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INITIAL CAPABILITY READOUT SYSTEM

FOR EARLY IMPLEMENTATION

INTO THE MOL/DORIAN SYSTEM

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ACKNOWLEDGEMENT

Contributions to this study were provided by the Space and Re-entry Division of the Philco Ford Corporation at Palo Alto, California in the areas of relay satellites, modulators, and demodulators, and by CBS Laboratories, Stamford, Connecticut in the area of laser scanners.

SECTION 1

INTRODUCTION

Recognizing the utility of a Readout System on intelligence gathering satellites, a study was undertaken by the General Electric Company to determine the feasibility of incorporating such a system on the Block II series of MOL vehicles. The study demonstrated that the incorporation of a limited readout capability is well within the present state-of-the-art and can be accommodated with only minor impact on the baseline system and at modest cost. This document contains a report on that study.

The unclassified (white) terminology for the Secret-Dorian-classified (black) Readout Subsystem is the Rho (ρ) Subsystem. This term will be used in telephone conversations and unclassified correspondence when referring to the Readout Subsystem. The fact that CBS Laboratories is a potential supplier is classified as black.

SECTION 2

GENERAL CONSIDERATIONS, REQUIREMENTS, AND RESULTS

This section presents a discussion of the various missions in which a Readout (R/O) System can effectively be used. It then presents performance requirements, a description of the recommended system, a brief description of the scanning and modulation techniques examined, the data link configurations that can be used, the general constraints under which the recommended system was developed, and a discussion of growth potential and possible future requirements.

This section is included to provide an overview of general requirements, approaches, and results of the study. Detailed considerations, approaches, and results may be found in Sections 3 and 4.

2.1 UTILITY OF A READOUT SYSTEM ON MOL

During the course of a mission, the MOL vehicle will have access to many targets which will be of immediate intelligence value. These targets are of the indicator warning and crisis management types. In addition, regularly scheduled targets having new or unusual activity, as well as unscheduled targets of opportunity, are all candidates which would be readout if a readout system was available on the vehicle.

Due to the nature of these targets, the intelligence value of their photographs decreases with time. It is important then to get the photographs of these targets to a user facility as quickly as possible.

The present baseline MOL vehicle has a mission duration of 30 days and mission durations of greater than 30 days are planned for Block II. Without a Readout System, all photographic data is unavailable until the end of the mission (meaning that some of it will be 30 or more days old). This time lag is acceptable for the primary (technical intelligence) mission of MOL but is unacceptable for the type of intelligence under consideration here. Thirty-day old crisis management data, for example, may be totally useless.

In addition to increasing the data return timeliness of critical data, the readout system can be used for the return of regularly scheduled photographs of technical intelligence targets. This provides some measure of insurance against a total data loss should there be an unsuccessful recovery of the hard copy data.

Other uses such as near real-time evaluation of main optics focus adjustments, and evaluation of man versus IVS can be envisioned with a Readout System on-board.

In summary, the addition of a Readout System would add a significant amount of versatility to the vehicle enabling the MOL to perform over and above its technical intelligence mission.

It is important to recognize the crew involvement to the gathering of these types of intelligence. They are the ones who select the targets of unusual interest and must evaluate the photographs and select those for readout that are of greatest importance. The addition of a Readout System imposes additional tasks for the crew but in this sense more fully utilizes the potential capability of the manned MOL as a surveillance system.

2.2 PERFORMANCE REQUIREMENTS

The MOL Dorian System can deliver photographs with [redacted] maximum resolution. It was felt that the readout system should have the capability to readout the photographs at this high resolution. At this resolution it was determined that approximately 625 sq mm of picture area could be readout in a typical four-minute station pass.

It was also recognized that a capability to readout larger areas at lower resolution would be a desirable feature for certain types of intelligence data. A goal of the Readout System design is to provide this additional capability. Hence, two choices of resolution and picture area will exist and can be selected by means of a switch.

Based on the above, and on hardware considerations, the following performance requirements were established for the Readout System:

a. Resolution - Selectable between [redacted] and one lower value. Typical lower values are [redacted] Selection is made by means of a switch on subsystem front panel.

b. Photographic Area Scanned:

Resolution		Area	
lp/mm	[redacted] Ground (Nadir)	Photographic (sq mm)	Approx (sq ft) Ground (Nadir)
[redacted]	[redacted]	625	8,100
		2500	32,400
		5000	64,800

c. Scanner Video Bandwidth - 200 kilohertz

d. System Output Bit Rate - 1.024 MBPS (SGLS compatible)

2.3 DESCRIPTION OF RECOMMENDED SYSTEM

The recommended initial capability Readout System is shown in block diagram form in Figure 2-1. Black and white film from the secondary camera will be processed on-board in the existing bimat processor. The film will then be viewed by the crewman using the existing viewer/handler. At this time, the crewman will select the areas of the photo to be transmitted via the Readout System. These selected areas will be cut (cropped) from the full photograph and slide-mounted for input to the scanner. The laser-type scanner will be mounted in Bay 2A above the VDP module storage rack in the Laboratory Module.

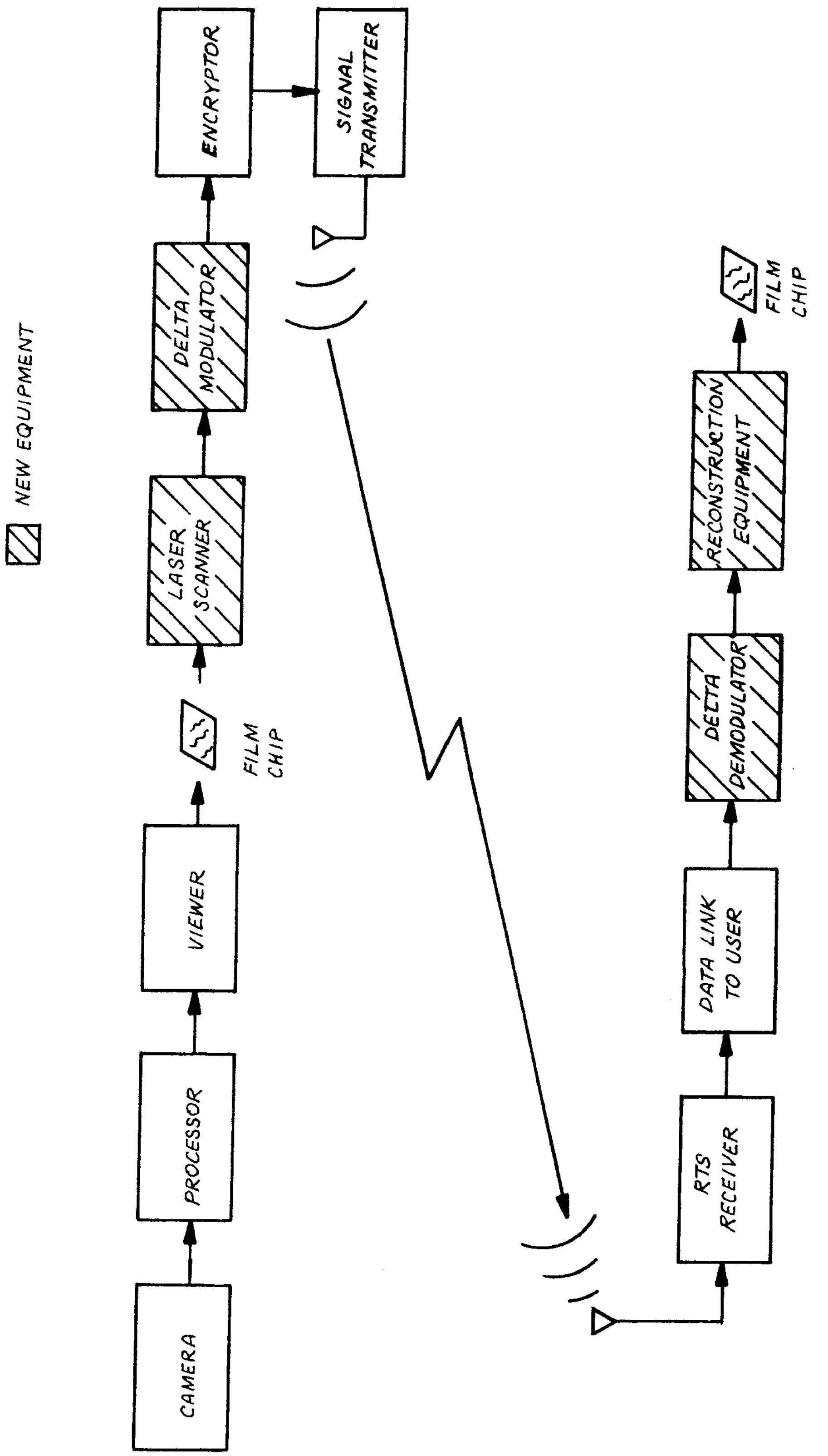


Figure 2-1. Readout Data Flow

The scanner will be initialized immediately prior to a station pass by the crewman manually turning it on and inserting a slide (film chip). At the beginning of the station contact, scan will be manually initiated and will continue until the entire slide has been scanned.

The scanner outputs a video signal to the modulator which in turn digitizes the video using a delta modulation technique and sends it to the existing encryptor. The encrypted data is transmitted over the existing SGLS to one of the remote tracking stations, where it is recorded on tape.

The data is then relayed to the user facility, assumed to be in Washington, D.C., by means of a communication satellite system such [redacted] DCSP or an SCS. This requires playing the tape into the relay satellite terminal equipment which must be located at the SGLS site. Real-time data from the MOL could be put through directly if the relay satellite system has sufficient bandwidth capability. The data is relayed through a communication satellite to terminal equipment located at or near the user facility and again recorded on tape. The transmitted photograph is reconstructed by playing back the data on tape into a demodulator which provides a video signal to the reconstruction device. The demodulator/reconstruction system is capable of operating in real-time with data directly out of the relay satellite terminal equipment.

There are, of course, many options to the system described above which affect complexity, need for new equipment, and cost of the system. Discussion of these options and the trade-offs involved may be found in Sections 3 and 4.

2.4 READOUT DEVICES AND TECHNIQUES CONSIDERED

2.4.1 SCANNERS

The scanner is the device that scans the input photographic transparency and outputs a video signal; this signal being a function of the density (or gray level) of the film. Various types of scanning systems were considered including vidicons, image orthicons, flying spot scanners, image disectors, and lasers. The study was narrowed to a comparison of a flying spot scanner, a focus projection scan (FPS) vidicon system, and a laser scanner since these were most likely to deliver high resolution. Sketches of these systems are shown in Figures 2-2 through 2-4 and detailed descriptions of the three systems can be found in Section 3.3.

Some of the parameters used to make the final choice were resolution, growth potential, reliability, maintainability, state-of-the-art development, weight, power, size, maximum chip size, operational simplicity, and safety (as well as specific detailed characteristics of the scanner concepts themselves). The tradeoffs and rationale leading to the selection of the laser scanner as the recommended method can be found in Section 4.1.

It should be pointed out here that while the laser scanner is the chosen method, there are several ways of mechanically implementing the laser. Further studies are required prior to selecting the actual mechanization technique. Several of these techniques are discussed herein.

2.4.2 MODULATORS

The modulator converts the scanner video output signal to a digital bit stream for input to the downlink equipment. Both pcm and delta modulation techniques were studied for this conversion. The two-bit delta modulation technique was selected primarily due to its bandwidth compression effect. Compared with (six-bit) pcm, it permits greater picture area to be transmitted in a given amount of time with equivalent resolution. The modulation techniques and comparisons are described in Section 3.4.

2.4.3 PRESENT STATE-OF-THE-ART

Neither the scanner nor the modulator require any advances in the state-of-the-art.

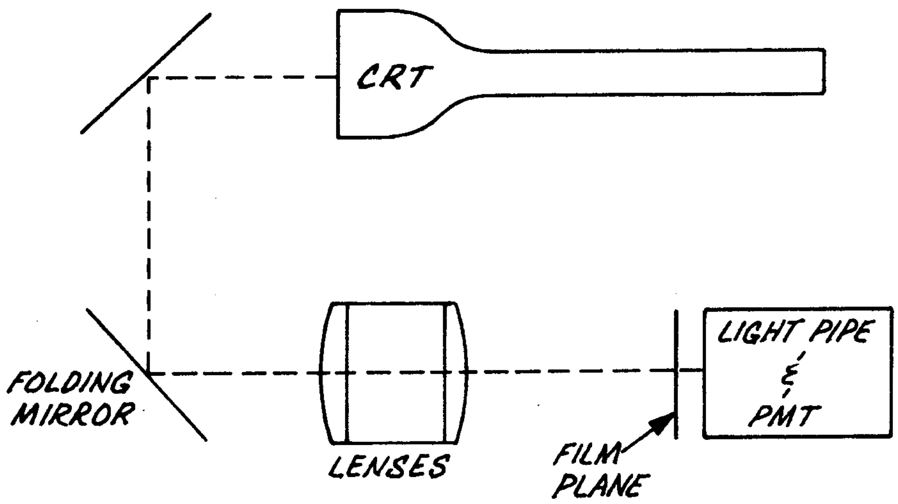


Figure 2-2. Flying Spot Scanner

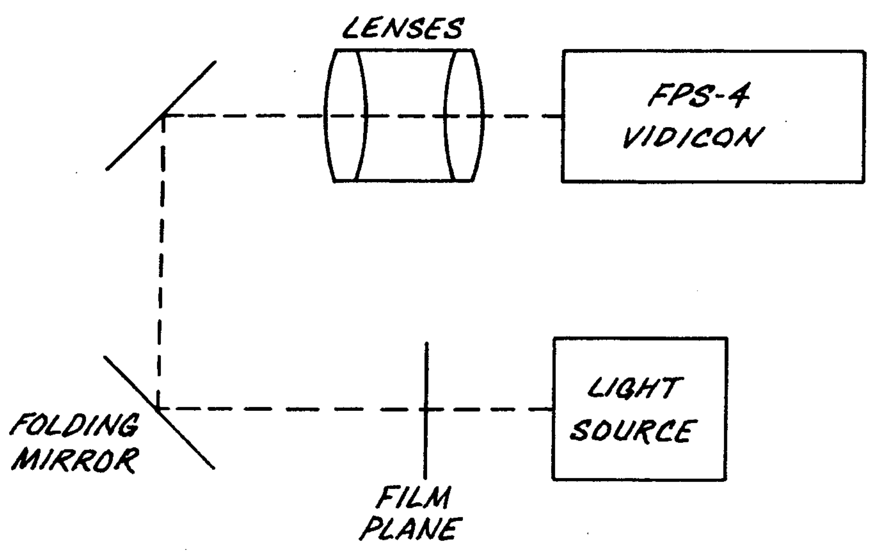


Figure 2-3. FPS Vidicon System

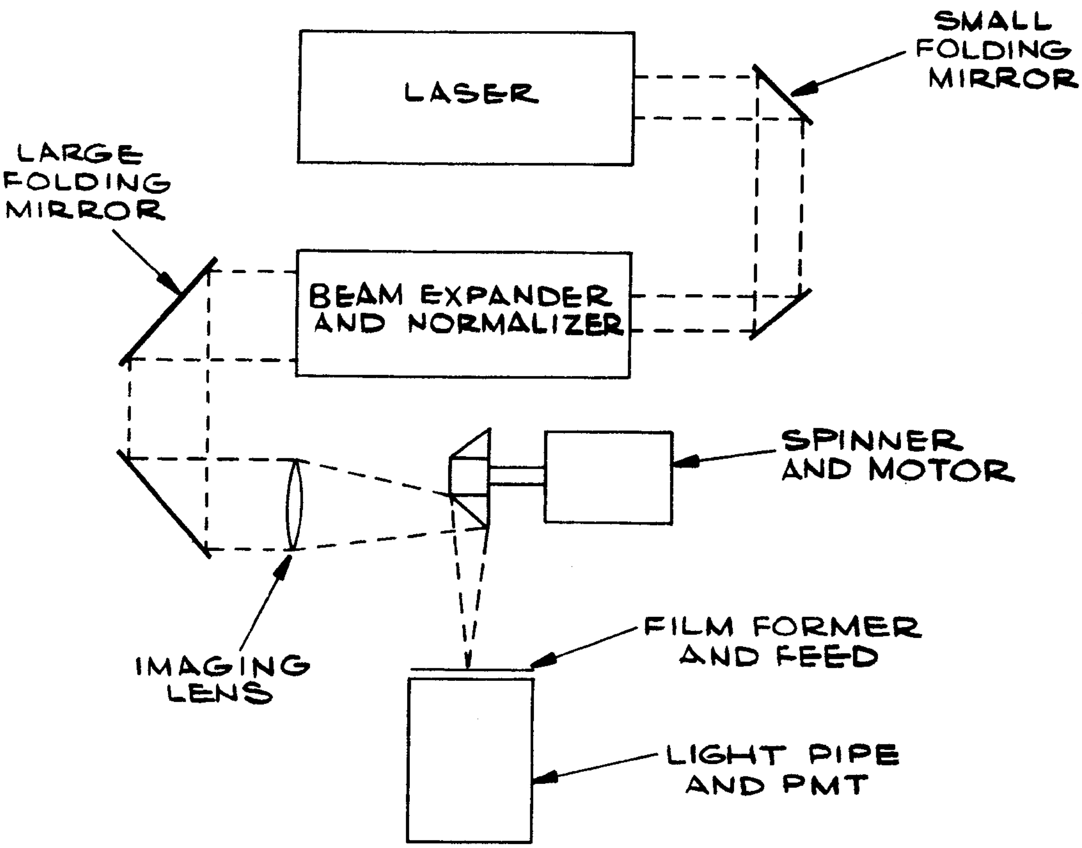


Figure 2-4. Typical Laser Scanner

Laser scanners have been operating in the laboratory at bandwidths of 50-100 megahertz (mhz) and this is not considered to be an upper limit. The bandwidth of the recommended initial capability system is 200 kilohertz (which does not approach the 50-100 mhz value).

[redacted] no problems are anticipated in qualifying them to operate in the MOL environment.

[redacted] No state-of-the-art problems exist here and in fact none are envisioned in the Readout System.

It is important to note that the initial capability Readout System does not involve the development of new hardware concepts.

2.5 DATA LINKS

For the initial system, the readout data will be returned to the user by the utilization of as much existing communication equipment as possible. The path from the modulator output on the vehicle to the remote tracking stations (RTS) utilizes all existing equipment exclusively, namely the SGLS.

Several methods may then be used to get the data from the RTS to the user facility. The longlines (presently 1,200 bps but soon to be upgraded to 2,400 bps and possibly 7,200 bps) could be used but this requires many hours of transmission time for each photographic chip.

The data could be flown in from the RTS but again the time lag involved is measured in hours.

A very attractive method is to make use of relay satellites, for example, the presently [redacted] or follow-on system such as DCSP or an SCS. Use of such systems permits the data to be relayed directly from the RTS to the user with time lags that are much less than either of the first two methods mentioned. [redacted]

It is recommended that this type of data relay be employed with the initial Readout System. The system does not come free however. [redacted] the terminal equipment does not exist at the SGLS sites. Hence, the necessary terminal equipment must be procurred to use the relay satellite system for readout on MOL. Further discussion may be found in Section 3.6.

2.6 GENERAL CONSTRAINTS

Early in the readout study, a constraint was established for the initial capability Readout System which requires that the inclusion of this subsystem should have minimum impact on the present MOL baseline design. This constraint was established to be consistent with the ground rule for improvements which states that there shall be no major modifications to the baseline system. It was recognized early in the study that minimum change, coupled with use of as much existing equipment as possible, would lead to a minimum cost system.

The minimum impact philosophy lead to the following approaches:

a. Finding a space for the subsystem in the LM which requires minimum relocation of existing equipment.

b. Sizing the subsystem envelope to fit this space.

c. Permitting only the most necessary modifications to present vehicle equipment.

d. Minimizing subsystem power requirements and scheduling subsystem usage to non-peak load periods to minimize impact on the EP&D Subsystem.

e. Minimizing subsystem weight in order to have minimum impact on booster launch capability as well as requirements on console structural support members.

f. Making maximum use of the existing vehicle capability consistent with providing a useful R/O System. An example of this is the proposed use of the SGLS rather than providing an entire new downlink system.

No such constraints have been established for advanced readout systems studies since it is expected that maximum system capability consistent with reasonable cost will be the major criterion rather than minimum impact on an existing system.

2.7 SYSTEM GROWTH

2.7.1 SCANNERS

Readout Systems for follow-on vehicles are expected to operate at bandwidths of 20 to 100 plus megahertz. Laser scanner technology is such that systems are presently operating in the laboratory in this frequency range. Transmission systems with bandwidths in this range have already been demonstrated by Bell Laboratories. It is also projected that satellite control satellites (SCS) having similar bandwidths will be operating in the future, thus providing relatively long real-time contacts between the MOL and the user of readout.

With this kind of capability available, it is expected that many sequences of photographs with large areas per photo will be readout. This requires a scanning device incorporating a film transport mechanism which is very similar to the continuous film laser scanners already developed by CBS Laboratories.

No attempt was made to define a specific system to be used in the future. A great deal more study must be done including understanding the results of the initial readout implementation before selecting an advanced system. The foregoing concept was postulated as the "type" of system that will be flying in the future in order to attempt to design an initial system that would have growth potential.

The recently completed study revealed that the scanner designs which work well with transport mechanisms are not readily adapted to fit the constraints of the initial system, especially in the weight, power and ease of operation areas. Similarly, systems that satisfy the initial system constraints do not directly grow into the advanced concepts.

It was concluded that this was not a serious enough consideration to warrant extensive development of a compatible system since the basic laser scan technique is common to both systems and it is only the mechanical devices to implement this technique that require change. Since the mechanisms for both the initial and follow-on concepts have already been demonstrated, the decision was made to select the one which best satisfies the initial constraints and, when the need arises to select the one which satisfies follow-on requirements.

2.7.2 DATA LINK

The choice of the SGLS as the readout downlink for the early system was made primarily to satisfy minimum impact and minimum cost constraints. The anticipated wide bandwidth readout system for later time periods will require much wider bandwidth transmission capability than presently exists in the SGLS network and will likely result in a new wideband transmitter and steerable antenna on the vehicle.

The wideband system could transmit directly to the ground stations as is planned for the initial system. However, using a Satellite Control Satellite in synchronous orbit as a relay would permit real-time transmission of data from MOL directly to the user facility for long periods of time. Direct communication could be maintained with an SCS for approximately one-third of the MOL orbit period. With several operating SCS's, full-time contact could be maintained for readout or any other purpose.

Further study effort must be undertaken prior to choosing the methods to be employed for advanced data links.

SECTION 3

DETAILED STUDIES

This section contains detailed information on the major areas of consideration for implementation of an early readout capability. The areas covered are those where there are significant tradeoffs to be made between concepts or methods of implementation (such as in the data conversion and modulator areas), and where studies had to be made to demonstrate that the system could be readily implemented with minimum impact (such as the data link and vehicle integration areas).

3.1 SYSTEM INPUTS

The inputs to the Readout System will be portions of processed high resolution black and white photographs taken by the Dorian camera system. The photographs will be those taken on the secondary camera and will have a maximum resolution of [redacted] It is expected that small batches of primary film will also be processed, probably at times when the primary film take-up cassettes are changed. This processed primary film can also be readout.

The secondary film will have the following characteristics:

a.	Film Type:	Similar to Type 3404
b.	Film Thickness:	0.0030 ± 0.0002 inch
c.	Weight Density:	0.022 ± 0.0012 lb/ft^2 (50% RH)
d.	Exposure Index:	4.0 using PS 485/SO-111 Process
e.	Support:	Estar thin base
f.	Image size:	$9.460 \begin{smallmatrix} +0.010 \\ -0.005 \end{smallmatrix}$ inches

The film will be processed using a Bimat processor with the following characteristics:

a.	Bimat Material:	Kodak Dry Bimat Transfer Film, Estar Base, Type SO-111 PS-485K
b.	Resolution Requirement:	Within 15% of the resolution obtainable with ground processing of the same latent image

The processed film will be reviewed by the crew on a viewer/handler mounted in Bay 4 with the following characteristics:

a.	Screen:	10 x 10 inches
b.	Microscope:	Stored within viewer, magnification 7-100X
c.	Film Handling:	Reel mounted, powered rewind, cutter-splicer, tape dispenser, leader supply.

The entire 9-inch photograph cannot be readout by the initial capability system due to the sheer magnitude of data in the photograph. It will be necessary then for the crew to examine the processed photographs using the on-board viewer/handler and select those areas of interest for readout. The crew must also cut (crop) and slidemount these areas of interest. The resulting input to the readout device will be a slide-mounted portion of a 9-inch photograph.

3.2 SYSTEM OUTPUTS

3.2.1 READOUT EQUIPMENT ON-BOARD

The on-board equipment converts the information on the input photographic slide to a serial bit stream in PCM format. This stream is compatible with the existing on-board encription equipment and in turn, with the SGLS downlink equipment.

3.2.2 USER FACILITY

The ultimate output of the entire Readout System, including the on-board equipment, the downlink, the data link to the user and the ground reconstruction equipment, is a reproduction of the slide that was input to the on-board equipment. The ground reconstruction equipment, assumed to be located at or near the users' facility will accept a digital bit stream from the data link, operate on this bit stream and generate the desired photographic reproduction.

3.3 DATA CONVERSION METHODS (SCANNERS)

This section describes the three scanner concepts that were investigated in detail and develops the information needed to make a tradeoff selection between the three concepts. The tradeoff is made in Section 4 based on information in this section.

It should be pointed out that much of this work was done prior to the time when 2-bit delta modulation was selected over 6-bit PCM for the modulations technique. Use of 6-bit PCM would have limited the video bandwidth of the system to approximately 64 Khz, and many of the examples herein use the 64 Khz value. This fact has no bearing on the analysis itself but it may serve as a point of confusion to the reader. It is pointed out here in the hope of avoiding that confusion. An example using the specific parameters for the recommended laser system may be found in Section 3.3.2.6.

3.3.1 FLYING SPOT SCANNER

In a flying spot scanner readout, electrons from the cathode of a flying spot scanner tube (kinescope with small spot size at the tube face) are focused and accelerated through a potential difference to impact the phosphor at the tube face. The phosphor serves as an electro-optical converter (i.e., electron input-photon output). With horizontal sweep and vertical deflection, an area scan or raster may be defined on the tube face. The spot at all positions in the area sweep is imaged onto the negative by an optical system. The negative modulates the photon output as a function of film density at the various positions as a function of time. This modulated photon output is collected and directed by a light pipe into a photomultiplier tube which converts the photons to an electrical signal. This signal is amplified and then processed as required (see Figure 3.3-1).

For picture reproduction, the same general arrangement is used except that the spot intensity is now modulated at all positions of an identical aspect ratio (may include magnification) sweep. The position of the original negative is also replaced by an unexposed negative or photographic paper which is exposed by the modulated flying spot (the tube face may also serve, with the aid of a camera, as an intermediate recording media).

Basic system characteristics and component properties determine to a large extent, the applicability of a flying spot scanner readout technique for a given mission. Improper application or operation may severely limit and degrade the output of such a device. Noted below are some of the limitations and pitfalls in FSS-use which will be examined in brief detail.

a. Phosphor persistence properties

b. Emitter-detector matching

c. Aging and exposure

d. Spot size/scan length

e. Deflection defocusing

f. Phosphor nonuniformity/noise

g. Stray emission

h. Regulated voltage supplies

i. Helium environmental effects.

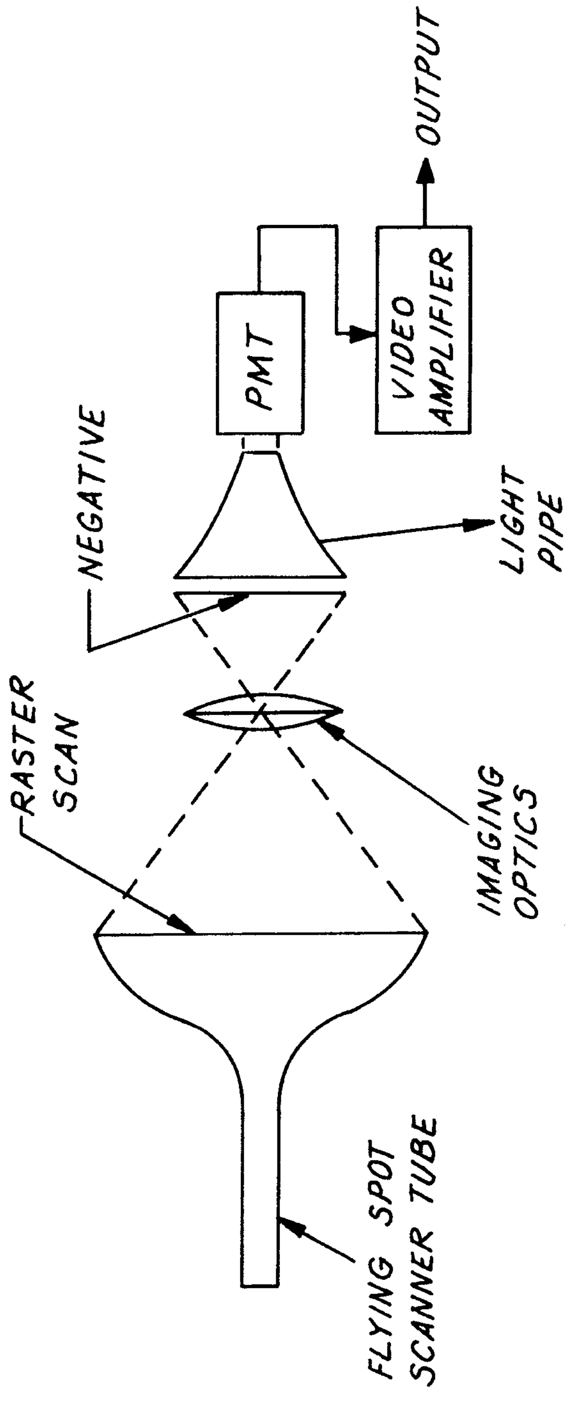


Figure 3.3-1. Flying Spot Scanner Readout System Block Diagram

3.3.1.1 Phosphor Persistence Properties

Upon impact and deceleration of the electrons at the tube face, the phosphor is stimulated to emit luminous radiation (here we have fluorescence and phosphorescence which persists after the excitation has been removed). The phosphor choice is an important consideration and coupled with S/N ratios, is a limiting factor of allowable bandwidth. This arises due to contamination effects of the picture element being scanned by a number of previously scanned elements. This phosphorescent effect adds to the output of the element being scanned and results in a higher output signal since the pickup (PMT) views the total area to be scanned at all times. A correction may be applied, in general, by subtraction from the output signal, a voltage derived from a fractional percentage of a number of just scanned elements. The characteristics of P16 phosphor indicate an 0.12 microsecond persistence (10% of excitation brightness after the excitation is removed) while P24 phosphor exhibits a 1.5 microsecond 10% decay persistence. Either of these two phosphors may be utilized for a 200 KCPS bandwidth, but the P16 phosphor allows for greater bandwidth growth potential.

3.3.1.2 Emitter-Detector Matching

The photons emitted by the phosphor are located in a spectral region characterized by that particular phosphor. P16 phosphor emits in a 0.34μ to 0.45μ (10% peak points) band with peaking at a nominal 0.38μ. P24 phosphor emits in an 0.43μ to 0.63μ region with peaking of the output at about 0.51μ. The relative output of the PMT is determined by both scanned negative modulation density characteristics and the emitter (phosphor) - detector (photo cathode) spectral distribution band match. Note further that the lens materials must be spectrally transparent in the range of interest. General films of interest are relatively transparent in the spectral range of interest.

3.3.1.3 Aging and Exposure

The aging characteristics of various phosphors have been shown to be invariant with exposure (energy density times time is a constant for a given situation). P24 provides a unique freedom from burn damage and is extremely desirable for output stability over extended time or short term high bombardment. Data indicates that 90% of the initial intensity is available from P24 after a 1 coul/cm^2 exposure, while only 25% of the initial intensity is available from the P16 after a comparable exposure. After 100 coulombs/cm^2, the P24 yields 40% of its initial output while the P16 is only 5%.

3.3.1.4 Spot Size/Scan Length

Generally quoted spot size is another matter for consideration. There are several factors which modify these ideal numbers to a more useful resolution figure including:

a. The method by which the resolution is evaluated (shrinking raster, slit-small compared to spot size-method, sine wave modulated spot scan, direct measure with microscope, etc.).

b. The degree of response or modulation depth required for a given resolution.

c. The spot size at the light output or beam current required for the application. We note that the spot size increases as the beam current is increased, i.e., an 0.7 mil spot size at 1μ amp beam current is noted to increase to > 1 mil at 20μ amps.

d. Deflection Defocusing - Spot size at particular light output is important for scanning applications as a large amount of light output is required to yield high S/N ratios with small spot size for high resolution readout. The aging effect may be partially compensated for by increasing the operating voltage. Increasing the beam current or number of electrons results in an increased spot size.

Scan length is a factor determined by FSS tube face scan and required de-magnification at the film plane for a required resolution. This factor will be examined in detail in a later section where a comparison of the various techniques will be made.

3.3.1.5 Deflection Defocusing

At non-central positions of the tube, deflection defocusing can be caused by:

a. The change in electron path lengths with deflection angle, thus requiring a different focus field strength for each radial distance of the spot from the center of the screen.

b. The non-uniformity of deflecting fields and electron motions.

c. The fact that when a roughly cylindrical beam meets a flat phosphor screen at an angle, the resultant figure is an ellipse.

This deflection defocusing results in an increased spot size at the outer edges of the scan raster.

3.3.1.6 Phosphor Non-Uniformity/Noise

On a typical FSS tube, there are tens of millions of 1 mil square elements. In this application, it is important that all or a very large percentage of the phosphor area be free of blemishes that would affect the performance of the system. In a given raster, a tube blemish (bright, dark, or color specks) will modify the light output of the tube at that part in the scan in the identical manner as the input negative.

Phosphor noise is caused by variations in light intensity from particle to particle or groups of particles. The noise is usually inversely proportional to spot size, and, as the spot is run through focus by varying the focus strength, the noise will hit a peak. Different screen deposition methods will produce varying amounts of noise. Settling of particles which are not sized will usually produce the noisier screen.

Phosphor non-uniformity shows up as a gradual change in the light output or color over the entire screen area. It is usually assumed in calculations, that the phosphor quantum efficiency is constant over the tube face. Thus, under the action of a constant electron density and fixed focused spot size, the photon output is a constant. The effects of non-uniformity may be corrected by monitoring the phosphor output (beam splitter or utilizing some part of the beam which is not in the field-of-view of the imaging lense) and modifying the output of the PMT (care must be exercised in timing so that corrections and element outputs are correctly time-phased) by a variable gain controlled amplifier.

The CRT faceplate is actually a part of the optical system and its quality is important. The faceplate glass should be optically specified for minimum number of defects (seeds, bubbles, chill wrinkles, and uneven surfaces). In optical systems employing low f number lenses, the depth of focus is very short and a high degree of flatness in the faceplate is required. Noted is the fact that even for a perfectly parallel faceplate, aberrations are introduced into the diverging beam. The correction depends on faceplate thickness and f number of the optical system.

3.3.1.7 Stray Emission

Stray emission in a CRT is an undesirable situation. This is a field emission from microscopic particles or surface irregularities in the lower gun structure. There is also the possibility of secondary electron emission from apertures in the gun. For field emission, a spot can be observed when the high voltage is on, regardless of the electron gun bias level. This stray emission can contaminate the readout signal.

3.3.1.8 Regulated Voltage Supplies

The cathode ray tube requires certain associated electronic equipment including:

a. High voltage supply

b. Electron gun supply

c. Focus coil and/or focus supply

d. Deflection coil and deflection amplifier.

The high voltage (anode voltage) should be as high as possible (consistent with tube rating, deflection power, environment, and possible X-ray problems). Lower beam currents at higher voltages will result in a smaller spot size compared to the same power at higher beam currents. As the voltage is increased, the beam becomes stiffer and requires more power for deflection through a given angle. There are also conditions on regulation, hum and ripple that must be met for specified resolution or spot size. Assume the following parameters: 5-inch diameter CRT, 20-degree deflection angle, 1 mil center screen spot size, allowable growth at screen edge due to HV supply is 10 percent or max spot diameter of 1.1 mils, useful screen for 20° ∢ is 2-1/8 inches, and the accelerating voltage is 25 KV. The allowable ΔV for these conditions is 2.08 volts, a rather stringent requirement on the high voltage supply.

Note further that the bias voltage should also be well regulated to prevent excessive unwanted modulation of the beam current which could lead to serious complications and degradations in readout.

3.3.1.9 Helium Environmental Effects

In manned vehicles or situations requiring a partial helium environment, the effects of permeation of the helium into operational equipment may become a critical factor, either limiting or restricting the use of various components. There are many references in the literature which consider the diffusion of helium through glasses and other solid substances. Unfortunately, gas collection inside some envelope does not define a component malfunction or failure. What is required are failure-time criterion for various external environments.

To illustrate this point, consider some basic calculations performed on cathode ray tubes. By standard methods, the amount of helium collected inside the tube in a 50 percent O_2- 50 percent He atmosphere at 5 psi after various time periods was calculated. Using typical (7740 glass) CRT performance properties, it was concluded that within a week the tube would start to fail at room temperature. The very fact that one can discuss tube failure requires that basic information on tube performance and properties be utilized.

Failure must also be defined with respect to end use. It is evident that the restrictions of helium permeation would be more stringent for a cathode ray tube in flying spot scanner applications than for character display operation. Assume that due to helium permeation, the basic spot size doubles. In FSS applications this would mean a decrease to half of the initial resolution. In character display applications, the results would be minor since each character is formed from many spots.

In order to reduce the helium permeation to acceptable limits in both CRT and PMT devices for reliable operation over a 30-day period, the use of soft glass envelopes, metallic coatings, thicker input windows in the case of the PMT, and special multiple enclosure techniques is contemplated.

The basic characteristics of a typically proposed FSS readout device are summarized below:

a. CRT: 5-inch face x nominal 16-inch length with typical P16 phosphor. Constructed of soft glass and metal coated on the curved surface.

b. PMT: S11 spectral response. Constructed of soft glass, thick soft glass input face, metal coated where possible, and closed in a metal container with a glass window.

c. Lens: Nominal 3-inch FL at f/2

d. Load: Indexing slide mechanism as in a slide projector.

e. Resolution: 30 lp/mm at 50% contrast for a 4-inch scan at 4:1 demagnification on a 25 mm x 25 mm film chip. Somewhat higher resolution at limiting contrast.

f. Average Power Dissipation: 30 to 40-watt range.

g. Weight: 20 to 30-pound range.

h. Outside Dimensions: 21 x 13 x 7 inches + elect.

i. Availability: 8 to 12 months.

j. Density Range: 0.1 to 2.0 range.

3.3.2 LASER BEAM SCANNERS

The basic system to be evaluated here is shown in block diagram form in Figure 3.3-2. Light from a CW laser source (1) is passed through a beam expander (2) and beam normalizer (3) for conditioning purposes. The normalized expanded beam is imaged onto the film by use of an imaging lense (4) and spinner (5). The spinner is a multi-facet minor which is used to scan the light beam over the film width. Note that other arrangements producing comparable results, such as the CBS disc and drum configurations, may also be considered. The film former and feed (6) is used to constrain the film to the required radius and move the film perpendicular to the scan direction for continuous readout. After passing through the film, the modulated light output is directed by a light pipe into a photomultiplier tube (7) which converts the information to an electrical signal. The video signal is then amplified, and, sampled and A/D converted at a later point. Each component is briefly examined in Sections 3.3.2.1 through 3.3.2.5. In Section 3.3.2.6 we consider various tradeoffs for resolution and bandwidth and a typical system. Section 3.3.2.7 is a general summary and extension to future missions.

