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INTRODUCTION TO THE DORIAN IVS SYSTEM

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INTRODUCTION TO THE DORIAN IVS SYSTEM

Intrinsic to the concept of the Dorian system is the need for precision image velocity compensation in order to maximize the resolution performance of the optical system.

Fundamentally, the problem is depicted in Figure 1, which shows a plot of ground resolution versus focal length. As the focal length is increased, the effect of the film graininess is diminished because of the relative size difference between the lens point spread function and the film grains. However, the light density in the image plane decreases inversely as the (f no.)^2, and thus exposure time must be increased proportionally. If an image velocity rate exists, the smear then is the product of the rate times the exposure time. Therefore, in order to maximize the resolution, the longest focal length was picked within the practical constraints of the manageable image velocity.

Initially, the allowable rates selected for image velocity were determined as those feasible with manned tracking and were set accordingly at a value of [redacted] In addition to this tracking error, there are additional contributors in the form of vibration and servo drive system noise errors. These terms, as indicated in Figure 2, added to a total budget of [redacted] (rss).

During the manned development (because of concern with the political sensitivity of manned overflight and cost effective reasons), it was decided that the Dorian capability should also be available in an unmanned configuration. At this point, studies of potential devices to perform the manned tracking function were undertaken, and the image velocity sensors now under development were identified.

Three different concepts are being pursued by Itek, Goodyear, and Hycon. The Itek device is basically a vidicon scanning device with mechanically introduced modulation of the image to provide a drive error signal for nulling. The Goodyear device involves the use of a correlation tube which electronically performs a mathematical correlation of the present scene with a formerly stored scene, and again through suitable modulation, provides an error signal for the servo drive. The third device is the Hycon image velocity sensor which utilizes a reticle wheel to modulate both a reference light and the scene, and by sensing phase changes provides an error signal proportional to the scene motion. A somewhat more complete description of the operation of these devices is presented in Appendix A.

In developing these devices, the requirements were specified in order to assure proper operation. The rate accuracy requirement was chosen at [redacted] in that it was shown to be feasible by early simulation and was sufficiently close to the manned tracking value to be compatible with the Dorian optical system optimization. The response times, in terms of slew and settle, were principally set by the frequency response of the basic instruments.

The initial capture rate of [redacted]/sec was established as a feasible rate using projected navigational accuracies, target location, and elevation errors. These data are given in Figure 3.

In addition to the rate and slew time requirements, an important specification parameter is the scene characteristics for which the sensor must work. A complete "scientific" description of typical scene characteristics is not currently available for sensor design. However, the description of the brightness variations in typical scenes as a function of spatial frequency has been addressed. This description provides an estimate of the scene brightness modulation present over which a given sensor must be capable of operation. These data, combined with the sensor sensitivity, provide a measure of the amount of signal available over a given noise threshold level (i.e., signal-to-noise ratio predictions for signal

While the contrast of the scene is used generally to describe, at least in a qualitative sense, the image quality expected of a photographic system, it is unsuitable for specifying sensor performance because it does not describe the instantaneous changes in brightness as the sensor scans across the scene. Therefore, in order to describe a meaningful set of parameters, the Wiener spectrum approach was used. That is to say, the statistical properties achieved in scanning the scene are used to describe the scene brightness characteristics. The Gambit and Gambit^3 systems use a focus sensor which is dependent on scene modulation. Assuming the Dorian target areas are of the same general type, data from this sensor should be indicative of the requirements for operation of the IVS on the Dorian system. In developing the scene characteristic specifications for Dorian, large amounts of G^3 focus data were used to calculate the Wiener spectrum brightness properties of the scenes, and the specifications were set for the Dorian system which would essentially capture 95 percent or better of the conditions that occurred on these flights.

The additional requirements of the sensor, such as its specific time constants and frequency responses, are related to the properties of the tracking mirror drive loop and are not fundamental requirements in the sense of mission-oriented operations. More specific explanation of the specification development is given in Appendix B.

In order to evaluate the performance of the sensors, a test program has been developed which ultimately will allow the selection of one of these sensors for incorporation in the Dorian system. The initial phase of this test program was a series of bench tests and tests run on a simulator which presented the scene to the IVS in such a way that the velocity at the center of the scene was zero, and major additional effort in order to resolve them. They include the dynamic null problem which is characterized by fluctuating erreneous IVS outputs as the instrument traverses stereo angles from fore to aft through nadir. Generally, the instrument performed satisfactorily around nadir to angles of 10-15^{o} off nadir, but developed major out-of-spec vacillations outside of this area. This problem is associated with the fact that the spatial frequency content in the scene is not uniformly distributed; as the stereo and obliquity angles change, the scene content changes, and the average velocity at the optical axis changes also. Another way of stating the problem is that the centroid of zero velocity drifts out of tolerance about the optical axis.

The second major problem is that the instruments generally were too insensitive and could not operate down to low enough levels of scene modulation. An additional problem peculiar to the Goodyear instrument was a drift in transient rate errors which may be contributable at least in part to the test conditions. The Itek instrument, while exhibiting little dynamic null type problems, had the additional problems of scene and error dependent nonlinear gains, scene dependent bias, and large transport lag associated with the vicidon frame rate time. The test program is described in Appendix C.

The need for more instrument sensitivity primarily is related to the Goodyear and Itek instruments and has been partially solved by increasing the amount of light available to the IVS from the main optical system. In addition, improvements in the tubes appear to make operation within specification feasible.

There are several schemes applicable for alleviating or solving the dynamic null problem such as aperture shading, aperture control, and electronic limiting, all of which show a reasonable degree of promise. If the solutions to the dynamic null problem fail to solve it completely, the other alternative would be at extreme stereo and obliquity angles to relax the specification tracking requirements on tracking rate. Obviously, this is undesirable in that it lessens the resolution of the resulting product, although the extent may be quite modest.

The results of the tests show a capability, at this time demonstrated by the Hycon instrument only, to work over most of the modulation light level specification, with the exception of cases of very low modulation at high average light level. In general, this case can exist if the scene consists of a snowfield with a small portion of it containing a target area of buildings or other high modulation content items. Therefore, the question arises as to what the system operation should be under these conditions. One approach is to use the rate data obtained from previous targets, and from it compute the proper rate for the upcoming target, and if the IVS fails to provide rate data as good as the computed data, the computed data alone would be used. While the present navigation and control system has not been required to perform better than the [redacted]/sec capture rate of the IVS or flight crew, by using various software techniques for computing the bias, the rate achievable can be the order of [redacted]. For comparison, the [redacted] rate will result in Dorian system performance comparable to that of the G^3 system. Thus, for the vast majority of targets, the IVS would provide Dorian quality imagery and for those few where insufficient modulation exists with high average light level, G^3 level pictures could be obtained for the unmanned system, and in the manned case, Dorian quality can still be achieved through manual operation.

An associated problem with the IVS sensor is the case where within the 3,000 feet or so field of view at the ground level of the sensor, part of the scene is obscured by a cloud edge. Here, the extent of the problem depends on the

FOCAL LENGTH CONSIDERATIONS

[redacted]

Figure 1

magnitude of the cloud modulation and the altitude difference of cloud to target, which will contribute to the total sensor error. Therefore, the question arises as to the desired discrimination ability of the IVS against cloud data.

In the early unmanned system discussions, it was proposed to operate the system on the IVS value if it was within the updated computed value and if not, to use the computed value, thus insuring picture quality of useful intelligence value. However, if cloud discrimination could be implemented, some additional number of pictures could be obtained approaching Dorian quality in the unmanned case. An additional factor in this concept is the fact that while the cloud edge is discriminated against, the centroid of the remaining scene velocity is no longer centered on the optical axis. This will result in errors, because the camera across-the-format device is built to take out differential format velocity errors assuming the center of the field is corrected. When the centroid of the tracked velocity point is not in the center of the field, significant errors will be introduced.

The present plan is to specify the IVS performance excluding clouds from the field of view and implement further studies in terms of implementation approaches and error contributions. Upon conclusion of these studies, the capability will either be included in the Dorian system or recommended for future advanced technology effort.

