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WIDEBAND STUDY REPORT
FOR ERTS
GROUND DISPLAY EQUIPMENT
INTERFACE REQUIREMENTS

JANUARY 1970 – APRIL 1970

CONTRACT No. NAS 5-11196

Prepared by

WESTINGHOUSE ELECTRIC CORPORATION
ELECTRONIC SYSTEMS SUPPORT DIVISION
FIELD ENGINEERING & SUPPORT
P.O. Box 1693 Baltimore, Md. 21203

For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

WIDEBAND STUDY REPORT
FOR ERTS
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Contract NAS 5-11196

Contracting Officer: R.T. Smith
Technical Officer: M.S. Maxwell, 731

Prepared By

Westinghouse Electric Corporation
Electronic Systems Support Division
Field Engineering and Support Department
P.O. Box 1693, Baltimore, Maryland 21203

For

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

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PREFACE

The objective of this study was to consider the data acquisition and processing requirements for a high resolution spacecraft system capable of telemetering image data to a ground receiver at rates from 100 to 300 megabits per second. Based on such requirements, suitable components were to be identified to perform the necessary functions which included data synchronization and recording and subsequent data processing to form annotated photographic images. A goal of primary importance was to determine those areas which might technologically limit the performance of the system for use in 1974.

The study identified suitable equipment to properly function in the 100-Mb/s to 200-Mb/s range. This included data recorders of the laser beam, electron beam, and multitrack transverse scan magnetic type, and high speed emitter-coupled logic for data synchronization. During data playback, the necessary buffering would be implemented with semiconductor memory units in combination with magnetic core arrays and used to merge the annotation data from a small high speed computer with the image data. Finally, image production would be performed by a laser image recorder. Input to this recorder would be from a data intensity control unit implemented by a semiconductor memory look-up table or a small high speed arithmetic unit.

At 300 Mb/s, none of the present data recording systems appeared suitable. Data synchronization at this rate appears difficult with present technology but should be possible based on new components recently announced; the other functions presented no problems.

Thus, on the basis of this study, ground station data handling at rates up to 300 Mb/s are expected to be feasible for operation during 1974 if the data recording limitations can be removed. It is therefore recommended that the development of such very high speed data recorders be encouraged, with emphasis placed on the design of multichannel electron beam or laser beam recorders for use at 300 Mb/s.

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SECTION 1

INTRODUCTION

This is the final report for a study conducted from February 1, 1970 to April 30, 1970 under contract NAS 5-11196, Mod No. 3.

The object of this study has been to extend the results of the recently completed analysis of the ERTS A/B requirements*. The emphasis of work for this task has been to identify possible areas which may technologically limit the data acquisition and processing of data in the 100-Mb/s to 300-Mb/s region.

The sensing of the earth by a satellite sensor several hundred miles above the earth surface can produce wideband data even for modest image resolution. The Earth Resources Technology Satellite (ERTS) multi-spectral sensor (MSS) planned for a 1972 launch has a resolution of about 200 feet and provides data at a 15 megabit per second (Mb/s) rate. Reduction of this resolution to 50 feet increases the data rate to over 200 Mb/s.

It is possible that with such required rates, limitations in the spacecraft, the communications system, or the data acquisition system may prevent satisfactory implementation. Since the subject of this study was the data acquisition system, the specific areas considered included high speed logic for data synchronization, wideband data recording and playback, data buffering, computer controlled annotation of this data, intensity correction

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* "Phase II Report for Study of ERTS Ground Display Equipment Interface Requirements", 2 January 1970, Westinghouse Electric Corporation. Contract NAS 5-11196.

based upon system calibration, and generation of black and white and color photographic images. Each of these specific areas was reviewed in sufficient detail to determine the performance limitations, if any.

At the 100-Mb/s rate the entire acquisition and processing system could be built using existing techniques.

At 200 Mb/s, the data recording should be achievable by 1974 using single channel laser or electron beam recorders, or a 5-channel magnetic transverse scan recorder. At this rate the data synchronization can satisfactorily function using available logic (MECL III).

At 300 Mb/s, none of the recording techniques considered seem very promising. One recorder, built by General Dynamics, requires at least 11 channels at a tape speed of 80 feet/sec. It is therefore unsuitable for this system because of the large tape usage. There is some possibility that the CBS laser data recorder could be made to function at this speed; however, this was uncertain. Although no specific data was obtained on multichannel laser or electron beam data recorders, it appears reasonable that a two-gun electron beam recorder could be constructed. The film could be 70 mm, instead of the present 35 mm, and have two transverse tracks recorded side by side, and hence accommodate the 300-Mb/s rate. Such a dual channel approach seems less reasonable for the laser beam data recorder because of the need for precise mechanical positioning of the film.

The data synchronization unit, if constructed of conventional logic elements, would function satisfactorily at 300 Mb/s using recently announced high speed components (MECL IV). The remainder of the data processing system can satisfactorily function at this rate. Use is made of small semiconductor memory units, conventional magnetic core buffer memory, a small high speed computer, and a laser beam image recorder.

The primary objective of this study has been to determine whether high rate data, from an ERTS type spacecraft, could be adequately handled at the ground stations. During the study, little or no attempt was made to select from among several suppliers of similar components. Instead, only one representative supplier was considered for each product form. For example, the laser beam data recorder was considered only on the basis of information supplied by CBS Laboratories.

SECTION 2

SYSTEM PARAMETERS

For this study we have assumed that the spacecraft will be in an orbit similar to that planned for ERTS A/B. At the 496 n.m. altitude the subsatellite point moves at 21.18 ft/msec. The on-board sensor will be one of the following three types:

1) A multispectral scanner with parallel sensors of the object plane type designed by Hughes for ERTS A/B. The mirror rate will be twice that of ERTS A/B, or about 30 scans/sec.

2) A scanner of the image plane type designed by Hycon. One essential difference between this and the preceding scanner is that this type scans only one line at a time (in each spectral band).

3) A multiple detector line array. This scanner also scans one line at a time, but can be multiplexed to handle all spectral bands either in parallel, like the Hycon unit, or sequentially.

It is assumed that the scanner will accept data in five spectral bands, each with the same resolution. Actually it is expected that the longest wavelength band (IR) will have a lower resolution, but the necessary use of synchronization data will eliminate any rate reduction associated with such reduced resolution. Sampling of the data will be uniform in the vertical and horizontal directions.

The swath on the ground covered by the sensor will be 100 n.m. A separate photographic image will be formed of each 100 n.m. x 100 n.m. area. Each scan period is assumed to be 70 percent efficient.

In the following sections on data recording and synchronization, the 100-Mb/s and 300-Mb/s cases are considered. For synchronization, the data is assumed to be in 7-bit word sequences, with each word representing a single video sample. Since this part of the system is primarily affected by the bit rate, very little would be changed by the use of a 6 or 8-bit word.

The remainder of the system is, however, affected by the word rate and the number of bits per word. Thus, use of a 6-bit word (at the 100 and 300-Mb/s rates) would produce a faster word rate than a 7-bit word. On this basis it was decided to compute the word rate for a 6-bit word and then process these words as if they contained 7 bits. In this manner the results would be conservative if either a 6 or 7-bit word was finally selected. This effectively increased the bit rates to 117 and 350 Mb/s.

If a video sample is taken each F feet (as measured on the earth surface) there will be $\frac{608000}{F}$ samples per 100 n.m. The S/C motion forces the average time between line starts to be $\frac{F}{21.18}$ msec. With 70 percent scan efficiency, only $\frac{0.7F}{21.18}$ msec is available for scanning the earth. There are, then, $\frac{608000}{F} \times \frac{21180}{0.7F} = \frac{18.4 \times 10^9}{F^2}$ samples/sec generated. With 5 spectral bands and 6 bits/sample, we have $\frac{552000}{F^2}$ Mb/s. These figures can be expressed in terms of the angular spacing (measured at the S/C) between samples. At the given S/C altitude this angle is $\frac{F}{496 \times 6080}$ rad or $\frac{F}{3.016}$ urad. Thus, with samples taken every 43 feet, or 14 urad, the required bandwidth is 300 Mb/s.

Let us next consider the number of parallel sensors, P, required for the object plane scanner with a mirror rate of 30 per second. This is given by the number of feet travelled per scan divided by the line to line spacing F:

$$P = \frac{21180}{30F} = \frac{706}{F}$$

Figure 2.1 shows the number of such sensors required for various line to line spacings; the required data rate is also noted.

A summary of some of these computations for the 100-Mb/s and 300-Mb/s cases is shown in Table 2.1. Since the number of parallel sensors required must be an integer, the mirror scan rate was slightly reduced from 30 scans/sec.

TABLE 2.1. SYSTEM PARAMETERS

Data Rate	100 Mb/s		300 Mb/s	
Bits Per Sample	6		6	
Scan Efficiency	0.70		0.70	
Spectral Bands	5		5	
Sample Spacing	74.3 feet		42.9 feet	
Sample Spacing	24.6 urad		14.2 urad	
Samples/Line	8190		14200	
Type of Scanner	Object	Image	Object	Image
Scans Per Second	28.6	286	29.2	495
Scan Period	35 ms	3.50 ms	34.3 ms	2.02 ms
Lines Per Scan (Per Band)	10	1	17	1

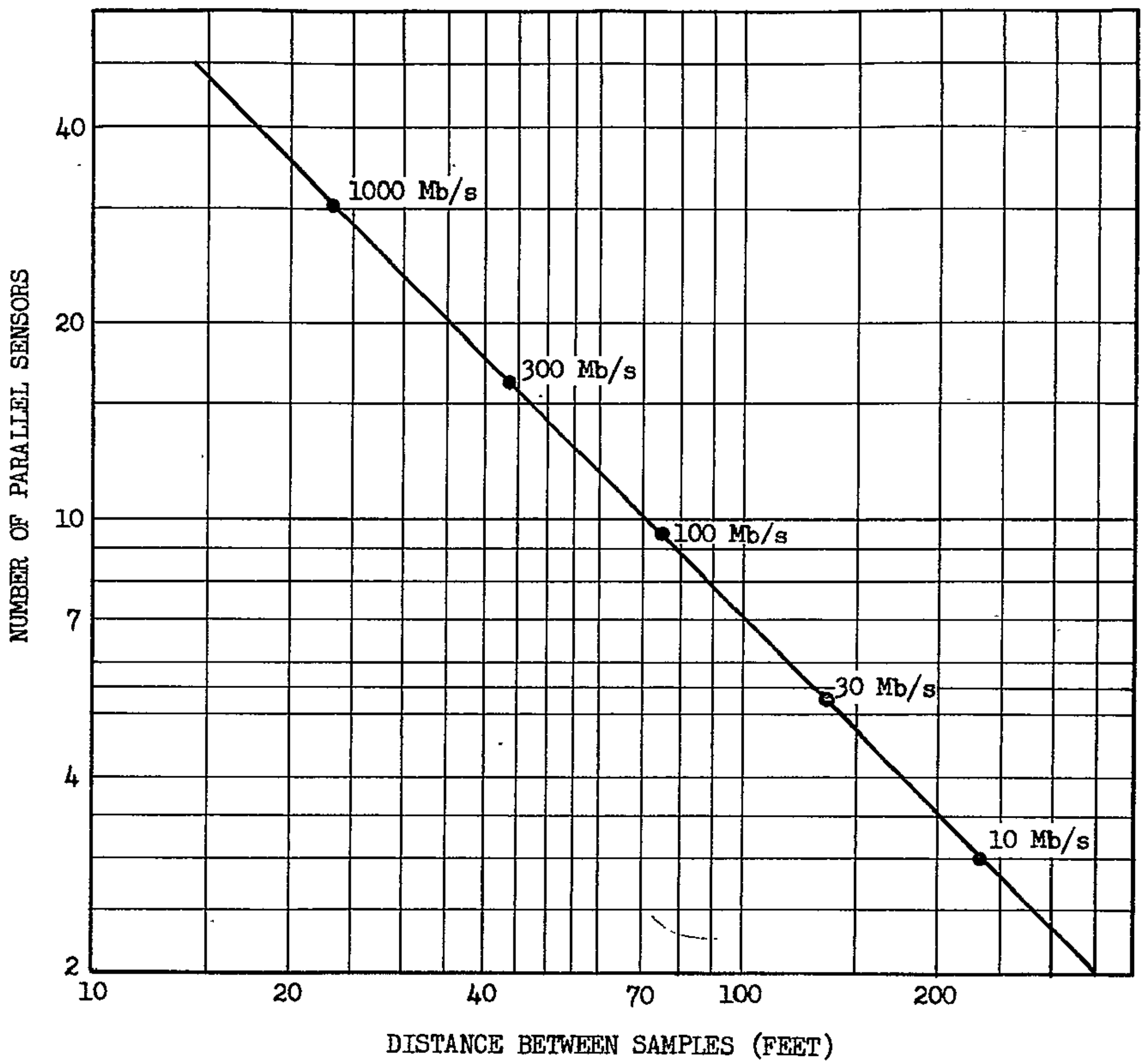

Figure 2.1. Number of Parallel Sensors Required for Object Plane Scanner

SECTION 3

DATA RECORDING AND PLAYBACK

There are basically five types of data recorders which have been considered for the storage of the 100 to 300 Mb/s data. These include magnetic tape recorders (longitudinal and transverse scan), laser beam recorders (longitudinal and transverse scan), and a transverse scan electron beam recorder. Only one of these techniques may achieve the 300-Mb/s rate by 1974, but several of them may achieve 200 Mb/s. Table 3.1 summarizes some of the essential properties of these recorders.

The intent of this survey was to list each wideband recording technique and to determine the properties of one representative recorder of each type. Of the recorders listed, the Synergistics unit has the lowest bit rate (21.8 Mb/s) and the greatest number of channels (36) to achieve this rate. Unless an unexpected improvement occurs prior to 1974, this approach is clearly not satisfactory for this task.

The other recorders may all achieve a 200-Mb/s rate, but the magnetic recorders require five or more channels to achieve this rate, compared to one channel for the optical systems. Thus data demultiplexing must be performed prior to magnetic recording. If the number of channels employed can be limited to the number of spectral bands (five in the case considered here), then data recombination during playback can be avoided. (It is assumed that during playback a photographic image will be formed from one spectral band at a time.) Thus the RCA recorder is satisfactory from this standpoint; less than 3500 feet would be needed to store the data for a 15-minute satellite pass at 200 Mb/s.

TABLE 3.1 DATA RECORDER SUMMARY

MANUFACTURER	GENERAL DYNAMICS	RCA	SYNERGISTICS	CBS	AMPEX
Tape Material	Magnetic	Magnetic	Laser Film	Laser Film	Electron Beam Film
Tape Width	1 inch	2 inch	8 mm	5 inch	35 mm
Scan Type	Longitudinal	Transverse	Longitudinal	Transverse	Transverse
Number of Channels	32	6	36	1	1
Bits per inch per channel	30,000	16000-32000	5,000	5,300	1600-2100
Channel Spacing (mils)	31	7.5	7.0	0.98	0.95
Density (Mb/in.^{2})	1.0	2.1-4.3	0.7	5.4	1.7-2.2
Scan Rate (inch/sec)	960	1250-2500	120	38,000	94,000
Bit Rate per channel (Mb/s)	28.8	40	0.6	200	150-200
Total Bit Rate (Mb/s)	921	240	21.8	200	150-200
Tape Speed (inch/sec)	960	28-56	120	8.4	75
Tape Length (feet)	12,500	9,200	2,000	1,000	3,700
Record Time at 200 Mb/s per 1000 feet (min.)	1.0	4.3-8.6	0.2	23.8	2.0-2.7

An attempt to employ only 5 channels at a time on the General Dynamics recorder would limit the data rate to 144 Mb/s and would require 7200 feet of tape for a 15-minute pass. This is obviously not a suitable approach. Using all 32 channels at 200 Mb/s will still require the use of 15,000 feet of tape per pass. This is substantially more tape than can be accommodated even on a 16-inch reel (9200 feet). Thus this recorder is less satisfactory than the RCA recorder for the factors considered.