3.3.2.1 Laser

For a 200Khz bandwidth, an S-20 photo-cathode response, 10^{-2} optical efficiency, and secondary emission ratio of 4, an 0.1 mw He-Ne laser will sufficice and allow a growth potential to 5 Mhz. Using a 1.0 mw laser, growth potential is to a 50 Mhz bandwidth. Other factors associated with laser use for this application include:

a. Warm-up Time - For stability purposes a 5 to 10-minute warm-up period is recommended. During a subsequent 4-minute interval, laser power should not change by more than 1 percent. The outside of the laser tube runs about 20°F above ambient. It may be possible to utilize low wattage heaters during laser off time for stabilization (partial).

b. Mode Stability - Design of the system is predicated on a TEM mode with Gaussian wavefront distribution. This is possible through laser life with minor ($\ll$ Å λ shift) variations. Lenses must have anti-reflection coatings so that no optical feedback can occur.

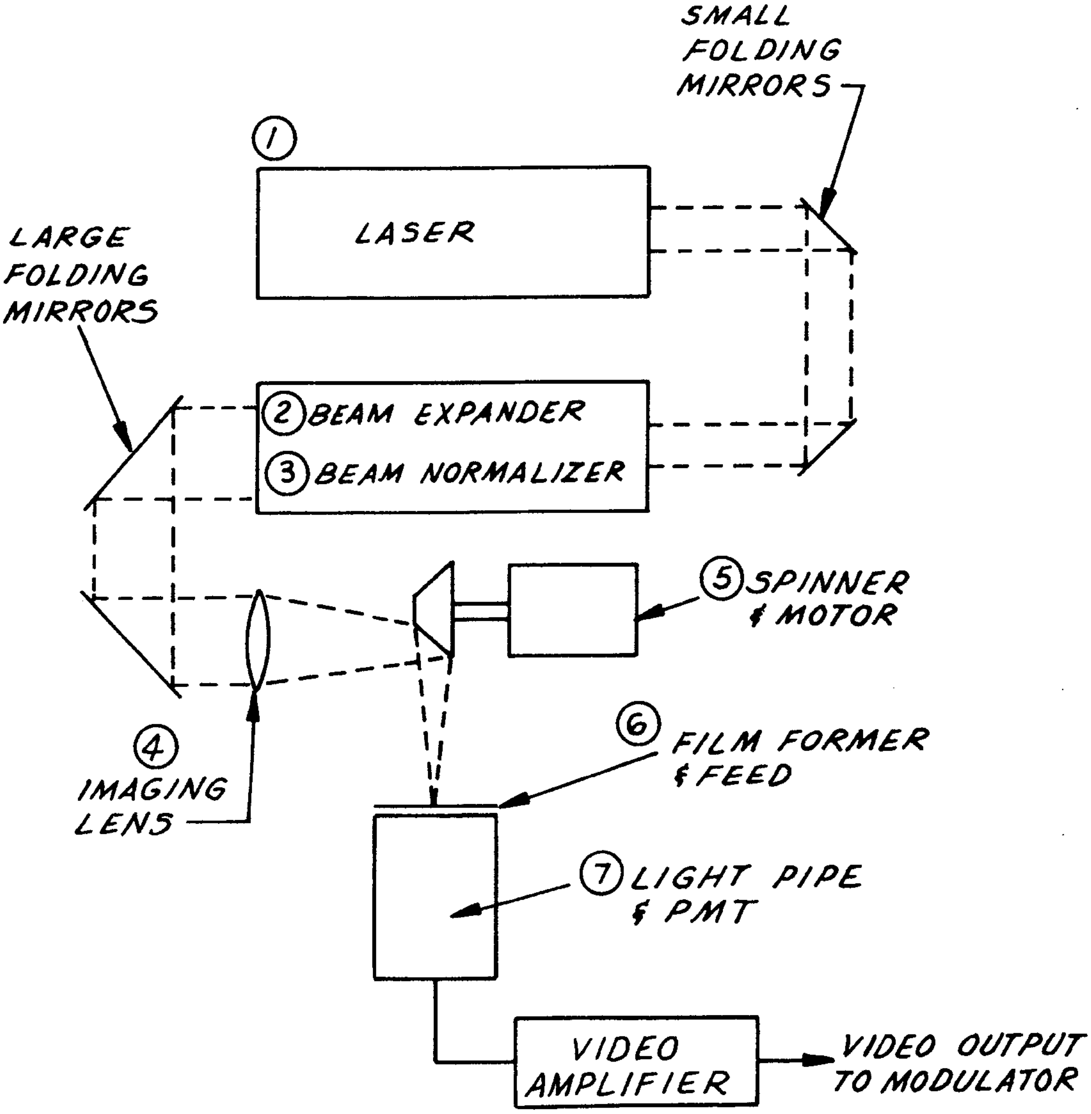


Figure 3.3-2. Basic Laser Scan System

c. Maximum Size - 16-inch length x 2-inch diameter, including collimator.

d. RFI and Shielding - No problems anticipated.

e. Degradation and Useful Life - This should be specified at 2 to 3-year storage followed by 3,000 hours useful life. Under worst-case conditions, on time is 1/6 of orbit (10 minutes warm-up + 4 minutes operation in a 90-minute orbit). This is approximately 100 hours operation during a 30-day (720-hour) mission.

f. Beam Divergence - Should be in the 10^{-4} to 10^{-5} radians range for required spot size.

g. Beam Size - A 2-mm laser output beam diameter will be expanded to the required operational diameter.

h. Weight - Approximately 1 pound + electronics.

i. Cavity Tube and Mirror Arrangement - Request here should be for a single unit with integral internal mirrors. Replacement if necessary could be made directly through simple alignment rings with no further optical alignment or positional requirements.

j. Output/Input Power - Required input for 0.1 mw output is approximately 2.5 watts. Assuming 25 percent power supply efficiency, input requirements will be approximately 10 watts.

k. Helium Environmental Effects - The gas laser is in essence a gaseous medium excited by electric discharge and containing within it a closed optical path in which optical energy can be contained for relatively long periods of time. The basic components common to all gas lasers are: a long cylindrical tube containing the gaseous medium (i.e., He-Ne), a means for exciting the discharge in the medium (DC or RF excitation), and a pair of mirrors facing each other (constitutes the resonator for the laser energy). Note that the complete laser structure may be sealed in a metal housing with only one end susceptible to helium permeation effects. The outside envelope of the laser tube is of fused quartz, pyrex, or cervet with end windows being about 10 mm thick. Of great concern is the output power variation with internal tube pressure. For a $\pm$ 3.5 percent variation in the output power of a 90 percent He-10% Ne gas laser, the internal gas pressure may be varied from 3.12 to 4.09 mm Hg or approximately 1 mm. Consider the gas mixture initially at 3.12 mm with 85% He-15% Ne. Then, the partial pressures are 2.66 mm Hg and 0.46 mm Ne. If 1 mm pressure of helium diffuses through the end window, the ratio constituents are then 89% He (3.66 mm) to 11% Ne (0.46 mm). It is expected that either mixture is in a range which would yield only small ($<\pm 5\%$) changes in output power. Consider expected results for a typical helium-neon laser with assumed parameters as, surface area $\cong$ 0.75 cm^2, internal volume $\cong$ 265 cm^3, wall thickness = 10 mm, the permeability constant = K = 10^{-10} at 25°C for SiO_2 windows, t = 60 days, and Δp = 13.4 cm. The amount of helium diffused for these conditions is 0.089 mm which is an insignificant amount added on to the original 3.12 mm. The calculation has been simplified by assuming steady state conditions (a more exact transient calculation reduces this amount significantly). Even with an expected 20°F above ambient temperature increase due to efficiency conversion losses, the laser should not seriously degrade in performance as a consequence of helium permeation into the envelope.

3.3.2.2 Beam Expander and Normalizer, Imagine Lens

The beam emerging from a laser exhibits a Gaussian distribution of intensity across the wavefront (typical values are 1 mm at the 1/e points and 2 mm at the 1% max intensity points). A beam expander is required to fill the aperture of the imaging lens. The beam expander is of the form of a simple telescope which expands in the ratio of the focal lengths.

For a Gaussian wavefront, unacceptable intensity changes are generated as the spinner or polygon (or other systems such as a series of imaging lenses attached to a rotating disc) moves through the illuminating cone defined by the spot imaging lens. To correct this effect, a normalizing filter is placed between the beam expander and the imaging lens.

The filter is densest at the center and its transmission increases radially as

$$T = e^{(\zeta^2 - \zeta_o^2)/2\sigma^2}$$

for a circular laser output

$$I(\zeta) = \frac{P}{2\pi\sigma^2} e^{-\zeta_o^2/2\sigma^2}$$

The output of this configuration is then

$$I\,T = \frac{P}{2\pi\sigma}\, e^{-\zeta_o^{\,2}/2\sigma^2} = \text{const.}$$

Required magnification is obtained by considering a diffraction limited spot-forming lens. The laser produces a source of highly collimated light. Such a beam of light entering the pupil of an aberration free lens will produce a spot whose size is limited by diffraction. In the diffraction optics region, the minimum spot size is given by:

$$d = k\,\lambda\, f = \frac{k\,\lambda\, F}{A}$$

where

d	=	spot size at geometric focus
λ	=	wavelength of light
f	=	f number
k	$\cong$	1.22
A	=	lens aperture
F	=	lens focal length

As an example, assume:

λ	=	6.328×10^{-4} mm
F	=	153 mm = 6 inches (tied in with spinner and scan length requirements).
d	=	spot diameter = 10μ = 10^{-2} mm.

Then, $A = 11.8$ mm with f/ 13 requirements. For a 5μ diameter spot (spot size is associated with required resolution), we would need a 23.6 mm diameter lens at f/6.5. Table 3.3-1 presents the requirements for various spot sizes.

Table 3.3-1. Focal Length and Aperture Requirements for Various Spot Sizes

Spot Size, d (microns)	f/#	Typical Focal Length and Apertures	
		F (mm)	A (mm)
15	19.5	76	4.05
10	13	76	6.08
8	10.4	76	7.60
6	7.8	76	10.1
5	6.5	76	12.1
4	5.2	76	15.2
3	3.9	76	20.2
2	2.6	76	30.4
1	1.3	76	60.7

For illustrative purposes assume a required growth diameter of 25 mm for the beam out of the expander. With a 2-mm beam at the exit mirror of the laser, $f_1 = 17.5\ f_o$. (Examine for f_o = 0.75 inches; here f_1 = 13.1 inches, $f_o + f_1$ = 13.85 inches). A 15-inch length by 2-inch diameter with mounting structure is a useable requirement for length and includes the normalizer or field flattener.

Other errors associated with imaging optics include collimation, aberration and vibration errors. The collimation error is entirely due to the divergence of the laser beam. For a divergence of 10^{-5} radians and a 76-mm focal length lens, the error is noted to be 0.76μ. The major aberration here is of spherical nature. With correctly selected lenses, the lateral spherical aberration should be less than 1μ. The vibration error is assumed to be negligible for a properly designed structure.

In any system of the type under consideration, where depth of focus is a critical parameter, temperature effects with subsequent displacements are of prime importance. In the case of parallel light the effects are negligible. In the beam expander and imaging lens to film plane distance, the keeping of fixed designed parameters is of a critical nature. The use of low coefficient support materials (i.e., invar with $\alpha = 0.8 \times 10^{-6}/^{o}C$) is recommended wherever possible. It is suggested that some form of refocus or defocus be included in the system. This is desirable both for correcting the system during initial setup and defocusing so that resolution can be varied. The recommended device is a variable thickness parallel plate of a modified optical glass micrometer (here thickness and not angles are changed) inserted in the converging beam of the objective lens in the beam expander.

3.3.2.3 Spinner and Motor

We wish to determine some typical values for the relationship between resolution, area scanned, and motor rpm. Examine first the required scan radius (R) for the film which is given as,

$$R = \frac{\text{(Scan Length) (\#Facets)}}{2}$$

This equation yields the radius which results in no dead time (scanning spot is always on the film). It is evident that short focal lengths and small aperture lenses may be used for short scanning lengths.

Consider the formula:

$$R = \sqrt{\frac{Bt}{A}}$$

where

$$\left.\begin{array}{l} B = \text{bandwidth} = 200 \text{ KCPS} \\ t = 240 \text{ sec} = 4 \text{ minutes station pass} \\ A = 25 \text{ X } 25 \text{ mm}^2 = \text{area of film clip} \end{array}\right\} \text{Typical values for the recommended system.}$$

R = Resolution = lp/ mm

Then, assuming a Kell factor = 0.5

$$R_1 = \frac{2 \times 10^5 \, (2.4 \times 10^2)}{4 \, (6.25 \times 10^2)} = 138 \ \ell p/mm,$$

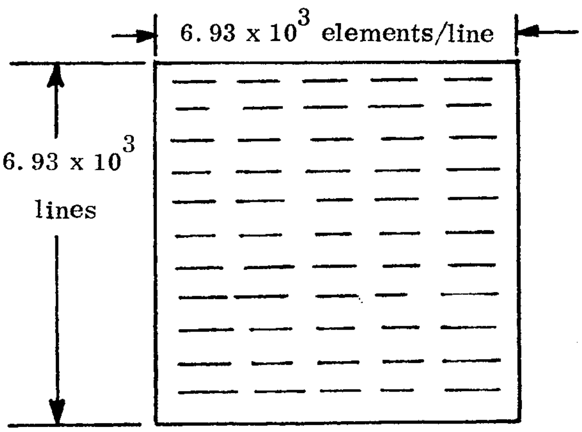
assuming that spot size was sufficient to obtain this resolution. In general,

Area (mm)	Number of 25 mm x 25 mm frames	($\frac{\ell p}{mm}$)
625	1	138
1250	2	98
1875	3	80
2500	4	69

Note that the important dimension here is the fixed 25 mm scan length. Note further that a given number of elements may be readout at a given rate, in a given time, i. e.

$$200 \times 10^3 \ \frac{\text{elements}}{\text{sec}} \ \times \ 240 \text{ sec} \rightarrow 48 \times 10^6 \text{ elements}$$

or



Thus, $6.93 \times 10^3 \ \frac{\text{elements}}{25 \text{ mm}} = 277 \ \frac{\text{elements}}{\text{mm}} = 138 \ \frac{\text{lp}}{\text{mm}}$

There are,

$$\frac{6.93 \times 10^3 \text{ lines}}{240 \text{ sec}} \rightarrow 28.9 \ \frac{\text{lines}}{\text{sec}}$$

The motor RPM is given as,

$$\text{RPM} = \frac{(\text{lines/sec})}{\#\text{ facets on spinner}} \times 60$$

For a 5 faceted spinner, motor RPM = 343 RPM.

Other conditions which must be met are:

a. The motor speed must be constant, or the result will be a non-linear scan. This requires the use of a series of pickups with D/ A feedback conversion in the motor drive, or some other series of fine control.

b. Depending on the spinning structure, the selected motor should have adequate torque to accelerate to speed in a reasonably short time (less than 1 minute).

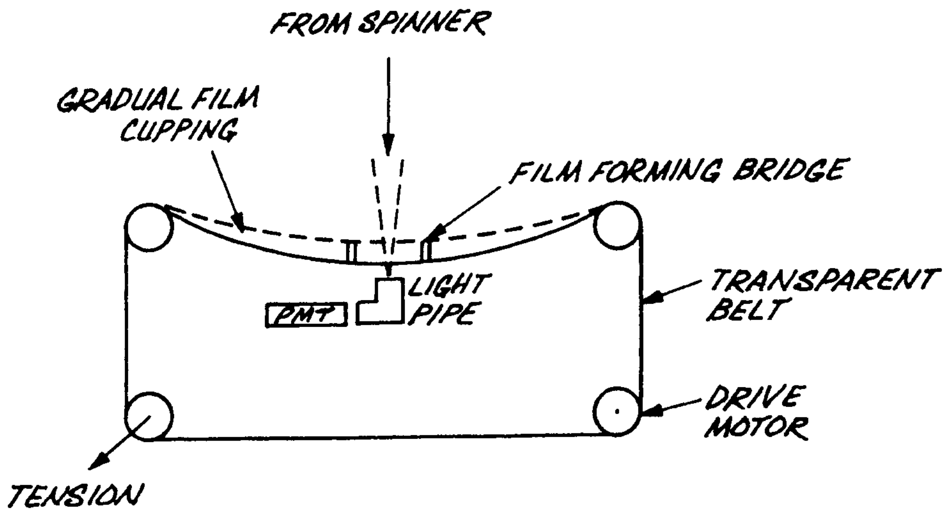
c. The spinner combination must be dynamically balanced to minimize vibration problems.

d. The structure must be designed so that g loads, windage, and bearing friction are not the limiting resolution factors.

3.3.2.4 Film Former and Feed

This is an extremely important part of the system as resolution may easily be seriously degraded by an improper film former and feed. It is suggested that the readout be referenced to the film emulsion face. The required radius is to be formed by passage over a curved,highly polished,radial shaped bridge. It is expected that tension applied along the direction of film motion will form the film to the required bridge curvature.

An example of a laser system is one based on a continuous transparent belt to which the film chip(s) is attached with the light pipe and photomultiplier tube placed as shown.



The film is cut into chips and loaded on the outside of the transparent belt. Attachment can be made with double-backed tape or other type pressure sensitive adhesive. The film emulsion is that side of the chip away from the belt so that the film emulsion face is in contact with the radius forming bridge. The film chips are attached in edge contact (can insert resolution and gray level standards between chips) on the belt. A number of film chip runs may be pre-stacked around the belt as desired. An indexing system and length monitor are included so that each run or series of film chips can be monitored.

Scan length for such a system would be changed by methods of changing the number of spinner facets or other appropriate techniques to be evolved.

There are some possible drawbacks to this technique, including a passing of the light through the transparent belt. This is of no consequence for an unmarred belt (no scratches or other marks which would reflect light by different amounts at various places) as the transparent belt can be considered as part of the light pipe.

Investigation of simple, reliable and mission optimal film handling techniques will form a large part of a study prior to selection of an optimal method of film transport. Prime candidates are the CBS suggested methods of disc or drum scan. Sketches of these systems are included at the end of this section. While it has been concluded that the laser scan method is the optimum one for this application, further study is required prior to the selection of the detailed film handling technique.

In the belt method considered here, the focused readout spot is scanned over the transparency in a fixed circular arc in space. Total area or consecutive line readout must be accomplished by moving the film past the sweeping spot at a predetermined rate.

Consider readout of a 25 x 25 mm frame in 240 seconds. The required film chip advance in a direction perpendicular to the scanning direction is:

$$\frac{25 \text{ mm}}{240 \text{ sec}} \longrightarrow 0.104 \ \frac{\text{mm}}{\text{sec}}$$

Other rates may be derived directly as:

Length of Film Chips During 240 sec run	Required Feed (mm/sec)
25 mm	0.104
50 mm	0.208
75 mm	0.312
100 mm	0.416

A suggested procedure to obtain various resolutions is to keep a fixed scan length and vary the resolution by spot defocusing effects as described previously. For edge stacked film chips of 25 mm x 25 mm area with 240-second readout, the required feed rates are tabulated in Table 3.3-2.

Table 3.3-2. Required Feed Rates for Various Resolutions

Area (mm^2)	No. of 25 mm x 25 mm frames	$\frac{lp}{mm}$	Total Length (mm)	Required Feed (mm/sec)
625	1	138	25	0.104
1250	2	98	50	0.208
1875	3	80	75	0.312
2500	4	69	100	0.416

In the situation under discussion, the number of lines increases as the length increases and the spinner motor speed would necessarily have to be adjusted in fixed steps.

The general conditions that the film feed or transport system must meet are noted below:

a. Continuously move the film at predetermined selectable velocity past the scanning spot.

b. Provide proper tensioning of the film for guidance and transport.

c. Provide proper support for contouring the film to the radial bridge so that no distortion occurs with resultant informational degradation.

d. Provide support so that motion is continuous (effects in velocity or displacement servo control).

3.3.2.5 Light Pipe and PMT

The purpose of the light pipe is to collect the modulated light passing through the scanned film and direct it to the sensitive surface of the photomultiplier tube. The phenomenon of total internal reflection is used. The result is an integration of the collected flux over the PMT photocathode which avoids non-uniformity effects. Reference is made to the literature which indicates typical spectral response characteristics for various types of photocathodes (RCA booklet PIT-703). It is evident that an S-20 response should be used with a 6328Å He-Ne laser. Typical tube characteristics are presented in Table 3.3-3.

Table 3.3-3. Tube Characteristics for S-20 Response

RCA Tube Type	Max. Supply Voltage	Sens. Cathode (A/W) at λ max.	Current Amp x 10^5	Window F = Flat C = Convex	Overall Length (In.) (no pins)	Dia. (In.)
4459	2300	0.064	66	7056C	6.31	2.06
4463	2000	0.068	1.6	7056F	5.81	2.31
7265	2400	0.073	430	0080F	7.50	2.38
7326	1800	0.077	4.9	0080F	6.78	2.38
C3100A	2000	0.068	2.5	7740F	5.71	2.10

Selection should be made on both characteristics and window glass materials. The use of 0080 glass results in a lower permeation constant to helium.

3.3.2.6 Specific System Considerations

We consider the preliminary design and projected characterisitcs of a typical laser scanner system. There are certain input constraints such as bandwidth and readout time which initially define requirements. It may be shown that,

$$t = \frac{4\ AR^2}{B} \qquad \text{(where Kell or Utilization Factor = 0.5)}$$

where:
t = time of readout (sec)
A = Area to be transmitted (mm^2)
R = Resolution (lp/mm)
B = Bandwidth

As an example, consider a low resolution, low bandwidth system defined by:

$t = 600$ sec = 10 minutes
$A = 64$ mm x 64 mm
$R = 17.5$ lp/mm
$B = 64 \times 10^3$ hz

Then, the number of areas of the above size that can be transmitted in this time for the conditions noted is:

$$\# \text{ frames} = \frac{tB}{4R^2 A}$$

NOTE: For other bandwidths, multiply specific factors by $\frac{B_1 \text{ (KCPS)}}{64}$

$$\# \text{ frames} = \frac{6 \times 10^2 \times 64 \times 10^3}{4\ (17.5)^2\ (64)^2} = 7.67 \text{ frames}$$

generally,

$$L = \frac{tB}{4} = \text{Const} = \frac{6 \times 10^2\ (64 \times 10^3)}{4} = 96 \times 10^5$$

for the conditions assumed here. Then,

$$A = \frac{9.6 \times 10^6}{R^2\ (\text{lp/mm})} \longrightarrow \text{mm}^2$$

Thus, for $t = 600$ seconds; $B = 64 \times 10^3$ hz, and $K = 0.5$, the resolution versus scanned area is tabulated in Table 3.3-4.

Note that the 600-second time of transmittal used above is for an average of 2, five-minute passes per day. Of more significance is the possible area to be transmitted per pass per 240-second interval since there will be an average of 6, four-minute passes per day. Consider no flyback or dead time, or line identification information insertion considerations.

Assume,

$t = 240$ sec.

$B = 64 \times 10^3$ hz

$L = \frac{tB}{4} = 38.4 \times 10^5$

$K = 0.5$

or,

$$A = \frac{3.84 \times 10}{R^2 \frac{(lp^2)}{mm}} \quad \left\{ \begin{array}{l} K = 0.5 \\ t = 240 \text{ sec} \\ B = 64 \times 10^3 \text{ hz} \end{array} \right.$$

NOTE

For other bandwidths multiply area factor by $\frac{B\ (Khz)}{64}$ (i.e., for a 200 Khz bandwidth, multiplication factor is 3.13). The 64 Khz bandwidth corresponds to the use of 6-bit PCM for encoding of the scanner video output. Use of delta modulation techniques permits a video bandwidth of 200 Khz, hence the above conversion factor.

Table 3.3-4. Resolution vs Scan Area

R $(\frac{lp}{mm})$	$R^2 (\frac{lp}{mm})$	A (mm^2)
10	100	96×10^3
20	400	24×10^3
30	900	10.7×10^3
40	1.6×10^3	6×10^3
50	2.5×10^3	3.84×10^3
60	3.6×10^3	2.67×10^3
70	4.9×10^3	1.96×10^3
80	6.4×10^3	1.5×10^3
90	8.1×10^3	1.18×10^3
100	10.0×10^3	960
110	12.1×10^3	794
120	14.4×10^3	666
130	16.9×10^3	568
140	19.6×10^3	490
150	22.5×10^3	427

Table 3.3-5 shows the number of frames for different frame sizes. The information presented is plotted in graphical form for a more useful interpretation of the results in the following figures:

a. Figure 3.3-3 - Resolution (lp/mm, K = 0.5) vs. area transmitted (mm^2) per 240-second for a 64 KCPS bandwidth.

b. Figure 3.3-4 - Resolution (lp/mm, K = 0.5) vs. one square frame size (X.X mm x mm) for 64 x 10^3 hz bandwidth and 240-second transmission time.

c. Figure 3.3-5 - No. of frames transmitted (for various sized frames) vs. Resolution (lp/mm) per 240-second for a 64 Khz bandwidth with K = 0.5.

d. Figure 3.3-6 - No. of frames transmitted (for various sized frames) vs. resolution (lp/mm) per 240-second for a 64 Khz bandwidth with K = 0.5 (ordinate compression of Figure 3.3-5).

e. Figure 3.3-7 - No. of frames vs. frame edge (mm) for various resolutions per 240-second for a 64 Khz bandwidth with K = 0.5.

These curves are useful for a determination of input parameters and their variations.

Consider a system defined by 1 line pair per millimeter = 2 scan lines/mm. For aperture and lens design considerations, it is important to know required spot size. Consider a system requirement of 100 lp/mm or 200 lines/mm. This is 0.2 lines/micron, or a line or resolution element size of 5 microns. We introduce a Kell factor to account for scan misalignment. To compensate for this misalignment we require a smaller spot, i.e., for the condition above and K = 0.715.

$$5 \text{ microns} \times 0.715 = 3.57 \text{ microns for } 100 \frac{\text{lp}}{\text{mm}}$$

In Figure 3.3-8, we tabulate resolution (lp/mm) vs. spot size (μ) for various correction factors. Figure 3.3-9 is a plot of spot size and number of scan lines/mm vs. resolution (lp/mm) for a system defined by 1 lp/mm = 2.8 scan lines.

Table 3.3-5. Number of Frames for Given Frame Size

R ($\frac{\ell P}{mm}$)	A $(mm)^2$	15 x 15	25 x 25	40 x 40	50 x 50	64 x 64	1 Square Frame Size (mm)
10	38.4×10^3	170.7	61.4	24.	15.4	9.38	196 x 196
20	9.59×10^3	42.6	15.3	5.99	3.84	2.34	98 x 98
30	4.26×10^3	18.9	6.82	2.66	1.70	1.04	65.3 x 65.3
40	2.4×10^3	10.7	3.84	1.5	0.96	0.59	40.0 x 49.0
50	1.53×10^3	6.8	2.45	0.96	0.61		39.1 x 39.1
60	1.07×10^3	4.76	1.71	0.67			32.7 x 32.7
70	783	3.48	1.25				28.0 x 28.0
80	600	2.67	0.96				24.5 x 24.5
90	474	2.11	0.76				21.8 x 21.8
100	384	1.71					19.6 x 19.6
110	317	1.41					17.8 x 17.8
120	267	1.19					16.3 x 16.3
130	227	1.01					15.1 x 15.1
140	196	0.87					14 x 14
150	171	0.76					13.1 x 13.1

CONDITIONS: $t = 240$ sec
$B = 64 \times 10^3$ hz
$K = 0.5$

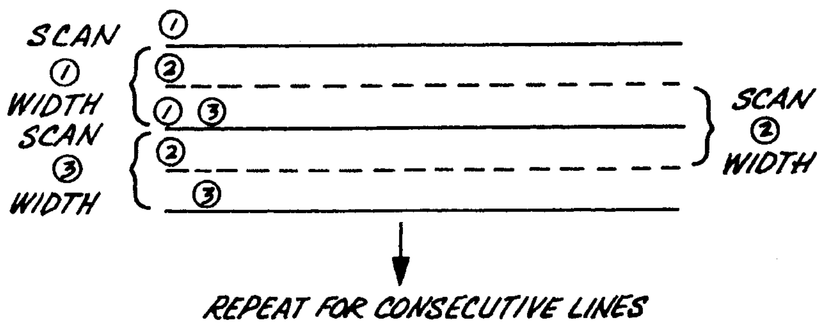
This is checked as,

$$@130 \ \frac{\ell p}{mm}, \quad t = \frac{4A R^2}{B} = \frac{4\,(227)\,(1.69 \times 10^4)}{6.4 \times 10^4} = 240 \text{ sec}$$

A more complete set of curves for various correction factors (2/k) is plotted in Figure 3.3.10. In Figure 3.3-11, we tabulate resolution (lp/mm) vs the number of scan lines/mm for the various correction or Kell factors.

The above noted parameters have been derived on the basis of obtaining resolution at close to 100 percent contrast. In general, these numbers can be degraded somewhat which results in a lower contrast or modulation with higher allowed spot size.

There is another less stringent definition that may be placed on Kell factor as, the ratio of line pitch (L) to the element size (D) in a rectilinear scanned array, i. e., a Kell factor of 0.5 represents an overlap of 50 percent between consecutive scan lines as noted below.



Under this definition, the required spot size is that defined for a Kell factor = 1, but the number of scan lines/mm is increased as 1/K. Consider results from a paper by L. Beiser, entitled "Laser Beam Scanning for High Density Data Storage and Retrieval," presented at the Soc. Photo. Sci. and Eng. at Newton, Mass. on June 7, 1967. The element size (2 elements per information cycle) is given as:

$$D = \sqrt{\frac{A}{1.2\ BU}} \times 10^{-4} \text{ in.}$$

where:

D = element size

A = area scan rate (in^2/min)

B = bandwidth Mhz

U = utilization factor

Consider a 25 mm x 25 mm frame to be scanned out in 4 minutes (A $\cong$ 0.25 in^2/min) at a bandwidth of 65 x 10^3 cps (6.5 x 10^2 Mhz). The utilization factor takes account of special or temporal inefficiency (considers blanking and Kell factor losses) and is assumed here as 0.5.

Then,

$$D = \sqrt{\frac{25 \times 10^{-2}}{1.2\ (6.5 \times 10^{-2})\ (0.5)}} = 6.43\ \mu$$

Consider an airy disc element shape having a width (D) at 1/e amplitude. The expression for the line frequency or resolution (R) at which the modulation is approximately 50 percent is given as,

$$R = 2.16 \times 10^2 \sqrt{\frac{BU}{A}} \quad \frac{\ell p}{mm}$$

$$R = 2.16 \times 10^2 \quad \sqrt{\frac{6.5 \times 10^{-2}\ (0.5)}{25 \times 10^{-2}}}$$

$$R = 21.6 \times 3.61 = 78\ \frac{\ell p}{mm}$$

Thus, using the previous conditions with the equation $t = \frac{4AR^2}{B}$, we arrived at a 79 lp/mm number. The spot size at 80 lp/mm from Figure 3.3-8 is given as 6.25 μ for a utilization factor of 2 (Kell factor of 0.5 with a 50 percent overlap for consecutive scan lines). The agreement is excellent.

One further matter we wish to note here is dead time. During any scanning interval, time is lost due to flyback, overscanning, time of indexing to subsequent frame, and line identification and sync insertion. Dead time is then defined as that period of the total scanning interval during which information from the storage medium is not being obtained.

As noted, this depends on many factors defined by the scanning system and mission requirements. In general, one should calculate an equivalent 1.05 (5% dead time) to 1.10 (10% dead time) area factor per frame to allow for this condition.

Armed with the preceding results we may now derive a specific laser scan system as per a set of given input requirements. We assume limiting values, noting that the system may be degraded (defocused) to perform within limits to less stringent requirements. The following initial constraints are imposed:

a. Resolution is [redacted] at 50 percent response, limiting.

b. 50 percent scan overlap of consecutive lines.

c. Limiting spot size at film plan is $\simeq$ 5 microns.

d. Bandwidth = 200×10^3 hz

e. Per pass scan time = 240 sec.

f. Scan width = 25 mm

g. 40 db (S/N) ratio.

Other desirable features include a variable scan width and rate and degraded resolution capability. These will be examined further in this section.