In conclusion then, the specifications for the IVS have been established based on manned system optimization data, operating experience on the G system, and the intrinsic properties of the servo drive system in which the sensor has to operate. Performance to date indicates that while problems have been identified, reasonable solutions are in work that will allow operation within specification over most of the desired operating regime. By utilization of the calculated rate command for the very infrequent cases of scene conditions where the sensor mal-

LOS RATE ERROR BUDGETS

AUTOMATIC (2σ)		MANNED (2σ)	
IVS ERROR	[redacted]	CREW ERRORS	[redacted]
VIBRATION		VIBRATION	
SERVO SYSTEM		SERVO SYSTEM	
TOTAL		TOTAL	

FIGURE 2

BASELINE OPEN-LOOP LOS RATE ERROR

		RATE ACCURAC μ rad/sec (o.95p
o SERVO PERFORMANCE		357
/ LOW FREQUENCY ERRORS (BIAS)	355	
/ HIGH FREQUENCY ERRORS		
o SERVO NOISE	26	
o STRUCTURAL VIBRATION	26	
o COMMAND ACCURACY		[redacted]
o EPHEMERIS ACCURACY (150 FT ALTITUDE ACCY.)		
o TARGET LOCATION ACCURACY (100 FT ALTITUDE ACCY.)		
RSS TOTAL		[redacted]
SPECIFICATION		

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Figure 3

APPENDIX A

IVS DESCRIPTIONS

Goodyear

1. The Goodyear IVS is functionally a spatial (two-dimensional) correlation detector. The system seeks to null the rate error by searching for a maximum of the spatial correlation function and tracking with whatever rate correction is necessary to maintain maximum correlation. The sensor consists of the "Correlatron" tube and an appropriate null-seeking feedback control loop. To perform the spatial correlation operation requires a series of time-related steps beginning with the "write" mode, in which the scene is initially stored on the intermediate storage grid or screen of the Correlatron tube. This stored scene will serve as a reference throughout the remainder of the cycle. During the "read" mode, the actual input scene is imaged on another screen placed in front of the storage plane, producing an equivalent electron beam replica of the scene. (See Fig. A-1.) The electron replica continues on to intersect the storage plane, and an output signal results which is a measure of the correlation, or agreement, between the stored and projected images. This signal is maximum when the two images are identical in every detail. The electron replica, while in transit to the storage plane, may be deflected in two (independent) orthogonal axes by magnetic field-producing coils.

At any time after initial storage, with non-zero input image motion, the actual scene will be displaced from the stored scene in the direction and distance described by the velocity vector times the elapsed time, resulting in a less than maximum correlation result. The field coils are energized to bring the actual scene to coincide, as much as possible, with the stored scene, and the degree of drive necessary to do this is a measure of the distance transversed, or equivalently of the scene rate. The feedback loop acts to maintain the displaced electron replica in coincidence with the stored image, giving analog data on the rate in each orthogonal axis, until the stereo angle change becomes too great. A block diagram of the sensor processing configuration is presented in Fig. A-2. At this time an "erase" mode is initiated and the entire cycle is repeated, with a new stored image and tracking acqui-

Itek

2. The Itek IVS depends for its operation upon the integration effect on a scene moved across a vidicon face and the fact that the high frequency content of a random signal is diminished in relation to the amount of "smear" of the signal. Figures A-3, A-4 and A-5 present a block diagram, pictorial schematic and summary of the operating principles of the Itek sensor. Consider the sensor with zero input rate. The input scene is imaged on the (fixed) vidicon tube face and by means of a nutator is swept sinusoidally across the tube face at a frequency equal to one-half the frame rate and in a direction parallel to the scan lines. (The sensor is capable of operation in both axes due to an arrangement of mirrors which transmit a portion of the input scene rotated through 90 degrees to the vidicon face. The complication is not necessary to an understanding of the basic operating principles of the device and will be ignored at this point in the discussion.)

For any given scan line, the degree of high-frequency attenuation in the output signal, as that line is scanned, is dependent upon the amount of smear in the image along the line. This is a well-known result and is easily derived with an equivalent smear or dispersion transfer function. The amount of smear for the line is related to the distance along the line that the image was swept by the nutator since the line was last scanned. If the image displacement function (due to nutation alone) is A sin wt, then the line scanned at times $0, \frac{\pi}{\omega}, \frac{2\pi}{\omega}, \frac{3\pi}{\omega}$ ... will exhibit smear porportional to A. On the other hand, the line scanned at $\frac{\pi}{2\omega}, \frac{3\pi}{2\omega}$ ... will exhibit smear proportional to 2A, and the corresponding signal will contain less high frequency energy. If the high frequency energy is isolated and filtered, the result is a second harmonic term (2ω) with no input rate. If now a linear input rate is superimposed upon the nutation oscillation, the smear characteristic will be different for positive and negative excursions of the image, and therefore the output signal will contain a fundamental frequency components more or less proportional to the input rate. Further, the phase of the fundamental indicates the direction of the input rate. The output signals are of course dependent upon light level, and the Itek design intends to suppress this dependence by using the second harmonic term to drive an AGC network. This approach assumes the second harmonic is affected solely by light level, which is in fact not true, but becomes a better approximation as null rate error is approached.

Hycon

3. The Hycon IVS is essentially a phase-lock loop where the output signal (rate error) is derived from the amount of error signal required to drive two pulse trains of slightly different frequencies into coincidence. Figures A-6 and A-7 present a pictorial schematic and a block diagram of the Hycon sensor. One of the pulse trains is obtained as the photodetector output of a stationary (with respect to the sensor) light source chopped by an intervening rotating slotted wheel. This is the reference signal and has a basic frequency equal to the number of slots in the wheel times the revolution frequency. The other pulse train is the output of another photodetector located at a fixed angle from the reference detector. The signal reaching this detector through the rotating slotted wheel is the focused image of the ground plane. At zero ground (input) rate, the basic frequency of this signal is the same as that of the reference, and comparison between them results in zero error signal. However, it is clear that if the image moves tangentially, the basic frequency will be altered by an amount proportional to the velocity. If the image moves in the direction of rotation, the frequency will be reduced by this amount; if it moves against the rotation, it will be so increased. Upon comparison of the two pulse trains, the phase-lock loop will attempt to restore coincidence, and the resulting feedback error signal is a measure of both rate error magnitude and direction. Amoung the advantages of such a system are simplicity in structure and the relative ease with which the system can be analyzed for error analysis and possible performance improvements.