Before considering the optical recorders we should note that the magnetic tape is in contact with magnetic heads during normal operation and can cause substantial head wear. For example, Newell Industries, Inc. rates their recorder head life (for a head capable of 20,000 bpi density) at 250,000 ips-hours. Applying this rating to the RCA unit we can estimate a head life of 100 to 200 hours. If each tape is played back five times (once per spectral band), only 20 to 40 hours of recorded data can be processed prior to head replacement.

The optical recorders, CBS and Ampex, do not have a head wear problem because scanning is performed by a beam of light or electrons. Although the number of bits per inch of the optical recorders is less than for the magnetic recorders discussed, the use of one narrow channel (optical) instead of many wide channels (magnetic) provides a significant compensating effect. Thus the CBS unit has the highest bit density, and the Ampex unit has only a factor of 2-3 less density.

As a result of this high bit density and the relatively wide film, the CBS unit has a tape speed of only 8.4 ips and has a record time, at 200 Mb/s of 23.8 minutes per 1000 feet of tape. This laser system has the possible potential of recording and playing back data at 300 Mb/s or more on one track; the electron beam unit, however, has a fundamental playback speed limitation at about 200 Mb/s due to the response time of the scintillation layer. This layer is used to convert the electron beam to light during the readout or playback process.

The electron beam approach, because of its lower bit density and narrower film, has only one-tenth of the CBS laser recording time at the same data rate and tape length.

On the basis of such anticipated performance estimates, the CBS laser data recorder is expected to best satisfy the system needs of those recorders considered. No attempt has been made to compare the CBS performance figures with those of similar recorders such as those being developed by Ampex and RCA. Furthermore, except for the magnetic head wear estimate, the reliability and maintainability of these units have not been evaluated. Finally, the initial and operating costs of these recorders was not determined since the two most suitable ones (laser and electron beam) involved new techniques requiring further development.

The following paragraphs include additional details of each of the five recorders considered. The parameters in table 3.1 were either supplied, or computed from numbers supplied, by the manufacturer. Expressions for these computations are given below:

$$\text{Bit per inch per channel} = \frac{\text{Bit Rate per Channel}}{\text{Scan Rate}} \quad (1)$$

$$\text{Channel Spacing}^{*} = \frac{\text{Tape Width}}{\text{Number of Channels}} \quad (2)$$

* Longitudinal case only

$$\text{Density} = \frac{\text{Bits per inch per Channel}}{\text{Channel Spacing}} \tag{3}$$

$$\text{Scan Rate} = \frac{\text{Bit Rate per Channel}}{\text{Bits per inch per Channel}} \tag{4}$$

Bit Rate per Channel - use equation (4)

$$\text{Total Bit Rate} = (\text{Bit rate per channel}) \times (\text{number of channels}) \tag{5}$$

$$\text{Tape Speed}^{**} = \frac{\text{Total Bit Rate}}{\text{Density} \times \text{Tape Width}}$$

3.1 GENERAL DYNAMICS

This recorder uses fixed longitudinal scan heads. The high bit density per track is produced in part by the use of the data modulation employed. In addition to the 1-inch tape 32-track system, 1/2-inch and 1/4-inch tape units with proportionately fewer channels are also available. The tape speed may be set in octaves from 15/32 ips to 960 ips. The inter-channel timing accuracy including digital record and playback is 5 nsec at maximum speed.

This type of recorder is given the name UNIDAR (Universal Data Recorder) by General Dynamics. There is some question whether these units are currently in production. Thus the inclusion of this recorder is only intended to represent the state-of-the-art for longitudinal magnetic recorders operated in the digital mode.

3.2 RCA

The recorder discussed here is a modification of a standard transverse scan magnetic video tape recorder, the TR70-CVR. This recorder was suggested by RCA in response to a request for information as shown as

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** Transverse case only

exhibit A. Specifications supplied by RCA for the performance of the modified unit are described in the letter of April 9 included as exhibit B at the end of this section. In addition, a list of the specifications of the TR70 are reproduced in part as exhibit C.

The TR70 has fade switching which provides for transient-free data after combining the output of four rotating heads. Fade switching is accomplished by linearly tapering the FM envelope at the output of the head switcher and adding the two channels together in a linear adder. This results in a transient that is 6 db below the noise level of the system. Automatic timebase correction is provided by the use of electronically variable delay lines. The rotating heads use air bearings to reduce jitter and bearing wear.

The letter from RCA indicated the use of DELAY modulation. Delay or Miller modulation of a binary data stream is a very effective means of encoding this data to utilize a minimum bandwidth. Direct recording of NRZ (non-return to zero) binary data produces satisfactory results only if the channel frequency response is adequate at DC (zero Hz). Although FM systems have the advantage of DC response, the bandwidth of an FM system is necessarily small compared to the total available bandwidth of the direct channel. At the high frequency end, NRZ can handle a bit rate of B Mb/s in a bandwidth of 0.75B MHz. However, since NRZ data can have long strings of ones and zeros during which no changes in the signal occurs, establishment of a clock is difficult.

The Manchester codes eliminate the need for DC response, and clocking is simplified because there is a data transition each clock period. However, a bandwidth of 1.5B MHz is required — twice that of the NRZ code.

The Miller code eliminates the disadvantages of the NRZ and Manchester codes; the bandwidth required is from 0.1B MHz to 0.75B MHz. In this code a one is represented by a transition in the middle of the bit cell, and a zero followed by a zero is represented by a transition at the end of the first zero's bit cell. To remove any ambiguities during readout, a "101" sequence should be present in the data.

3.3 SYNERGISTICS

The specifications for this unit are included at the end of this section as exhibit D. The maximum film speed given is 60 ips; however, we have been advised that operation at 120 ips has been achieved. Although the performance of this unit is far below that of the other recorders noted, it has been included because of its unique design and relatively low cost.

A general description of this recorder appears in the February 16, 1970 issue of Electronics, "Laser Recorders Pick Up Where Magnetic Machines Leave Off In Speed, Capacity". A more complete and technical discussion is presented in an article available from Synergistics entitled "Multitrack Laser Film Recorder", dated August 8, 1969. The following is abstracted from this article:

> In appearance and mechanical configuration, the Multitrack Laser Film Recorder (MLFR) is similar to a conventional instrumentation magnetic tape recorder. The MLFR can be conceived as a modification of a conventional magnetic tape recorder, in which the magnetic tape heads are replaced by an electro-optic head and the magnetic tape is replaced by a reel of microfilm. Thirty-six tracks are recorded on a strip of film 8 mm wide. The actual area occupied by these 36 tracks is 0.252 inch, so that each track is

spaced 0.007 inch centerline to centerline. Because of the low crosstalk between the channels of the electro-optic head, it is possible to do this 36-channel recording with a single static head. It is also possible, since there is no equivalent to the magnetic fringing field, to make each of the recorded tracks occupy the full 0.007 inch available. On playback, to promote machine-to-machine interchangeability of the record and also to take account of the film skew, the playback head senses only the recording in the center 0.004 inch of the recorded track.

The electro-optic head consists of a continuous gas laser, cylindrical optics to form the beam to the desired shape, a 36-channel electro-optic modulator, and a 36-channel solid-state photodetector. A drawing of the electro-optic head is shown in figure 3.1. The output from the laser is a circular beam of light approximately 0.8 mm in diameter at the $1/e^2$ intensity points. The beam of light passes through an optical assembly, which reshapes the beam into an elliptical cross section that is approximately 1 inch wide by 0.01 inch thick. This elliptical cross section beam is incident on an array of 36 modulator cells arranged side by side. The light emerging from this array of modulator cells is reshaped so that at the surface of the record the beam is approximately 0.24 inch in width across the film and approximately 0.0002 inch in thickness, measured longitudinally to the film.

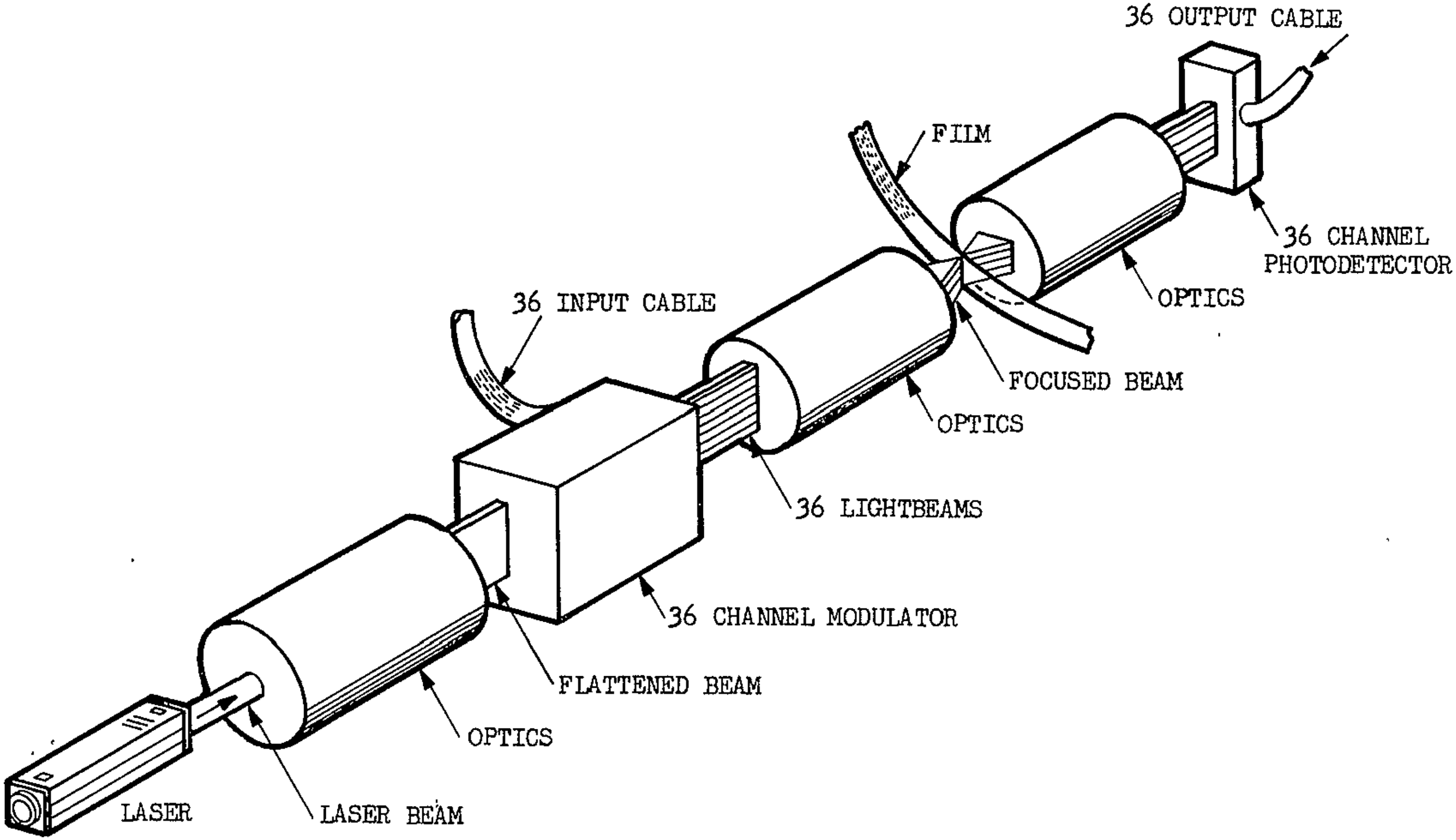

Figure 3.1. Electro-Optical Head

Optics placed on the opposite side of the head from the laser expand the light which passes through the film to the same geometry as that on the modulator cell. This expanded beam is then incident on a 36-channel photodetector.

The modulator cells use deuterated KDP in the same configuration as used for very wide bandwidth modulators. Each of these cells requires approximately 100 volts peak-to-peak to obtain 100 percent modulation. The bandwidth of the modulator cell itself greatly exceeds the bandwidth required for recording, but the overall bandwidth of the machine is determined by the electronics and the optics.

The motivation behind combining laser technology with photographic film for recording purposes is that the laser is capable of delivering high light power to the film. This makes it possible to use low speed films of the microfilm class, permitting the attainment of high recording signal-to-noise ratios at high data packing densities. These microfilm materials typically require on the order of 200 to 1000 ergs/cm^2 light energy exposure to produce a density of about unity after development.

3.4 CBS

CBS Laboratories currently has under development laser beam widebeam data recorders using both 35-mm and 5-inch wide film. The original request for information on these recorders and the reply (exhibits E and F) are included at the end of this section. Since the 5-inch recorder has the higher bandwidth (200 Mb/s), this unit was selected as representative of the current art in laser beam data recorders.

A detailed technical discussion of such a recorder is given in a group of four papers presented in September 1969 entitled, "A Laser Beam Wideband Data Recorder".

The recorder is of the transverse scan type. This approach was selected instead of the helical scan primarily to employ the technology developed for the laser beam image recorders. A major distinction between data and image recorders is the requirement for scan line separation during recording for the data recorder and for line-following during reproduction.

If the film were a rigid body, the shape and length of each scan line could be perfect. Thus the exit of spot A on line N could occur simultaneously with the entrance of spot B on line N+1 during recording and playback. If this were the case, both amplitude and phase continuity from one line to the next would be insured. Furthermore, if the spot cross section were rectangular, crosstalk between scan lines would not exist.

To compensate for position changes of the film during readout a rectangular mark is used during recording. The region of the film (at the edges) not exposed during recording (because of the mask) will appear very dense after development since a reversal film is employed. The light pipe system which collects the transmitted light during readout can therefore be oversize by the anticipated limits of film wander. A slit in the recording mask will produce a mark on the film which can be used during readout to control the spinning mirror phase angle for compensation of the time base error.

Correction for variations in film size from record to readout is provided by adjusting the film to spinning mirror distance. Focus and film surface curvature corrections are simultaneously provided.

Another difficulty associated with film dimensional stability and its transport through a recorder is commonly referred to as skew. Correction for skew is provided by use of a servo-controlled rotary table which supports the film, and by use of a broad record track.

Generation of an approximately rectangular spot shape is performed by use of a multiple spot superposition technique. During recording the track will be generated by two superposed spots. After processing, the recorded track is read out by one of the spots. Thus the recorder is converted to a readout machine with minimal changes to the optical system.

3.5 AMPEX

A wideband electron beam recorder has been developed by Ampex and was demonstrated at Rome Air Development Center in September 1969. A technical discussion of this unit is included in their report, "Wideband Magnetic, Electron and Laser Beam Recorders and Elements of Optical Processing".

The unit employs electron beam recording on direct positive silver halide film and readout using the scintillator method. Line scan is generated by magnetic deflection of the electron beam; the space between lines is primarily formed by motion of the film. Unlike magnetic and laser transverse scan data recorders, alternate lines proceed from left-right and right-left. These adjacent lines are connected by an extremely fast transition (1 nsec) of the beam.