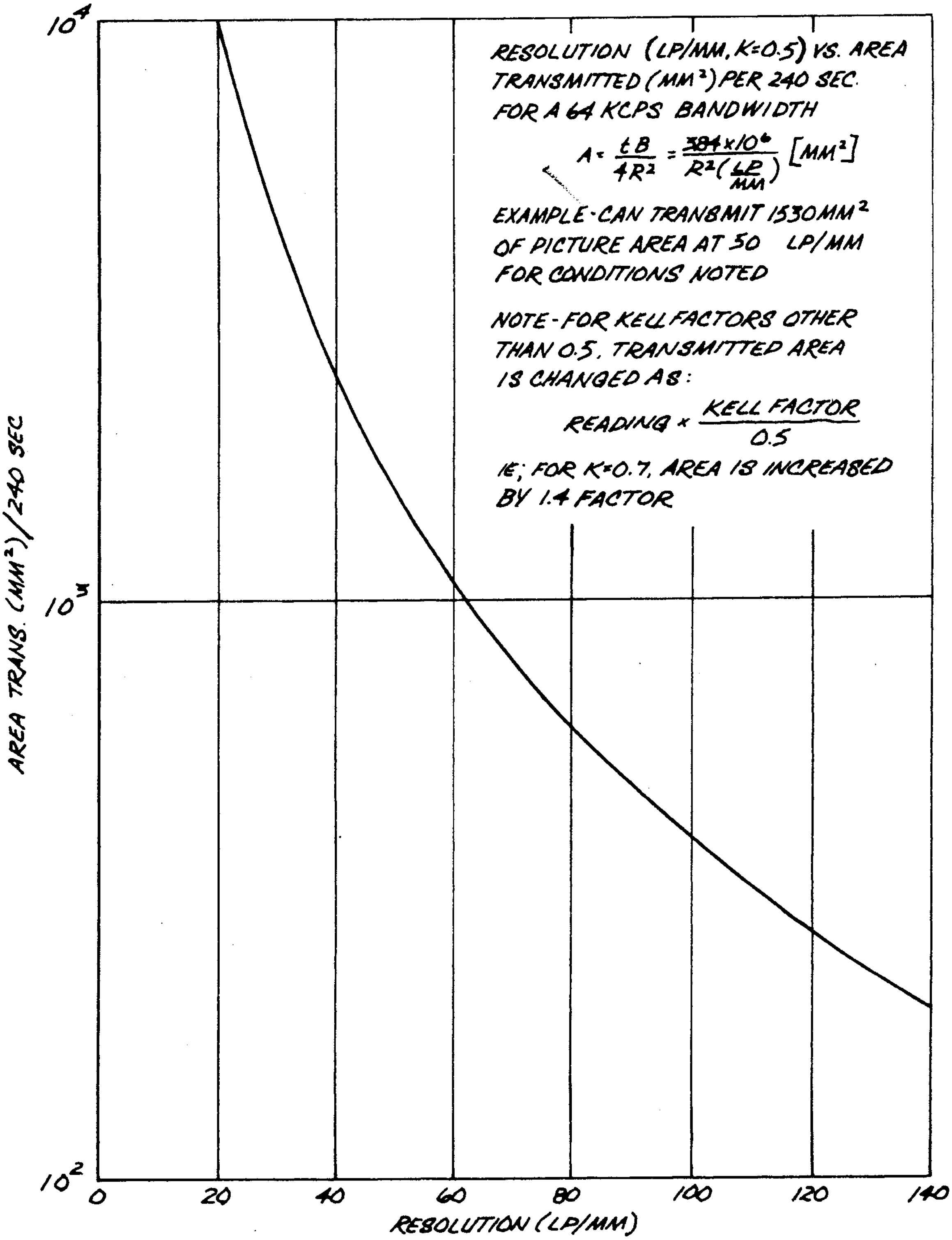


Figure 3.3-3. Resolution vs Area Transmitted

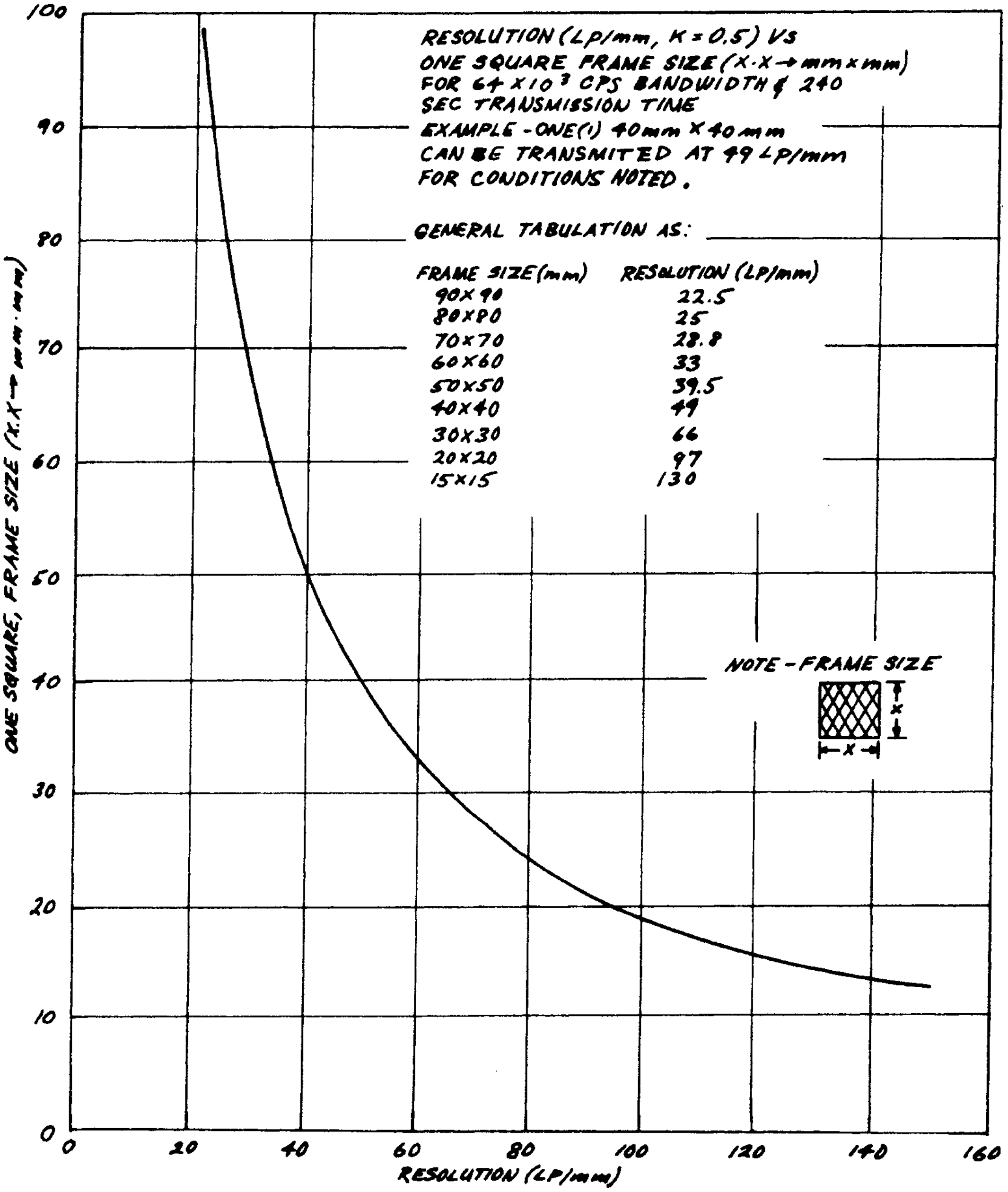


Figure 3.3-4. Resolution vs One Square Frame Size

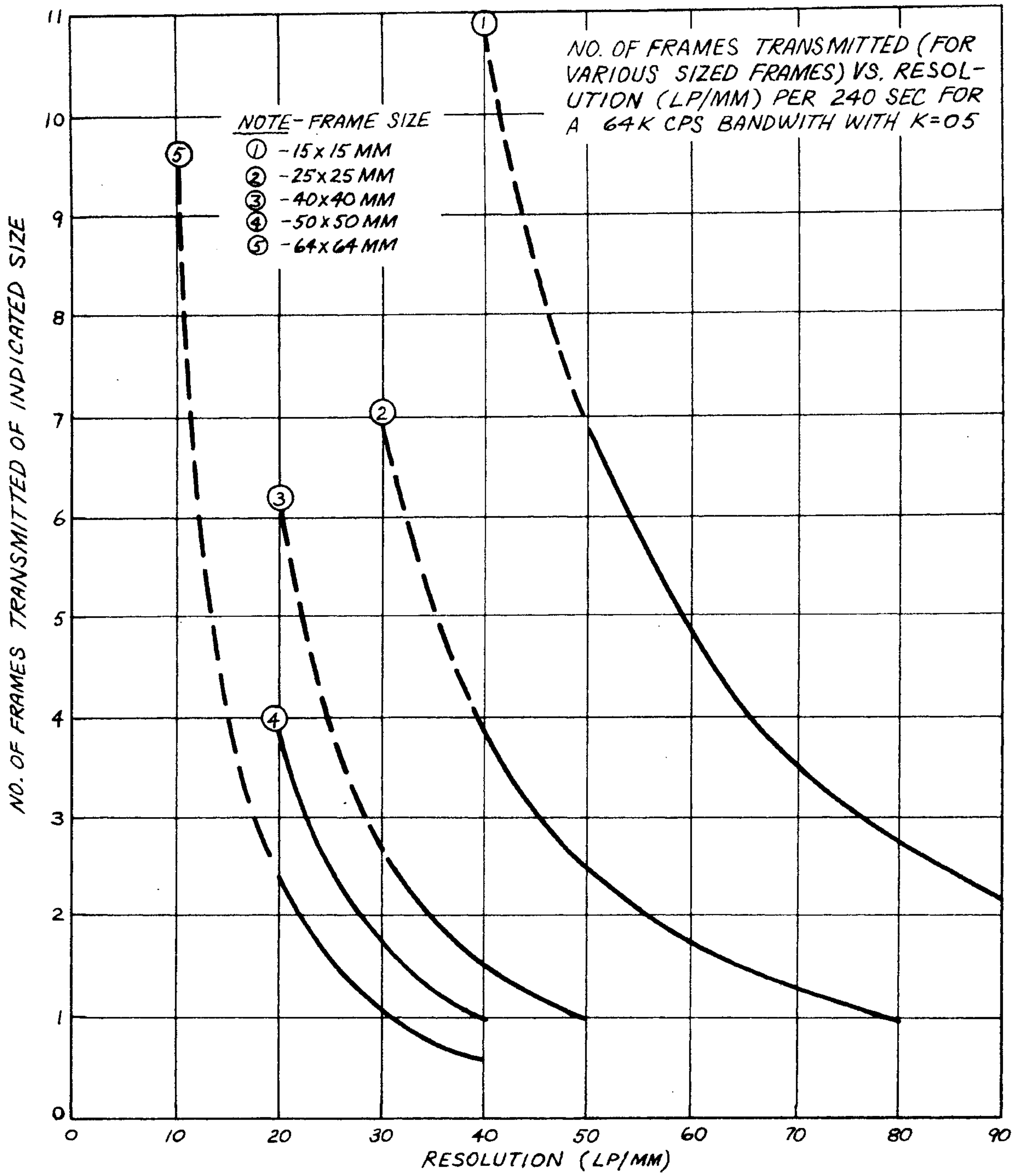


Figure 3.3-5. Number of Frames Transmitted vs Resolution

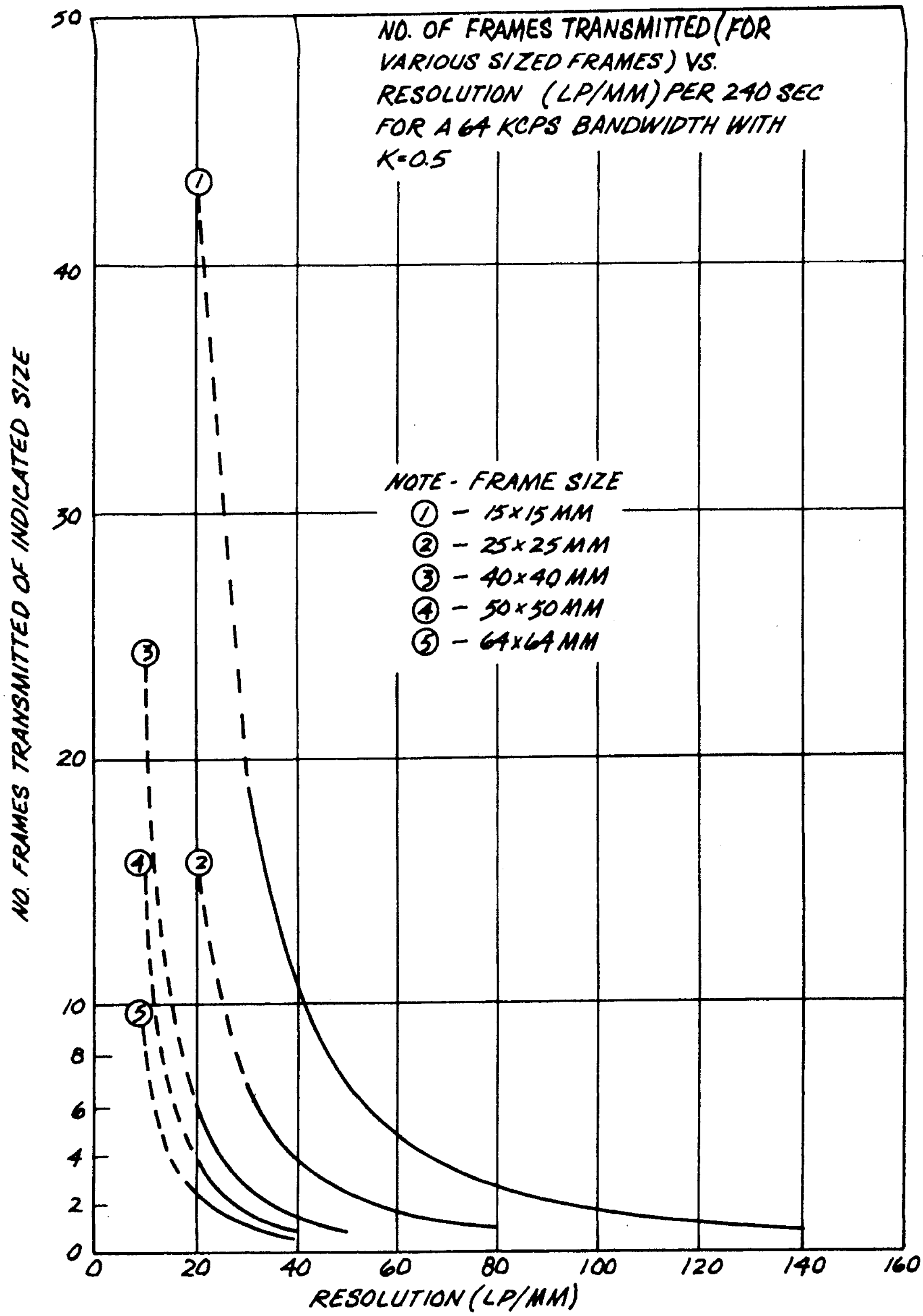


Figure 3.3-6. Number of Frames Transmitted vs Resolution (Compressed Ordinate)

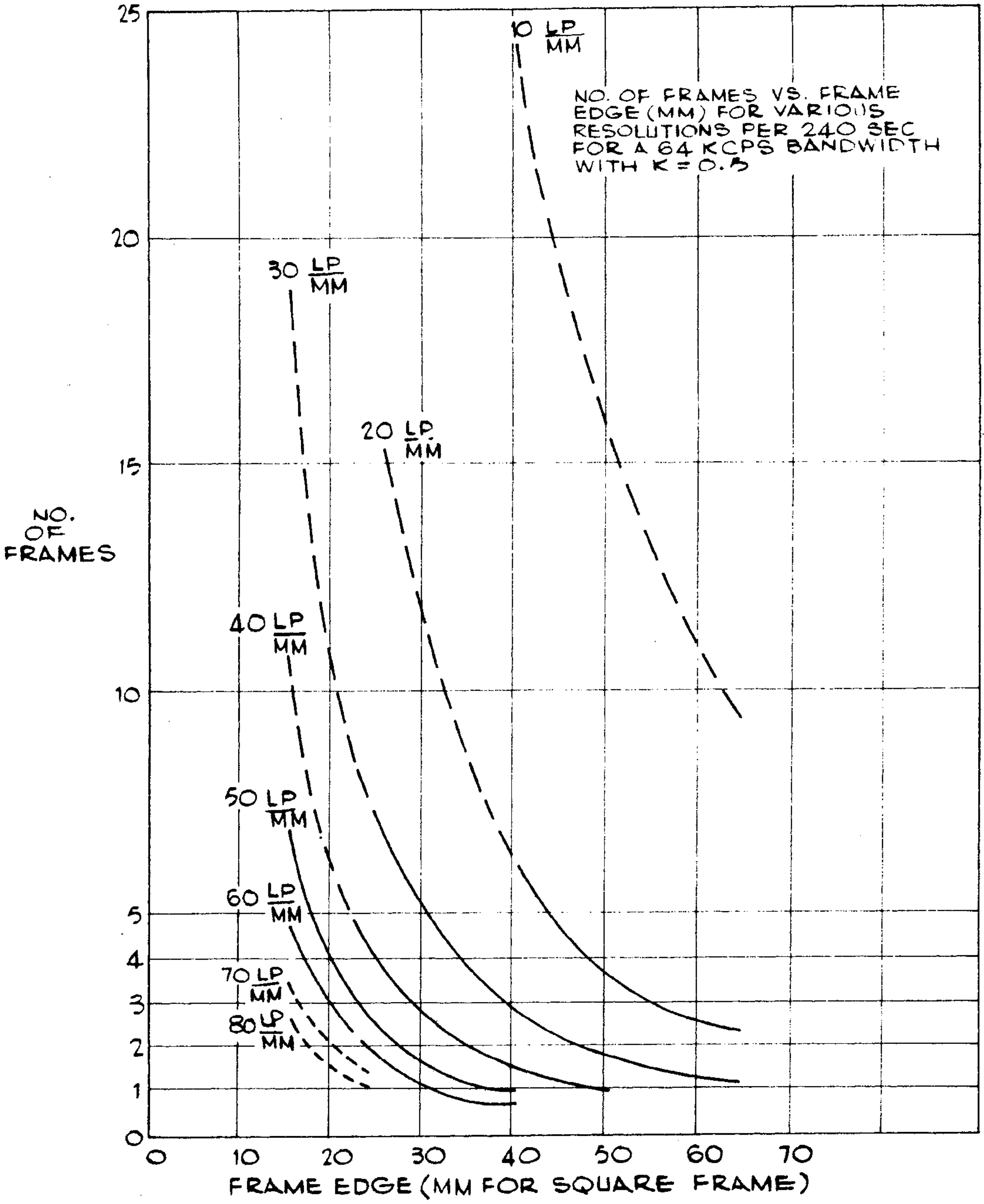


Figure 3.3-7. Number of Frames vs Frame Edge

Res. $\frac{lp}{mm}$	$\frac{1}{Res.}$ $\frac{\mu}{lp}$	Spot Size (μ) For Correction Factors and Kell Factors													
		2.0 K = 1.0	2.1 K = .953	2.2 K = .909	2.3 K = .87	2.4 K = .833	2.5 K = .80	2.6 K = .771	2.7 K = .741	2.8 K = .715	2.9 K = .69	3.0 K = .667	3.5 K = .571	4.0 K = .50	5.0 K = .40
20	50	2.5	23.8	22.7	21.8	20.8	20.0	19.2	18.5	17.9	17.2	16.7	14.3	12.5	10.0
40	25	12.5	11.9	11.4	10.9	10.4	10.0	9.63	9.27	8.94	8.63	8.34	7.15	6.25	5.0
60	16.7	8.95	7.96	7.59	7.27	6.95	6.69	6.41	6.19	5.95	5.77	5.57	4.77	4.17	3.33
80	12.5	6.25	5.96	5.69	5.44	5.21	5.0	4.81	4.64	4.47	4.31	4.17	3.57	3.13	2.5
100	10	5.0	4.77	4.55	4.35	4.17	4.0	3.85	3.71	3.57	3.45	3.34	2.86	2.5	2.0
120	8.33	4.17	3.97	3.79	3.63	3.47	3.33	3.21	3.09	2.98	2.87	2.78	2.38	2.08	1.67
140	7.14	3.57	3.40	3.25	3.11	2.97	2.86	2.75	2.65	2.55	2.46	2.38	2.04	1.79	1.43
150	6.67	3.34	3.17	3.03	2.90	2.78	2.67	2.56	2.47	2.38	2.30	2.22	1.91	1.67	1.33
160	6.25	3.13	2.97	2.84	2.72	2.60	2.50	2.40	2.32	2.23	2.16	2.09	1.78	1.56	1.25
180	5.56	2.78	2.65	2.52	2.42	2.32	2.23	2.14	2.06	1.98	1.92	1.85	1.59	1.39	1.11
200	5.0	2.5	2.38	2.28	2.17	2.09	2.0	1.93	1.85	1.79	1.72	1.67	1.43	1.25	1.00
220	4.45	2.28	2.16	2.07	1.98	1.89	1.82	1.75	1.68	1.62	1.57	1.52	1.30	1.14	0.91
240	4.17	2.09	1.98	1.89	1.81	1.74	1.67	1.60	1.54	1.49	1.44	1.39	1.19	1.04	0.84
260	3.85	1.93	1.83	1.75	1.67	1.61	1.54	1.48	1.43	1.38	1.33	1.29	1.10	0.96	0.77

Figure 3.3-8. Resolution vs Spot Size

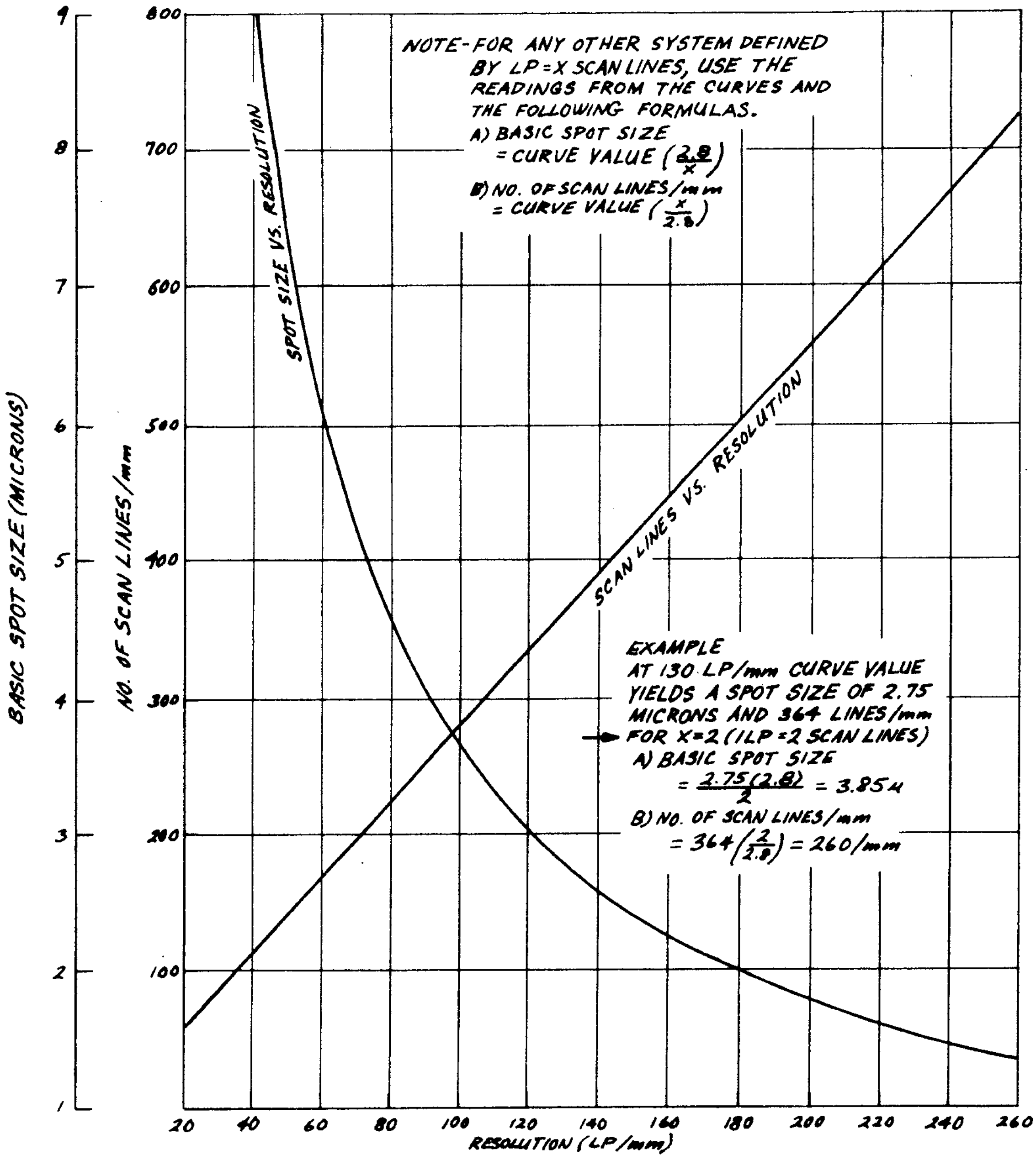


Figure 3.3-9. Spot Size and Number of Scan Lines/mm vs Resolution

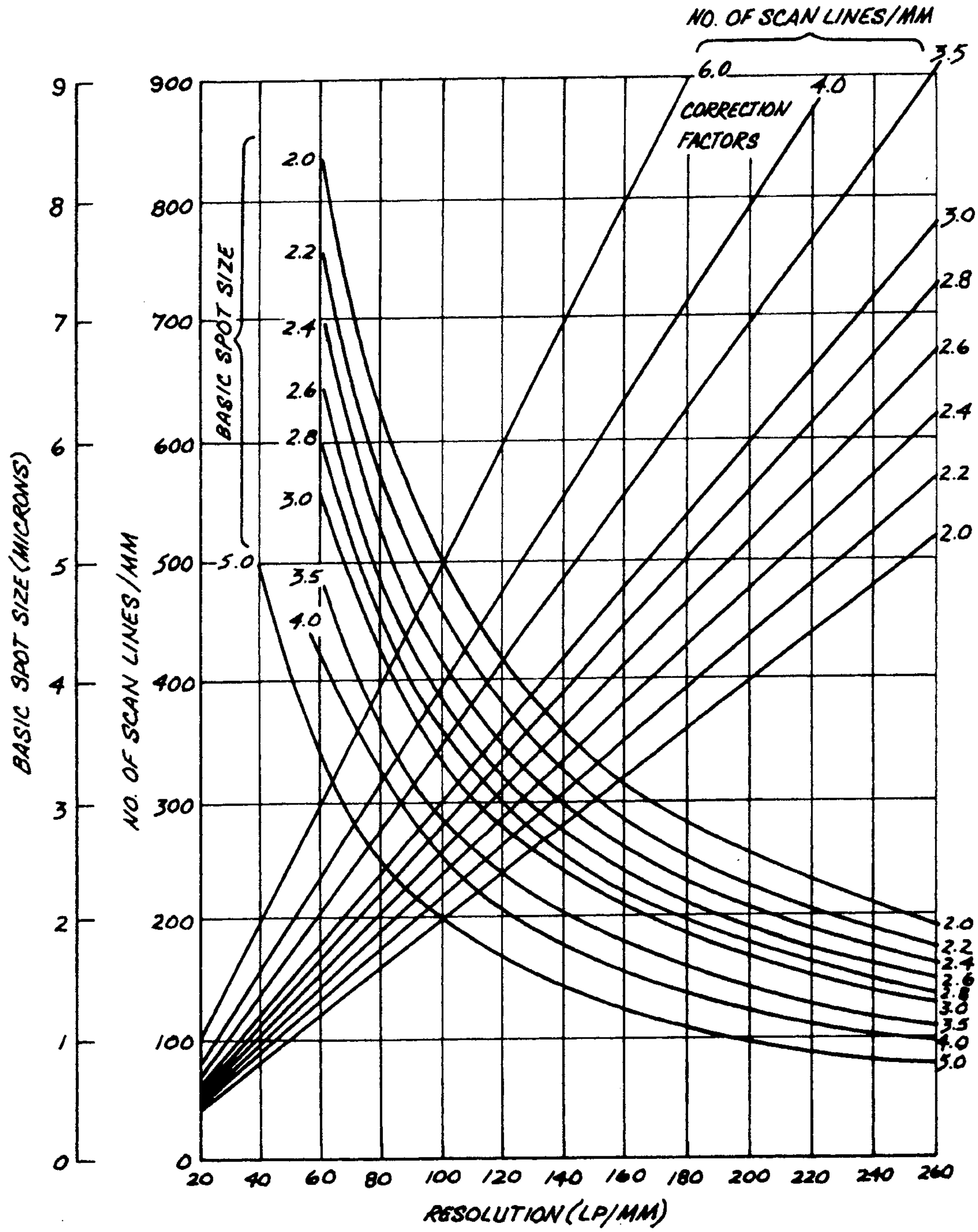


Figure 3.3-10. Basic Spot Size and Number of Scan Lines/mm vs Resolution

Res. lp/mm	Number of Scan Lines/mm For Correction Factors and Kell Factors													
	2.0 K = 1.0	2.1 K = 0.953	2.2 K = 0.909	2.3 K = 0.87	2.4 K = 0.833	2.5 K = 0.80	2.6 K = 0.771	2.7 K = 0.741	2.8 K = 0.715	2.9 K = 0.69	3.0 K = 0.667	3.5 K = 0.571	4.0 K = 0.50	5.0 K = 0.40
20	40	42	44	46	48	50	52	54	56	58	60	70	80	100
40	80	84	88	92	96	100	104	108	112	116	120	140	160	200
60	120	126	132	138	144	150	156	162	168	174	180	210	240	300
80	160	168	176	184	192	200	208	216	224	232	240	280	320	400
100	200	210	220	230	240	250	260	270	280	290	300	350	400	500
120	240	252	264	276	288	300	312	324	336	348	360	420	480	600
140	280	294	308	322	336	350	364	378	392	406	420	490	560	700
150	300	315	330	345	360	375	390	405	420	435	450	525	600	750
160	320	336	352	368	384	400	416	432	448	464	480	560	640	800
180	360	378	396	414	432	450	468	486	504	522	540	630	720	900
200	400	420	440	460	480	500	520	540	560	580	600	700	800	1000
220	440	462	484	506	528	550	572	594	616	638	660	770	880	1100
240	480	504	528	552	576	600	624	648	672	696	720	840	960	1200
260	520	546	572	598	624	650	676	702	728	754	780	910	1040	1300

Figure 3.3-11. Resolution vs Number of Scan Lines/mm

A. Laser

1. Size: 16 inches L x 2-inch dia.
2. Weight $\cong$ 1 pound or less, not including electronics
3. Power In/Out: 10 watts/0.1 mw
4. Output Beam Dia: 2 mm
5. Beam Divergence: 10^{-4} radians
6. Warmup Time: 5 to 10 minutes
7. Useful Operating Life: 3000 hours (includes on/off cycling)
8. Maintenance: Direct replacement of cavity tube and mirrors (no alignment required).
9. Helium Effects: Described in a later paragraph.
10. Type: He-Ne, TEM mode, $\lambda = 6328\mathring{A}$

B. Beam Expander and Normalizer, Imaging Lens - Examine first the imaging lens. In the region of diffraction limited optics,

$$A = \frac{1.22\,\lambda F}{d}, \qquad f\# = \frac{F}{A} = \frac{d}{1.22\lambda}$$

For

$$\lambda = 6.328 \times 10^{-4}\ \text{mm}$$

$$F = 3\ \text{inches} = 76\ \text{mm}$$

$$d = 5\ \mu = 5 \times 10^{-3}\ \text{mm}$$

Then,

$$A = \frac{1.22\,(6.328 \times 10^{-4})\,(76)}{5 \times 10^{-3}} = 11.7\ \text{mm}$$

The important dimension here is the focal length which is tied in with the scan length and spinner requirements. The f number of the required lens is f/6.5. Thus, we have for various focal lengths:

f (in.)	A (in.)
2	0.31
3	0.46
4	0.62
5	0.77
6	0.92

Thus, for a 3-inch focal length lens, the requirement is for a 0.46-inch aperture (lens should be diffraction limited). It is suggested that an f/4 or higher lens be utilized with stopped down aperture as required.

Requirement is for a nominal 2-mm output laser and 12-mm output diameter beam. Magnification here is then 6X or optimal magnification is 9X. As various lenses may be used, we allow a 2-inch diameter x 15-inch maximum length.

C. Spinner and Motor - For a 25 mm scan length we require a 0.80-inch scan radius for a 5 facet spinner and a 1.60-inch scan radius for a 10 facet spinner. The 10 faceted mirror spinner, although harder to fabricate to required dimensional tolerances, is more desirable due to a larger film forming radius with less strain on the film.

The proposed method of scan is a 50 percent overlap between consecutive lines. Readout rate is based on a full spot size (50% amplitude) i.e.,

[redacted] $\frac{lp}{mm}$ (2) $\rightarrow$ [redacted] $\frac{lines}{mm}$

Therefore, spot size is then [redacted]. Thus, the film advance in a direction perpendicular to the scan with 50 percent overlap is 2.2 μ/line. For a 25 mm film length, we require:

$$\frac{25\text{ mm}}{[\text{redacted}]\ \frac{\text{mm}}{\text{line}}} = [\text{redacted}]\ \text{lines}$$

Motor RPM here is given as:

$$\text{Motor RPM} = \frac{\text{No Lines/sec}}{\text{\# Facets on Spinner}} \times 60$$

For a total 240-second readout:

$$\text{Motor RPM} = \frac{[\text{redacted}]}{10} \times 60 = [\text{redacted}]\ \text{RPM}$$

The requirements for motor power depend on windage and allowed time to accelerate to speed and to change to another rotational rate for varied resolution readout. We estimate a 5 to 10-watt requirement.

D. Film Former and Feed - The required readout radius is formed by passage over a curved highly polished radial shaped bridge. In this system, the referenced readout plane is the transparency emulsion. A typical system discussed previously is one based on a continuous transparent belt to which the film chip is attached.

Using spring tension rollers, we estimate a 5-watt requirement for the drive motor.

E. Light Pipe and PMT - The light pipe will be designed as required. The PMT will have a S-20 response. A typical tube is an RCA 7265 which is 7.50 inches overall length and 2.38-inch diameter.

F. Electronics - Associated with the scanner are various electronic packages. These include the spinner motor servocontrol and the film drive feedback. The output amplifier is also considered to be part of this system. One may also include an output level circuit (i.e., a beam splitter and photo-detector) tied to the amplifier to correct any light level fluctuations in the system. We estimate this electronics as 7 pounds and 6 watts.

A general summary on which we base size, weight and power requirements is presented in Table 3.3-6. Estimated power is in the 30/40 watts range with a requirement for 30/40-pound package.

G. Ground Reconstruction - Reconstruction on the ground (assume there are associated tape recorders for redundancy) is to be made by a mirror image laser system with an included Pockle's type modulator. The laser power for recording must be adequate to expose the film to the maximum desired density. Required laser power is given by:

$$P_o = \frac{Eak}{BT}$$

where:

E = Emulsion sensitivity for max density $\cong$ 25 ergs/cm^2

B = Optical transfer efficiency = 0.02

T = Time of exposure over area (sec)

a = Scanned area on film (cm^2)

k = Reciprocity failure factor (higher power for short exposure) = 4

$\frac{a}{T}$ = Area scan rate (cm^2/sec).

Table 3.3-6. Estimated Weight and Power Requirements

Component	Size (inches)	Weight (pounds)	Power (watts)	Comments
Structure and Optical Bench	-	10	-	Optimized as required.
1. He-Ne Laser	16L x 2Dia.	1	10 (includes Power Supply)	Output beam Dia=2mm; Beam divergence=10^{-4} rad; 0.1 mw output power.
2. Beam Expander	15L max x 1-1/2Dia.	2	-	Nominal 9X magnification.
3. Normalizer	2D max	Neg.	-	See Text.
4. Imaging Lens	2L x 1-1/2Dia.	0.5	-	f/6.5 diff limited. Use f/4 or higher and stop down f = 3 inches with 0.5-inch clear aperture.
5. Spinner and Motor	-	4	5 to 10	Wattage defined by time/speed requirement.
6. Drive, Film Feed, and Former	-	3	5	Basic film handling investigation required.
7. Light Pipe and PMT	Tube 7.5L x 2.5Dia.	2	2	See RCA Pamphlet PIT-703.
General Mechanical	-	3	-	As Required.
Electronics	-	7	6	Includes spinor motor servo control and film drive feedback.
Total Estimate		30/40 pounds	30/40 watts	

Consider a 1 inch x 1 inch film chip with readout in 240 seconds. Linear scan rate is:

$$\frac{a}{T} = \frac{2.54 \text{ cm}}{240 \text{ sec}} \times 2.54 \text{ cm} \rightarrow 2.68 \times 10^{-2} \ \frac{\text{cm}^2}{\text{sec}}$$

Thus,

$$P_o = \frac{25(2.68 \times 10^{-2})\ (4)}{2 \times 10^{-2}} = 129 \ \frac{\text{ergs}}{\text{sec}} = 12.9 \times 10^{-6} \ \frac{\text{joules}}{\text{sec}}$$

$$= 13 \ \mu \text{ watts}$$

Consider ground reproduction or reconstruction at a magnified aerial rate, i.e., the original 1 inch x 1 inch film chip is to be reconstructed into a 9 inch x 9 inch photo. The enlargement factor here is $9^2 = 81$ with required power as,

$$P_o = 13 \times 10^{-6} \times 81 = 1 \text{ mw}$$

This requirement is easily fulfilled by a number of commercial off the shelf lasers.

The ground reconstruction at a magnified image leads to a number of advantages among which is enlarged "write" spot size. A [redacted] spot enlarged 5X requires a reconstruction spot of [redacted] diameter. Thus, requirements on diffraction limited lenses and high precision spinners as are necessary for AVE equipment may be relaxed somewhat for the AGE "write" counterpart.

Both He-Ne and Argon lasers may be used in the AGE. All factors being equal, a blue light output in the 0.4 range is preferrable due to lower diffraction limits ($\delta = \frac{1.22\tau}{a}$) and maximum film emulsion sensitivities in this region. The Argon laser produces a series of wavelengths. The 4880Å max output may be isolated by filter techniques. Other reconstruction techniques are possible (i.e., FSS) but a mirror image laser type system is recommended due to the fact that peculiarities tend to cancel in certain instances.

3.3.2.7 General Summary and Extension to Future Missions (Growth Potential)

In the last section specific system generation for a laser scanner device was examined. Expected parameters are summarized below:

a. [redacted] at 50 percent response.
b. 50 percent scan overlap of consecutive lines.
c. Basic spot size at film plane 4.4.
d. Per pass scan time = 240 seconds.
e. Bandwidth = 200×10^3 hz.
f. Scan width $\cong$ 25 mm (fixed for a given system)
g. 40 db (S/N) ratio
h. 30 to 40-watt power requirement
i. 30 to 40 pounds weight.

It is important to note that the system designed herein is to be considered a typical one. Other laser scanner systems, employing the same principles but other mechanization techniques have been suggested by CBS Laboratories per GE request. All of these systems have the same general characteristics described in the previous paragraph.

We examine here the extension to future missions or growth potential. Desirable in any general system are variable scan width, and variable scan rate and resolution. These factors have been discussed previously. It was noted that:

a. The scan length may be changed by various techniques including a change in the scan radius (attendant changes must also be made in the positioning of the imaging lens and film former radius) or changing the number of facets on the spinner. The scan length decreases, for a fixed radius, as the number of spinner facets increases with attendant increase of line scan out rate per revolution. Systems considered included a motor with a "n" faceted spinner on one side and one with m facets on the other. (180-degree indexing would yield two scan lengths). Another possiblity is the use of a flip mirror in the parallel light path to direct the flux to either of two systems with different scan length characteristics.

b. In general, various resolutions may be obtained by degrading readout spot size by insertion of a variable thickness parallel plate in the beam expander.

It is noted that the selected laser output power of 0.1 mw should be sufficient to accommodate an increased bandwidth capability of > 5 Mhz.

The approach taken here is of a general nature and based on a mechanical rotating scanner. Low bandwidth requirements coupled with relatively low resolution requirements could lead to a vibrating type laser scanner with significant power savings. It would be one of the aims of a study program to optimize the scanning technique with respect to mission parameters.

3.3.3 FPS VIDICON TYPE SCANNER

The FPS vidicon camera tube is a GE development with included future planned effort for increasing resolution and input face size. This concept employs magnetic focus and electrostatic deflections which (superimposed in the same volume) yields inherently higher performance than conventional camera tubes where focus and scanning are accomplished in sequential fashion. The simultaneous approach performs the required camera tube functions with the added convenience of electrostatic deflection, minimal volume and overall weight as well as reduced power requirements. The FPS is magnetically self-shielding and can be designed for spot demagnification. This permits high resolution performance in a camera tube of small size, low voltage, and low power consumption.

Examine a typical requirement for an optical resolution on the tube face in the vertical direction of 17.5 lp/mm. Optical magnification of the photograph will be used to permit this system to transmit the [redacted] film resolution. With a raster size of 64 x 64 mm, there will be (17.5 x 64) 1120 optical resolution elements in the field-of-view. The required optical resolution (r) is one part in 1120 or 0.893 parts per thousand.

The optical resolution is related to TV resolution by a factor of 2 (line pairs). That is 2 TV lines are required to distinguish one line pair. Let N equal the number of TV lines per frame required to produce a TV resolution of n. Then,

$$N = \frac{n}{(K)\,(K_V)} = \frac{n}{0.65}$$

where K is the Kell factor equal to 0.7 and K_V is vertical duty cycle (typically equal to 0.93).

In order to have the same optical resolution in both horizontal and vertical directions, the bandwidth must be considered. Another factor that has to be considered is the S/N ratio. The vidicon tube is an equivalent current generator that has an extremely high inpedance. The inherent noise level of the device is small and the noise limitation is determined by the video preamp that follows the tube. The equivalent noise current of the preamp referred to the input may be considered as the only source of noise. Since the pickup tube has an upper limit for output signal current, the dynamic system range is determined by the preamp which dicates the illumination level for the scene that is in view. As the noise power of the source is a function of the bandwidth, and the system is signal amplitude limited, the S/N may be enhanced by reducing the bandwidth of the video.

Based on an optical resolution of 1120 optical lines there must be a TV resolution of at least 2240 TV lines. In order to achieve this value, there must be N TV lines per frame or

$$N = \frac{n}{K} = \frac{2240}{0.7} \longrightarrow 3200 \text{ where K is the Kell factor.}$$

The vertical rate will be strongly influenced by the capability of the target material used in the pickup tube. Typical compatable materials lead to a vertical frame rate of 2 cycles per second. Based on this estimate and 3200 horizontal lines/frame, the total time required for each line in the horizontal direction would be 156 μ sec. Based on previous experience, a flyback time of 10 μ sec. is expected. Thus the active horizontal scan is approximately 146 μ sec. Since this active time must be divided into 3200 lines or 1600 cycles, the video bandwidth required for the system is:

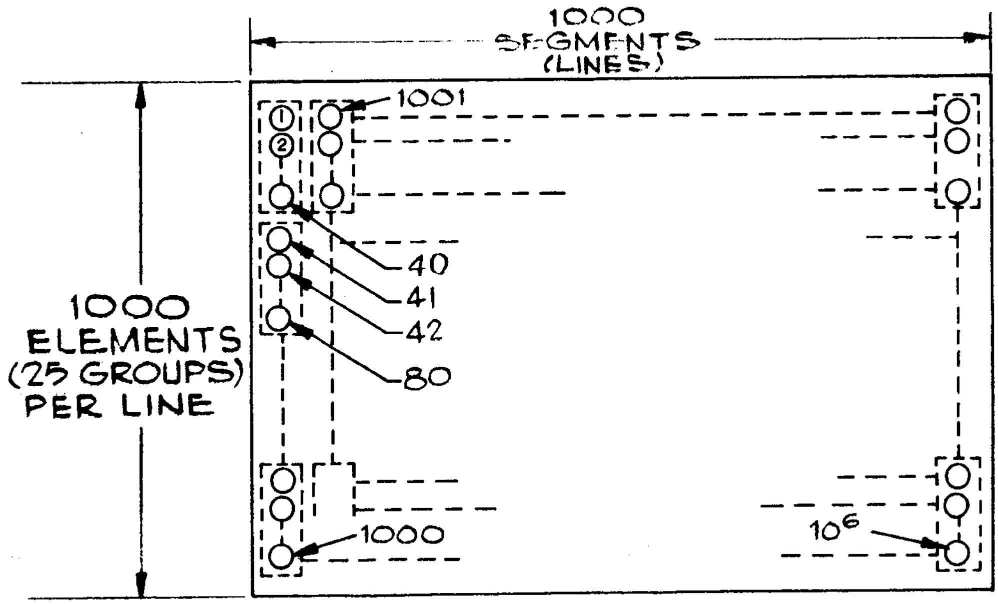
$$B = \frac{1600}{146 \times 10^{-6}} = 11 \text{ MHz}$$

The previous considerations were based on a readout at 17.5 ℓp/mm, Kell factor = 0.7, 64 x 64 mm frame, and 2 frames/second readout. In the considered application of the TV camera system, requirements are for reading out of a frame in a short time (i.e., 240 seconds). If one had a target material with these storage capabilities, the above derived bandwidth could be reduced considerably, specifically by a factor of 1/480. The proposed solution is considered in the following sections and represents a bandwidth compression by readout of a small part of the total readout area each time the last scan is repeated.

At times it is desirable to slow down the data rate from a data scanning system without slowing down the actual scanning rate of the system. This can be advantageous, for example, in handling the data from a fast scan television camera. The basic idea is to pick out one or more data elements of the information each time the information is scanned at the high rate. Then, each time the fast scan is repeated, a different information element, or a different group of information elements, are selected. The fast scanning would be repeated until all of the data elements have been readout. The slow readout of the data elements makes it possible to process the data (record and/or transmit) at low bandwidths.

This technique solves the problem of how to handle the wideband video information from electro-optical systems without the use of shuttering, wide bandwidth tape recorders or other memory devices with a capability of storing all of the wideband video data for a complete picture. For example, a picture having a 1000 horizontal by 1000 vertical line resolution and digital encoding of the video signal to four bits, the required storage capacity is in the order of four million bits. This idea eliminates the need for this storage or dependence on optimum system configuration and reduces the storage requirement by many orders of magnitude along with the capability of reducing the required bandwidth of the memory used. The technique is illustrated in Figure 3.3-12 and the block diagram of the system is illustrated in Figure 3.3-13.

