

Final Report

submitted to

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812**

August 24, 1994

for Contract NAS8 - 38609

Delivery Order 97

entitled

Optical Analysis of Crystal Growth

by

**Gary L. Workman Ph.D.
Principal Investigator**

and

**Andrea Passeur
Physics Graduate Student**

**Sabrina Harper
Optics Undergraduate Student**

**Materials Processing Laboratory
Center for Automation & Robotics
University of Alabama in Huntsville
Huntsville, Alabama 35899**

**(NASA-CR-196514) OPTICAL ANALYSIS
OF CRYSTAL GROWTH Final Report
(Alabama Univ.) 60 p**

N95-12386

Unclass

G3/76 0026408

TABLE OF CONTENTS

TGS EXPERIMENT	1
Particle Specifications	1
HARDWARE DESCRIPTION	3
Optical Bench	3
Camera System	4
UNIDEX Stepper Motor Controller	4
UNIDEX Specifications	5
UNIDEX Programming Capabilities	5
Software	5
Storage	6
Advantages of Optical Disks	6
Positioning Stages	7
ITEX SERIES 151 IMAGE PROCESSING SYSTEM	8
Description	8
ITEX Hardware	9
ITEX Software	10
APPLICATIONS OF THE SERIES 151 SYSTEM TO HGS RESEARCH	11
Introduction	11
Contrast Stretching	11
Outline Area of Interest	12
Rotate Area of Interest	13
EXPERIMENTAL APPROACH	16
Conclusions	18
APPENDIX A: OPTICAL BENCH LAYOUTS	A1
APPENDIX B: ILLUSTRATION OF CAMERA SYSTEM	A13
APPENDIX C: CAMERA SYSTEM SPECIFICATIONS	A17
APPENDIX D: IMAGE TRANSFER AND STORAGE PROCEDURE	A20
APPENDIX E: ALGORITHMS FOR READING FROM AND WRITING TO THE OPTICAL DISK	A23
APPENDIX F: ATS100-200 POSITIONING STAGE SPECIFICATIONS	A26
APPENDIX G: ORIGINAL "IM_GEOM.C" PROGRAM	A28
APPENDIX H: MODIFIED "IM_GEOM.C" PROGRAM	A31
APPENDIX I: IMAGE MATRICES AND ACQUISITION PROCEDURES	A34

TGS EXPERIMENT

Crystal growth in microgravity was studied aboard IML-1 in January 1992. Using triglycine sulfate (TGS), researchers hoped to identify fluid convection components from crystal growth, g-jitter, and residual microgravity. Identifying these components and correlating them with other events enable more accurate characterizations of the space shuttle environment and its effects on crystal growth. Small microspheres were added to the fluid surrounding the crystal seed in order to characterize the microgravity environment and its forces.

Particle Specifications

While performing the tests to determine the particle concentration in the solution, it was noted that extremely small particles were invisible during the real-time recording. In contrast, large particles were usually damaged by the stir motor which produced unwanted nucleation sites. Therefore it became necessary to establish a median particle diameter range of approximately 200u to 650u, with enough spacing between diameters to be able to distinguish each particle from another. The three diameters used were 199u, 383u, and 646u.

Due to cohesive and adhesive properties of the particles, excess quantities were needed in the solution to accommodate for clumping and sticking to the container walls. Although the large numbers of particles provided measurable data, they also caused tracking difficulties, especially during shuttle maneuvers or other large disturbances.

The particle spheres were measured in mass, from which the particle concentration per unit volume of solution could be calculated. The following list gives the specifications.

<u>Particle Diameter</u>	<u>Measured Mass</u>	<u># Particles per gram</u>
199 u	0.0391 g	2.3 x 10E5 /g
383 u	0.2812 g	3.2 x 10E4 /g
646 u	1.4060 g	6.4 x 10E3 /g

The total number of spheres of each size is given by the following calculations:

$$\begin{array}{rcl}
 199 \text{ u:} & (2.3 \times 10^5 /g)(0.0391 \text{ g}) & = 8993 \text{ spheres} \\
 383 \text{ u:} & (3.2 \times 10^4 /g)(0.2812 \text{ g}) & = 8998 \text{ spheres} \\
 646 \text{ u:} & (6.4 \times 10^3 /g)(1.4060 \text{ g}) & = 8992 \text{ spheres} \\
 & & \text{-----} \\
 & \text{Total} & = 26983 \text{ spheres}
 \end{array}$$

The cell's volume is 1.8 liters, including the heat exchanger. Therefore, the average particle concentration was

$$\begin{array}{rcl}
 26983 \text{ spheres}/1800 \text{ cc} & = & 15 \text{ spheres/cc} \\
 & = & 5 \text{ spheres/cc of each size.}
 \end{array}$$

HARDWARE DESCRIPTION

Optical Bench

The optical bench, which is only slightly adjusted for each type of analysis, is a Mach-Zehnder type interferometer modified for holography with the reference plane at the center of the crystal's cell. The camera is fitted with a microscope objective which accepts the hologram format and has a magnification range of 2.5X - 100X.

The optical bench used to produce an interferogram image requires an equal distance in the object and reference beams, with the reference plane still at the center of the crystal cell. This configuration is designed for two methods of interferometry: (1) the real-time holographic method and (2) the classical Mach-Zehnder method. Real-time holographic interferometry superimposes a recorded cell wavefront from a hologram over a current test cell experiment, and relative changes are identified by the created fringes similar to other experiments. In the classical Mach-Zehnder method, the set-up is identical, but the test-cell experiment is replaced by a plane wavefront, and the relative changes are once again compared with previous fringe patterns.

For the Schlieren analysis, the optical bench is similar to that used in interferometric research, with the Schlieren knife-edge probe inserted where the image converges to a point. Appendix A shows the bench layout with the probe in place in front of the interferometric screen. This configuration, used by HGS, reaches a resolution to less than 20 μm and a deflection of one degree. The optical bench configuration for shadowgraph analysis is the same as that of the Schlieren system, except that the focusing lens and knife-edge is removed (See Appendix A).

Specifications of the Optical Bench:

- Degree of reference beam alignment: < 22.5 deg. +/-10 arc sec
- Maximum rotation of hologram: 180 degree
- Magnification range: 2.5X - 100X
- Resolution (interferometry): 2×10^{-5} diff. in refr. index
- Resolution for Schlieren analysis: < 20 um
- Deflection for Schlieren analysis: 1 degree

Camera System

The camera system (used to observe the holographic images) contains a COHU Inc. Model 6410 miniature Camera Head and its Camera Control Unit (CCU), designed specifically for general monochrome applications requiring a small lightweight camera (see Appendix B for illustration). The Camera Head has a 1/2 inch format CCD image sensor that uses the frame transfer method as well as an IR blocking filter and a C-mount adapter that accepts most types of fixed focus and TV lenses. The CCU is separate from the Camera Head for easier access, and all of the interfacing connectors are located on its rear panels. Appendix C lists the camera's electrical, environmental and mechanical specifications.

UNIDEX Stepper Motor Controller

The Aerotech UNIDEX Model IIIa Motion Control system is responsible for the point-to-point linear (x-axis and y-axis) translation of the camera in order to pan the live image on command. The UNIDEX can be accessed using the command buttons on the front panel or through the host computer. In programming, it uses the standard RS 274D motion control language command structure and four programmable inputs allowing it to store program interruptions and alter the program flow according to external conditions.

UNIDEX Specifications:

- Max Data Rate: 159 kHz
- Memory: up to 28K
- Operating Modes: edit, auto, single, immediate, remote
- Processing Time: 1.4 msec for basic point-to-point mode

UNIDEX Programming Capabilities:

- Sends information on command
- Unconditional jump
- Subroutine call (two types)
- Repeat cycles (maximum count 65,535)
- Soft conditional skip
- Store and recall positions
- Dwell to 4000.000 seconds
- Programmable halt with service request
- Programmable message display
- Controllable from host computer, joystick or its own keypad

Software

The Computerized Holographic Image Processing (CHIP) program converts the live images into storable computer files and provides some basic image enhancements. In addition, CHIP serves as one of two methods used to control the UNIDEX motor controller, which in turn moves the camera (the other method is performed manually). The CHIP program was originally established for automated Schlieren analysis, but it is also efficient for surveying holograms in a three-planar image matrix.

The Series 151 Image Processing System with the ITEX 151 library of image processing functions is used to consistently align the holograms, which is crucial for accurate fluid/particle tracking data. The Series 151 system contains its own family of hardware modules that perform in conjunction with an IBM compatible. This system has many image enhancement features that could prove beneficial to image data analysis, some of which were examined for HGS applications. Further information about the Series 151 system as well as the results of this review are detailed later in this report.

Storage

Once the images are converted by CHIP, the images occupy 0.25 Megabytes of memory. Locally, they are stored on 90 Megabyte Bernoulli disks; however, the optical disk drive is required for long-term storage. This drive is accessed through the fiberoptic network that is linked to the Marshall Space Flight Center central computer network, allowing for world-wide image communication. The images are transferred to the optical drive by way of a VAX controller. The complete procedure is located in Appendix D.

For random-access storage, the optical disk requires three items of hardware: a host computer, an optical disk drive, and a host adapter with an appropriate hardware/software connection. HGS implemented the optical disk to store permanent images through the Software for Optical Archival and Retrieval (SOAR), which appropriates the hardware and manipulates the data using existing VAX data access methods and applications software. The SOAR software retains directory information in a magnetic working file while writing the actual data to the optical disk, after which it copies the directory information to the disk's reserved lower blocks.

Advantages of Optical Disks

- More data storage in the same space: each side holds about 1 Gbyte of data, which would otherwise require over 11 Bernoulli disks, 26 1600-bpi tapes, or 3200 floppy disks.
- Has random access of the Write Once Read Many (WORM) optical disk
- Greater data access rate (greater than 200 kbyte/sec)
- Write-Once Read-Only characteristic, preventing accidental overwriting
- Longer shelf-life

Appendix E shows the algorithms for (a) reading from and (b) writing to the optical disk. The corresponding commands (such as OINITIALIZE and OCOPY) are also given.

Positioning Stages

The Aerotech Model ATS100-200 positioning stages are used to hold and maneuver the camera head within its horizontal plane. Made from a special cast aluminum alloy, the stage base is a box design employing a pre-loaded ballscrew to eliminate backlash, and high quality duplex bearings to eliminate axial play. Three stages, one each for x, y, and z-axis positioning, are used in conjunction with the UNIDEX motor controller for positioning accuracy within +/- 1um/200 mm and bi-directional repeatability of 0.3 um. Specifications for the positioning stages used by HGS are listed in Appendix F.

ITEX SERIES 151 IMAGE PROCESSING SYSTEM

Description

The ITEX Series 151 image processing package is a new system installed by HGS primarily to aid in acquiring and aligning fluid/particle holographic images. This system, however, has many additional features potentially applicable to holographic image processing, some of which were examined by HGS throughout this year.

The Series 151 is an image processing system efficient for real-time, high-resolution image processing. The system controls acquisition, display and storage through a host IBM PC or PC compatible. It is comprised of a set of Series 150 boards in a 7- or 12-slot enclosure and connects through a single-slot interface on the host computer. Each board plugs into a VMEbus backplane with a specialized connector for the high-speed PixelBus video buses.

The 151 system has two timing modes for operation: normal and programmable. Normal (video) mode uses the timing and synchronization of the video source, such as the mode of the "live" image on the console. Programmable timing allows faster data transfer and some operations such as Area-of-Interest (AOI) processing. An image undergoing this processing is not displayed until the operation is complete and the time base is returned to a displayable format (such as video). Once in the video bus, the data is synchronized to either the normal or programmable timing mode.

The hardware required to run the Series 151 consists of an IBM host PC with 512K memory and a diskette drive, a video camera to acquire live images, and a video monitor. At HGS, the Microsoft C compiler (version 4.0) is used to compile programs with ITEX 151 library functions. The Series 151 software, which resembles the C language, lets a user access the memory and the hardware directly in addition to the more complicated image processing operations. The system provides its own software program called the

Interpreter, which simplifies programming and invokes most of the specialized ITEX functions as well as a few C constructs.

ITEX Hardware

The equipment listed below describes the different modules, the three underlined modules being the core components of the system.

- ADI-150 Analog/Digital Interface - acquires and displays the image data, generates the timing for the modules. It is the interface module that supplies data and synchronization to the other modules and instills the camera and monitors. The output displays images in monochrome color but could change to pseudocolor or true color with software control.
- DPI-150 High-Resolution Display Processor - serves as a display and graphics controller; enables nondestructive overlays such as menus and text; it supports a live video window and allows a live image (AOI) to be displayed anywhere on the monitor; has two memory ports to allow simultaneous display and image acquisition.
- FB-150 Frame Buffer - contains 1 MByte of total memory for all frame storage, necessary for high-performance image processing. It has one 512 x 512 x 16-bit frame store (referred to as frame store A) and two 512 x 512 x 8-bit frame stores (referred to as frame stores B1 and B2). Frame store A accumulates processed images requiring more memory, such as those from summations and convolutions. Frame stores B1 and B2 hold one complete video image at a time. The frame memory is accessible to the CPU and all modules.
- ALU-150 Pipeline Processor - performs common image processing operations such as image averaging, subtraction, convolutions, morphology, min/max detection, thresholding. It also performs conditional processing, which provides control over the pipeline by letting condition-based decisions affect the resulting images. Most of the operations done in the ALU-150 perform in real-time.
- HF-150-1K Histogram/Feature Extractor - allows you to extract pixel information from an image and perform real-time statistical analysis of pixel intensities in the image. Histogram information describes the contrast, brightness and dynamic range of the image. Feature extraction information accelerates the dimensional calculations and measurements. Up to 16 features and 16000 points are supported.
- RTMP-150 Real-Time Modular Processor - serves as the mother-

board for up to three plug-on computational modules; provides interface to the computer and the Pixelbus. Through software control, the pipeline position of the computational modules can be altered for efficient algorithm execution.