Following chemical development of the film, the recording consists of lines of varying light transmittance on a high density background. On playback a plastic scintillator coating, which is part of the film package, acts as a light source with a fast response (figure 3.2). A constant current

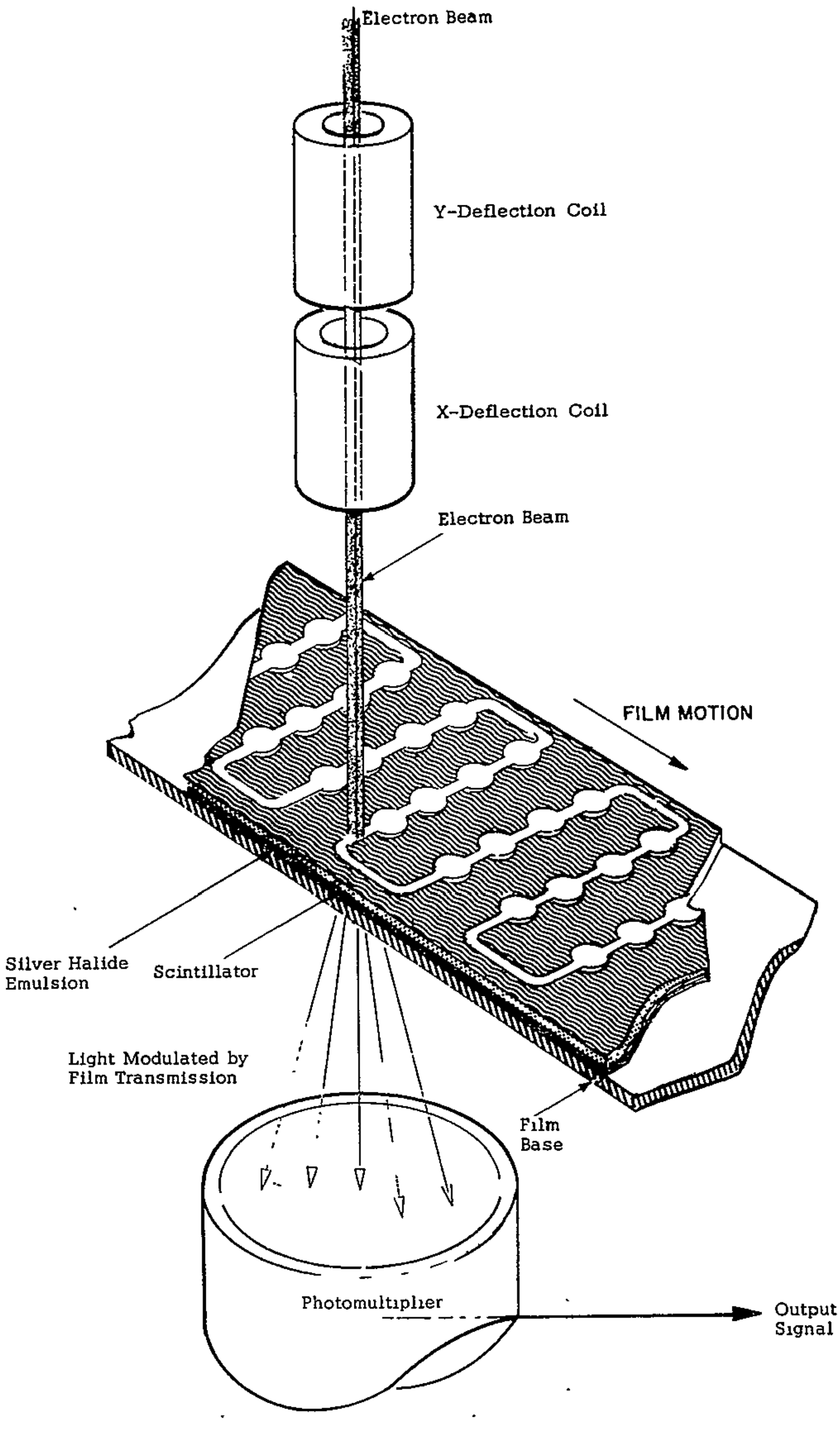

Figure 3.2. Basic Reproduce Process

beam travels on the recorded lines causing scintillator light emission. The light transmitted through the film carries the signal modulation and is reconverted into an electrical signal by a photomultiplier.

The critical parts of the system are concerned with line tracking and timebase correction. Tracking errors can be caused by variation of film speed from record to playback, and film size, shape and position errors. Line tracking is maintained by a closed loop servo system using spot wobble. The readout electron beam is sinusoidally deflected or wobbled approximately one spot diameter peak-to-peak, orthogonal to the recorded lines. Thus the photomultiplier output will be modulated as the spot is wobbled back and forth across the recorder line.

If the playback signal is perfectly centered on the recorded line, the photomultiplier output signal will not contain the fundamental component of the wobble frequency, f. Thus the magnitude and phase of this frequency at the output are a measure of the tracking error. The detected error signal can then be fed back to the beam deflection system to reposition the playback beam. Film speed is also derived from this error measurement. The spot wobble frequency was chosen to be 213.75 MHz for the 100-MHz recorder to permit adequate filtering to remove the wobble frequency and sidebands from the baseband signal.

Timebase correction is predicated on generation of timebase error signals. These error signals are formed from pilot tones at 0.356, 2.85 and 99.75 MHz recorded with the data. Precise position control of the beam is derived from these tones to an rms error of less than 1 nsec.

To help define the characteristics of such a machine for 1974 delivery, an inquiry was sent to Ampex. This letter and the reply (exhibits G and H) are at the end of this section. A subsequent telephone conversation was held with Mr. Diermann of Ampex which resulted in a clarification of his earlier remark about m-ary recording (exhibit H) and a possible fundamental limit on EBR data readout rate:

1) The use of m-ary ($m > 2$) recording can possibly reduce the effect of scratches and emulsion dropouts. Microscopic evaluation of the EBR film indicates that many of these defects are small enough to be contained within the space of a single m-ary character. The additional difficulties (such as D/A conversion) of multi-level recording compared to binary may, however, offset potential gains.

2) The EBR data recorder has a data readout rate limit imposed by the scintillator coating on the film. This coating -- used to convert the electron beam to light -- has a 3-db frequency response of 175 MHz. Thus digital readout rates requiring bandwidth above 100 MHz are unlikely, since the scintillator must operate at the wobble frequency which is at least twice the baseband width. Of course, this does not restrict the writing rate; only the readout rate.

Westinghouse Electric Corporation

February 18, 1970

Mr. Don Hoger
Recording Equipment Operation
Building 10-5
RCA
Camden, New Jersey 08102

Dear Mr. Hoger:

As part of a new contract with NASA we are conducting a study, part of which involves wideband data recording. The objective of the study is to determine whether there are technological limitations in any part of the planned system which would prevent its implementation and delivery by 1974. The function of the wideband data recorder is to accept digital data at a fixed rate between 100 and 300 megabits per second. Recorders will be employed at ground acquisition sites for data gathering; playback of this data will be performed at a central processing site at the same or a reduced data rate.

Attached to this letter is a list of the parameters of interest to help us determine the present state-of-the-art in wideband data recording. It would be appreciated if you would supply the values of these parameters for your wideband data recorders now under development. Of particular interest is the digital data rate at a measured or computed bit error rate.

Finally please provide your estimate of the values of these parameters for a 300 Mb/s data recorder for delivery by 1974. If this data rate is too high, use whatever rate is felt to be achieveable in this time frame.

This letter is not a request for a proposal. Any questions should be addressed to me; I can be reached by telephone at A/C 301-765-3683.

Sincerely yours,

Harold D. Ausfresser,
Fellow Engineer
Experimental Systems
Mail Stop 807

HDA:db

Enclosure:

EXHIBIT A

RCA | Defense Electronic Products | Defense Communications Systems Division
Camden, New Jersey 08102 | Telephone (609) 963-8000

Mr. Harold D. Ausfresser
Mail Stop 807
Westinghouse Electric Corporation
Electronics Division
Friendship International Airport
Box 1897
Baltimore, Maryland

RCA

Dear Mr. Ausfresser: April 9, 1970

The enclosed list of parameters represents what we feel is a realistic digital recording capability for equipment which we currently have under development at RCA, and which could be produced for delivery for 1974 as indicated in your letter. These developments would utilize a tape recorder or recorders based on our TR70-CVR equipments. I am including a brochure on the current production CVR for information. It is difficult to generalize on requirements such as this and in order to provide more detail, we would need to understand specific application requirements and performance parameters in order to trade off various possible approaches.

If you have any specific questions concerning this information, I suggest you contact Mr. O. E. Bessette on Extension PC-6272.

Very truly yours,

D. T. Hoger

D. T. Hoger, Administrator
Recording Equipment Operations
Product Planning

/lcj

Enclosure

EXHIBIT B (Page 1 of 2)

RECORDER: MODIFIED TR70 CVR

High Frequency @ Attenuation 28 MHz @ -3db	Direct Record - Mag. Tape
Low Frequency @ Attenuation 0.8 MHz @ -3 db	
Digital Rate @ Error Rate	40 MBPS @ 5 x 10^6 per channel
S/N Ratio	30-36 db pp/rms
Time Base Stability	1-5 nanosec
Tape Width	1-2 inches
Track Width	0.005 inches
Tape Length Up to 16 inch Standard Reels	(Length depends on tape type)
Tape Speed	
Line Period	
Line Spacing	0.0075 inches
Recording Time	3 hours max.
Packing Density	16,000 - 32,000 bPi
Max/Min Tape Speed	0 - 480 ips
Scan Velocity	10 - 4000 ips
Number of Channels	1 - 6
Distortion	1%
Modulation For Digital Recording	Delay
Isolation Between Tracks	-50 db

COMMENTS:

EXHIBIT B (Page 2 of 2)

Specifications

General

Recording Medium . Magnetic tape 2 in wide NAB Reels to 14 in
Tape Speed ... . 7 5 or 15 inches per second
Recording Time .. .. .. 76/192 min on a 14 in. reel (7200 ft)
Rewind Time . ... Approx 6 min. for 7200 ft reel
Recording Time Reference .. . . Internal Crystal
Playback Time Reference .... Internal Crystal
Reference Switchable to Video Sync for TV Recording Purposes
Stopping Time . .. Approx 0 5 sec from Record or Play Mode
Start Time for Stabilized Video and
Auxiliary Information .. . . Approx 5 seconds from stop, approx. 3 seconds from standby or set-up
Tape Interchangeability .. Tapes made on any machine may be reproduced on any other machine providing they are made in accordance with all applicable recommended practices
Tape Timer . .... Accumulated time measured in minutes and seconds at 15 ips

Video Channel

Bandwidths: (Front Panel Selectable)

		BW
STD I	Hi Band Sine 6MHz	30Hz to 6MHz ± 1.5db
STD II	Hi Band Pulse	(See T_r and O S below)
STD III	Hi/Lo Sine 4MHz	30Hz to 4MHz ± 1.5db

Signal/Noise	Full Track	Half Track
STD I	38	36
STD II	40	38
STD III	40	38

Linearity . . .... Within 5% measured from max dynamic range to 20 db below max.
Rise Time (STD II) . ... ⩽100 ns
Overshoot (STD II) .... ⩽10%
Transient Level . ... 6db below peak noise
Input Volts/Imped. ... . 0.5VPP to 1 5VPP/75 ohms
Output Volts/Imped. .... 1.0VPP/75 ohms
No. of Video Outputs 2
Time Base Stability
Data Storage Unit (Tone Wheel Servo) 150ns rms absolute phase error (Approx. 300 ns peak)
Data Reproduce Unit (Electronic Time Base Correction "–3" option) 10ns rms absolute phase error (Approx. 20ns peak)

Distortion (Sine Mode)

All intermodulation, harmonic, or spurious distortion products shall be at the specified level when recording 2 half amplitude sinusoids (–6db each) anywhere within the bandwidth of the recorder. (Ref. 0db level is full dynamic range) Observation of the rms 0db level and distortion component rms level shall be made with a 5 KHZ filter.

	Distortion Level
STD I	–25db
STD III	–35db

Auxiliary Channels* (15 ips operation)

No. of Aux Channels 2
Freq Response .... Aux 1 50Hz to 10 KHz ±3db
Aux 2 350Hz to 10 KHz ±3db

Signal-to-Noise Radio .... Aux 1 30db rms sig/rms noise
Aux 2 30db rms sig/rms noise
Volts In/Impedance . Aux 1 – 20dbm to + 18dbm / 10K Bal. Bridging
Aux 2 – 20dbm to + 18dbm / 10K Bal. Bridging
Volts Out/Impedance Aux 1 + 18dbm/600 ohms w 1000Hz In @ 0db
Aux 2 + 18dbm/600 ohms w 1000Hz In @ 0db

*digital replacement specifications available on request

Mechanical Specifications

Transport . .... Centrally located at 45 degree angle and at a reel height of 48 inches (122 cm)
Cooling .... Filtered, forced air
Weight, Shipping . Approximately 1800 lbs
Dimensions
Width (overall) .... 55 inches
Width (less end panels) . . 53 inches
Height ... . 71¼ inches
Depth ... . 26½ inches

Models

Two basic models are available
TR70 CVR with 150ns rms absolute time base stability
TR70 CVR-3 with 10ns rms absolute phase time base stability
Any unit available with half or full track

Equipment Supplied

All models include the following equipment complement.
1 TR70 CVR Tape Recorder (Console Mounted) complete
1 Headwheel Panel Assembly (Air-bearing)
1 Kit of Maintenance Materials

Built-in self test features

Set-up and evaluate such parameters as:
Input Level
Deviation (Gain)
Output Level
Shoe Position
ATC Alignment
Pulse Response
Signal-to-Noise

Synergistics

Synergistics PDR-5
36-Channel Laser Recorder

General Description

The Synergistics PDR-5 is a multi-track laser film recorder to be used for recording digital and PCM signals. It is particularly designed for application in high volume data collection systems. It records 36 tracks of data on 8 mm wide microfilm. The Synergistics PDR-5 recorder requires no mechanical adjustments and has a minimum of moving parts.

Special Features

*Up to 4 x 10^9 bits per 10-1/2 inch reel

*Up to 10^7 bits per second input or output data rate

*Permanent record on 8 mm mylar-based microfilm

*Slowed down time scale reproduce capability

*Single 36-channel record-reproduce, head stack

*More economical record

*Greater head life (No wearing parts)

Signal

The Synergistics PDR-5 records data on 36 parallel tracks on 8 mm film.

PACKING DENSITY: The Synergistics PDR-5 will record and play back at packing densities of up to 5,000 words per inch. Each word consists of 36 parallel bits. The playback electronics deskews the individual bits so that 36 bits appear simultaneously at the output.

SIGNAL ELECTRONICS: The record-reproduce electronics are all solid state. The reproduce electronics contain pulse restoration and resynchronizing circuitry so that the output from the recorder is suitable for direct application to a buffer or other digital circuitry. Channel 18 can be set aside as a clock channel.

MAXIMUM DATA RATE: Is greater than 10 megabits per second. The recorder will handle data rates between zero and 10 megabits/second.

INPUT IMPEDANCE: 5000 ohms

INPUT-OUTPUT LEVELS. 0 Volts, false; 5 volts, true.

Head

Head construction: single stack, 36-channel record-reproduce.

TRACK SPACING: 0.007 inches on center

TRACK WIDTH: 0.004 inches

TRACK REGISTRATION: A recorded track, as measured from the reference edge of the film, is within ± 0.001 inch of the nominal track center line.

HEAD ORIENTATION: Alignment of the head is perpendicular to the direction of film travel to within ± 1 minute of arc.

FILM: EASTMAN KODAK S0382, AGFA 8E75 or equivalent

PROCESSING: CONVENTIONAL microFilm processing (i.e., 4 min. in D19 at 68°F, plus fixing and washing or equivalent).