The basic system can best be understood by a description of a typical application of the idea to a spacecraft TV system employing a fast scan vidicon to take pictures of the earth. Figure 3.3-12 illustrates the number of picture elements in a picture containing 1000 by 1000 line resolution. As can be seen in the figure, there are a total of 10^6 elements in the complete picture. In this particular spaceborne system,the data transmission rate is limited to 2.5 kilobits/second because of the limitation in available vehicle power for the transmitter. The standard camera system which is desireable for use in this system utilizes a horizontal frequency of 15 KHz and a vertical sweep frequency of 15 cycles/second. In this system, each picture element is being encoded to 16 gray levels (i. e., a four-bit



1. STORE 40 PICTURE ELEMENTS (40 × 4 = 160 BITS).
2. TRANSMIT 160 BITS DURING ONE NORMAL TV PICTURE SCAN TIME.
3. ONE PICTURE SEGMENT IS TRANSMITTED IN 1.6 SECONDS.
4. THE EFFECTIVE CAMERA MOVEMENT DUE TO ATTITUDE CONTROL RATES BETWEEN ADJACENT SEGMENTS OF THE PICTURE IS SIGNIFICANTLY LESS THAN ONE PICTURE ELEMENT.

Figure 3.3-12. Bandwidth Compression Technique

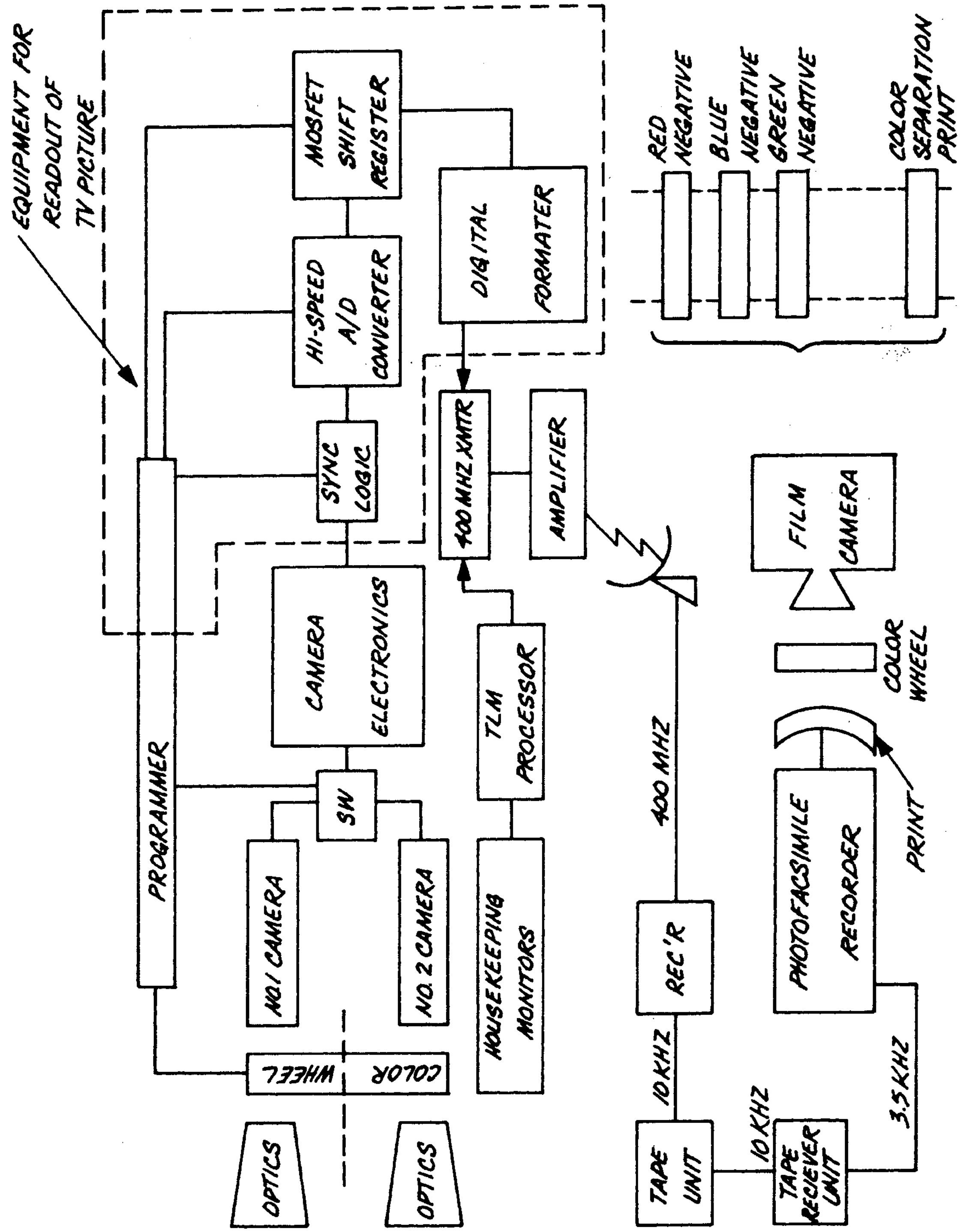


Figure 3.3-13. Bandwidth Compression System Block Diagram

digital word). The relationship between the transmitter rate and the vertical sweep time is such that 40 picture elements can be transmitted to the ground while one complete vertical frame is swept by the camera. For this reason, the picture is divided into groups (each group containing 40 picture elements). As shown in Figure 3.3-12 (starting with the first picture element on the first line), the element is encoded to digital and dumped into a small buffer memory having a total capacity of 160 bits (40 picture elements x 4 bits per element). As the first horizonal line is swept, the encoding and the dumping of the 4 bits into the small buffer memory takes place. As the second line is swept by the camera, the first picture element in that line (the No. 2 picture element as shown in Figure 3.3-12) is encoded and stored in the memory. The process continues until all 40 picture elements (the first picture element of each of the 40 lines) are encoded and stored. As the camera scans the other lines of the picture, the 160 digital bits representing these 40 elements are transmitted to the ground. During the next scan, the next group of 40 picture elements are encoded and stored in the buffer memory (i.e., in this case starting with the 41st and ending with the 80th as shown in Figure 3.3-12). The process continues until 25 of these groups have been encoded and transmitted, thereby completing the transmission of one vertical line of picture information to the ground station. During the 26th scan of the picture, the second picture element on the first horizonal scan line is encoded and dumped into the buffer storage (picture element 1001).

The process continues to get the complete second vertical line of picture elements transmitted to the ground. This process is continued, from line to line, until the complete picture has been encoded and transmitted to the ground. In this particular application, the advantage of doing the encoding and storage (going vertically down the picture rather than horizonally) is that a much slower A/D converter and memory can be used if the vertical approach is taken. The reason for this is that if we took the first 40 picture elements along the horizonal line (or any 40 consecutive picture elements along a horizonal line), the time duration of one picture element, (67 nanoseconds) would require a complete encoding and entering of the digital word into the buffer memory in a 67 nanosecond period of time. This is difficult and requires very high speed, high powered circuitry. The approach taken where one picture element on each horizonal sweep is encoded and stored, results in 67 microseconds of time allowed for the encoding and storage process. The saving in equipment complexity and power is very significant. There are various ways that could be used to pick out a particular picture element on each horizonal line for encoding. Digital counting techniques, as well as digital counting and D/A conversion techniques, or analog voltage ramp generator techniques, could be considered. The method chosen for this particular system was the development of a digital word, converting this to analog and incrementing the digital word one quantum level each time it is desired to move to the next vertical line of picture elements. The output of the D/A converter is compared against the actual voltage applied to the camera deflection plates. When the two voltages are equal, a switch is opened which allows circuitry to sample the analog value of the video signal at that time. The advantage of selecting the picture elements transmitted to the ground is not a function of the camera analog sweep voltage but of the much more accurate analog voltage developed at the output of the D/A converter.

In this example, the basic technique is applied so that the camera system is allowed to scan at its normal high frequency rate on a continuous basis while the actual video information desired from the picture is transmitted at the mich slower transmitter bit rate.

The discussion in subsequent paragraphs is based on the fact that the noise of vidicon pick-up tube is a negligible quantity when it is compared to the noise of the preamp that is in cascade with the signal lead of the tube. This fact is well documented in the literature. An additional problem that is encountered in high resolution TV systems is the fact that the modulation transfer function of the tube falls off at an alarming rate as a function of the spatial frequency that is present in the optical image. A basic problem that exists in this particular system is that of obtaining the spatial resolution at a contrast ratio of 1:1.12.

In order to assess this problem let us examine the signal current that will be present in the tube and then determine the specifications that are necessary for the preamp.

Assuming that a given number of shades of grey are required for the image, each shade of grey will be brighter than the adjacent shade by factor of the sixth root of 2, which is equal to 1.12. We use the light transfer characteristics shown in Figure 3.3-14. This curve is derived from the signal current equation:

$$i_s = KI^{\gamma}$$

where

i_s = signal current

I = illumination

K = constant = 0.412

γ = gamma = 0.88

From Figure 3.3-14, it is seen that if one foot candle were on the face plate of the pickup tube, there will be 300 nA of signal current. However, this is the DC current that is present when the tube is flooded with light. In order to determine the AC signal current that would be present for a particular spatial frequency, the MTF curve of Figure 3.3-15 must be applied. Assuming a 300 nA DC signal at 1 FC, there would be approximately 65 percent of this at 17.5 ℓp/mm (this is an AC signal of 195 nA) for a 100 percent contrast image. If the adjacent objects that have to be discriminated in the image plane have a contrast of 1.12, the signal current from the adjacent sector will be (195/1.12) -174 nA. The difference in signal current is 21 nA.

With an equivalent noise current in the preamp of 1.5 nA, a signal to noise ratio of 23 db can be attained. Although this is not as high a figure as is desireable, experience has shown that it will yield a good picture on a TV monitor. Note that a higher input illumination would yield a corresponding higher output and S/N ratio.

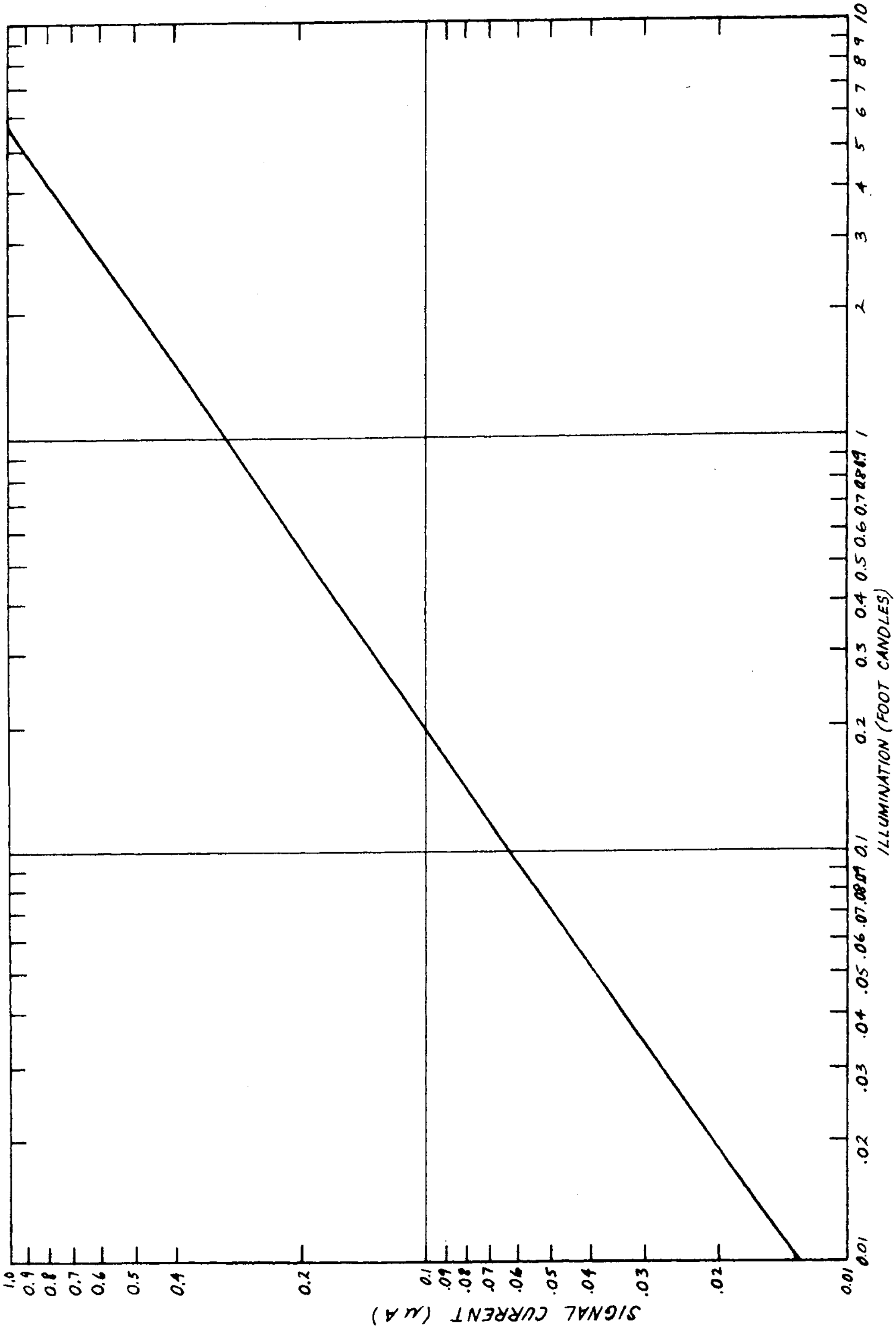


Figure 3.3-14. Light Transfer Characteristics

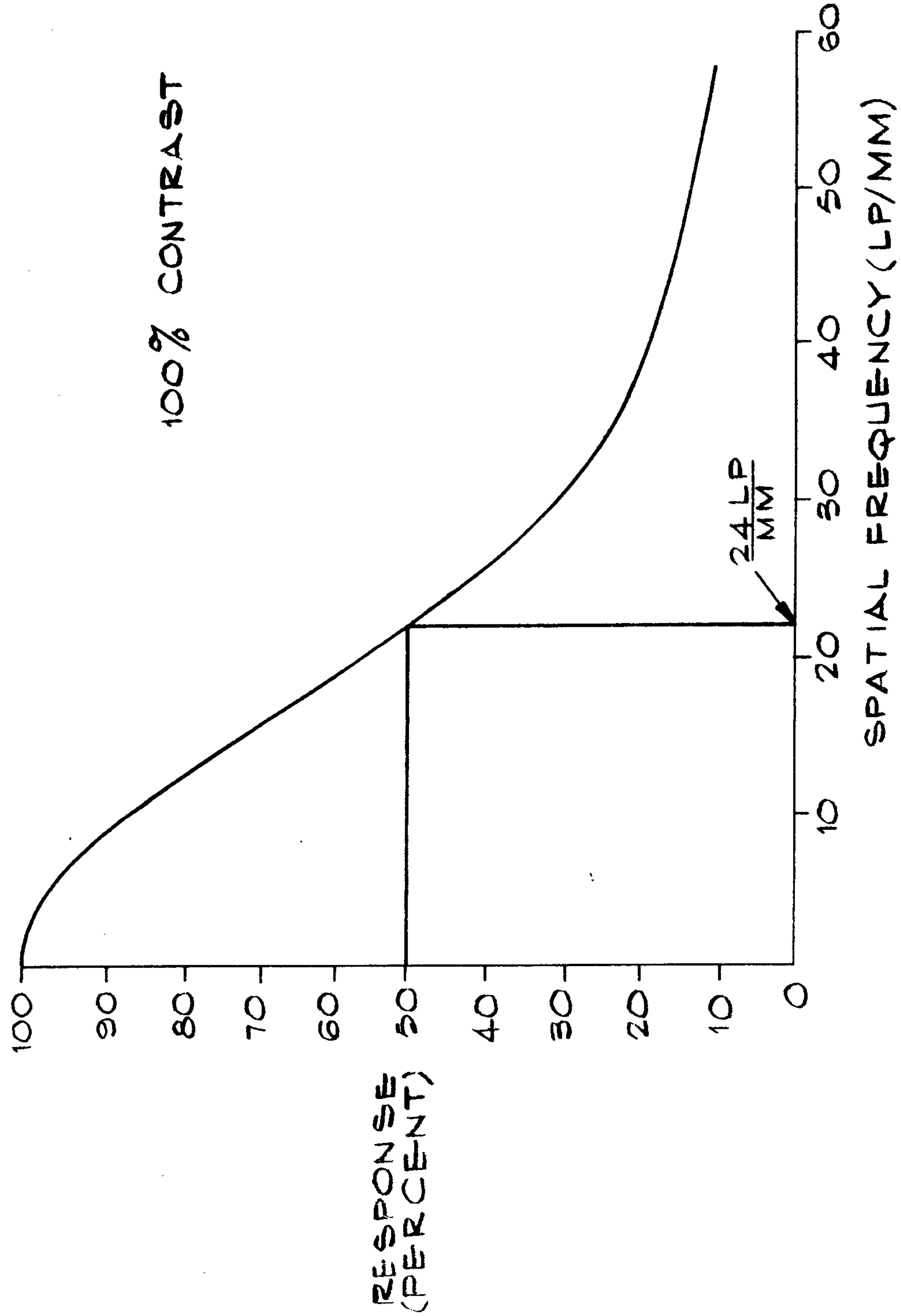


Figure 3.3-15. Vidicon Modulation Transfer Function

[redacted]

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3.5 DATA SECURITY CONSIDERATIONS

3.5.1 ENCRYPTED TRANSMISSION

The existing operational encryptors are basically scramblers with no change in the data transmission rate between input and output and operate at rates up to 1.024 Mbps.

An encryptor is presently part of the baseline MOL equipment and is compatible with the recommended 2-bit delta modulation technique. No significant problems can be identified in switching out the present input (telemetry) to the encryptor and switching in the delta modulator output. This will permit the readout data to be transmitted to earth using already existing equipment in the vehicle with the addition of the switching mechanism.

The encryptor along with the rest of the on-board SGLS equipment is a Douglas responsibility. Inclusion of the switching capability for readout will require a new interface with Douglas to cover this area.

3.5.2 UNENCRYPTED TRANSMISSION

It is expected that in the future, encryptors will operate at rates up to 20 Mbps. For Readout Systems operating at higher rates, other secure downlinks must be used.

In theory, a communication link can be made secure by means other than actual encrypting. A method that deserves consideration is that of spacial compacting. This is to say, confining the antenna beam pattern into a solid angle which can be contained within a secure volume of space. The mechanization of this approach involves an antenna of large aperture. The following equations show the relationship for gain, G, half power beam width, θ_0, and pointing loss, Lp:

$$G(db) = 10 \log \left[n \left(\frac{\pi D}{\lambda} \right)^2 \right]$$

$$\theta_o = \frac{70 \lambda}{D}$$

$$L_p \text{ (db)} = -20 \log \left[\frac{\sin \left(1.39 \frac{\theta_\epsilon}{\theta_o/2}\right)}{1.39 \frac{\theta_\epsilon}{\theta_o/2}} \right]$$

where:

n	=	antenna aperture efficiency
λ	=	wavelength
D	=	diameter of aperture in feet
θ_ϵ	=	antenna pointing error

Figure 3.5-1 shows G and θ_o versus aperture diameter. By use of a series approximation, the antenna pointing loss can be written as:

$$L_p = -3 \left(\frac{\theta_\epsilon}{\theta_o/2} \right)^2$$

This representation is a good measure of the pointing loss out to $\frac{2\theta_\epsilon}{\theta_o} = 1.33$, where it is in error by approximately 3 percent.

Figure 3.5-2 shows how the achievable antenna gain is affected by pointing loss. For example, if one has a 10-foot antenna diameter, a pointing error of 2.0 degrees would result in about a 4.7db loss. The MOL system has the capability to point to better than 1/4-degree which minimizes this loss. However, as pointing error is decreased, cost and equipment complexity increase. For some specified system pointing loss, then there is an optimum size antenna to use for link gain.

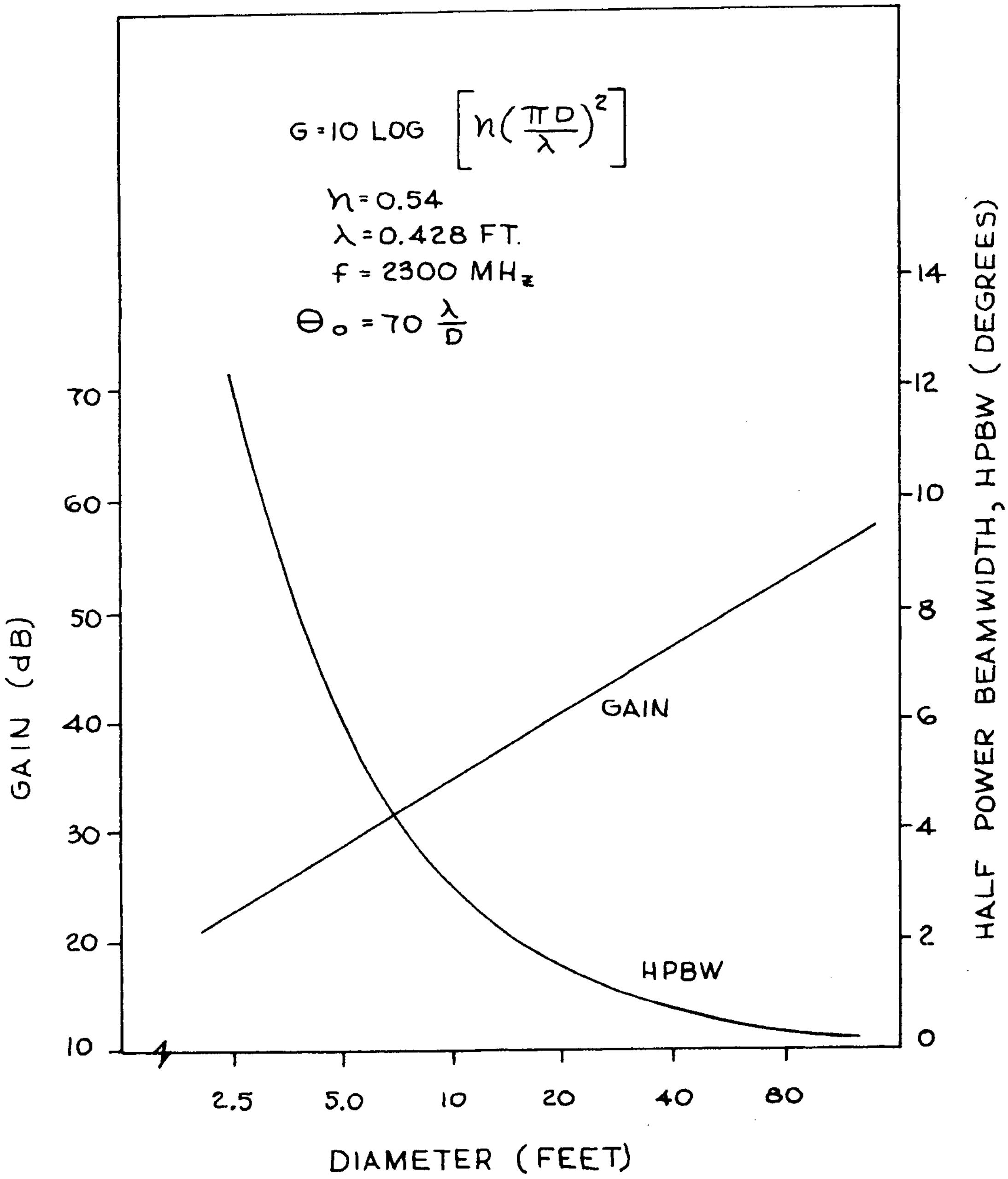

Figure 3.5-1. Parabolic Antenna Beamwidth and Gain vs Diameter

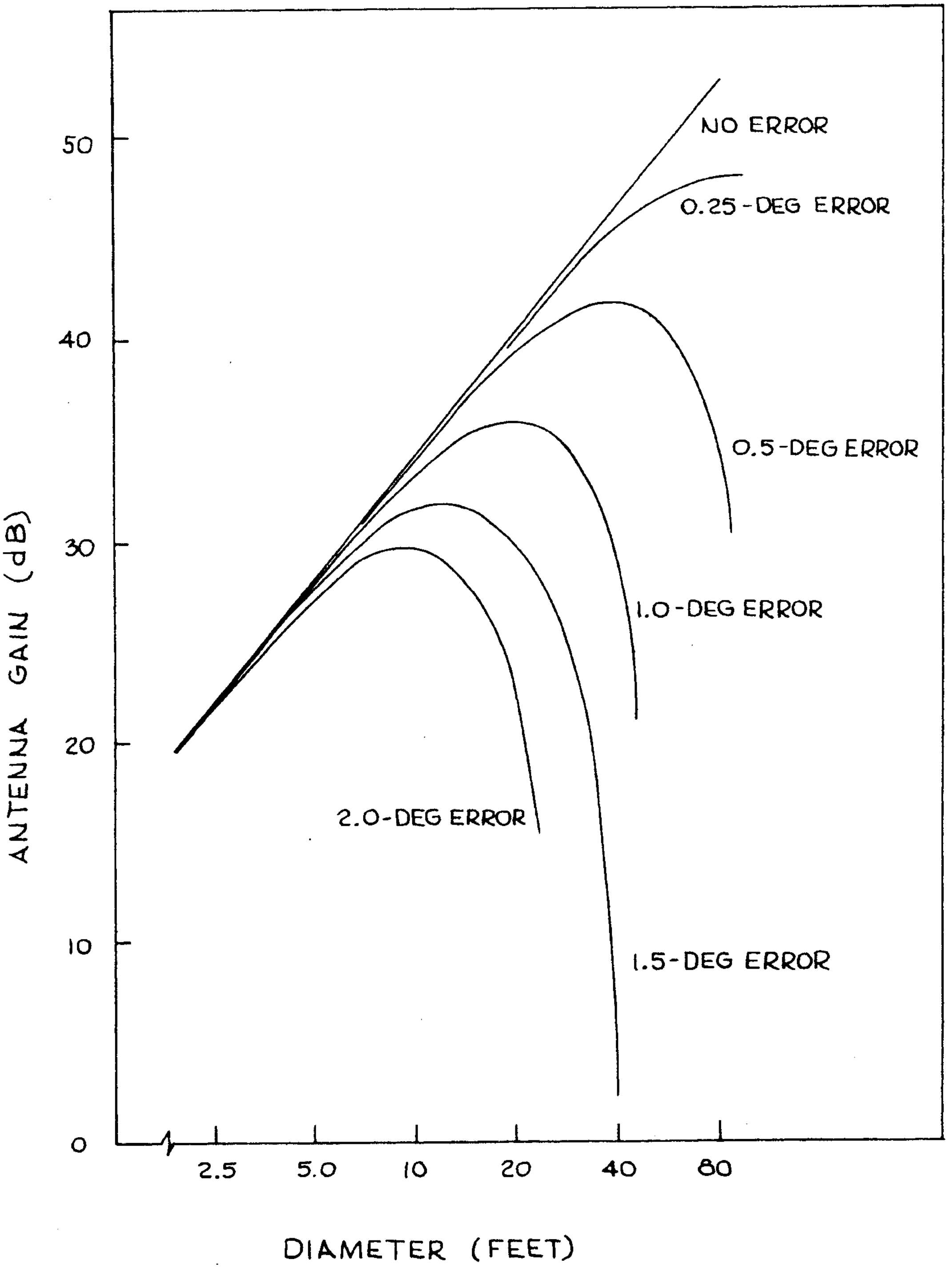

Figure 3. 5-2. Antenna Gain vs Diameter for Various Pointing Errors

Another factor which must be considered is the antenna pattern footprint, due to the geometry of the data link. To obtain a lower bound on the size of this footprint one can examine an overhead pass for a flight at altitude, h, communicating through an elevation angle, ϵ, over a half power circular beamwidth, θ_o. For this case the footprint will be elliptical with axes:

$$\text{minor axis} = \frac{h \sin \theta_o}{\cos^2 \frac{\theta_o}{2}}$$

$$\text{major axis} = \frac{h \sin \theta_o}{\sin^2 \epsilon \cos^2 \frac{\theta_o}{2} - \cos^2 \epsilon \sin^2 \frac{\theta_o}{2}}$$

If one constrains the elevation angle to be above 20 degrees and half power beamwidth to be small, the two equations reduce to:

$$\text{minor axis} = h \theta_o$$

$$\text{major axis} = h \theta_o \csc^2 \epsilon$$

with an error of less than 2 percent low.

Figure 3.5-3 is a plot of the second expression with θ_o as a parameter. The value of the curves for $\epsilon = 90$ degrees, is the minor axis of the elliptical footprint and remains fixed for an overhead pass. One can see the tradeoff involved in the link. For a given allowable dimension on the secure footprint, a choice must be made between a large diameter antenna with communication over a large range of elevation angles and a smaller antenna with a limited elevation angle range. This choice is complex and requires that many factors be considered. For example, if a $\frac{df}{h} = 0.01$ is chosen as a secure footprint, reference to

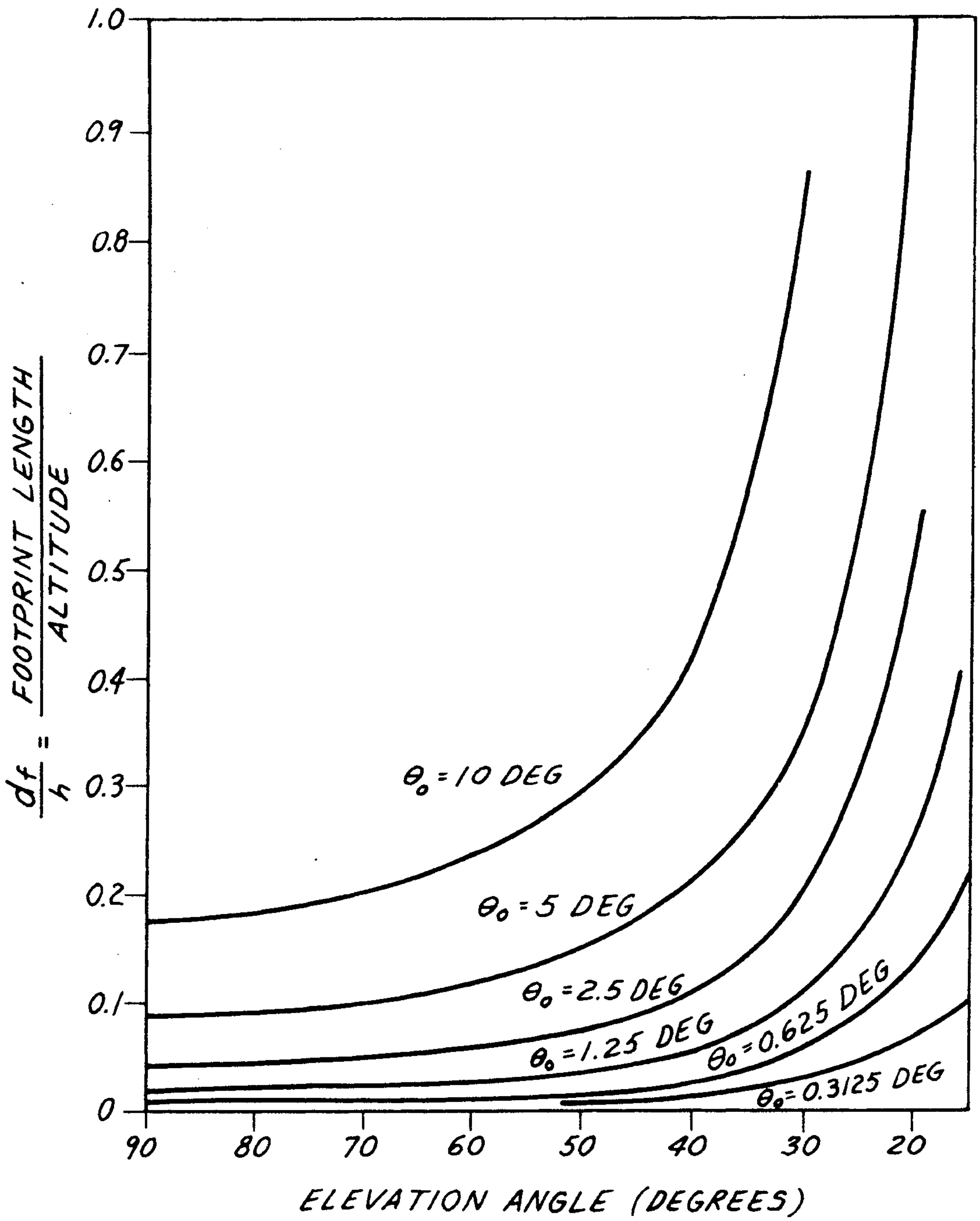

Figure 3.5-3. Major Dimension of Normalized Antenna Pattern Footprint vs Elevation Angle

Figure 3.5-3 shows that two possible antenna choices are: $\theta_o = 0.625$ degree with the elevation angle constrained above approximately 65 degrees and $\theta_o = 0.3125$ degree with elevation angle above 43 degrees. These half power beamwidths correspond to antenna diameters of (from Figure 3.5-2) approximately 55 feet and 110 feet, respectively. Immediately, a change from S-band to X-band seems to be reasonable. This would reduce the size of the antennas by approximately a factor of four - still quite large. Other factors which must be considered as part of the system design are:

a. Gain in link

b. Pointing losses

   1. Effect on link
   2. Effect on steering complexity

c. Solar pressure on this "sail"

   1. Effect on attitude control of vehilce
   2. Thermal problems

d. Design of a space erectable antenna

   1. Tolerance on the surface
   2. Reliability of deployment and erection

e. Size and weight

f. Change in transmission time

g. Change in system bandwidth

   1. Clock rates
   2. Transmission bandwidth
   3. Antenna bandwidth

h. Effect on required transmitter power

It is clear that this approach is not a minimum impact one. It requires not only the addition of hardware to the outside of the vehicle but it would require redesign of the electronics part of the data link.

In a direct comparison with the encryptor approach to secure transmission, it is obvious that the encrypted link (since it requires no new equipment) is the superior method for the present application.

3.6 DATA LINKS

3.6.1 SGLS

3.6.1.1 Introduction

The Space-Ground Link Subsystem is an integrated tracking, telemetry, analog and Command Subsystem designed to meet the requirements and constraints of most of the present and planned SSD satellite programs. The system is capable of receiving, frequency multiplexed onto a single RF carrier in the band from 1.76 GHz to 1.84 GHz, command, analog, and tracking data.

Similarly, multiplexed onto a single RF carrier in the band from 2.2 GHz to 2.3 GHz, telemetry, analog and tracking data can be transmitted to the ground station. This description will deal with the down link, primarily with the high rate PCM capability.

The intent is to establish the link and subsystem performance as an indication of the proposed readout capability.

The SGLS vehicle equipment shall perform the following functions:

a. Receive the RF signal transmitted from the ground station.

b. Demodulate the RF signal and send the resulting signals to the proper user subsystems.

c. Coherently translate the received RF signal by a fixed ratio of 256/205.

d. Detect and filter the ranging code.

e. Modulate the transmitted signal with a composite telemetry, ranging, and analog signal.

f. Transmit the modulatored signal to the ground station.

3.6.1.2 Description

Figure 3.6- shows the basic SGLS system configuration and Figure 3.6-2 the simplified block diagram. Referring to the vehicle of Figure 3.6-2 one sees the configuration includes, for the down link service, a telemetry block, two transmitters, a multiplexer for their utilization, and an antenna. Transmitter No. 1 generates a carrier which is coherent with the up-link carrier and which is phase modulated with a composite waveform containing analog, low rate PCM ($\leq$ 128 Kbps), and PRN ranging data. The second transmitter generates a non-coherent carrier 5 Mhz below carrier 1. This carrier is phase modulated with the baseband high-rate PCM at rates from 128 Kbps to 1024 Kbps. Figure 3.6-3 shows the baseband spectral occupancy for the two carriers. (The optional services are indicated with dotted lines). Note that no sub-carriers are used for the high rate PCM on carrier 2, and further that modes 5, 6 and 7 are dual carrier modes. This necessitates the inclusion of the hybrid couples with the antenna and the incursion of an additional 3 db loss in the transmission path. This factor is included in Item 2 of the link calculation, Table 3.6-1.

The high rate PCM (or coded delta-modulation) non-return to zero spectrum is bi-phase modulated directly onto carrier 2, such that the first nulls of the spectrum occur at $\pm$ 1024 Khz from the carrier frequency and the second nulls at $\pm$ 2048 Khz. The dual carrier spectrum is shown in Figure 3.6-4. The choice of two carriers was made in the interest of higher transmission efficiency (i.e., higher SNR). However, because of the hardware expediency of one antenna some of this advantage is lost.

In the ground station receiver, the two carriers are separated with 4 Mhz bandpass filters. Demodulation of the high-rate PCM requires that a coherent reference carrier be reconstructed at the ground receiver. This is necessary since the bi-phase, or $\pm$ 90-degree phase deviations, of carrier 2 result in the complete suppression of that spectral line. Reconstruction is accomplished in an in-phase/quadrature (I-Q) loop as shown in Figure 3.6-5.

The bit synchronizer follows the PCM demodulator and develops the timing for the "integrate and dump" matched filter detector.

3.6.1.3 Performance

The high rate PCM down link is shown in Table 3.6-1 and Figure 3.6-6. In brief, one sees that at an error rate of 10^{-3}, and using the standard 60-foot antenna, the link has a grey-out range of approximately 1350 nautical miles. If a ground station with a 15-foot antenna is to be used the grey-out range shrinks to approximately 340 nautical miles.

Figure 3.6-6 is a plot of the performance margin-vs-range bit error rates of 10^{-3} and 10^{-5} and for antenna diameters of 15 and 60 feet.

3.6.1.4 Physical Characteristics

Table 3.6-2 shows size, weight, and power for the basic SGLS units.

The delta modulator used for readout is a separate piece of equipment which will interface with the SGLS equipment. The delta modulator will have a volume of approximately 125 cu. in., will weigh 8 pounds, and will consume 7 watts.

3.6.2 WIDE BAND TRANSMITTER WITH STEERABLE ANTENNAS

For the follow on flights a communication link from the Orbiting Vehicle directly to a Satellite Control Satellite (SCS) could be established. In such an application, the need for narrow beam, steered antennas is evident. Much work has been done on systems at X-band utilizing monopulse error schemes driving mechanically gimballed antennas. Similarly, high bit-rate systems utilizing bandwidths up to 100 Mhz are under development. These two factors are compatible with the planned satellite systems such as the SCS, and will permit real-time transmission of data to the ground during the entire orbital period.

