 0$, and let the angular velocity of the target = $\dot{\psi}$. Then, at any place in the image plane,

$$\dot{X}_i = Y_i \dot{\psi}$$

and

$$\dot{Y}_i = X_i \dot{\psi}$$

The data in Fig. 4-3 present a comparison of velocities at the indicated points. The velocities indicated for the actual system are those present under the extreme conditions of 40-degree roll and 30-degree pitch. The velocities indicated for the target drive are those resulting from an angular velocity, $\dot{\psi}$, of 0.05 radian per second. This velocity was chosen to make the maximum along-track velocities present in the portion of the scene viewed by the along-track sensing portion of the IVS the same in both cases.

Error velocities are introduced into the system by driving the target along the x and y axes. Since the velocities of interest are along the X and Y axes, the target must be driven in accordance with the following equations:

$$\dot{x} = \dot{X} \cos\psi - \dot{Y} \sin\psi$$

$$\dot{y} = \dot{X} \sin\psi + \dot{Y} \cos\psi$$

This is accomplished by exciting a pair of sine-cosine potentiometers (whose shafts are positioned by the table rotation) with the desired X and Y command voltages. The outputs of the potentiometers are then summed to provide \dot{x} and \dot{y} commands that are continuous functions of \dot{X} , \dot{Y} , and ψ , as shown in Fig. 4-4.

In order to keep friction at a minimum, the precision ball screws which drive the x and y tables will not be preloaded to take out backlash. This limits the range of sinusoidal input velocities and frequencies which can be provided by the tables without excessive distortion of the image velocity. Therefore, an oscillating refractor plate will be included in the target drive to provide the low-velocity and high-frequency sinusoidal image velocities. Fig. 4-5 illustrates the range of input image velocity and frequency which will be covered by the tables and the refractor plate.

4.1.2 Test Console

All the necessary circuitry and test equipment for controlling and monitoring the IVS and target drive will be contained in a three-bay console. The console contains a TV monitor, a two-channel oscilloscope, a 12-channel Visicorder, a differential voltmeter, a low-frequency function generator, and all the necessary power supplies. The sensor control panel will provide On-Off, Operate, Roll Angle and Focus Position commands to the IVS. The presence of go, no-go signals such as Operational Readiness, Lock-On, and Saturation will be visually displayed. A control will be provided to initiate transfer to the redundant system.

The target drive control assembly contains all the circuitry necessary to resolve \dot{X} and \dot{Y} commands for the x and y servoloops, the servocircuitry itself, and the control circuitry for the oscillating refractor plate, as well as switches for energizing the rotation motor and the light source. Fig. 4-6 is a block diagram of the x and y servoloops. An Inland torque motor (model T-1342A) is mounted directly on the end of the lead screw which drives the table. The

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motor is driven by an Inland power amplifier (model 150A), and the loop is compensated to yield the closed-loop frequency responses shown in Fig. 4-7. Curve no. 1 is the response to velocity input commands, while curve no. 2 is the response to torque disturbances, T_D , such as changes in friction and motor ripple torque. Since the system is type 1, a constant friction torque does not introduce a steady-state error as long as the friction level does not cause permanent saturation of the loop.

All signals of interest, from both the IVS and the special test setup, will be brought out to a patch panel. The input terminals of the test equipment will also be brought out, and by appropriately inserting patch cords in the panel, may be connected to the signal or signals of interest.

4.2 ENVIRONMENTAL CHAMBER

Fig. 4-8 is a representation of the anticipated arrangement of the environmental chamber and target drive. The chamber door, including an optical window, will be an integral part of the target drive. The chamber itself will be carried on a cart. After the IVS is attached to the door and aligned with the target drive optical system, the chamber will be rolled up and mated with the chamber door. To avoid transmission of vibration to the target drive, the vacuum pumps, refrigeration unit, and other auxiliary equipment will be mounted in a separate unit. The chamber will be constructed of stainless steel and will be approximately 3 feet in diameter and 3 feet long. It will be used for temperature cycling, thermal altitude, operation after vacuum, and oxygen compatibility tests during qualification, and for the temperature portion of the acceptance test for the qualification, preproduction, and prime units.

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BIF-059-0002-68

Table 4-1 — Target Drive Characteristics

Optics	f/7, telecentric
Uniformity of illumination	Within 5 percent across format
Filter range	Neutral density 0.08 (83 percent transmission) to 1.5 (3 percent transmission)
Image format	2.8-inch diameter circle
Target size	15 × 15 inches
Scale	6,000:1
Material	Glass plate
X-Y velocity range	±0.002 inch per second to ±2.0 inches per second
Velocity accuracy	±2 percent or 0.002 inch per second, whichever is greater
Response time	<50 milliseconds to first crossover within 2 percent at <150 milliseconds
Rotation velocity	0.05 radian per second ± 5 percent
Rotation range	±45 degrees
Maximum test time between rotation stops	30 seconds
Maximum test time between X-Y stops (at 0.5 inch per second)	6 seconds