WIDTH: 8 mm ± 0.025 mm

THICKNESS 2.75 mils

BASE: MYLAR (or equivalent)

Film Transport

The film transport consists of a high inertia capstan drive to minimize wow and flutter.

START TIME: Start time to 60 ips is less than 4 seconds

STOP TIME: Stop time is less than 4 seconds from 60 ips.

REEL SIZE: 10-1/2 inches maximum.

REEL CAPACITY: 2000 feet of 8 mm film, plus a 12-foot opaque leader on both ends of the film.

EXHIBIT D (Page 1 of 2)

DYNAMIC SKEW: The peak interchannel time displacement error between channel 18 and any other channel is given in the following table.

FILM SPEED:	MAX. INTERCHANNEL TIME DISPLACEMENT ERROR:
ips	microseconds
30	2
15	4
7-1/2	8
3-3/4	20
1-7/8	45

FILM SPEED CONTROL: Discrete selection of film speed is made by switch from the front panel. The speeds available are 60, 30, 15, 7-1/2, 3-3/4, or 1-7/8 inches per second. The film speeds and fast forward and reverse are electrically selectable.

REWIND TIME: Fast forward and reverse for 10-1/2 reel with 2,000 feet of film is less than 2 minutes. The film is under control by the machine at all times and is stopped automatically by the leaders while the leader is still threaded through the machine.

FILM FOOTAGE COUNTER: 5 digits

FILM BREAK SENSING: The transport is automatically stopped by the release of the take-up reel tensioning arm if the film breaks. End of film is sensed at its junction to the leader.

FRONT PANEL CONTROLS:

ON-OFF	OPEN DOOR
PLAY	LOAD POINT FORWARD
RECORD	LOAD POINT REVERSE
FORWARD	FILM LOADED (light)
STOP	FILM READY (light)
REVERSE	FILM SPEED SELECTOR

Physical Characteristics

The Synergistics PDR-5recorder is constructed on a standard 19-inch panel format. It is housed in a rugged cabinet.

CABINET SIZE: 88 inches high, 24 inches wide, 30 inches deep.

WEIGHT: 600 pounds

Power Requirements

800 watts, 117, ± 10 volts single phase, 60 Hz, AC

Operation

The operation of the Synergistics PDR-5recorder is similar to a magnetic tape recorder. The only exception is that after recording the film must be processed by conventional photographic means. This processing can be handled either by the customer's own facility or by local microfilm processing establishments. Prior to processing, the film must be protected from light. To facilitate handling of the reels in daylight, opaque leaders are attached to both ends of the film to shield them from light. The film is loaded and taken out of the machine under daylight conditions. After loading and closing the cover, a film advance button is pushed which will advance the film up to the end of the leader so that active film is under the record head. Playback is accomplished by the same machine, and this operation may be done with the cover open or closed, whichever is more convenient.

About Synergistics:

Synergistics, Inc is a manufacturer of complete on-line data collection and processing systems and a variety of proprietary peripheral devices On-line systems, made by our Ikon Data Systems Division, have been installed in business data processing centers in several U.S. cities The systems' unique integration of high speed hardware and sophisticated software enables them to communicate with up to one thousand Touch Tone telephones with audio answer back

Synergistics also manufactures a low-cost self encoding keyboard for computer input, communications applications, and display terminals. Other equipment being developed includes a completely new method for permanently recording and retrieving magnetically stored alphanumeric information on documents such as credit cards, tags, tickets, badges, etc.

For further information on the PDR-5 Laser Recorder, please contact:

General Manager
Laser Recorder Division
Synergistics, Inc.
10 Tech Circle, Natick, Mass. 01760
(617) 655-1340

Synergistics, Inc.

EXHIBIT D (Page 2 of 2)

Westinghouse Electric Corporation

February 18, 1970

Mr. Leo Beiser, Staff Physicist
Electronic Systems Department
CBS Laboratories
High Ridge Road
Stamford, Connecticut 06905

Dear Leo:

Many thanks for your help on high resolution image recorders. As part of a new contract with NASA we are conducting a study, part of which involves wide-band data recording. The objective of the study is to determine whether there are technological limitations in any part of the planned system which would prevent its implementation and delivery by 1974. The function of the wideband data recorder is to accept digital data at a fixed rate between 100 and 300 megabits per second. Recorders will be employed at ground acquisition sites for data gathering; playback of this data will be performed at a central processing site at the same or a reduced data rate.

A review of two of your reports* has enabled us to determine some of the characteristics of your wideband data recorders. The parameters shown on the following pages were obtained or estimated from these reports.

It would be appreciated if you would confirm or correct the numbers shown and supply those not already included. Of particular interest is the digital data rate at a measured or computed bit error rate.

Finally, please provide your estimate of the values of these parameters for a 300 Mb/s data recorder for delivery by 1974. If this data rate is too high, use whatever rate is felt to be achieveable in this time frame.

This letter is not a request for a proposal. Any questions should be addressed to me; I can be reached by telephone at A/C 301-765-3683.

Sincerely yours,

Harold D. Ausfresser
Fellow Engineer
Experimental Systems
M/S 807

* "A Laser Beam Wideband Data Recorder" and "Advanced Wideband (50 MHz) Data Recording/Reproducer System".

HDA:db
Enclosure:

EXHIBIT E (Page 1 of 3)

RECORDER: 70 mm CBS LBR

High Frequency @ Attenuation	50 MHz @ ±3 db
Low Frequency @ Attenuation	0.001 MHz @ ± 3 db
Digital Rate @ Error Rate	100 Mb/s @
S/N Ratio	25 db pp/rms
Time Base Stability	
Tape Width	70 mm
Track Width	
Tape Length	1000 feet
Tape Speed	8 ips
Line Period	
Line Spacing	25 um
Recording Time	25 minutes
Packing Density	12 x 10^6 bits/inch^2
Max./Min. Tape Speed	20:1
Scan Velocity	26000 inch/sec
Number of Channels	1
Distortion	
Modulation For Digital Recording	
Isolation Between Tracks	

COMMENTS:

Precision tachometer on spinner shaft for timing reference. Spot is 7 um diameter.

RECORDER: 5" CBS LBR

High Frequency @ Attenuation	50 MHz @
Low Frequency @ Attenuation	
Digital Rate @ Error Rate	
S/N Ratio	
Time Base Stability	
Tape Width	5 inch
Track Width	4.63 inch
Tape Length	
Tape Speed	
Line Period	117.5 usec
Line Spacing	25 um
Recording Time	
Packing Density	
Max/Min. Tape Speed	20:1
Scan Velocity	40,000 inch/sec
Number of Channels	1
Distortion	
Modulation For Digital Recording	
Isolation Between Tracks	-40 db

COMMENTS:

Film used is Kodak SO-239 reversal. Film gamma control must be precise.

EXHIBIT E (Page 3 of 3)

CBS
LABORATORIES

March 10, 1970

Mr. Harold D. Ausfresser
Experimental Systems - M/S 807
Westinghouse Electric Corporation
Friendship International Airport
P. O. Box 1897
Baltimore, Md. 21203

Dear Harold:

Congratulations on your new study contract with NASA -- looks interesting.

To provide you with the most practical and accurate information, I asked our Branch Manager on Wideband Recording, Robert Walker, to fill-in and authenticate the data. Having just reviewed it with him, I am confident of the data submitted in the accompanying two charts.

You may note that we followed your lead and listed the bandwidth with a ± tolerance. Although one may normally expect a (-) tolerance at band edge, our system includes optional high frequency peaking which, under some cases, may provide a rise in response at band edge. Also, the digital error rate is left somewhat to your discretion, taking into account your taste in interpreting the error as a function of S/N ratio. In any event, the error rate is low.

Regarding achievement of 300 Mb/s data recording rate by 1974 delivery time, I think we're in good shape. We need a 150 MHz upper bandwidth limit; a 50% increase over our present 100 MHz recorder. Several things are in our favor --

1. we have some room in shaft speed
2. we have a lot of room in selection of a shorter wavelength laser to reduce facet size and allow a further increase in shaft speed
3. we have some new scanner developments which may be coming out of the Labs soon to profoundly ease the burden upon the rotating system.

Certainly, we would like to give 300 Mb/s some careful thought before committing ourselves. But, it looks good.

Keep ~~us~~ posted. Regards to Ted Foster.

Leo Beiser
Staff Physicist
Electronic Systems

cc: J. Fulton
R. Walker
A. Axelrod

EXHIBIT F (Page 1 of 3)

RECORDER: 70 mm CBS LBR

High Frequency @ Attenuation	50 MHz @ ± 3 db
Low Frequency @ Attenuation	0.001 MHz @ ± 3 db
Digital Rate @ Error Rate	100 Mb/s @
S/N Ratio	25 db pp/rms
Time Base Stability	1 part 10^9
Film Width	70 mm
Track Width	15 um
Film Length	1000 feet
Film Speed	8.38 ips
Line Period	117.5 usec
Line Spacing	25 um
Recording Time	24 minutes
Packing Density	12 x 10^6 bits/inch^2
Max./Min. Film Speed	20:1
Scan Velocity	19,000 inch/sec.
Number of Channels	1
Distortion	-33 db 3rd harmonic
Isolation Between Tracks	-40 db

COMMENTS:

Precision tachometer on spinner shaft for timing reference.
Spot is 7 um diameter. (5 u to $\frac{1}{e^2}$)

EXHIBIT F (Page 2 of 3)

RECORDER: 5" CBS LBR

High Frequency @ Attenuation	100 MHz @ ± 6 db
Low Frequency @ Attenuation	50 cps ± 3 db
Digital Rate @ Error Rate	200 Mb/s @
S/N Ratio	18 db PP/RMS
Time Base Stability	1 part in 10^8
Film Width	5 inch
Track Width	15 um
Film Length	1000 ft.
Film Speed	8.38 ips
Line Period	117.5 usec
Line Spacing	25 um
Recording Time	24 minutes
Packing Density	12×10^6 bits/inch^2
Max/Min Film Speed	20:1
Scan Velocity	38,000 inch/sec
Number of Channels	1
Distortion	-33 db 3rd harmonic
Isolation Between Tracks	-40 db

COMMENTS:

Film used is Kodak SO-239 reversal. Film gamma control must be precise.

EXHIBIT F (Page 3 of 3)

Westinghouse Electric Corporation

February 18, 1970

Mr. Jim Kelly
Ampex Corporation
3620-27th Street, South
Arlington, Virginia 22206

Dear Jim:

Many thanks for your help on our recently completed study for NASA on the ERTS program. As part of a new contract with NASA we are investigating the developmental status of wideband data recording systems. The overall objective of this study is to determine whether there are technological limitations in any part of a planned spacecraft imaging system which would prevent its implementation and delivery by 1974. The function of the wideband data recorder is to accept digital data at a fixed rate between 100 and 300 megabits per second. Recorders will be employed at ground acquisition sites for data gathering; playback of this data will be performed at a central processing site at the same or a reduced data rate.

A review of one of your reports* has enabled us to determine some of the characteristics of your wideband data recorder. The parameters shown on the following pages were obtained or estimated from this report.

It would be appreciated if you would confirm or correct the numbers shown and supply those not already included. Of particular interest is the digital data rate at a measured or computed bit error rate.

Finally please provide your estimate of the values of these parameters for a 300 Mb/s data recorder for delivery by 1974. If this data rate is too high, use whatever rate is felt to be achieveable in this time frame.

This letter is not a request for a proposal. Any questions should be addressed to me; I can be reached by telephone at A/C 301-765-3683.

Sincerely yours,

H. D. Ausfresser,
Fellow Engineer
Experimental Systems
Mail Stop 807

* "Wideband Magnetic Electron and Laser Beam Recorders And Elements of Optical Processing".

HDA:db
ENCLOSURE:

EXHIBIT G (Page 1 of 2)

RECORDER: AMPEX EBR

High Frequency @ Attenuation	100 MHz @ -8 db
Low Frequency @ Attenuation	0.5 MHz @ -3 db
Digital Rate @ Error Rate	
S/N Ratio	20-26 db (pp-ms)
Time Base Stability	1.0 ns
Tape Width	35 mm
Track Width	30 mm
Tape Length	1875 feet
Tape Speed	37.5 ips
Line Period	13.3 usec
Line Spacing	12 um
Recording Time	10 min.
Packing Density	
Max/Min Tape Speed	1
Scan Velocity	89,000 inch/sec
Number of Channels	1
Distortion	-27 to -30 db
Modulation For Digital Recording	
Isolation Between Tracks	

COMMENTS:

Scintillation layer decay limits number of playbacks. Frequency response limit imposed by spot size. Precise control of film gamma required to minimize distortion. Spot is 6 um width. Film is SO-214, a Kodak Direct Positive scintillator-covered, electron beam sensitive film, requires developer & fixer processing.

EXHIBIT G (Page 2 of 2)

AMPEX CORPORATION

401 BROADWAY • REDWOOD CITY, CALIFORNIA 94063
(AREA CODE 415) 367 2011 • TWX 415-364 9034 • TELEX 34 84164

10 March 1970

Westinghouse Elec. Corp.
Defense and Space Center
Friendship International Airport
Box 1897
Baltimore, Maryland, 21203

Attention: Mr. H.D. Ausfresser

Dear Mr. Ausfresser:

This is in response to your letter of 18 February to Jim Kelly, requesting a confirmation of the performance data of the 100MHz electron beam recording system.

Our wideband recording work so far, has been in the analog field; all I can give you for the digital area at this time are some predictions, subject to change within the next year or two.

First, let me comment on the analog data:

High Frequency:	100 MHz at -6 to -8 db; depending on quality of spot adjustment.
Low Frequency:	0.5 MHz at 0 db; no signals below 0.5 MHz are permitted due to pilot frequency at 356 KHz.
Film Length:	2000 ft. - 4 mil/3700 - 2.5 mil.
Film Speed:	75 ips
Line Spacing:	24 µm
Recording Time:	5.5 min - 4 mil/10 min - 2.5 mil.

In a digital recorder, we would use a modulation method of more than two, say m levels, in order to spread each binary digit over more space to make it less susceptible to scratches and emulsion dropouts. This will require conversion of incoming high speed binary digits into m-ary digits before recording. A data rate of 150 to 200 Mb/s appears feasible at this time. It is difficult to make predictions on the error rate without sufficient experimental support with respect to scratches and dropouts. A rate of 10^4, however, will be not too difficult to achieve.

Please call me at (415) 367-3367 if I can be of further help. If it is of mutual benefit, I will be glad to stop by for further discussions during one of my trips to the east coast.

Very truly yours,

J. Diermann

J. Diermann, Manager
Electron Beam Recording Section
Research Department

cc: J. Kelly

AMPEX

EXHIBIT H

SECTION 4

DATA SYNCHRONIZATION

This serial bit stream can either be recorded directly using a laser or electron beam technique or divided into a number of parallel data channels each at a lower bit rate. A good example of the latter case is the transverse scan magnetic recorder which will accept up to six 40-Mb/s data streams. Regardless of the recording method, processing of this data during playback is to take place one spectral band at a time. Thus a major data synchronization function is to separate the data by spectral band into five channels, either prior to or after recording. In what follows, the post recording case is specifically considered. Since playback is to occur at the record rate, it is reasonable to describe this process as if no recording and subsequent playback were involved.