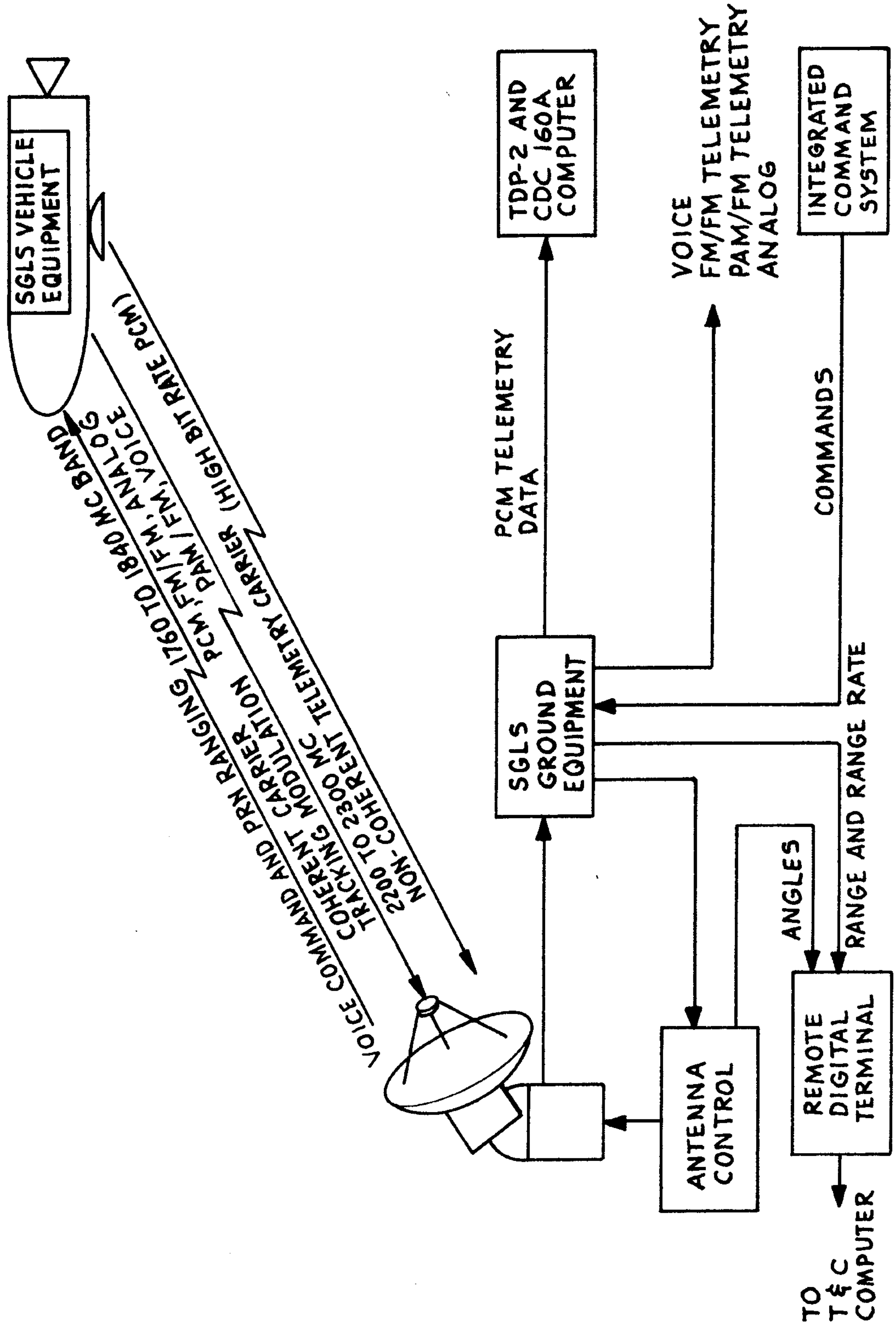

Figure 3.6-1. Basic SGLS System Configuration

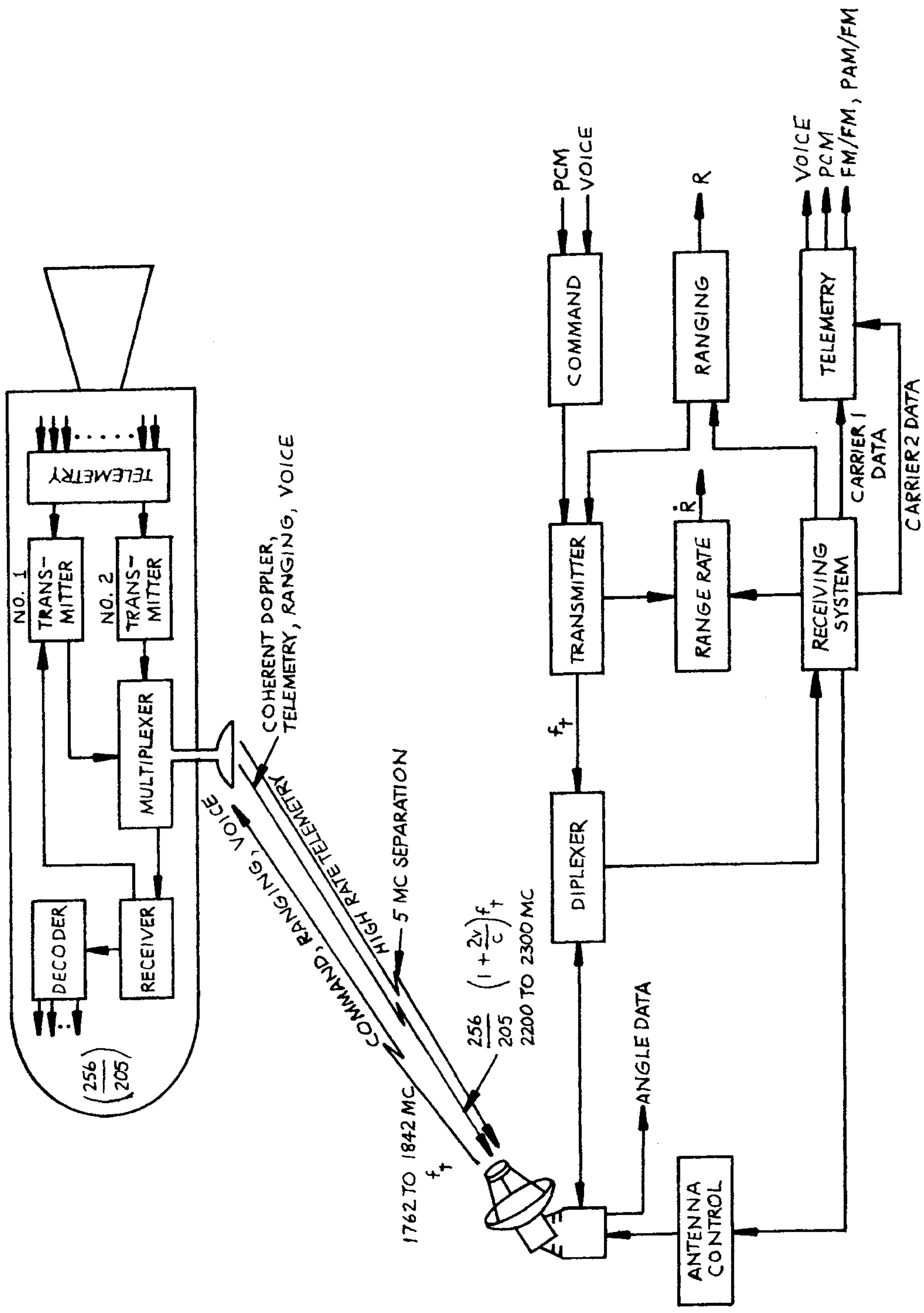

Figure 3.6-2. Simplified System Block Diagram

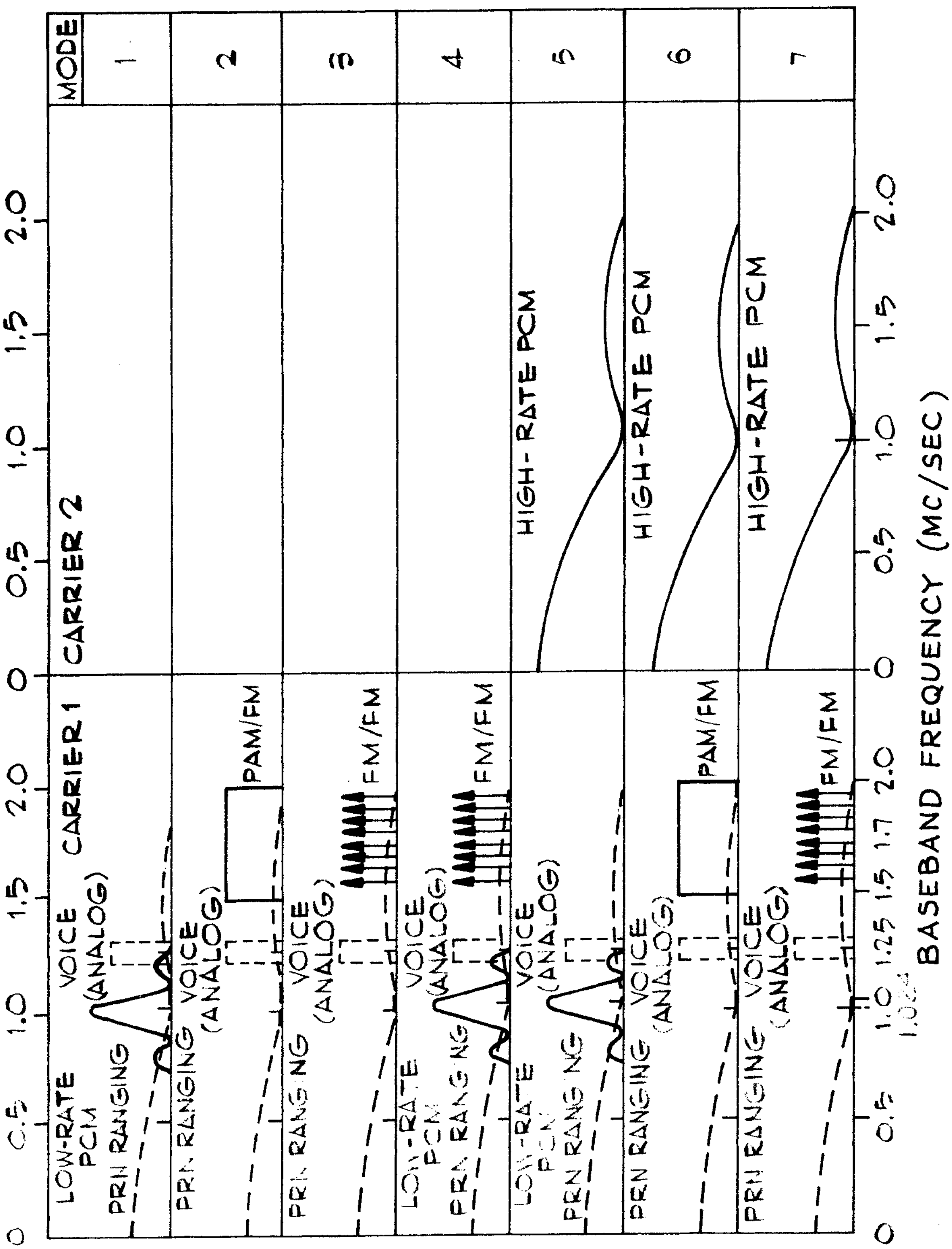

Figure 3.6-3. Space-to-Ground Link Baseband

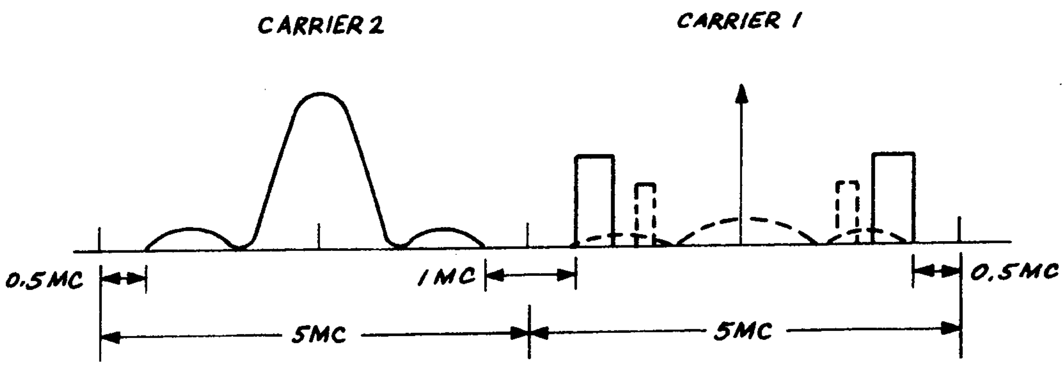

Figure 3.6-4. Dual Carrier Configuration

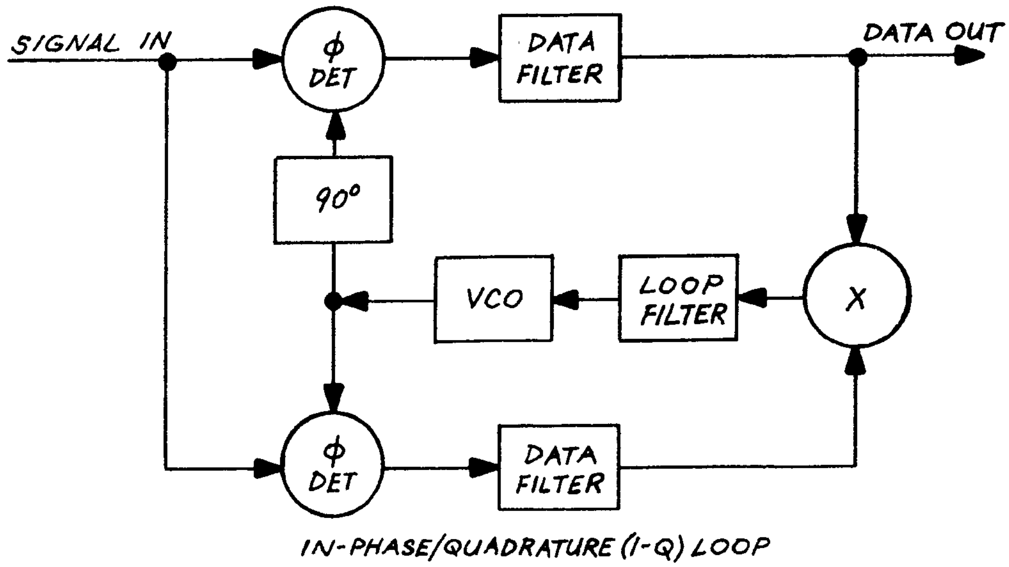

Figure 3.6-5. Coherent Carrier Demodulator

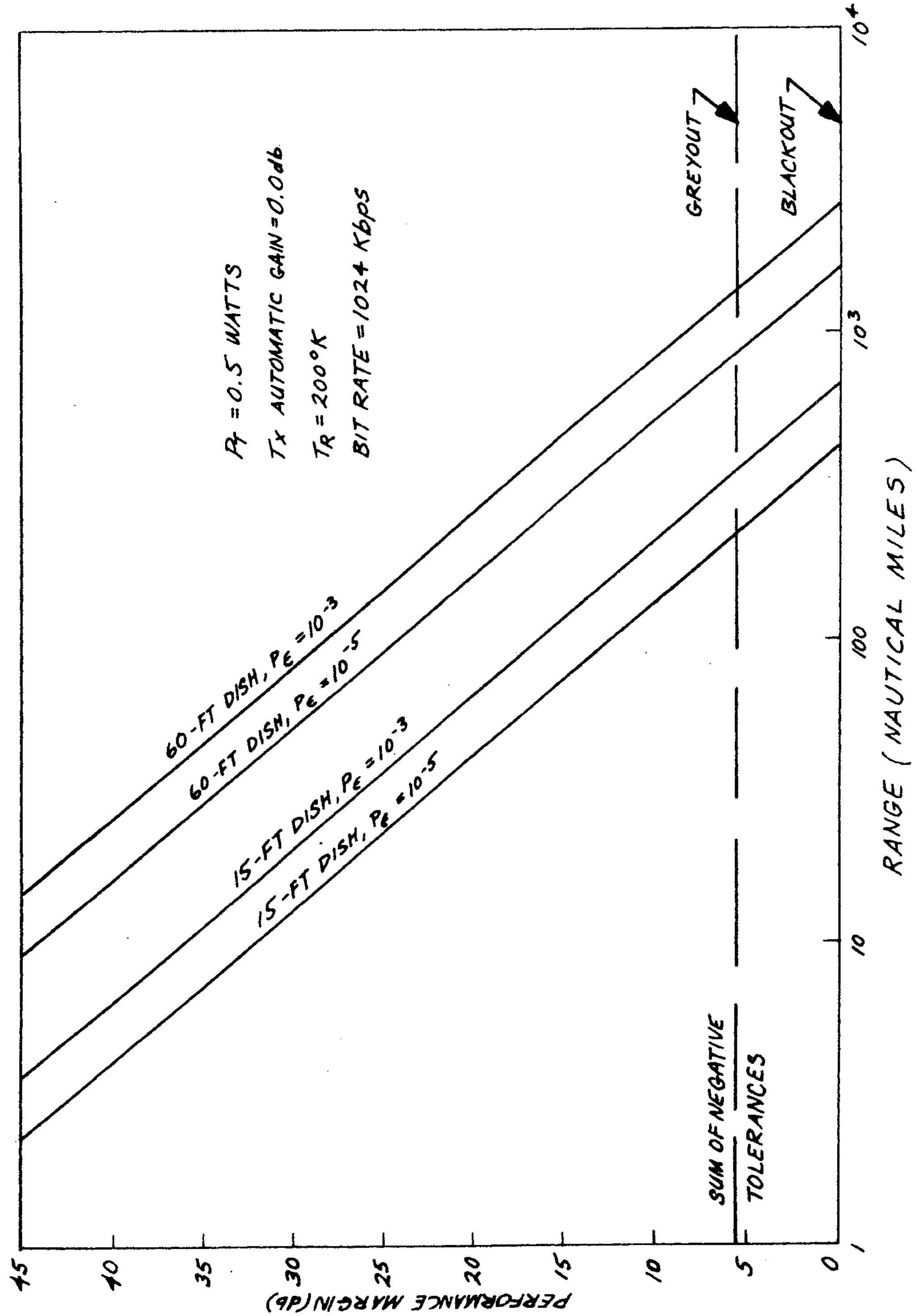

Figure 3.6-6. SGLS Downlink Standard System

Table 3.6-1. Link Calculation forCarrier 2 of the SGLS Standard System

Item No.	Parameter	Nominal dB	Adverse dB
1.	Pt (1/2-watt)	27	-0.5
2.	Transmission Circuit Loss	-3.8	-0.5
3.	Spacecraft Antenna Gain	0.0	-3.0
4.	Antenna Pointing Loss	0.0	-0.0
5.	Space Loss (2300 MHz) (600 nmi)	-160.6	-0.0
6.	Polarization (L-CP)	-3.0	-0.0
7.	Receiving Antenna Gain	49.0 (60 ft)	-0.5
8.	Receiving Circuit Loss	-2.6	-0.5
9.	Net Circuit Loss	-121.0	-4.5
10.	Received Power	-94.0	-5.0
11.	Noise Density ($T_R = 200^0 K \pm 40^0 K$)	-175.6	+0.8
12.	Detection Noise (BW (1024 KHz)	60.1	-
13.	Detector Noise Power	-115.5	+0.8
14.	Theoretical Required Threshold SNR	9.6 } 12.7	($Pe = 10^{-5}$)
15.	Degradation due to Demodulator and IF	3.1 }	(8.6, $Pe = 10^{-3}$)
16.	Required Signal	-102.8	+0.8
17.	Margin	8.8	-5.8

Table 3.6-2. Vehicle Equipment Volume, Weight and Power

Basic SGLS Units	Volume (cu. in.)	Weight (pounds)	Power at 28 VDC (watts)
Receiver	109	3.1	1.5
2-w Transmitter	59	2.4	23.3
500-mw Transmitter	59	2.4	8.3
PCM Telemetry Encoder	217	6.6	7.7
Signal Conditioner	59	1.5	0.4
Baseband Assy Unit	72	2.2	0.2
PCM Converter	100	3.0	6.9
Communications Converter	43	1.7	1.0
Transmitter Converter	59	1.7	5.7 (2.2)
Multiplexer	123	1.4	---
Total with 2-w Transmitter	841	23.6	46.7
Total with 500-mw Transmitter	841	23.6	28.2
Total with both Transmitters	900	26.0	57.2
All of the above are included in the MOL baseline allocations.			

3.6.3 LASER COMMUNICATION LINK

Work has been done (by Perkin-Elmer for Marshall Space Flight Center) on a laser communication system designed for deep space use. This system is to provide bit rates of 10^6 at ranges of up to 100 million miles and at an error rate of 10^{-3}. Built with state-of-the-art components, the major components of the system consist of:

a. A space borne helium-neon laser transmitter (λ = 6238 angstroms) with a 16-inch telescope for collimating and pointing the laser beam.

b. An Earth receiving station with a 10-meter diameter telescope. The Earth station has an argon laser beacon (λ = 4880 angstroms) for beam pointing mechanization.

This system, when operating, should receive an approximate power of -87 dbm at the 10-meter telescope obtained from a spot size of 200 miles diameter on the surface of the Earth. The transmitting beam from the space vehicle should have beam spread of 0.4 arc sec or 1.95 μ rad. The pointing of the beam is extremely critical requiring a precision of approximately 0.1 arc sec.

If this same system were used from 100 miles, its ground spot size would be about one foot in diameter. The pointing requirements would be about 11 arc seconds since the spot is aimed at a 32.8-foot diameter telescope. There is clearly room for modification.

Both the ground terminal and the space borne transmitter could be reduced in size for operation in near earth orbits. For example, if a receiving telescope of two-foot diameter were used a received power about 10 db higher than the original system could be obtained with a minimum Earth spot size of 20,000-foot diameter. This would correspond to a transmitting beam width of greater than 2 degrees, requiring some diverging optics at the spacecraft transmitter. The pointing requirements would be approximately 1 degree. Easing the pointing requirements is an important achievement for a laser link. Maintenance of communications depends on accurate steering of the beam which can be accomplished by active tracking methods. However, the complexity of the steering mechanization is an inverse function of the beam width. The problem of leading the target is not a serious one from Earth orbit especially with the larger beam width.

This approach is intended for future flights since it requires the addition of new equipment with both internal and external modifications to the vehicle. Laser technology will certainly be able to provide such devices in the time span of interest.

The laser link is not expected to be an eventual replacement for more conventional radio links but merely another way to transmit data.

Some of the major problems of lasers which detract seriously from their utility are low electrical efficiency and the dependence on good Earth atmospheric seeing conditions. Stations located in good weather areas such as the southwest area of the United States may alleviate the latter problem.

Carbon dioxide (CO_2) lasers are more efficient and can generate higher powers; however, these devices suffer from several severe shortcomings which include:

a. Wideband modulators and detectors are not available at the 10.6 micron wavelength

b. The availability of good optical glass at that wavelength requires the use of more complex optics.

c. The CO_2 laser is highly dependent on the coherence properties of the atmosphere.

3.6.4 AVAILABLE SGLS STATION CONTACTS

It has been concluded that the SGLS, including the encryptor system, best satisfies the requirements for the initial readout transmission link. Figure 3.6-7 shows all SGLS wide band station contacts available to MOL during days 3 and 4 and is typical of the remainder of the flight. This information was extracted from the 80-degree Baseline Flight Vehicle Time Line Report (Vol. II and IV of V, Document ZB01047, dated 22 March 1968), since as of this writing the 90-degree Timeline Report had not been fully negotiated. However, based on discussions to the present, the 90-degree timeline will be very little different from the 80-degree timeline with respect to the relationship between the used and unused station contacts. An examination of Figure 3.6-7 shows that 7-8 station contacts exceeding four minutes duration are not presently planned to be used on days 3 and 4 and several more of shorter duration are also available. In general, over many days of this mission an average of 6-7 four-minute contacts are not used. These contacts would be used as backups to other regularly scheduled contacts should the regular contact fail; however, they presently are not scheduled for anything else and there is no reason why they could not be used for readout. Therefore, it is planned that there will be about 6 four-minute station contacts per day available for readout.

3.6.5 DATA RELAY TO USER

Once the data is received on the ground at an RTS, it must be returned to the user at some central facility assumed to be in Washington, D.C. There are three alternatives for return of this data:

3.6.5.1 Long Lines

There presently exist 1200 bps communications lines between the remote tracking stations and the Satellite Control Facility at Vandenberg. It is planned to increase the bit rate

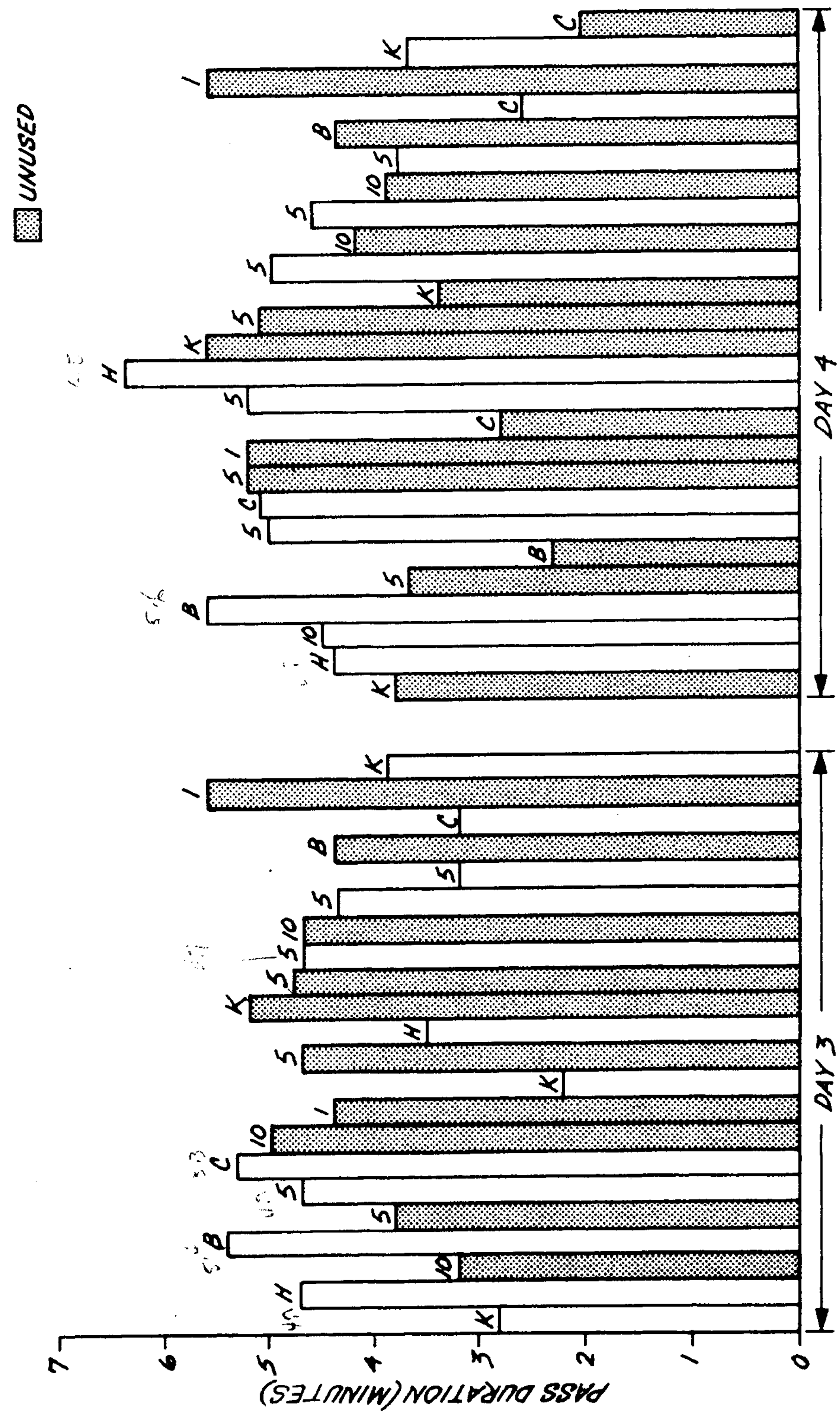

Figure 3.6-7. RTS Coverage, 80-Degree Timeline, 2.5-Degree Cone

of these lines to 2400 bps and possibly 7200 bps in the future. At 7200 bps, it would take approximately 9 1/4 hours to transmit one high resolution 25 x 25 mm chip from an RTS to the STC due to the 7200 bps limitation of the long lines. It is unreasonable to expect to be able to tie up the communications lines for such periods of time, hence this method is unacceptable.

3.6.5.2 Fly the Data

The readout data, stored on tape, could be flown from the RTS's to Washington. This involves flights from several RTS's each day since each chip in general is read out at a different RTS. Total cost of this method will depend on the number of flights and the distances involved.

The aircraft flight time will cause delay of many hours in getting the data from the RTS to Washington. The acceptability of these time lags is difficult to access since it is rather subjective, depending in many cases on the data content itself.

This is a method that can be used, however, compared to the relay satellite method described below, it is considered to be a second choice.

3.6.5.3 Relay Satellites

The use of relay satellites is an entirely feasible method to transmit data from the RTS's to Washington. [redacted]

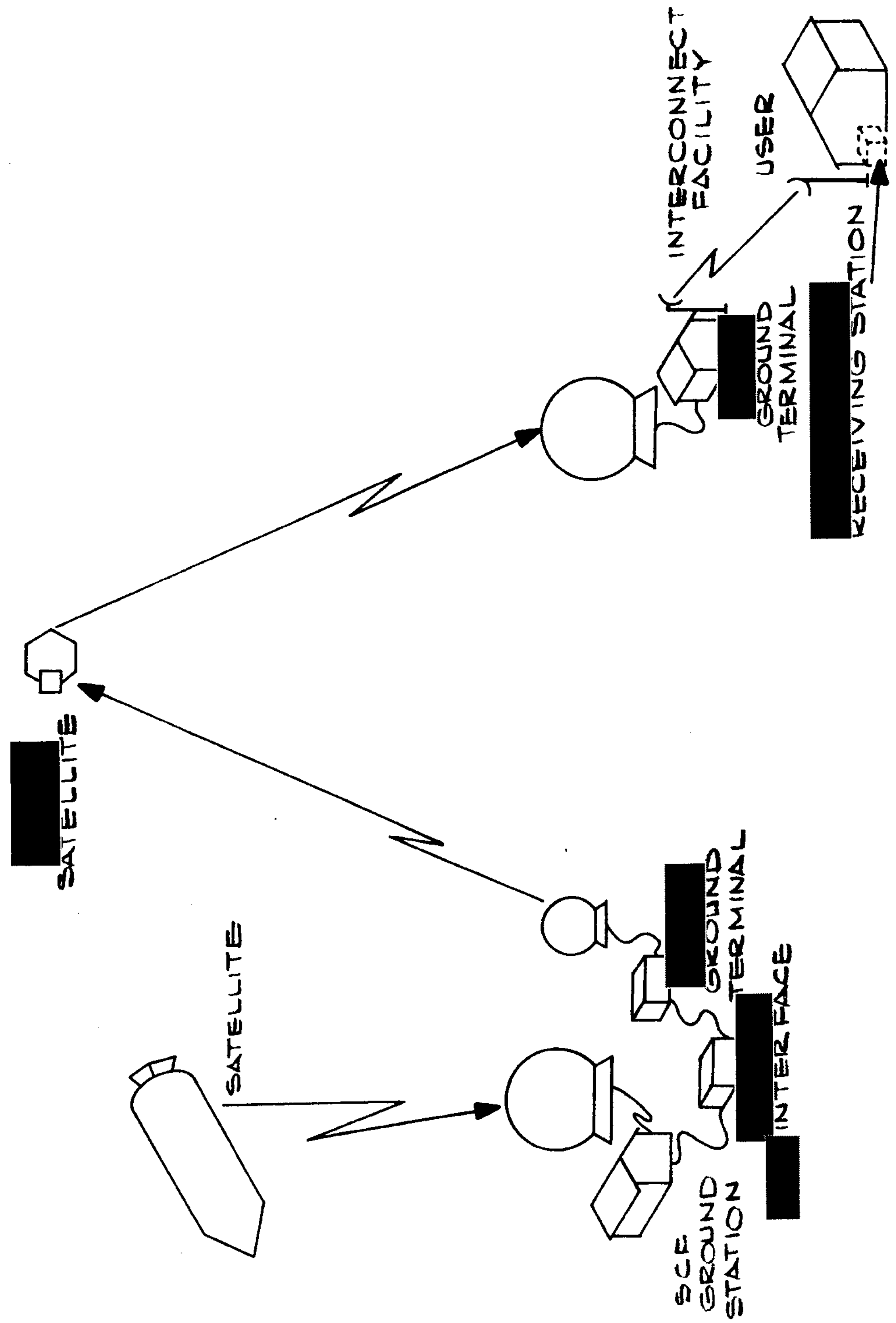

Figure 3.6-8. Satellite Data Relay System

At the present time the relay satellite terminal equipment does not exist at the RTS's. This equipment would have to be installed prior to the MOL readout flights. However, MOL will not be flying until the past 1971 time-period and it is reasonable to expect that based on past growth in the use of relay satellites much of this equipment will be available by then.

It is also expected that a follow-on relay satellite, the DCSP, will be operating in the MOL time period. Based on inputs from Philco-Ford, this satellite will have no less capability [redacted]

Based on the above, it is recommended that the relay satellite system be used as the data relay between the RTS's and Washington.

3.6.6 GROUND RECONSTRUCTION EQUIPMENT

The end result of the entire readout system is the delivery of a photograph at the user facility. Due to the secure nature of the data, it is expected that ground reconstruction equipment will not be desired at any other (intermediate) point in the system. Therefore, the image reconstruction equipment will be required at one location only.

The reconstruction equipment will be a mirror image of the on-board equipment and will consist of a delta demodulation and a laser write device. [redacted] The laser write device will be similar to presently existing laser ground reconstruction devices.

3.7 VEHICLE INTEGRATION

3.7.1 SCANNER INSTALLATION

The three basic systems considered have similar volume, optical path lengths, and weight requirements. These systems are:

1. Flying Spot System (FSS)
2. TV System
3. Laser Scanner System (Disk Type and Drum Type).

All material in this section applies to all three systems unless a paragraph is identified for a particular system.

3.7.1.1 Component Configuration

Component packaging configuration has been developed based on efficient utilization of space in Console 2 and provisions for necessary optical path lengths and internal parts. Figures 3.7-1 through 3.7-4 show the proposed internal configurations.

All controls and the film sample insertion opening are located on the front panel surface. No operational access is required inside the console.

3.7.1.2 Installation Philosophy

The Laboratory Module general arrangement is shown in Figure 3.7-5. The film sample that is to be transmitted will be processed, viewed, and prepared for transmission in Console 4.

The following locations in the Lab Module were considered for installation of the R/O Subsystem.

a. Forward of Bay 2 - Mount the subsystem on top of the console structure on the left inboard side as shown in Figure 3.7-6. This space is MDAC's and would require negotiation for it. Placing the subsystem on top of Bay 2 would require re-packaging of the MDAC valve box. This would be a high cost rework. Also it would be necessary to remove the Rho subsystem to provide clearance for installation and removal of the film handling structure located in the forward section of Bay 1.

b. Other MDAC Areas - Space has been reserved in a MDAC bay for readout equipment. This space is considerably larger than required for the Readout Systems under consideration here. It was felt that since very time consumming negotiations would be required with MDAC to obtain use of this space, and to obtain the mounting interfaces, harness interfaces, and coolant for the R/O component, that it would be advantageous to locate the subsystem in a GE Bay. This would also leave the space in the MDAC bay available for other equipment.

c. Console 2 Panel E Area - Panel space is available but there is inadequate space behind the panel. The space behind the panel is assigned to Eastman Kodak and is filled with components and harnesses. This also would be an operationally awkward location requiring the crew members to move from the viewer in the top section of Bay 4 to the bottom of Bay 2. This location is shown in Figure 3.7-7.

d. Console 2 Panel A - Mount the R/O Subsystem on the front panel area above the VDP module storage rack. Move the analog encoder currently mounted on Panel 2A to Panel 8A.

The last location was chosen for the following reasons:

a. It is the most efficient location considering operational (crew) requirements and is still located within a GE-controlled console.

b. It requires the least amount of changes in console component harness and plumbing installations based on the current console configuration.

c. This location places the film insertion opening approximately 30 inches from the viewer and is in the same station plane as the viewer which is located on top of Bay 4.