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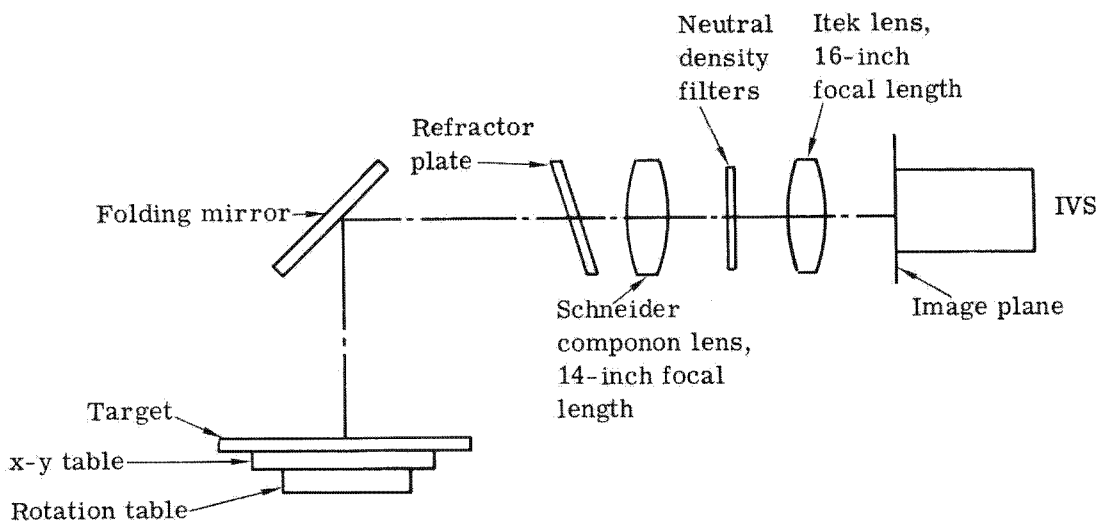


Fig. 4-1 — Target drive schematic

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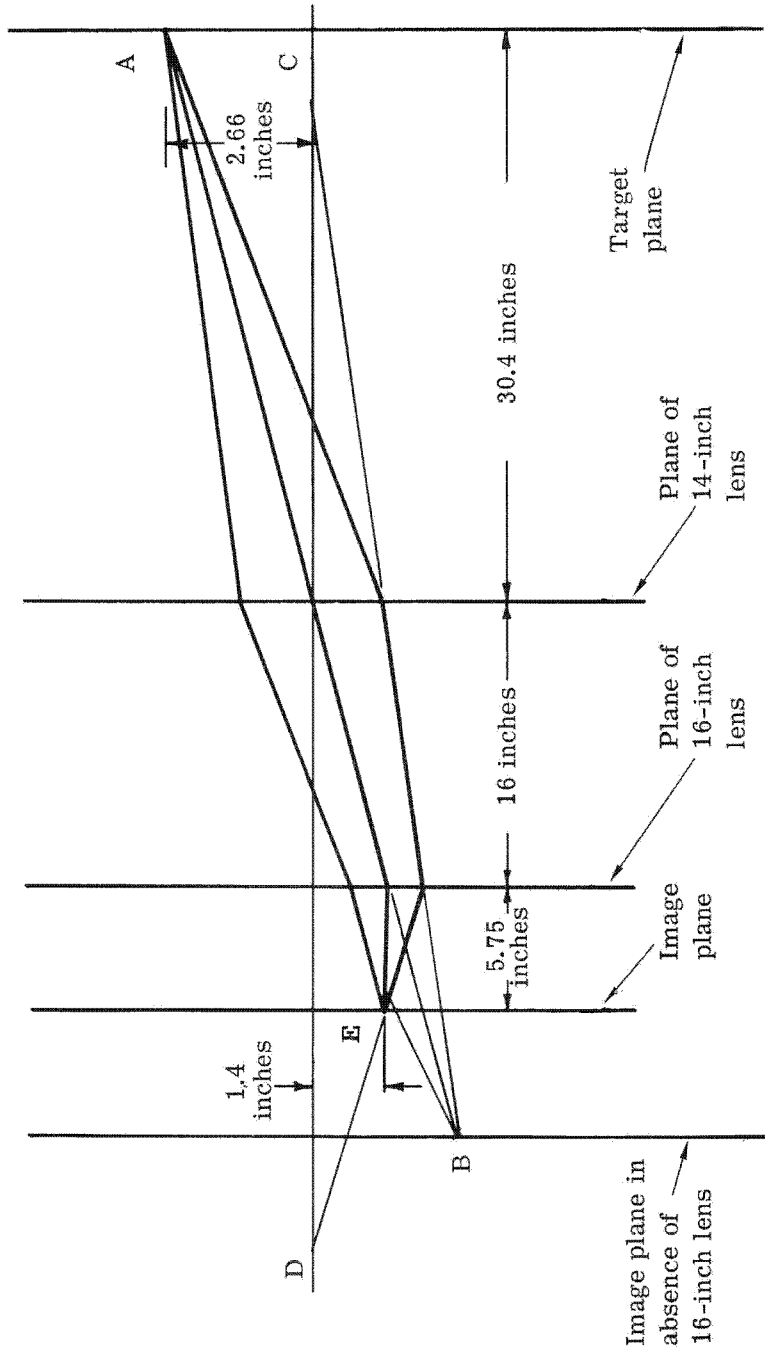


