GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT INITIATION

Posted
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Date: March 20, 1975

Project Title: A Laser Scanner for 35mm Film

Project No: E-21-657

Co-Principal Investigators: Dr. W. R. Callen; Dr. T. K. Gaylord

Sponsor: National Aeronautics and Space Administration
Marshall Space Flight Center

Agreement Period: From 2/25/75 Until 2/24/76

Type Agreement: Contract NAS8-31193

Amount: $49,967 NASA
5,000 GIT (E-21-333)
$54,967 Total

Reports Required: Monthly Progress Reports; Final Technical Report

Sponsor Contact Person (s):

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Marshall Space Flight Center,
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Mr. Harvey L. Smith
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Alabama 35812

Assigned to: Electrical Engineering

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RA-3 (6-71)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: October 12, 1978

Project Title: A Laser Scanner for 35mm File

Project No: E-21-657

Co-Project Directors: Dr. W. R. Callen and Dr. T. K. Gaylord

Sponsor: National Aeronautics and Space Administration; Marhsall Space Flight Center

Effective Termination Date: 4/24/77

Clearance of Accounting Charges: 4/24/77

Grant/Contract Closeout Actions Remaining: none

Otis, Please check this one in the book for actions remaining.

Property not yet cleared - being donated thru GSA-Excess channels which drags on + on + on + on + on + on + on + on etc.

- _ Final Invoice and Closing Documents
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ________________

Assigned to: EE (School/Laboratory)

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CA-4 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

SCHOOL OF
ELECTRICAL ENGINEERING

April 7, 1975

Mr. J. H. Kerr
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 1 on Contract NAS8-31193 for the Period 25 February 1975 to 1 April 1975.

Dear Sir:

Activities during the first month of the subject contract included calculations for the horizontal and vertical deflector bandwidth requirements. A Zenith acousto-optic modulator was borrowed for observation. Preliminary examination indicates that the deflected spots are suitable for our application.

Due to the cost of off-axis, low f-number aspheric elements (lenses and mirrors), the possible use of spherical elements is being considered. A number of spherical lenses are being tested. The reflections from selected coated lenses have been found to be negligible.

The optical breadboard has been ordered.

Expenditures and man-hours effort during the first reporting period are:[1]

Technical Effort	$ 0
Materials and Supplies	0
Equipment	916
Travel	0
Total Expenditures to Date	$916

Next month's activities will include a preliminary system design of the scanner.

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[1]Expenditures to date reflect no contract funds spent on Technical Effort, because Georgia Tech personal service charges are established on a quarterly basis.

The projected expenditures for the remainder of the program are:

Technical Effort	$34,567
Materials and Supplies	9,500
Equipment	4,084
Travel	900
Total Projected Expenditure for Completion of the Program	$49,051

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ELEPHONE: (404) 894-2901

May 7, 1975

Mr. J. H. Kerr
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 2 on Contract NAS8-31193 for the Period 1 April 1975 to 1 May 1975.

Dear Sir:

Activities during the second month of the subject contract included the development of a preliminary scanner design using an acousto-optic deflector and a light deflecting galvanometer. Studies of spinning polygonal mirrors are being performed to determine their suitability for use in a non-random access type of scanning operation. The linearity of scan of the spinning mirror system is being compared to that of the acousto-optic system.

A conference paper entitled "The Potential of Multi-Port Optical Memories in Digital Computing" by C. O. Alford and T. K. Gaylord was presented at the 1975 International Optical Computing Conference, held in Washington, D.C., April 23-25, 1975. Professor Alford, whose specialization is computer processing and techniques, is now doing preliminary research on the structure and architectural aspects of optical data storage systems. A copy of the paper is attached.

The electro-optic modulator sent to Georgia Tech from Marshall has been received.

Expenditures and man-hours effort during the first two reporting periods are:

Technical Effort - 69 man-hours	$1,338
Materials and Supplies	0
Equipment	916
Travel	122
Total Expenditures to Date	$2,376

The projected expenditures for the remainder of the program are:

Technical Effort	$33,229
Materials and Supplies	9,500
Equipment	4,084
Travel	778
Total Projected Expenditures for Completion of the Program	$47,591

Next month's activities will include refinement of the scanner design and preliminary effort on installation of the optical breadboard at Georgia Tech.

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

Enclosure

... Computing Conference, pp. 121-125, April 25, 1975

THE POTENTIAL OF MULTI-PORT OPTICAL MEMORIES IN DIGITAL COMPUTING

C. O. Alford and T. K. Gaylord
School of Electrical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Summary

A high-capacity memory with a relatively high data transfer rate and multi-port simultaneous access capability may serve as the basis for new computer architectures. The implementation of a multi-port optical memory is discussed. Several computer structures are presented that might profitably use such a memory. These structures include (1) a simultaneous record access system, (2) a simultaneously shared memory computer system, and (3) a parallel digital processing structure.

Introduction

It is widely recognized that the characteristics of optical memories are different from those of conventional computer memories. Thus, they may play roles that are different from the roles played by existing magnetic and semiconductor memories. One potential capability of optical holographic memories as suggested by Rajchman [1] is the replacement of a large fraction of the conventional computer memory hierarchy. In this situation a series of slow and large, and fast and small memory devices would be replaced by a single optical memory unit. This may be possible due to the potential coexistence of both high capacity and fast access times in an optical memory--two features that do not exist together in conventional memories.

In addition, there are other ways that optical memories may be distinctly different from conventional memories. One of these is the multi-port capability--the capability of stored data in the memory to be accessed simultaneously by multiple users through each of the memory's ports. This is to be contrasted with space multiplexed (interleaved) and time multiplexed conventional memories which are sometimes represented as being "multi-port." However, a true multi-port memory allows simultaneous access to its data through each memory port.

Multi-Port Optical Memories

Multi-port optical memories could be of a variety of designs. A possible example of a multi-port holographic memory is shown in Fig. 1. In this diagram, the recording medium is being used as a two dimensional store rather than a three dimensional store [2]. There is one page of binary data stored in holographic form at each x-y location of the recording medium. This memory is basically the same as a conventional optical holographic memory [3] except that 1) there are three extra beam deflectors and 2) there is one read-out detector matrix for each memory port. The extra beam deflectors are of key importance in this memory system. The first reference/read-out beam deflector produces N beams deflected by varying amounts in the y direction. The second reference beam deflector is a one dimensional array of deflectors to produce deflection of the reference beams by varying amounts in the x direction. Finally, the readout deflector array is a two dimensional array of deflectors directly behind the recording medium to steer the reconstructed data beam to the appropriate memory port [4]. Notice that this memory configuration uses a single page composer for writing in data at all x-y hologram locations in the recording medium.

The complexity of a multi-port optical memory is thus greater than that of a single port optical memory. However, the cost of additional memory ports beyond the second port would be relatively small. For each additional port, the primary additions would be another read-out detector matrix and an increase in laser power. There would be one reference/read-out beam for each of the N ports. With additional ports, the basic object beam and reference/read-out beam configurations as illustrated in Fig. 1 would not be changed. An upper limit on the number of ports would obviously be imposed by the amount of usable space available behind the inverse Fourier transform lens.

Simultaneous Record Access System

One of the prime purposes of a high-capacity optical memory is to store vast quantities of records or information such as libraries, insurance data, medical data, seismic data, criminal data, defense data, tax information, patent records, telephone numbers, stock market information, etc. Users of such a storage bank would need to have access to page information. Further, multiple user capability is required to make such a system cost effective. A possible structure for this system is shown in Fig. 2.

Data is stored in page format in the multi-port optical memory. Access to any page is via a terminal (CRT type) through one of the memory access ports. The data requirements of each terminal are, in some applications, low enough to have one memory port support several terminals through a multiplexer. Since a single page access may require on the order of 1 μsec and since each human user would take on the order of 1 minute to scan a page and reach a decision on the next access, a single port operating through a multiplexer could theoretically support 10^6 terminals. However, maximum data rates between the port and the terminal will reduce this number to the order of probably 100. Thus ten ports could support 1000 users and this could be extended to more users by increasing the data rates on the external circuitry.

Trade-offs are between port speed, multiplexer speed and numbers of ports. The most effective system would match the total number of users at one port to an economical multiplexer such that the average access time for any user is reasonable (approx. 1 min.). This access time divided by the number of users per port fixes the multiplexer speed and memory access time per page. If a slower memory access time can result in a less expensive memory or if this can be traded for additional memory ports at the same expense, these would make desirable trade-offs.

The normal mode of page read-out is a binary pattern of a discrete number of bits. It is conceivable, however, that certain information, such as pictures and figures, would be read out of the optical memory in a non-encoded format. The transfer of this type of information to a readable display for multiple users, presents a number of new design problems and trade-offs.

The user terminals are normally used in the read-only mode and are not allowed to perform write operations to memory. Writing would be done by an input terminal through a separate memory port. Since this is also a low speed operation, this port could be multiplexed to other terminals for further read-only usage.

Simultaneously Shared Memory Computer System

The record access application did not require any transformations on the data accessed by the user. If such transformations are necessary, arithmetic logic units must be added to the architecture. One such structure is shown in Fig. 3. The system is essentially the same as most current time-sharing structures. Several users are allowed access to a processing unit. Primary memory is allocated and user programs are executed independently of the multi-port secondary memory, if possible. Calls to special application programs and large blocks of data are achieved by swapping that data in and out from the multi-port memory.

The secondary memory serves as a backing store mass memory device. Its multi-port structure, however, makes it functionally equivalent to several disk drives and its transfer rate makes it superior to the parallel operation of disk units. The possibility exists of placing most of the operating system in the optical memory and decreasing the size of the primary memory units for each central processor unit (CPU).

Some of the parameters needed to characterize such a system are number of bits per page, number of pages, number of ports, access time, primary memory size, write protection scheme, and division of the operating system between the primary memory and the multi-port memory. Trade-offs exist between these parameters and it would appear that if primary memory can be effectively reduced by utilizing the optical memory, a more cost efficient time sharing system would result. Since swapping of information between memories is a common problem in time-sharing systems, the potential access ease and speed of moving pages in and out of the optical memory would be a definite improvement. Other trade-offs exist between the number of ports and number of users and the port speed necessary for a single CPU.

Parallel Digital Processing

There are many scientific problems which require an enormous number of computations. One approach to this problem has been a multi-processor parallel computation technique. Essentially all processors are dedicated to solving one step of the problem. The results are then transfered to the appropriate processor that is dedicated to solving the next step of the problem. Likewise, the first processor also receives new input data and the step-wise computation continues. Problems arise from synchronization and system reliability when the parallelism is carried as far as that in Illiac IV. While no structure is being proposed which would duplicate the Illiac IV performance, it is believed the multi-port memory with a minicomputer multiprocessor structure could give surprising performance.

A possible structure based on a single bus (Unibus) architecture similar to the Lockheed Sue computer is given in Fig. 4. Each minicomputer (module) contains its own processor, data source, and instruction memory. The Unibus allows this module to function as a separate computer independent of the other processors and the multi-port memory. Each module is connected to the multi-port memory through a port and a page memory buffer. This buffer is then tied to the Unibus for transfers to the processor and other memory units. Transfers between modules are made on an outer bus connecting each module.

An alternate configuration which places control of all processors under the direction of one control computer (CPU) is shown in Fig. 5. Instructions are kept in the optical memory and fetched by the control computer. These instructions are sent along the outer bus to selected CPU modules. Modules can then execute similar instructions or different instructions according to the demands of the control computer. All data on which the modules will operate moves through the ports, page buffers, and data memories to be transformed by the processors.

Some of the characteristic parameters of these systems are number of bits per page, number of pages, number of ports, page transfer rates, bus transfer rates, and types of synchronization signals. Trade-offs exist between computational speed of the processors, number of ports and access time. It would seem that the control computer of Fig. 5 would have to be considerably faster than the other processors and possibly the port under its control, port 0, would have to have a higher speed than other ports.

Acknowledgements

This work was supported in part by the National Science Foundation under Grant No. GK-37453 and by the National Aeronautics and Space Administration under Contract No. NAS8-30246.

References

1. J. A. Rajchman, "Promise of Optical Memories," J. Appl. Phys., vol. 41, pp. 1376-1383, March 1, 1970.
2. e.g. L. d'Auria, J. P. Huignard, C. Siezak, and E. Spitz, "Experimental Holographic Read-Write Memory using 3-D Storage," Appl. Optics, vol. 13, pp. 808-818, April 1974.
3. e.g. W. C. Stewart, R. S. Merzrich, L. S. Cosentino, E. M. Nagle, F. S. Wendt, and R. D. Lohman, "An Experimental Read-Write Holographic Memory," RCA Review, vol. 34, pp. 3-44, March 1973.
4. A possible technology for this is described in Y. Ninomiya, "High s/n-Ratio Electrooptic Prism-Array Light Deflectors," IEEE J. Quantum Electron, vol. QE-10, no. 3, pp. 358-362, March 1974.

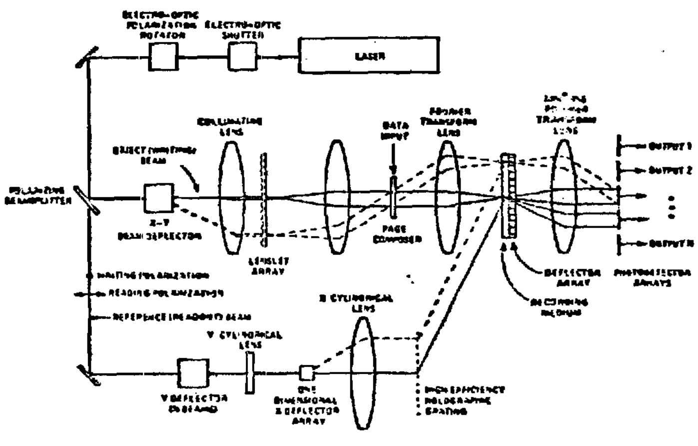

Fig. 1. A multi-port optical memory.