FIG A-1 GOODYEAR CORRELATRON PRINCIPLE OF OPERATION

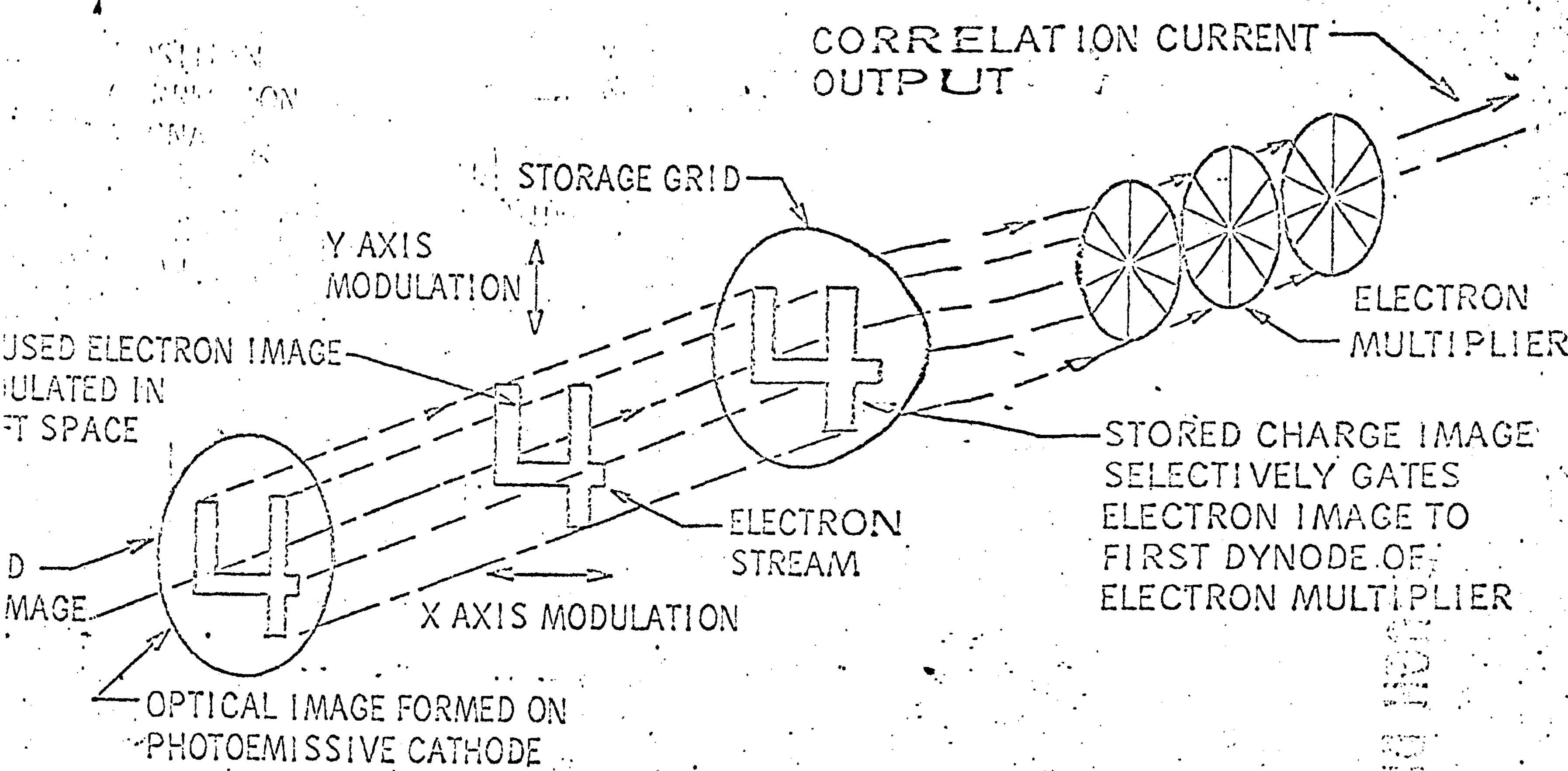

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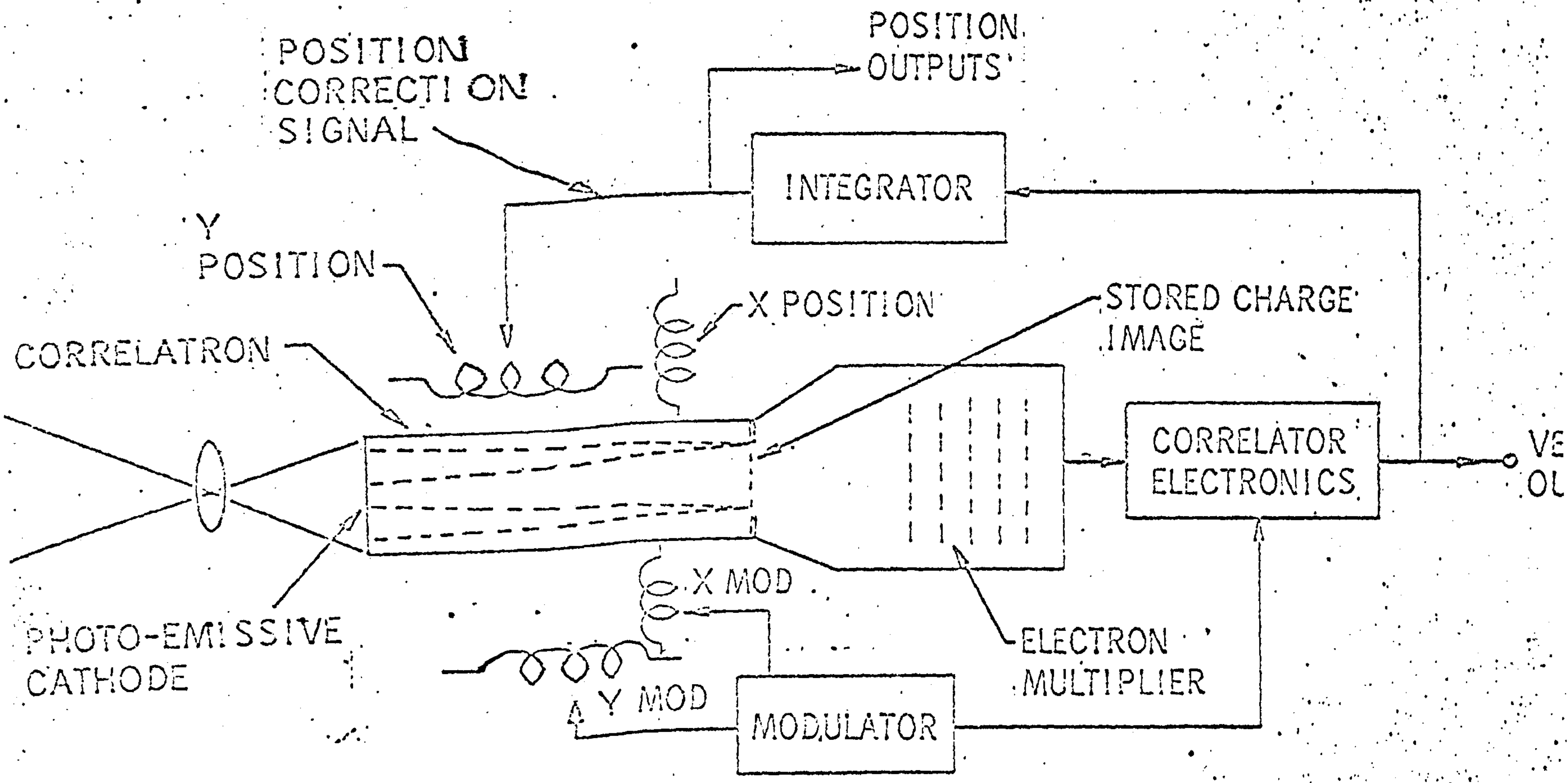
FIG A-2 — GOODYEAR SIMPLIFIED BLOCK DIAGRAM



MODES:

1. WRITE
2. READ
3. ERASE

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Fig 4.3 - ITEK IVS SENSOR HEAD