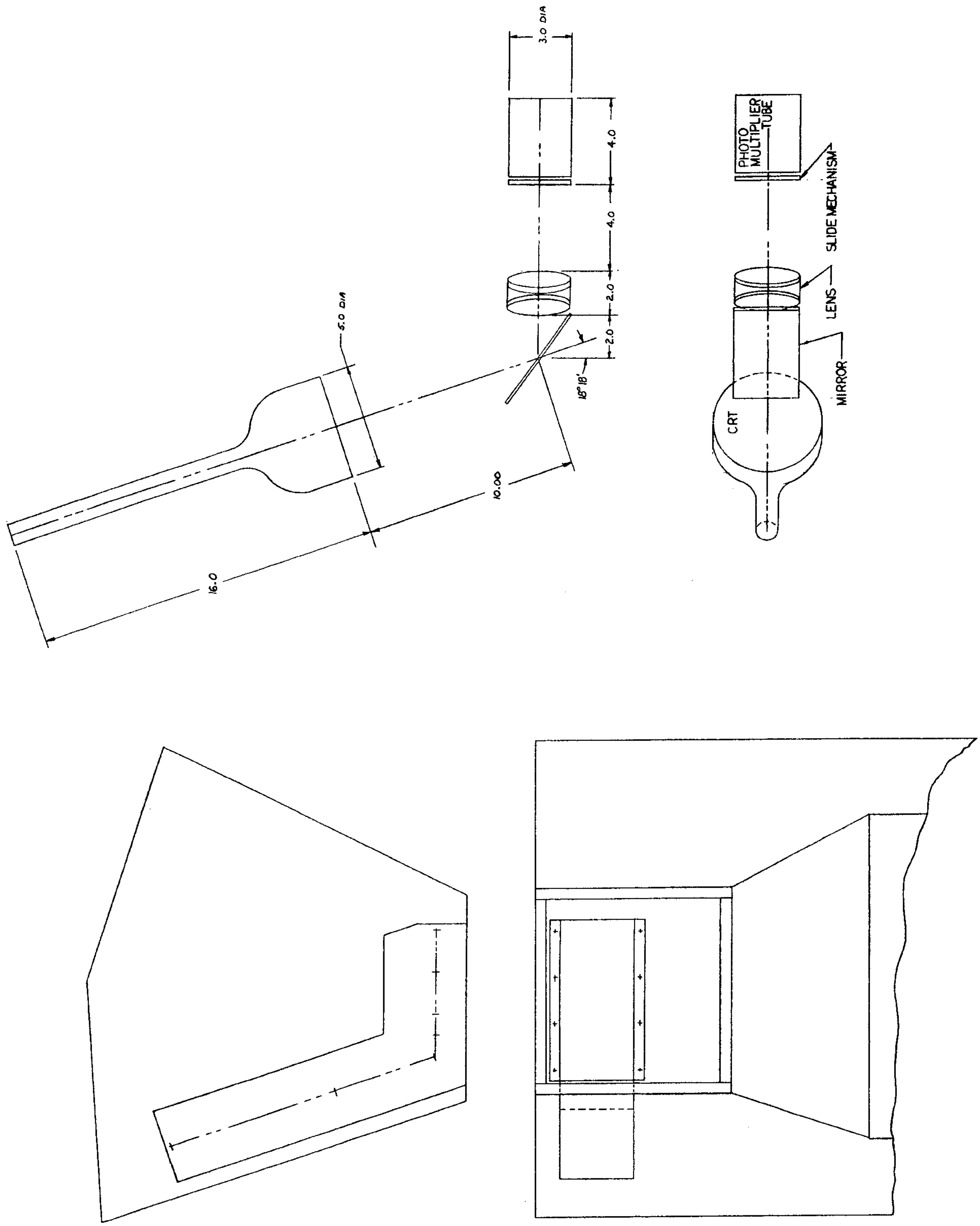

Figure 3.7-1. Flying Spot System Internal Configuration

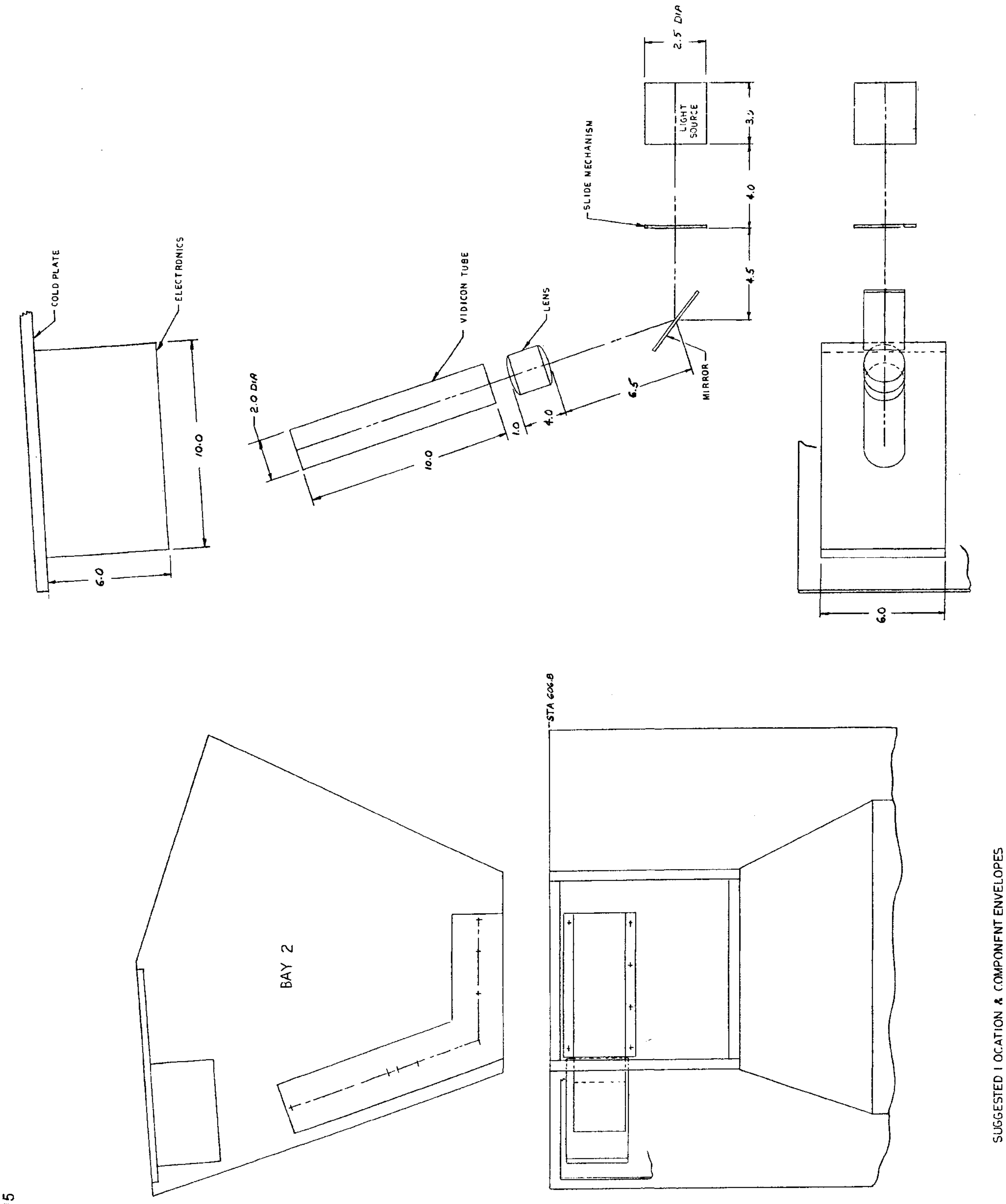

Figure 3.7-2. TV System Internal Configuration

HANDLE VIA BYEMAN SYSTEM ONLY
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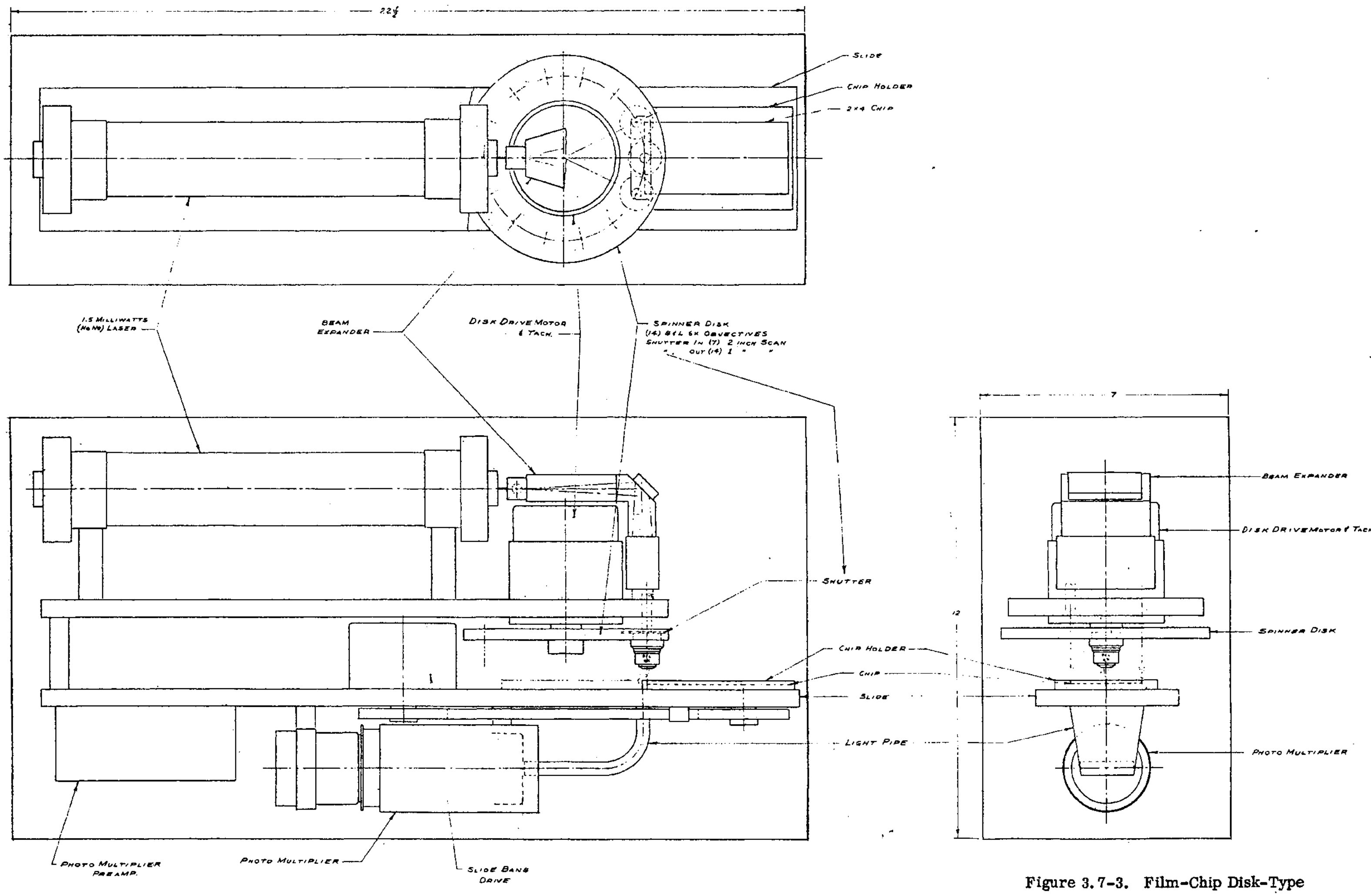

Figure 3.7-3. Film-Chip Disk-Type
Laser Scanner System Internal Configuration

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HANDLE VIA BYEMAN SYSTEM ONLY
~~SECRET~~/DORIAN

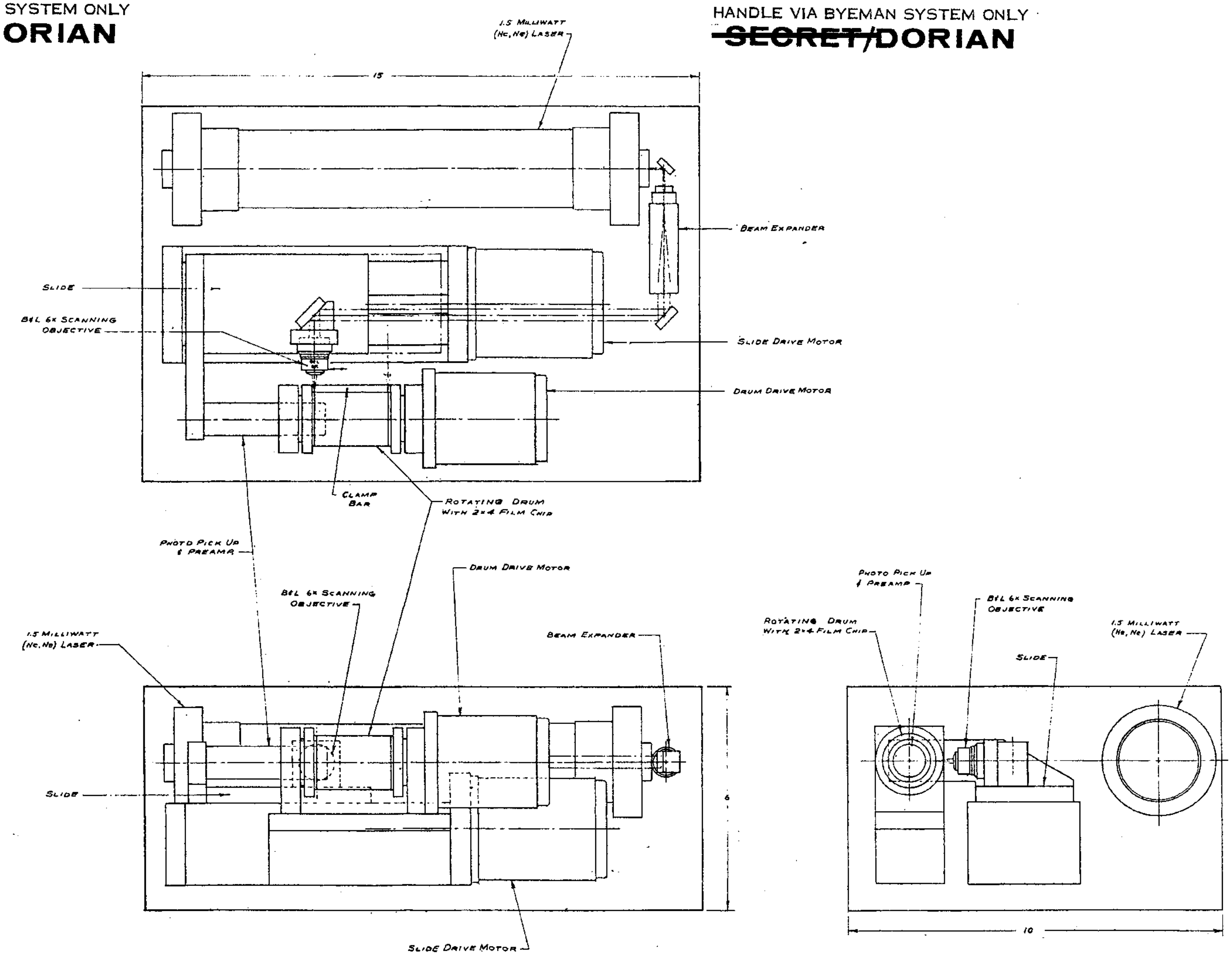

Figure 3.7-4. Film-Chip Drum-Type Laser Scanner System Internal Configuration

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HANDLE VIA BYEMAN SYSTEM ONLY

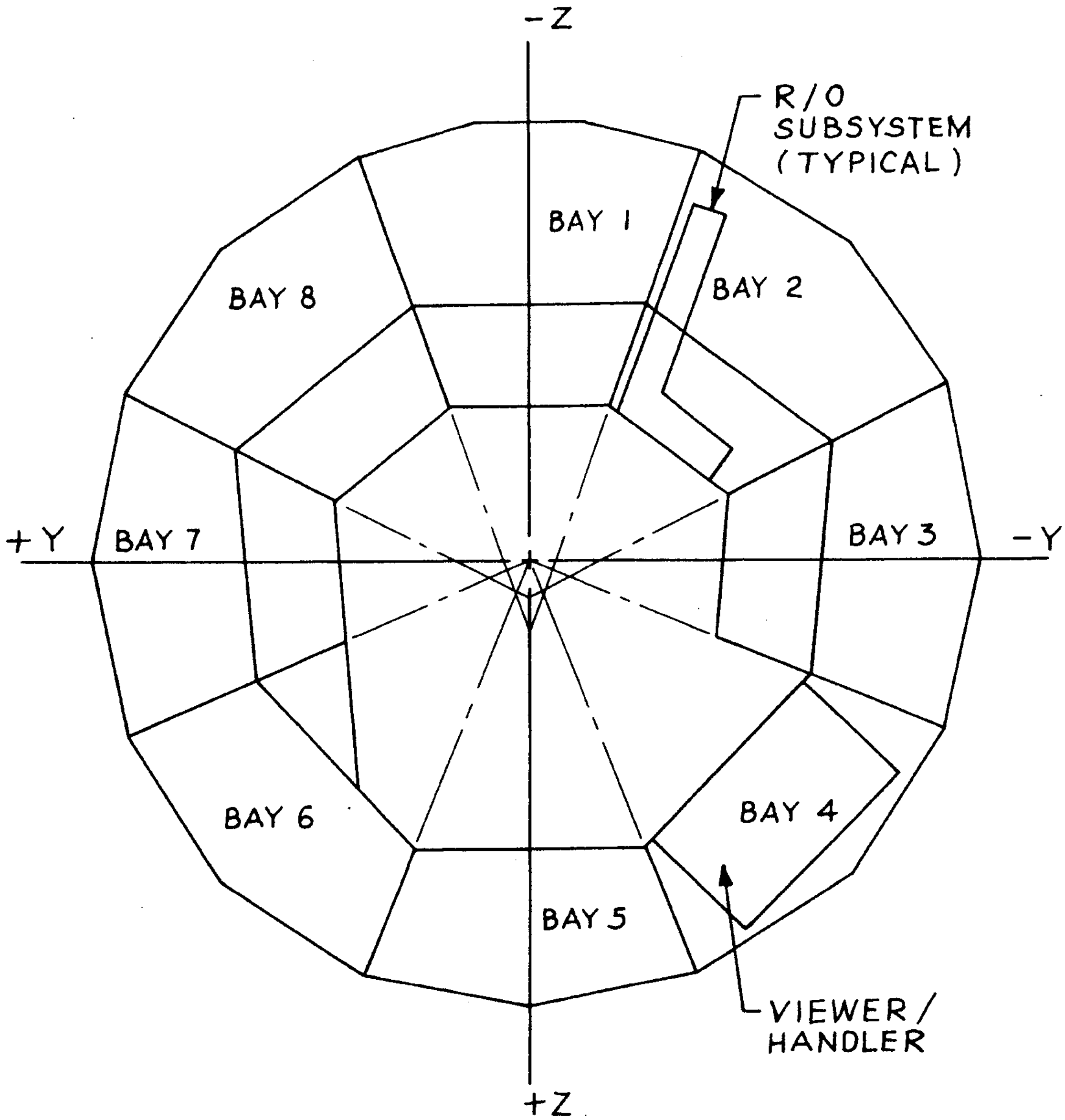


Figure 3.7-5. Laboratory Module Arrangement, View Looking Aft at Station 606.8

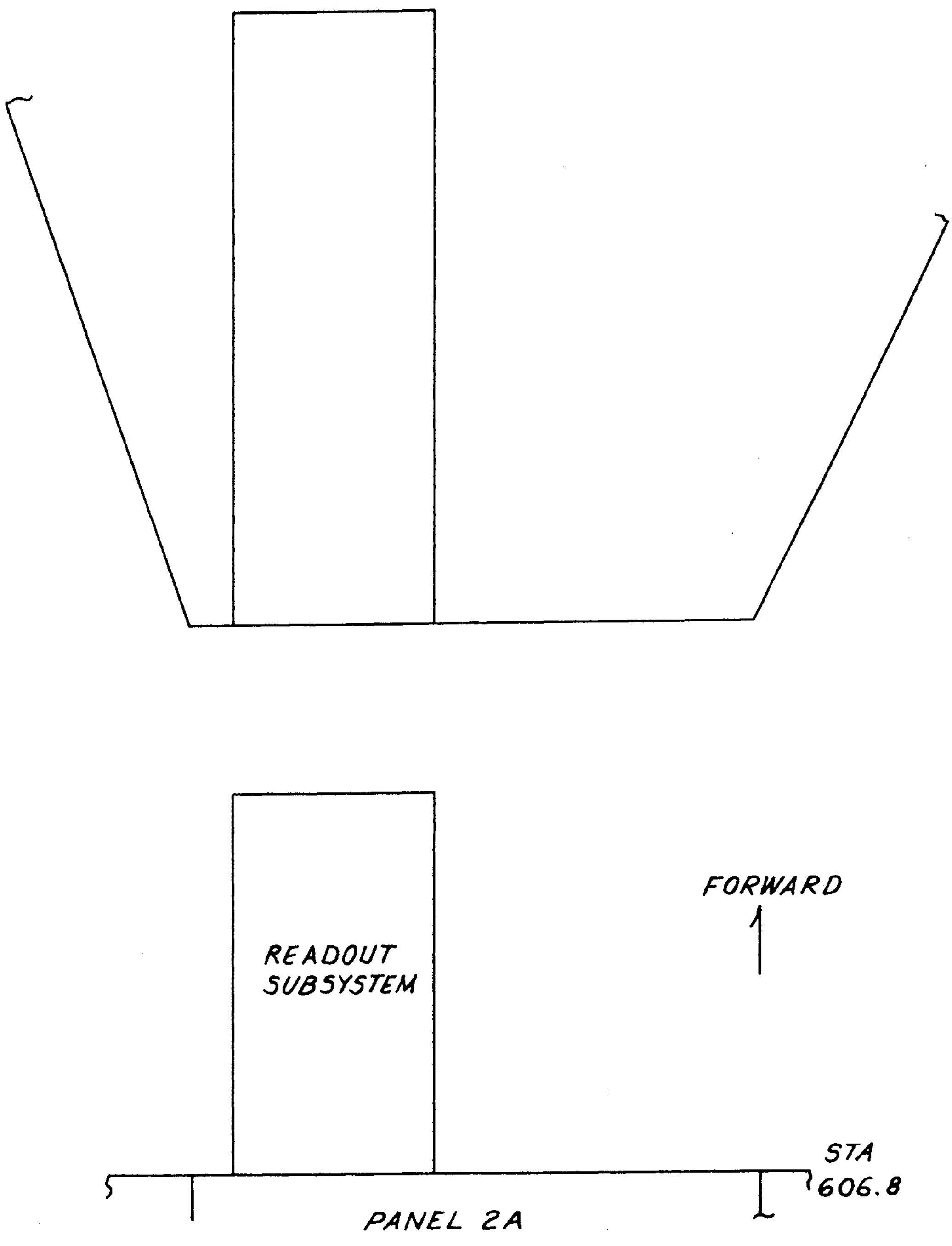


Figure 3.7-6. Possible Readout Subsystem Installation Forward of Bay 2

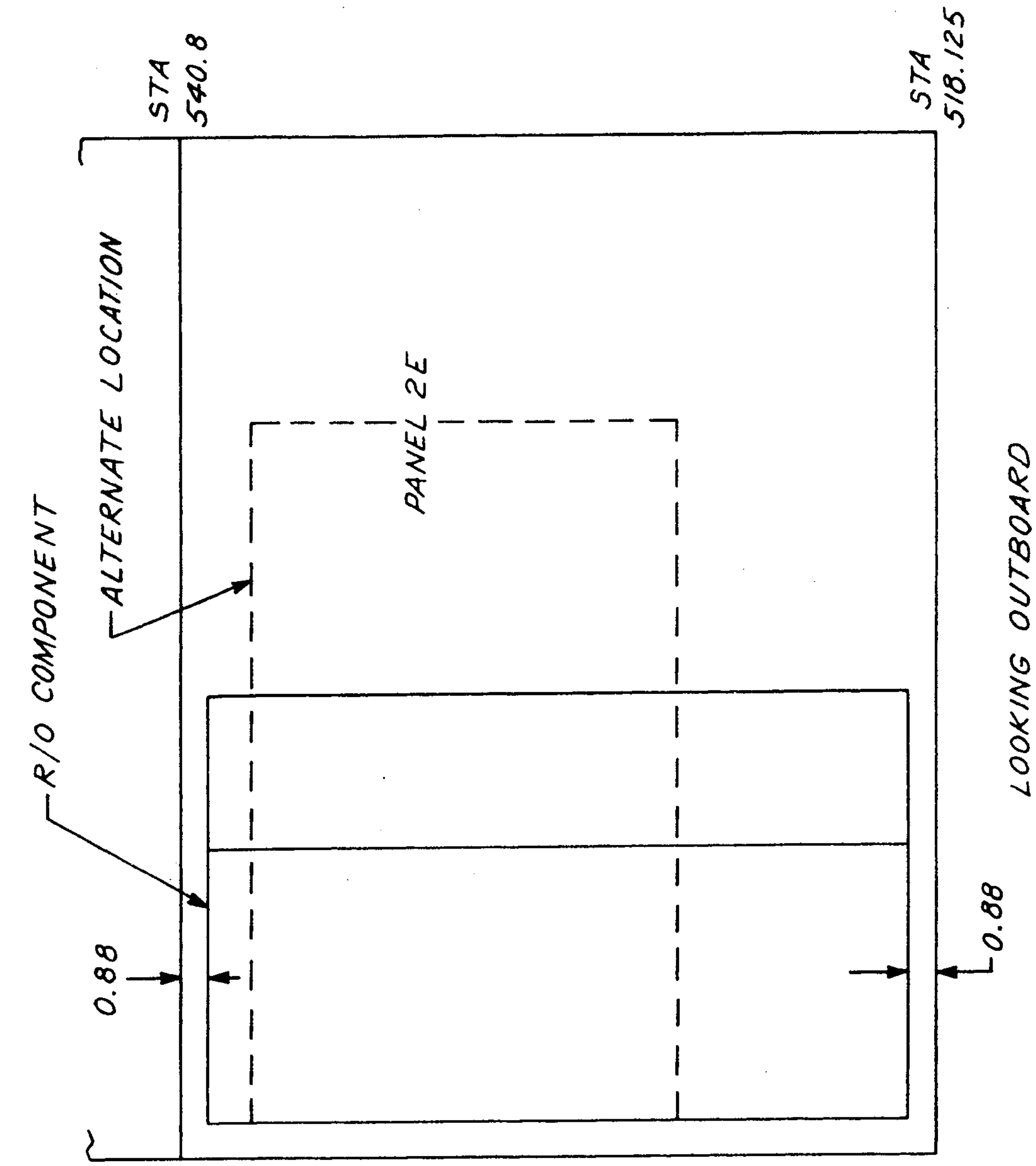


Figure 3.7-7. Possible Readout Subsystem Location on Panel 2E

3.7.1.3 Installation

3.7.1.3.1 Subsystem Configuration

The proposed component external configurations and installation are shown in Figures 3.7-8 through 3.7-12.

The $71^{\circ}42''$ angle break in the first two subsystem packages provides a configuration that meets the component internal optical path length requirement and efficiently uses available space in the console. This configuration requires a minimum change to harness routing and shall be supported on the console inboard face (front panel) and at other points on a new structural member to be added to the structure as shown in Figures 3.7-8 and 3.7-9.

The subsystem shall be installed and removed through the front panel area. The disk or drum type laser systems shall be supported on the console inboard face (front panel) and at other points on the existing channel (s). Figures 3.7-10 and 3.7-11 show two possible installations of the disk type configuration. Figure 3.7-12 shows the drum type installation.

3.7.1.3.2 Existing Component Relocation

The analog encoder is presently located on the console 2A panel. The encoder must be moved elsewhere to allow installation of the R/O Subsystem in 2A. This encoder requires panel mounting for orbit access. Space currently exists on Console 8 Panel A and is a possible area for relocation of the analog encoder. Harness changes are enumerated in the harness section.

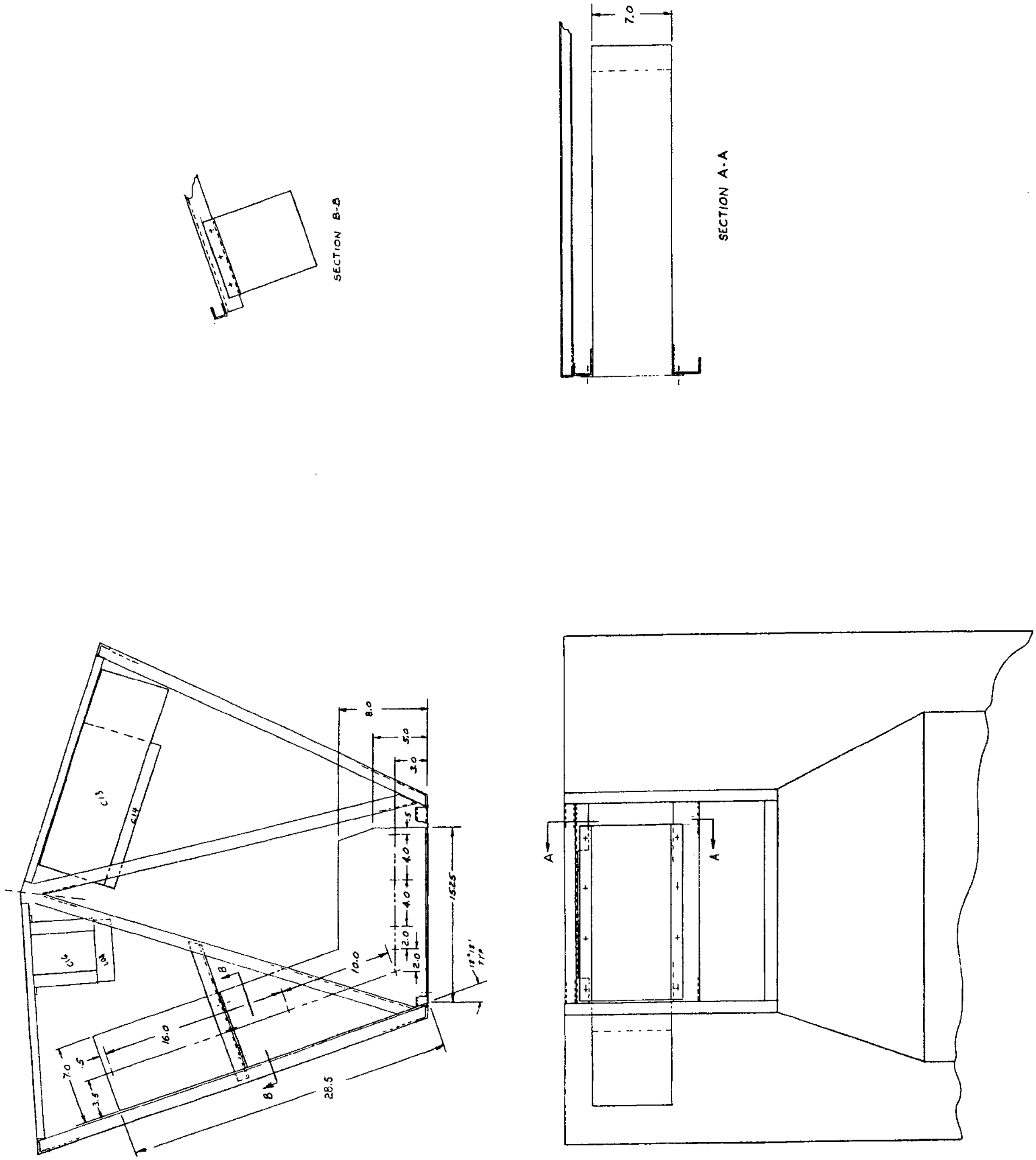


Figure 3.7-8. Flying Spot System External Configuration and Installation

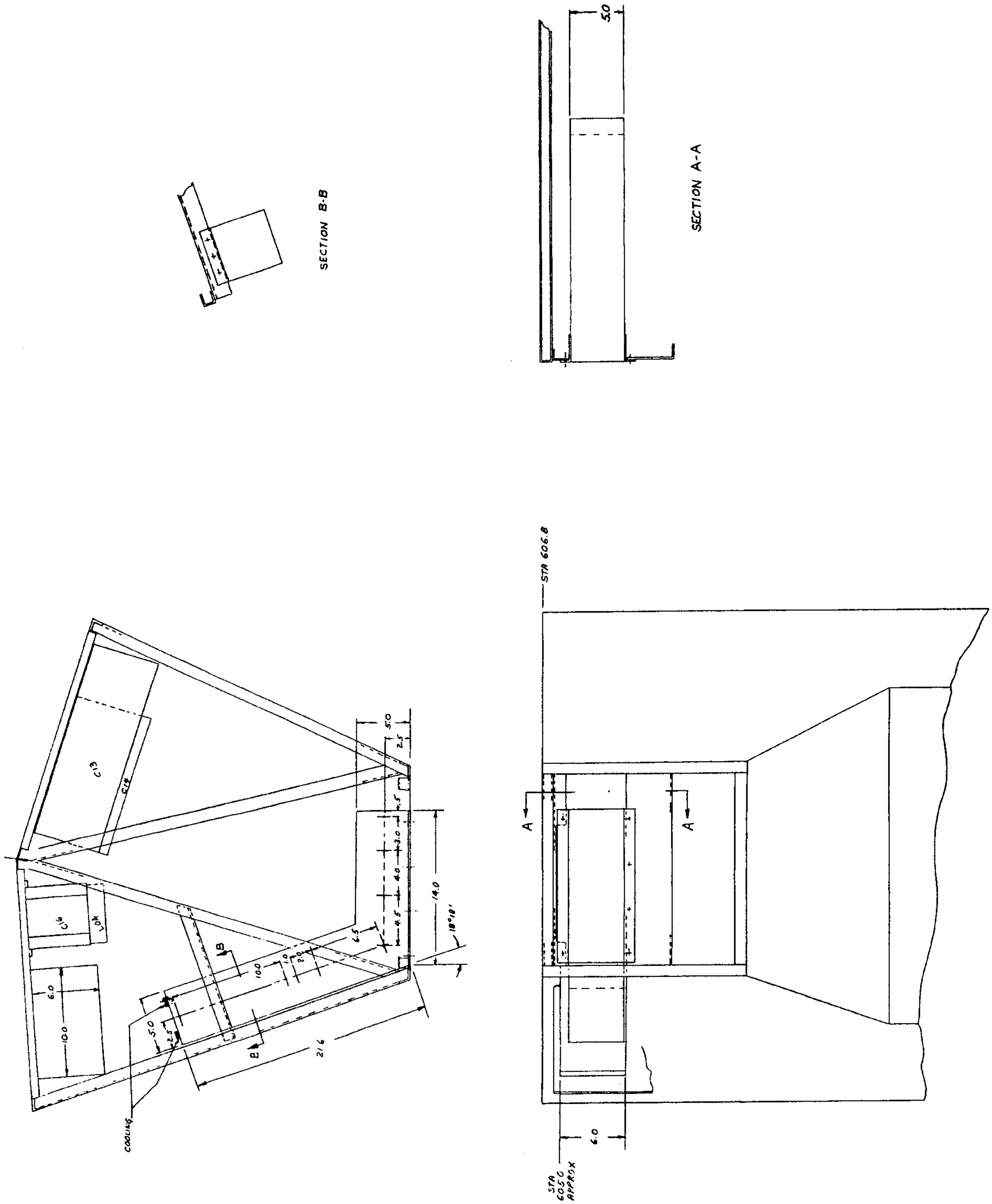


Figure 3. 7-9. TV System External Configuration and Installation

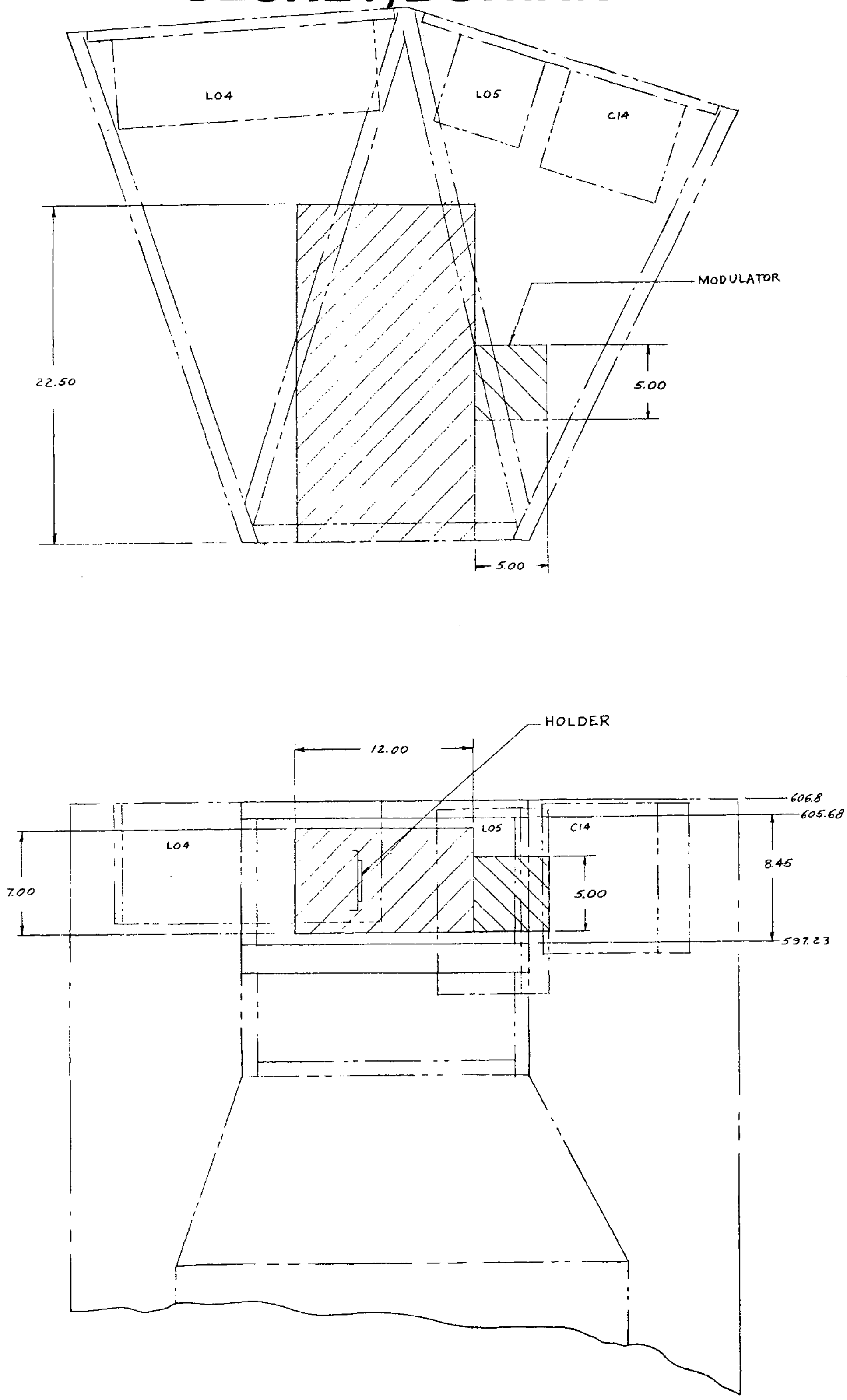


Figure 3.7-10. Film-Chip Disk-Type Laser Scanner System External Configuration and Installation (Alternative No. 1)

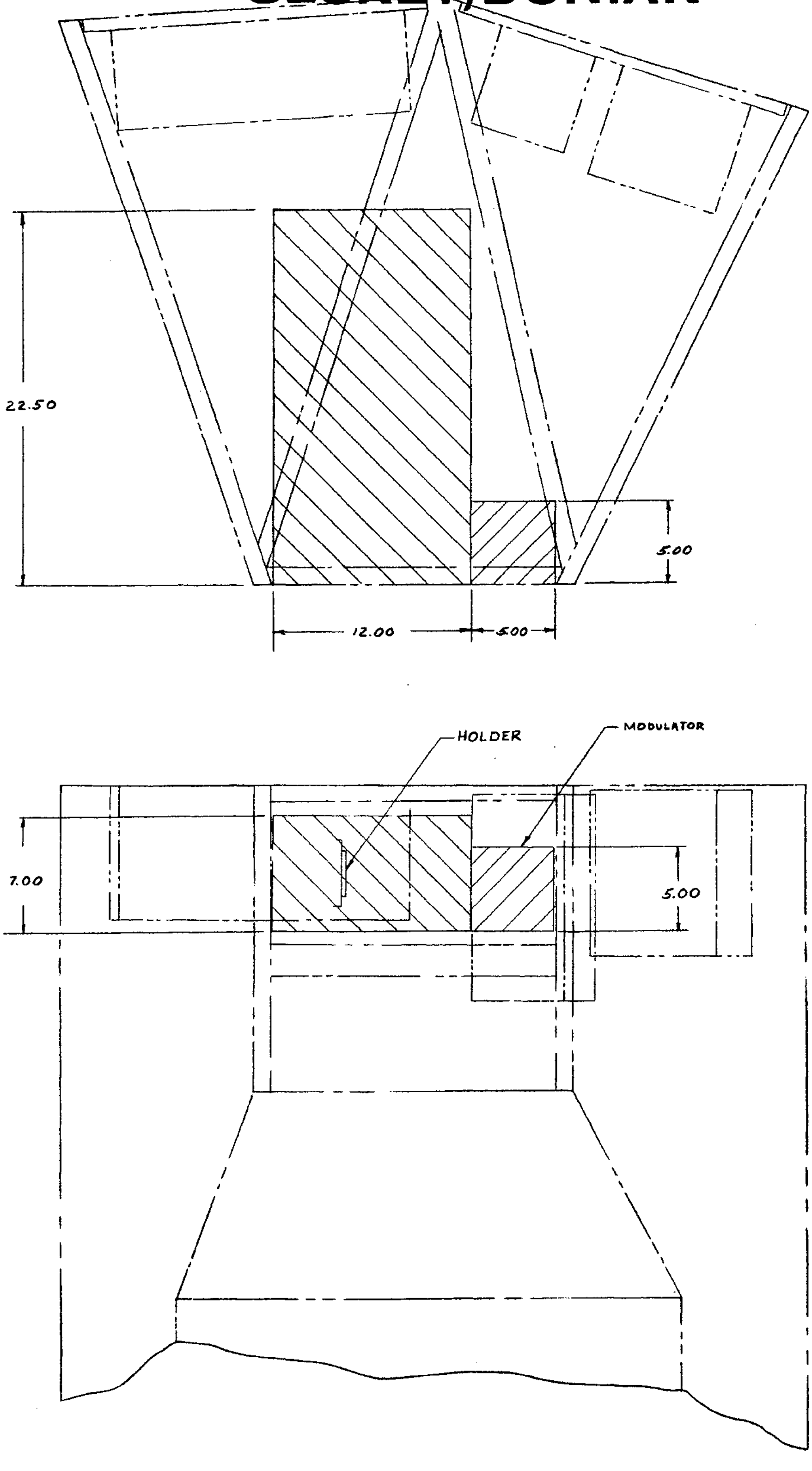


Figure 3.7-11. Film-Chip Disk-Type Laser Scanner System External Configuration and Installation (Alternative No. 2)

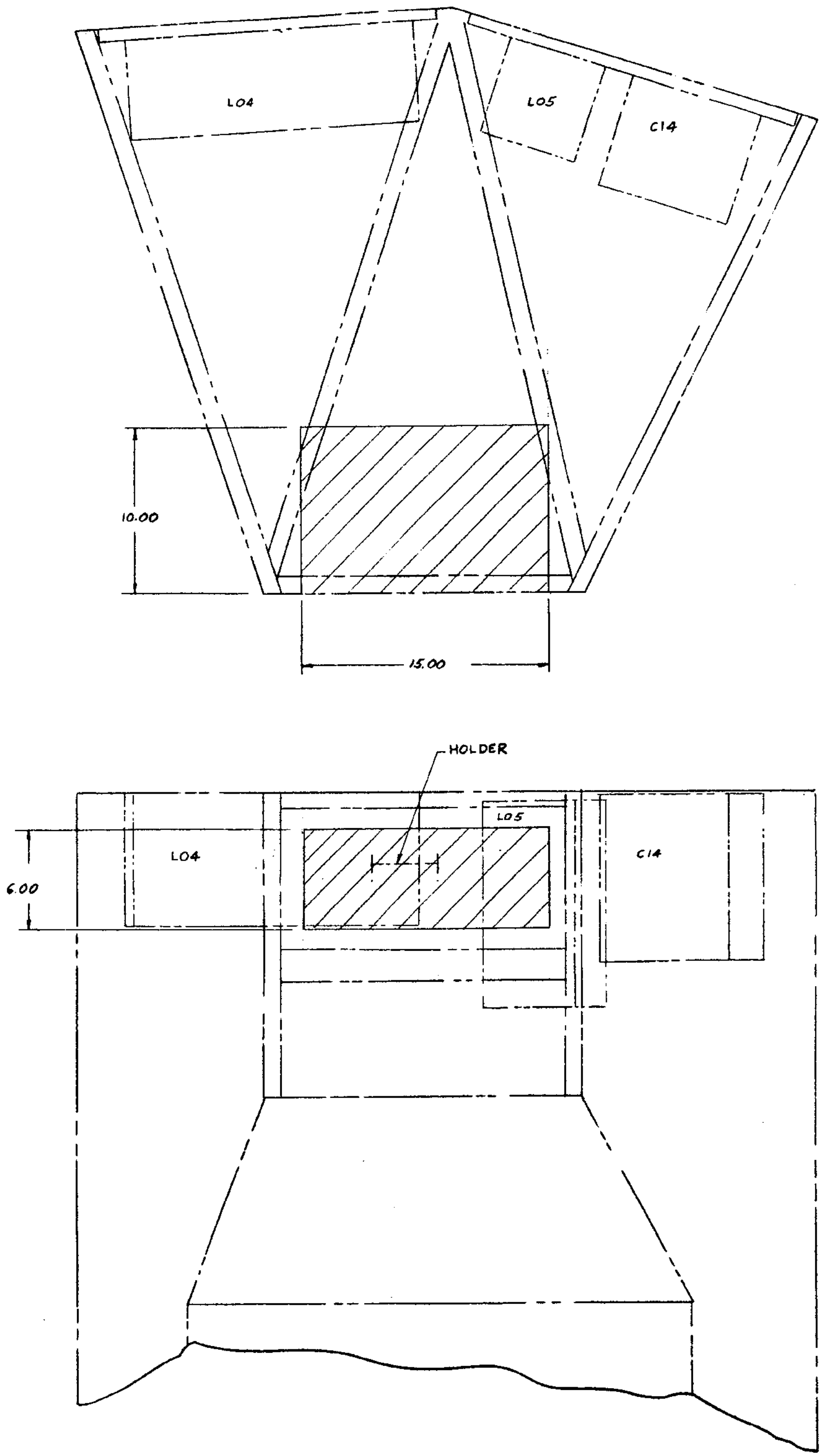


Figure 3.7-12. Film-Chip Drum-Type Laser Scanner System External Configuration and Installation

3.7.1.3.3 Electronics Box Installation

The TV system only requires a separate electronics box that is approximately 6 x 6 x 10 inches and requires mounting on a console heat exchanger (cold plate). Current console packaging does not have space available for this component. Rearrangement will be required to accommodate this box.