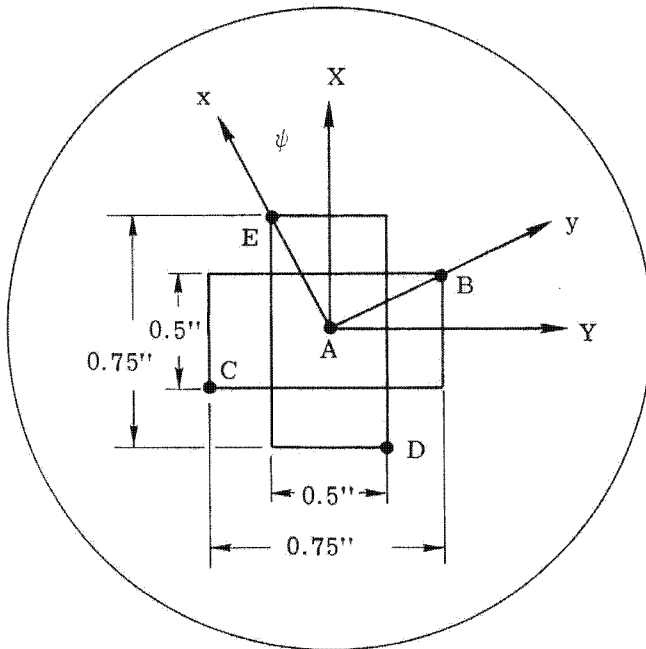
Fig. 4-2 — Target drive optical path

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BIF-059-0002-68



Velocities, milli-inches per second

Point	Actual		Target Drive	
	\dot{X}	\dot{Y}	\dot{X}	\dot{Y}
A	0	0	0	0
B	19	6	19	-13
C	-19	-6	-19	+13
D	-5	-4	13	19
E	5	4	-13	-19

Fig. 4-3 — Sensor format referenced to 2.8-inch diameter circle and table of velocities for roll: 40 degrees, and pitch: 30 degrees

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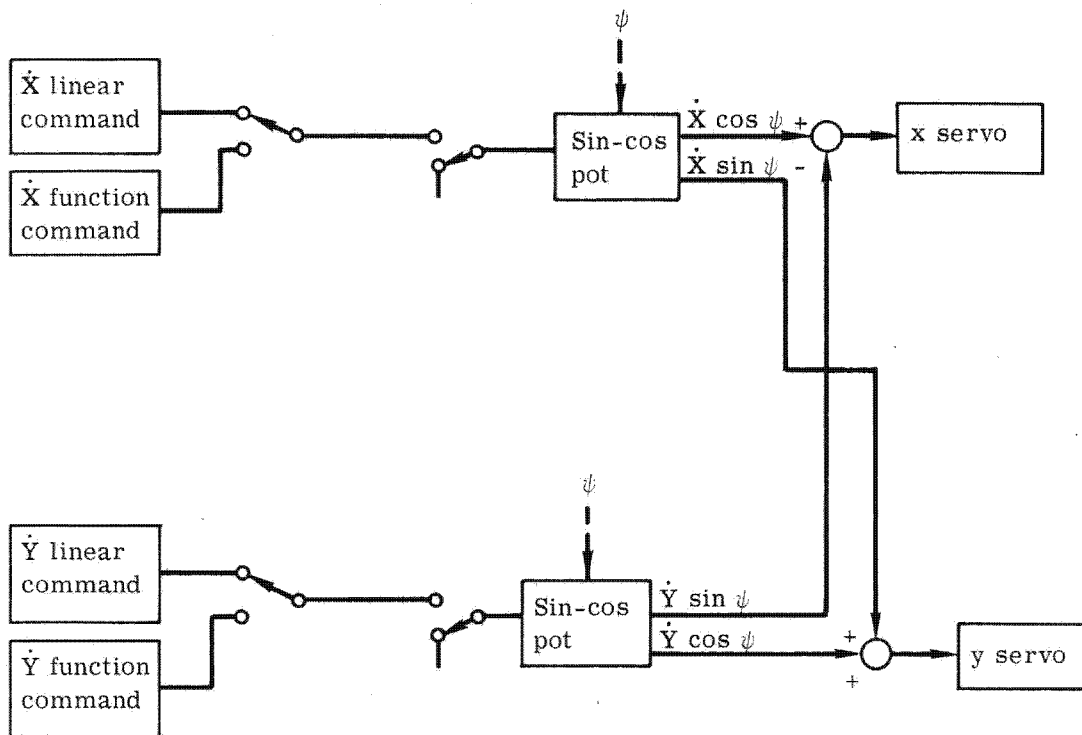