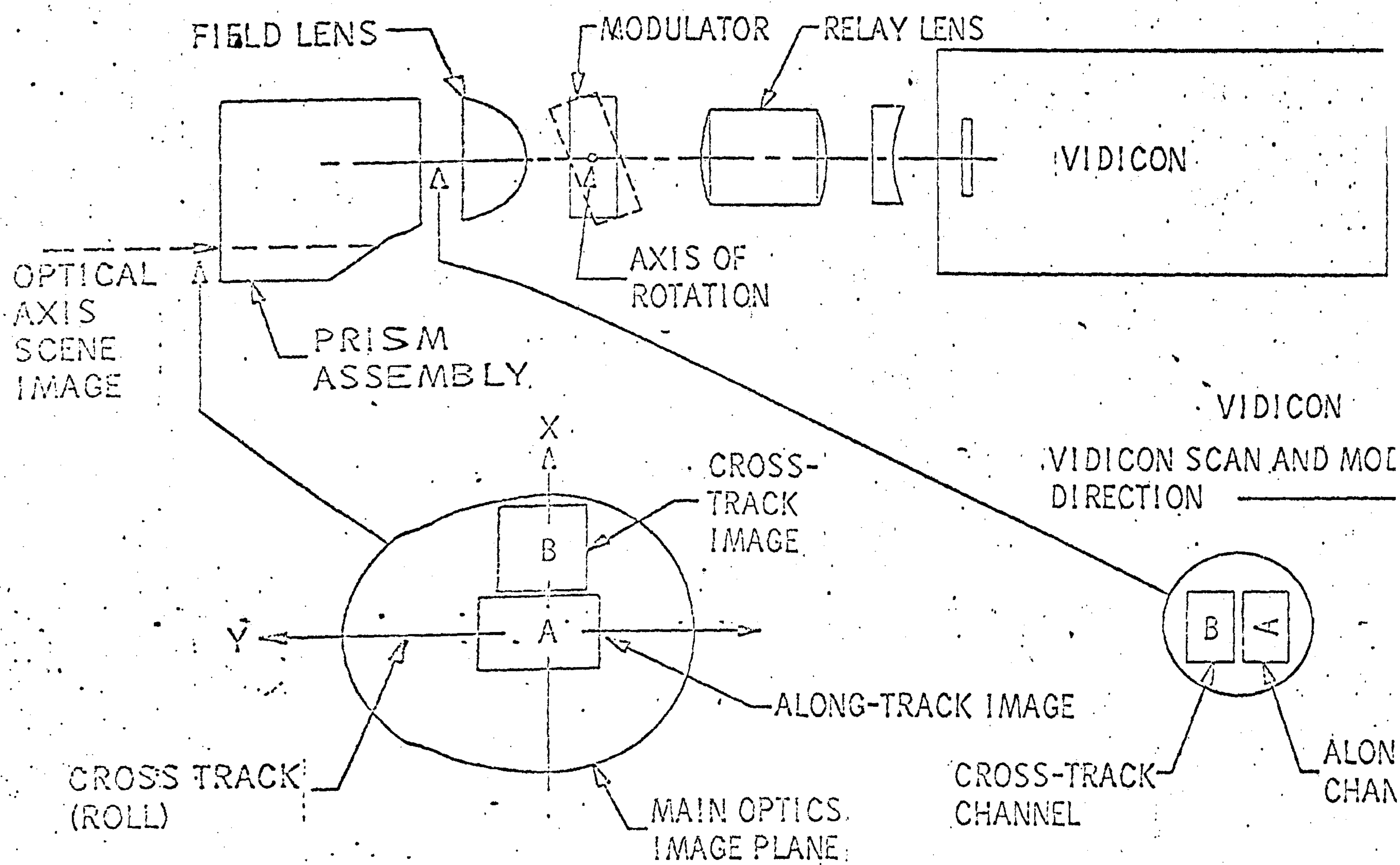

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FIG. A-4 ITEK SINGLE-AXIS SENSOR CONCEPT

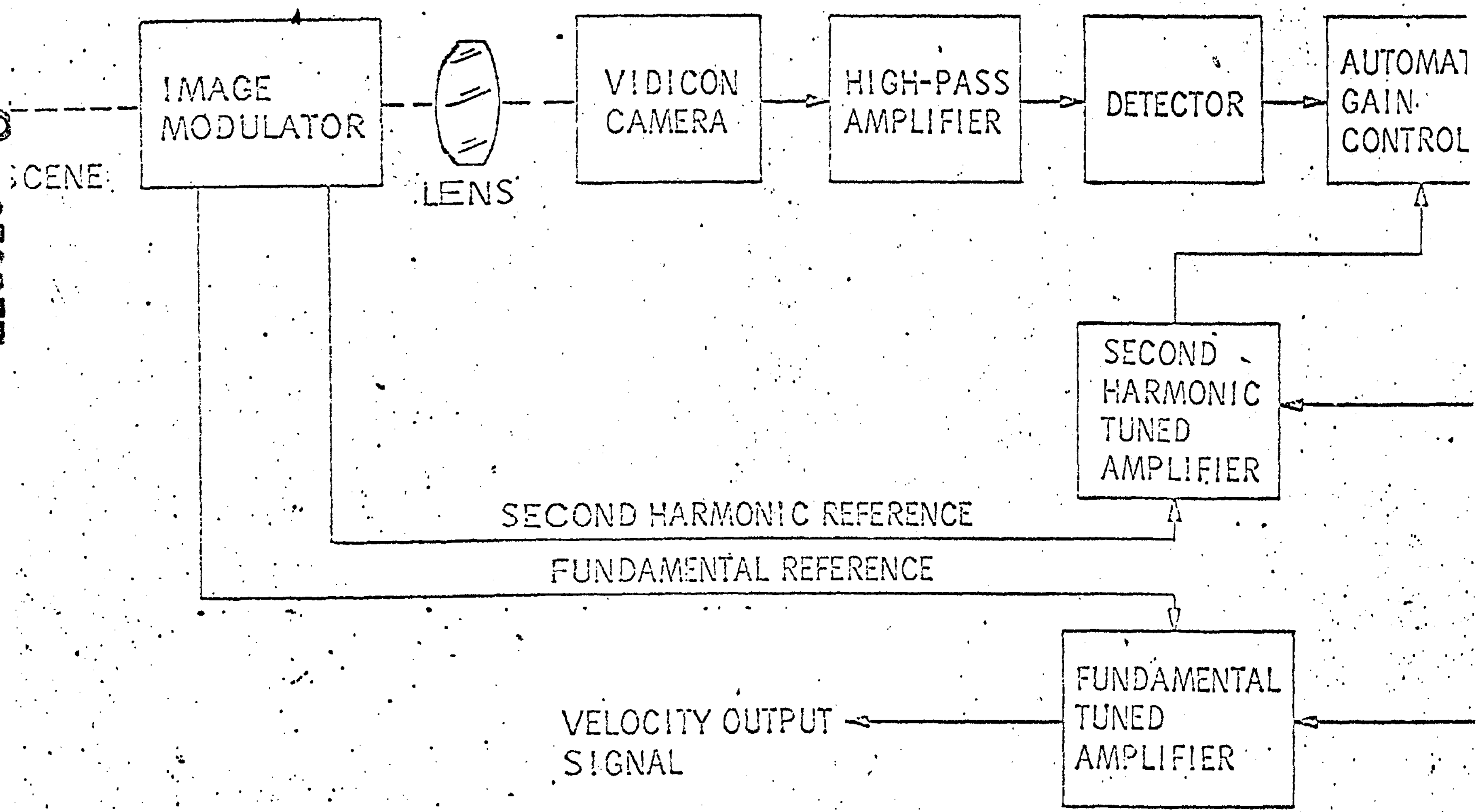

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FIG. ~~A~~-5 ITEK IVS SIGNAL PROCESSING

