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DESIGN OF AN EXPERIMENTAL PROGRAM FOR EVALUATION OF LBR SYSTEMS--ETC(U)

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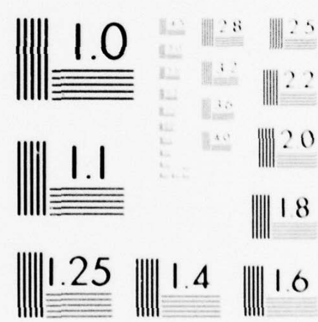

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Design of an Experimental Program for Evaluation of LBR Systems

AD A071526

Dr. N. Balasubramanian
Bala
P. O. Box 884
Cupertino, CA 95014

April 1979

Prepared for

U. S. ARMY CORPS OF ENGINEERS

ENGINEER TOPOGRAPHIC LABORATORIES

FORT BELVOIR, VIRGINIA 22060

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: 18 ETL-0182	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. ~~TITLE (and Subtitle)~~: 6 Design of an Experimental Program For Evaluation of LBR Systems.	5. ~~TYPE OF REPORT & PERIOD~~ COVERED: 9 Contract Rep[redacted]t.
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 Dr. N./Balasubramanian	8. CONTRACT OR GRANT NUMBER(s): 15 DAAK 70-78-C-0125
9. ~~PERFORMING ORGANIZATION~~ NAME AND ADDRESS: Bala, P.O. Box 884, Cupertino, CA 95014	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA 22060	12. ~~REPORT DATE~~: 11 6 Apr[redacted]79
	13. ~~NUMBER OF PAGES~~: 55
14. MONITORING AGENCY NAME & ADDRESS (if ~~different from Controlling Office~~): 12 48p.	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

LBR Design, LBR Testing

20. ABSTRACT (~~Continue on reverse side if necessary and identify by block number~~)

Design and characteristics of an experimental laser beam recording system (LBR) is presented. The experimental LBR has a scanning subsystem serving both as an image sampler and an image recorder. Specific recommendations for an experimental program are outlined to evaluate EBR parameters and trade offs for selected applications.

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SUMMARY

Many applications in mapping require the use of Laser Beam Recorders(LBR) as output devises. While many complex and expensive LBR systems have been designed and fabricated, a detailed evaluation of the effect of system parameters associated with LBR systems has been lacking. The intent of this investigation is to design an experimental program for such an evaluation from the point of view of mapping applications. In this report a unique eperimental Laser Beam Scanning system to be used an experimental bed is described and its design details are presented. The advantages of the proposed experimental system are also outlined. Some of the experiments, with particular emphasis towards Mapping applications are documented.

1 Introduction

The recent dominant growth of digital processing techniques in various phases of topographic mapping operations has greatly intensified the need for good and economical image recorders to serve as hard copy output devices for computer systems. To date, systems based on laser scanners seem to represent the best candidates to meet such needs. While there has been considerable effort devoted to the design and development of one of a kind laser beam recording systems to meet specific needs, more general evaluation of the system parameters associated with laser beam recording systems has been lacking. Development of more general, simple and economical laser recording systems requires an understanding of the contributions of the system parameters to the overall image quality of the final output and an evaluation of the tolerances associated with hardware implementation. It is in this context that this study is being undertaken to establish the basis for evaluation of the various system parameters associated with a general laser recording system. The main objective of this study is to design an experimental program for evaluating the various system characteristics of laser beam recording systems. In this report, the design and characteristics of an experimental laser beam recording system to be used as an experimental tool for further investigation is presented. The principle of operation of the experimental laser beam scanning system which serves both as an image scanner as well as an image recorder is described. The advantages of the proposed experimental laser beam scanning system are outlined from the viewpoint of the proposed evaluation program. Specific recommendations for an experimental program are made along with a summary and conclusions of this study on the design of the experimental program for the general investigation of laser beam recording systems.