Fig. 4-4 — Target drive controls

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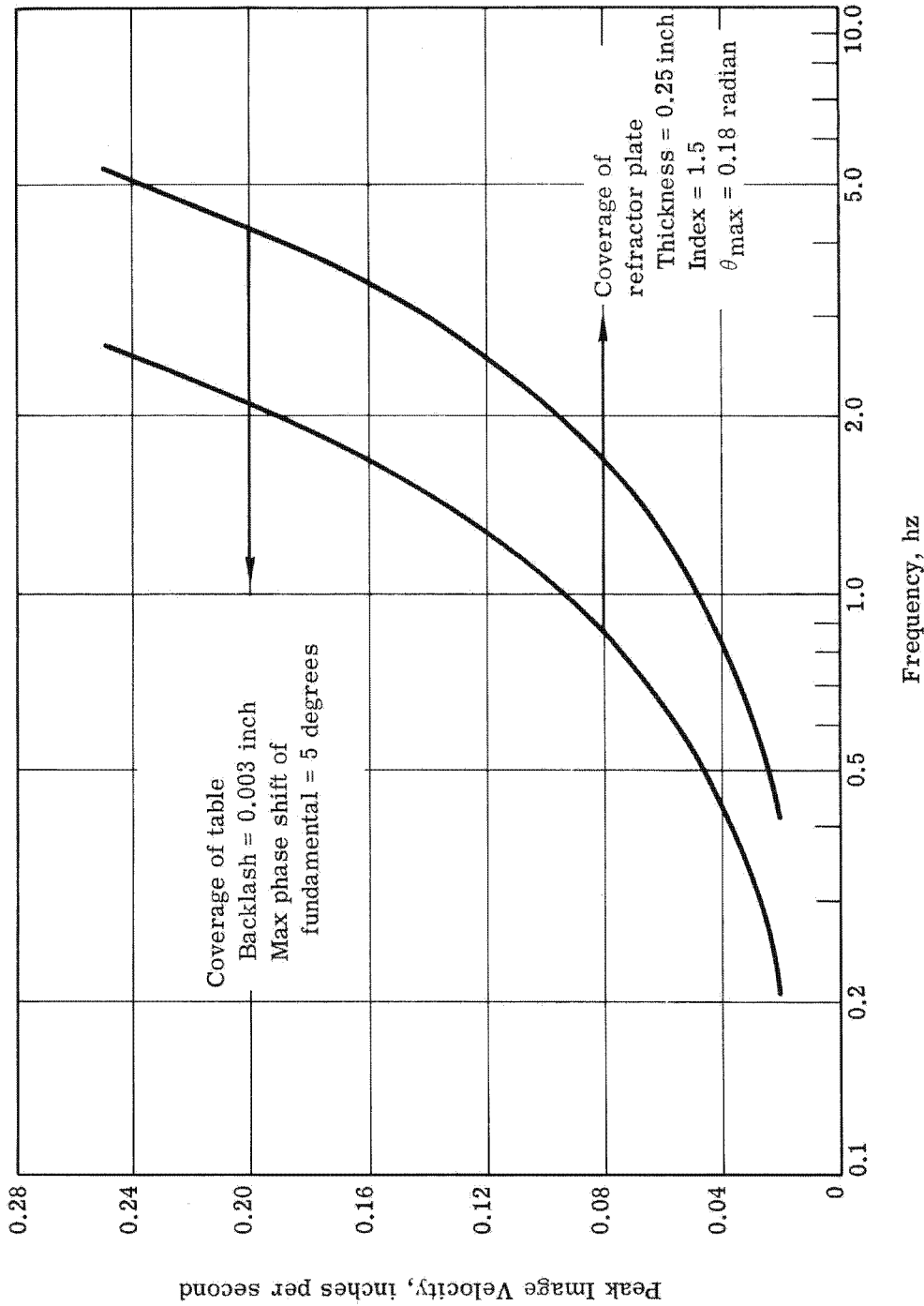


Fig. 4-5 — Useful ranges of table and refractor plate for frequency response tests

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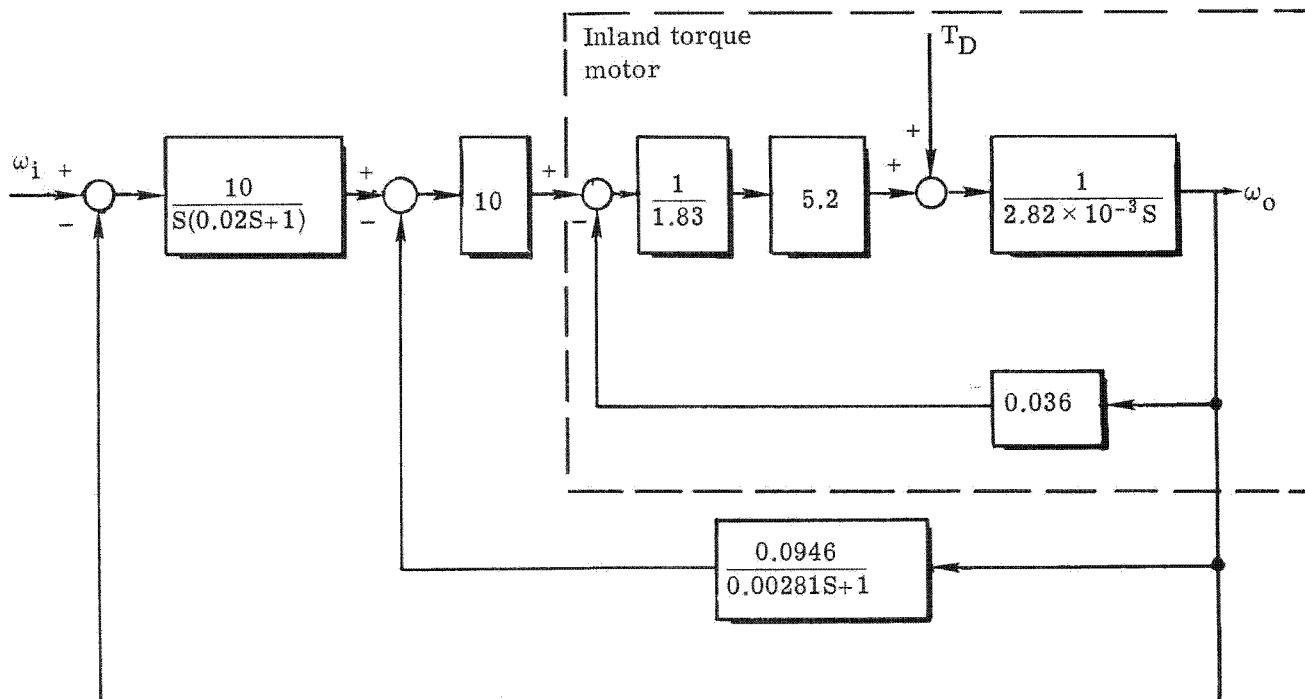