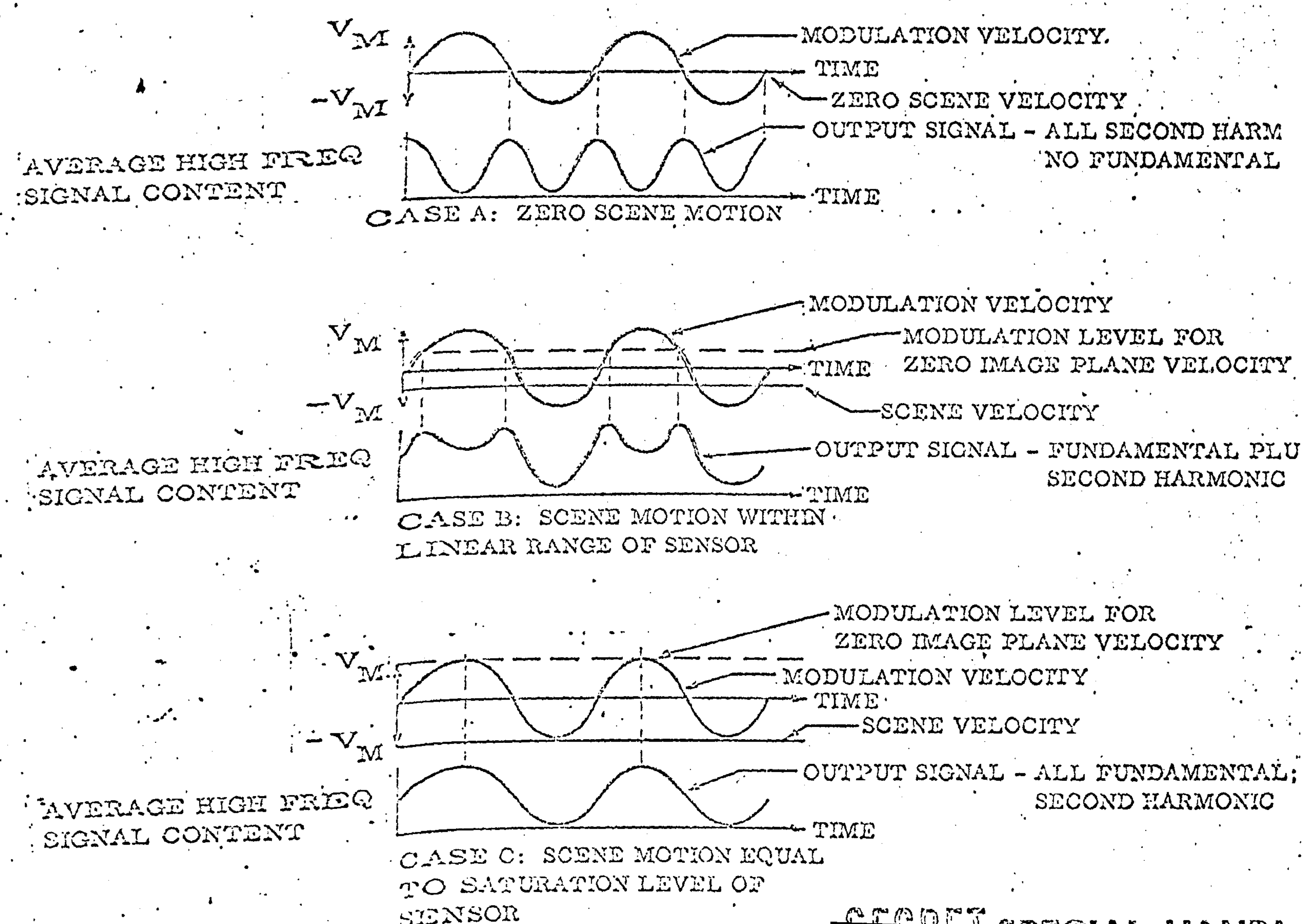

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FIG. A-6

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HYCON SCANNER HEAD

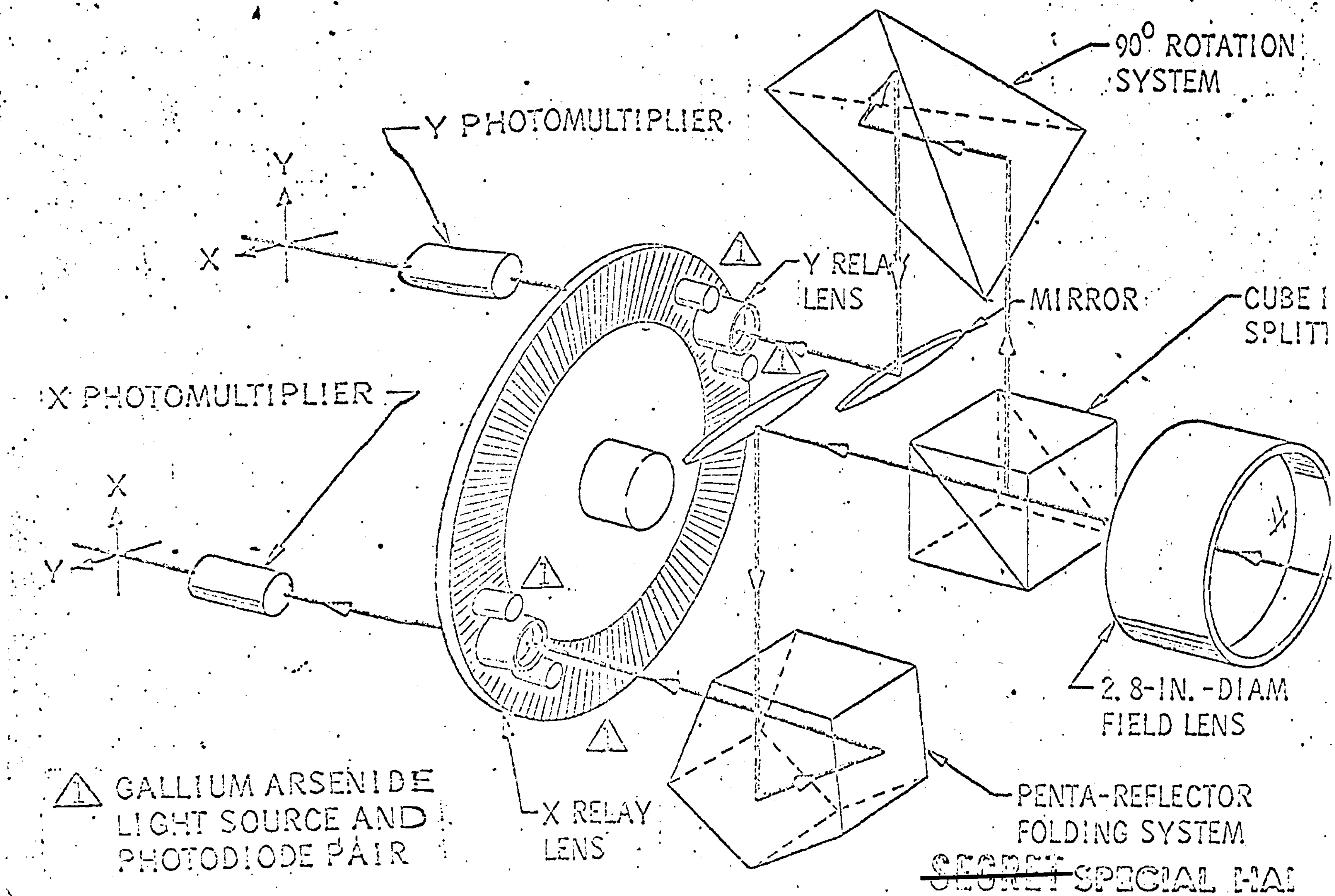

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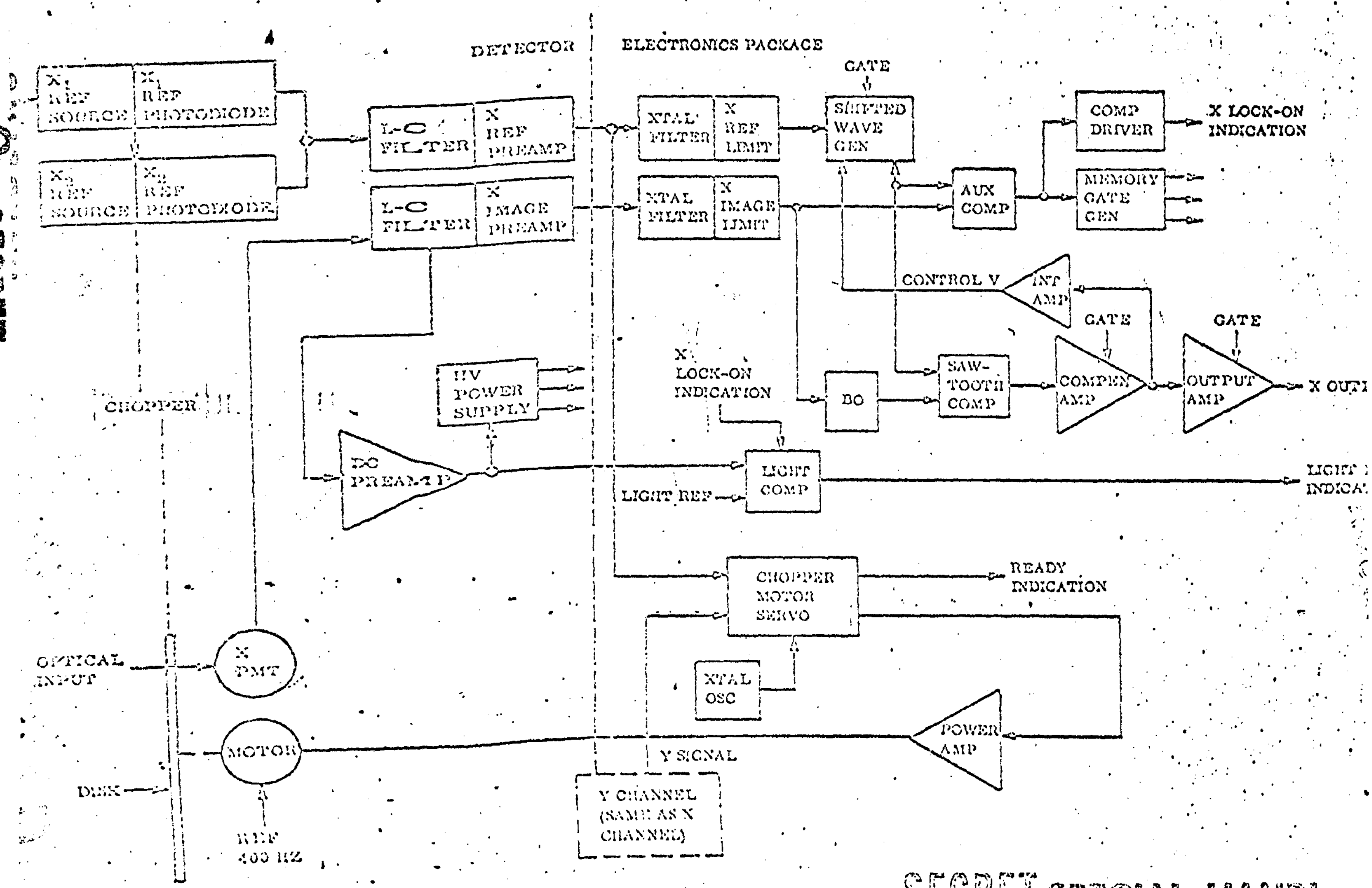
FIG A-7 HYCON SYSTEM BLOCK DIAGRAM