1.2 Objectives

Laser beam recording systems, and in fact any image recording device in general, can be characterized by system parameters that are not specific to any particular system configuration or system design. Examples of such system parameters are:

1. spot size

2. intensity distribution within the spot

3. overlap between adjacent spots

4. overlap between adjacent scan lines

5. method of grey scale modulation

6. dynamic range of modulation

These system parameters not only determine the characteristics of the image produced in terms of resolution and contrast but also greatly influence the susceptibility of the cosmetic quality of the output of the system to errors, such as scan line stability and jitter. Tolerances on hardware components that contribute directly to the above-mentioned system errors determine to a large extent the economics of laser beam recording systems. This is the main motivation behind this proposal for an investigation of the various system parameters associated with laser beam recording systems. The main objectives of this study are:

1. List and characterize the significant system parameters associated with laser beam recording systems.

2. Design a simple experimental laser beam recording system that would permit experimental and empirical evaluation of the various system parameters defined earlier. The laser beam scanning system is to be flexible enough to permit

variations of significant system parameters.

3. Develop test procedures to permit quantitative evaluation of the output generated using the experimental laser beam recording system under conditions of varying system parameter characteristics.

1.3 Scope of this Report

In this report the specifications of the experimental laser beam recorder system are outlined. The proposed experimental laser beam system is then described along with the design details necessary for its fabrication. The advantages of this experimental laser beam system from the viewpoint of the proposed experimental program are outlined. Some of the experiments to be performed with the experimental laser beam recording system are described. Finally, the conclusions of this study are documented along with specific recommendations for follow-on work.

2 Definition of System Parameters and Specification of the Experimental LBR

The main objective of this study is to design an experiment that would permit a general investigation of the effects of various system parameters of the laser beam recorder on the quality of the reconstructed image. Since the output is likely to be used for many applications and subsequent processing and data extraction, the term "quality" has to be based on some measurable parameters and not based on subjective evaluation of the output. The experimental apparatus used during this investigation must be capable of generating reconstructed images that exhibit precisely the characteristics that are likely to be encountered in a practical LBR system. The system parameters that are common to all image recording systems and that have significant impact on the "quality" of the reconstructed image are:

1. the size of the scan spot
2. the intensity distribution within the scan spot
3. the overlap between scan spots along the scan line
4. the overlap between scan lines
5. method of grey scale modulation

6. the dynamic range of grey scale modulation used

7. the nonuniformity of scan spot overlap along the scan line

8. the nonuniformity of scan line spacing

9. registration and geometric fidelity of scan format

10. laser power stability in relation to the modulation frequency

The experimental laser beam recording system to be used in the experimental investigation must possess sufficient flexibility to vary the system parameters listed above. The required specifications of the experimental laser beam recorder are:

1.	Image area	-	50 mm Square
2.	Spot size	-	.02 mm Min and Variable
3.	Number of spots	-	2000 x 2000
4.	Spot overlap	-	90% Max and Variable
5.	Grey scale	-	256:1 Max
6.	Laser Power Density	-	5 W/Cm^2 Max
7.	Type of Film	-	Flexible
8.	Construction	-	Stand alone, Table top operation

3 Description of the Experimental LBR System

The basic principle of a simple laser beam recorder system is shown in Figure 1. The collimated beam from the laser is modulated using the acousto-optic modulator. The scan spot shaping optics produce the laser spot that is to be scanned across the film. The scan optics in conjunction with the scanner form a one-to-one image of the spot produced by the scan spot shaping optics. The galvanometer scanner provides scanning along one direction and the translation stage on which the recording film cartridge is mounted provides scanning along the second direction. While the laser scanner system shown in Figure 1 represents a simple system, it presents a major disadvantage when considered as a candidate for the experimental laser beam recorder to be used for the system parameter evaluation program. The problem is one of management and handling of digital data that is to be used in generating the required image output. The specifications for the experimental laser beam recorder call for an image format of $50mm^2$ and a nominal spot size of 25 microns. This means that the volume of data to be handled during the generating of a single frame is four million points