Some means must be provided to properly interpret the serial bit stream from the spacecraft. In particular, it must be possible to recognize the start of each scan line and to group the bits so that samples of a particular spectral band can be selected. The data synchronizer does not include the functions of the bit synchronizer; it is assumed that the bit synchronizer is a part of the communications system. This recognizes that the bit synchronizer design must be known to determine the S/C transmitter power, modulation technique, etc., to achieve a desired bit error rate. It is assumed that the bit synchronizer outputs a NRZ (non-return-to-zero) binary signal and a clock at the bit rate.

4.1 SYNCHRONIZATION ANALYSIS

In the S/C the data will be transmitted as a fixed frequency bit stream. We can partition this stream into groups of bits representing one or more data samples and associated bits, such as parity. Such a group of bits is termed a word. To minimize the complexity of the S/C and ground equipment a small word size is desirable, but not smaller than the number of bits per sample. On this basis a word size of from 6 to 8 bits is appropriate.

For this analysis a 7-bit word has been chosen. A sequence of five words is termed a field and contains the data for the five spectral band components of one spatial sample. This part of the format is independent of whether an image or object plane scanner is employed.

Data synchronization can be based on recognition of a sequential group of these 7-bit words or by recognition of a single longer word. For example, COMSAT Laboratories uses a single word of about 20 bits in length for their time division multiple access satellite communications system.* However, their synchronization problem differs from this one in that their word must also identify the origin of the message. The data format employed in the following analysis is shown to be adequate but is not shown to be optimum in the sense of minimizing the number of synchronizing bits or the complexity of the data synchronizer.

The first step in data synchronization (after bit synchronization) is word synchronization. It is assumed that the time between successive scans is not precisely constant so that word sync must be acquired once per

---

* T. Sekimoto and W. Schrempp, "Unique Word Detection In Digital Burst Communications", IEEE Trans. on Communication Technology, August 1968, pp. 597-605.

scan. The format of the sync data will be presented; then the method of acquiring sync will be described. Finally, it will be shown that the probability of incorrectly achieving word sync is less than 2×10^{-8}.

Scan start is sensed in the S/C just prior to the scanning of useful image data. In the time before this event, a fixed ONE-ZERO binary bit pattern is transmitted. Immediately after this event, a sequence of six 7-bit Barker* code words are sent. This is followed by the complement of this code. Normal data fields of 35 bits each then appear; however, the first field contains S/C time and perhaps other status messages.

The 7-bit Barker code (1110010) is checked against each set of 7 consecutive bits from the S/C. If these bits from the S/C are identical to this code, all 7 bits will match. If the pattern is of the ONE-ZERO type there will be either 3 or 4 matches out of 7. With the ONE-ZERO pattern, followed by repetitions of this code, there will never be more than 4 matches except when the bit pattern and the code are identical, in which case 7 matches occur. In any one check if 6 or 7 matches occur this is termed a mate. We may note that a single error in any group of 7 bits will not produce a mate incorrectly or cause a failure to recognize a mate.

Once a mate is achieved, checking of all sets of 7 bits ceases; only the 7 bits following the 7-bit mate is checked. If a second mate is not found, checking of all sets of 7 bits recommences. This process continues until three mates in a row are found; when this happens we have obtained word sync. Then checking for the complement of the Barker code commences. Recognition of this event denotes that normal data fields will follow.

---

* R. H. Barker, Group Synchronization of Binary Digital Systems, in: "Communication Theory" (W. Jackson, ed.), Academic Press, 1953.

The probability that a given set of 21 sequential bits will incorrectly produce three mates equals the probability that there are at least two errors in each of the first, second, and third 7-bit sequences:

$$\text{Prob (3 sets of 2 errors)} = (3 \times 2 \times 10^{-6})^3 \approx 10^{-15}$$

This is based on a bit error probability of 10^{-3} and the fact that there are 3 (out of 7) places for the first error to occur and 2 for the second error. Note that an error in some bit locations reduces rather than increases the number of matches. Since there are many such sets of 21 bits, the probability of falsely achieving word sync is higher than the previous figure. The worst case occurs for the object scanner at the 300-Mb/s rate. If it is assumed that the time between scan starts may be as much as 10 percent greater than or less than nominal, this period of uncertainty can be about 7 msec. At a 300-Mb/s rate this corresponds to about 2×10^6 bits. Then the probability that any set of 21 consecutive bits will falsely indicate word sync is less than $2 \times 10^6 \times 10^{-15} = 2 \times 10^{-9}$.

The probability that correct word sync will not be recognized is now computed. Missing word sync implies the presence of at least two errors in certain combinations of Barker code words. If each of these code words is given a number from 1 to 6, two or more errors in each of the following pairs of code words is sufficient to prevent acquisition of word sync: 1-4, 2-4, 2-5, 2-6, 3-4, 3-5, and 3-6. The probability of this event is approximately $7\,(7 \times 6 \times 10^{-6})^2 = 1.2 \times 10^{-8}$.

Once word sync is achieved the Barker code complement must be detected. There will be at most three additional non-complemented code words prior to the complemented one, depending upon when word sync was acquired. A match of four or more is required to detect the complement code.

Thus four errors are needed to mistake the code for its complemented form or visa versa. The probability of this event is about $7 \times 6 \times 5 \times 4 \times 10^{-12} \approx 10^{-9}$. Since at most 4 checks are possible (3 non-complemented plus 1 complemented code), the probability of not correctly achieving frame sync is less than 0.4×10^{-8}.

Thus it has been shown that adequate sync can be achieved with the suggested format. Note that subsequent bit errors cannot affect word or frame sync. Of course if bit sync is lost, even temporarily, word and frame sync is also lost. Reacquisition of such word and frame sync will occur at the start of the following scan. If bit sync is to be lost only once per ten thousand lines, the probability of bit sync loss should be:

$$\frac{1}{300 \times 10^6 \times 10^4 \times 2 \times 10^{-3}} = 0.2 \times 10^{-9}$$

for the 300-Mb/s case (2×10^{-3} seconds is the approximate line period). This is loss of bit sync once every 20 seconds.

4.2 SYNCHRONIZER DESIGN

Several approaches have been considered in the implementation of the data synchronization algorithm described. They differ primarily in the method of comparing the code word and the input bit stream. One method uses an analog summation to determine the number of bits in the input which agree with the code word. The second method uses digital summation, and the third method uses a sequential or counting process.

The first two methods were recently suggested by O. G. Gabbard of COMSAT Laboratories and have not been thoroughly investigated. The analog approach is currently being employed by COMSAT, and has the advantage of simplicity. The outputs of each of seven gates, each activated by one bit each of the code word and the input data stream, are converted to analog form using a resistive network. The sum signal is compared to a threshold level and converted to a logic signal which depends upon the sum. With the use of film resistors and a high gain threshold detector (now being developed by Motorola), response times of about 3 nsec could be achieved. A factor of two speed increase can be obtained by employing two such detectors simultaneously, operating on overlapping groups of input bits.

The second method -- digital summation -- is similar to the first approach and probably will require duplicate logic to operate at 300 Mb/s. Prior to a discussion of the logic of the third method, a description of the components to be employed for implementation is presented.

Recent published work by Westinghouse* and COMSAT** indicates that high speed logic can most effectively be implemented using Motorola emitter coupled logic (MECL). In both reports MECL units were employed, and a great deal of emphasis was placed on the packaging of these units to form a digital system. The Westinghouse study was concerned with the typical military environment; the circuits were obtained in chip form and bonded to an alumina substrate encapsuled in a 60-pin package. JK flip-flops and dual 4 input OR-NOR gates were chosen as the major components. A 19-stage modular shift register, using eight substrates, was fabricated and successfully tested at a 64-MHz clock rate.

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* "High Speed Digital Circuitry" Westinghouse Electric Corporation for AVWC, Wright-Patterson Air Force Base, AFAL-TR-68-365, Sept. 1969.

** "High Speed Digital Logic For Satellite Communications", COMSAT Laboratories, Electro-Technology, April 1969.

The COMSAT approach used double-sided printed circuit boards in constructing the logic for a 50-Mb/s digital communications system. The performance of the individual cards is given as 70 Mb/s. In addition it was indicated that excellent results have been achieved at speeds up to 150 Mb/s. The key difference in the speeds achieved appears to rest mainly with the specific components used in the MECL series. The Data Technology Corp., Palo Alto, California has been licensed to manufacture these high-speed digital logic cards in the U. S.

A new series of MECL, MECL III, is available from Motorola. These components have gate switching times of 1 nsec, and flip-flop toggle and shifting rates greater than 300 MHz. Since the higher cost MECL III is compatible with MECL II, only the highest frequency parts of the logic will require the MECL III elements.

Based on typical performance characteristics of Motorola's high speed MECL III logic family, systems can be developed today to handle the proposed 300-Mb/s input data rate. Motorola document DS9101R1 describes a flip-flop (MC 1670) which can (by overdriving the clock and adjusting the supply voltage) be made to operate at 500 MHz. A minimum toggle rate of 300 MHz is guaranteed for this device. In Supplement 1 to that document, counting circuits are described which operate to 350 MHz with no "tweeking" of the clock or supply voltage. However, in more complex systems, if designed with worst case guaranteed performance characteristics, one is limited to a data rate of about 200 MHz with presently available circuits.

This is based on an assumption of one flip-flop delay and one gate delay per clock interval where:

Clock Interval = FF Delay + Gate Delay + Clock Width and Clock Slew Allowance

= 2.2 ns + 1.6 ns + 1.2 ns = 5.0 nsec

COMSAT Laboratories is currently developing MECL III logic cards. These cards are specified to each operate at 250 Mb/s although they will probably not be employed in a system at a rate higher than 200 Mb/s. Ten such designs are expected to be completed during 1970. Their emphasis has been on the use of general purpose rather than functional cards for better maintainability and for a fast design capability. These cards will be available from one or more manufacturers licensed by COMSAT.

A higher speed logic family (designated MECL IV) has been announced (Electronics, December 8, 1969, p. 34) which has gate delays of about 0.7 nsec. This family should include flip-flops with 500 to 1000-MHz toggle capability in about one year at the R&D level (Electronics, March 16, 1970 p. 129). The MECL IV family is very likely to make its greatest impact in the Medium Scale Integration area, and devices such as Quad D flip-flops capable of operating in the shift mode at 500 MHz should be available in the 1972-1973 time period.

A system which could be used to synchronize on input data streams with data rates of 100 Mb/s or 300 Mb/s is now described. The design assumes typical operating characteristics of the MECL III logic family and is intended to give insight into the feasibility of designing systems of this type in the 1973-1974 time period.

The system described is intended to provide one of five bands of PCM data which inputs serially at a 100-Mb/s or a 300-Mb/s rate. To synchronize with the data, the system must detect three successive words containing a known 7-bit code. Subsequent detection of the complement of the code word indicates data start. The logic design, by minimizing the number of flip-flop and gate levels which the signal must traverse each clock period, fully utilizes the speed of the MECL components.

The input data is fed into a shift register (figure 4.1) which is tapped at some point to feed the data into a group of seven exclusive OR (EOR) circuits. The other input to each of the EOR circuits is one bit of a seven-stage circulating register containing the known code word. Initially the serial data input will be a repetitive ONE-ZERO pattern. The EOR will provide a ONE state output for each MATCH between the circulating code and the serial input. This output enables the 2-bit MISS counter when it is in the ZERO state, hence the counter advances when the bits do not match. Since more than one MISS is not acceptable, the MISS counter does not count past two. In order to tally misses in the proper 7-bit time frame, a seven-stage ring counter, synchronized to the circulating fixed code word, samples the count every seven pulses. If two misses are detected, the 2-bit sequential HIT counter is reset to ZERO. If less than two misses are detected, the sequential HIT counter is advanced by one count. When the ONE-ZERO pattern is present all MISS counters will count to two and no hits will be noted.

Once the sequence of Barker codes commences, one of the outputs of the circulating register will be in time phase with the incoming data; hence a serial bit by bit comparison will be made at one of the seven EOR

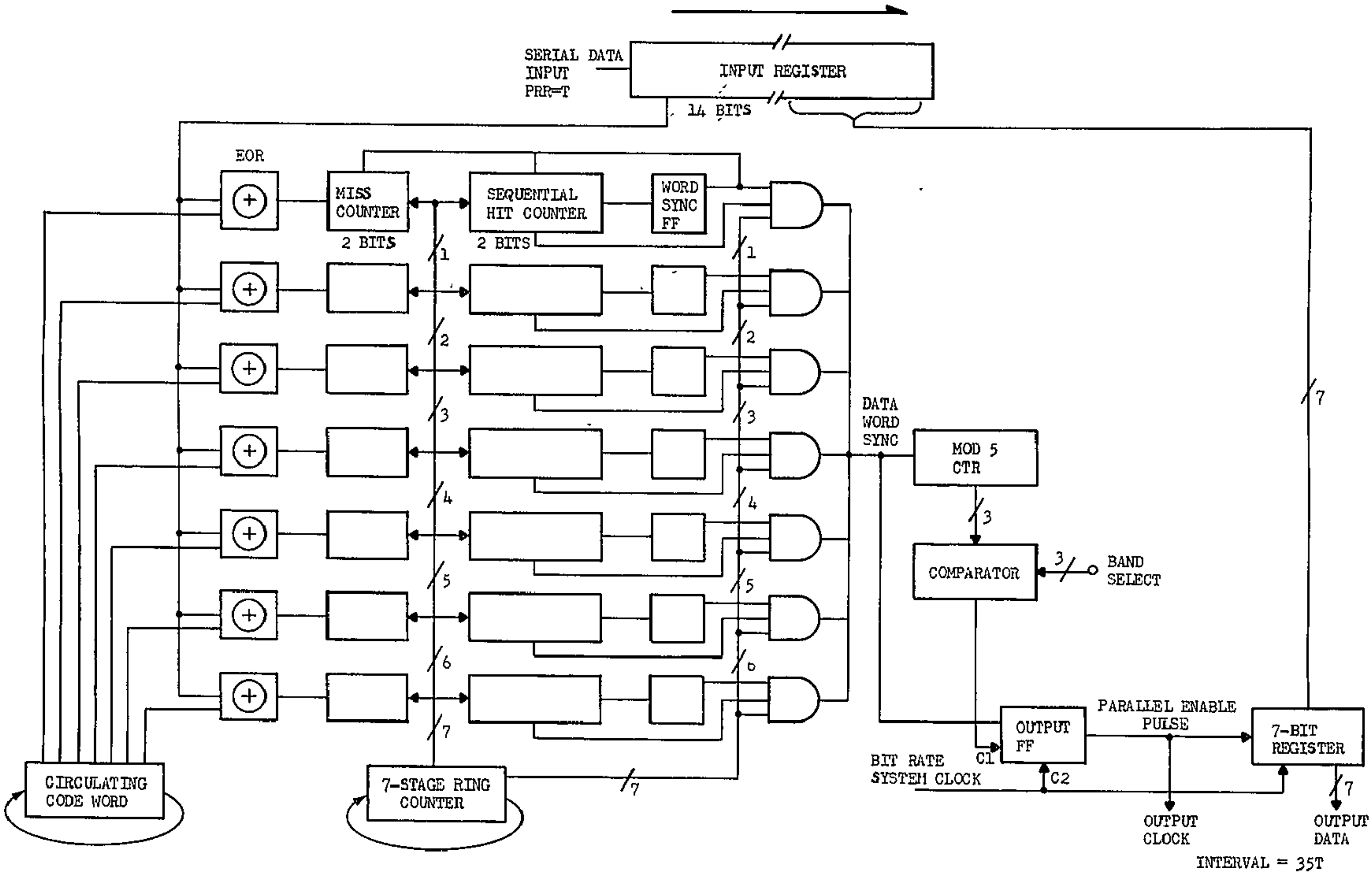

Figure 4.1. Data Synchronizer Logic

circuits. If there are less than two errors in the data, the proper sequential HIT counter will be advanced. When the HIT counter reaches a count of three (produced by three sequential hits) the WORD SYNC flip-flop is set. This state is fed back to the MISS and HIT counters so that they will act together as a 4-bit match detector in anticipation of the arrival of the Barker code complement. When four or more complement matches within the 7-bit cycle determined by the ring counter are obtained, a DATA WORD SYNC (DWS) pulse is generated which is in phase with the data. The data is presented in five sequential 7-bit groups (bands). This DWS pulse advances a modulo 5 counter. The counter outputs are compared with a 3-line band code, and when the counter matches the band select inputs, the output flip-flop is set which pulses (Parallel Enable Pulse, PEP) a 7-bit register. This register pulls the proper 7-bit word from the extended input register. The PEP pulse also informs the rest of the system that new data is present at the output of the 7-bit register.