3.7.1.3.4 Potential Packaging Problems

With the exception of the TV system electronics package, there are no packaging problems at present. However, the packaging arrangement of the baseline system is still not firm and there is no guarantee that the Panel 2A space will not be used for growth of existing components. It is important to note that only the customer can reserve this space for readout and this must be done as soon as possible.

3.7.1.4 Console Structure

The Console 2 structure shall require the following changes and analyses to support the R/O Subsystem (see Figures 3.7-8 through 3.7-12).

a. Existing Structure Members - The console frame will require re-analyses of stress levels in each member including loads added by this new subsystem. Members shall be resized as required by this analysis.

b. New Members (FSS and TV Systems only) - Add a new member for support at the outboard end of the subsystem. Size and shape will be determined by stress and analysis.

c. Subsystem Interface Points - Add brackets, nutplates, etc. as required to support the R/O Subsystem. Actual locations and sizes shall be determined by analysis.

d. VDP Module Storage Rack Support (FSS and TV Systems only) - This rack is located just aft of the location proposed for the new subsystem. The rack edge is now supported by struts running to the top of the console. To install the R/O Subsystem, the strut must be relocated and additional support added to support the rack left hand corner.

e. Electronics Box Installation (TV System only) - Inserts shall be added to the heat exchanger (cold plate). The box shall be designed to maximize heat loss to the heat exchanger and minimize heat transfer to the console atmosphere.

3.7.1.5 Coolant Plumbing

The R/O Subsystem requires cooling and it is an LM requirement that radiation to the console atmosphere is not acceptable. Therefore, internal cooling is required. The console coolant supply shall be plumbed between the visual display projector and the console outlet in a series hook-up. Coolant (water) shall enter the R/O component at 75 lb/hr minimum and 102°F maximum.

3.7.1.5.1 Flying Spot System

This system generates approximately 30 watts of heat when operating.

3.7.1.5.2 TV System

The vidicon tube generates 4 watts of heat when turned on, but it requires cooling because the heat is generated in a very small volume and the tube temperature must not exceed 70°C (158°F) or degradation will occur. The electronics box, which is mounted on a heat exchanger, will generate approximately 27 watts of heat which will be dissipated to the heat exchanger.

3.7.1.5.3 Laser

This system generates approximately 50 watts of heat when operating. The following plumbing changes are required for the R/O Subsystem installation:

a. Plumbing routing - Tubing shall be routed from the VDP coolant outlet located at about Station 555 to the R/O Subsystem at approximately Station 603 and then from the Subsystem coolant outlet to the console outlet located at the forward end of the console at Station 606.8. This will add approximately 4.5 feet to existing tubing length.

b. Support Brackets - Brackets shall be redesigned to support new tubing routing.

c. Interface Negotiations - Changes to Interface Specification IFS-MOL-707003 must be negotiated with MDAC to increase coolant system volume. Dependent on final design of the subsystem an increase in pressure drop through console to include pressure drop through the subsystem and the additional tubing may have to be negotiated.

d. Component Pressure Drop - The pressure drop through the subsystem (including fittings) using water flow at 75 lb/hr and 102°F shall not exceed 0.15 psi.

3.7.1.6 Harness and Harness Installation

3.7.1.6.1 Existing Harness Routing-Changes

Harness and harness supports that currently run along side of the console through the area to be occupied by the new component shall be moved 4 to 6 inches towards the center of the console for the FSS and TV systems. This move effects one and possibly two fore and aft cable runs. To accommodate the laser system, harnesses to components mounted on outboard part of console shall require routing closer to the components.

3.7.1.6.2 Re-route Harness to Analog Encoder

The analog encoder shall be relocated elsewhere (most likely Console 8A) and this change shall require re-routing the harnesses to the new location.

3.7.1.6.3 Additional Harnesses

Additional wires and connectors shall be added to existing harness assemblies running from existing components in Consoles 2, 8, and MDAC interfaces to the new R/O Subsystem and to the modulator. These wires shall consist of 28-Volt power leads and no more than 20 low level signal leads.

3.7.1.7 Panel 2A and Subsystem Controls

Either Panel 2A shall be re-designed to be compatible with the new subsystem and its controls, or the component may replace the panel. A tradeoff study between the approaches must be conducted to evaluate delta weight, cost, and ease of installation.

Requirements for the panel are as follows:

a. Controls - Controls shall be mounted in the subsystem and, if a panel exists, access provided through the panel by use of cutouts. Recessed switches and electroluminescent lighting conforming to SAFSL 10011 shall be used. Controls shall be the same approved hardware as used elsewhere in the Lab Module.

b. Appearance - Finish, color, and lettering format shall be compatible with the balance of the Lab Module as defined in SAFSL 10011.

3.7.1.8 Access

R/O component mounting bolts are on the front panel accessible from the crew area and other mounting bolts are accessible from the top of Console 2 through MDAC space. This access through MDAC space will be negotiated as a change to ICD-MOL-707031. Presently there is no MDAC hardware above this area.

To remove the R/O component with internal cooling, it is necessary for MDAC to drain and purge the LM coolant system which requires about 22.5 hours in-line time. A study will be made to determine if it is possible to use an auxiliary heat exchanger attached externally to the component. With such a heat exchanger, it would be possible to remove the R/O component and leave the heat exchanger connected to the coolant system. This study will evaluate cooling efficiency, weight increase, reliability, and decreased time for replacement.

3.7.1.9 Laboratory Module Structural Subsystem

Impact requiring additional allocations to the Lab Module Structural (LMS) Subsystem are:

a. Weight Increase (pounds)

			Flying Spot System	TV System	Laser System
1.	Subsystem Weight (not included in LMS Subsystem weights)		(30)	(20)	(35)
2.	Modulator (not included in LMS Subsystem weights)		(8)	(8)	(8)
3.	Structure (approximately 7% of component weights)		2.66	1.89	3.01
4.	VDP Module Storage Rack Support Redesign		0.1	0.1	0.0
5.	Plumbing		0.65	0.65	0.65
	(a) Tubing 4.5 ft. at 0.1 lb/ft	0.45			
	(b) Fittings (2)	0.10			
	(c) Supports	0.10			
6.	Panel (may be less depending on approach used)		0.2	0.2	0.2
7.	Harness support (for relocation and new harness)		0.5	0.5	0.5
	Total LMS Subsystem Weight Increase		4.11	3.34	4.45
	Total LM Weight Increase		34.11	23.34	39.45

Note: Above weights do not include new harness weight or any auxiliary equipment.

b. Coolant Pressure Drop Increase (estimate)

1.	R/O Subsystem (or heat exchanger)	0.15 psi
2.	Fittings and Tubing	0.11
	Total Pressure Drop Increase	0.26 psi

3.7.1.10 Conclusions

The TV system has an additional electronics package to mount and this will involve re-arrangement of other components mounted onto cold plates. Other than this, weight appears to be the only tradeoff between the systems in the installation area and, unless weight is very critical, this would not appear to be a major factor in a tradeoff study. Total weight increase due to the scanner accommodation is a minimum of 23 pounds for the TV system and a maximum of 39 pounds for the laser system.

All three approaches can be readily accommodated in Panel 2A with no significant problems.

3.7.2 MODULATOR INSTALLATION

The Readout System requires a modulator which is approximately 5 x 5 x 5 inches in dimension. This modulator develops only 7 watts when operating and hence need not be mounted on a heat exchanger. Due to its small size, it can be mounted almost anywhere in reasonably close proximity to the scanner. Figures 3.7-10 and 3.7-11 show potential locations for this box as mounted with the disk type laser scanner system and these are typical of the type of installations that can be used for the modulator. The added weight of the brackets, nutplates and other mounting hardware is included in the weight breakdown in the previous section.

3.7.3 POWER

Anyone of the three candidate subsystems will require 30 to 50 watts for short intervals.

Designing the R/O Subsystem for manual operation minimizes impact on the EP&D Subsystem. Any of the three candidate subsystems will require between 30 and 50 watts for short intervals. The combination of manual operation and low current requirement (less than 2 amps) makes direct switching at the unit practical. Therefore, EP&D would only be required to feed raw power from the circuit breaker panel to the unit without communication with the power controller. However, in final design of the system the advantages of a power switch on the console to provide remote control for turn on should be evaluated. A study will also be made to determine the desirability of providing raw 28 watts to the subsystem by sharing an existing circuit breaker or providing an additional breaker. Neither of these are significant tradeoff factors.

The actual impact of the R/O Subsystem on peak and average power apportionment will be analyzed by defining a new MPSS check mode exclusive of the existing CA and CB modes. When the final R/O operational mode is defined then a more pessimistic power requirement of 70 watts will be assigned to the R/O Subsystem to take into account worst-case operation.

Since the R/O Subsystem operates at non-peak times, no peak power problems are anticipated for the R/O operational mode. A study will be made to determine how many other functions could be combined with it. The addition of the R/O Subsystem is not expected to significantly impact average power, but close attention must be given to operational sequences since early turn on may impact average power more than the actual transmission phase. Required warm up time is expected not to exceed five minutes for any of the three candidate systems.

It is concluded then that the only tradeoff factor involved is the actual power consumed since all systems have the same degree impact on the EP&D Subsystem. Power will only be a significant tradeoff factor if the average power in the vehicle is extremely critical.

3.7.4 EFFECTIVENESS/RELIABILITY

The mission effectiveness of the R/O Subsystem shall be at least 0.99 for the 30-day mission where effectiveness is defined as the probability that the R/O Subsystem is in an operating state to perform its intended functions within the performance limits of the specification.

The design of the R/O components and the selection of parts shall be such that the numeric allocation can be met with a minimum use of internal redundancy. In addition, the design shall be such that any failure in the R/O Subsystem will not adversely affect the crew safety and mission effectiveness of the baseline system. Specific concepts being considered to attain this objective are:

a. No failure in the R/O Subsystem will adversely affect the buss supplying electrical power.

b. Investigation of methods to separate the R/O cooling loop from the baseline loop (via heat exchangers for example) to minimize the risk of the R/O Subsystem adversely affecting the baseline system.

Three approaches to a suitable design have been investigated as follows:

a. The Flying Spot Scan System

b. The Television Camera System

c. The Laser Scan System

Based on the preliminary information available, a reliability comparison of the three systems has been prepared (see Table 3.7-1).

From a reliability viewpoint, therefore, it is obvious that the laser scan system is the best. It is reiterated, however, that these are only ROM estimates. As the three systems become better defined, more accurate calculations could be performed but it is not anticipated that the outcome with respect to preference of one system versus the other will change. This judgment is based on the fact that the first two systems contain tubes, which contain a heater and are subject to filament deterioration as well as helium degradation at a more rapid rate due to the higher temperatures involved. An electron multiplier tube does not employ a heater and, therefore, runs cooler. In a earlier study for another subsystem, it has been found that the failure rate for the electron multiplier is significantly lower than that for any electron gun device containing a heater.

The failure rate for an electron multiplier electronics package was estimated at 40.5×10^{-6} F/H in this same study and is being used here as a first cut ROM figure in systems 1 and 3. Note that system 1, the flying spot scan system uses a CRT as a light source. The CRT is in the same class as a vidicon with respect to failure rate; hence, for a first cut estimate, the CRT and electronics have been equated to a vidicon and electronics.

Use of a laser as a light source poses some problems, since there is little or no failure rate data on these devices. The type under consideration here is a helium-neon laser. This is in essence a pair of special concentric glass tubes containing the gas mixture.

Table 3.7-1. Readout Subsystem Reliability Comparison

Item	Failure Rate x 10^{-6}
(1) Flying Spot Scan System	
Cathode Ray Tube and Electronics	150
Photomultiplier and Electronics	40.5
Video Amplifier	10
A/D Converter	15
Mechanical Linkage and Miscellaneous	10
Total	225.5
(2) Television Camera System	
TV Camera	150
Lamp and Control	2
Bandwidth Compression Electronics	5
Video Amplifier	10
A/D Converter	15
Mechanical Linkage and Miscellaneous	10
Total	192
(3) Laser Scan System	
Laser Exciter	-
HV Supply	9.5
Xenon/Lamp	0.003
Laser	0.2
Expander	0
Light Mirror and Drive Motor (Motor only)	8.0
Photomultiplier and Electronics	40.5
Video Amplifier	10
A/D Converter	15
Mechanical Linkage and Miscellaneous	10
Total	93.203

MTBFs corresponding to these failure rates are as follows:

(1) 4400 hours

(2) 5200 hours

(3) 10750 hours

The laser is assumed to be "lased" by a xenon flash lamp driven by a high voltage supply. Due to simplicity, the laser itself is assumed to have a very low failure rate as indicated. End of life of this type laser is by definition when the ratio of gases within the tubes changes sufficiently such that "lasing" no longer occurs. Two failure mechanisms are at work, absorbtion of the neon into the glass and the passage of helium into the laser, due to differential pressure and the 70 - 30 oxygen-helium environment.

It should be emphasized that the presence of helium does not affect failure rate per se; however, it does affect life expenctancy. It is important that these two items are not confused.

3.7.5 EMI

The design requirements specified to control Electro magnetic Interference (EMI) for those portions of the MOL Space System designed, controlled, or integrated by GE are defined in GE MOL Specification No. DP1690, Section 3 which is derived from, and provides interpretation and expansion of SSD Exhibit 64-4. The requirements of Specification No. DP1690 will be applied to the R/O Subsystem.

Special attention has been given to such noise generators as cathode ray tube fly-back transients and turn-on transients, but no unique EMI problems which are expected to require attention beyond the normal precautions associated with good design practice have been identified.

The subsystem will be protected from conducted interference susceptibility by isolating primary power from secondary power within the unit. Adequate shielding will be provided to attenuate any radiated interference to an acceptable value. Internal shielding of secondary power leads will be provided to attenuate generated noise radiation.

From an EMI standpoint there are no significant tradeoff factors between the three candidate approaches.

3.7.6 ENVIRONMENTAL CONTROL

The subsystem shall be designed to withstand the environmental boundary conditions specified in GE Specification No. DR1100, Table I, Environmental Criteria for Internal Components Zone Z - Pressurized Compartment.

The environmental boundary conditions of DR1100 cover the range of environments encountered by the subsystem during storage, transportation, pre-launch activities, launch and the mission. The environments include, but are not limited to, such factors as temperature, pressure, vibration, shock, humidity and other natural environmental stresses.

DR1100 also defines the qualification tests which shall be performed to demonstrate the subsystem's performance and design adequacy. The severe qualification environments assure long life and reliability for GE AVE hardware.

The subsystem shall be designed to operate in both pre-launch and the LM on-orbit thermal environments in a manner consistent with LM thermal control methods. These thermal environments and control methods are defined in requirements negotiated with MDAC in IFS-707003 and IFS-707005 and with EK in IF101.2.6.

In essence, LM thermal control is accomplished by rejecting as much subsystem heat as possible into a coolant fluid provided by MDAC, for eventual rejection to space. The subsystem heat rejection to the cabin atmosphere is to be minimized. To meet this commitment, for components with significant heat dissipation and duty cycles such as those of subsystem considered, active cooling methods using cold plates or an integral cooling loop are required in conjunction with low emissivity subsystem external surfaces.

Cooling methods must also accommodate special considerations unique to specific subsystem designs. For example, in systems using TV tubes, it is desirable to maintain TV tube external surface temperatures to 70°C (158°F) or less to minimize helium permeation. To accomplish this, a detailed thermal design would be necessary which would probably use internal cooling, as indicated by preliminary analyses.

A specific subsystem design might also permit the separation of the electronic components from the remainder of the subsystem. For this case, the electronics could be packaged and mounted to an available cold plate, providing active cooling for the package. The cold plate approach is desirable, since the interface between the heat source and the cold plate is quite straight forward, and LM thermal control is not compromised.

The anticipated size and shape of the optical portion of the subsystem, and the required spacial relationship of this portion of the subsystem to the front panel indicates that integral cooling would be a reasonable approach. The integral cooling approach judiciously routes the coolant to the internal area rejecting heat.

The subsystem is expected to generate no more than 50 watts for not over a ten minute interval. The transient temperature response of the system to this heat rejection pulse is of course dependent on the thermal design of the coolant heat exchanger. Previous experience in integral cooling of the visual display projector, which is a similar subsystem from a thermal viewpoint, would indicate that only small temperature transients will occur. At the design point, a increase in coolant temperature of 1.3°C (2.3°F) would be the upper limit, assuming the entire absorption of 50 watts by the coolant. Good thermal design practices in the subsystem along with integral cooling, and the relatively large thermal capacitance of the subsystem would restrain the temperature response of the subsystem to small values.

Removal of the subsystem, which may be necessary to have access to other components, requires a purge of the coolant and disconnecting the coolant loop from the subsystem where integral cooling is used. To decrease the length of time required for removal of the subsystem, a cooling scheme using cold plates would be attractive. When using cold plates, the coolant system is not disturbed when changing a component.

The advantage of cold plate interface simplicity must be weighed against the probable increased weight. The weight increase is a result of both the added cold plate and the subsystem design changes providing an adequate conductance path to the cold plate. The cold plate weight could be minimized by not using it as a structural member, by tailoring its size for the specific application, and by locating it on the side of the component nearest the major heat generating source. An adequate cold plate design exists, and could readily be adapted to provide the thermal sink necessary to meet LM thermal control requirements.

Each of the three candidate systems could be readily adapted to either the integral cooling or the cold plate cooling methods. A detailed thermal analysis, coupled with a mechanical design study assessing access tradeoffs would rapidly indicate the desirable approach. No one of three systems considered is clearly superior to the others on the basis of its thermal characteristics, and no unique cooling problems should occur with any of them.

3.7.7 OTHER SUPPORTING EQUIPMENT

A limited amount of other equipment will be required to support the R/O Subsystem. This equipment will be used to crop and mount the selected protion of the photograph. This equipment could be a separate item or it could be made a part of the viewer/handler. More information on the capabilities of the viewer/handler and a study of cropping and mounting techniques are required prior to selection of the techniques and equipment used for this operation.

A limited number of additional crew restraints may be required in the LM due to incorporation of the R/O Subsystem. An examination of the needs for restraints coupled with simulation of crew action during use of the subsystem are required to establish exact requirements for additional restraints.

3.8 DEVELOPMENT RISK

The risk involved in developing the initial readout capability is very low. Laser scanner technology is well developed and the types of scanners considered for this application have been demonstrated both in the laboratory and in the field. [redacted] Relay satellites have also proven to be an excellant means for transmission of intelligence data and the MOL SGLS downlink is a field tested system. Based on these considerations there appears to be no area where risk can be identified.

The effect of inclusion of readout on the primary mission is minimal. The interfaces with baseline equipment are, 28 VDC power, diagnostic telemetry, fluid cooling and the output signal. The power and diagnostic telemetry lines can easily be protected from the effects of a R/O Subsystem failure by suitable circuit design within the R/O Subsystem.

Similarly, the SGLS equipment can be protected by suitable circuit design and by the fact that the R/O Subsystem can be easily switched out from the encryptor input.

The fluid loop in the R/O Subsystem is no different from the loop in any other equipment (integrally or cold plate cooled), and hence the inclusion of this subsystem presents no more risk of fluid loop failure than any other equipment.

It is concluded then, that the inclusion of the R/O Subsystem in the MOL vehicle will have practically no effect on the probability of success of the primary mission. If the possibility of an unsuccessful primary film recovery is considered, then the photographs that were readout could conceivably be the only photographic data recovered from a mission.

SECTION 4

SYSTEM TRADEOFFS AND SELECTION

This section summarizes the tradeoff involved in the choice of components and methods for the initial capability Readout Systems.

The choice of the scanner was complex, involving many parameters and, since it is the fundamental part of the readout system, it was felt that it warrants a tradeoff matrix and discussion in a separate section of the report.

The choices of the modulation techniques, down link and data relay links were relatively clear cut and were described in their respective paragraphs in Section 3. They are summarized here for completeness of this section.

4.1 TRADEOFF MATRIX AND SELECTION

Table 4-1 is a tradeoff matrix showing all of the significant parameters which must be considered in the choice of a scanner for early use on MOL. The X in the columns on the right of the table indicate the system which is superior in that characteristic.

Early in the study it was decided that the Readout Systems must be able to deliver the maximum resolution available in the Dorian photographs [redacted]. The fixed SGLS data rate and fixed station contact times determine the maximum area that could be read out at this resolution.

There is one very serious problem in the FSS and Vidicon systems however, in attempting to realize the high resolution. Consider available bandwidth given by:

$$B = \frac{2\ AR^2}{TK}$$

or

$$A = \frac{BTK}{2R^2}$$

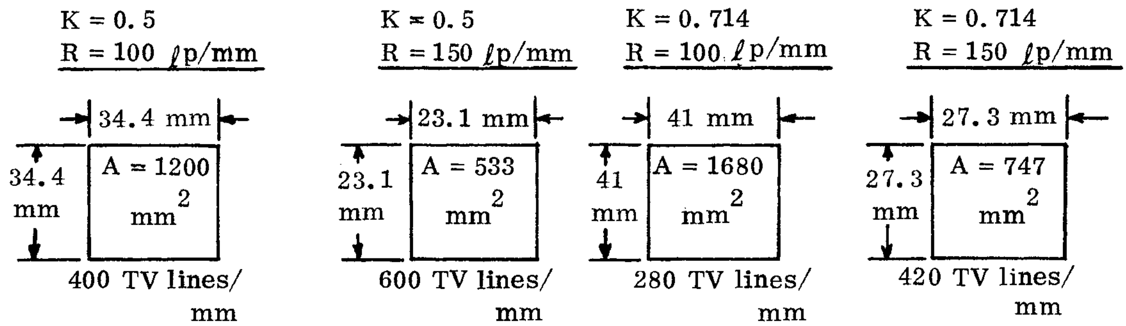
Table 4-1. Scanner Tradeoff Matrix

Parameter	Laser Scanner (L)	FPS Vidicon Scanner (V)	Flying Spot Scanner (FS)	L	V	FS
Weight	30/40 pounds	20/30 pounds	20/30 pounds		X	X
Volume	Fits Allowable Space	Elect. Package Requires Separate Mounting	Fits Allowable Space	X		X
Power	30/50 watts	20/30 watts	30/40 watts		X	
Warmup Time	5 minutes	2 minutes	5 minutes		X	
Film Readout	Moving ⊥ to Scan	Stationary	Stationary		X	X
Film Shape	Circular Radius or Flat	Flat	Flat	X	X	X
Format Uniformity	Dictated by moving spot over trans.	(Blemish in sensitive surface is permanent degradation. Also off axis degradation).		X		
Spot size vs. photon magnitude	Independent (Det. by laser properties)	Fixed condition (tube and illumination)	Spot Size inc. with beam current	X		
Helium permeation characteristics	Excellent (Shield PMT)	Poor (Special Tech. Req.)	Poor (Special Tech. Req.)	XX		
Scan Length Variation	Mechanical switching for two lengths.	Continuously Variable	Continuously Variable		X	X
Resolution Variation	Defocus	Defocus	Defocus	X	X	X
Scan Rate Variation	1-2 minutes required for stabilization	Continuously Variable	Continuously Variable		X	X
Min. Spot Size and Format Size (See Section 3.3)	Limited by optics, collimation of beam and scanning facets and mech. considerations	(Limited by Electron Optics) Scan tube length and demagnification	Capabilities of vidicon in TV lines	X		
Bandwidth Capability	High	High	Limited to 10 MCPS (p16) without comp.	X	X	
Frame Edge Degradation	Small	Electro-Optic Effects	Electro-Optic Effects	X		
Ease of Maintenance	Direct replacement of laser or PMT	Special Focusing Considerations	Not very practical to carry spare tube and align	X		
Growth Potential	Very high-limited by laser input power and mech. considerations	Limited by PC characteristics and special electronics	High	X		X
Special Considerations	Direct output to video amplifier	Requires special sample bandwidth comp. tech. for low bandwidths	Direct output to video amplifier	X		X
Aging Characteristics	Excellent	Good	Good	X		
Cost	Highest		Lowest			X
Availability	1 to 2 years	1 to 2 years	1 to 2 years	X	X	X
Max. Chip Size (100 Lp)	Several Inches by Several Inches	11 X 11 mm	12 X 12 mm	XX		

where the notation used is as defined in Section 3.3. Take, $B = 200 \times 10^3$ cps (in more exact calculations a 5% to 10% dead time should be used resulting in a 2.5% to 5% area reduction factor) and $T = 240$ seconds. Thus:

$$A\,(\text{mm}^2) = 2.4 \times 10^7 \quad \frac{K}{R^2\,(\ell p/\text{mm})^2}$$

The following table is constructed which indicates the nominal allowable area and required TV lines/mm for any type of Readout System with various Kell factors (K) and resolutions (R):



In the laser Readout System, photons from the laser are focused on the developed film emulsion. Spot size is determined by imaging optics and laser output beam collimation. The scan length is determined by a derived scan radius and the number of facets on the multifaceted spinner. A laser system could be designed for any of the indicated conditions. This is not the general case for the FPS vidicon or flying spot scanner readout.

In the FPS vidicon scanner, a diffuse light source is used to illuminate the input negative which is imaged on the target face of the vidicon. Resolution here is determined primarily by the spot size of the electron beam readout. Assume that an available tube can produce the equivalent of 3000 TV lines across its face at an acceptable contrast (assume a unity aspect ratio and equal vertical and horizontal resolutions). The width or height of the input negative that can be scanned during a single imaging is only 10.7 mm at 100 lp/mm and 7.16 mm at 150 lp/mm with a Kell factor of 0.714 in both cases.

In the flying spot scanner, a face generated raster is imaged on the input negative at some demagnification. This demagnification is dictated by film plane spot size required to yield a given resolution. Consider a 4.5-inch scan at the tube face from a 1.3 mil generated spot at an acceptable contrast. This is the equivalent of 3460 TV lines at either the tube face or in the image plane. The width or height of the input negative that can be scanned during a single imaging (without reimaging a subsequent frame) is 12.4 mm at 100 ℓp/mm and 8.25 at 150 ℓp/mm using a Kell factor of 0.714 in both cases.

It is then evident that at high resolutions, both the FPS vidicon and FSS readouts are severly limited in scan width or height. This is not the case with the laser beam scanner. To utilize available bandwidth over the allowed transmitting time, a number of smaller frames may be read out. If these frames are discrete areas of the original input negative, no serious degradation is expected except for a possible small bandwidth reduction. If these smaller frames are some part of a larger area to be transmitted, then indexing requirements can cause a sizeable reduction in available bandwidth or total scanned area. The resultant segmented reproduction can suffer from introduced edge lines and resolution element displacement.

A 12 x 12 mm chip represents approximately a 450-foot square on the ground and this small size imposes a very serious limitation on the scene content of any given chip transmitted using the FSS or vidicon systems. This, coupled with the fact that the laser system is a superior system in most other areas (see Table 4-1), makes the choice of the laser system for MOL readout rather obvious.

It must be emphasized that while the laser is the chosen scanner method for the initial readout capability, further study is needed to determine which method of mechanization is best for this mission. The continuous belt method was used as an example in Section 3.3. Two others, the disk and drum methods, have been suggested by CBS Laboratories and, based on preliminary examination, appear to fully meet all performance requirements. Future studies will be aimed at making this selection.

4.2 SUMMARY TRADEOFFS FOR OTHER EQUIPMENT

a. Modulator

1. Choices are 6-bit PCM or delta modulation

   (a) PCM requires 6 bits/sample

   (b) 1-bit delta requires 1 bit/sample

   (c) 2-bit delta requires 2 bits/sample.

2. Compared to PCM, delta modulation permits more samples to be transmitted per unit time.

3. Two-bit delta has superior rise time response over 1-bit delta.

4. Studies and experience show 2-bit delta is equivalent to 6-bit PCM for scene transmission.

5. Conclusion: Use 2-bit delta.

b. Downlink

1. Choices are SGLS or new system

2. SGLS

   (a) Bit rate = 1.024 MBPS

   (b) Encryptor - exists

   (c) Transmitter - exists

   (d) Antenna - exists

3. New System

   (a) Bit rate - higher than SGLS, permits greater data return.

   (b) Need new encryptor - questionable if high rate (> 20 MBPS) encryptors will be available.

(c) Need new transmitter

(d) Need new antenna - if data is unencrypted, steerable antenna is required.

4. Conclusion: New system violates minimum impact constraint; therefore, use SGLS.

c. Data Link

1. Choices are long lines, fly data, or relay satellites

2. Long Lines

(a) Bit rate - presently 1,200 BPS, may grow to 7,200 BPS

(b) Chip transmission time = 9.25 hours

3. Fly Data

(a) Time lag - many hours

(b) Cost - high, depends on number of chips and distance flown.

4. Relay Satellites

(a) Bit rate = 1.024 MBPS

(b) Chip transmission time = 4 minutes (real time)

5. Conclusion: Use relay satellite.

SECTION 5

IMPLEMENTATION OF THE READOUT (R/O) SUBSYSTEM

This section presents a discussion of the kinds of things that must be carefully considered during the design, development, testing and operation of the R/O Subsystem. The areas discussed were investigated during the study to determine if any problem areas exist and to develop an understanding of the work effort involved in the task of implementing readout on MOL.

It is emphasized that the items discussed are not to be interpreted as problem areas, in fact no major problem areas have been identified throughout the course of the study.

5.1 INTERFACES

5.1.1 ELECTRICAL

The R/O Subsystem has electrical interfaces with the EP&D Subsystem,the encryptor/ data link and the diagnostic Telemetry Subsystem. The interface with the EP&D Subsystem consists of the 28 vdc power supply lines and the R/O Subsystem will draw 30-50 watts.

The R/O Subsystem output is a serial digitized signal from the delta modulator which will interface with the SGLS data link via the encryptor. These equipments are a MDAC responsibility and therefore this interface must be negotiated with them.

Several diagnostic telemetry points within the subsystem will be monitored and will interface with the GE portion of the PCM telemetry system. The R/O Subsystem will be using the PCM transmitter in real-time to transmit to ground station sites that would not otherwise be contacted; hence, the diagnostic telemetry will be recorded for future playback. Selected parameters to be considered for addition to the telemetry list are:

a. Analog signals to be converted to PCM:

1. 28-volt raw power
2. Selected secondary voltage(s)
3. Critical temperatures
4. Laser operation
5. Film transport motion (laser only)
6. Video signal average value.

b. Event signals to be converted to PCM

1. Power on
2. Transmission active
3. Resolution select.

This subsystem is not expected to be associated with the Monitor and Alarm Subsystem for the following reasons:

a. Crew safety is not involved

b. Operation is manual with visual indicators

c. The circuit breaker will safe the unit in case of malfunction.

5.1.2 MECHANICAL

Mechanical interfaces will be with the console structure and the coolant plumbing system. The subsystem will mount through the front panel of Console 2 and be supported both by the structural members in the front of the console and a (new) structural member to be installed at the outboard end of the component.

Coolant will be routed to the subsystem via plumbing from the VDP and from the subsystem to the console outlet. Since coolant management in the MOL is a MDAC responsibility, this interface also must be negotiated with them.

5.1.3 CREW

There is a direct interface with the crew via the controls and displays on the front panel. These will typically include:

a. Controls
   1. Power on/off
   2. Scan start
   3. Resolution select.
b. Displays
   1. Power on/off
   2. Secondary voltages up
   3. Scanner operating.

There is also a film/scanner/crew interface with the manual insertion (and removal) of the film chips into the scanner. The use of film chips also creates an interface between the crew, the film and the cropping mechanism. This cropping mechanism may be a separate piece of portable equipment or it may be included in the Eastman Kodak viewer/handler. If it is included in the viewer/handler, then a new interface must be negotiated with EK.

5.2 OPERATIONAL SYSTEMS CONSIDERATIONS

The available bandwidth and the access time to a ground station defines the amount of visual data that can be transmitted. Intelligence requirements establish the lowest acceptable level of ground resolution. These constraints aid in defining the size of the film chip. The size of the film chip in turn determines the size of the on-board vehicle readout equipment. It is obvious that any system design activity must consider the capabilities of the ground station facilities and that there will be tradeoff studies to determine the optimum combination of design features at all locations.

As in the other study areas, the operating procedures will have a major effect in establishing the design limits of hardware. But there can be no real knowledge of how the complete system will function and how the system elements will interact without operational experience. Empirical data is needed.

An early capability for image readout will provide this data base of practical experience. It is planned that the readout equipment will be designed to make maximum use of the human operator so that it will have the flexibility and adaptability to resolve the presently unknown operational difficulties. Fortunately, the man-oriented system is the more practical approach in terms of the existing technology, the existing ground facilities and the time remaining to the operational date.

5.2.1 ON-BOARD SEQUENCE OF OPERATION

The inclusion of a Readout System in the MOL will result in significant changes to operational procedures. The expansion of mission objectives and the greater use of man also implies a reassessment of the relative value of all man tasks. This will ensure that unnecessary tasks are eliminated and that each task will be allocated the time necessary to its accomplishment.

5.2.1.1 Crew Activities

The determination that a portion of an image contains information suitable for transmission by a telemetry link is an indispensible function of the readout system. This image interpretation and decision process is also a uniquely human function. The addition of a Readout System therefore not only imposes additional tasks on the crewman but also increases the system dependence on the man. In this sense, a system incorporating readout more fully utilizes the potential capability of the manned MOL surveillance system.

Table 5-1 presents two related lists of operations and functions that are an essential part of obtaining, selecting, preparing and transmitting a frame of readout data. The lists include only a generalized breakdown of tasks. However, they indicate the nature of the changes that will need to be incorporated in a mission timeline and task analysis.

Detailed items will depend upon the presently undefined details of the hardware concept that is implemented.

Therefore, it must be understood that the lists of Table 5-1 are not intended to completely specify the implied system but are intended to illustrate the nature and number of added tasks. The table also provides a frame of reference for the following discussion of crew activities.

In an early system there will be constraints on the flexibility of the system (e.g., there will be little provision for obtaining imagery of targets of opportunity). The targets for which a telemetered image will be requested must be known far enough in advance to permit incorporation of specific targeting information and operator instructions in up-link data an appreciable time before the target pass.

Table 5-1. Typical Sequence

Crewman	Sequence	System
	Pre-pass	
		Accept and store readout target data
		Present cues
Study Cues		Alert crewman
		Print-out hand copy instructions
Read instructions		
Shut off alert		
	Pass	
		Alert crewman to R/O pass
		Insert secondary platen
		Make exposure
		Remove secondary platen
	Post-pass	
Remove film from camera		
Insert in processor		
		Develop film
Remove from processor		
Inspect in viewer		
Locate desired area		
Cut and frame chip		
Resplice or patch film		
Code, index and file chip		
or		
Place in scanner magazine		
	R/O Station Pass	
Turn on scanner prepass		
Establish ground contact		
Initiate scan		
Voice communication to ground		
Turn off scanner		
Remove film chip		

However, the target identification and camera pointing correction functions will be more demanding on the crewman than the usual photographic sequence. The pre-pass cue should be more specific with respect to the area selected for readout. If the readout area is not expected to be located at the center of format, a separate cue may be required.

The desired readout feature may be mobile (or variable in appearance) within the expected location. The crewman will need additional instructions on how to identify the desired area. This information may require a near-current hardcopy printout of these instruction. The on-board computer memory could retain this copy from the time of latest data uplink until time of target passage.

Not all target groups will contain targets for which an image readout is desired. The crewman will therefore need to be alerted immediately prior to the sequence of exposures containing a readout image since his activities will then be different than for a regular photographic sequence (e.g., he may wish to carefully center the target in the main optics so as to obtain optimum resolution).

Because of the present incomplete definition of the detailed operational sequences, a continuing evaluation of crew activities will be necessary until the hardware design and the operational concept have been specified in detail. It is entirely possible that the additional tasks imposed on the crewman and the additional demands on existing on-board computer memory will require a reassessment of the relative importance of individual tasks. This in turn could lead to changes in the presently planned operational sequences.