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APPENDIX B

IVS SPECIFICATION

A. The IVS specification lists the performance requirements necessary to meet the overall tracking mirror velocity error allocation. The sensor performance requirements have been developed as a part of the overall system error analysis for the GE AVE. The dynamic performance (frequency response), saturation, scale factor, noise, and threshold are requirements which are compatible with the tracking mirror settling time requirement and velocity error allocation. Table B-1 presents a summary of the critical IVS requirements, origin of requirement, and the effect of the requirement on other parameters.

The operating light level and image contrast requirements as stated in the specification have been derived from data originally used in the G^3 focus sensor design. The use of these data provides a definition of input light level modulation and average scene brightness. The specification provides a definition of scene brightness characteristics in terms of a two-dimensional Wiener spectrum.*

The Wiener spectrum data is used as being more meaningful than previous definitions of contrast ratio in that it is (1) less subject to different interpretations, (2) based on a logical description of scene content (spatial frequency), (3) relatable to contrast ratio if a spatial frequency bandwidth is defined, and (4) includes the factors the produce brightness variation with differing scene content.

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*A useful method of describing a random image process is by use of its mean-square amplitude spectrum. This statistic is equivalent to the autocorrelation function and gives another measure of the separation at which fluctuations of the process may be expected in the plane of definition. The mean-square amplitude spectrum is usually referred to as a Wiener spectrum. It is a two-dimensional analog of the noise power density spectrum used to describe the one-dimensional noise processes in purely electronic fluctuations. The generic name, Wiener spectrum, is commonly used to eliminate the situation of a power spectrum having the dimensions of $(\text{power})^2$ per unit bandwidth (i.e., scenes repre-

The term contrast ratio, which is used widely, does not provide an adequate definition of input scene brightness characteristics for a scene dependent sensor. Since all known scene dependent sensor mechanizations are spatial filters or possess some form of spatial filtering, the definition of contrast ratio must include a qualification with regard to a range of spatial frequencies. If we assume the total scene brightness consists of an average or "DC" brightness term and an "AC" or brightness variation, the scene brightness can be expressed as:

$$B = B_o \pm \sigma$$

Then an expression of contrast ratio would be of the form:

$$C = \frac{B_o - \sigma}{B_o + \sigma}$$

It is obvious that the "AC" brightness term, σ, infers an RMS brightness which can be related to an integral of brightness variation per unit bandwidth over a selected bandwidth of spatial frequencies. Thus, to adequately use the term contrast ratio when defining typical scene characteristics, a spatial frequency bandwidth must also be defined. Thus, the definition of a Wiener spectrum and average scene brightness provides the required information and can be related or expressed in terms of contrast ratio over a specific spatial frequency bandwidth, if desired.

Historically, the development of the scene Wiener spectrum was initiated during the G^3 focus sensor development. At the initiation of this development, the input scene light modulation characteristics were unknown. Previous estimates or guesses had been made with regard to the scene brightness characteristics in terms of a Wiener spectrum, but actual data was nonexistent. The use of a description in terms of a two-dimensional power or Wiener spectrum is mere! the application of communication theory to electro-optical sensor design.

Initial studies involving the description of scene brightness content in terms of a Wiener spectrum used G photography. Initially, 76 microdensitometer tone traces of actual photography were obtained. These traces covered approximately one mile on the ground. Of the 76 tone traces, approximately 20 were of different scene character. The data obtained was converted to input scene brightness in foot-lamberts and processed via a digital computer program to obtain a one-dimensional power spectrum of scene brightness versus spatial frequency. These one-dimensional power spectra possessed approximately the same character. That is, the input scene brightness power spectrum decreased with increasing frequency. Subsequent additional analyses by Eastman Kodak and Aerospace have demonstrated the same characteristics. These data were corrected to the extent possible for the optical system MTF, but were limited to a range (on the ground) of 1 cycle per 200 feet to 1 cycle per 10 feet.

Using the above data, and assuming an isotropic process (i.e., circular symmetry), a two-dimensional Wiener spectrum can be obtained. These initial estimates of scene "modulation" were used to predict the G^3 focus sensor signal levels. Subsequent flight data verified these estimates.

At the initiation of the Dorian Program, the only data available were those developed for the G^3 focus sensor design. This information was of limited quantity and did not contain a sun elevation angle condition below 25°. However, this information was used as the initial specification for IVS input scene brightness characteristics. Additional microdensitometer tone traces of G^3 photography were requested;

however, the time lag in obtaining such data is extremely long. It was then proposed to use the focus sensor telemetry data from G^3 flights to add additio data for the IVS input specification. The telemetry and calibration of the G^3 focus sensor is such that the input scene brightness modulation over a narrow two-dimensional spatial frequency bandwidth can be obtained, since the transfer function of the focus sensor/optics is known at the operating spatial frequency of 1 cycle per 30 feet on the ground, The data from Flights 8, 9, 10, 11, 12, and 13 have been used to obtain approximately 900 additional data points. Using these data, the input scene Wiener spectrum gain or level as a function of sun elevation angle has been obtained over the range of 5 to 90 degrees for an average Wiener spectrum shape determined from the analysis of microdensitometer tone traces of actual photography. In addition, the average or "DC" scene brightness has been obtained for each of these measurements, and a plot of the Wiener spectrum gain versus average scene brightness has also been provided. These data were used as a requirement for IVS operation and as the basis for evaluating the three competitive Image Velocity Sensors.

It should be noted that there are many assumptions associated with the adopted model of scene characteristics, but the assumptions and/or weaknesses are known. This model at least provides a uniform and understandable definition which can be used by all contractors in their design and subsequent evaluation. Historically, numerous philosophical discussions involving input material were held with the various IVS contractors, and the only real information generated during these meetings was that a scientific definition of scene brightness characteristics was lacking. As a result of these discussions, it was apparent that a consistent definition should be made or an unbiased comparison of the proposed sensors would be impossible.