- **CM150-RTS Real-Time Sobel Computational Module** - performs Sobel gradients and 8 x 8 real-time convolutions, Laplacian edge detection, blurring and FIR filters.
- **CM150-LUT16 Look-Up Table Processor** - performs linear and nonlinear transformations on inputs (one 16-bit or two 8-bits), addition, subtraction, ratioing, histogram equalization, thresholding, logical operations, barrel shift and 16-bit point transformations; programmable through host computer.
- **CM150-CNV Convolver**- executes real-time filtering and convolutions on an image using a 3 x 3 or 4 x 4 programmable kernel. It eliminates edge effects of convolution and performs in both linear and nonlinear transformations.

ITEX Software

The Interpreter is the ITEX 151 program that operates the ITEX system by invoking its own set of library functions. In addition to its own functions, the Interpreter accepts the general ITEX functions and some C language functions. As a result, a program written in C can accept many of the ITEX functions (given certain conditions). The Interpreter lets you create personalized ITEX-oriented programs (called script files) from either of two editors: the standard ASCII editor or the Interpreter's Interactive Editor, which executes the command before storing it. It is easily incorporated into any operating system and can be combined with other programs that have their own editing/compiling capabilities.

Script files are files that perform particular functions associated with the ITEX system. They are executable by a typical operating system such as DOS as well as through the ITEX Interpreter. Script files have many advantages that are time-saving and useful for quick testing of algorithms, functions, or programs.

APPLICATIONS OF THE SERIES 151 SYSTEM TO HGS RESEARCH

Introduction

In order to implement some of the ITEX system's many features into the different types of fluid analysis, each feature was examined from the core software programs to determine their specific functions. Next, the feature was executed on each type of image (microscopic image, interferogram, Schlieren, and shadowgraph) to visually analyze its effects on the processed image. After examining many of the features from ITEX, it was determined that this particular image processing system is not as efficient for actual data analysis as is the CHIP program, but it does provide useful ways to align the microscopy images, which is crucial for accurate particle velocity and acceleration study.

Contrast Stretching

The ITEX system's Contrast Stretch feature has proved very helpful for faint low-contrast diffuse holograms, because it essentially causes fluid data from the image to appear brighter while the dark particle data maintains a relatively low intensity value. There are many low-contrast images spread sporadically throughout the three runs, causing two major problems: alignment with Real-Time subtraction becomes extremely difficult, and the particle edges are sometimes too dim to detect accurately. Although the particle edges do not appear any sharper after Contrast Stretching, they do become more visible and therefore more traceable. In addition, since the entire image is brighter, the real-time subtraction is more effective.

Contrast Stretching enhances the image contrast by generating a histogram of a selected area of the image, called the page area, and then uses this histogram to load the specified LUT. This in turn equalizes the brightness values over the entire image. The procedure for using Contrast Stretch is relatively simple, as the directions below demonstrate.

- Acquire the live starter image on the SDP151 (ITEX) monitor
- From the Main Menu, select Image Enhancement option
- Once in the Image Enhancement menu, select Contrast Stretch (the operation is performed automatically)
- Save the new image so that it can be used for Real-Time subtraction alignment with the next image

Outline Area of Interest

ITEX has features that allow the user to draw graphic lines on an image, and for the fluid and particle image data, two of the most useful graphics features are called "Set Area of Interest" and "Outline Area of Interest," located in the Image Graphics menu. Since both diffuse and non-diffuse images use vertical and horizontal references for alignment, an outline can be drawn around the border of the image of the sting (crystal holder), which is the primary reference. This method can be used in conjunction with the Real-Time Subtraction method of aligning the images, but it is also very helpful when comparing a poorly developed faint image with one of high intensity, which is difficult to do with Real-Time Subtraction or if Contrast Stretching cannot compensate for the intensity differences.

During data acquisition, the user must constantly compare images with earlier starter images throughout the sequence to keep all images aligned; otherwise, hologram #250, for example, could stray off line as much as 20 pixels from #1, even though it appears to be exactly in line with hologram #249. The coordinates of the outline are preserved in memory so they are consistent with each image, preventing holograms from eventually veering off course.

The general procedure to Outline the Area of Interest follows, but it can be adjusted for other similar images and problems if necessary.

- Choose a correctly aligned starter image (Image Restore)
- From the Main Menu, select "Image Graphics" menu
- Select "Outline Area of Interest"

- Select the "Rectangle" option
- Starting at the top left corner of the image, use the mouse to draw the rectangle border at or near the horizontal and vertical edges of the sting
- Save the image with the outline on it for aligning the next starter image (if necessary). Unless it is saved, the outline disappears when another image or operation is selected
- Under the "Image Geometry" menu, select the "Reset Frame Position" option to set the AOI back to full screen and to reinitialize the necessary values. This step is necessary when anything but "Whole Screen" is selected as the Area of Interest

Rotate Area of Interest

Another potential source of error in aligning the images is the placement of the hologram on the holder. The hologram is held in place on the glass plate holder by a small vacuum tube. Even if the hologram is placed perfectly by hand, it may get slightly jarred or rotated by the suction (See Figure 1). The ITEX system contains commands that can rotate the image frame, so when used in conjunction with Outline Area of Interest, the frame can be aligned angularly in the vertical (x-y) plane along the hologram holder.

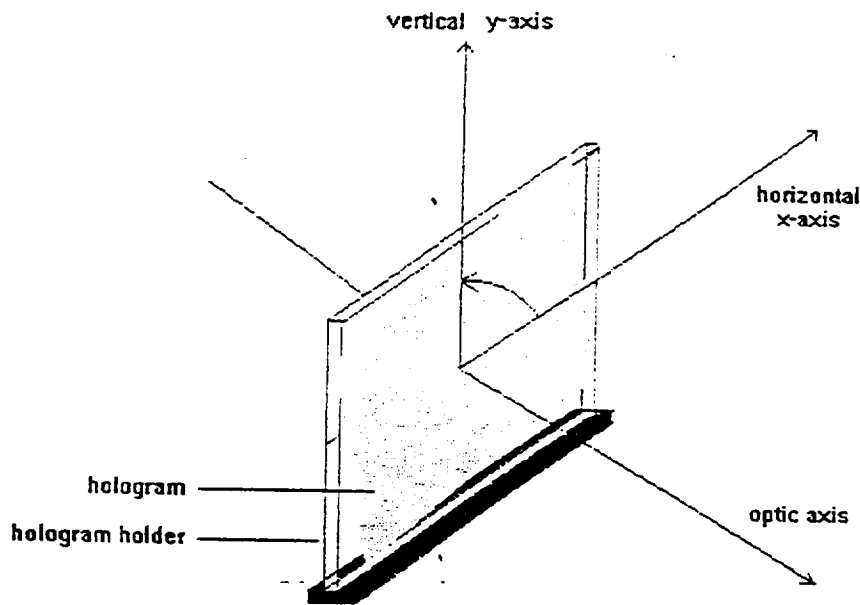


Fig. 1- Diagram of hologram holder with a hologram oriented at an incorrect angle in the x-y plane

The ITEX hardware cannot rotate the hologram or its direct image. The most effective ways to rotate the direct image is to either remove the vacuum and readjust the hologram on the holder (for larger adjustments), or rotate the camera (for fine tuning). ITEX can, however, rotate an acquired image after being stored as a frame, so the user can experiment with the alignment without changing the actual image.

The current rotation feature implemented by ITEX is called "Compress Rotate AOI 90 Degrees," under the Image Geometry menu. Appendix G contains the program "IM_GEOM.C" containing this menu. This feature is useless for the purposes of HGS, since the image may only require adjustment by 1-2 degrees. A similar function called **rotate**, however, allows for these smaller angles, but it must be added to the menu and therefore, written into the "IM_GEOM.C" program.

The "Compress Rotate 90 Degrees" program has a configuration similar to that necessary for a new rotation feature. For convenience, the program was modified by adding two separate operations, "Rotate Image Clockwise" and "Rotate Image Counterclockwise." Each operation, when clicked by the mouse button, immediately acquires the current AOI and rotates it by one degree in the selected direction. When clicked again, the feature rotates the latest image by one more degree, and so on. The function has the following syntax:

rotate (frame, destframe, x, y, dx, dy, angle)

where frame=page in the program (set to B1 by a header file); destframe is the destination frame (unchanged); x, y, dx, dy are the coordinates of the AOI; and angle is set to -1 degrees for clockwise and +1 for counterclockwise. The function then becomes

rotate (page, page, x, y, dx, dy, -1)

or

rotate (page, page, x, y, dx, dy, +1).

Note that the "Rotate 90 Degrees" feature must compress the image to keep all of it in memory after rotating it. The rotate function does not compress the image, but it does begin to "clip" enough of the image to fit it into the destination frame when it rotates. In this case, setting the angle to one degree has a negligible effect on the size of the image and does not present a problem.

Appendix H contains the new "IM_GEOM.C" program with the rotation features implemented. Also included are the names of the two features in the Image Geometry menu. A general procedure to align the particle images is as follows.

- Acquire a previous starter image.
- Using Real-Time Subtraction, compare it to the live image and check the rotation
- Recall the previous starter image, without the sting borders outlined using the Outline Area of Interest option
- Under the Image Geometry menu, select the "Rotate Image Clockwise" or "Rotate Image Counterclockwise" option
- Using the Outline Area of Interest feature, outline the sting borders and check for correct vertical and horizontal alignment

This procedure consumes only a small amount of time to invoke once the steps are learned. It should be noted that when comparing the starter images with the outline drawn around the sting border, the user should be placed in a consistent point of view to the monitor.

The results of the research shows that the three methods range from moderately beneficial to absolutely necessary, but all methods require some extra time to operate. It is concluded that the Contrast Stretch feature, which increases contrast between particles and the fluid, is simple, easy, and essential to brighten low quality images for easier real-time comparisons with neighboring images. The Outline Area of Interest is important when checking for improper rotation of the image and for general alignment. Finally, the Image Rotation feature allows a new and accurate way to turn the image without touching the hologram; however, this method is very timely and often difficult to view.

EXPERIMENTAL APPROACH

Initially, two crystal growth experiments were planned. One was to last 24 hours; the other was to last 60 hours. The experiments had to be broken down into three shortened runs because of problems encountered during flight. Run 1A lasted 8.5 hours; Run 1B lasted 28.5 hours; and, Run 1C lasted 19 hours. The cap did not retract in the Run 1A cold cell and the Run 1B heated cell. With the heated cell of Run 1C, the experiment was successfully accomplished.

During Run 1A, 1050 images were obtained from the 114 holograms recorded. Run 1B consisted of 133 holograms in which data is still being reconstructed. Finally, 2350 images were obtained from the 136 holograms that were taken during Run 1C.

The Computerized Holographic Image Processing (CHIP) program was used to record the images into computer files. Each of the filenames indicates its position in the matrix (See Appendix I). The following steps are required for initialization of the CHIP program:

1. Make a directory of each hologram. Keeping a directory is important so that the image files (which have like labeling) are not overwritten. The directory name is the same as the sleeve number of the hologram (ex. 2T1CP100). Each image is stored into one file in this directory, the filename referring to its location in the matrix. The filename is in the form *vertical position.angle*, where the *vertical position* is the matrix y-value, and the *angle* denotes the matrix x-value and focus positions. Referring to Figure ? of Appendix ?, for example, the file 1405.2B stores the image located in the matrix block with the vertical (y) position "1405," horizontal (x) position "2," and plane (focus) position "B." The filename for the very first image is 0.1A. All directories are located on Bernoulli disks which contain 90 MB of memory.

2. **Find the reference point.** This step requires focusing on the middle plane, then finding the appropriate starting point on the plane.
 - Use the joystick manually to position the sting at approximately the monitor's center in order to offer a "good" sting view;
 - To focus, flip the x-axis dial to FOCUS and move the joystick in the positive or negative x-direction. The camera is now set at the "B," or middle plane;
 - Flip the x-axis dial back to HORIZONTAL and position the camera to center the matrix over the sting (500 steps were chosen).

3. **Initialize the CHIP program for use.** This step connects the CHIP program to the UNIDEX and prepares the files for storing the images.
 - On the UNIDEX, press RESET so that the display reads SYS RDY;
 - While in the hologram's directory, type CHIP to enter the CHIP program;
 - Once in the CHIP program, press the UDX ONLINE and AUTO UDX keys to connect the program to the UNIDEX;
 - Press HOLO CODE and enter the last six digits of the hologram name (from the earlier example, the last six digits would be 1CP100);
 - Press ANGLE and enter the appropriate angle and plane (1A, 2B, etc.);
 - Move the camera to the desired plane: on the UNIDEX, flip the xx-axis dial to FOCUS. Press INCX, enter 1827, then press GO to execute. The image on the screen should change in focus but not in position.