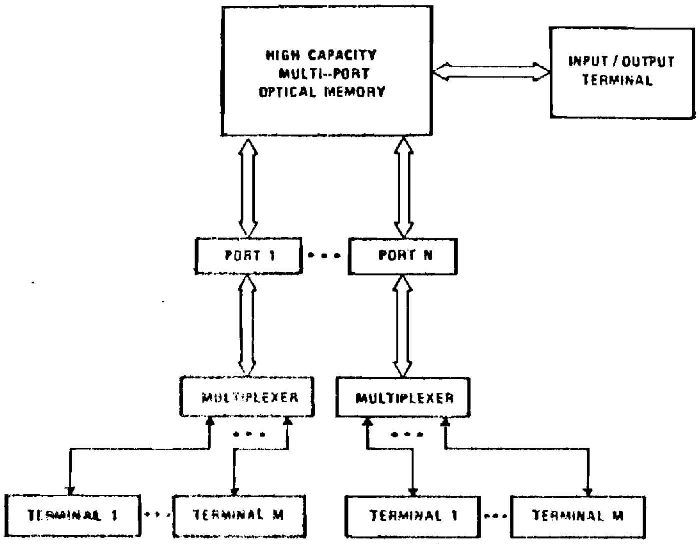

Fig. 2. Computer architecture for a record access system.

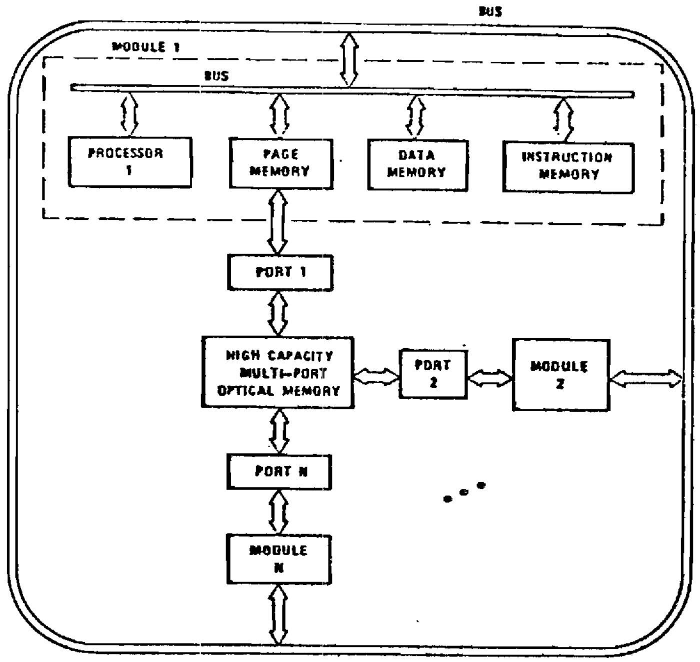

Fig. 4. Computer structure for parallel processing.

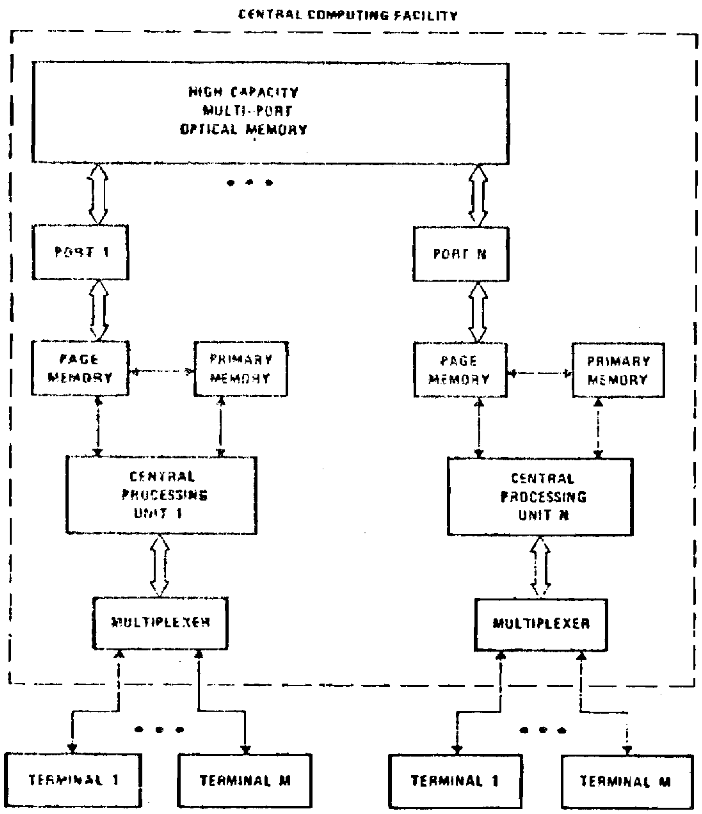

Fig. 3. Simultaneously shared memory computer system.

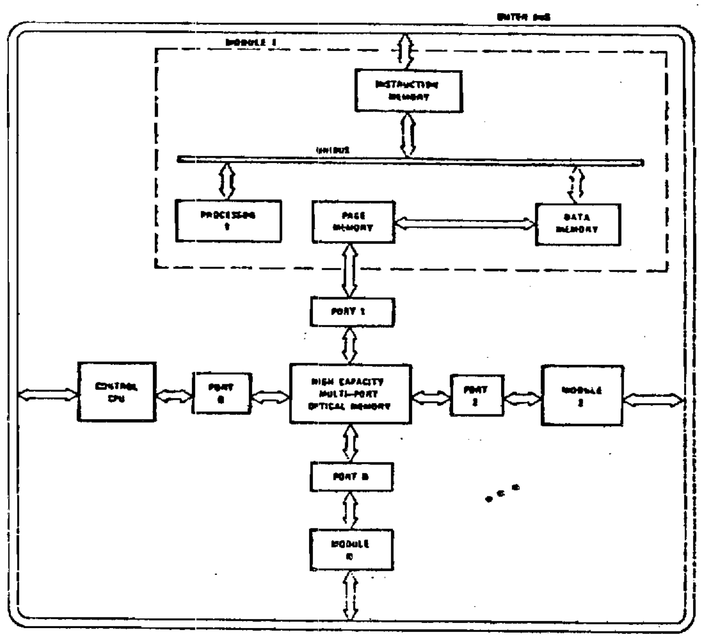

Fig. 5. Synchronized parallel processing computer structure.

E-21-651

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

TELEPHONE: (404) 894-2901

June 7, 1975

Mr. J. H. Kerr
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 3 on Contract NAS8-31193 for the Period 1 May 1975 to 1 June 1975.

Dear Sir:

Activities during the third month of the subject contract included the development of an alternative scanner design using two polygonal mirrors, a small twelve-faced mirror, and a larger six-faced mirror. Both polygonal mirrors would be driven by synchronous motors and voltage controlled oscillators. The primary disadvantage of this approach is the cost of a reliable spinning mirror system and the difficulty in controlling the rotational speed of the mirrors over a large number of scans.

Sources and prices are being extensively investigated for procurement of an acousto-optic deflector. Two types are under consideration. The first type employs a circular beam and small aperture deflecting cell, but the resulting spot is not sharply defined. The second type uses cylindrical optics to expand the beam to increase the effective aperture of the deflecting cell. This type exhibits the highest resolution, but involves longer optical path lengths. The Zenith Optical Systems Group is negotiating the sale of its product line of acousto-optic devices and, contrary to their initial reports, their inventory is unavailable for sale until the transaction is finalized. We are continuing to pursue this vendor, but Datalight and Isomet also are providing quotations to us.

Expenditures and man-hours effort during the first three reporting periods are:

Technical Effort - 138 man-hours	$2,676
Materials and supplies	0
Equipment	2,086
Travel	122
Total Expenditure to Date	$4,884

Next month's activities will include continued effort on design of the system and evaluation of quotations on the acousto-optic deflectors.

The projected expenditures for the remainder of the program are:

Technical Effort	$31,891
Materials and Supplies	9,500
Equipment	2,914
Travel	778
Total Projected Expenditure for Completion of the Program	$45,083

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

E-41-651

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

TELEPHONE: (404) 894-2901

July 7, 1975

Mr. J. H. Kerr
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 4 on Contract NAS8-31193 for the Period 1 June 1975 to 1 July 1975.

Dear Sir:

Activities during the fourth month of the subject contract included initial design of the electronics to interface the video signal with the acoust-optic deflector and the light deflecting galvanometer.

The optical design has been refined to include a 135 mm f/2.8 lens instead of a 200 mm f/2.8 lens. A study of commercially available photographic lenses indicates that the shorter focal length lens is more satisfactory from the standpoint of performance, delivery time, and cost.

The test equipment necessary to develop and test the scanner has been defined. This test equipment includes a dc power supply, a function generator, and a multimeter.

The optical breadboard and mounts have been installed at Georgia Tech. Mounts for the electro-optic modulator and lenses are being completed.

Expenditures and man-hours effort during the first four reporting periods are:

Technical Effort - 207 man-hours	$4,014
Materials and Supplies	45
Equipment	2,337
Travel	122
Total Expenditure to Date	$6,518

Next month's activities will include continued effort on the electronic system design and further evaluation of quotations on the acousto-optic deflector.

The projected expenditures for the remainder of the program are:

Technical Effort	$30,553
Materials and Supplies	9,455
Equipment	2,663
Travel	778
Total Projected Expenditure for Completion of the Program	$43,449

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

TELEPHONE: (404) 894-2901

August 7, 1975

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 5 on Contract NAS8-31193 for the Period 1 July 1975 to 1 August 1975.

Dear Sirs:

Activities during the fifth month of the subject contract included the evaluation of the quotations for the acousto-optic beam deflector. FJW Industries has responded verbally with a price of approximately $6,000 for the model that formerly was the Zenith D150R, with driver. This model would have a ten week delivery time, and no guarantee on linearity. The Isomet deflector is priced at $8,300, and has a resolution of 400 Rayleigh spots. The Datalight device offers 600 spots resolution, defined by the $1/e^2$ point. The driver accepts a 10 bit, binary addressable random access input or an externally triggered linear ramp, which can be varied by an external clock. The spacing variation is less than 3% between adjacent points. The Datalight system is priced at approximately $10,500, for a 60 to 90 day delivery.

The desired linearity of scan can be accomplished by programming a ROM that is sequentially read into a D/A that drives a voltage controlled oscillator. The ROM can be programmed to account for nonlinearities in the voltage controlled oscillator and in the acousto-optic beam deflector.

J. Weaver met with NASA EF-13 personnel on 25 July 1975 to discuss problems and decisions concerning the acousto-optic deflector. Necessary scanning specification changes to include application to liquid crystals were discussed.

Expenditures and man-hours effort during the first five reporting periods are:

Technical Effort - 437 man-hours	$ 8,288
Materials and Supplies	296
Equipment	2,646
Travel	172
Total Expenditure to Date	$11,402

Next month's activities will include design of a feedback system for flat format illumination and further definition of the resolution and response time of the acousto-optic deflector for writing on a liquid crystal.

The projected expenditures for the remainder of the program are:

Technical Effort	$26,279
Materials and Supplies	9,204
Equipment	2,354
Travel	728
Total Project Expenditures for Completion of the Program	$38,565

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ELEPHONE: (404) 894-2901

September 7, 1975

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 6 on Contract NAS8-31193 for the Period 1 August 1975 to 1 September 1975.

Dear Sirs:

Activities during the sixth month of the subject contract included the design of the mounts for the modulator and lenses. The modulator mount has been fabricated.

A detailed study of the literature reporting the performance of acousto-optic deflectors and techniques for deflecting a gaussian beam is being conducted.

Two techniques for obtaining flat format illumination are being considered:

(a) sampling the zeroth order spot intensity; and

(b) using a ROM addressed by the horizontal deflection signal.

Expenditures and man-hours effort during the first six reporting periods are:

Technical Effort - 667 man-hours	$12,562
Materials and Supplies	477
Equipment	4,462
Travel	172
Total Expenditure to Date	$17,673

Next month's activities will include calculation of the resolution necessary to write a specified number of spots on a liquid crystal PROM. Further discussion with Datalight will occur to insure that their deflection system will meet this resolution.

The projected expenditures for the remainder of the program are:

Technical Effort	$22,005
Materials and Supplies	9,023
Equipment	538
Travel	728
Total Projected Expenditure for Completion of the Program	$32,294

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ELEPHONE: (404) 894-2901

October 7, 1975

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 7 on Contract NAS8-31193 for the Period 1 September 1975 to 1 October 1975.

Dear Sirs:

Activities during the seventh month of the subject contract included a study of the writing characteristics of the Hughes liquid crystal page composers. Our study indicates that the laser scanner should be designed more as a general purpose scanner rather than specifically tailored to write at standard television rates on the Hughes device, because of possible difficulties with slow response time and rapid decay of the stored image.

Datalight has been contacted again; further discussion on specifications will be held at the time of order.

J. Weaver visited with EF-13 personnel on 10 September 1975 to discuss both the television rate and the point-by-point modes of operation of the scanner. It was decided that Sperry Rand Corporation will design and fabricate the necessary interface circuitry.

The vertical galvanometer, driver, and other government furnished equipment has been received by Georgia Tech.

Expenditures and man-hours effort during the first seven reporting periods are:

Technical Effort - 897 man-hours	$16,836
Materials and Supplies	1,075
Equipment	4,624
Travel	376
Total Expenditures to Date	$22,911

Next month's activities will include redesign of the lens system based on new specifications for the horizontal deflector (58 mm deflector aperture with a maximum deflection angle of 6.25 milliradians). Methods to obtain a highly linear output plane scan will be studied.

The projected expenditures for the remainder of the program are:

Technical Effort	$17,731
Materials and Supplies	8,425
Equipment	376
Travel	524
Total Projected Expenditure for Completion of the Program	$27,056

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ELEPHONE: (404) 894-2901

December 7, 1975

Mr. J. H. Kerr
Mr. H. F. Smitth
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 9 on Contract NAS8-31193 for the Period 1 November 1975 to 1 December 1975.

Dear Sirs:

Activities during the ninth month of the subject contract included the presentation by W. R. Callen of a paper entitled "A Coherent Light Scanner for Optical Processing of Large Format Transparencies." This paper was presented at the Electro-Optics/International Laser Conference and Exposition in Anaheim, California, November 11-13, 1975. Our work was quite well received and we are responding to numerous inquiries concerning it. A copy of the entire paper will appear in the proceedings of that conference and will be forwarded to you.