Table B-1

SUMMARY OF IVS SPECIFICATION REQUIREMENTS

Critical pec. Requirement	Status of Requirement	Reason For Requirement	How Reqmt. Was Derived	Effe on Othe
tional Character- cs Dynamic Signals	0 to ±0.3 in/sec	To operate at max. errors that can be present at end of slew.	Corresponding rate error at saturation permits settling of tracking mirror drive within slew & settle time reqmts.	Affects image Affects req'd i mainta resolut Affects drive l
Linearity	±25% - .0225 - .3 in/sec ±10% - threshold -.0225 in/sec	Large signal region performance is based upon reqmts for settling time; null signal linearity is based on stability & servo tracking rate accuracy.	Analysis & error allocation of tracking mirror drive dictated linearity and noise allocations.	Interac respon
Noise	Separately defined sensor noise to include effects of sampling.	Limits on IVS noise so that IVS will be compatible with servo performance requirements.	By consideration of the effects of sampling of noise transmission through the system. Analysis of complete control loop requirements.	Interac respon conver

Table B-1 (Cont'd)

Critical ...ec. Requirement	Status of Requirement	Reason For Requirement	How Reqmt. Was Derived	E... on
...ctional Character- ...ics (cont'd) Frequency Response	Provides phase and amplitude bands as a function of frequency which allows sensor filtering to reduce sensor noise.	To achieve req'd response and stability of tracking mirror drive servos.	Based on slew and settling time requirements including effects of sampling, delays, and disturbances.	Affects drive p... slew, s... trackin...
...face Requirements Light Level	Aerospace & PPAC input data on light level, transmissibility and vignetting.	Guarantee that IVS will work over expected range.	Based on COA trans-missibility and the existing IVS appor-tionment.	Affects t... act with null and detector magnific... sensitivi...
Image Contrast	Based on present Wiener Spectrum data. GE will supply test scenes to contractors.	Defines req'd range of sensor operation. Sensor operation is strongly dependent upon contrast and scene content.	Aerospace Wiener Spectrum data of typical scenes	Affects t... to IVS. total ligh...
Image Residual Motions	Req'd that sensor be insensitive to residual motions in image. (off-axis rates)	Major source of system error if IVS senses off-axis rates.	Tracking mirror drive error allocation.	Affects s... view and capabilit...

APPENDIX C

IVS TEST PLANS

The GE test program to date has served to evaluate the performance of the competitive IVS units and aid in the selection of a unit for prime use. This portion of a comprehensive over-all IVS test program has been referred to by GE as the Evaluation Test Program. This Evaluation Test Program has consisted of tests of the breadboard IVS units on a Bench Tester and Open Loop Tester. A brief summary of these test configurations is presented below and an evaluation test program schedule is presented in Table C-1. The detailed test procedures associated with these test configurations and the specific IVS units are presented in References 2 through 7.

1. Bench Tester - The primary purpose of the Bench Tester was the functional checkout of each breadboard IVS unit prior to formal tests in the Open Loop Tester. Secondary tasks were those of obtaining quantitative operational data to supplement those which would be obtained from the open loop tests so as to provide a check of critical parameters. Upgrading of the tester also permitted additional tests such as image rotation. The Bench Tester was composed of the following items:

a. Sensor Mount - A K&E instrument stand with height and rotation adjustments was used for sensor mounting. A compound table with two-axis translation as well as rotation was also mounted to the instrument stand. This assembly permitted alignment of a telecentric lens system and also permitted focus adjustment.

b. Optical System - The optical system consisted of a telecentric lens system which duplicated the performance of the Open Loop Tester optical system and that of the optical system in the MOL vehicle. The main difference was that the target scene was placed at approximately

22 inches from the front element of the collimator section, and a 5-inch diameter portion of the scene was reduced to 2.8 inches in the image plane of the sensor. A light shield was constructed to fit over the optical system to eliminate stray light.

c. Target and Target Motion - A photograph was taken of the high contrast urban scene at a reduced scale of 5.6 so that the spatial frequencies in the Bench Tester image plane would be consistent with those of the Open Loop Tester (OLT). An x-y plotter was used to drive the scene target. The target was mounted to the pen carriage of the plotter. For scene rotation tests, a separate variable speed drive assembly was used to rotate the target material.

d. Illumination - Scene or target illumination was provided by four floodlights illuminating the target material. A DC power source was used to control these lights. A calibration of average scene illumination at the 2.8 inch IVS interface versus the supply voltage to the lights was made. The AC modulation signal or Wiener Spectrum for the scene used was calibrated from previous data obtained on the OLT.

The Bench Test Plan for each IVS breadboard unit (See Ref. 2 through 4) called for the functional verification of the following common parameters:

(1) Illumination threshold and saturation levels at zero velocity.

(2) Null threshold velocity

(3) Linearity and saturation velocity

(4) Frequency response

(5) Effects of voltage variation upon parameter values

(6) Special features of each sensor

Additional quantitative tests which were performed upon the Bench Tester were:

(1) Effects of illumination levels upon sensor parameters

(2) Image rotation effects

(3) Effects of power interrupt upon performance

These tests were conducted in conjunction with the Open Loop Test Program described later.

Each vendor was notified when the bench tests were scheduled to begin. Vendor representatives were present during the initial alignment, power application and testing of each sensor. Their presence assured that any early malfunctions or deviation in sensor performance would be noted or corrected.

All tests performed on the Bench Tester were formally conducted and documented. In addition, a specific detailed test procedure was written for each sensor and for any subsequent special testing. A summary of the Bench Tester results can be found in Reference 8. Many of the sensor anomalies observed on the Open Loop Tester were first observed during the Bench Tester Evaluation.

2. Open Loop Tester - The purpose of the Open Loop Tester (OLT) was to formally evaluate the performance of the three contending IVS units with a realistic simulation of the orbital operating conditions expected. Secondary tasks were to evaluate any observed anomalies and attempt to determine the cause of these anomalies.

A complete design, analysis, and experimental program was conducted to verify the adequacy of the OLT for IVS evaluation. (See Ref. 9 through 11). In the OLT, the scene dynamics were provided by using a lens system were driven on a carriage, and the carriage motion with respect to the fixed photographic scene simulated the relative motion of the vehicle passing over a target. The object material which was located on the platen contains scene characteristics which were consistent with real-world targets (e.g., contrast, spatial frequency distribution, and geometrical shapes). Image motion was generated by controlling the relative position of two lenses mounted on axes which were mutually perpendicular (Dynalens). The two axes of the Dynalens were controlled and commanded separately to induce image motion to the IVS.

The principal optical elements of the OLT consisted of a collimator telecentric lens system and deviating prism (Dynalens) using a variable prism technique to deflect the line of sight (LOS) from the target material in amplitude and rate.

During typical sensor evaluation testing, the IVS was moved in a straight path first towards an object (simulated target) and then away from this object in a path parallel to the object platen gimbal axis. (See Figure C-1.) This motion was scaled to simulate the change in range between the IVS (orbital vehicle) and the object (target) as the orbital vehicle tracked a target. The object material was held on a platen that was supported by a single-axis gimbal. The angle of the platen gimbal was preset to position the IVS with respect to the platen. This axis generated the correct geometry for the obliquity.

A complete simulated tracking run of a target (e.g., from a forward to an aft looking stereo half angle) using the simulator started with the IVS approaching the object platen with the platen initially position so that an oblique angle was formed between the IVS line of sight and platen. As the IVS approached the target platen, the IVS mounting platform rotated to continually point at the center of the target or the platen. At nadir, the IVS moved away from the platen as the IVS mounting platform continued to rotate to angular positions corresponding to aft-looking stereo angles.

When different roll angle positions of a target were being simulated, the gimbal axis of the target platen was preset to an angle that corresponded to the desired roll angle. The roll axis or target platen gimbal remained fixed during any one target pass.

The previous description provided the means by which the orbital changing geometric conditions were simulated for IVS testing. The addition of intentional image velocity with respect to the IVS was provided via a Dynalens. The Dynalens was located behind the collimator lens. When the Dynalens was in the neutral position, light passed through it without deflection. When the Dynalens system was commanded to deflect the line of sight, one of its two plates was tilted with respect to the other one. This caused a proportional deflection of the light rays entering the Dynalens. Each Dynalens plate was one-axis actuated; the two axes were mutually perpendicular. This permitted the generation of complex line-of-sight deflections in response to smear motion commands. The light then passed through a telecentric lens assembly which focused an image at the optical interface with the IVS being tested.