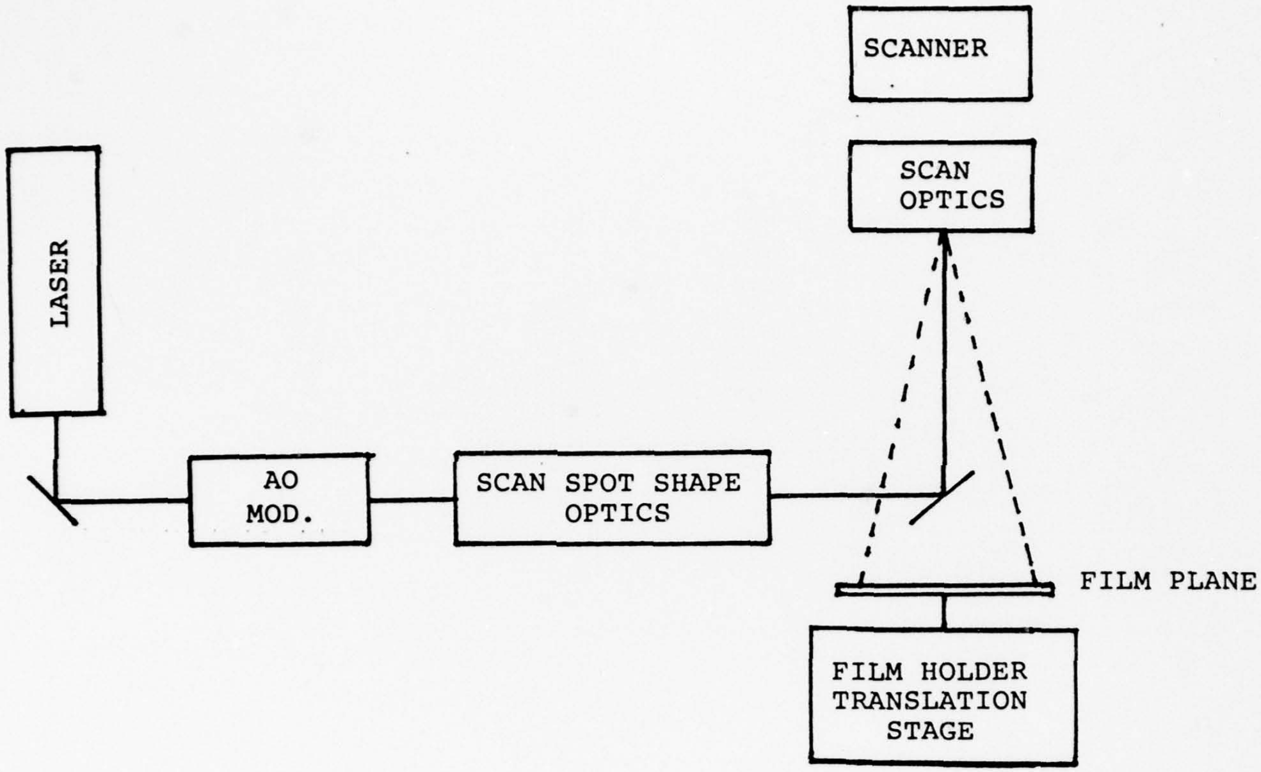


FIGURE 1. Experimental Laser Beam Writer

with eight bits at each point to represent grey scale. This requirement makes a simple and straight forward approach to the design of an experimental laser beam recorder as an experimental tool unattractive.

The problem of managing and handling voluminous data is overcome in the laser beam recorder system shown in Figure 2. The system shown in Figure 2 is similar in concept to the simple system shown in Figure 1, except for the fact that a second channel has been added to serve as an image scanner. In the system shown in Figure 2, orthogonal polarization components are used in the two channels and because the beam splitters BS1 and BS2 are polarization beam splitters, the two channels are totally independent. This permits simultaneous scanning of the two channels without any interactions between them. If a film transparency were to be placed at the final scan plane in channel two as shown in Figure 2, the video signal generated by the scanning spot size on the film transparency can be converted to represent the stream of digital data required to modulate the laser beam in channel one to produce the required final image output. This system organization permits the image transparency to be used as a read-only memory from which the digital data required for the construction of the final output plane is retrieved.