Expenditures and man-hours effort during the first nine reporting periods are:

Technical Effort - 1,181 man-hours	$21,658
Materials and Supplies	1,469
Equipment	4,633
Travel	617
Total Expenditure to Date	$28,377

Next month's activities will include a visit by W. R. Callen to MSFC to discuss progress to date and to coordinate present efforts.

The projected expenditures for the remainder of the program are:

Technical Effort	$12,909
Materials and Supplies	8,031
Equipment	367
Travel	283
Total Project Expenditure for Completion of the Program	$21,590

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ELEPHONE: (404) 894-2901

January 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 10 on Contract NAS8-31193 for the Period 1 December 1975 to 1 January 1976.

Dear Sirs:

Activities during the tenth month of the subject contract included the study of the request for quotation from MSFC to modify the existing scanner design to have the capability of random scanning by command from a digital computer at a variable rate. A response to this request is in preparation.

After discussion with both MSFC and Datalight, it was decided to investigate the linearity of scan (spot displacement versus frequency) of the proposed acousto-optic deflector.

Expenditures and man-hours effort during the first ten reporting periods are:

Technical Effort - 1,323 man-hours	$24,070
Materials and Supplies	1,776
Equipment	4,636
Travel	617
Total Expenditure to Date	$31,099

Next month's activities will include a study of the linearity of the beam deflection and focussing system.

The projected expenditures for the remainder of the program are:

Technical Effort	$10,497
Materials and Supplies	7,724
Equipment	364
Travel	283
Total Projected Expenditure for Completion of the Program	$18,868

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

:LEPHONE: (404) 894-2901

February 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 11 on Contract NAS8-31193 for the Period 1 January 1976 to 1 February 1976.

Dear Sirs:

Activities during the eleventh month of the subject contract included a study of the linearity of the beam deflection and focussing system. This includes quantifying (a) deflection angle versus frequency for the first order of the acousto-optic deflector and (b) spot displacement versus deflection angle for the focussing lens. The beam deflector was simulated using a function generator and a light deflecting galvanometer. It was found that no significant deviation from linearity occurred in the spot displacement versus deflection angle relationship.

A response to the request for quotation for modification of the laser scanner design has been forwarded to MSFC.

Expenditures and man-hours effort during the first eleven reporting periods are:

Technical Effort - 1,494 man-hours	$27,517
Materials and Supplies	1,871
Equipment	4,714
Travel	617
Total Expenditure to Date	$34,719

Next month's activities will include fabrication of a circuit to program the ROM (read-only memory) of the acousto-optic beam deflector.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 7,050
Materials and Supplies	7,629
Equipment	286
Travel	283
Total Projected Expenditure for Completion of the Program	$15,248

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

:LEPHONE: (404) 894-2901

March 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 12 on Contract NAS8-31193 for the Period 1 February 1976 to 1 March 1976.

Dear Sirs:

Activities during the twelfth month of the subject contract included the fabrication of a circuit to program fusible ROM's. Several ROM's have been programmed and tested using this circuit. Because of the size of the ROM (approximately 10^4 fusible junctions) required to linearize the acousto-optic beam deflector when used in the digital mode, it has been decided to have the ROM programmed by the vendor.

Expenditures and man-hours effort during the first twelve reporting periods are:

Technical Effort - 1,665 man-hours	$30,964
Materials and Supplies	1,915
Equipment	4,714
Travel	617
Total Expenditure to Date	$38,210

Next month's activities will include modification of the galvanometer used as the vertical deflector in order that it be easily rack mountable.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 3,603
Materials and Supplies	7,585
Equipment	286
Travel	283
Total Projected Expenditure for Completion of the Program	$11,757

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

2 - SP - 837

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ELEPHONE: (404) 894-2901

April 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 13 on Contract NAS8-31193 for the Period 1 March 1976 to 1 April 1976.

Dear Sirs:

Activities during the thirteenth month of the subject contract included the publication of the proceedings of the Electro-Optics/International Laser Conference, in which a paper by our group appears.[1] It is significant to note the large number of papers at this conference that are devoted to optical computing and wideband laser recording. Also published during this month was the report of a simple, effective optics demonstration platform that was developed at Georgia Tech.[2] Both a copy of the conference proceedings and the journal article will be forwarded under separate cover to MSFC.

Expenditures and man-hours effort during the first thirteen reporting periods are:

Technical Effort - 1,836 man-hours	$34,411
Materials and Supplies	1,945
Equipment	4,714
Travel	862
Total Expenditure to Date	$41,932

Next month's activities will include a contract modification to extend the flexibility of the laser scanner.

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[1] W. R. Callen, J. E. Weaver, R. G. Shackelford, and J. R. Walsh, "A Coherent Light Scanner for Optical Processing of Large Format Transparencies," Proceedings of the Electro-Optical Systems Design Conference-1975, Chicago: Industrial and Scientific Conference Management, Inc., November 1975, pp. 487-493.

[2] T. K. Gaylord, J. E. Weaver, and W. R. Callen, "A Mobile, Rigid, Vibration-Isolated Optics Demonstration Platform," American Journal of Physics, vol. 44, no. 3, pp. 310-311, March 1976.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 156
Materials and Supplies	7,555
Equipment	286
Travel	38
Total Projected Expenditure for Completion of the Program	$8,035

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

E-21-601

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ELEPHONE: (404) 894-2901

May 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 14 on Contract NAS8-31193 for the Period 1 April 1976 to 1 May 1976.

Dear Sirs:

Activities during the fourteenth month of the subject contract included the formal contract modification to provide that the laser scanner have the capability of random scanning by command from a digital computer at a variable rate. This contract modification is reflected in the budget figures listed below.

On April 29, W. R. Callen presented an invited lecture, "Optical Scanning and Processing Techniques," to a joint meeting of the Institute for Electrical and Electronics Engineers and five other professional societies (American Society of Mechanical Engineers, Florida Engineering Society, Society of American Military Engineers, Panama City Scientific Society, and Society of Naval Architects and Marine Engineers) at Panama City, Florida.

Expenditures and man-hours effort during the first fourteen reporting periods are:

Technical Effort - 1,864 man-hours	$34,691
Materials and Supplies	1,964
Equipment	4,714
Travel	900
Total Expenditure to Date	$42,269

Next month's activities will include design efforts to accommodate the contract modification.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 3,154
Materials and Supplies	13,236
Equipment	286
Travel	0
Total Projected Expenditure for Completion of the Program	$16,676

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:gc

cc: J. Weaver

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ELEPHONE: (404) 894-2901

June 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 15 on Contract NAS8-31193 for the Period 1 May 1976 to 1 June 1976.

Dear Sirs:

Activities during the fifteenth month of the subject contract included the publication of a paper describing the development of a laser course at Georgia Tech.[1] Although this course development was not a direct part of the funded research on this Contract, it illustrates the symbiotic relationship between sponsored research and university programs.

Datalight Corporation, one potential vendor, has been contacted concerning the deflector necessary to satisfy the modified contract. We are awaiting their response.

Expenditures and man-hours effort during the first fifteen reporting periods are:

Technical Effort - 1,892 man-hours	$34,971
Materials and Supplies	2,072
Equipment	4,714
Travel	900
Total Expenditure to Date	$42,657

Next month's activities will include further effort on development of the laser scanner.

[1] D. C. O'Shea, W. R. Callen, and W. T. Rhodes, "Course on Lasers for Undergraduate Students," American Journal of Physics, vol. 44, no. 5, pp. 417-420, May 1976.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 2,874
Materials and Supplies	13,128
Equipment	286
Travel	0
Total Projected Expenditure for Completion of the Program	$16,288

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:km

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

TELEPHONE: (404) 894-2901

July 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 16 on Contract NAS8-31193 for the Period 1 June 1976 to 1 July 1976.

Dear Sirs:

Activities during the sixteenth month of the subject contract included discussions with vendors to determine the feasibility of purchase of a suitable deflector for the laser scanning system. One initial response (Datalight Corporation) was based on an acoustic cell of dense flint glass with an optical aperture of 120 mm. We feel that this type of system is undesirable because of the large and expensive optical components required. The acoustic transit time for this cell is approximately 32 μsec, which would produce a large spot when the system is operated at video rates. Alternate approaches are under investigation.

Expenditures and man-hours effort during the first sixteen reporting periods are:

Technical Effort - 1,920 man-hours	$35,251
Materials and Supplies	2,362
Equipment	4,715
Travel	900
Total Expenditure to Date	$43,228

Next month's activities will include further effort on procurement of the deflector for the scanning system.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 2,594
Materials and Supplies	12,838
Equipment	285
Travel	0
Total Projected Expenditure for Completion of the Program	$15,717

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:kam

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ELEPHONE: (404) 894-2901

August 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 17 on Contract NAS8-31193 for the Period 1 July 1976 to 1 August 1976.

Dear Sirs:

Activities during the seventeenth month of the subject contract included further discussions with Datalight Corporation concerning the procurement of a deflector for the laser scanning system. Two possible systems were proposed: (1) The first system, fabricated with flint glass, would operate at a 32 MHz center frequency and have a time-bandwidth product of 697. This system would exhibit high diffraction efficiency (60-70%) and a flat response versus angle characteristic. The cell thickness would be 12 mm and would require 75 mm optics. This system exhibits a fairly long acoustic transit time of 19.7 μsec. (2) The second system, fabricated with fused quartz, would operate at a 135 mHz center frequency and have a time-bandwidth product of 757. This system typically exhibits a diffraction efficiency of 30-40%, with a $\pm$1.5 db variation over the scan range. The cell thickness would be less than 10 mm and would require 50 mm optics. The acoustic transit time of this system is approximately 8.4 μsec.

The price estimate for each system is approximately equal. Georgia Tech will furnish the optics because of delivery time and mounting specifications.

Expenditures and man-hours effort during the first seventeen reporting periods are:

Technical Effort - 1,986 man-hours	$36,060
Materials and Supplies	2,367
Equipment	4,716
Travel	900
Total Expenditure to Date	$44,043

Mr. J. H. Kerr
Mr. H. F. Smith
Contract NAS8-31193

7 August 1976

Next month's activities will include submission of requests for final bids for the deflector system.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 1,785
Materials and Supplies	12,833
Equipment	284
Travel	0
Total Projected Expenditure for Completion of the Program	$14,902

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:kam

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ELEPHONE: (404) 894-2901

September 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 18 on Contract NAS8-31193 for the Period 1 August 1976 to 1 September 1976.

Dear Sirs:

Activities during the eighteenth month of the subject contract included the sending of requests for bids on the acousto-optic beam deflector to at least three potential vendors. Because a maximum aperture width of 50 mm was specified for the acousto-optic beam deflector, Georgia Tech was able to order the necessary cylindrical lenses to illuminate the deflector aperture and to refocus the output to a small spot. Mirrors specified to be flat to within $\lambda/4$ per inch, along with the proper mounts, have been ordered for the moving coil galvanometers.

Expenditures and man-hours effort during the first eighteen reporting periods are:

Technical Effort - 2,052 man-hours	$36,869
Materials and Supplies	11,100
Equipment	5,000
Travel	900
Total Expenditure to Date	$53,869

Next month's activities will include review and selection of the acousto-optic beam deflector bids and design of the cylindrical optics mounts.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 976
Materials and Supplies	4,100
Equipment	0
Travel	0
Total Projected Expenditure for Completion of the Program	$5,076

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:kkm

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

LEPHONE: (404) 894-2901

October 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 19 on Contract NAS8-31193 for the Period 1 September 1976 to 1 October 1976

Dear Sirs:

Activities during the nineteenth month of the subject contract included the return of bids on the acousto-optic beam deflector. Two companies, Datalight, Inc. and Coherent Associates did not choose to submit bids. Isomet Corporation did return a bid for an acousto-optic deflector based on a TeO_2 crystal. This deflector is the Isomet model LD-401-2x acousto-optic deflector modified by an enlarged crystal to meet a time-bandwidth product of greater than 750. The accompanying driver is the Isomet model D101-2, which has a maximum deviation from a linear voltage-angle relationship of less than .25% of the full angular swing. The Isomet deflector has the advantage that high resolution is obtained with simple spherical optics. One disadvantage is that it exhibits an elliptically polarized output beam. This response is being carefully considered to determine its feasibility.

Expenditures and man-hours effort during the first nineteen reporting periods are:

Technical Effort - 2,080 man-hours	$37,149
Materials and Supplies	11,411
Equipment	5,000
Travel	900
Total Expenditure to Date	$54,460

Next month's activities will include detailed evaluation of the Isomet bid.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 696
Materials and Supplies	3,789
Equipment	0
Travel	0
Total Projected Expenditures for Completion of the Program	$4,485

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabriaction of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:kkm

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

.EPHONE: (404) 894-2901

November 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 20 on Contract NAS8-31193 for the Period 1 October 1976 to 1 November 1976

Dear Sirs:

Activities during the twentieth month of the subject contract included the selection of Isomet Corporation as the vendor for the acousto-optic beam deflector, an integral part of the scanner. The selection of the Isomet system will result in a more straightforward design that does not involve the use of cylindrical optics, a feature required by some of the other systems considered.

Expenditures and man-hours effort during the first twenty reporting periods are:

Technical Effort - 2,108 man-hours	$37,429
Materials and Supplies	11,432
Equipment	5,000
Travel	900
Total Expenditures to Date	$54,761

Next month's activities will include an examination of the electrooptic modulation system.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 416
Materials and Supplies	3,768
Equipment	0
Travel	0
Total Projected Expenditure for Completion of the Program	$4,184

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:kkm

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

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December 7, 1976

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 21 on Contract NAS8-31193 for the Period 1 November 1976 to 1 December 1976.

Dear Sirs:

Activities during the twenty-first month of the subject contract included a simulation of the scanner optical system using light deflecting galvanometers to verify the original design concept. The result of the simulation is that it is not possible to focus the beam onto the deflection mirror and to achieve raster scan of a focused spot. This difficulty can be corrected by repositioning one of the lenses. The result is in agreement with our further analysis of the system.