Appendix I also gives the step-by-step procedures to record all necessary images on the hologram matrix. There are separate procedures for TGS runs 1A and 1C due to the cell center's being obstructed (Run 1A) or unobstructed (Run 1C), but all initializations discussed up to this point are the same. Each procedure is written to capture a single plane or depth of the matrix, and at its conclusion the film must be replaced with the next

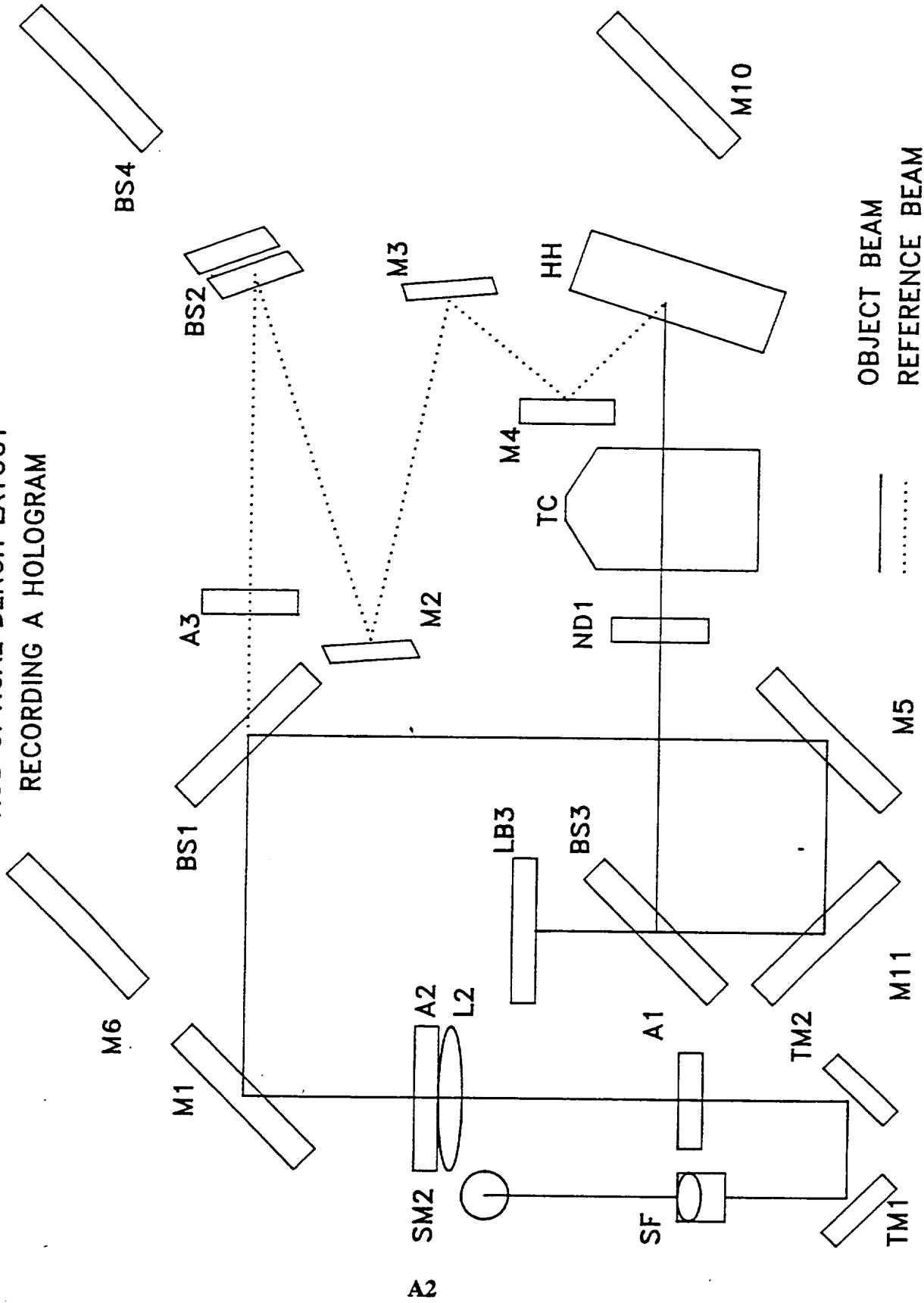
hologram. After all necessary images are surveyed in one plane, the procedure may be repeated for the remaining planes. This approach is used to minimize position errors induced by the switching of step motors with the UNIDEX controller.

Conclusions

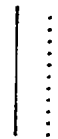
Having used these methods to record and store the crystal growth data, researchers have made several conclusions. From the recorded images and the tracked particles, researchers found that particle motion did not obey the model of g-jitter that they had thought. They concluded that possibly g-jitter was a function of time and spatial coordinates. Researchers believed that the growth rate of the crystal was lesser affected by higher frequencies of g-jitter. However, the crystal grown in space was used to create a detector which had an improved detectivity. Researchers had hoped to prove that crystals grown in space are, more-or-less, perfect. They did show, however, that the growth on the TGS crystal was more uniform than one grown in our atmosphere on Earth.