If the system described were implemented with presently available single flip-flops, EOR circuits, and gate circuits in the MECL III family, the following integrated circuits would be required:

Circuit Type	Quantity	Power
Flip Flops	74	16.3
Triple EOR	6	1.5
Quad Gate	6	1.5
Total	86 IC's	19.3 watts

The Motorola Supplement 1 to DS9101R1 describes packaging techniques suitable for circuits of this speed. Essentially it is suggested that the flat packages be mounted stud-side-up so that proper cooling can be obtained. Also, for optimum transmission of high speed signals, a multilayer board consisting of microstrip transmission lines as signal conductors should be used.

While subsystems of 15-20 circuit complexity can be readily implemented with the straightforward approach, a board containing 86 circuits in this configuration might be unwieldy and would, due to excessively long transmission lines, retard the system speed performance somewhat.

Of course, when increasingly complex devices such as the quad D flip-flop mentioned earlier become available, the component count will be reduced to about 30 integrated circuits. At this point, the suggested approach of a multilayer board with conventional packaging would be quite applicable.

An alternate packaging method which would provide the desired density on a single multilayer board would be the method utilized in the development of a high speed digital arithmetic unit at the Westinghouse Defense and Space Center. The method employs integrated circuit chips mounted to a ceramic substrate having metallized interconnects on both sides of the substrate. The substrate measures 1.2 inches x 1.17 inches and can accommodate 20 integrated circuits. It is placed in a 60-pin metal can which can dissipate in excess of 5 watts. In the digital subsystem developed, eleven cans containing a total of 132 MECL III circuits along with 18 interface circuits are mounted on a multilayer board measuring 6.2 inches x 7.4 inches.

The signal interconnect paths on the substrates do not need to be treated as transmission lines even with MECL III circuits. Signal paths on the multilayer board are microstrip transmission lines with a characteristic impedance of 80 ohms. (For optimal speed performance such as is required by the Data Synchronizer described above, the characteristic impedance could readily be made 50 ohms.) This board dissipates 50 watts; hence the 20-watt dissipation of the proposed system should present no problem.

Other devices which have been built at the Westinghouse Defense and Space Center using the multichip packaging technique and MECL III integrated circuits include an 11-stage ring counter operating at 250 MHz.

SECTION 5

DATA BUFFERING AND INTENSITY CONTROL

The data is made available from the data synchronizer as a sequence of 7-bit words. These words are provided for one selected spectral band and at a fixed rate. The rate is 3.33×10^6 and 10×10^6 words per second for the low and high rate cases. The image scanner, which produces one line per scan, requires a small and relatively simple buffer configuration. The object scanner buffer must accept the data for up to 17 lines and then output this data one line at a time. This object buffer is therefore appreciably larger than for the image case and is complicated by the need for data rearrangement. The object case is discussed first.

5.1 OBJECT BUFFER

The low rate buffer must store $8190 \times 1.23 = 10{,}070$ samples/line at 7 bits/sample and 10 lines/scan. The 1.23 factor provides needed room for the left and right annotation data. Thus 705,000 bits are required. For the high rate case we need storage for $14{,}200 \times 1.23 = 17{,}500$ samples/line and $17{,}500 \times 7 \times 17 = 2{,}080{,}000$ bits.

The buffer will be divided into two sections -- an input and a main buffer. The input buffer accepts the data at the high input rate and rearranges the data so that the main buffer can operate at a relatively slow rate. The main buffer cycle time, T, may be reduced by having a word length, W, equal to some multiple, M, of the 7-bit sample length. For the low rate, case $T_l = \dfrac{M_l}{3.33 \times 10^6}$ and for the high rate $T_h = \dfrac{M_h}{10 \times 10^6}$; $W = 7\ M$.

For reasonably priced memories, $W \leq 70$; therefore $M \leq 10$. Furthermore the cost per bit of memories increases significantly for $T < 1$ usec. Thus $M_l \geq 3.33$ and $M_h \geq 10$. Finally the number of words, N, of memory for such a buffer is of the form 2^i for $i = 8, 9, \ldots, 15$ typically. From table 5.1 for the low rate case we note that 14,400 is the largest number less than $2^{14} = 16,384$, and 25,200 is the largest number less than $2^{15} = 32,768$. T_l for these two cases is 2.1 usec and 1.2 usec, respectively. The number of bits purchased will then be 49 x 16,384 = 800,000 and 28 x 32,768 = 920,000, respectively. Since the approximate price per bit for the slower (2.1 usec) memory is about 5 cents compared to 6 cents for the faster memory (1.2 usec), and fewer bits are needed for the former, the cost is clearly less for the $M_l = 7$ case. Total cost is about 40,000 dollars.

For the high rate case there is little choice, but fortunately an efficient arrangement is possible since 29,800 (table 5.1) is not much less than $2^{15} = 32,768$. At this size the cost is about 4 cents a bit; thus the total cost is about 92,000 dollars and the data cycle time is 1 usec.

TABLE 5.1. OBJECT SCANNER BUFFER REQUIREMENTS

M	Bits/Words	Words Required	
		Low Rate	High Rate
4	28	25,200	---
5	35	20,200	---
6	42	16,800	---
7	49	14,400	---
8	56	12,600	---
9	63	11,200	---
10	70	10,100	29,800

In both cases all the samples in one buffer word will correspond to adjacent samples of the same line of data. The buffer words can be allocated in two ways -- by blocking or interleaving. With the block system, consecutive buffer words correspond to the same line of data. Thus for the low rate case the first 1440 words would be used for line 1, the second 1440 words for line 2, and so forth until line 10 is completed using a total of 14,400 words. With the interleaving system, line 1 would be stored using buffer words 1, 11, 21, 31, ...; line 2 would use words 2, 12, 22, 32, ..., etc. Selection of one of these methods will depend upon an analysis of the memory control electronics.

The function of the input buffer is now known. For the low rate case it must accept 7-bit samples at a 3.3×10^6 sample/sec rate with successive samples from different lines of the same scan. The output must be in the form of 49-bit words, all from the same line, spaced at 2.1-usec intervals. The high rate case has a sample rate of 10×10^7 samples/sec with a required output of 70-bit words at 1.0-usec intervals. The input data rates can be handled most readily using a semi-conductor memory for the input buffer. Table 5.2 presents the results of a survey of such memories. The size is for a single element usually using a 16-pin dual in-line lead configuration; the size is expressed in number of words x bits per word. Combinations of these elements to increase the word length or the number of words is readily accomplished. A minimum cost configuration can be achieved using the 16 x 4 element as a building block.

For the low rate case, 14 of these can be grouped to form seven 16 x 8 sub-memories at a cost of 560 dollars. Only 7 of the 8 bits of each sub-memory is employed to store the 7-bit samples. The first set of samples

TABLE 5.2. SEMICONDUCTOR MEMORY SURVEY

Manufacturer	Size	No. of Bits	Cycle Time (nsec)	Cost ($)	Price/Bit ($)
Advanced Memory Systems	32 x 8	256	20	768	3.00
INTEL	16 x 4	64	50	40	0.62
Raytheon	16 x 1	16	50	23	1.45
	16 x 4	64	50	40	0.62
	64 x 4	256	100	250	1.00
(Not released)	128 x 4	512	100	--	--
Fairchild	16 x 1	16	50	30	1.87
	16 x 4	64	50	40	0.62
(Not released)	64 x 2	128	50	--	--
	256 x 1	256	100	--	--
Motorola	16 x 1	16	50	18	1.11
Signetics	8 x 4	32	55	32	1.00
(Not released)	16 x 4	64	55	--	--
Sylvania	16 x 1	16	50	43	2.60
	16 x 4	64	50	91	1.42
Texas Instr.	16 x 1	16	50	11	0.68

from lines 1-10 are loaded as ten words in sub-memory number 1; the final six words of each sub-memory are not used. The second set of samples from lines 1-10 are loaded into sub-memory #2, etc. After all 7 sub-memories are loaded, the entire input buffer is unloaded with a sequence of ten 49-bit parallel transfers to the main buffer.

The high rate case requires 40 such elements to form ten 32 x 8 sub-memories. The operation is similar to that above. The write rate is once per 100 nsec; the read rate is once per 1 usec. The parts cost is 1600 dollars.

Both the main buffer and the input buffer must be duplicated to permit simultaneous writing and reading. Both input buffers can write into either main buffer. During one scan, one main buffer (M_a) is accepting data while the other main buffer (M_b) is providing output data. Similarly, while one input buffer is accepting data from the data synchronizer, the other is providing output to main buffer M_a.

5.2 IMAGE BUFFER

The image buffer requirements are simple and can be readily met with a small memory. Since only one line is scanned at a time, the storage requirements are 10,070 x 7 = 70,500 bits for the low rate case and 17,500 x 7 = 122,000 bits for the high rate case. Table 5.3 includes these buffer requirements.

For the low rate there is little difference in cost for $M_1 = 5$ or $M_1 = 10$. Since the associated equipment will clearly be cheaper for $M_1 = 5$ (35 bits/word) this memory is selected. At these memory sizes the cost is about 10 cents per bit even at cycle times slightly below 1 usec. The cost of this memory is about 7000 dollars.

TABLE 5.3. IMAGE SCANNER BUFFER REQUIREMENTS

M	Bits/Word	Words Required	
		Low Rate	High Rate
4	28	2520	---
5	35	2020	---
6	42	1680	---
7	49	1440	2500
8	56	1260	2190
9	63	1120	1950
10	70	1010	1750

For the high rate case a good choice is for $M_h = 9$ (63 bits/word). This requires a memory cycle time of 0.9 usec but still yields a minimum cost memory of about 12,000 dollars.

5.3 INTENSITY CONTROL

The data rate out of the buffer is not significantly different than the input rate; it is assumed to be identical. This output data should be corrected for undesireable non-linearities in the data acquisition system; furthermore, the allocation of photographic gray levels to specific signal levels may be on a non-linear basis. This transformation may readily be performed using a look-up table in what may be termed an intensity control memory. Ideally there should be a different look-up table for each sensor in the S/C. The three different types of sensors will be treated separately.

5.3.1 OBJECT PLANE SCANNER

As discussed in Section 2 this scanner has 10 and 17 parallel sensors in each spectral band for the low and high data rate cases, respectively. Since the data for only one spectral band at a time will be processed, we shall therefore be concerned only with the parallel sensors in one band. The data from these sensors is loaded in parallel to the buffer and read out one line at a time from this buffer.

Since each line of output data is produced by a single sensor, only one look-up table is required for each output line. This look-up table memory is organized to have $2^7 = 128$ words with 7 bits per word. The 7-bit input to this memory (the output of the main buffer) is used to address the look-up table. The output of the memory is the 7-bit contents of the addressed word. Since this memory must operate at the basic word rates of 0.3 usec and 0.1 usec for the low and high rate cases, a semi-conductor memory has been chosen.

As with the input buffer the basic building block is the 16 x 4 unit. Sixteen of these units can be grouped to form a 128-word x 8-bit memory; only 7 of the 8 bits are employed. The cost for these units is 640 dollars.

The contents of the look-up table must be changed once each output line since another sensor was employed to gather the data for the following line. Loading of this table is a function of the annotation computer.

5.3.2 IMAGE PLANE SCANNER - SINGLE DETECTOR

This is the simplest case insofar as the look-up table is concerned. Only a single detector is used in each spectral band; thus only one table is required. Implementation is as noted above, but there is no requirement to change the table contents for each line.

5.3.3 IMAGE PLANE SCANNER - MULTIPLE DETECTOR

With this type scanner we have as many sensors as there are elements per scan line -- 8190 for the low rate case, and 14,200 for the high rate case. If the input-output relationship for each sensor is independent of the others, many thousands of look-up tables would be needed if exact compensation were desired. A more practical approach is to permit an approximate compensation. Two types of approximation appear reasonable.

One can approximate this relationship by a straight line which is characterized by a slope, a, and an offset, b. The compensated output, x_c, would be of the form $x_c = ax_i + b$ for input x_i. Even though there would probably be only a small number of different values for a and b, a large look-up table of 8190 or 14,200 words would be required to select the proper values of these parameters. Additionally, a small high speed arithmetic unit would be needed to compute x_c from a, b and x_i.

For the a, b look-up table, we assume use of a core memory with a 1.0-usec cycle time. For the slope constant, a, about 7 bits are required to handle gain changes greater than 2:1 without significant truncation error. The offset constant, b, needs about 5 bits or ± one-eighth of full scale. These 12-bit words can be grouped to form a major look-up table word of 12N bits to reduce the effective memory cycle time to 0.3 and 0.1 usec for the low and high data rate cases, respectively. Thus N = 4 and N = 10 for these two cases, and the respective number of memory words is 2048 and 1420. The memory output is to a 48 or 120-bit semiconductor shift register which makes these constants available at the correct time for the arithmetic unit.

The arithmetic unit response time is primarily determined by the needed multiplier -- in this case with 7-bit x 7-bit inputs. Westinghouse has recently developed a 12-bit x 12-bit multiplier which produces the output product in less than 0.1 usec. It is therefore expected that the required arithmetic unit response of 0.1 usec can be met at this time.

The second type of approximation involves the use of a number of selectable look-up tables. The input-output relationship for each sensor is not assumed to be of any particular form. However, this method will not be efficient if there are many different relationships which require different compensation.

A major look-up table is required as before, but instead of storing the a, b constants, the address of the selected look-up table is stored. With 12 bits, up to 4096 tables can be selected; this is obviously too large, but the major look-up memory sizes computed before are applicable. With 6 bits, 64 tables can be selected; the major memory word length is then only one-half that previously computed.

There does not seem to be any reasonable method for determining the number of such tables required. The consistency in manufacture, the type of variation (slope, curvature and offset) and the acceptable error level will determine this number. If we assume that 64 tables are needed, the cost of just these elements is 64 x 640 = 40,960 dollars. Gating associated with these tables further increases the cost.

It is therefore likely that the first approach using an arithmetic unit is preferable, unless there is little variability in the sensor relationships.

SECTION 6

ANNOTATION SYSTEM

The function and operation of the annotation system for this wideband system are similar to that suggested for the ERTS-A/B system. The annotation system consists of a computer with an associated magnetic tape unit and a typewriter and specialized interface hardware to provide for data transfer from and to the remainder of the ground processing system.

Input data to the computer comes from the magnetic tape unit, which provides the annotation data, and from the core buffer, which supplies calibration data from the S/C video. Output data describing the annotation in coded form goes to an annotation control unit; data is also supplied to a calibration control unit and a timing control unit.