Expenditures and man-hours effort during the first twenty-one reporting periods are:

Technical Effort - 2,122 man-hours	$37,569
Materials and Supplies	11,443
Equipment	5,000
Travel	900
Total Expenditures to Date	$54,912

Next month's activities will include further examination of the electrooptic modulation system.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 276
Materials and Supplies	3,757
Equipment	0
Travel	0
Total Projected Expenditure for Completion of the Program	$4,033

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:da

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

.EPHONE: (404) 894-2901

January 7, 1977

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 22 on Contract NAS8-31193 for the Period 1 December 1976 to 1 January 1977.

Dear Sirs:

Activities during the twenty-second month of the subject contract included an examination of the electrooptic modulation system that was originally sent to us from MSFC for incorporation into the laser scanning system. The modulation system qualitatively appears to be in good working order, except that it has been necessary to order a special purpose cable that was not included with the modulator.

Expenditures and man-hours effort during the first twenty-two reporting periods are:

Technical Effort - 2,136 man-hours	\$37,709
Materials and Supplies	11,452
Equipment	5,000
Travel	900
Total Expenditure to Date	\$55,061

Next month's activity will include procurement of the cable for the modulation system and further testing.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 136
Materials and Supplies	3,748
Equipment	0
Travel	0
Total Projected Expenditure for Completion of the Program	$3,884

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:da

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

EPHONE: (404) 894-2901

February 7, 1977

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 23 on Contract NAS8-31193 for the Period 1 January 1977 to 1 February 1977

Dear Sirs:

Activities during the twenty-third month of the subject contract included the ordering of the special purpose cable to interconnect the modulator and driver. The required cable is a Twinax, 124 ohm, balanced line with PL-75 connectors. Due to questions involving the optical design of the scanning system, the scanner is being simulated using currently available light deflecting galvanometers.

Expenditures and man-hours effort during the first twenty-three reporting periods are:

Technical Effort - 2,140 man-hours	$37,749
Materials and Supplies	11,720
Equipment	5,000
Travel	900
Total Expenditure to Date	$55,369

Next month's activity will include further simulation of the optical scanner.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 96
Materials and Supplies	3,480
Equipment	0
Travel	0
Total Projected Expenditure for Completion of the Program	$3,576

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:kkm

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

EPHONE: (404) 894-2901

March 7, 1977

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser for 35 mm Film"

Subject: Monthly Letter Report No. 24 on Contract NAS8-31193 for the Period 1 February 1977 to 1 March 1977

Dear Sirs:

Activities during the twenty-fourth month of the subject contract included further study of the optical scanner by simulating the acousto-optic beam deflection system with a light-deflecting galvanometer system. It was found that focussing the laser beam on the galvanometer axis and reimagining the focussed spot with a single lens does not result in a scanning beam, as is apparent from analyzing the geometrical optics of the situation. Hence, the required scanning of a focussed spot will be implemented by placing a galvanometer directly in the output beam of the acousto-optic beam deflector, with a lens at the output of the deflector pair.

Expenditures and man-hours effort during the first twenty-four reporting periods are:

Technical Effort - 2,144 man-hours	$37,789
Materials and Supplies	11,903
Equipment	5,000
Travel	900
Total Expenditures to Date	$55,592

Next month's activity will include receipt of the acousto-optic beam deflector by Georgia Tech and modulator testing.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 56
Materials and Supplies	3,297
Equipment	0
Travel	0
Total Projected Expenditures for Completion of the Program	$3,353

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:kkm

cc: J. Weaver

E-21-657

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

EPHONE: (404) 894-2901

April 7, 1977

Mr. J. H. Kerr
Mr. H. F. Smith
EF-13
NASA/Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Title: "A Laser Scanner for 35 mm Film"

Subject: Monthly Letter Report No. 25 on Contract NAS8-31193 for the Period 1 March 1977 to 1 April 1977.

Dear Sirs:

Activities during the twenty-fifth month of the subject contract included the receipt of the acousto-optic beam deflection system by Georgia Tech from Isomet Corporation. The deflector has been initially examined and tested in both the manual and the sweep modes of operation. When operated in the sweep mode, the minimum duration of the sweep scan was found to be approximately 80 microseconds. A circuit is being developed to generate a 500 by 500 dot pattern to test the scanner resolution. Initial observations indicate that the lens at the output of the acousto-optic deflector must have a relatively long focal length (approximately 300 mm) to generate a final 2.5 cm x 2.5 cm scanned area.

Expenditures and man-hours effort during the first twenty-five reporting periods are:

Technical Effort - 2,150 man hours	$37,845
Materials and Supplies	12,910
Equipment	5,000
Travel	900
Total Expenditures to Date	$56,655

Next month's activity will include completion of the scanning system and preparation of the final report.

The projected expenditures for the remainder of the program are:

Technical Effort	$ 0
Materials and Supplies	2,290
Equipment	0
Travel	0
Total Projected Expenditures for Completion of the Program	$2,290

New Technology Statement

A thorough review was conducted during the reporting period by the technical staff assigned to Contract NAS8-31193 to determine if any reportable items of new technology as defined in NASA Form 1162 resulted from the above described technical efforts. The engineering techniques applied to fabrication of the laser scanner were carefully reviewed, and no reportable items of new technology were uncovered.

Respectfully submitted,

W. R. Callen
T. K. Gaylord
Project Directors

WRC/TKG:kkm

cc: J. Weaver

CONTRACT NAS8–31193

A LASER SCANNER FOR 35mm FILM

W. R. Callen and J. E. Weaver
School of Electrical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

April 1977

FINAL REPORT FOR PERIOD 25 FEBRUARY 1975–24 APRIL 1977

Performed for:

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

SCHOOL OF ELECTRICAL ENGINEERING
Georgia Institute of Technology
Atlanta, Georgia 30332

FINAL REPORT

PROJECT NO. E-21-657

A LASER SCANNER FOR 35 mm FILM

by

W. R. Callen and J. E. Weaver

RESEARCH CONTRACT NAS8-31193

25 February 1975 to 24 April 1977

Performed for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

ABSTRACT

This report describes the design, construction, and testing of a laser scanning system that was delivered to Marshall Space Flight Center. The scanner is designed to deliver a scanned beam over a 2.54 cm by 2.54 cm or a 5.08 cm by 5.08 cm format. In order to achieve a scan resolution and rate comparable to that of standard television, an acousto-optic deflector is used for one axis of the scan, and a light deflecting galvanometer is used for deflection along the other axis. The acousto-optic deflector has the capability of random access scan controlled by a digital computer.

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LIST OF FIGURES

I. INTRODUCTION

For experiments involving the processing of data stored as a two-dimensional scene, optical techniques are frequently convenient. The use of holographic techniques applied to nonlinear media has greatly expanded the potential for three dimensional high capacity optically based mass memories. The development of optical integrated circuits and miniature lasers and modulators has brought optical systems much closer to the realities of day-to-day existence.

Most laser systems used in the analysis of data or in the implementation of logical operations require some type of scanning system. In addition, many commercial systems, such as television displays, employ laser scanning systems [1-3].

Georgia Tech previously developed a laser scanning system useful in optical processing systems [4,5]. That scanner had two principal features:

1. The scanned beam was random access addressable, and was perpendicular to the image page.
2. The intensity of the scanned beam was controllable, such that constant light intensity could be maintained after passage through the image plane.

Because the above described scanner was optimized for optical processing applications, which require a non-focussed beam of high coherence, it employed a pair of light deflecting galvanometers coupled by a relay mirror. The galvanometers were placed at the focus of a large diameter parabolic mirror. This system is described in Chapter IV of this report.

The scanning system developed under this contract was designed to provide a scanned focussed beam over a 2.54 cm by 2.54 cm format, or over a 5.08 cm by 5.08 cm format, with a resolution and rate comparable to that of standard television. As with most scanning systems, there is a trade-off between scanning rate and system resolution, within any given economic constraint. The result of this trade-off, as described in Chapter III of this report, is that a resolution equal to that of standard television was achieved, with a slightly lower scan rate than that of standard television. However, a higher scan rate can be achieved by reducing the scanned format. This type of scanner could be potentially useful as a flying spot scanner for video display of transparencies.

II. OPTICAL SYSTEM DESIGN

A. Overall Approach

A schematic diagram of the optical scanning system is shown in Figure 1. The laser output is controlled in irradiance by a Pockel's effect modulator. After the modulator, the beam passes through beam forming optics that tailor the shape of the beam for acceptance by the acousto-optic modulator, which provides one dimension of the scan. The other dimension of the scan is provided by a large light deflecting galvanometer. The resultant scanning beam is focussed by a lens onto the scan plane.

B. Laser Selection

Because of the increased sensitivity of film, nonlinear crystals and other recording media to light in the blue and green portion of the spectrum compared to that for light in the red portion of the spectrum, an argon laser is chosen as the design standard. The argon laser is the only commercially available laser capable of high power (greater than one watt), continuous-wave output in the blue or green region of the spectrum. In particular, our system is optimized for operation at 514.5 nm, one of the stronger output lines of the argon laser.

C. Light Deflection System

1. Introduction

The choice of light deflection systems for the laser scanner is principally influenced by the design goal of achieving a scan rate and resolution comparable to that of standard television. The scan of a

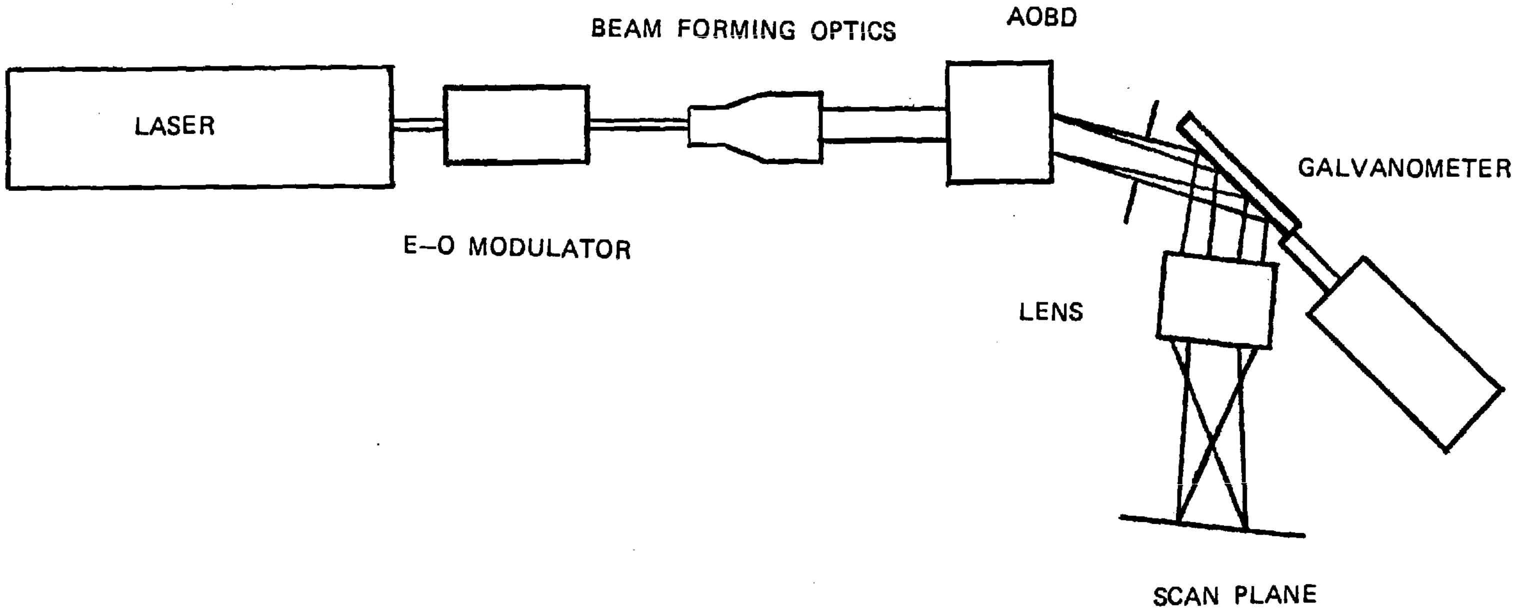


FIGURE 1. SCHEMATIC DIAGRAM OF LASER SCANNER

standard television operates at a rate of 525 lines per frame, with 30 frames per second, for 1.58×10^4 lines per second, which corresponds to a writing time of one line of 6.35×10^{-5} seconds. The required response time of the deflector is determined by this scan time of approximately 60 microseconds. The required detector bandwidth then is approximately the inverse of this, or 16 kilohertz. Standard television has approximately 600 resolvable spots.

Several types of scanning mechanisms can be considered for design of the scanner: (1) galvanometer (electromechanical) deflectors, (2) acoustooptic deflectors, and (3) electrooptic deflectors. For each type of deflector there are trade-offs with regard to resolution, access time, and cost. Among the three types, galvanometer deflectors offer high resolution and relatively slow access time for moderate cost, while electrooptic deflectors offer fast access time, but exhibit relatively poor resolution and are relatively expensive. Acoustooptic deflectors are an intermediate choice with regard to all three qualities at present. In general, galvanometer-based deflection systems are preferable because of ease of alignment, lack of beam distortion, and cost [6].

2. Acoustooptic Deflector

Since the performance of our system is based largely on that of the acoustooptic deflector, we review here some of the principal mechanisms underlying the operation of such a deflector. When a sound wave moves through a medium, a density variation and a corresponding variation in the index of refraction is produced [7]. This varying index of refraction acts as a series of "moving mirrors" inside the material. The moving mirrors are separated by a distance equal to the wavelength of the sound in the medium. The plane of each mirror is perpendicular to the direction of the sound wave. For efficient diffraction of light from the moving mirrors to occur, two conditions must be met: (1) reflected light from any given portion of a mirror must add in phase with light reflected from a different portion of the mirror, and (2) reflections from two different mirrors (acoustic wave fronts) must add in phase. The first condition implies that the angle of incidence of the optical wave relative to the acoustic phase fronts must equal the angle of reflection. The second condition requires that the Bragg condition must be satisfied:

$$2\lambda_S \sin\theta = \lambda/n \quad , \tag{1}$$

where λ_S is the wavelength of the sound within the medium, θ is the angle of incidence within the crystal of the light beam with respect to the acoustic wavefronts, and λ/n is the free space wavelength of the light; the crystal has refractive index n. The geometry is shown in Figure 2.