APPENDIX A
OPTICAL BENCH LAYOUTS

HGS OPTICAL BENCH LAYOUT RECORDING A HOLOGRAM



OBJECT BEAM
REFERENCE BEAM



HGS REAL TIME CLASSICAL M. Z. INTERFEROMETER 1

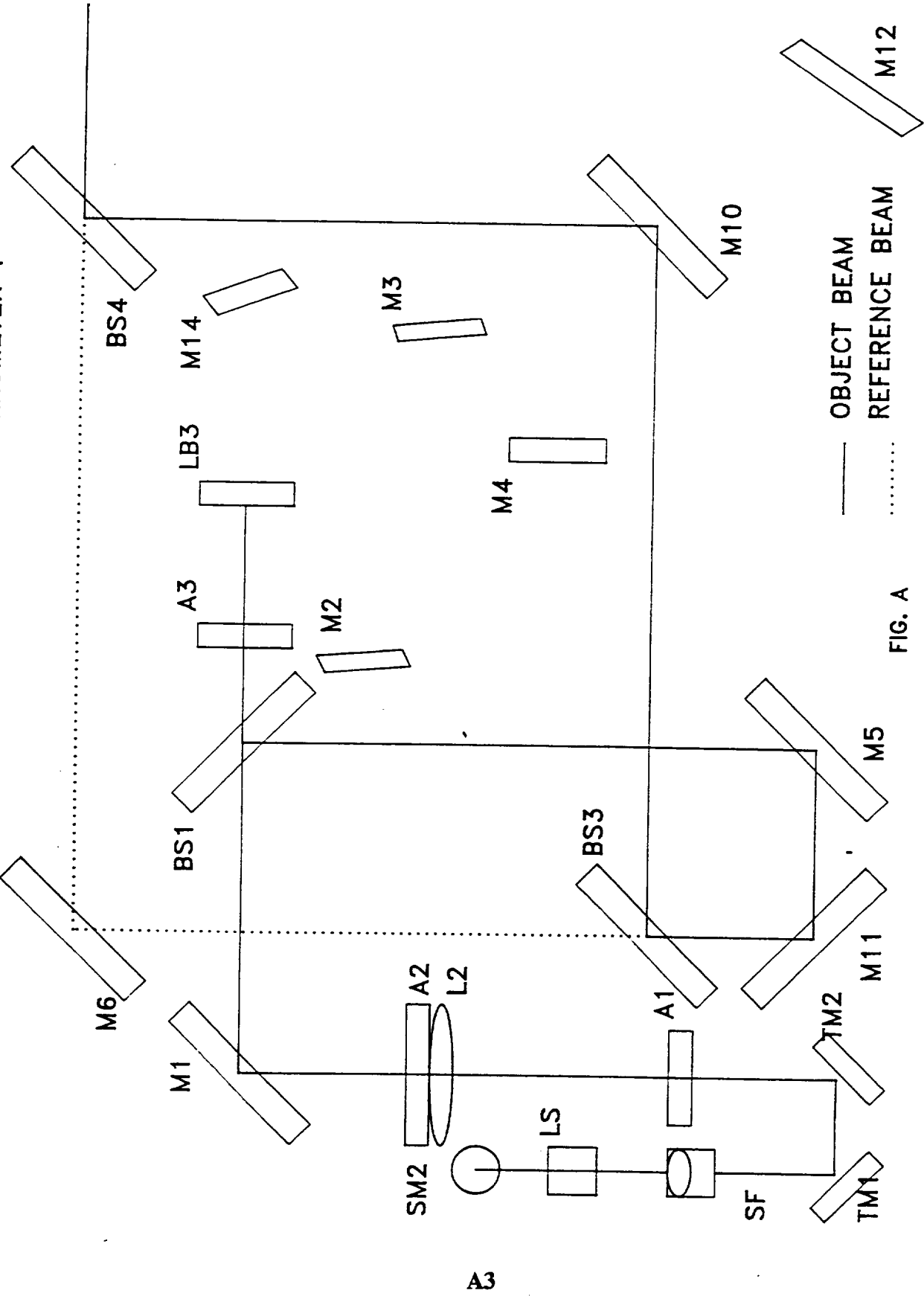


FIG. A

HGS REAL TIME CLASSICAL M. Z. INTERFEROMETER 2

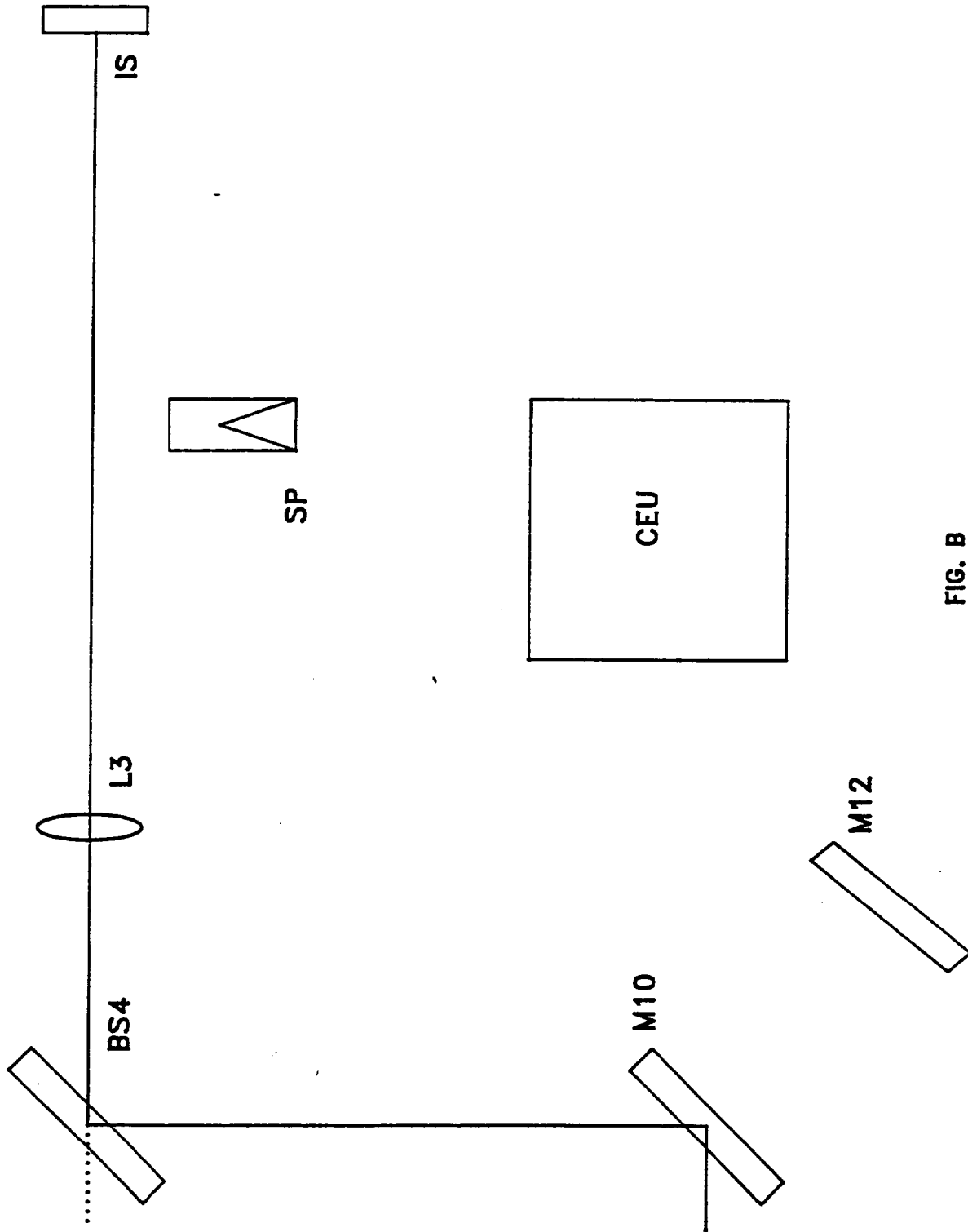


FIG. B

HGS HOLOGRAPHIC CONSTRUCTION AND REAL TIME VIDEO 1

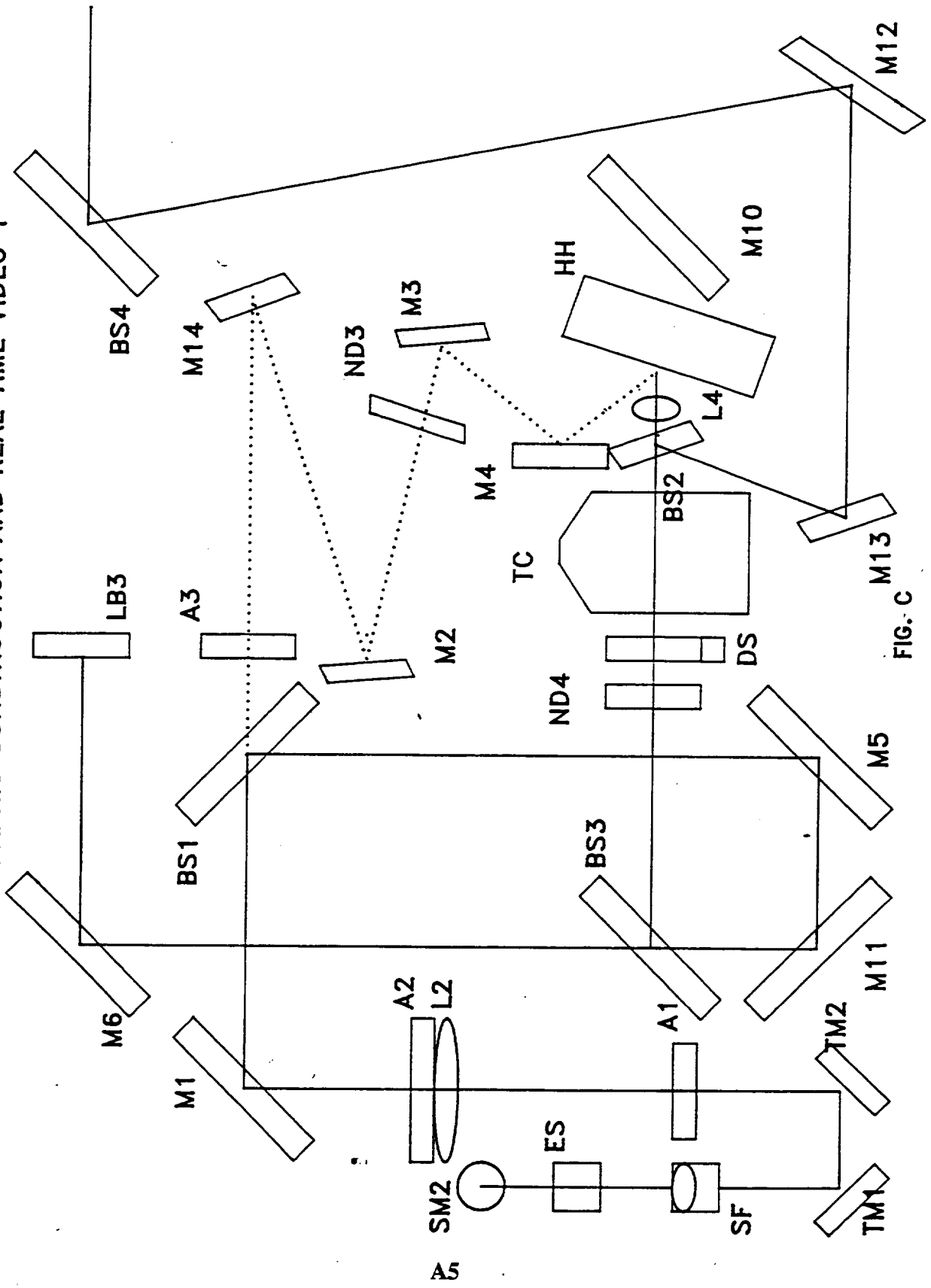


FIG. C

HGS HOLOGRAPHIC CONSTRUCTION AND REAL TIME VIDEO 2

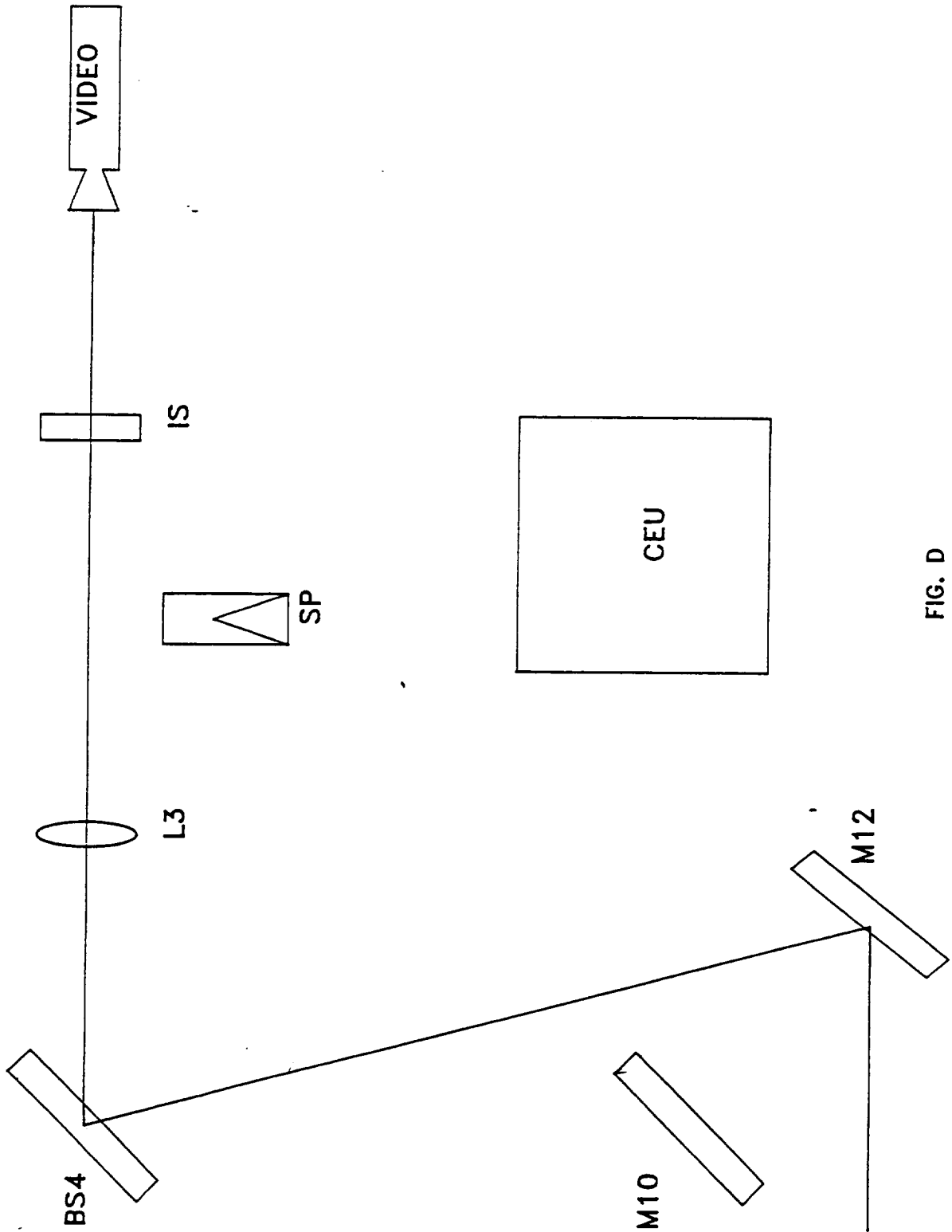