Fig. 4-6 — Target drive servo block diagram

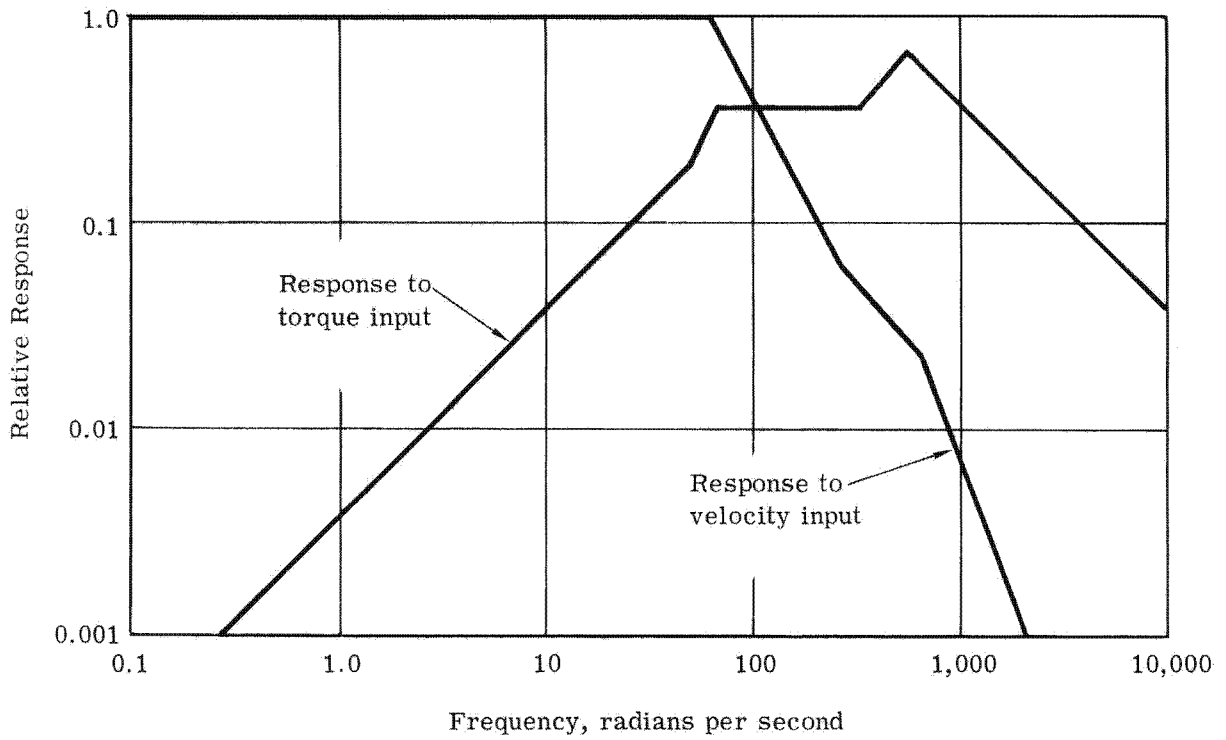
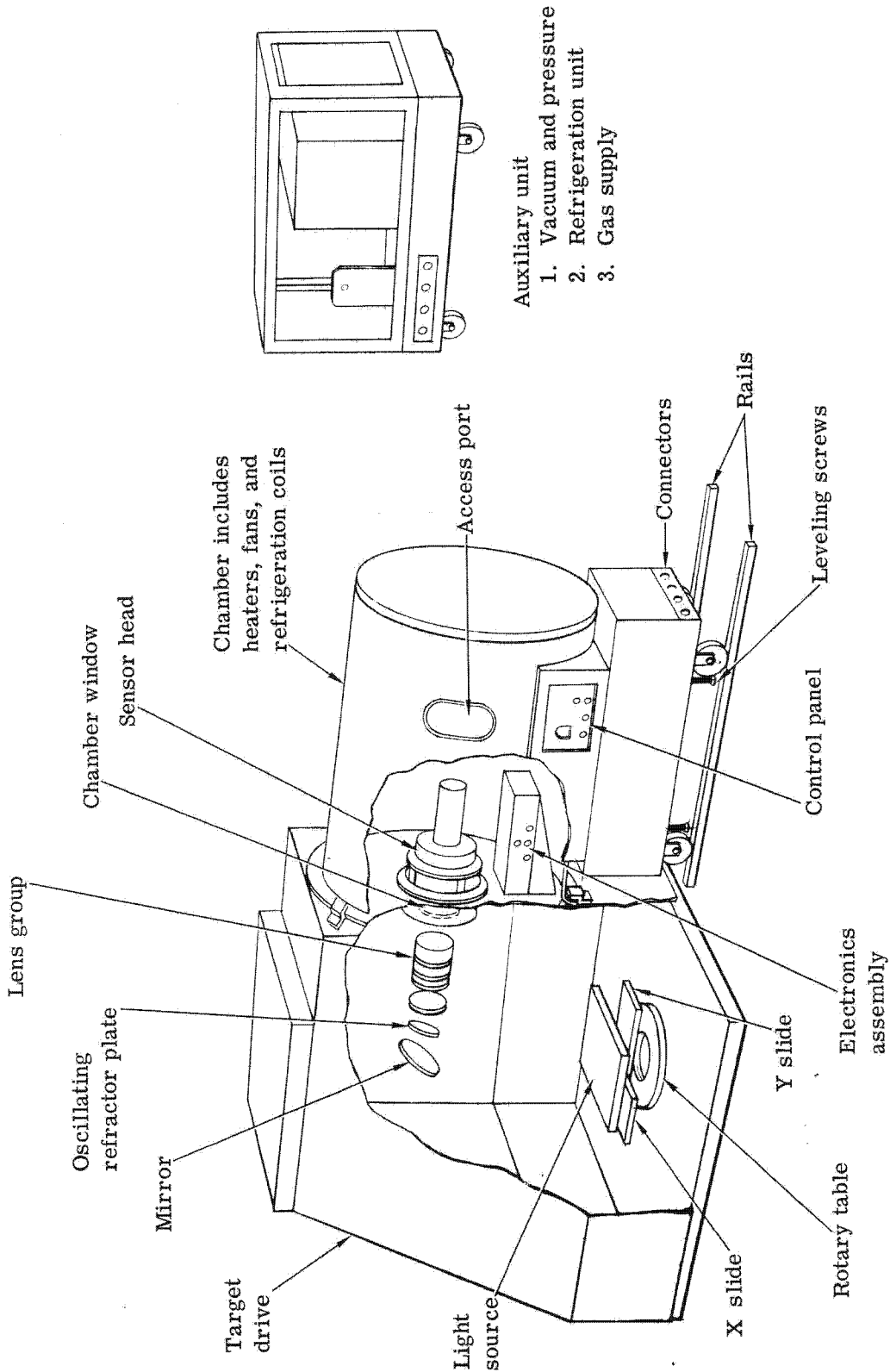