The simulated targets or test scenes used during the evaluation of the IVS units were consistent and based upon the definition of input scene conditions presented in the IVS specification. Three different two-dimensional scenes were used. Scene content consisted of (1) a high detail city scene, (2) a low detail rural scene, and (3) a random dot target. The average scene brighness was measured at the IVS interface, and the scene modulation was measured by taking high resolution photographs through the optics at the IVS image plane. These photographs were then scanned with a microdensitometer and processed via a computer program to obtain a Wiener spectrum of the scene statistics. These data were then correlated (see Ref. 11) with the specification levels, and a calibration was made of illumination level and Wiener spectrum level (modulation). In addition to the scene average illumination and modulation calibration, a "haze" generator was used to increase the average illumination level at the IVS interface without increasing the modulation. This "haze" generator was included in an overall calibration of input scene illumination.

Prior to initiation of IVS testing, a design effort was carried on at GE to develop the OLT for IVS evaluation. A detail OLT specification was written (see Ref. 9). Subsequently, a detailed evaluation of the OLT was performed and the results are documented in Ref. 11. This OLT design included such features as the automatic refocus of the image in real time during dynamic testing to compensate for slant range changes, an optical system MTF which matched the actual MOL optics to 50 l/mm over typical operating conditions, aperture variation during testing to simulate the vignetting of the actual orbital system and a maximum vibration or noise image rate of 0.0025 inch/sec. (IVS threshold specification = .01 inch/sec).

The detailed tests performed on the candidate IVS units are defined in References 5 through 7. The results of these tests are documented in References 12 through 14. The overall summary covering the IVS evaluation tests is presented in Reference 8.

Testing was conducted in an extremely formal manner and fully documented. Vendor representatives were present during a major portion of the tests associated with their units. Additional tests were performed at the request of and under the direction of the various IVS vendors.

3. Closed Loop Tester - The purpose of the closed loop tester is to evaluate the performance of the IVS units using a realistic simulation of orbital operating conditions and the TM (tracking mirror) drive dynamics. The closed loop tester uses the open loop tester hardware together with an analog computer simulation of the TM drive dynamics and disturbances. The actual TM drive dynamics are provided by analog computer simulation driving the Dynalens system to control the image motion in two axes.

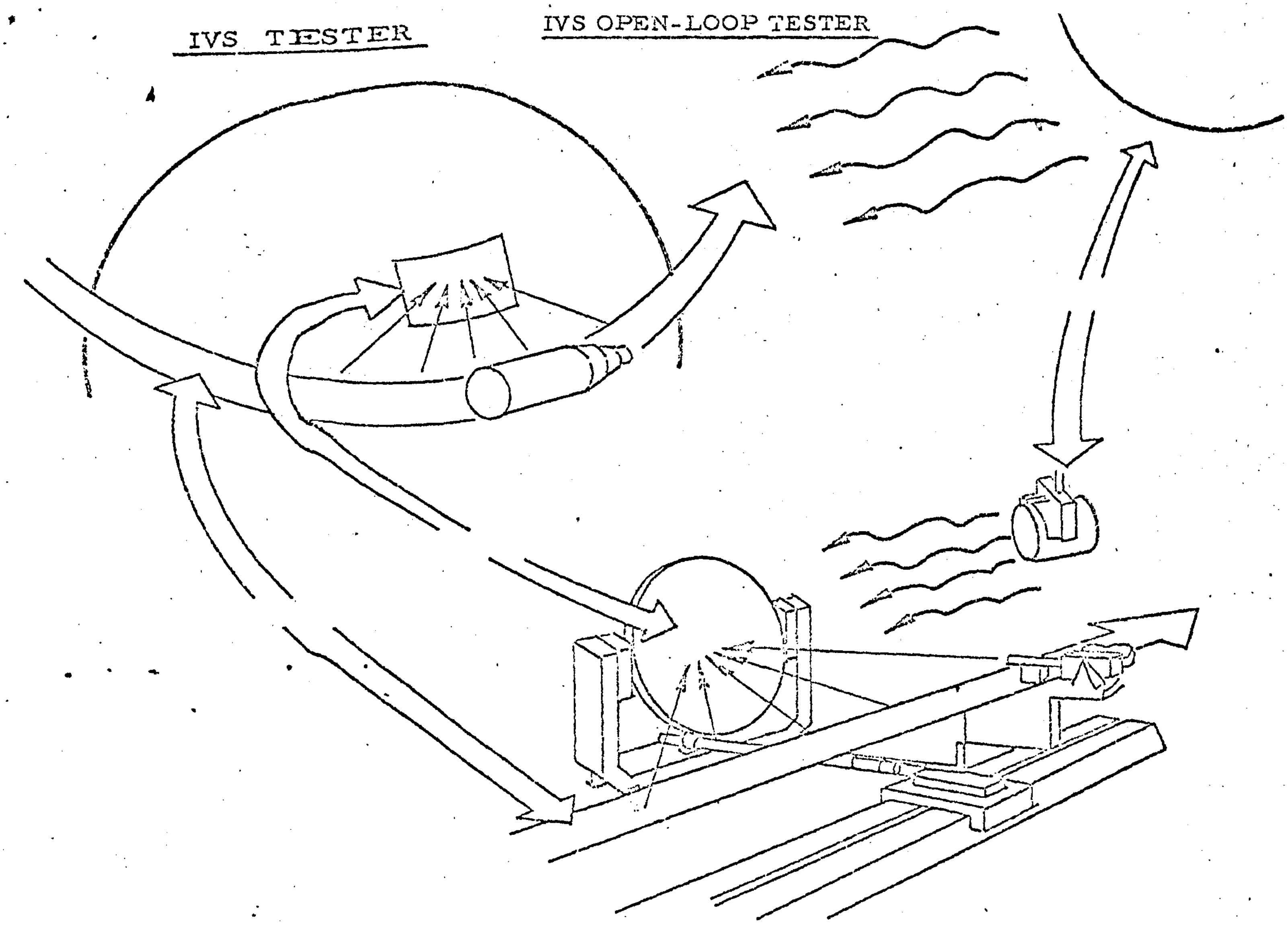
TABLE C-1

IVS SUBSYSTEM PROGRAM SCHEDULE

1. BREAD BOARD TESTS COMPLETE	1 OCT 68
2. ENGINEERING PROTOTYPE EVALUATION MODEL DELIVERY	
GOODYEAR AND HYCON	1 OCT 68
ITEK	1 DEC 68
3. VENDOR EVALUATION TESTS (CLOSED AND OPEN LOOP)	1 OCT 68 THRU 3
4. FINAL EVALUATION REPORT	1 MAR 69
5. SELECTION OF ONE VENDOR	NO LATER THAN 28 FEB 69

FIGURE C-1

IVS OPEN-LOOP TESTER



REFERENCES

1) Performance/Design and Product Configuration Requirements for Image Velocity Sensor Specification No. EC 701A, Rev. 5, 4 Dec. 1967 DIN 3701-236-5

2) Beta Bench Test Procedure (Paul) = Goodyear, March 5, 1968 DIN 3808-212-1

3) Beta Bench Test Procedure (Peter) = Itek, March 11, 1968 DIN 3808-220-5

4) Beta Bench Test Procedure (Mary) = Hycon, March 21, 1968 DIN 3808-224-3

5) Beta Subsystem Evaluation Test Procedure (Peter) = Itek DIN 3808-208-6

6) Beta Subsystem Evaluation Test Procedure (Mary) = Hycon DIN 3808-226-3

7) Beta Subsystem Evaluation Test Procedure (Paul) = Goodyear Revision I DIN 3808-226-04

8) Beta TestEvaluation Report to be released 15 May 1968 by G. E.

9) Beta Tester Specification, 10 November 1967, DIN 50102-32-3

10) Beta Tester Readiness Test Plan, 20 November 1967 DIN 50102-34-1

11) Beta Tester Readiness Report, DIN 50102-42-1, 7 March 1968

12) Beta Subsystem Test Data (Mary), DIN 3808-210-4 (Hycon)

13) Beta Subsystem Test Data (Peter), DIN 3808-208-6 (Itek)

14) Beta Subsystem Test Data (Paul), DIN 3808-210-4 (Goodyear)