FIG. D

HGS HOLOGRAM RECONSTRUCTION

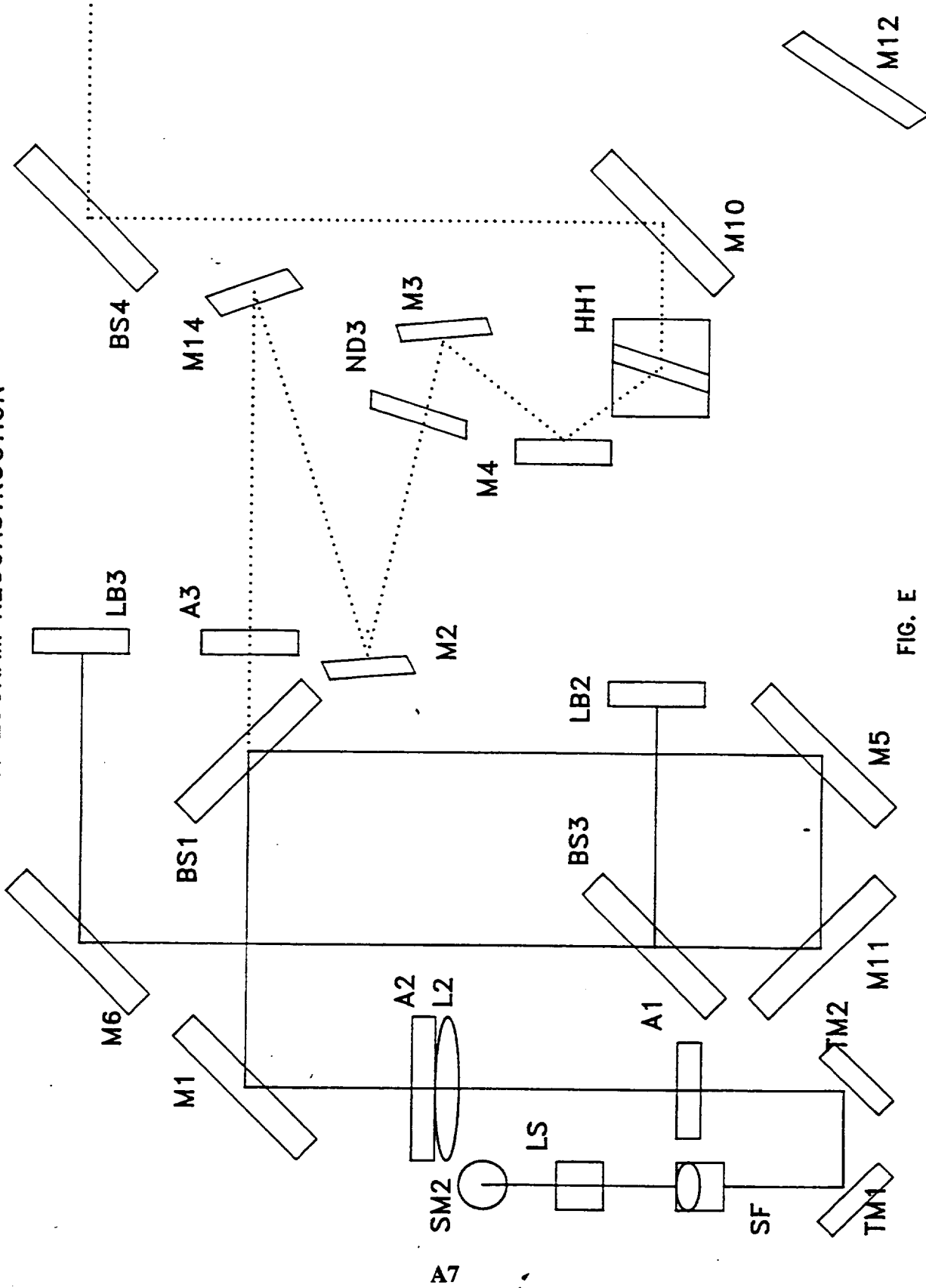


FIG. E

HGS MICROSCOPY WITH RECONSTRUCTED HOLOGRAM

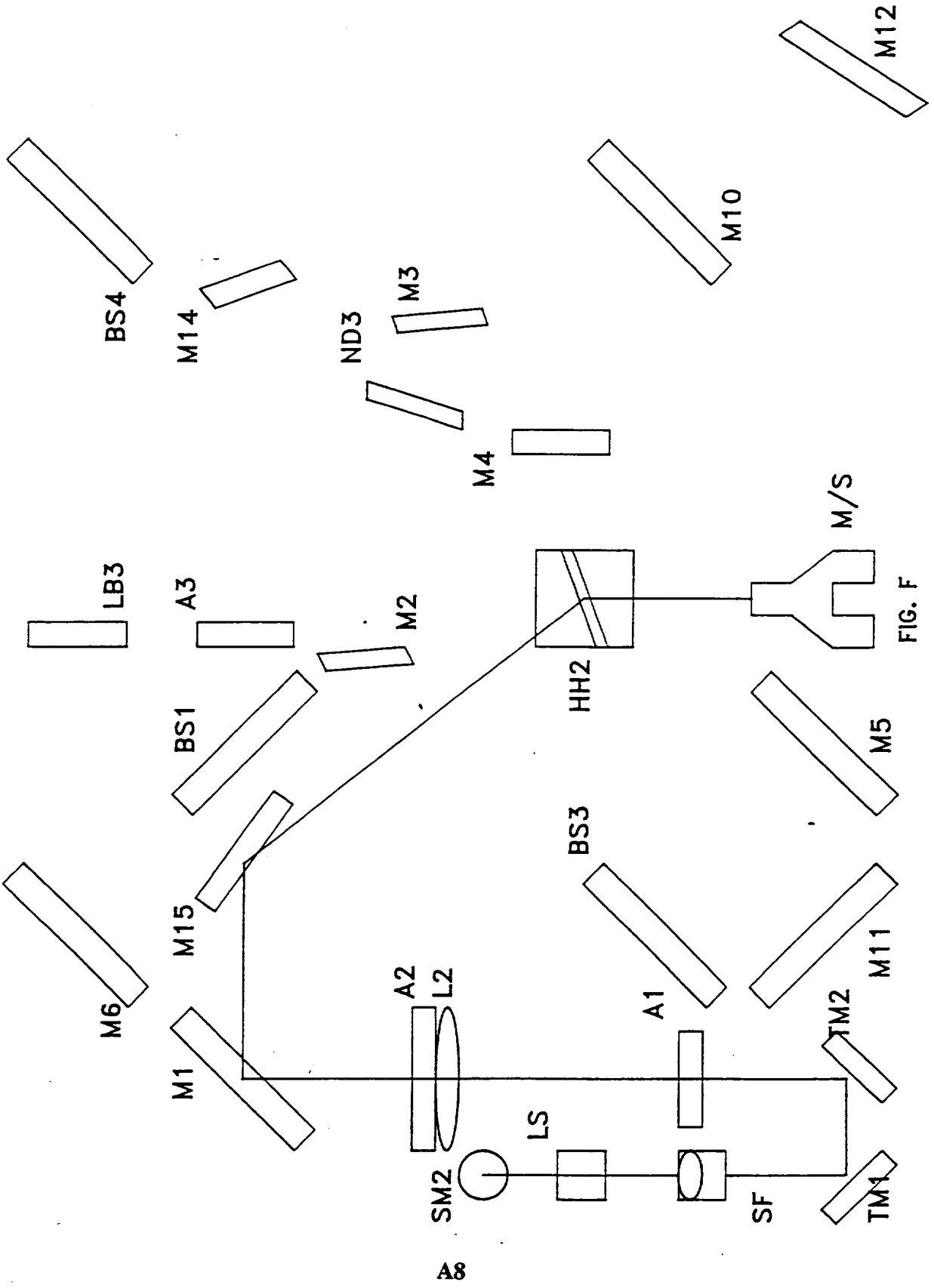


FIG. F

HGS HOLOGRAM INTERFEROMETRY RECONSTRUCTION 1

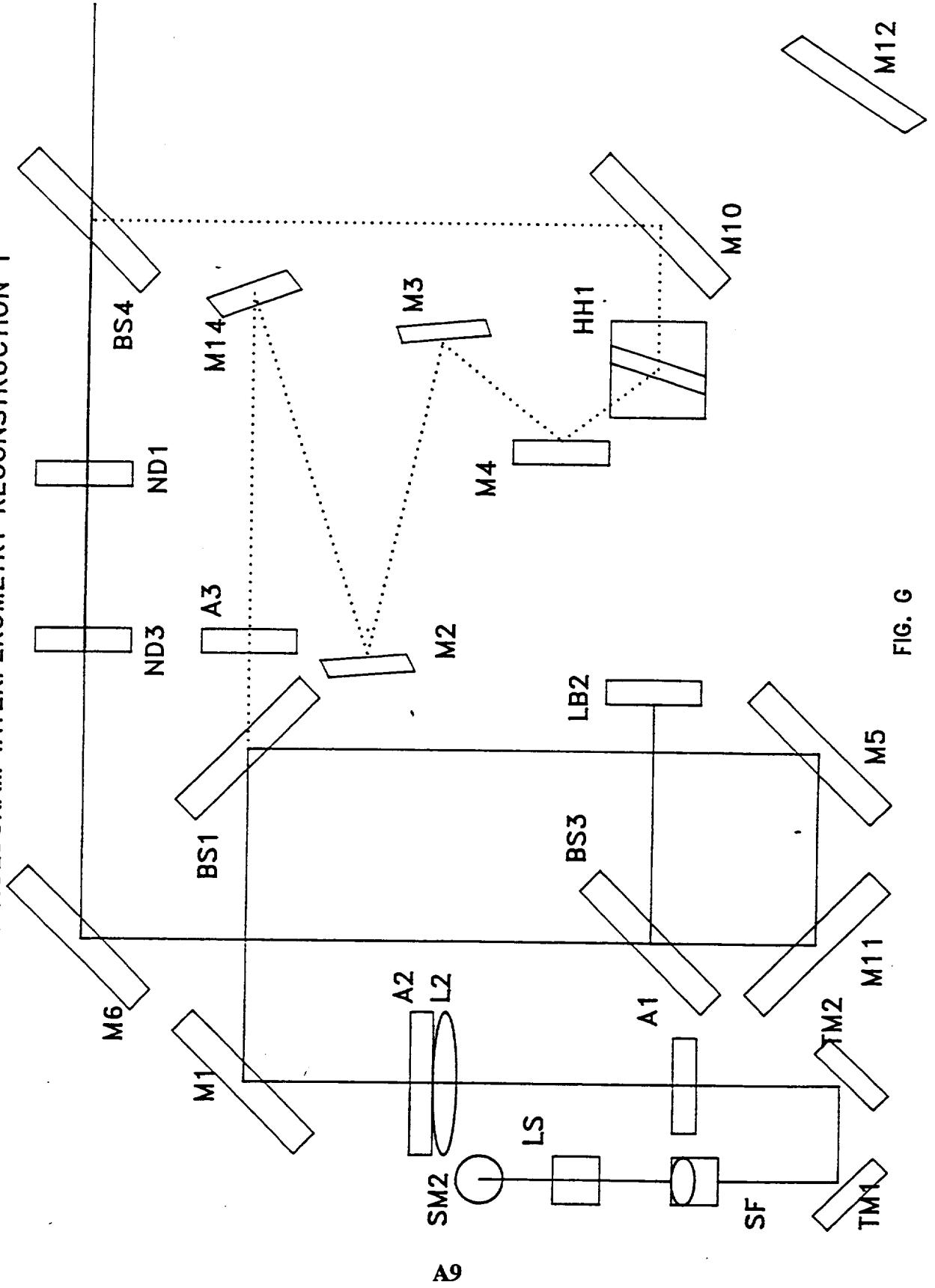
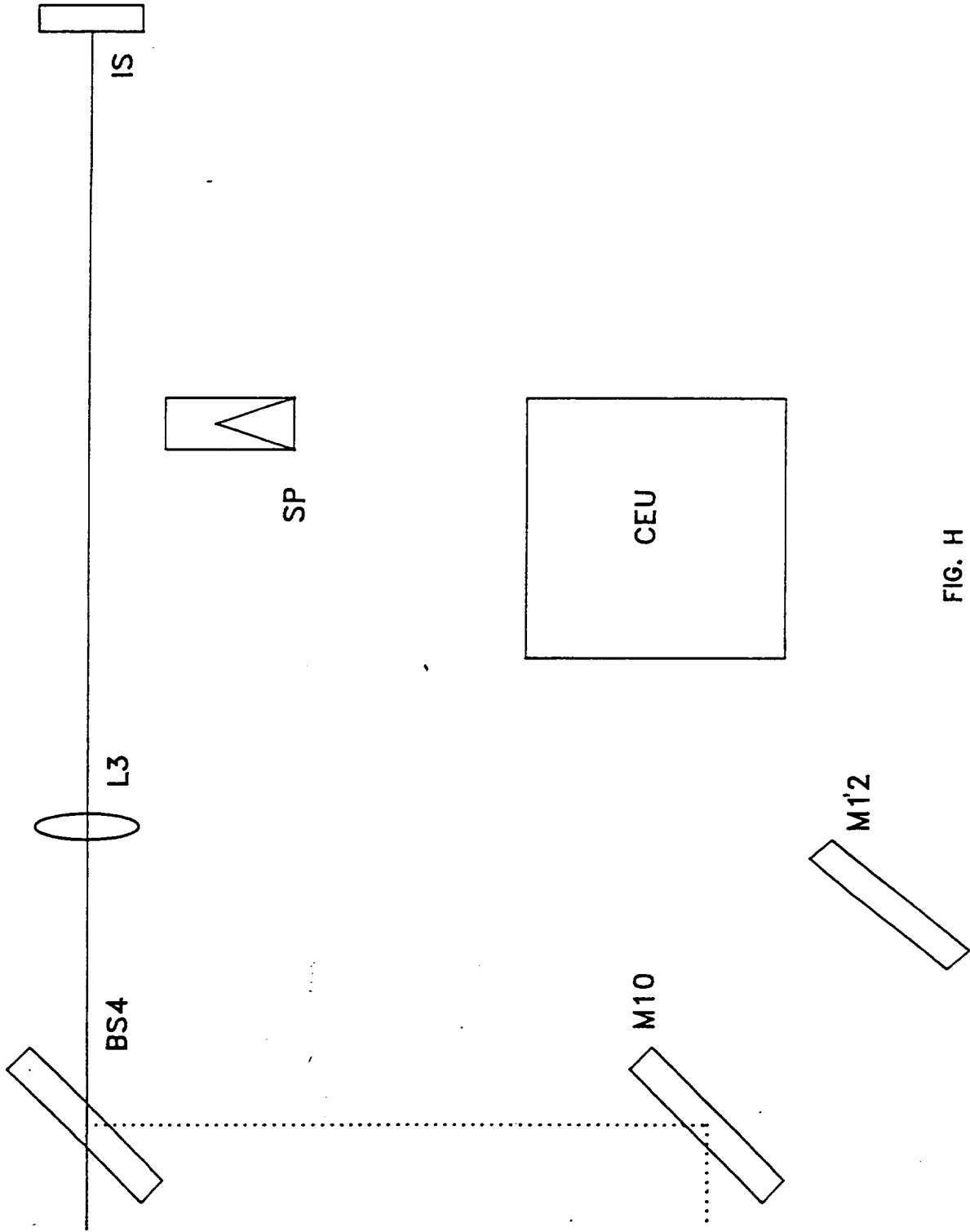


FIG. G

HGS INTERFEROMETRY RECONSTRUCTION 2



A10

FIG. H

HGS SCHLIEREN RECONSTRUCTION 2

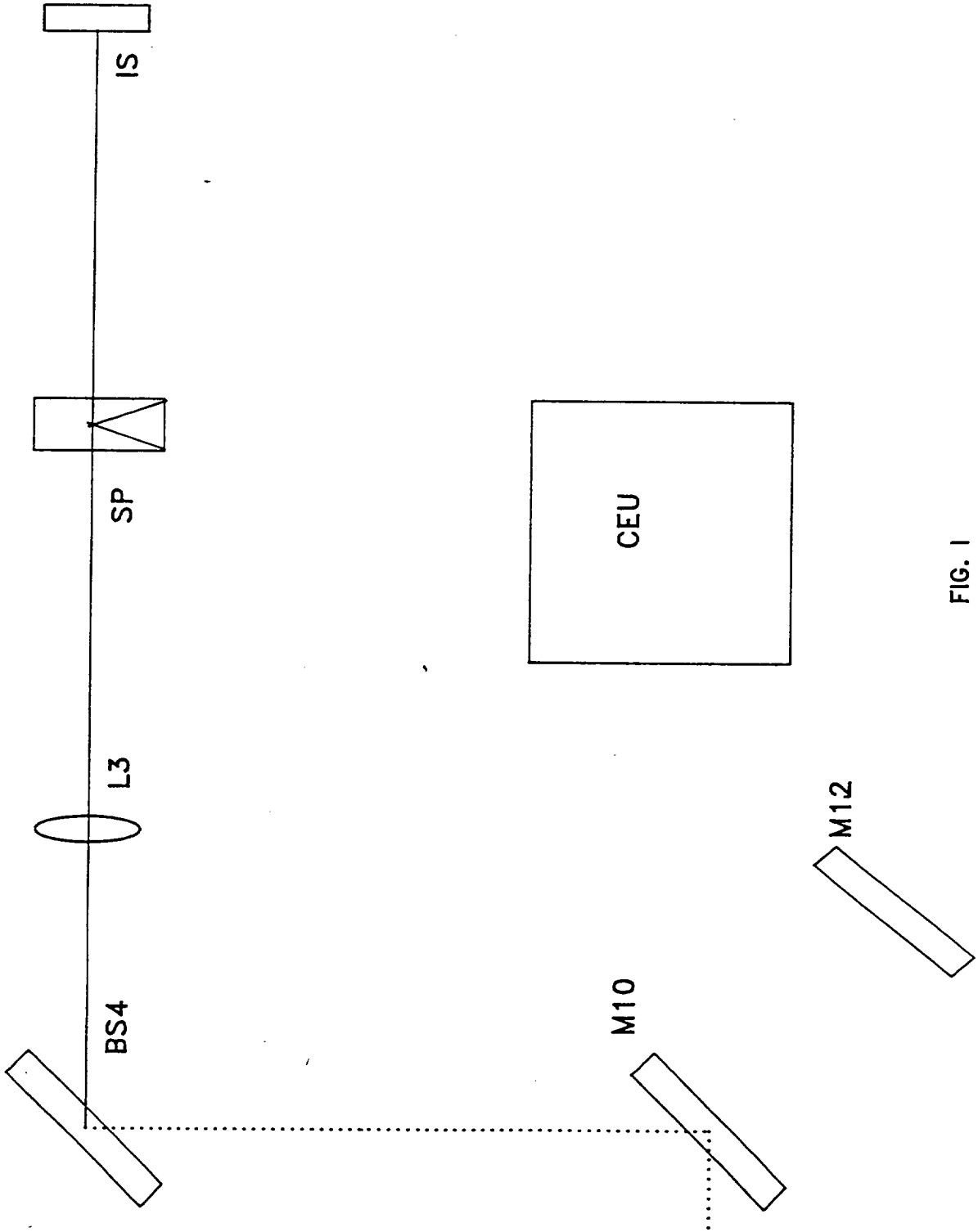
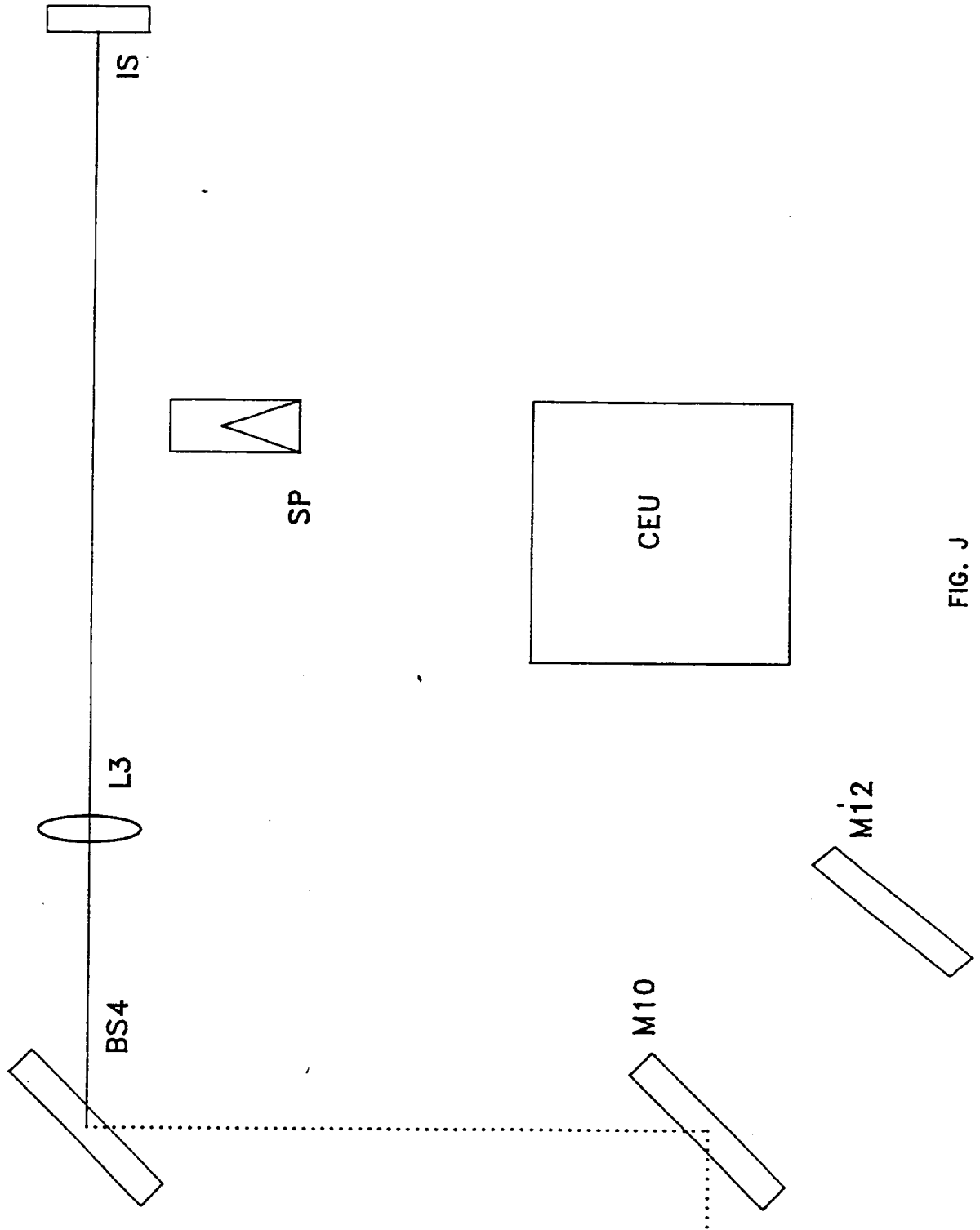