The Bragg condition for light diffraction may be viewed as the annihilation of one photon representing the incident light wave and one photon representing the acoustic wave and the simultaneous creation of a new photon representing the diffracted wave. This is shown in Figure 3, where $\vec{\kappa}_i$, $\vec{\kappa}_s$, and $\vec{\kappa}_d$ represent the wave vectors of the incident light wave, the sound wave, and the diffracted light wave, respectively. Since $\omega_D = \omega_i + \omega_s \approx \omega_i$ and $\kappa_D \approx \kappa_i = K$, we therefore have that

$$\kappa_s = 2K\sin\theta, \quad \text{or} \tag{2}$$

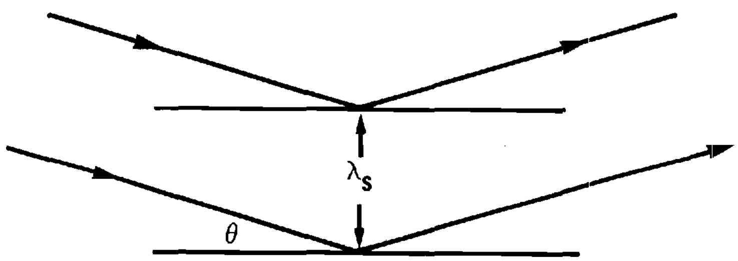


FIGURE 2. GEOMETRY OF BRAGG SCATTERING BY ACOUSTIC WAVEFRONTS, SPACED A DISTANCE λ_s APART.

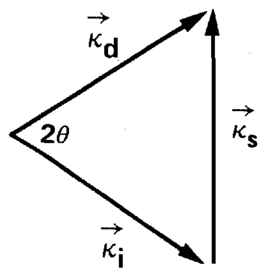


FIGURE 3. PHOTON PICTURE FOR BRAGG SCATTERING. THE INCIDENT LIGHT WAVE IS REPRESENTED BY $\vec{\kappa}_i$, THE DIFFRACTED WAVE BY $\vec{\kappa}_d$ AND THE ACOUSTIC WAVE BY $\vec{\kappa}_s$

$$2\lambda_s \sin\theta = \lambda/n \quad , \tag{3}$$

the Bragg condition stated earlier.

From the foregoing discussion, we see that for a given wavelength of light and frequency of the sound wave, there is a unique angle of incidence and diffraction. To achieve light deflection over an angular range, we select a sound frequency that corresponds to a deflection angle in the middle of the angular spread desired, and then adjust the incoming light beam to the corresponding angle of incidence. By then varying the sound frequency, a range of deflected angles is achieved. The change in the angle of diffraction is related to the change in frequency of the sound wave by [7]

$$\Delta\theta = \frac{\lambda \Delta\nu_s}{n v_s} \quad . \tag{4}$$

The number of resolvable spots N is equal to the ratio of $\Delta\theta$, the maximum deflection angle, to the full angle of the beam divergence, θ_d. The beam divergence θ_d is approximately λ/nD, where D is the beam diameter, so we have

$$N = \frac{\Delta\theta}{\theta_d} = \frac{\lambda \Delta\nu_s nD}{n v_s \lambda} = \Delta\nu_s \left(\frac{D}{v_s}\right) \quad , \tag{5}$$

or

$$N = \Delta\nu_s \tau \quad , \tag{6}$$

where τ is the time required for a sound wave to propagate across the diameter of the optical beam. This time-bandwidth product is a frequent specification of an acousto-optic deflector and gives a specification that is independent of the criterion used for a resolvable spot.

Usually for a light deflection system, we are interested not only in the angle of the reflected light, but in the amount of reflected light. From a consideration of nonlinear coupled wave equations describing the interaction of light and sound in the medium, it can be shown that the ratio of diffracted irradiance to incident irradiance is

$$\frac{I_{diff}}{I_{in}} = \sin^2 \frac{\pi \ell}{\sqrt{2}\lambda} \sqrt{M\ I_{acoustic}}\ , \tag{7}$$

where $I_{acoustic}$ is the intensity of the acoustic wave, ℓ is the interaction length, and M is a diffraction figure of merit. M is given by

$$M = \frac{n^6 p^2}{\rho v_s^3}\ , \tag{8}$$

where n is the refractive index, v_s the velocity of sound, ρ the mass density of the material, and p is the photoelastic constant. The value of M of tellerium dioxide (TeO_2), the material used in our deflector, relative to that of water is five.

Two principal sources of error in acoustooptic deflectors are (1) misadjustment of the Bragg angle, and (2) the deflector alignment is not correct over the entire angular range because of the varying frequencies that must be used. The first source of error is generally not significant. For example, a Bragg angle error on the order of 12% produces only approximately a 5% reduction in intensity of the diffracted beam [8]. An interesting aspect of the second source of error is that a given percentage deviation in frequency above the center frequency causes a larger roll-off in intensity of the diffracted beam than does the same percentage deviation in frequency below the center frequency. The deflector can be made to exhibit equal intensity roll-off in both directions by aligning the beams at the Bragg angle at a frequency slightly higher than the center frequency.

3. Description and Specification of Acousto-Optic Beam Deflector

The specifications used in the purchase of the acousto-optic beam deflector are shown in Figure 4. The system can be operated in four distinct modes: manual, external input, sweep, and digital. The manual mode is operated by a ten turn potentiometer mounted on the driver. This potentiometer can vary the output frequency of the driver by approximately ±250 KHz. The manual mode of operation yields a stationary deflected beam whose position can be varied by turning the potentiometer. The external input is operated by applying a voltage between zero and -8 volts, which in turn varies the RF output frequency. By applying a ramp or sawtooth external input from a function generator, scanning can be achieved. In the sweep mode, the driver automatically scans through a frequency range with the application of an external trigger pulse. The range of the frequency scan is determined by two potentiometers located on the front panel of the driver.

The digital mode requires a 12 bit digital input, with the first bit the most significant bit and the twelfth bit the least significant bit. A digital input of all zeroes corresponds to a driver output

SPECIFICATIONS - ACOUSTO-OPTIC BEAM DEFLECTOR

Deflector	
Aperture	50 mm maximum
Laser input	514.5 nm, less than 1 watt
Time-bandwidth product	Greater than 750
Deflection efficiency	Greater than 30%; less than 3 db variation over full swing of deflected beam
Driver	
Positioning modes	Manual - from panel front
	Analog - 0 to 5 volt full swing input. Deflection angle must be linear with input voltage; the maximum deviation from a linear voltage-angle relationship must be less than .025% of the full angular swing.
	Digital input - 9 bit TTL parallel addressing for 512 uniformly separated angular positions. (Less than 1 spot to spot center spacing variation.)
	Clock input - for stair step scan.
Maximum input power	120 vac, 15 amps, 1ϕ
Mechanical	
	Deflector and driver must be separate units. Driver must be rack mountable. Deflector must have provisions (tapped holes) for mounting.

FIGURE 4. SPECIFICATIONS FOR ACOUSTO-OPTIC BEAM DEFLECTOR.

frequency of 62.72 MHz, while an input of all ones corresponds to a driver output frequency of 131.16 MHz. The entire digital input-output table is included in Chapter III, System Evaluation.

The detailed operating manuals that accompany the acousto-optic deflector and driver are included under separate cover [9,10].

4. Galvanometer Deflector

In order to achieve a scan rate comparable to standard television, the horizontal deflector must be able to scan at a rate such that 30 frames per second are displayed. One of the fastest and cheapest electromechanical systems is that of a light deflecting galvanometer. The galvanometer acts as a driven angular oscillator with a driving term proportional to the current. The result for a critically damped galvanometer is that, within the range of application, a deflection angle proportional to current is obtained. To obtain a full scan in 1/30 (.03) of a second, the galvanometer must be able to swing twice its full deflection angle in 1/30 second. The galvanometer chosen for our system is the General Scanning Model 320 PD, which is capable of a 20° mechanical rotation, peak-to-peak. This model has a resonant frequency of 165 Hz, and can be driven sinusoidally at up to 85% of its frequency, or 140 Hz, which corresponds to a period of .007 seconds, well within the .03 second scan requirement [11-13].

D. Modulator

In order to achieve a beam pattern that has intensity variation, a modulator must be employed. In order to be able to write 500 resolvable spots in each dimension at standard television rates, the modulator must be able to respond to a signal whose period is equal to the active write time of standard television divided by 250 (500 resolvable spots corresponds to 250 full cycles), or $T = 56 \times 10^{-6}$ sec/250 = 2.24×10^{-7} sec. This corresponds to a bandwidth requirement of 4.46 MHz. The only modulator available for use in our system is the Coherent Associates Model 3003 Modulation System, which has a bandwidth of 3 MHz, and therefore provides the limiting factor in our system [14].

E. Scanner Controller

The driver for the acoustooptic beam deflector may be controlled by a microcomputer system. The KIM-1 microcomputer system, from MOS Technology, Inc. is included with the laser scanner.

F. Focussing System Alignment

In order to fill the aperture of the acousto-optic beam deflector, the laser beam is expanded and collimated by a pair of lenses whose focal lengths are in the ratio $\frac{200\text{ mm}}{3\text{ mm}}$. The light deflecting galvanometer is placed almost as close as possible to the output aperture of the acousto-optic beam deflector. This eliminates the need for any relaying optics, and the resultant beam behaves as if it were a collimated beam emanating from a single two-axis deflector. A focussed raster scan is obtained by placing a lens at the output of the deflector pair. The format size d is related to the full angle beam divergence θ as shown in Figure 5, by

$$d = 2f \tan \theta/2 \quad , \tag{9}$$

which for small angles reduces to

$$d = f\theta \quad . \tag{10}$$

For a square scan format, each deflector should swing through the same angle, and a cylindrically symmetric lens can be used.

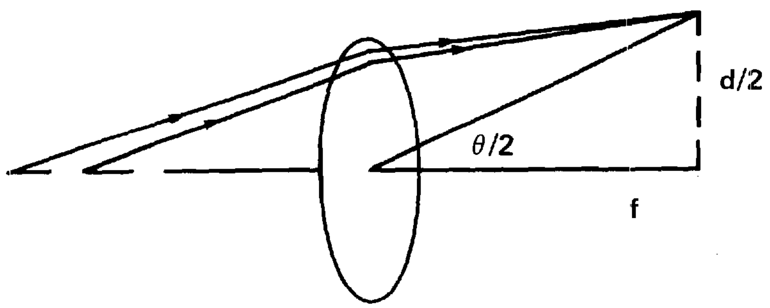


FIGURE 5. FORMATION OF THE FOCUSSED SCAN BY A LENS. THE DEFLECTOR ANGLE HAS A FULL ANGLE OF DEFLECTION OF θ AND FORMS A PATTERN OF SIDE d IN LENGTH.

III. SYSTEM EVALUATION

The system was aligned as discussed in Chapter III, Section 8, and a lens was employed to obtain a focussed format. A picture of the experimental arrangement is shown in Figure 6.

The focussing lens had a focal length of 500 mm and each deflector operated through a full angular swing of approximately .06 radians. From Equation 10, the resultant format size is approximately $d = .06(500) =$ 30 mm.

The system was operated in the manual, sweep, and external input modes of operation. Square raster patterns were obtained in both the sweep and external input modes of operation. The pattern obtained in the sweep mode when the galvanometer operated at a rate of 24 Hz and the acousto-optic beam deflector at a rate of 11.43 KHz is shown in Figure 7. In the sweep mode, the acousto-optic beam deflector seemed to exhibit nonlinearities around 12 KHz. In the external input mode, however, a square raster pattern of approximately even irradiance was obtained using a ramp function of frequency 15.775 KHz, approximately the rate of standard television. In the external input mode, the upper frequency limit of operation before nonlinearities in the pattern appeared was about 16 KHz. Detailed data sheets from the manufacturer are shown on the next four pages.

ISOMET	TEST DATA SHEET	ACOUSTO-OPTIC DRIVER	
TEST PROCEDURE NO.	SOURCE CONTROL DRAWING	MODEL NO. D 101-2	SERIAL NO. 1420
CODE IDENT NO. 07720	CUSTOMER P.O. NO.	TESTED BY	DATE 8 MAR 77

MANUAL TUNE MODE

Manual Tune Potentiometer	Driver Output Frequency	Driver Output Power (Max.)
000	62.85 MHz	2.8 W
100	70.32 MHz	3.0 W
200	77.26 MHz	3.1 W
300	83.93 MHz	3.1 W
400	90.69 MHz	3.0 W
500	97.38 MHz	2.9 W
600	103.96 MHz	3.0 W
700	110.62 MHz	3.2 W
800	117.10 MHz	3.4 W
900	124.08 MHz	3.4 W
000	131.33 MHz	3.2 W

EXTERNAL INPUT MODE

Ext Input Voltage	Driver Output Frequency	Driver Output Power (Max.)
0.00 volts	62.67 MHz	3.0 W
-1.00 volts	75.733 MHz	3.1 W
-2.00 volts	88.243 MHz	3.2 W
-3.00 volts	100.474 MHz	3.3 W
-4.00 volts	112.766 MHz	3.5 W
-5.00 volts	125.465 MHz	3.4 W
-6.00 volts	MHz	
-7.00 volts	MHz	
-8.00 volts	MHz	
-9.00 volts	MHz	
-10.00 volts	MHz	

AUTO SCAN MODE

Lower Freq. Limit 63.67 MHz – 87.96 MHz
Upper Freq. Limit 84.83 MHz – 131.15 MHz
Sweep Output 0 Volts to -5.4 volts Max.

Operator Notes:

All test data taken after a one (1) hour warm up period.