6.1 ANNOTATION REQUIREMENTS

The computer requirements based on the annotation arrangement are presented first. The image area is 7.3" x 7.3" of the total 9" x 9" area. To determine the location of this image area and the size of the alphanumeric characters, the character height is defined as 1 unit. Let the pattern height (or width) be 1.5 units. At the top of the picture* there are 4 lines of characters and 2 patterns (resolution chart, RC, and longitude marks) which require 7 units of height. Similarly, the bottom requires 3 units for a total of 10 units. Since there is a total of 9.0 - 7.3 = 1.7 inch for this annotation, the characters are vertically spaced 0.17 inch apart. This is about the line-line spacing of a standard typewriter. The character height can then be set to 0.10 inch and 0.06 inch wide with a character-character

* See Phase II report, Figure 4.5.

horizontal spacing of 0.083 inch. Thus there can be 12 characters per inch, or 88 characters per 7.3-inch line (including blanks). The annotation data will be output to the annotation control unit as a sequence of horizontal line segments. Each segment will be coded using two computer words of 16 bits or more each, which includes 7 bits for intensity, 14 bits to indicate the position of the segment, and 10 bits to indicate the segment length. One bit will be used to indicate whether the pair of words represents a normal line segment or a new line for the object scanner case. With few exceptions all characters, when scanned horizontally, have at most two intersections. Thus not more than 2 x 88 = 176 line segments are required to express one scan line of characters.

The only other significant annotation requirement is associated with the resolution chart (RC). Unlike the character generation, this requirement may depend upon the image resolution. For the 100-Mb/s case there are 8190 samples per 7.3 inch; for the 300-Mb/s case there are 14,200 samples per 7.3 inch. Each half of the RC will consist of 10 cycles each of 7 frequencies having periods of 2, 4, 8, 16, 32, 64, and 128 samples. The total number of segments is two per cycle, or 140 segments per half of the RC, and 280 segments total. The total number of samples in each half of the RC is 2540. Although this number is not precisely one-fourth of 8190 or 14,200, it is sufficiently close so that this RC will be satisfactory for both bandwidths.

TABLE 6.1. ANNOTATION PARAMETERS

Total Picture Area	9" x 9"
Earth Image Area	7.3" x 7.3"
Character Line Spacing	0.17"
Character Height	0.10"
Character Width	0.06"
Character Horizontal Spacing	0.083"
Height (Width) of Patterns	0.25"
Characters in 7.3 Inches	88
Segments Per Character Per Scan	2
Character Segments Per 7.3 Inches	176
Spatial Frequencies Per RC	7
Cycles of Each Frequency	10
Segments per RC	140
RC Segments Per 7.3 Inches	280

These annotation parameters are presented in table 6.1. We note that the number of segments required for both characters and the RC is less than or equal to 280; this number will be employed for estimating the computer needs.

The rate of transfer of this data and parameters related to this rate will now be developed. The number of samples placed on the film will be 1.23 times the number of samples within each line of the earth image, or 10,000 and 17,500 for the 100 Mb/s and 300 Mb/s cases. With a 70% scan efficiency, 30% of the scan period is used for scanner retrace as shown in table 6.2. When data is being accepted by the main buffer from the video

TABLE 6.2. ANNOTATION RATE SUMMARY

S/C Bit Rate (Mb/s)	100		300	
Sample Per 9" Line	10,000		17,500	
Max. Line Segments	280		280	
Computer Words Per Segment	2		2	
Max. Computer Words/Line	560		560	
Type of Scanner	Object	Image	Object	Image
Total Scan Period (ms)	35.0	3.50	34.3	2.02
Active Scan Time (ms)	24.5	2.45	24.0	1.41
Retrace Scan Time (ms)	10.5	1.05	10.3	0.61
Left-Right Annotation (ms)	3.5	0.35	3.4	0.20
Top (Bottom) Annotation (ms)	28.0	2.80	27.4	1.61
Lines Per Scan	10	1	17	1
Avg. Computer Word Rate (kHz)	200	200	350	350
Peak Word Rate (kHz)	440	440	500	500

tape (during 70% of the scan period) data transfer from the computer is not possible. Thus the left and right annotation must be completed during part of the scanner retrace time. One third of this time (or 10% of the scan period) is allocated for this task. The top and bottom annotation data transfer can take place during the active scan time as well, for a total of 80% of the scan period. The left and right annotation horizontal space is more than one-eighth ($\frac{10\%}{80\%}$) of the top (or bottom) horizontal space; however it is expected that very few segments will be required there, and hence the required annotation rate from the computer will be slower than for the top annotation.

The computer average word rate is the number of computer words per line (560) divided by the top annotation time for the image scanners. The object scanner rates are higher by the factor of the number of lines per scan. The results are 200 kHz and 350 kHz for the 100-Mb/s and 300-Mb/s cases. Actually, the peak required word rate is slightly higher than these figures. For example, during the output of the RC lower spatial frequencies the computer will be waiting because the buffer cannot accept this data fast enough. Say that the buffer will accept samples at a rate of B usec per sample. Assuming that the computer can output one word every W usec, let us compute the time to output the two RC patterns. The time for one cycle of the RC having a period of P samples is 4W (for the computer output of two segments) plus BP (to load the buffer with P samples). Summing up for the seven spatial frequencies and ten cycles of each frequency, the total time for two RC patterns is $T = 2(280W + 2540B)$. For the 100-Mb/s case for $B = 0.3$ usec and $T = 2800$ usec, we have $W = 2.2$ usec for a peak rate of 440 MHz. Similarly for the 300-Mb/s case $B = 0.1$ usec and $T = 1610$, then $W = 2.0$ usec for a peak rate of 500 kHz.

In addition to processing such annotation data, the computer must receive calibration data and output data to the calibration control unit. The calibration data, it is assumed, is generated in the S/C during the retrace time and for about 5% of the total scan period. For each spectral band and line the calibration will consist of up to $2^7 = 128$ different samples. Two samples will be sent to the computer at a time in one computer word. For the 100-Mb/s case the word transfer rate will be $\frac{128}{2 \times 0.175} = 370$ kHz; for the 300-Mb/s case this rate is $\frac{128}{2 \times 0.1} = 640$ kHz.

These samples are processed in the computer by averaging them with previous calibration values. Then the calibration control unit is loaded once per output line to the image film recorder. These 128 numbers are loaded during 5% of the scan period and thus require rates equal to that of the calibration data input.

The other functions of the computer involve relatively slow data transfers.

6.2 COMPUTER SELECTION

A summary of the computer storage requirements, presented in table 6.3, indicates that about 10,000 words are required. Of the storage needs, the largest single factor is associated directly with picture generation.

It is assumed that up to eight full lines of alphanumeric characters will be written (five at the top and one at each of the other sides). This requires about 700 words; storage of the other patterns requires an additional 500 words. The data describing the annotation peculiar to each picture is computed off-line by another computer and provided

TABLE 6.3. COMPUTER STORAGE

PICTURE GENERATION	
Lines of Characters	8
Characters Per Line	88
Core Storage Per Character (Words)	1
Total Character Storage (Words)	704
Other Pattern Storage (Words)	500
Annotation Program Storage (Words)	1000
Annotation Output Buffer (Words)	560
Number of Buffers	2
Total Output Buffer (Words)	1120
Total Annotation Storage (Words)	3324
CALIBRATION	
Calibration Samples Per Line	128
Samples Per Word	2
Computer Input Per Line (Words)	64
Calibration Input Buffer (Words)	128
Calibration Output Buffer (Words)	128
Program Storage (Words)	1500
Total Calibration Storage (Words)	1756
OTHER	
Real Time Monitor (Words)	1000
I/O Routines (Words)	1500
Teletype Routines (Words)	1500
Total Other Storage (Words)	4000
TOTAL STORAGE REQUIRED	10,000

to the annotation computer in the form of a magnetic tape record. This data is read from the tape prior to the start of a frame (set of pictures of the same object in different spectral bands). The annotation program converts this data to the required form for use by the annotation control unit. The program will require about 1,000 words. Output of the annotation data requires the use of two computer buffers; one is loaded while the other is being unloaded. Since it is estimated that 280 segments per line will be sufficient, the output buffer size should be 1120 words (using two words per segment in each buffer).

The sensor calibration function involves accepting 128 samples per line, smoothing these numbers, and outputting 128 values to the calibration control unit. The input and output computer buffers are similar to that for annotation and use a total of 256 words. An added 1000 words are employed for program control of these operations.

The remaining computer functions include the real time monitor, input-output (I/O) routines, and teletype routines. The computer will not exercise direct control of the positioning of the video data tape. However, the start time of each frame will be read from the annotation tape, and this time will be transmitted to the timing control unit. When the video tape has been correctly positioned to coincide with the annotation time, an interrupt will be sent by the timing control to the computer. Upon receipt of this interrupt, the annotation program will begin execution. The teletype will be used as the communications media between the operator and the computer programs. All annotation header information will be printed, as well as start times and spectral band information. Any hardware errors may be sent to the computer via appropriate interrupts and these error conditions will be printed by the teletype routines. Any required initial input data will be entered by the operator via the teletype.

Estimated computer execution times and storage requirements were obtained from an examination of existing 1108 computer programs as well as experience drawn from the design and implementation of previous computer systems.

The data rates for these tasks does not exceed 500-kHz transfer rate. Computer evaluation was based on the units previously reported as part of the ERTS-A/B effort. Of the five computers considered, the DDP-316 was eliminated because the maximum I/O transfer rate is 312 kHz. Also, the SCC-4700 was eliminated because the prices of SCC computers are presently being changed with no quoted price being available at the present time. The remaining three computers all meet the requirements and have properties summarized in table 6.4. The PDP-15 has the following three important advantages over the DDP-516 and the EMR-6130:

1) The price is cheaper by at least 17%.
2) The word length is 18 bits rather than 16, thus allowing the computer to directly address four times as much core memory and thereby cutting the software cost associated with the programming effort.
3) The computer must access the following peripherals: teletype, timing control unit, mag tape unit, 128-word look-up table, and external core buffer. The PDP-15 would allow each of these devices to communicate with the computer via a separate I/O channel, once again reducing the software cost associated with the I/O transfers.

TABLE 6.4. COMPUTER COST AND CAPABILITY COMPARISON

COMPUTER	PDP-15	DDP-516	EMR-6130
CPU +12 K + ASR-33	30.5	41.0	62.5*
High Speed Arithmetic Unit	2.8	3.5	Included
Interrupt Hardware	3.0	1.6	6.0
Real Time Clock	.5	1.5	1.5
One 9-Track, 800-bpi, 150-ips, Mag Tape Unit and Controller	41.0	41.1	50.0
KSR-35 and Controller	5.0	4.3	2.6
High Speed I/O	Included	7.0	7.7
Total	$82.8K	$100.0K	$130.3K
Cycle Time (nsec)	800	960	750
Buffered I/O Channels	8	1	1
Bit Size	18	16	16
Maximum Word Transfer Rate (kHz)	1000	1040	1280

* Core capacity is 16K instead of 12K.

The selection of the Digital Equipment Corp. PDP-15 computer was, as noted before, based only on the five computers previously considered satisfactory for the ERTS-A/B mission. Of major significance is the fact that at least one currently available computer can satisfactorily process the data associated with the 300-Mb/s case. It is reasonable to expect that a more complete search will, especially at some time in the near future, uncover a yet more acceptable computer.

6.3 ANNOTATION CONTROL UNIT

The annotation control unit interfaces the computer and the main core buffer. All annotation data is routed through this unit. Its function is to accept line segment data from the computer at a relatively low rate and output individual samples to the main buffer at a high rate.

This unit accepts two sequential 16-bit words from the computer. These 32 bits are loaded into four registers:

1) Intensity - 7 bits
2) Segment position - 14 bits
3) Segment length - 10 bits
4) Type code - 1 bit

If the type code is ONE (used only with the object scanner case), the line address of the main buffer is incremented by one unit; the other bits are ignored.

Normally the type code will be ZERO. The segment intensity and position are transmitted to the buffer. The position is then incremented and the length decremented, and a second sample is sent to the buffer. This process is repeated until the segment length is decremented to zero. At this time an interrupt is sent to the computer to request the next line segment.

SECTION 7

IMAGING SYSTEM

The imaging system consists of the image film recorder and special data control equipment, such as the D/A converter and a timing unit to maintain proper synchronism between the data stream and the film recorder. The requirements, and the types of film recorder which meet these requirements, are similar to that discussed in the ERTS Phase II report. A major difference arises from the need for better resolution, linearity, etc., in proportion to the square root of the data rate. Since the ERTS A/B scanner data rate is 15 Mb/s, improved performance by about a factor of 3 to 5 is required for the 100 to 300-Mb/s cases.

In the discussion that follows, to avoid repetition, it is assumed that the reader is familiar with at least Section 4.1 of the ERTS Phase II report.

7.1 REQUIREMENTS

The most significant requirement for a film recorder is the resolution. Before resolution can be adequately defined we must specify the desired shape for the exposing beam of light or electrons. There are a number of beam shapes which, when properly spaced, do not display any line structure for a uniform input. These include the rectangular, triangular and $\cos^2$ shapes, but exclude the gaussian shape. Of these, the triangular shape is best for reconstructing images with detail, that is, for non-uniform inputs; the rectangular shape is poorest. The difficulty of generating the triangular shape, compared to the $\cos^2$ shape, is the basis for the selection of the $\cos^2$ beam as a compromise.

The optimum diameter of the $\cos^2$ beam is equal to the line-line spacing of the image. ERTS A/B has a line spacing of 77 urad (measured at the S/C) and a total image height of 200,000 urad (or 100 nautical miles). Thus there are $\frac{200,000}{77} = 2600$ lines per picture. However, the total picture size including annotation requires additional lines for a total of $2600 \times 1.23 = 3200$. (See table 7.1.)

The modulation transfer function (MTF) for a beam with shape

$$\frac{1}{T} \cos^2 \left(\frac{\pi x}{2T}\right); \; -T \leq x \leq T$$

is given by

$$\text{MTF}(w) = \frac{\sin wT}{wT\left[1 - \left(\frac{wT}{\pi}\right)^2\right]}$$

for line spacing T and spatial frequency w. It is readily shown that MTF $(w^*) = 0.5$ at $w^* = \frac{\pi}{T}$. Expressing the spatial frequency in cycles instead of radians and in terms of the raster height instead of the line-line spacing we obtain

$$f^* = \frac{w^* M}{2\pi} = \frac{M}{2T}$$

The number of TV lines at MTF = 0.5, is then given by

$$TVL^* = 2f^* = \frac{M}{T} .$$

Thus the resolution expressed in terms of TVL* is numerically equal to the number of spots vertically.

The spot position repeatability specification is based on the desire to produce color composites from combinations of individual black and white pictures. To limit the image degradation caused by misregistration of

TABLE 7.1. IMAGE RECORDER REQUIREMENTS

Data Rate (Mb/s)	15	100	300
Line Spacing (urad)	77	24.6	14.2
Number of spots vertically	3200	10,000	17,300
Resolution (TVL @ 50% MTF)	3200	10,000	17,300
Spot position repeatability (%)	0.0078	0.0025	0.0014
Line Spacing Repeatability (%)	10	10	10
Linearity (%)	0.10	0.03	0.02
Sweep Rate (lines/sec.)	91	286	495
Film Width			
Film Limitation (mm/in.)	64/2.5	200/7.9	346/13.6
Eye Limitation (mm/in.)	320/12.6	1000/39.4	1730/68.2
Registration Limitation (mm/in.)	82/3.2	256/10.1	457/18.0

spots, no spot should depart from its nominal position by more than one-fourth spot diameter. Thus two superposed spots will be out of register by at most one-half spot diameter. Expressed as a percentage of the full scale picture height the spot position repeatability is given by $\frac{100}{4 \times \text{resolution}}$, where the resolution is expressed in TVL at 50% MTF.