The continuing analysis and evaluation of alternative crew activities during the photographic sequence represents an increment of effort over that presently planned. However, once the design has been frozen, the tasks do not differ from those presently anticipated.

Once the readout photography is complete, the exposed film must be stored for processing at a later time. This procedure should not differ greatly from the present procedure for black and white secondary film. One difference will be the recording of which frames on the secondary storage reel contain the desired readout images. This is because not all secondary frames would contain readout imagery and because there will be no time during a target pass for the abstraction of individual chips from the complete photographic frame.

When time is available, the crew will retrieve the reel of exposed film and develop it. There are alternate procedures to be considered for operations after developing. These procedures will depend on the details of the physical equipment that is selected or designed. Disposition of those frames containing readout imagery is one detailed procedural problem.

At least the following two alternate procedures will be investigated:

a. The frame containing data to be readout is located and the complete frame is removed from the reel and the film on the reel spliced together again. The readout chip would be cut out and the remainder of the frame destroyed or filed.

b. The readout chip can be cut from the appropriate frame after which the cut area of the frame would be patched so that the structural integrity of the film strip would be retained and/or the other frames would be protected from the edges of the cut.

Since the readout chips will be accumulated waiting for a time when there is access to a ground station, there will be a priority of transmission sequence that will not correspond to the exposure sequence. This implies a need for random access to the stored readout chips that will be controlled by the crewman.

The decision to use separate chips will in turn influence the design of the storage and access mechanism for use by the crewman. The use of separate chips also influence or are influenced by the design of the readout device. In this early configuration that is planned to evaluate readout capability and to develop an optimum operating procedure, it will be advantageous to have much of the access, sorting, transfer, and filing of the readout chips performed by the crewman. Manual operations will permit trials of different operating procedures or provide adaptive flexibility for any one planned procedure.

Such dependence on manual operations will inevitably increase the load on the crewman. There will be a need to determine the optimum combination of hardware configuration and operating procedures. These additional trade-off studies and the definition of crew tasks will be completed prior to the establishment of firm design of details for the system hardware or any commitment to specific operational procedures.

5.2.1.2 Timelines

The timeline studies typically have two purposes. One is to provide a time correlation of the sequence of operations with the "real world" time sequence of targets and ground contacts. This real world time sequence will vary as the orbit parameters of the vehicle are changed. The second purpose is to establish realistic definitions of the demands of an operating system on its hardware components. Such demands include duty cycles, thermal environments, power loadings and such things as time and angular increments between targets. Typically, more than one timeline will be required to adequately define the limiting conditions for all the planned missions.

There are usually no unassigned time intervals in an efficient system. The optimum use of time requires the utilization of all of it. In the use of man as part of a complex system this requirement is difficult to satisfy. Not only is man limited by comparatively slow response times and the time dependent factor of fatigue, but other intangible performance factors such as boredom and psychological stress influence the allocation of his time. For this reason, it is difficult to establish a definition of the operational limits where a crewman is theoretically most efficient. Test programs are usually required.

These comments are significant in the sense that a number of iterations of the timeline for even a nominal mission may be necessary before a suitable one is developed.

Obviously additional timelines will be required for missions flown at environmental extremes. The addition of readout capability to MOL increases the number of crewman tasks and the number of equipment functions. There must therefore be an adjustment of any prior timeline schedule to include these extra items. However, if the original schedule were efficient, it is quite likely that some of the original items will need to be eliminated to make time for the new tiems. The relative priority of events scheduled in the timelines thus becomes an important issue that must be considered in the generation of timelines. This applies not only to the relationship of readout activities relative to other activities but also to the relative importance of individual readout images.

5.2.2 PRIORITY PLANNING

The very existence of a readout capability implies that the readout images have a greater urgency associated with them than other images. In addition, the importance of readout images will vary when compared to one another. This will be because of the inherent differences in the importance of the objects or events visible on the ground.

The probability that events of certain locations will merit use of readout capability can be determined in advance and can be scheduled in advance. The importance of other locations will be entirely contingent upon the existence of certain objects or activities in the field-of-view when the vehicle passes over. The priorities of these kinds of targets cannot be pre-assigned effectively. Mission planning and priority planning therefore must be conducted so as to provide the utmost flexibility for accommodation of these targets. Such flexibility will, of course, be limited by the capabilities of the hardware system and the crewmen.

5.2.2.1 Regularly Scheduled Targets

Certain targets will have such constant activity and contain such an ever changing amount of information that it will be practical to pre-plan transmission of a readout image whenever these targets are available.

The present mission plans provide access to important targets at least four times in a 30-day mission. A pre-planned readout target would have the same probability of being cloud covered (i. e., approximately 50 percent) as any other target. It would also have a decreasing value as a readout target as the time to the end of the mission (when all imagery is returned) decreases. For this reason, a regularly scheduled readout target would be a variable priority. It would be most important at the start of the mission and decrease to a very low priority at the end of the mission.

The assignment of priorities is not the responsibility of this contractor. However, the above considerations indicate that the operations plan and system capability should allow for a repetitive input to the airborne computer memory assigning current priorities to the target list.

A priority updating capability is not a new concept. However, the proper use of data obtained from regularly scheduled readout data may be one of the methods of obtaining the information needed to update the target lists and reassign target priorities during the mission.

5.2.2.2 Special Requests

One of the important applications of a readout system is the identification of the need for more information of a particular kind and at a particular location. Previously unscheduled targets can be acquired only as a result of a special request supported by the essential revisions to the timeline data.

At the very best the response time for the total intelligence system will be lengthy. The original information must be acquired, processed, stored until communication is possible, telemetered and relayed from the ground-station to a central processing agency. Then the decision for action must be made and the reverse process followed through the communication loop.

Since the special request may of itself lead to information that will require further cycles of target assignment to MOL, the relative priority of any special request will be very high. The ground command center may have to include a complete reassignment of target data and priorities as part of the uplink data whenever it makes a special request for imagery. This will require more transmission time and/or a wider bandwidth data link.

The capability constraints resulting from the possibility of special target requests would exist regardless of whether a readout system existed or not. However, an effective operational use of readout capability will require a more frequent use of special requests. This in turn will need to be reflected in a highly automated and flexible planning and sequencing function that could operate in near real-time.

5.2.2.3 Crisis Operation

Use of MOL capabilities during crisis operations would require the assignment of the highest possible priorities to a readout function and a radical change from the basic mission of the MOL which is the gathering of technical intelligence. On the other hand, for example, the acquisition of strategic intelligence is quite similar and would require little modification of the basic MOL system.

Use of MOL in crisis operations to provide repetitive near-real-time visual data of a limited global area would require such distortions of normal functions and procedures as to greatly degrade its basic performance. All targets outside the crisis area would be lost and the mission life could be shortened so drastically that it might not last throughout the crisis.

Nevertheless, a capability for response to a crisis condition must be considered in establishing design requirements and in preparing the software implicit in operational plans since readout capability is an important adjunct to any use of MOL in crisis operation.

5.2.3 CHIP SELECTION

It has been assumed in earlier sections that the imagery to be used for readout would be scheduled in advance from the ground. This is primarily because the system will initially have an exceedingly limited capability for visual search in real-time operation. Because of this pre-assignment of targets there will be a proportion of images made and processed that will contain no useful readout information.

The crewman must evaluate each of the images obtained to select those suitable for transmission and to precisely locate the small part of the total image that should be transmitted.

5.2.3.1 Criteria

The crewman will have no single criteria for his decisions but they will fall into the following four categories:

a. Determination that image quality is suitable for transmission.

b. Identification that the target contains useful information

c. Ascertaining that a single chip area will contain relevant information

d. Determination that transmission of this image will not interfere with a higher priority image or function.

This selection of image chips will be one of the more important uses of human jugement in the MOL mission. The crewman will not be working in real-time but he will be working under the stress of a tight schedule related to the next passage over a suitable ground station. He will have a near infinite number of possible choices regarding location of the film area to be cropped and transmitted. He cannot know precisely what he must select and he may have to decide between alternate areas of apparently similar value.

The further identification of criteria for use in selection of readout images will be an important part of plans for implementation of the Readout System.

5.2.3.2 Examination and Selection

The crewman will use a light table and low power microscope to examine the film. Assuming an image area meets all the criteria for transmission, there is still one more set of data that must be obtained prior to image transmission.

The small part of the image that will be transmitted must be accurately indexed to refer to the coordinates of the complete image frame and the center of image format must be accurately correlated with the proper ground coordinates. Additional details such as exposure, and filters should also be recorded for the readout chip. This additional data must be transmitted with the readout image for it to have value to the intelligence function on the ground.

The recording of this data can either be fully automated (which implies complex hardware) or a data readout by the crewman who must arrange for correlation and separate transmission of the data. Wide differences in the on-board sequence of operation can occur depending on the design details of an automatic system or the method used by the crewman to transmit the correlation data.

The range of possibilities is so great and the cost of an incorrect choice so high, in terms of transmission time or hardware complexity, that operational procedure tradeoff studies should be made to aid in evaluating the candidate systems. In later systems, the tradeoffs would be between different equipments but in earlier systems they will be between hardware and operating procedures. Incorrect choices for the early Readout System may lead to extreme variations in system capability because there is already little margin for error and because there is no backlog of operating experience to direct intuitive decisions. The design of later systems will not be so handicapped. For these reasons, it is planned to expend an additional effort early in the design to establish as rational a balance as possible between hardware and procedures.

5.2.3.3 Use of Auxiliary Equipment

Much of what was said concerning studies required for the examination and selection of images applies to the use of auxiliary equipment. However, there are a few features that will be common to all systems.

Some degree of mechanization of film handling will be required because in the zero gravity conditions many loose film chips as small as 25 x 25 mm would be difficult to handle (but so would unattached lengths of highly elastic film).

So it seems reasonable that the film will be viewed as part of a continuous strip on a reel until it is decided to abstract data from it. Then the cutting-patching-splicing-mounting device will be pivoted or slid over the image area. From a operational point of view it should either be an integral part of the viewing device or immediately adjacent and convenient to it.

It should also provide a convenient method of mechanically locating and indexing the film chip with respect to the overall image frame. The man will locate the device but the indexing and measurements will be mechanical and precise.

Whatever the details of equipment design may be, there will still be some time in the sequence when the man will need to handle and inspect the mounted film chip. He will also need to see that these chips are put in proper order for later transmission and/or stored in some manner which will permit easy and random access. Here, as in all of the readout design considerations, complexity of procedures and crew time will be weighed against complexity of equipment.

An automated system would be highly desirable, for then the computer could assign the proper priority to any one film chip and at the proper time retrieve it from files and put it into the scanner transmitter device. The man and his judgement are not needed for this function. However, in early systems his use as an adaptable and readily available acquisition and sorting device will be the only acceptable method. Selection of the proper combination of man and machine will be considered during the design.

5.3 MAINTAINABILITY

Maintenance capability shall be provided to ensure the success in meeting the probability of launch on time requirements. Preventive maintenance may be used to alleviate or reduce the likelihood of a failure while corrective maintenance will be used to restore the failed equipment to an operational condition. The maintenance design criteria of SAFSL 10032 shall be complied with for all equipment. The ground and in-flight maintenance of the R/O components shall not cause any injury to either flight or ground personnel.

Ground maintenance at the launch site shall normally be restricted to the removal and replacement of the failed unit. All maintenance of equipment removed from the vehicle shall be accomplished at the factory. The AVE and the supporting AGE shall provide the capability of isolating the failure to the planned levels of replacement. Maintenance procedures and equipment shall be configured so as not to contaminate the FV during maintenance operations. While the vehicle is installed on the launch pad, the design installation shall be such that the failed equipment will be capable of being removed, replaced and revalidated within 24 hours except for any additional time delay that may be incurred due to the draining and purging of the liquid cooling system. All of the R/O components are mounted in the LM and shall be capable of being removed and replaced prior to launch without affecting the integrity of other vehicle systems.

In-flight maintenance shall not be utilized to meet the numeric effectiveness requirements. Currently, no in-flight maintenance is planned; however, this will be reevaluated during the design cycle.

5.4 SAFETY

The equipment design shall be consistent with GE AVE criteria that all hazards to personnel and equipment are eliminated or reduced to an acceptable level. No single failure in equipment or procedures shall be a cause of a casualty to a crew member (Class III or Class IV, MIL-S-38130A) or prohibit an abort.

Specific hazard sources to be eliminated or controlled include:

a. The minimizing of fire hazards by selection of non-flammable materials, limiting ignition sources, and limiting flame propagation paths.

b. Reduction to acceptable values of the amounts of toxic materials which could be outgassed into the vehicle atmosphere.

c. Electrical wiring shall be designed so that potential ignition due to damaged wire insulation shall be minimized. This shall include load protection to restrict the current level and duration in shorted wires. Where voltages dangerous to personnel are present, adequate protection, warning and grounding practices shall be used.

d. Fluid cooling systems shall be designed to minimize the possibility of the liquid leaking into the vehicle environment.

e. Cutting of the film may involve the use of sharp instruments which, if not properly selected and guarded, could result in cuts to the crew and to ground personnel involved in testing the system. The cutting process itself may result in slivers of film freed to contaminate the atmosphere.

f. Glass in optical portions of the system must be protected to prevent breakage and to contain the glass particles if breakage should occur.

g. If the laser scan approach is chosen, the laser beam, if not properly protected, poses hazards in the form of burns and possible blindness to the crew and ground personnel involved in operating or testing the equipment. A special study of the crew-equipment interface will be necessary to eliminate these hazards.

5.5 SIMULATION

Simulation of the Readout Subsystem and its associated equipment shall be incorporated into the three major MOL simulators:

a. Mission Development Simulator (106)

b. Mission Module Simulation Equipment (111) (Mission Simulator),

c. Neutral Bouyancy Simulator.

By incorporating this equipment, several critical functions necessary to integrate the Readout Subsystem into the MOL baseline can be performed. These are:

a. Verification of the ability of the flight crew to perform the intended functions of the readout and associated equipment with the control and display interface provided, and recommendations for improvement of this interface.

b. Development of optimum procedures for the use of the equipment, and integration of these procedures into the overall on-orbit time-lines.

c. Familiarization and thorough training of all flight crew members with the equipment and the procedures for its use.

These functions will be performed under conditions of both nominal and non-nominal operation of the R/O Subsystem and all associated equipment.

The bulk of this effort can be performed in a ground based, one-g environment, where relatively long time periods can be denoted to the study of any particular task element. However, for complex mechanical tasks such as film cutting and mounting, and intra-vehicle transfer from the lower to the upper laboratory areas zero-g simulation provides necessary insight into the ease which these tasks can be performed. Furthermore, it is necessary that the crew become familiar with the performance of these tasks in the weightless environment. The neutral bouyancy simulator provides this environment and the necessary equipment to meet these objectives.

The simulation program planned for the Readout Subsystem is based on the following assumptions:

a. The 106 and 111 will be built to the following compliance documents issued as of 1 August 1968: SAFSL 34003, SAFSL 34004, CEI 400AI.

b. The neutral buoyancy simulator will be available (provided by other contract funds).

c. The viewer will be available in both the 106 and 111 (provided by other contract funds).

d. No photographic telemetry will be provided from the Mission Simulator to the STC.

e. Processed photographs (stimulus material for the 106 and 111) will be GFE.

f. Access to the R/O Subsystem in the 111 will be provided by MDAC.

5.5.1 EXPERIMENTS AND TESTING

Experiments will be conducted in which the simulated R/O Subsystem is used in conjunction with the subsystems with which it interfaces in the 106, 111, and neutral buoyancy simulators. These experiments will be concerned with the areas of procedures development, man-machine interface validation and (in the case of the 111 and neutral buoyancy simulator) crew training. These areas will be studies under nominal operating conditions and in conditions of equipment malfunctions.

5.5.1.1 Procedures Development

Mission procedures and timelines will be developed for the following subtasks:

a. Cutting and removal of the selected film area

b. Mounting of the film chip

c. Insertion of the mounted film chip in receiver

d. Pre-station pass turn-on and warm-up of the scanner

e. Initiation of data transmissions

f. Termination of data transmissions

g. Removal of the mounted film chip from the receiver slot

h. Storage of the mounted film chip

i. Processing and/or handling of the remaining film strip

j. Post-station pass shutdown of the subsystem.

5.5.1.2 Crew Training

The simulated R/O Subsystems as configured in the 111 and neutral buoyancy simulator will be used to train the crew in the procedures and techniques required for the manipulation of this subsystem within the timelines established during procedures development.

5.5.1.3 Man-Machine Interface Validation

During the procedures development and crew training processes described above, the design aspects of the man-machine interfaces will be validated. These will include operation of the film viewer, film cutter, film chip mounting mechanism, front panel of the R/O Subsystem and film chip storage device.

5.5.1.4 Malfunctions

Contingency mode operations simulation will be conducted, with selection of tasks based on available malfunction analysis. These will include such tasks as complete R/O Subsystem operations under unpressurized pressure suit conditions.

5.5.2 SIMULATION MODIFICATIONS/ADDITIONS

5.5.2.1 SLM Subsystem

The R/O Subsystem shall be mocked up to include all crew/Readout Subsystem interfaces.

This includes all indicators and controls required to activate and process the film sample, as well as all necessary hardware for mounting of film sample, placing sample mount in the scanning equipment, removing mount from scanner, removing film from mount, storage of mount and disposition of film sample.

5.5.2.1.1 Cutter

The film cutter can be either a separate piece of portable equipment or part of the viewer/ handler. The design and location will follow that of the AVE design with modifications as required for 106/111 and neutral buoyancy simulators.

5.5.2.1.2 Ancillary Equipment

Equipment required for the R/O Subsystem simulation, but not supplied as part of the subsystem include the film viewer (being negotiated as a part of another contract) and source material (GFE processed photographs.)

5.5.2.1.3 Restraints

Restraint systems to be evaluated in zero gravity simulation will be either GFE or supplied by General Electric under separate contract.

5.5.2.1.4 Deletions

The R/O subsystem will not include simulation of actual scanning or telemetry of data.

5.5.2.1.5 Exchange Hardware

The panel mockups and cutter manufactured for the 106 will be used in the 111 at the completion of the 106 development program. The neutral buoyancy simulator panels will be similar to those of the 106/111. They will duplicate the cutter function, film, mount, R/O panel interface and the switch positions on the panel. The displays will not function on the panel and no signal will be accepted by or provided from the panel mock-ups.

5.5.2.1.6 Location

a. MDS - The R/O Subsystem shall be located adjacent to the film viewer which is exterior to the SLM cabin mockup.

b. MMSE - The R/O Subsystem shall be located in Bay 2 Panel A in the SLM. It shall be provided to MDAC for integration into the total MOL mission simulator.

c. Neutral Buoyancy Simulator - The R/O Subsystem shall be located on Bay 2 Panel A in the SLM crew station mockup.

5.5.2.2 Computer Subsystem

(This section refers to the 106/111 systems only.)

5.5.2.2.1 Crew Monitor

The computer will store all crew actions such as placement of film in the subsystem, power, scan, etc.

5.5.2.2.2 R/O Simulation

The computer will provide the proper time lines to drive the R/O display such as scan time, ground station locks on and alarms.

5.5.2.3 Interface Subsystem

Power conditioning shall be provided to drive all the displays on the R/O Subsystem. This will be accomplished through the Digital Interface Unit (DIU) in the 106 and the Signal Conditioning Switching Unit (SCSU) in the 111. All signals necessary to interface with telemetry simulations shall also be provided.

5.5.2.3.1 111 Interface Drawing

Necessary interface drawings for mechanical and electrical interfaces with MDAC shall be provided to insure proper integration of the MOL mission simulator. This includes all interfaces with the SLM, IOS, and computer.

5.5.2.4 Simulation Control Console

Controls and displays will be added to the Instructor's Operating Station (IOS) to provide simulation control and monitoring of the R/O Subsystem.

5.6 TEST PLANS

Testing of the R/O Subsystem will be integrated into the presently planned MOL test plans so that a minimum of perturbations are caused. A block diagram of the planned in-house test flow is shown in Figure 5-1.

5.6.1 COMPONENT TESTS

Component tests are performed prior to the inclusion of the subsystem in the system test configuration and are designed to:

a. Demonstrate the ability of the component to operate within specified limits.

b. Evaluate performance at off design conditions.

c. Provide confidence that the components will sustain the environmental levels of the mission and are ready to be submitted for qualification.

The component tests shall include the following:

a. Performance Tests - Component development performance tests are conducted to measure the performance characteristics of the equipment under ambient environmental conditions. Results of these tests provide a baseline for comparison of all later test results.

b. Vibration Tests - The purpose of these tests is to evaluate the functional performance of the component during and subsequent to vibration. The levels are identical for development and qualification tests and are specified in General Electric Specification DR1100.

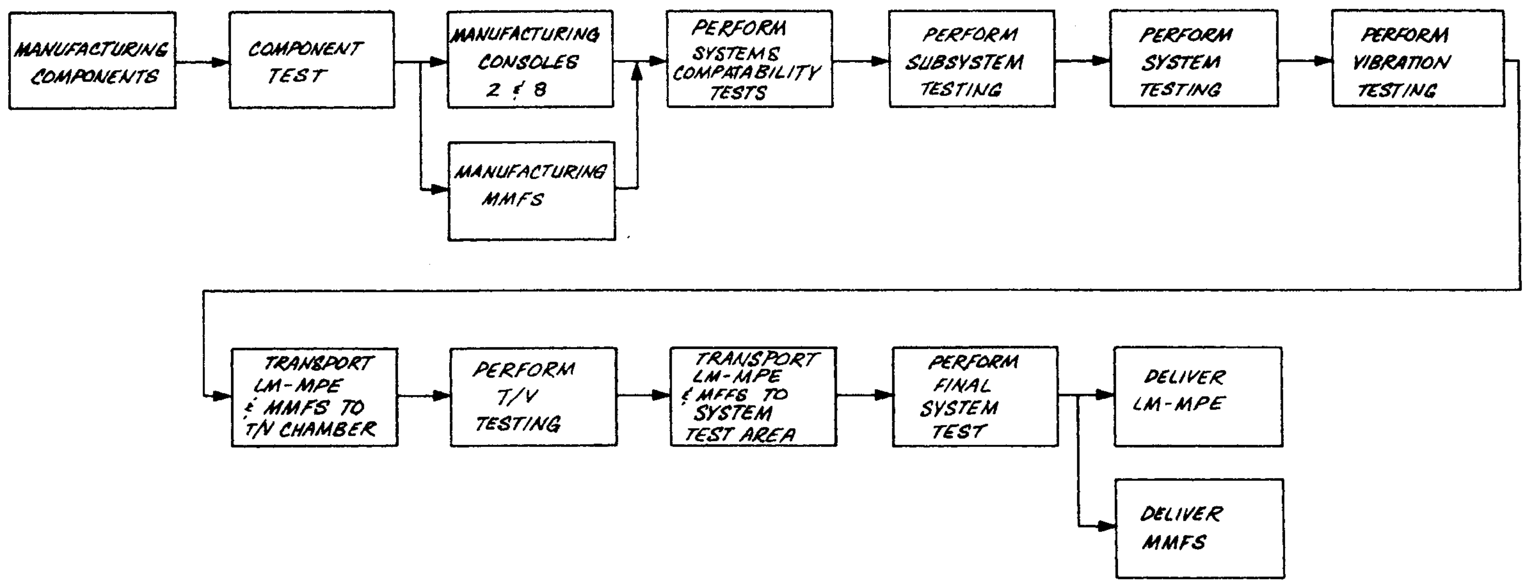


Figure 5-1. In-House Test Flow

c. Thermal Tests - The purpose of this test is to evaluate the functional performance during the specified thermal environment.

d. EMC Tests - The purpose of the EMC testing is to develop components which will be compatible with other components with respect to EMI. Specifications and requirements for susceptibility and generation are delineated in SSD Exhibit 64-4 with approved deviations contained in SAFSL Exhibit 14001.

5.6.2 SYSTEMS CONFIGURATION TESTS

The basic objective of the systems performance test is to verify operability of the system. In the systems configuration, subsystem tests shall be conducted to prove the functional performance of each subsystem. The R/O Subsystem would be part of the LM-MPE which consists of all the GE AVE equipment that is installed in the LM (i. e., Console 2, Console 8 and the acquisition optical assemblies). The R/O Subsystem will be tested after the following prerequisites have been satisfied:

a. The EP&D, Telemetry and Command Subsystem tests which affect the subsystem shall have been successfully completed.

b. All AGE and STE used in this test shall have been checked-out, validated, and calibrated.

c. All associate and government furnished equipment shall have been checked-out and validated.

The R/O Subsystem tests will utilize a 1951 USAF test chart and a step table in place of the film. This test will check the capability of the subsystem to respond to various gray levels and low and high contrast targets. The response of the photo-multiplier tubes and amplifiers will be checked to verify their operation within specified limits.

The R/O Subsystem would also be tested during the Test Integrated Mission Profile (TIMP) systems test. The normal operation sequence is tested during TIMP along with failure modes, negative modes, and null modes. The capability of the subsystem to operate under various failed conditions, to operate only those functions commanded, and to remain inoperative when required will be verified.

5.7 CHECKOUT SYSTEM REQUIREMENTS

The MOL Computer Integrated Test Equipment (CITE) is the checkout system used with the Mission Payload System Segment. CITE is a programmable ground checkout system used to perform electrical subsystem and/or integrated AVE system tests. CITE is functionally divided into two groups: Standard CITE is the non-AVE oriented portion of the system and Test Adapter Equipment (TAE) provides the connecting link between the AVE and the standard portion of CITE. The TAE provides AVE stimuli generation and control and it monitors the output of the AVE.

The addition of a new subsystem, such as R/O, necessitates a study of the subsystem and its test requirements to determine to what extent the TAE must be expanded and/or modified to satisfy the new requirements. In addition, any new TAE must be examined to determine if it has any effect on the test support software used with the digital computer that is part of standard CITE. Generally speaking, the design of standard CITE and its supporting software is general purpose and flexible enough to accomodate changes and additions which do not require unusual stimuli or special conditioning equipment.

A block diagram showing the interconnection of CITE with the R/O Subsystem is shown in Figure 5-2.

An examination of the R/O Subsystem and its test requirements indicate that the following capability must exist in CITE.

a. A test slide or a series of slides must be available to provide a test input to the scanner.

b. A ground data handling system must be provided to take the output from the AVE telemetry system and reconstruct from it an image in suitable form for comparison with the test slide (item a). This equipment should also be capable of operating on the output signal from the subsystem while by passing the telemetry link. This signal, together with its associated clock signal, will be available via hardwire test points on the subsystem.

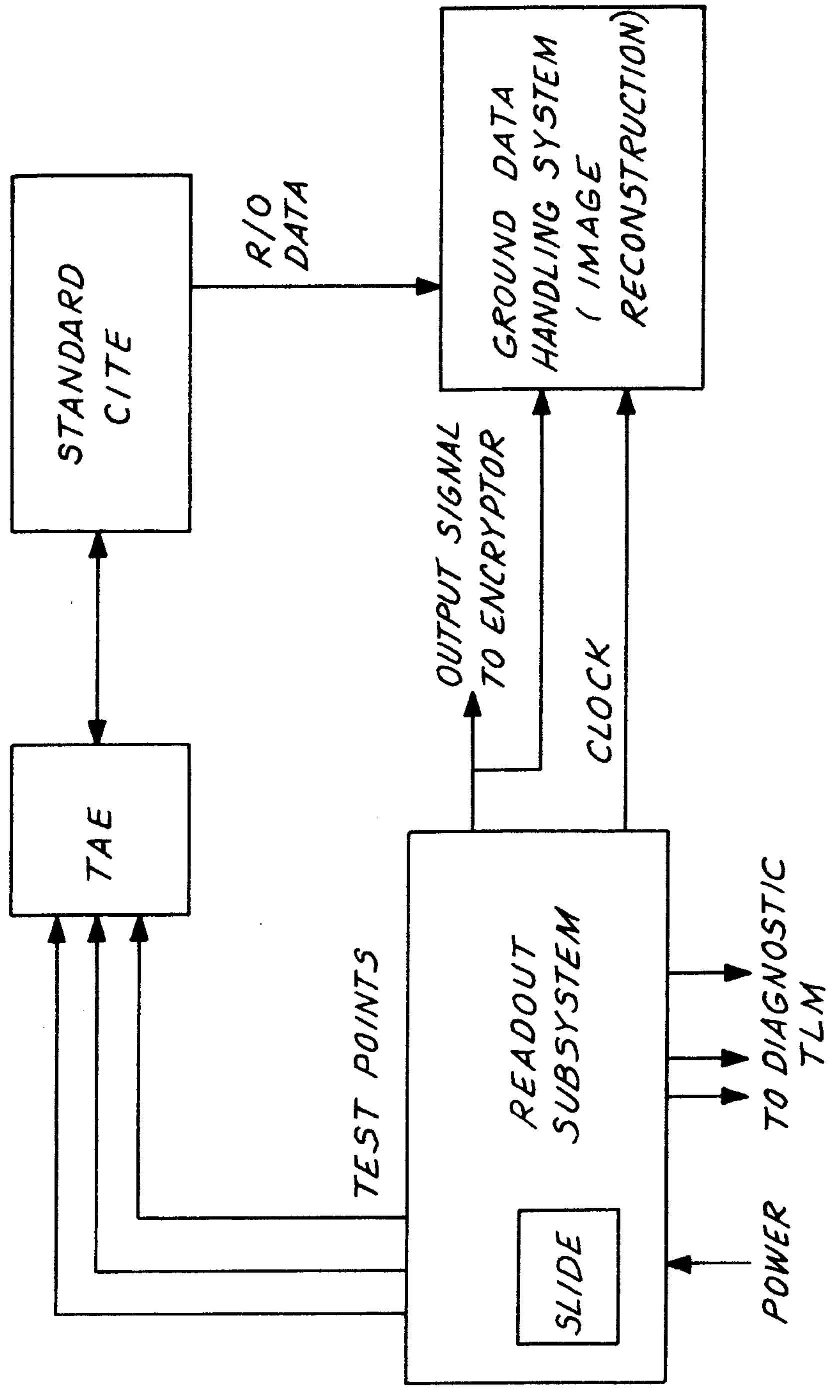


Figure 5-2. Checkout of Readout Subsystem

c. A telemetry decommutator is necessary to recover the R/O Subsystem data from the diagnostic telemetry signal and display it in some manner.

d. A data acquisition, processing and display system is necessary to collect and display data from the hardwire test points available from the subsystem.

A comparison of these requirements with the presently planned capability of CITE indicates the following:

a. The test slide material is not currently planned for; however, satisfactory slides will be available since they are necessary for subsystem development and acceptance tests. They can also be used for checkout of the subsystem in flight.

b. The ground data handling system is not currently planned as part of CITE. However, the equipment used during subsystem development and acceptance testing can be used. Since there will be no direct tie-in to CITE, except for the input signal, the use of this equipment during system testing does not present any new problems.

c. The capability to decommutate and display data in the diagnostic telemetry stream already exists in CITE and can be used without modification.

d. The capability to collect and display data via hardwire from the AVE test points already exists and can accomodate the additional signals from the subsystem without change.

In general, the requirements of the R/O Subsystem can be satisfied by the presently planned checkout system without change, provided that the appropriate slide material and the image reconstruction equipment are provided with the subsystem.

A limited amount of test adapter equipment (namely, cables) will have to be provided to connect the R/O Subsystem to the reconstruction equipment and standard CITE. These cables will be designed during development of the R/O Subsystem.

5.8 MAN'S ROLE ON-BOARD

5.8.1 GENERAL

Certain functions that man performs will be of value to any complex subsystem that must perform for long periods in an autonomous environment. In this sense the Readout System will be benefited by having man on-board the MOL. The crewman can make adjustments which will ensure optimum efficiency and effectiveness of the Readout Subsystem. He can prolong the Readout Subsystem's useful life by preventative maintenance operations. He can perform those minor repairs and/or replacements that will return a failed component to an operable condition.

In addition to these service functions, the presence of the crewman will permit a much simpler design for the Readout System. He can serve as a substitute for a mechanical positioning device; a selective switching device; or a computer operated device providing time delays, correlation of diverse signal inputs, and transformation of signal inputs from one context to another. These are advantages that always accrue from the presence of a human operator. Without him, these functions would require additional and complex servo-mechanisms interfacing with a computer and its memory banks.

5.8.2 MAN'S ROLE IN EARLY CONFIGURATIONS

The function performed by the Readout System includes many subtasks that can be performed only by the crewman. These tasks require the recognition of visual images and the making of decisions concerning the meanings of those images. These general capabilities, plus the ones mentioned above, can be directly related to specific tasks and/or operations. These tasks are discussed in the following sections.

5.8.2.1 Image Recognition

At present this is a unique human function. Even when perception devices become available, man's ability to extrapolate from data in dissimilar cues or from verbal information will make him indispensable in any system where real time identification of images is required.

5.8.2.2 Relevance of Image Content

Identification of the relevance of any image once it is recognized requires use of abstract concepts of value and a large data base to justify any decision. On rare, but important occasions, the observed target area will contain unanticipated information relevant to the total MOL mission, but having little relation to the originally specified target. There is no way to perform this function except through direct use of man's capabilities.

5.8.2.3 Location of Most Important Area

The variable size and location of targets for readout in conjunction with the limited area of the readout chip requires value judgments in the precise location of the area to be abstracted. More than one important area may have to be omitted because of chip size. The evaluation process and the mechanical location of the chip extraction device are so intimately related that this task also is a uniquely human function.

5.8.2.4 Ranking of Value of Chip Content

There will be limits to the system transmission capability that will make a priority list for sequence of transmission a necessity. There must also be an identification of the relative importance of the information contained in each chip. Whether the making is derived from the identification code of the chip or whether the crewman assigns a priority directly, the evaluation process is a human process that cannot be mechanized.

5.8.2.5 Coding of Readout Chips

Once a chip has been selected, it must be identified by coding of different kinds. Data allowing correlation of the chip image with ground coordinates must be provided.

A more general kind of coding is also required. Priority and on-board filing indices are obvious requirements but coding to identify the chip content is less obvious although equally necessary. The content of a chip will not be entirely predictable so that a simple ground coordinate reference will not adequately identify a chip for the eventual user. A code incorporated into the chip permitting rapid location of patricular kinds of intelligence information is also a requirement. Selection of such a code is another unique human function because of the random variability of the code categories as applied to similar images.

5.8.2.6 Verbal Data

It will be necessary at times to provide a verbal description of the surrounding conditions that led to the selection or priority assignment of a particular chip. The intelligent selection of only the pertinent data requires a human operator.

5.8.2.7 Variable Procedures

During early missions when no empirical data will exist to permit optimization of operational procedures, there will be a great advantage to having many of the operations under the direct control of the crewman. He will provide the flexibility essential to an effective operation when variations in procedure are needed. In some cases, a man on-board would be the only way in which a radical change in mission objectives could be implemented.

5.8.3 MAN'S ROLE IN FUTURE CONFIGURATIONS

A small number of the tasks described above can be modified in a more mature MOL configuration. Automation of the more mechanical tasks such as chip preparation and filing, or sequential selection and transmission of chips at the proper time, are likely candidates. But most such additions will be used only to decrease the effort required for man to perform the functions that he alone can provide. None of the tasks listed can be mechanized out of existence.

The principal gain in future systems will be the release of man for more extensive use of his unique capabilities. Rudimentary spatial filtering techniques, for example, may permit him to undertake more complex image recognition tasks and some search for targets that have not been pre-programmed.

SECTION 6

SCHEDULE

Figure 6-1 shows a typical schedule in months from start for development and qualification of the Readout Subsystem. Since the laser scanning and delta modulation techniques have already been developed, the effort involved in developing the flight hardware is primarily one of repackaging and qualification. Inputs from potential subcontractors indicate that this is a realistic schedule.

Adequate time is available in this schedule to develop and integrate the operational procedures, simulation facilities, and AGE required to support the Readout Subsystem.

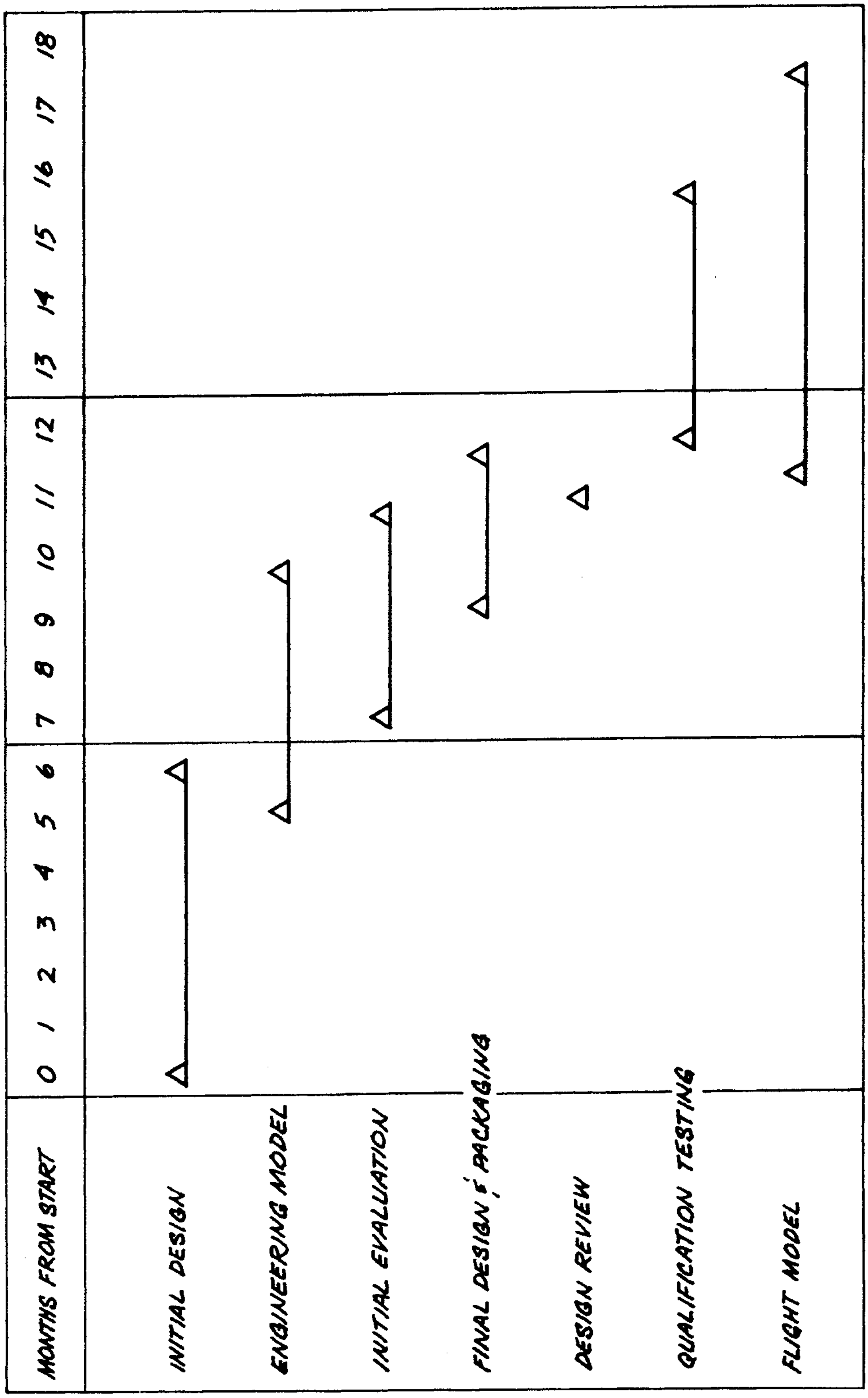


Figure 6-1. Typical Component Schedule