FIG. 1

HGS SHADOWGRAPH RECONSTRUCTION 2



A12

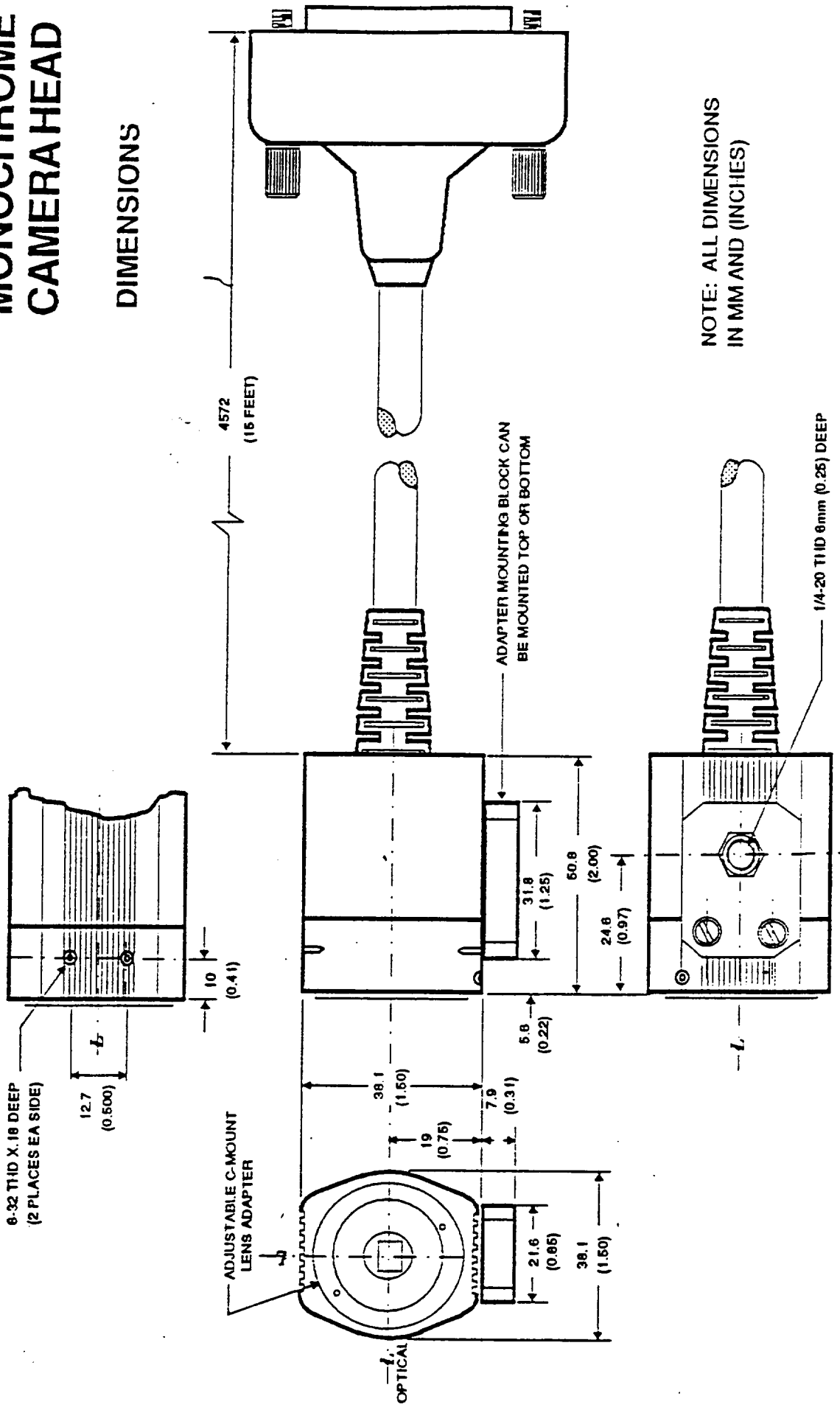
FIG. J

APPENDIX B

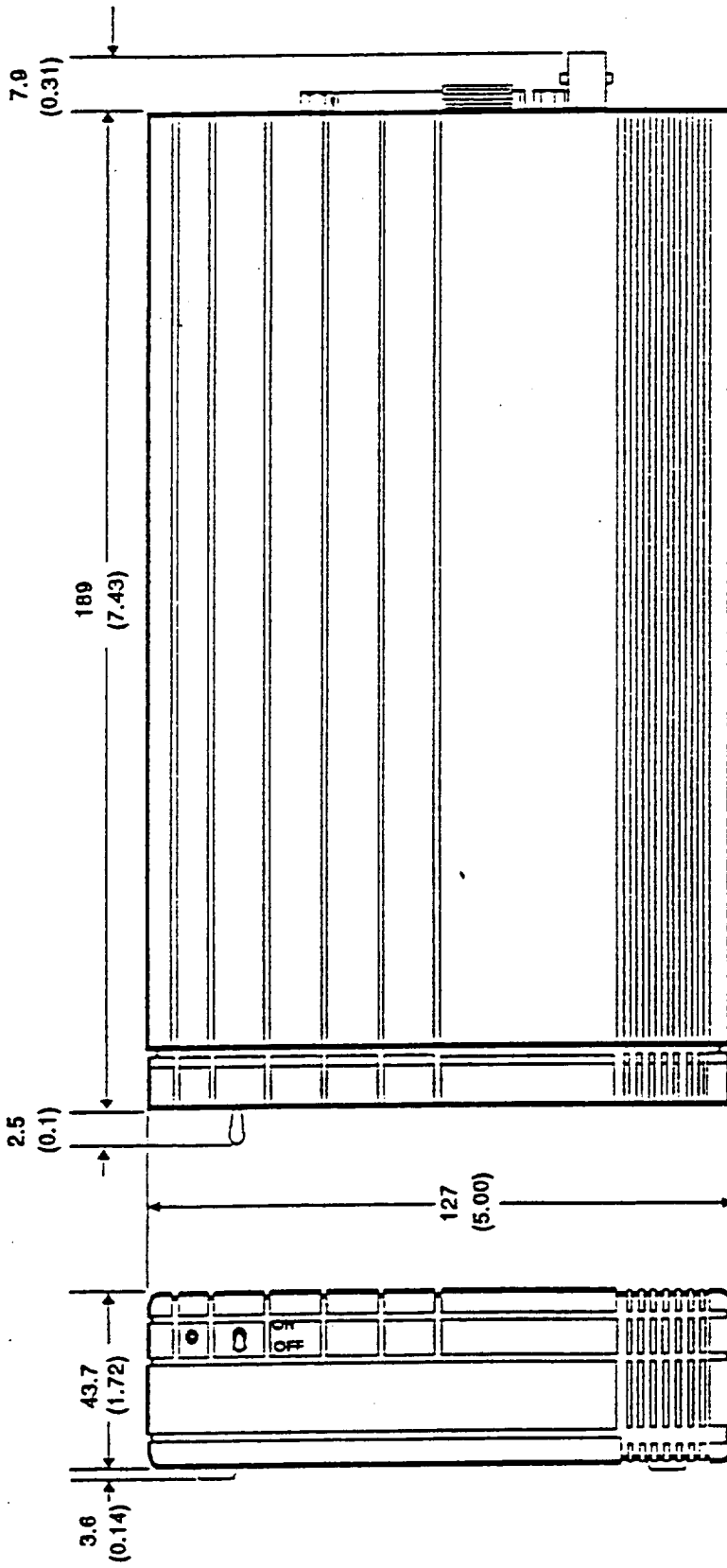
ILLUSTRATION OF CAMERA SYSTEM

MONOCHROME CAMERA HEAD

DIMENSIONS

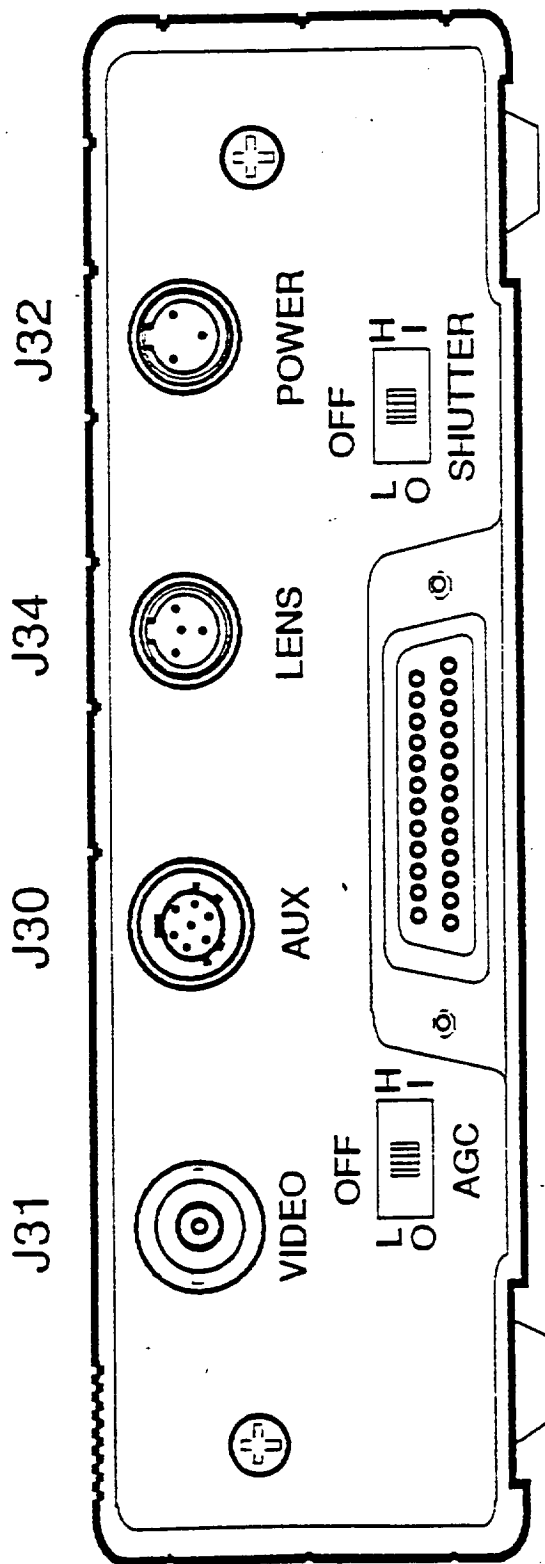


NOTE: ALL DIMENSIONS
IN MM AND (INCHES)



**CAMERA
CONTROL
UNIT**

DIMENSIONS



J33
CCU Rear Panel Connectors

APPENDIX C
CAMERA SYSTEM SPECIFICATIONS

Specifications

ELECTRICAL

Imager	Single CCD using frame transfer method
Image Area	6.4 x 4.8 mm (corresponding to 1/2-inch format)
Active Picture Elements	739(H) x 484(V)
Number of Pixels	774(H) x 242(V)
Cell Size	8.5 μm (H) x 19.75 μm (V)
Resolution	Horizontal: 550 tv lines Vertical: >350 tv lines
Sensitivity	(2850 K faceplate illumination) See table 1A
Contrast Variation	<5% overall at 25 °C
Video Output	1.0 Vp-p, 75 ohm, unbalanced
Auto Black	Maintains setup at 7.5 \pm 5 IRE units if picture contains at least 10% black
Gamma	0.5 or 1.0, jumper selectable
Agc, internally peak-average adjustable; switch selectable, rear of CCU	Off: fixed gain Low agc: 0 to 6 dB gain High agc: 0 to 20 dB gain
Auto Lens Drive Signal	Separate auto-lens video eliminates agc/auto-lens interaction. Internal agc peak-average adjustment
Signal-to-Noise Ratio	55 dB (gamma 1, gain 0 dB) 8 MHz bandwidth, unweighted
Electronic shutter, switch selectable, rear of CCU	Off: standard (1/60 s) Low: 1/1000 s High: 1/2000 s
Sync References	Standard: RS-170 crystal Optional: genlock (with horizontal phase adjustment) and H and V drive Optional: zero-crossing line-lock, internally selectable in 60° increments, 0° to 300°
Power Options	Ac or dc 12 V \pm 10% Ac 115 V \pm 10%, 60 Hz (with wall transformer)
Power Consumption	4.2 watts

ENVIRONMENTAL

Ambient Temperature Limits	Operating: -10 to 50 °C (14 to 122 °F) Storage: -30 to 70 °C (-22 to 158 °F)
Humidity	Up to 95% relative humidity, noncondensing
Vibration	15 g's at 60 Hz. From 60 to 1000 Hz, 5 g's rms random vibration without damage.
Shock (less lens)	Up to 15 g's in any axis under nonoperating conditions per MIL-E-5400T, paragraph 3.2.24.6: Camera Head up to 30 g's
Altitude	Sea level to equivalent of 3048 meters (10,000 feet) [508 mm/20 inches of mercury]

MECHANICAL

Dimensions	See fig. 1 and 2
Weight	Camera head, less lens: 113 grams (4 oz) CCU: 822 grams (29 oz)
Lens Attachment	C-mount
Lens	Accepts most types of manual- and auto-iris tv lenses
Camera Head Mounting	6-32 holes top (2) and bottom (2); adaptor provides single 1/4-20 hole. See fig. 1
Connectors	See fig. 3 and table 3

APPENDIX D

IMAGE TRANSFER AND STORAGE PROCEDURE

IMAGE TRANSFER AND STORAGE PROCEDURE

The following steps will allow the user to store image files on the optical disk housed in SSL (Space Science Lab). This procedure assumes that the images have already been acquired using the CHIP program and are stored on the Bernoulli disks.