Fig. 4-7 — Closed loop frequency response

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BIF-059-0002-68



- Auxiliary unit
1. Vacuum and pressure
 2. Refrigeration unit
 3. Gas supply

Fig. 4-8 — Target source with environmental test chamber

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BIF-059-0002-68

5. DESIGN AND DEVELOPMENT PROGRAM

This section discusses the principal areas requiring further analysis and design before production release.

5.1 ELECTRONICS ASSEMBLY

5.1.1 Camera Control Electronics

As noted earlier, a standard camera has been used in the development program to date. Since the IVS uses the television system in a nonconventional manner, the camera was modified by Itek to provide additional required output signals. Examples of these additional outputs are field-splitting timing signals and a subtracted (or ac) video signal free of blanking levels. A developmental camera is now on order from Lear Siegler Corporation incorporating these and other special requirements by design rather than by adaptation. In addition to the above mentioned special circuits, this camera will include the following special features:

1. Power supply capability to provide regulated voltages required for the signal processor
2. Low-noise video preamplifier which optimizes the noise-bandwidth product as it affects sensor performance
3. Deletion of aperture corrector circuits
4. Use of approved/high reliability components
5. Packaging of electronics compatible with inclusion in the Itek electronics assembly
6. Image intensifier with automatic gain control.

5.1.2 Signal Processor Electronics

The effort on the signal processor electronics can be divided into two parts: redesign of present circuits, and the design of circuits to satisfy additional requirements.

The redesign effort will concentrate on improving performance and simplification of design. The prime area where improved performance is expected is the video amplifier and, in particular, the AGC of the video amplifier.

The objective in this review of the video amplifier will be to reduce the number of components and improve signal-to-noise ratio. All other portions of the processor are subject to scrutiny with the hope of simplification and consequently improving reliability and weight, size, and power requirements.

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Three areas of new design effort are required. The final test and monitoring subsystem must be designed. The cloud detector requirements must be studied to determine how cloud presence may best be detected. Once this has been determined, circuitry and systemology to measure cloud cover must be designed and developed. Finally, circuits to meet electrical interface requirements must be finalized.

5.2 SENSOR HEAD ASSEMBLY (see Fig. 3-10)

5.2.1 Camera Assembly

Helium permeation is a significant problem with the use of vidicon or intensifier tubes in the specified environment.

A standard vidicon tube without fiber optic face plates has been evaluated for performance in a helium environment. Results of this test led to the redundant window design utilized in the dual camera system.