CSI APPROVAL	DATE	ISOMET QC APPROVAL QCE	DATE 3-25-77	PAGE OF

ISOMET	TEST DATA SHEET	ACOUSTO-OPTIC DRIVER	
TEST PROCEDURE NO.	SOURCE CONTROL DRAWING	MODEL NO. D101-2	SERIAL NO. 1120
CODE IDENT NO. 07720	CUSTOMER P.O. NO.	TESTED BY OO	DATE 3/7/77

TEST DATA - DIGITAL OPTION

(1MSB,) (12LSB)

DIGITAL INPUT 1	2	3	4	5	6	7	8	9	10	11	12	OUTPUT FREQUENCY MHz	DRIVER OUTPUT PWR (WATTS)
0	0	0	0	0	0	0	0	0	0	0	0	62.72	3.0W
0	0	0	0	0	0	0	0	0	0	0	1	62.73	3.0W
0	0	0	0	0	0	0	0	0	0	1	1	62.76	3.0W
0	0	0	0	0	0	0	0	0	1	1	1	62.83	3.0W
0	0	0	0	0	0	0	0	1	1	1	1	62.96	3.0W
0	0	0	0	0	0	0	1	1	1	1	1	63.25	3.0W
0	0	0	0	0	0	1	1	1	1	1	1	63.81	3.0W
0	0	0	0	0	1	1	1	1	1	1	1	64.94	3.1W
0	0	0	0	1	1	1	1	1	1	1	1	67.19	3.2W
0	0	0	1	1	1	1	1	1	1	1	1	71.62	3.2W
0	0	1	1	1	1	1	1	1	1	1	1	80.26	3.2W
0	1	1	1	1	1	1	1	1	1	1	1	96.99	3.0W
1	1	1	1	1	1	1	1	1	1	1	1	131.16	3.3W

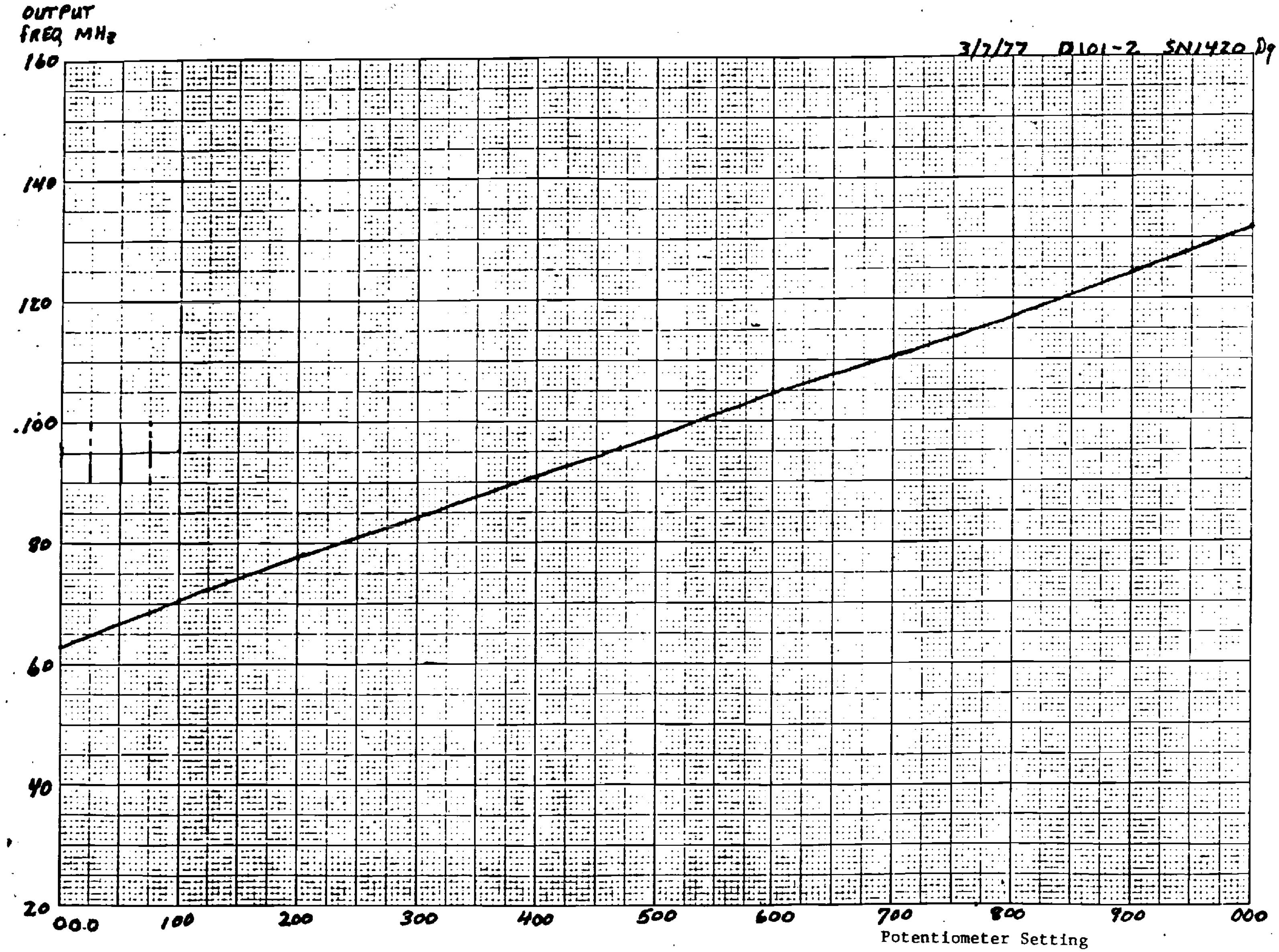
ANALOG V ALL 1S -5.41

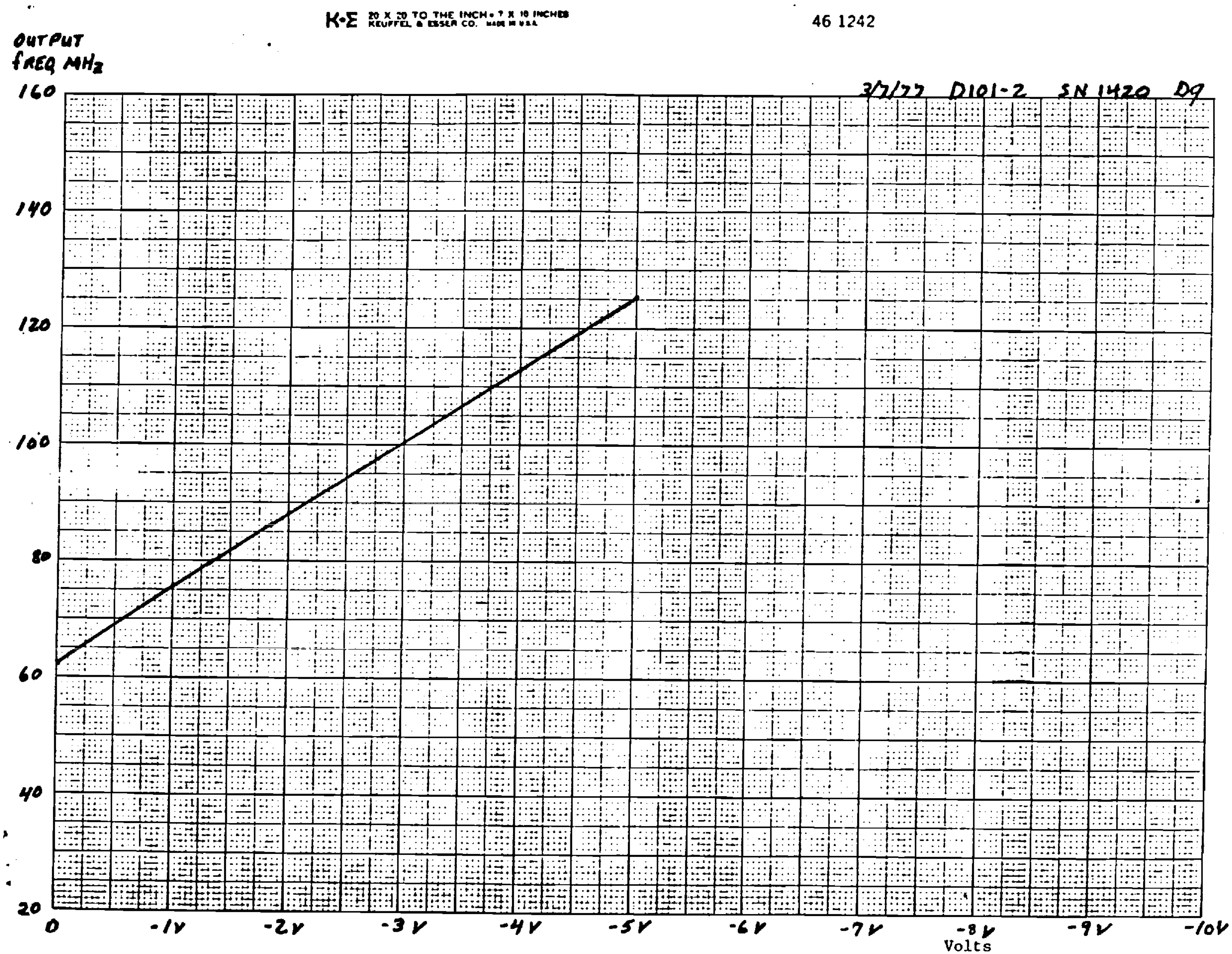
ANALOG V ALL 0S -1.0 mV

CSI APPROVAL	DATE	ISOMET QC APPROVAL QCE	DATE 3/7/77	PAGE OF

3-7-77

K·E 20 X 20 TO THE INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1242




K•E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1242
OUTPUT
FREQ MHz
3/7/77 D101-2 SN 1420 D9
160
140
120
100
80
60
40
20
0
-1V
-2V
-3V
-4V
-5V
-6V
-7V
-8V
-9V
-10V
Volts

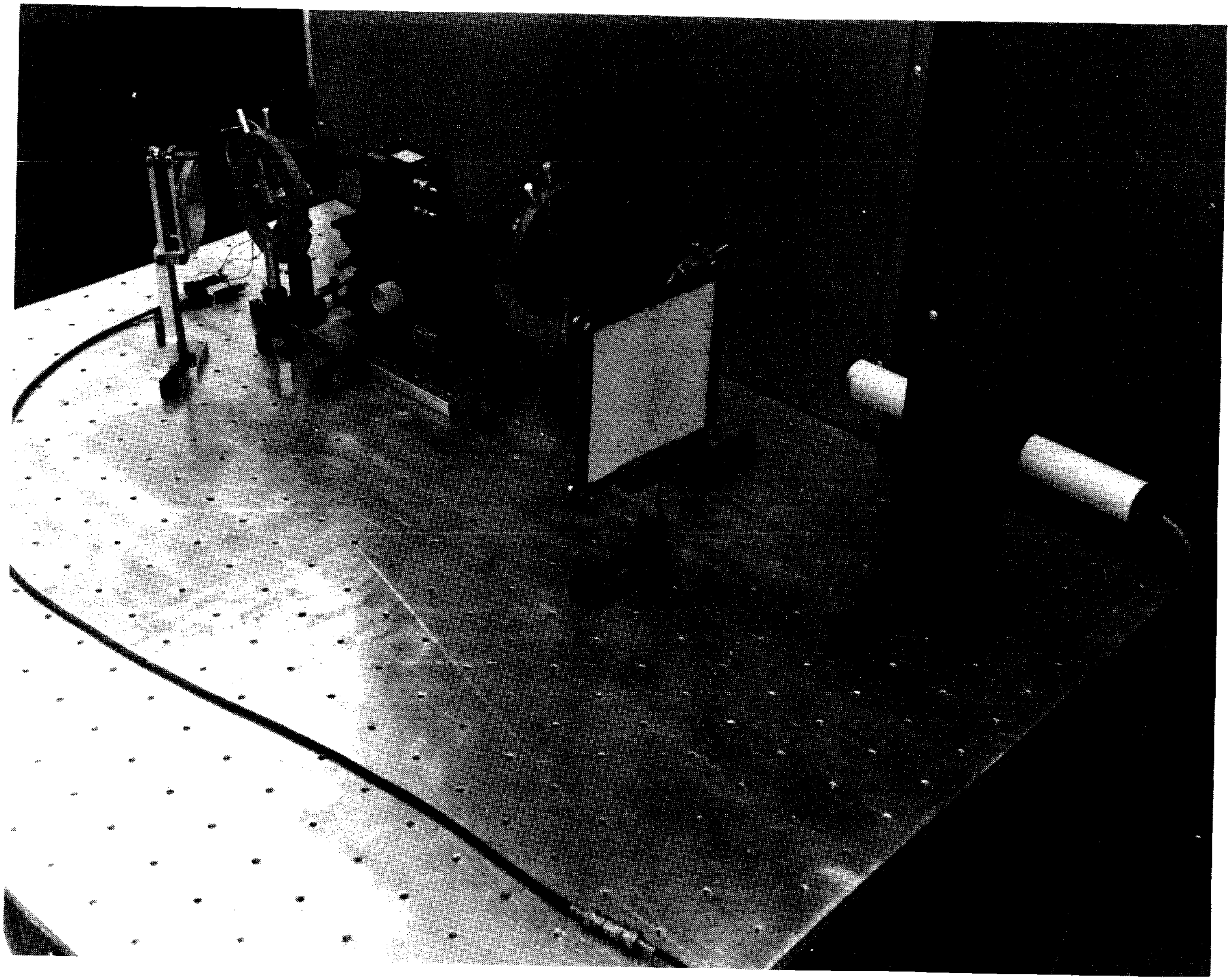


FIGURE 6. LASER SCANNER IN OPERATION.

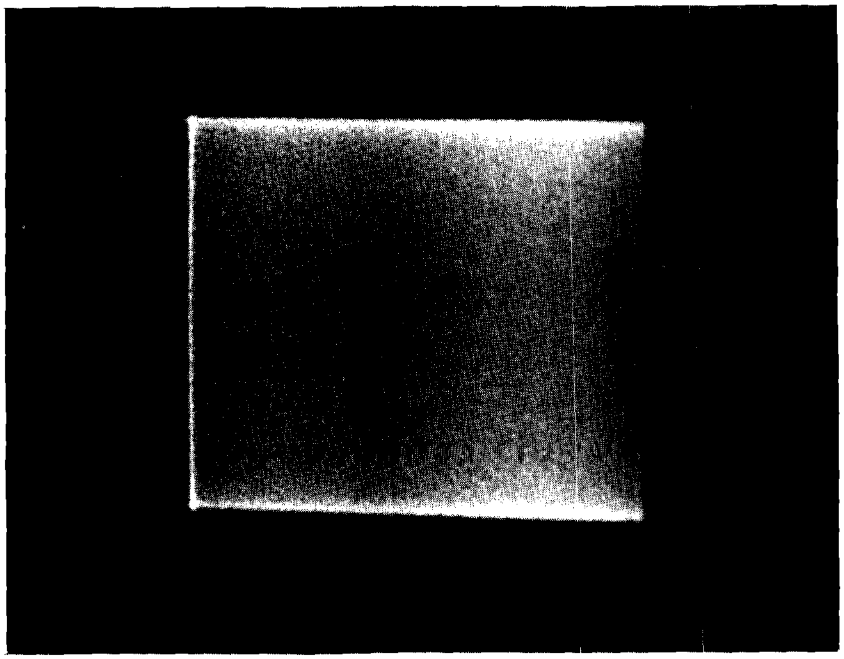


FIGURE 7. SCANNED PATTERN OBTAINED IN THE SWEEP MODE OF OPERATION OF THE LASER SCANNER.