- Type "CD DECNET" to change the current directory to the network directory
- Type "STARTNET" to start the network
- Type the username and password at the SSLMOR VAX prompt:
 USERNAME: _____
 PASSWORD: _____
(The system forces a password change periodically.)
- Create the needed directories on the SSL VAX scratchpad:
 CREATE /DIR SSL\$SCRATCH:[SCRATCH.2T1CP099]
- Type "set host sam" to logon onto the SAM VAX
- Type the username and password at the SAM VAX prompt:
 USERNAME: _____
 PASSWORD: _____
(The SOAR software menu should appear.)
- Use the OMOUNT (option #3) menu selection to mount the optical disk:
 - accept default pseudo device name (QSA0:)
 - accept default physical device name (SAM\$DUA0:)
 - specify the magfile disk and filename:
 DISK3:[SOARDATA]MAG.IML1_PC.\$SOAR\$
 - answer "Y" to the /SYSTEM prompt
 - answer "Y" to the /WRITE prompt
 - answer "N" to the /NOSECURE prompt
- + Press <CTRL + F9> to get back to the DOS prompt
- + Type NFT to enter the Network File Transfer program
- + Transfer the image files using the following syntax
 COPY/IMAGE E:\2T1CP099*.*
 SSLMOR"HGS"::SSL\$SCRATCH:[SCRATCH.2T1CP099]*.*
(The previous step copies the images from the Bernoulli disk to the directory specified on the SSLMOR disk.)
- + Type "exit" to return to the DOS prompt

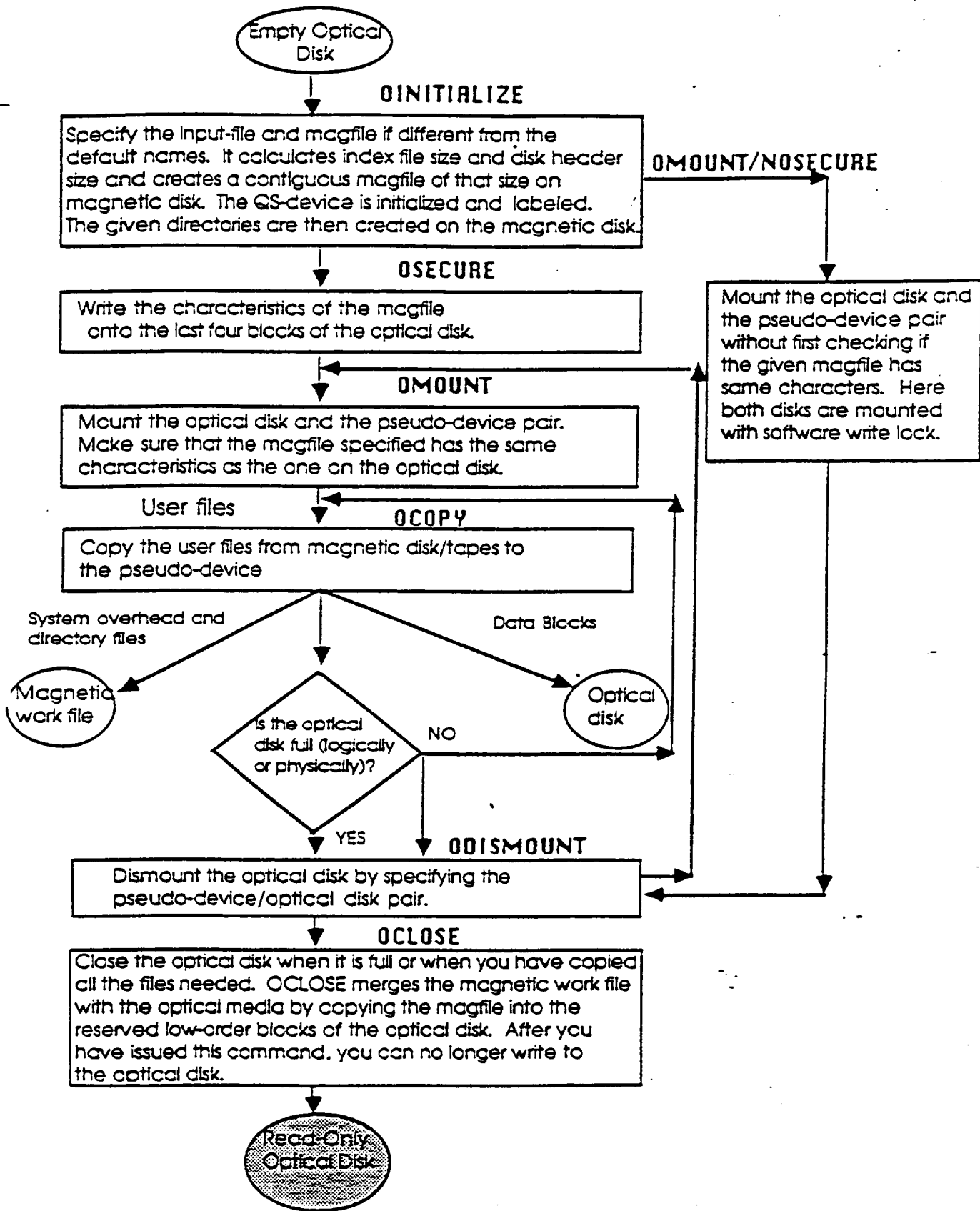
- + Type "exit" to return to the SAM VAX prompt
- + Use the OCOPY (option #4) menu selection to copy files to the optical disk:
 - specify input file
SSL\$SCRATCH:[SCRATCH.2T1CP099]*.*
 - specify output file
QSA0:[RUN1C.RUN1C_090S.099]*.*
 - answer "Y" to the /LOG prompt
 - answer "Y" to the /VERIFY prompt
 - answer "Y" to the /ERROR prompt
- Repeat the steps marked above with the "+" symbol until all the image files have been copied to the optical disk

NOTE: At this point in the procedure all the files should have been successfully copied onto the optical disk. The following steps prepare the optical disk for removal and cleans up the SSLMOR VAX scratchpad disk.

- Use the ODISMOUNT (option #5) menu selection to dismount the optical disk
 - accept default pseudo device name (QSA0:)
 - accept default physical device name (SAM\$DUA0:)
 - enter disk label (IML1_MIC_PC)
- Use the LOGOFF FROM THE NODE (option #0) menu selection to escape from the SOAR software. This will put you back to the SSLMOR VAX prompt.
- Delete all the files in each subdirectory created on the scratchpad disk:
DEL SSL\$SCRATCH:[SCRATCH.2T1CP099]*.*;*
- Change the protection for each subdirectory created on the scratchpad disk:
SET PROTECTION SSL\$SCRATCH:[SCRATCH]2T1CP099.DIR
/PROTECTION=OWNER:D
- Delete each subdirectory that was created:
DEL SSL\$SCRATCH:[SCRATCH]2T1CP*.DIR;*

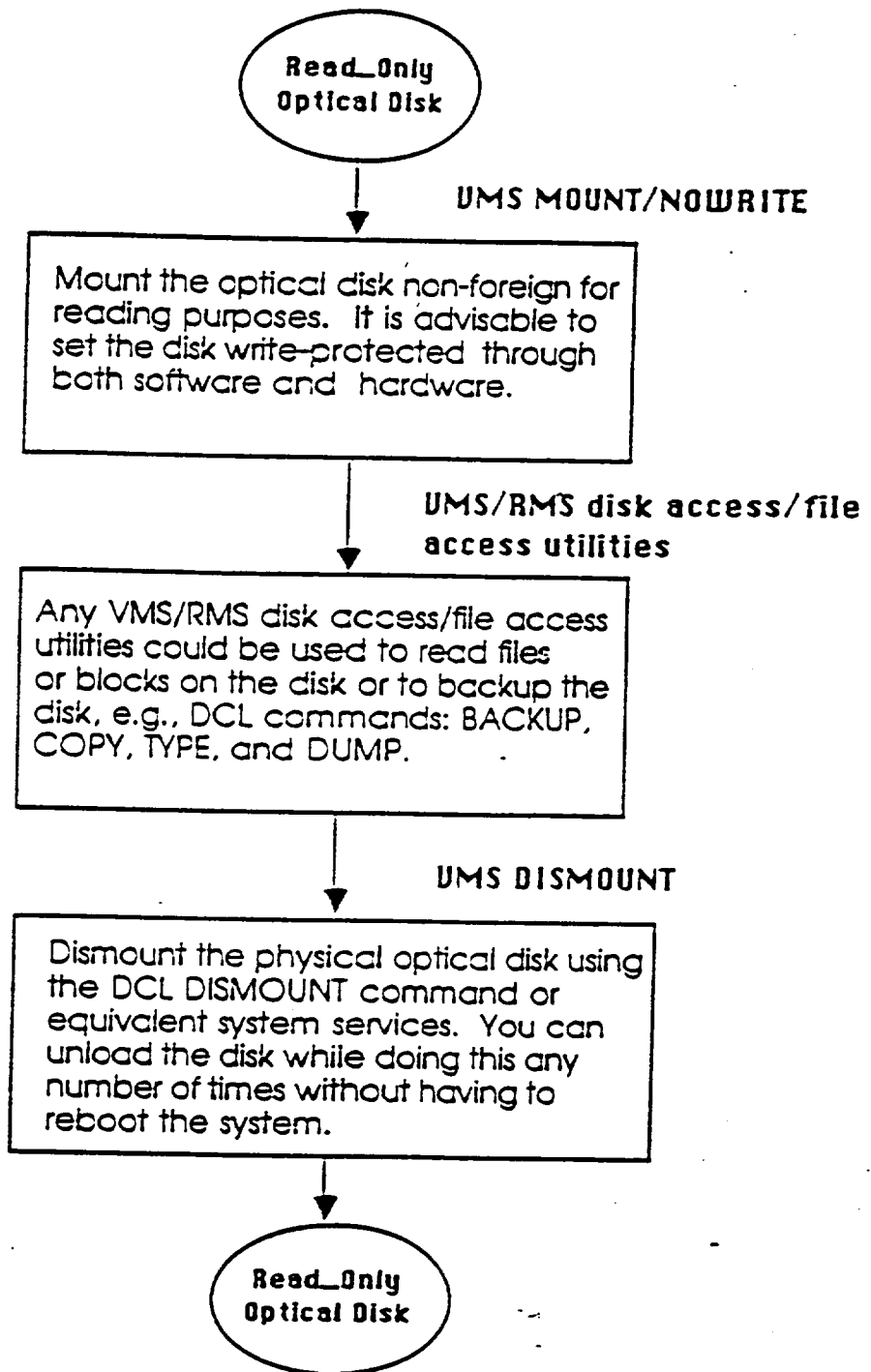
APPENDIX E

**ALGORITHMS FOR READING FROM AND WRITING
TO THE OPTICAL DISK**



Actions taken during the write phase of the optical disk.

All SOAR operations are done on the QS-device. Only the OCOPY command should be used to write to the device.



Actions taken during the read phase of the optical disk.

The QSDRIVER and SOAR software are no longer needed and should not be used. All operations should be performed on the physical optical disk.

APPENDIX F

ATS100-200 POSITIONING STAGE SPECIFICATIONS

ATS100-200 Positioning Stage Specifications

Total Travel		200 mm (8 in)	
Mechanical Drive System		Precision ground ballscrew	
Linear Resolution (2 mm lead)		1 μm (40 uin) @2000 steps/rev motor resolution (0.1 μm to 10 μm available)	
Max. Travel Speed:	Stepping Motor	50 mm/sec (2 in/sec)	
	DC Servo Motor	100 mm/sec (4 in/sec)	
	HAL Option	25 mm/sec (1 in/sec)	
Max. Load Carrying Capability:			
	Horizontal	22.7 kg (50 lbs)	
	Vertical	10.0 kg (22 lbs)	
	Side	11.4 kg (25 lbs)	
Accuracy:	Standard	+/- 6 μm (+/- 240 uin)	
	HAL Option	+/- 1 μm (+/- 40 uin)	
Repeatability:	Standard	+/- 0.7 μm (30 uin) bi-directional	
	HAL Option	+/- 0.3 μm (12 uin) bi-directional	
Straightness and Flatness of Travel:			
		<u>Standard</u>	<u>HAL</u>
	Differential	2 μm/25 mm	1 μm/25 mm
	Maximum Deviation	+/- 3 μm	1.75 μm
Nom. Stage Weight:	W/out Motor	1.2 kg (2.6 lbs)	
	W/ Motor	2.8 kg (6.1 lbs)	
Material		Aluminum	
Finish		Stage and table: Clear Anodize	

APPENDIX G
ORIGINAL "IM_GEOM.C" PROGRAM


```

- /*****
- /*
- /*          IM_GEOM.C
- /*
- /* This module contains routines that utilize the Geometry functions
- /* found in ITEX. Included are the image rotation feature and its
- /* backup commands. Copyright (c) 1991: Infrascan Inc. (604) 273-8655
- /*
- /*****

```

```

#include <stdio.h>          /* Necessary initialization header files */
#include <string.h>

```

```

#include "itexsrc.h"
#include "cursor.h"
#include "stddefs.h"
#include "itex150.h"
#include "ms_mouse.h"
#include "menu.h"
#include "util.h"
#include "im_geom.h"      /* header file exclusively for IM_GEOM.C */

```

```

static short ps_x = 120;          /* pan and scroll variables */
static short ps_y = 120;

```

```

- /***** image_geometry() *****/
- /*
- /* This menu is called from the main menu, and handles operations
- /* related to moving and scaling images portions.
- /*
- /*****

```

```

void image_geometry()
{
extern char system_name[];          /* menu header */
extern short x, y, dx, dy;         /* global AOI */
extern int frame;                  /* current frame */
extern int page;                   /* current page */
extern char page_name[];          /* name of current page */
short item_selected;              /* item selected from menu list */
int temppage, tempframe;          /* temporary variables for holding */
char tempname[6];                 /* the current page */
int page1, page2;
short x1, y1, dx1, dy1;
short x2, y2, dx2, dy2;          /* coords of AOI's for area copy etc */
static char *menu_list[] =
{
"Set Area of Interest",          /* Image Geometry Menu */
"Pan and Scroll",
"Hardware Zoom X 1",
"Hardware Zoom X 2",
"Reset Frame Position",
"Mirror AOI on Vertical Axis",
"Squish Image to Area of Interest ",
"Copy Areas",
"Compress Rotate Area of Interest 90 Degrees",
"Software Zoom X 2",
"Software Zoom X 3",
"Software Zoom X 4",
"EXIT to Main Menu"

```

```

item_selected = NONE_SELECTED;                                /* Set up menu screen */
do {
    display_menu(system_name, "Image Geometry Menu", menu_list);
    item_selected = menu_selection(item_selected);

    switch (item_selected) {
    case 0:
        /* Set Area of Interest to execute geometry commands */
        get_aoi(&x, &y, &dx, &dy);
        update_status();
        break;
        .
        .
        .

    case 4:
        /* Reset Frame Position */
        fb_roam(frame, 0, 0);                                /* Resets pan & scroll registers */
        break;
        .
        .
        .

    case 8:
        /* Compress Rotate Area of Interest 90 Degrees */
        rot90(page, page, x, y, dx, dy, 1);
        break;
        .
        .
        .
    }
}
while (strncmp(menu_list[item_selected], "EXIT", 4));