Additional testing and evaluation is required to determine the permissible helium permeation into the intensifier tube. Results of this evaluation will be used as design criteria for the windows and relative volumes to be incorporated in the sensor head.

5.2.2 Optical System

The optical system will be closely modeled to the dual camera version. Areas requiring additional development effort are described below.

5.2.2.1 Spectral

The intensifier has a slightly different spectral characteristic than the previously used vidicon. Transmission and resolution spectral range must be re-evaluated and optimized for the intensifier.

5.2.2.2 Beam Splitter

Despite the high light gain characteristic of the intensifier, it is still desirable to provide as efficient a system as feasible. Studies will be made to investigate the relative transmission of a multilayer dichroic beam splitter versus partially silvered surfaces.

5.2.2.3 Resolution

The required MTF of the relay system must be re-evaluated for use with an IV system operating at higher light levels.

It may be possible to simplify the elements in that the vidicon modulation is greatly improved with the gain supplied by the intensifier. The simplification would result in a weight and fabrication cost reduction.

5.2.3 Modulator Assembly

During the development phase, modulator assembly improvement efforts will be directed toward the possibility of substituting more compact flexures for the present torsion wire arrangement. Also of prime concern will be the packaging of the tachometer-torquer unit for optimum shielding effectiveness against the 15-cps fields.

Breadboarding and testing will be performed in order to optimize both areas.

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BIF-059-0002-68

5.2.4 Structure

In order to optimize the proposed IVS design, it is necessary that both analytical and experimental techniques be employed; these approaches will be pursued concurrently. Dynamic and shock spectrum response, in most cases, are the limiting criteria for the major structural elements; a major effort will be placed on the evaluation of these criteria. Stress distortion analyses will also be performed to evaluate optical degradation resulting from the thermal environment.

The analytical development program will proceed as follows:

1. Perform a dynamic analysis of the proposed design to obtain the following data:
 - a. Random acceleration response at critical points in the structure
 - b. Transmissibility
 - c. Natural frequencies
 - d. Mode shapes.
2. Based on the results of the dynamic iteration, the following analyses or determinations will be performed:
 - a. Fragility limits of attached equipment such as the vidicon, camera, prisms, and motors will be investigated for excessive g loading.
 - b. Induced stresses will be calculated.
 - c. Component natural frequencies will be investigated for resonances.
3. The analytical model will now be modified in areas that need improvements and another analytical iteration will be performed.

This analytical procedure will be iterated to optimize the structure.

Several computer programs are available at Itek for both dynamic and static analysis. Those most applicable to the analysis of the proposed IVS structure are listed below:

1. FORCED VIBRATION, RANDOM AND SINUSOIDAL, developed by the Avco Corporation, Wilmington, Massachusetts. This program can solve the sinusoidal or random response of linear mechanical systems with a maximum of 40 degrees of freedom. The random excitation is assumed to have stationary and ergodic properties; if the excitation is a Gaussian random process, then the response will be Gaussian.
2. SABOR III, developed by the Aeroelastic and Structures Research Laboratory of MIT, Cambridge, Massachusetts, a program for the matrix-displacement finite-element method of analysis of thin shells of revolution subjected to asymmetric or axisymmetric loading.
3. FAMOUS (Frequencies and Modes of Undamped Structures) developed by the Aeroelastic and Structures Research Laboratory of MIT, Cambridge, Massachusetts.
4. FRAN (Framed Structural Analysis Program) developed by IBM. A generalized three-dimensional approach for a complete analysis of all types of complex structures with rigid, semirigid, and free connections subjected to various loading conditions.

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6. SELF TEST

This section describes a method of introducing a velocity controlled stimulus to the IVS for testing each channel (x and y). The system will provide a net velocity vector orientated to a target at 45 degrees to the sensing axes. The target will be projected at a 1:10 scale factor into the beam splitter/prism assembly and imaged at the same plane as the aerial image. (See Fig. 6-1.)

6.1 OPTICS

The projection system will consist of a small source, a reflector, a target transparency, projection lens and folding mirrors as required for packaging (see Fig. 6-2). To prevent vignetting within the sensor relay system, it is planned to provide a telecentric image of the stimulus target. This might be accomplished by locating an additional lens element a focal length from the exit pupil of the projection lens. Another approach would be to use suitable aperture stops. Additional effort will be required to investigate the vignetting problems without a telecentric image and optimize the optics of a telecentric system if it is required.

6.2 TARGET DRIVE

As the required accuracy of the input velocity is not great, a sophisticated target drive is not required. The proposed solution is to use an open loop gearhead servo motor with a linkage to convert rotating motion into nearly sinusoidal. The system provides velocity half cycles of ± 0.050 inch per second maximum at a frequency of 1/4 hz. (See Fig. 6-3.)

Alternate frequencies and velocities could be supplied by varying the motor rotational rate. Another scheme is the use of a solenoid supplied with triangular pulses and with its armature axially spring restrained. Further investigation would be required with this approach to evaluate the potential oscillation.

6.3 SUMMARY

The availability of a beam splitter in the main optical path provides a convenient means of introducing a second stimulus source for self testing the IVS. The self test system is quite flexible and more precise velocity or alternate profiles and amplitude can be supplied if required.

It is estimated that the additional weight required for the system is one pound.