IV. A COHERENT LIGHT SCANNER FOR OPTICAL PROCESSING OF LARGE FORMAT TRANSPARENCIES

A coherent light scanner for optical processing of large format transparencies was developed under a previous NASA contract with the Georgia Institute of Technology, Contract No. NAS8-28591, but was officially reported in the literature [5] during the contracting period that is the subject of this report. Since some of the considerations discussed there have bearing on the general topic of laser scanner development, Reference [5] is duplicated herin.

A COHERENT LIGHT SCANNER FOR OPTICAL PROCESSING OF LARGE FORMAT TRANSPARENCIES

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Introduction

Optical techniques are desirable for experiments involving the processing of large amounts of data stored as a two dimensional scene. Processing by computer usually requires digitizing an image and performing a two-dimensional Fourier transform numerically, which may be both costly and time-consuming. A schematic diagram of a standard optical processing system used for pattern recognition is shown in Figure 1.[1] The image to be processed is placed in the image plane of the processor and is illuminated by a coherent beam of light, as from a laser. The image can be in the form of film or can be produced by an image forming light modulator controlled by computer.[2,3] The spatial Fourier transform of the imput image appears in the focal plane of the first transform lens.[4]

If no additional elements are incorporated in the optical processor, the inverted image appears in the back focal plane of the second transform lens. By placing a matched filter of a second image in the transform plane, the spatial correlation of the two images appears in the output plane. The matched filter, which is a holographic record of the Fourier transform of the second image, can be produced by either optical or computer methods. The degree of correlation of the transform of the input image with that of the matched filter in the transform plane is indicated by the light irradiance distribution in the output plane. If the input image is not centered on the optical axis, the correlation plane irradiance distribution shifts by a distance proportional to the misregistration distance.

Illumination of the input image can be accomplished by two principal approaches:

1. illumination of the entire transparency, or

2. illumination of an area smaller than the transparency format, and then scanning over the entire format, repeating the optical data processing operation at each location.

The first approach--illumination of the entire transparency--necessitates the use of large aperture collimating optics and a powerful laser. The position of objects in the input plane is determined by a detector array or correlation plane scanner. Although the second approach requires a parallel scanning beam, it does not require the use of large aperture optics or a powerful laser. By collecting the light over a region of the correlation plane, the position of the portion of the image that correlates with the matched filter can be determined from the position of the scanning beam at the time that a relative maximum is detected in the correlation plane. Thus, correlation plane scanning may be eliminated.

A conceptual design of a traffic pattern analyzer using optical correlation is illustrated in Figure 2. Although this system is not meant to describe an actual on-line traffic analyzer, it exhibits features common to many correlator-based systems. The film transport contains the aerial photographs to be processed. The marginal information associated with the aerial photographs--

altitude, time, and possibly position and azimuth--can be stored as a data block that is automatically read at the film transport and entered into the computer. The computer positions the film for a desired frame and controls the laser scanner to examine a prescribed path, e.g., a highway. The holographic filter is the matched filter against which the aerial photographs is searched for the presence or absence of a vehicle or other object of interest.

The television display of the film being processed is strictly for operator convenience. At any single laser scanner position, the correlation plane may be scanned to examine the intensity contours of spots in the correlation plane for further identification.

Ideally, the operator of such a system would be able to instruct the processor to count the number of vehicles travelling in a certain direction in a given area at a specific time. Individual positions of distinct vehicles could be recorded. By examining the change in position of a number of vehicles on two consecutive frames taken a few seconds apart, an estimate of traffic flow could be determined. Such a system would allow traffic engineers to recover and process vast amounts of traffic data in a short time.

Many approaches have been employed to develop laser scanners for such diverse applications as writing television images, recording images on film, and storing data in optical memories. Most of these scanners are optimized by reducing the area of the beam and by increasing the bandwidth of the positioning mechanism. Unlike the types of scanners mentioned above, accurate random access positioning and beam parallelism are necessarily emphasized for a scanner to be used in an optical data processing application. Although the choice of deflectors for a system application may not be simple, galvanometer type deflectors offer higher resolution and beam quality, with a corresponding sacrifice in access time, compared to electro-optic and acousto-optic deflectors.[5] Rotating polygonal mirror systems are useful for many video rate scanning operations, but are not random access by nature and, in general, are significantly more expensive. The laser scanner discussed below has the following novel features:

1. the scanning beam is random access addressable and is perpendicular to the input image plane, and

2. the irradiance of the scanned beam is controlled such that a constant average irradiance is maintained after passage through the image plane.

Optical System

A schematic diagram of the laser scanner is shown in Figure 3. The laser output irradiance is controlled by a Pockel's cell modulator. The beam passes through a spatial filter, is expanded and recollimated, and then is reduced to the desired diameter by an adjustable aperture assembly. The laser beam is then focussed onto a light deflection system that acts as a flat mirror with two angular degrees of freedom. The deflected and diverging beam is collimated by an off axis paraboloidal section. The collimated beam is then directed parallel to the optical axis by the paraboloidal section.

To deflect the beam effectively in two angular degrees of freedom, two flat mirrors mounted on the rotating shafts of moving iron galvanometers and a spherical relay mirror are used. The beam from the laser is focussed to a spot on the axis of rotation of the horizontal deflecting galvanometer mirror. The diverging beam is collected by a spherical mirror, positioned such that the center of curvature is slightly to one side of the focussed spot. The light reflected by the spherical mirror then images the focussed spot at an equal distance on the opposite side of the center of curvature, with unity magnification. By placing the axis of the second moving iron galvanometer mirror at this point, two dimensional deflection from a point is obtained. By employing controllable galvanometer deflections, random access to any position in the scanned format is possible.

Optical Design

To analyze the design of the scanner, we consider the collimated parallel scanning beam that passes through the transparency and works backward toward the laser. To avoid occultation of the scanned format by the deflector mirrors, an off-axis parabolic section is used. Our system is designed for scanning over a 10.0 cm by 10.0 cm format. As shown in Figure 4, half of a parabolic mirror of 33.0 cm diameter is quite adequate. A focal length of 115 cm was chosen because of the significant increase of cost for lower f-number. Interferograms of both sections after cutting indicated a deviation of less than $\lambda/10$ over the scanned portion of the mirror.

The required format dimension of 10.0 cm and the parabola focal length of 115 cm require that the deflectors scan through a half-angle of approximately two and one-half degrees, which is compatible with standard deflectors. (A maximum half-angle scan of three degrees requires a minimum focal length of the parabola of 96 cm.)

In the previous discussion of the overall system, we indicated that the two axis deflection is obtained by closely positioning two orthogonal galvanometers on opposite sides of the center of curvature of a relay spheroidal mirror. The circular deflector mirrors can be positioned with a minimum center-to-center separation of 4 mm. The f-number of the spherical relay mirror must be low enough to accomodate the deflection angle of the galvanometers, and the focal length must be long compared to the separation between galvanometers. A focal length of 30.5 cm results in the two focussed spots being 3.3 milliradians off axis, which produces negligible aberrations. A half angle scan of three degrees requires that the f-number be less than ($\frac{1}{4}$ sin 3°), or approximately F/5. An F/4 spheroid was fabricated from a standard 76 mm (3 inch) diameter optical blank. A slower mirror could have been used, but an F/4 mirror was chosen to eliminate possible problems with edge effects due to mounting and surface finish. The central 60 mm of this mirror is spherical in shape within a tolerance of $\lambda/5$.

The galvanometer light deflectors are mounted in a fixture that allows fine orthogonal positioning. A single thin lens of focal length 110 cm is used to focus the beam on the first galvanometer mirror axis. Preceeding the thin lens is a spatial filter and collimator assembly using standard commercial optics mounted in a modified holder for long-term positioning stability. Any one of a series of circular apertures 1.2 mm to 10 mm in diameter mounted on interchangeable metal slides can be placed immediately behind the collimating lens to vary the beam diameter. The beam diameter must be greater than the largest dimension of the object being searched for in the image plane. Figure 5 illustrates how this would be determined for an aerial photograph of an automobile. From the figure,

$$\text{Beam diameter} \simeq \text{object size} \times \frac{\text{focal length}}{\text{aircraft height}} \qquad (1)$$

As an example, an object diameter of 10.7 meters (35 feet) photographed by an aircraft at a height of 610 meters (2000 feet) using a .305 m (12 inch) focal length lens requires a beam diameter of approximately 5.4 mm.

Between the laser and spatial filter is an on-off shutter and Pockel's effect modulator to control the beam irradiance. A feedback system has been designed to maintain constant average irradiance in the beam after passage through the film transparency. This feedback system can correct for local variations in the average film optical density. The laser used in the system is an argon ion laser capable of TEM_{00} output of approximately 800 mW at 514.5 nm or 300 mW at 488.0 nm.

System Performance

The response time of the scanner is essentially determined by the response of the galvanometer driven mirrors, as they are much slower than any other component. To measure the response time, a step voltage is applied to the galvanometer. The galvanometer contains a position detector circuit that delivers a current in direct proportion to the mirror deflection. By displaying the response to a square wave and the square wave itself on a storage oscilloscope, the response time of the galvanometer is estimated to be approximately two milliseconds.

A more significant test of the scanner's performance is that of beam parallelism and spot size variation during the scanning process. By directly measuring the Fourier transform as the beam scans, the effect of both factors can be observed. The test procedure is shown in Figure 6. The scanning beam was focussed to a spot by a F/3.5, 45 cm focal length Cooke triplet. The spot was imaged by a microscope on a ground glass camera back. The spot, when examined with the beam stationary, was an Airy disc pattern. With the beam scanning at a horizontal rate of 700 Hz and a vertical rate of 28 Hz, no motion of the transform was detected visually. Several one second time exposure photographs were taken, as shown in Figure 7, corresponding to an enlargement of 63.5 diameters. From the photo and from visual inspection, we estimate that the shift in the pattern is less than 1/10 of the radius of the first dark ring. For the 2.7 mm aperture, the radius of the first dark ring is 6.0 mm, which results in a shift of

$$\Delta X < .1 \times \frac{6.0 \text{ mm}}{63.5} < 10\mu \quad (2)$$

A positional shift in the transform corresponds to an angular deviation of the scanner of

$$\Delta\theta = \frac{\Delta X}{f} < \frac{10^{-5}\text{m}}{45.7 \times 10^{-2}\text{m}} \quad (3)$$

or

$$\Delta\theta < 2 \times 10^{-5} \text{ radians.} \quad (4)$$

A photograph of the scanner in operation is shown in Figure 8.

Conclusion

The successful operation of a laser scanner that is constructed from readily available components of modest cost indicates further progress in the development of hybrid optical-digital processing schemes. The scanner has been demonstrated to exhibit the degree of spatial invariance necessary for certain optical processing applications. Data in the form of large format transparencies can be processed without the expense, space, maintenance, and precautions attendant to the operation of a high power laser with large aperture collimating optics. The scanned format and scanning beam diameter may be increased by simple design modifications. By employing acousto-optic deflectors with different relay optics, higher scan rates can be achieved, at the sacrifice of resolution.

Acknowledgements. This work was developed under NASA Contract NAS8-28591. We would like to express appreciation to Mr. Joe Kerr, Mr. Frayne Smith, and Mr. Ellington Pitts of NASA/MSFC and to Mr. John York and Mr. Bill Evans of Sperry Rand Corporation, Space Support Division for their assistance and support.

References

1. A. Vander Lugt, "Coherent Optical Processing," Proc. IEEE, vol. 62, pp. 1300-1317, October 1974.
2. David Casasent, "The Optical-Digital Computer," Laser Focus, vol. 7, pp. 30-33, September 1971.
3. R. G. Shackelford and J. R. Walsh, "Design and Fabrication of an Experimental Image Forming Light Modulator," NASA Technical Brief No. B73-10182, June 1973.
4. J. W. Goodman, Introduction to Fourier Optics, New York: McGraw-Hill, 1968.
5. J. David Zook, "Light Beam Deflector Performance: A Comparative Analysis," Appl. Optics, vol. 13, pp. 875-887, April 1974.

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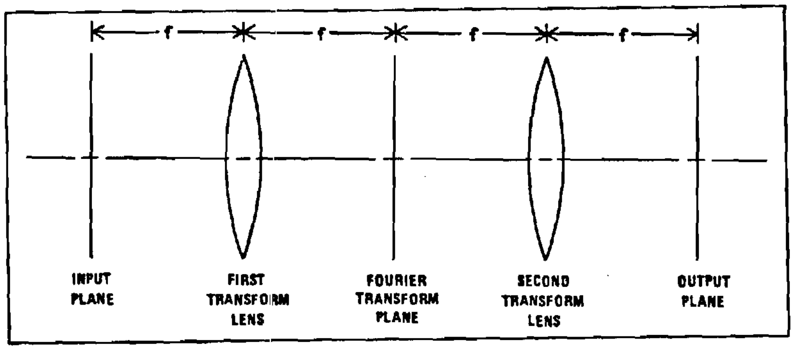


Fig. 1. Basic optical processor.