The line spacing repeatability is specified to be 10 percent of the nominal line spacing. With the $\cos^2$ shape, if the line spacing is 1.1 times nominal, the minimum amplitude between lines drops to 0.84 compared to 1.00 for nominal spacing. At 0.9 nominal spacing the amplitude between lines becomes 1.16. With film developed to a contrast index of 1, this corresponds to a density change of about 0.06, an acceptably small change.

The linearity error is expressed as a percentage of the picture height. It is a functional error which does not significantly vary from picture to picture. This error can limit the use of the data in the production of maps or in correlating the data with existing maps. The specification used here limits the deviation of any one line, from its ideal position, to at most about three line spacing units.

The film width must be sufficiently large to: (a) Minimize resolution losses due to the film MTF; (b) eliminate or minimize resolution losses due to film enlargement to the final required size; and (c) permit adequate registration of images to form color composites. If film of width W has F lp/mm limiting resolution, there are WF line pairs (lp) across the film. Let S be the system resolution in line pairs at 50% MTF. System spatial frequency S should correspond to a film spatial frequency of $\frac{WF}{4}$ to satisfy condition (a) above. Then

$$\frac{S'}{2} = S = \frac{WF}{4}$$

where S' is the system resolution expressed in TVL at 50% MTF. Thus $W = \frac{2\,S'}{F}$. The limiting resolution of black and white films used with laser or electron beam image recorders will typically be very high, thus permitting the use of a narrow film strip. However, if a color image is to be formed by successive contact printing of such black and white transparencies, the color film resolution may be a limiting factor. If we assume the use of color film with 100 lp/mm limiting resolution we can compute W for each case shown in table 7.1.

Let us next compute the desired final film size based on direct viewing needs. The human eye can just detect two points about 0.1 mm apart from a viewing distance of 25 cm. This corresponds to a limiting resolution, H, for the human eye of about 10 lp/mm. The limiting resolution of an optical system in line pairs is often approximately equal to the resolution at 50% MTF expressed in TVL. A good match between the eye and the picture occurs when each has the same limiting resolution. Under these conditions $S' = HW$ and

$$W = \frac{S'}{H}.$$ In this manner no image enlargement is required.

Pin registration of an image, as discussed in the Phase II report, can be held to an error of $\pm$ 0.00025 inch under good conditions. This error, E, is about 0.0064 mm. Letting this error equal that of the spot position repeatability percentage error, P, we have:

$$\frac{P}{100} W = E \text{ or } W = \frac{100E}{P}.$$

The widths computed for these different limitations are included in table 7.1. If color composites are to be formed, the minimum active film width is limited by the registration. This assumes that the film product —

probably a transparency -- will be viewed by a magnifier of about 4X magnification. Thus film of 12 or 20-inch width (including a border) would be sufficient to handle the 100-Mb/s and 300-Mb/s cases.

7.2 DISPLAY DEVICES

This section includes a discussion of high resolution image recorders. We shall commence with a discussion of the general concepts employed by each recorder and then consider the performance of these units. We can classify these recorders by the source of the exposing energy. Of the various sources, only the laser and electron beams appear promising for this application. Of the image recorders considered in the Phase II report, the cathode ray tube (CRT) system has been deleted because of several factors, including insufficient resolution (2500 TVL at 50% MTF). The crater lamp recorder (CLR) has been rejected because of its low writing rate (60 lines/sec). The other two recorders, electron beam (EBR) and laser beam - moving film (LBR), are considered in this report. Reference is made to the discussion included in Section 4.1 of the Phase II report to avoid a repetition of that material here.

A second type of laser beam recorder is being developed which is structurally similar to the CLR. This configuration is compatible with the needs of this task and is potentially much less expensive than the moving film system illuminated by a fast rotating mirror, as discussed in the Phase II report. The newer LBR, which uses a rotating drum, is being built for NASA/GSFC as part of the direct readout ground system for ITOS-D and SMS by Image Information Inc. of Norwalk, Connecticut. This unit uses a rotating drum and a stationary optical beam as shown in figure 7.1. Drum position control involves use of a phase lock loop and feedback of drum position and speed. Jitter will be limited to about 1 part in 100,000 of drum rotation.

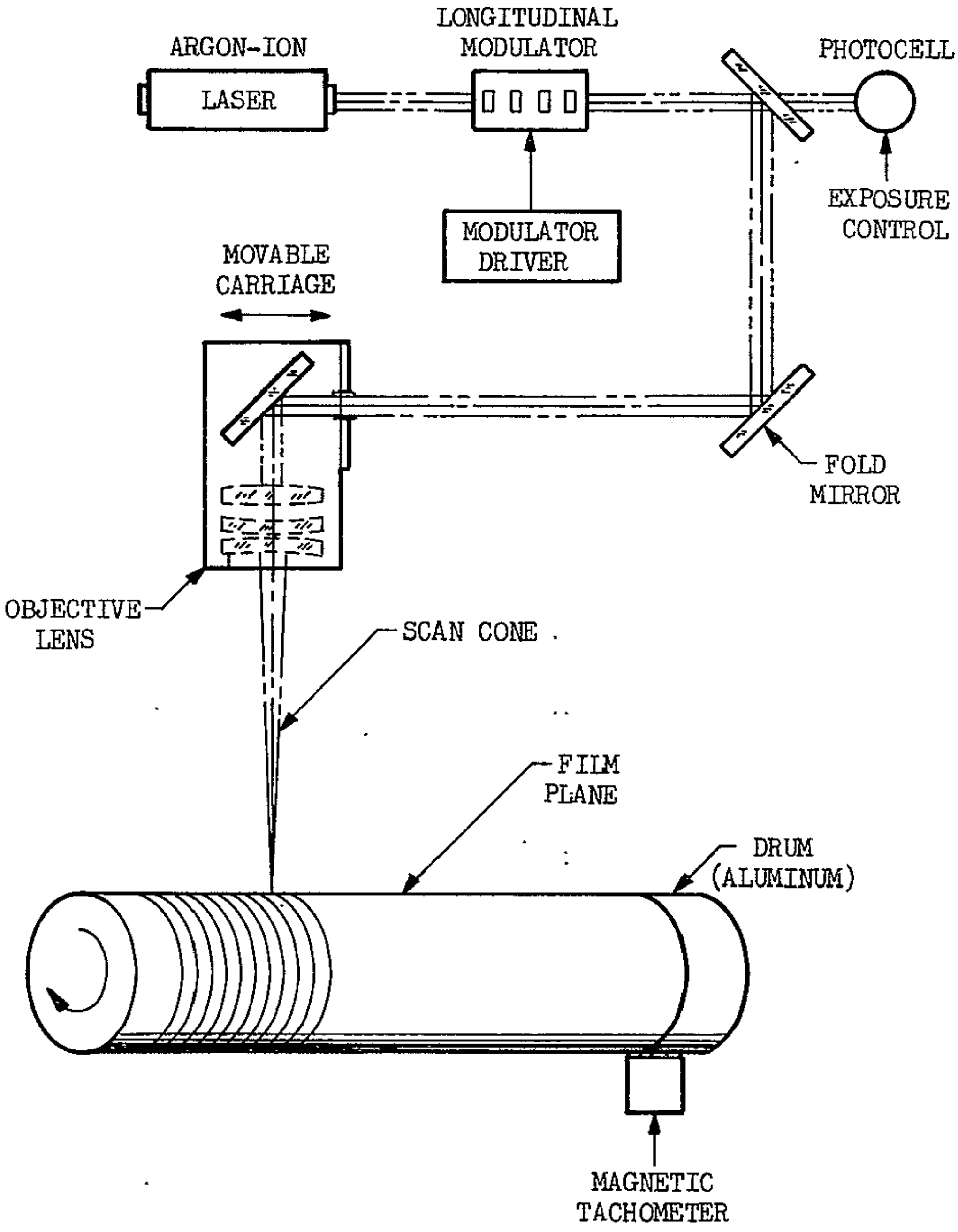

Figure 7.1. Laser Beam Drum Recorder

The drum circumference is about 24 inches; its length is also 24 inches. Line scan is produced by drum rotation, and line spacing by stepper motor control of the movable optical carriage.

The system is designed to operate with 3M dry silver film products with thermal development. A processing temperature of 250°F with a contact time of 15 seconds is employed. After air cooling the image may be immediately viewed. An image density range of 2.3 at a gamma of 1.15 is planned.

The film has a resolution in excess of 2000 lp/mm. The performance of this recorder, as discussed below, does not represent the full capability of this type of device. In general, the specification reflects the ITOS requirements. System resolution of 10 lp/mm at 73% MTF is held to be a readily achievable goal. Similarly, achieving 0.1 percent scan linearity and synchronization is considered well within the state-of-the-art.

Equipment life for this type of recorder should be very good. Rotating speeds are low, and thus bearings should last indefinitely. The gas laser light source should last several thousand hours and provide sufficient energy density to expose the film at the writing rates required.

The unit should be convenient to operate. Loading includes the drawing of film from the roll supply, film cutting to form a 22-inch film sheet, and the forming of this film on the drum. After exposure and thermal processing, the film sheet is delivered to a light table for immediate inspection.

7.3 COMPARISON OF IMAGE RECORDERS

The preceding section included a discussion of two types of laser beam recorders; one uses moving roll film and the second uses cut film on a drum. The performance figures included here groups both types of LBR's together for comparison to the EBR. This review is based on a letter from CBS Laboratories reproduced at the end of this section as exhibit I. The image system parameters for the LBR and EBR are included in table 7.2.

A comparison of tables 7.1 and 7.2 shows that the EBR expected resolution of 10,000 TVL at 50% MTF is just adequate for the 100-Mb/s case but inadequate for the 300-Mb/s case. Moreover, for formation of color images, the spot position repeatability and film size do not meet requirements. Other EBR limitations include relatively poor line spacing repeatability, linearity, and life.

The LBR is satisfactory in all respects except that at 300 Mb/s the spot position repeatability is slightly out of specification. Thus, some form of LBR should be chosen for the imaging recorder.

TABLE 7.2. IMAGE SYSTEM PARAMETERS

Image Recorder (CBS)	LBR	EBR
Typical Film Size	9 inch	70 mm
Resolution (TVL @ 50% MTF)	20000	6000
Max. Developmental Film Size	44 inch	5 inch
Resolution (TVL @ 50% MTF)	66,000	10,000
Linearity (% of scan line)	0.01	0.1
Repeatability of Spot	0.002	0.03
Line Spacing Repeat	10%	25%
Life (Hours before replacement)	1000	200
Sweep Rate (lines/sec)	10,000	10,000

7.4 DATA CONTROL

There are two other functions relating to the imaging system. The first is the means for converting the digital data from the look-up table to analog form for input to the image recorder. The second is the timing control which must be established and maintained to keep the data recorder output at the proper rate so that the image recorder can accept it.

Regardless of the type of scanner employed, the sample rate to the film recorder is 3.3 MHz for the 100-Mb/s case and 10 MHz for the 300-Mb/s case. A high speed D/A converter is required to accept the output of the look-up table memory and to provide an analog signal to the image film recorder. A unit recently developed by Westinghouse and representing the state-of-the-art is capable of satisfactory operation at these rates. This converter will attain its final steady state value to within one percent error in less than 15 nsec.

The timing system will be similar to that suggested for ERTS A/B. The image recorder will supply the master clock for maintaining synchronism of the buffer unload through the intensity control memory and the D/A converter to the image recorder. Although the data loading of the buffer does not need to be in precise synchronism with the image recorder, a maximum tolerable timing error does exist. As discussed in Section 6, the S/C scanner has a 70 percent efficiency. Buffer loading takes place during this time and an additional 10 percent for transfer of annotation data to the buffer. This data, representing 80 percent of the available time of a scan period, can be loaded during any part of the scan period. If this data is normally input to the buffer during the middle of the scan period, timing errors may be as great as $\pm$ 10 percent of this period.

For the object scanner this timing error may therefore be as great as 3.4 msec for either the low or high data rates. The image scanner requires much tighter control, with timing tolerances of 350 usec and 202 usec for the low and high rate cases. The latter figures may be substantially increased, if necessary, by the use of additional buffering. This should be practical because, as noted in Section 5, the image scanner buffers are quite small.

CBS
LABORATORIES
A Division of Columbia Broadcasting System Inc
High Ridge Road
Stamford Connecticut 06905
(203) 327-2000

September 29, 1969

Mr. Ted Foster, Senior Engineer
Mail Stop 645
Electronics Division
Westinghouse Electric Corp.
Box 1807
Friendship International Airport
Baltimore, Md.

Dear Ted:

Congratulations for attempting to document some of this technology, and thanks for inviting our review. I offer a general increase in detailed capability, as follows:

	LBR	EBR
Resolution (TV lines @ 50% MTF)	> 20,000 (1)	> 10,000 (2)
Image Size	> 20" (3)	5" (4)
Linearity (% of scan line)	<< 0.01 (5)	< 0.1
Repeatability of spot position	< 0.002 (5)	< 0.03
Line spacing repeatability	10	25
Life (hours before replacement)	> 1000	> 200 (6)
Sweep rate (lines/sec)	> 10,000 (7)	> 10,000 (8)

Notes:

1. Diffraction-limited f/2 on 70 mm and f/6 on 5" film. 9" format could yield 40,000 elements/scan; 100,000 elements per scan reasonable limit, especially at lower sweep rates.

2. CBS' - EBR at NASA provides 6,000 elements/scan on 70 mm format. Expect > 10,000 O.K., if allowed to conform to 5" film surface; perhaps limit at 20,000 per scan.

3. CBS has 20" design now at 20,000 elements/scan. Also, 66,000 elements over a 44" scan in development now.

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4. Ampex and General Electric have 5" format now. Believe this is reasonable limit, where increased format width may not necessarily increase the total resolution, due to increased deflection distortion.

5. 0.01% is "only" one part in 10,000. Linearity to one part in 50,000 is present CBS art, if we discount film processing differential variations. Repeatability, therefore, as indicated.

6. Replacement of e-beam cathode not fair comparison with replacement of laser. Cathode on turret easily and economically replaced.

7. At CBS, 60,000 rpm for 10-facet (f/6) spinner = 10,000 scans/sec. Allow order of magnitude increase for reduced facet size (reduced resolution).

8. e.g., std. T.V.

General comments re "reduction of ambiguity" --

a. Bravo! Resolution at 50% response! Perhaps, at 25% MTF more realistic system requirement, to include recording optics, storage medium, and residual instrumental imperfections (due to the recording process alone). To be interpreted as resolution elements along the scan lines; not across the lines. ("TV lines" may be confusing). Resolution across the lines another thing, again! (that includes sampling redundancy and spot contour considerations).

b. "Linearity" is really "non-linearity" in this context. However, misnomer is prevalent.

c. "Line spacing repeatability" -- to be interpreted either as uniformity of subsequent scan lines, or "repeatability" of an entire raster of scan lines upon itself. I assume the first interpretation; the second is devastating for the e-beam recorder, and requires critical tracking of the e-beam.

d. "Repeatability of spot position" -- assume <u>along</u> scan line, with given "linearity".

You have performed a difficult and noble task in trying to pin-down some of these parameters. I'm enclosing a couple of papers (which you may already have) which may help rationalize some of these numbers. Let's keep in touch.

Best regards to you and to Harold Ausfreisser.

Sincerely,

Leo Beiser

Leo Beiser
Staff Physicist
Electronic Systems Department

Encls.

EXHIBIT I (Page 2 of 2)