```

APPENDIX H
MODIFIED "IM_GEOM.C" PROGRAM

```

- /*****
- /*
- /*          IM_GEOM.C
- /*
- /* This module contains routines that utilize the Geometry functions
- /* found in ITEX.  Included are the new image rotation features called
- /* Rotate Image Clockwise and Rotate Image Counterclockwise, and their
- /* backup commands, as implemented by Andrea Paseur.
- /* Copyright (c) 1991: Infrascan Inc. (604) 273-8655
- /*
- /*****
-
- #include <stdio.h>          /* Necessary initialization header files */
- #include <string.h>
-
- #include "itexsrc.h"
- #include "cursor.h"
- #include "stddefs.h"
- #include "itex150.h"
- #include "ms_mouse.h"
- #include "menu.h"
- #include "util.h"
- #include "im_geom.h"          /* header file exclusively for IM_GEOM.C */
-
- static short ps_x = 120;          /* pan and scroll variables */
- static short ps_y = 120;
-
- /***** image_geometry() *****/
- /*
- /* This menu is called from the main menu, and handles operations
- /* related to moving and scaling images portions.
- /*
- /*****
-
- void image_geometry()
- {
-     extern char system_name[];          /* menu header */
-     extern short x, y, dx, dy;          /* global AOI */
-     extern int frame;                   /* current frame */
-     extern int page;                    /* current page */
-     extern char page_name[];           /* name of current page */
-     short item_selected;                /* item selected from menu list */
-     int temppage, tempframe;           /* temporary variables for holding */
-     char tempname[6];                  /* the current page */
-     int page1, page2;
-     short x1, y1, dx1, dy1;
-     short x2, y2, dx2, dy2;           /* coords of AOI's for area copy etc */
-
-     static char *menu_list[] =
-     {
-         "Set Area of Interest",          /* Image Geometry Menu */
-         "Pan and Scroll",
-         "Hardware Zoom X 1",
-         "Hardware Zoom X 2",
-         "Reset Frame Position",
-         "Mirror AOI on Vertical Axis",
-         "Squish Image to Area of Interest ",
-         "Copy Areas",
-         "Compress Rotate Area of Interest 90 Degrees",

```

```

- "Rotate Image Counterclockwise", /* new option */
- "Rotate Image Clockwise", /* new option */
- "Software Zoom X 2",
- "Software Zoom X 3",
- "Software Zoom X 4",
- "EXIT to Main Menu"
};

item_selected = NONE_SELECTED; /* Set up menu screen */
do {
- display_menu(system_name, "Image Geometry Menu", menu_list);
- item_selected = menu_selection(item_selected);

- switch (item_selected) {
- case 0:
- /* Set Area of Interest to execute geometry commands */
- get_aoi(&x, &y, &dx, &dy);
- update_status();
- break;
- .
- .
- .

- case 4:
- /* Reset Frame Position */
- fb_roam(frame, 0, 0); /* Resets pan & scroll registers */
- break;
- .
- .
- .

- case 8:
- /* Compress Rotate Area of Interest 90 Degrees */
- rot90(page, page, x, y, dx, dy, 1);
- break;

- case 9:
- /* Rotate Image Couterclockwise */
- rotate(page, page, x, y, dx, dy, -1); /* rotate by -1 deg. */
- break;

- case 10:
- /* Rotate Image Clockwise */
- rotate(page, page, x, y, dx, dy, 1); /* rotate by 1 deg. */
- break;
- .
- .
- .

- }
- }
- while (strncmp(menu_list[item_selected], "EXIT", 4));
- }
- .
- .
- .

```

APPENDIX I

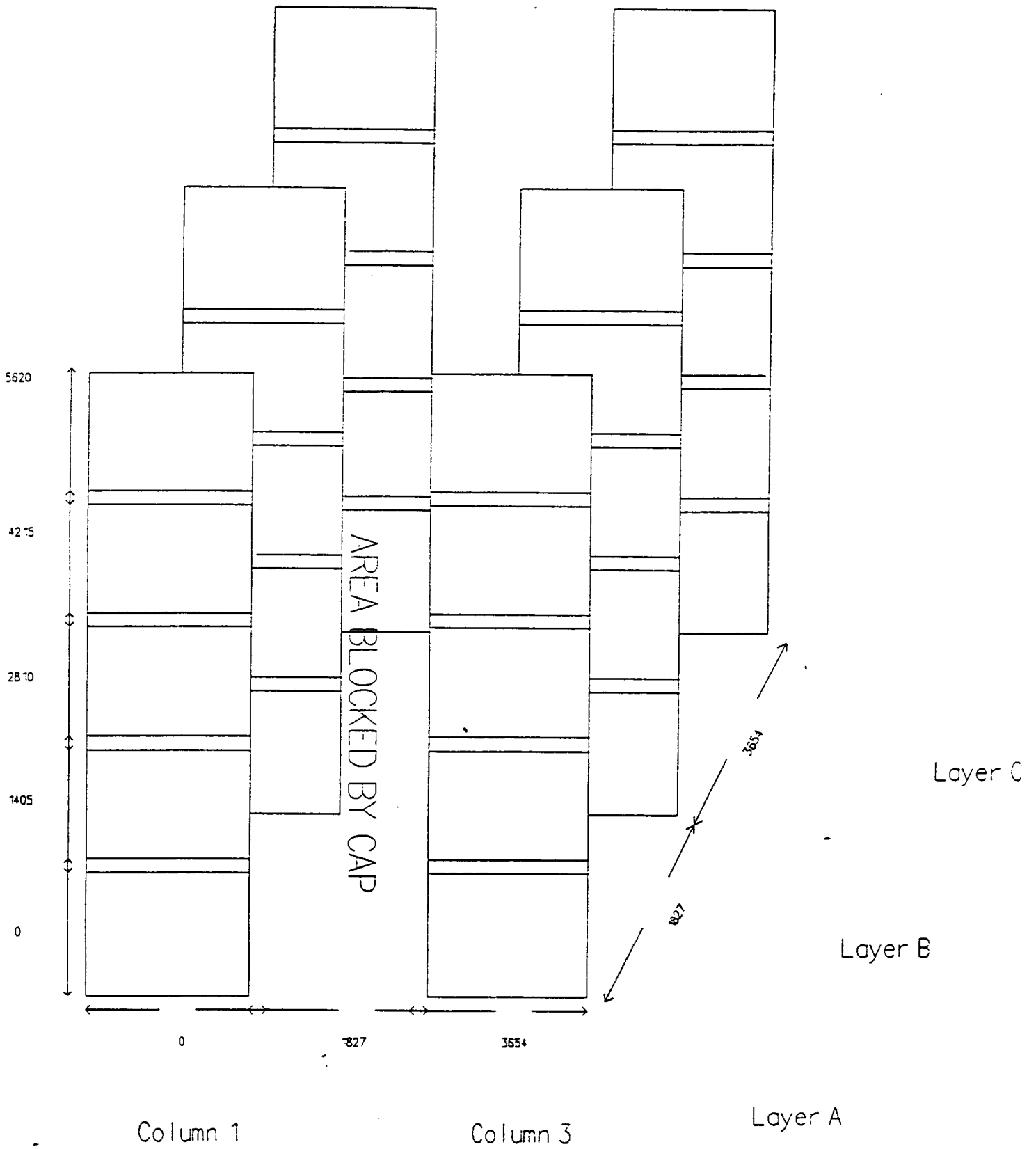
**IMAGE MATRICES AND ACQUISITION
PROCEDURES**

IMAGE ACQUISITION PROCEDURE FOR THE TGS 1A EXPERIMENT

Using the Unidex, move the camera to the reference point on the image.
While in the appropriate directory, enter the CHIP program.
If the camera is not in the correct plane of focus, move to it now.

```
CM TRANSLATION
HOLOCODE
ANGLE 1(PLANE A,B,ORC)
AUTOGRAB
INC X -100
GO
INC X 0
INC Y -1405
GO (4 TIMES)
ANGLE 3(PLANE A,B,ORC)
INC X 8400
INC Y 0
GO
INC X 0
INC Y 1405
GO (3 TIMES)
AUTOGRABOFF
RESET X,Y
AUTO UNIDEX OFF
UNIDEX ONLINE OFF
EXIT
EXIT
```

RUN 1A IMAGE MATRIX



All units in steps (1 step = 5 microns)

Frame size = 2030W x 1562H

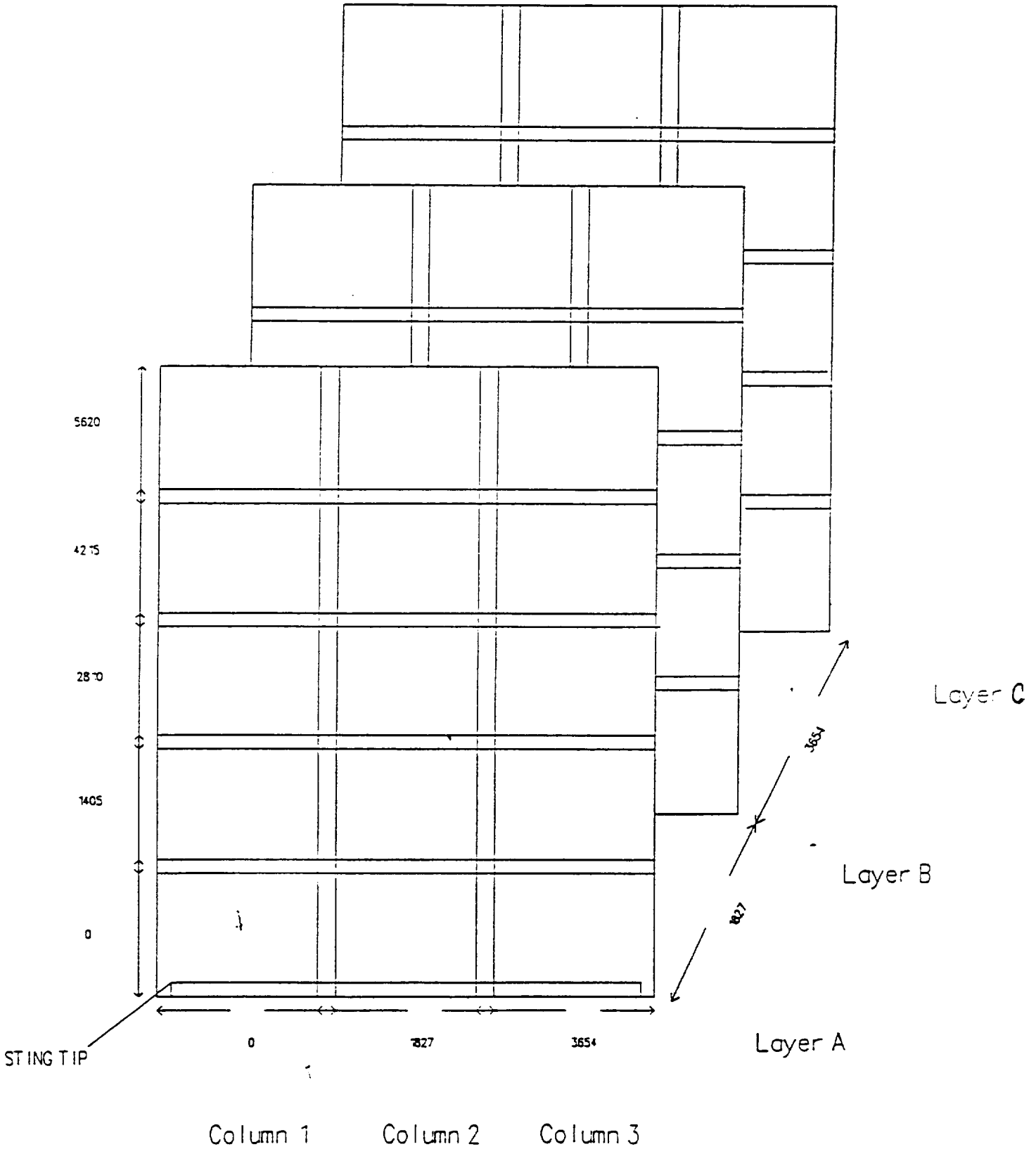
A36

IMAGE ACQUISITION PROCEDURE FOR THE TGS 1C EXPERIMENT

Using the UNIDEX, move the camera to the reference point on the image. While in the appropriate directory, enter the CHIP program. If the camera is not in the correct plane of focus, move it now.

```
CM TRANSLATION
HOLOCODE
ANGLE 1(PLANE A, B, OR C)
AUTOGRAB
INC X 500
GO
INC X 0
INC Y -1405
GO (4 TIMES)
ANGLE 2(PLANE A, B, OR C)
INC X 1827
INC Y 0
GO
INC X 0
INC Y 1405
GO (4 TIMES)
ANGLE 3(PLANE A, B, OR C)
INC X 1827
INC Y 0
GO
INC X 0
INC Y -1405
GO (4 TIMES)
AUTOGRAB OFF
RESET X,Y
AUTO UNIDEX OFF
UNIDEX ONLINE OFF
EXIT
EXIT
```

RUN 1C IMAGE MATRIX



All units in steps (1 step = 5 microns)

Frame size = 2030W x 1562H



Report Documentation Page

1. Report No.		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Optical Analysis of Crystal Growth				5. Report Date	
				6. Performing Organization Code UAH/CAR	
7. Author(s) Gary L. Workman Andrea Passeur Sabrina Harper				8. Performing Organization Report No.	
				10. Work Unit No.	
9. Performing Organization Name and Address University of Alabama in Huntsville Research Institute, Box 212 Huntsville, Alabama 35899				11. Contract or Grant No. NAS8-38609 D.O. 97	
				13. Type of Report and Period Covered Quarterly	
12. Sponsoring Agency Name and Address				14. Sponsoring Agency Code NASA/MSFC	
				15. Supplementary Notes	
16. Abstract Processing and data reduction of holographic images from Spacelab presents some interesting challenges in determining the effects of microgravity on crystal growth processes. Evaluation of several processing techniques, including the Computerized Holographic Image Processing System and the image processing software ITEX150 will provide fundamental information for holographic analysis of the space flight data.					
17. Key Words (Suggested by Author(s)) Holography, Schlieren, Microgravity Materials Processing, Crystal Growth			18. Distribution Statement cc. CN22D (3) AT-01 (1) EL64/McIntosh (1) ONRR (1) NASA/Sci. & Tech. Inf. Fac. (1+ repro) Vaughan/UAH (1)		
19. Security Classif. (of this report)		20. Security Classif. (of this page)		21. No. of pages	22. Price