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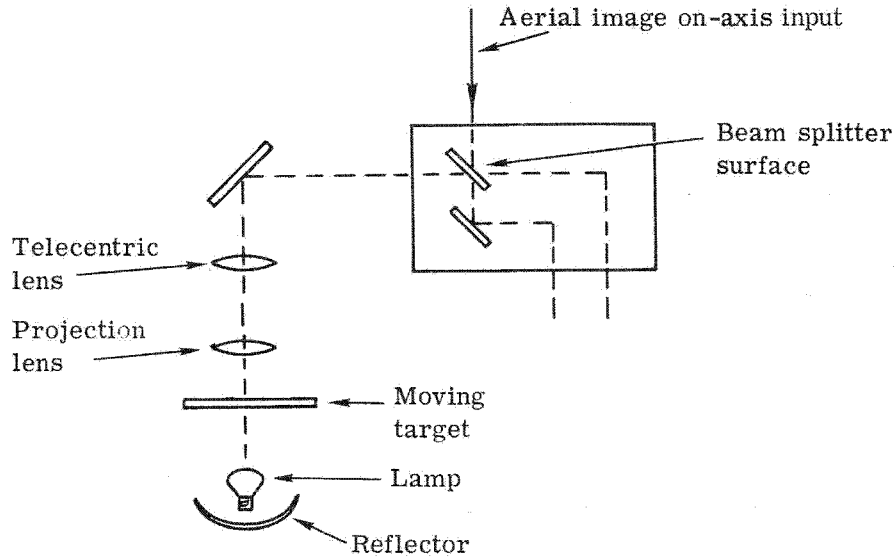


Fig. 6-1 — Schematic arrangement of self test system

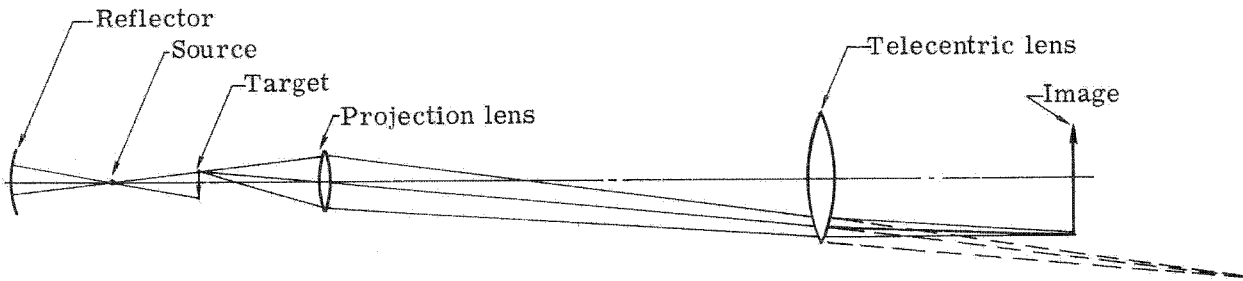


Fig. 6-2 — Projection system

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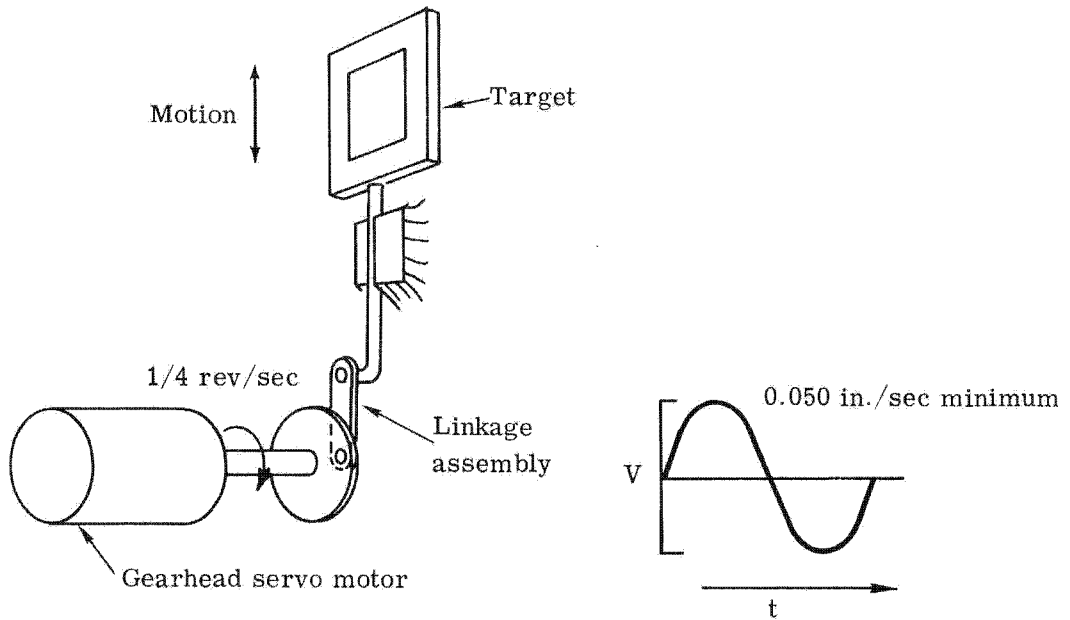


Fig. 6-3 — Target drive

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