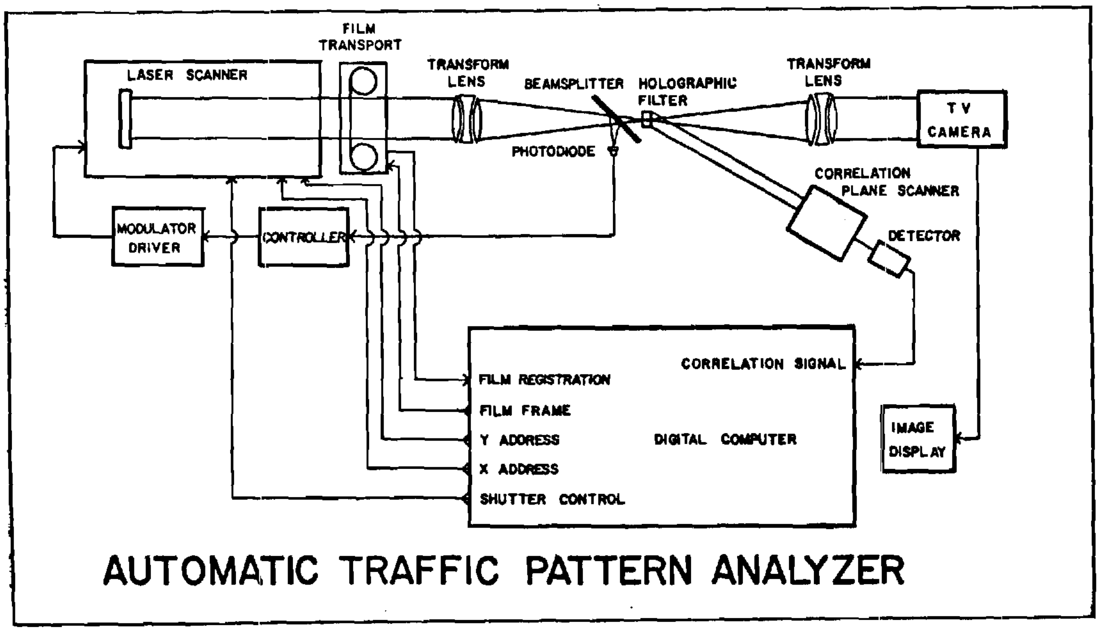
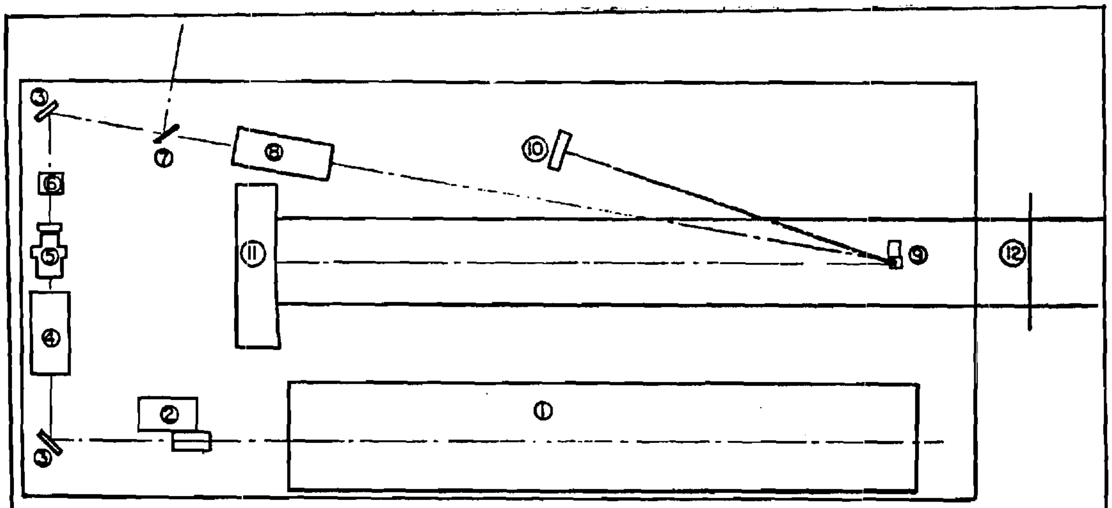


Fig. 2. Example of a hybrid optical-digital processor for analysis of traffic patterns.



1.) ARGON ION LASER
2.) SHUTTER
3.) FLAT MIRROR
4.) POCKEL'S EFFECT MODULATOR
5.) SPATIAL FILTER COLLIMATOR ASSEMBLY
6.) APERTURE ASSEMBLY
7.) BEAMSPLITTER
8.) VARIABLE FOCUS LENS SYSTEM
9.) GALVANOMETER DRIVEN MIRROR ASSEMBLY
10.) f/4 SPHERICAL MIRROR
11.) f/3.5 PARABOLIC MIRROR
12.) FILM PLANE SHOWING SCANNED FORMAT

Fig. 3. Laser scanner optical system.

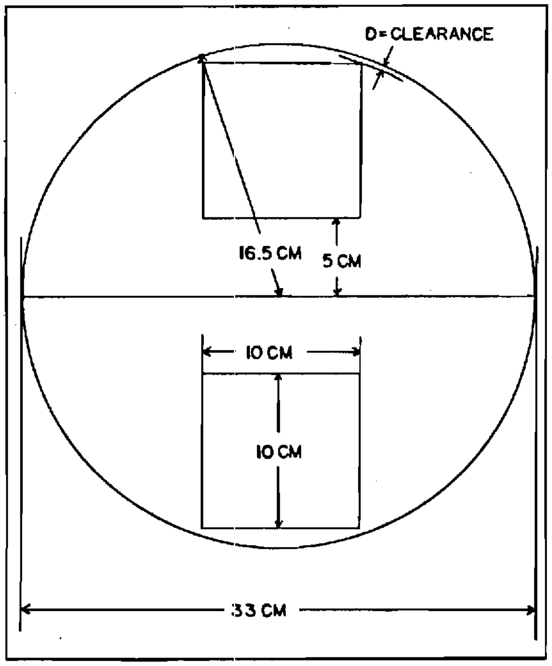
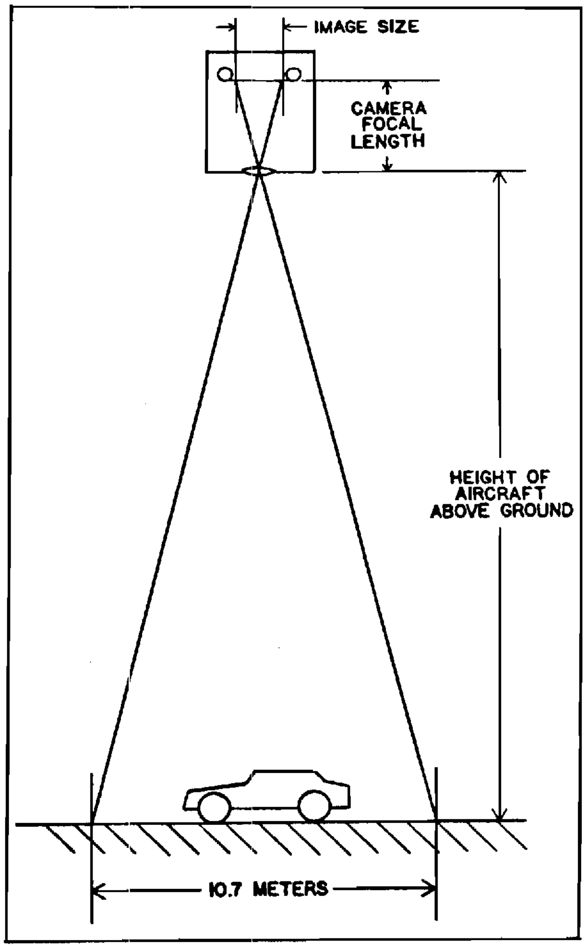


Fig. 4. Format projection on surface of parabolic mirror.

Fig. 5. Scaling of aerial photograph.



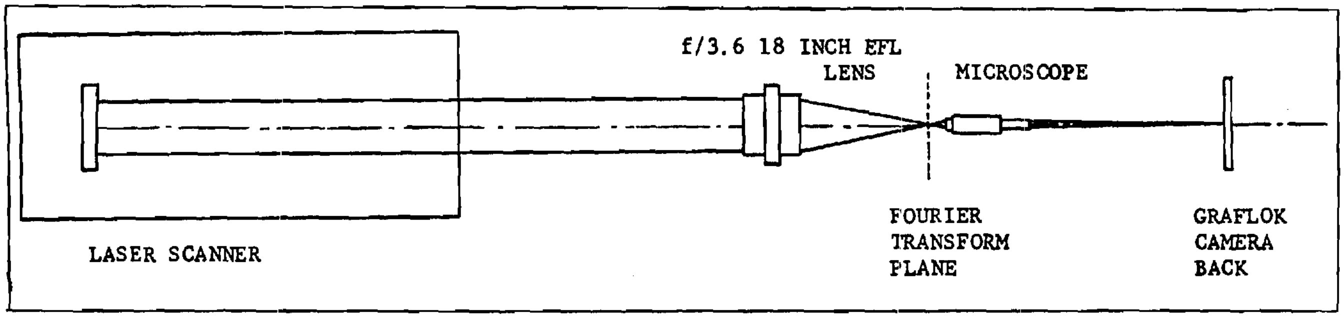


Fig. 6. (Above) Fourier transform spatial invariance test.

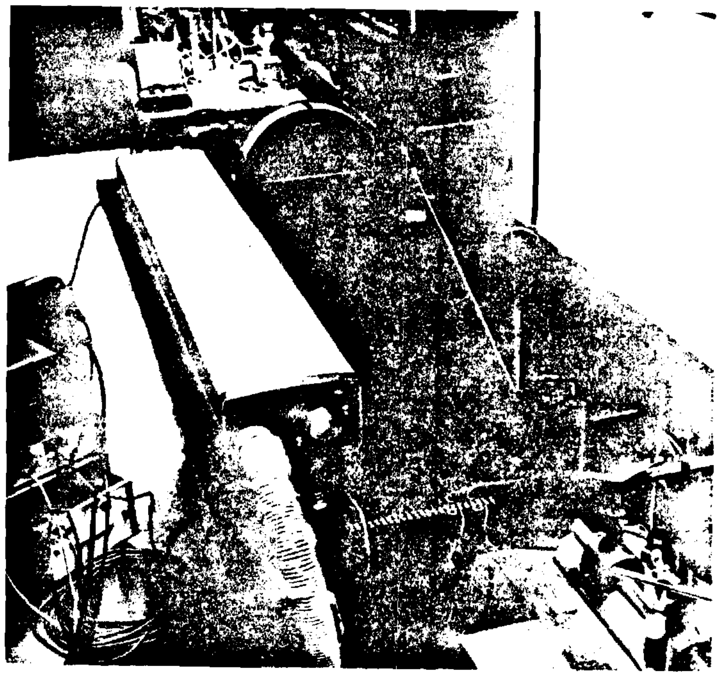


Fig. 8. Laser scanner during operational test. A single horizontal line is being traced by the scanner on the aerial photograph (lower right hand corner).

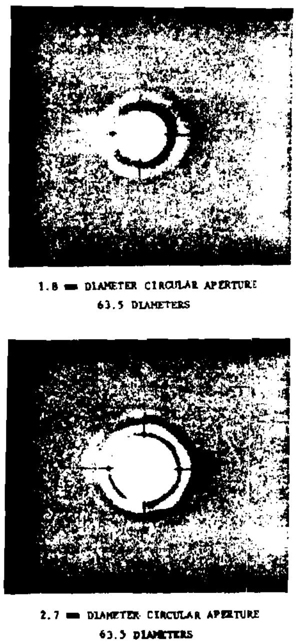


Fig. 7. Photomicrographs of Fourier transform patterns obtained using test apparatus of Fig. 6.

V. ACKNOWLEDGEMENTS

We would like to express our appreciation for the cooperation of Mr. H. Frayne Smith, Mr. Joseph Kerr, and Mr. Ellington Pitts of NASA/MSFC and Mr. John York of Sperry Rand Corporation.

REFERENCES

[1] J. D. Beasley, "Electrooptic laser scanner for TV projection display," Applied Optics, vol. 10, no. 8, pp. 1934-1936, August 1971.

[2] I. Gorog, J. D. Knox, and P. V. Goedertier, "Television rate laser scanner I. General considerations," RCA Review, vol. 33, no. 4, pp. 623-666, December 1972.

[3] I. Gorog, J. D. Knox, P. V. Goedertier, and I. Shillovsky, "Television rate laser scanner II. Recent developments," RCA Review, vol. 33, no. 4, pp. 667-673, December 1972.

[4] W. R. Callen, J. E. Weaver, R. G. Shackelford and J. R. Walsh, "Development of a coherent light scanner," Final Report on NASA Contract NAS8-28591, October 1973.

[5] W. R. Callen, J. E. Weaver, R. G. Shackelford, and J. R. Walsh, "A coherent light scanner for optical processing of large format transparencies," Proceedings of the Electro-Optical System Design Conference - 1975, Chicago: Industrial and Scientific Conference Management, Inc., November 1975, pp. 487-493.

[6] J. David Zook, "Light beam deflector performance: a comparative analysis," Applied Optics, vol. 13, no. 4, pp. 875-887, April 1974.

[7] A. Yariv, Introduction to Optical Electronics, Second Edition. New York: Holt, Rinehart, and Winston, Inc., 1971, pp. 337-353.

[8] All About Bragg Angle Errors in Acousto-Optic Modulators and and Deflectors. Springfield, VA: Isomet Corporation Application Note.

[9] Operations and Maintenance Manual--Model D-100 Acousto-Optic Driver. Springfield, VA: Isomet Corporation, December 1976.

[10] Instruction Manual for Isomet Series LD-401 Acousto-Optic Deflectors. Springfield, VA: Isomet Corporation, September 1974.

[11] P. J. Brosens, "Fast retrace optical scanning," Electro-Optical Systems Design, vol. 3, no. 4, pp. 21-24, April 1971.

[12] Robert Compton, "Optical scanners; comparisons and applications," Electro-Optical Systems Design, vol. 8, no. 2, pp. 16-32, February 1976.

[13] H. M. Tenney and J. C. Purcupile, "Laser/galvo scanner design," Electro-Optical Systems Design, vol. 7, no. 10, pp. 40-45, October 1975.

[14] Operating and Maintenance Manual for the Model 3003 Modulation System. Danbury, Connecticut: Coherent Associates, Inc.