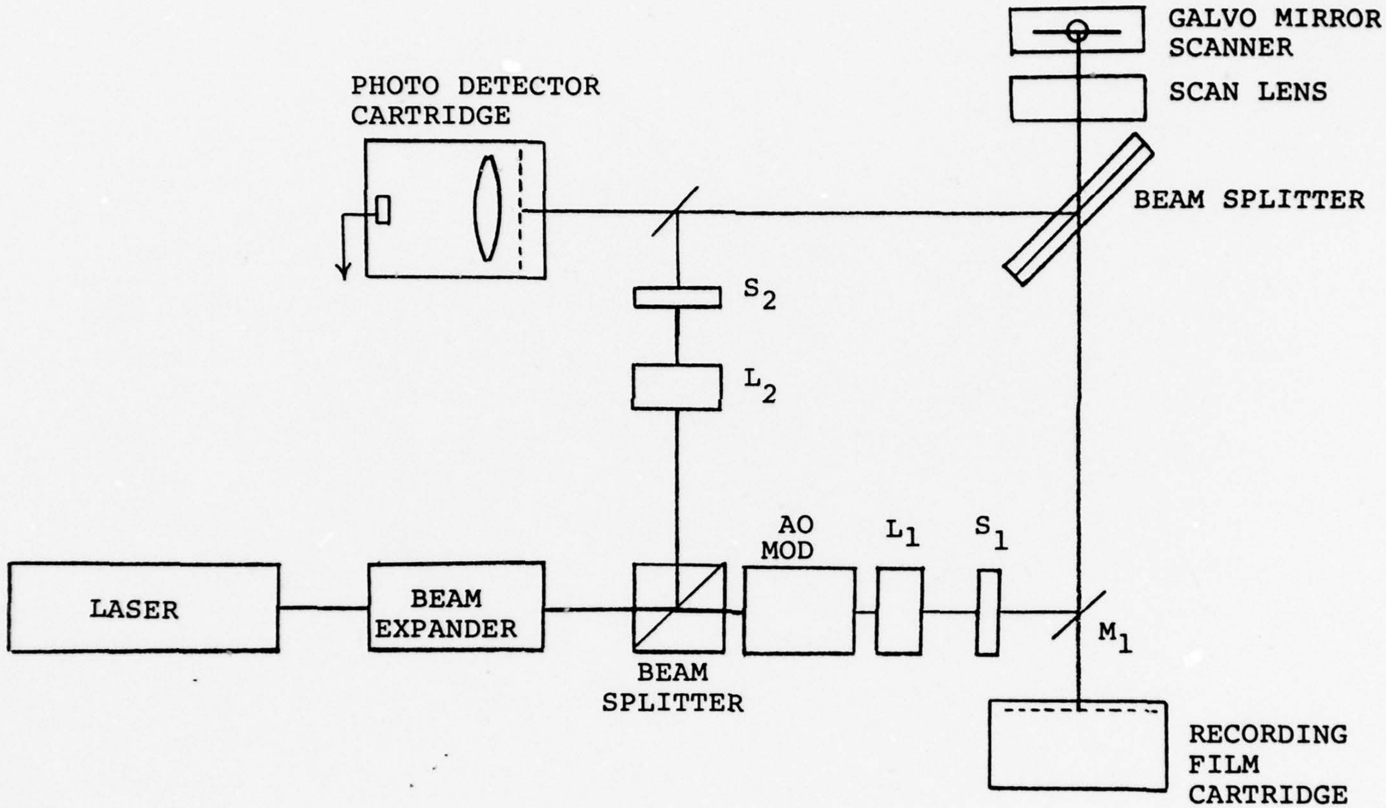


FIGURE 2. Dual Channel Laser Beam Scanning System

The significant advantages of the dual channel laser beam scanning systems are:

1. It overcomes the problem of handling large amounts of data required to generate the test picture.

2. It permits the system to be used as a stand-alone instrument without the need for interfacing with any large or mini computer systems.

3. The scan spot shape of the image scanning channel can be changed easily to simulate any image sampling system independent of the characteristics of the image recording spots.

4. The use of the same scanner for both scanning and image recording simultaneously relaxes the tolerances associated with scan distortion and scan registration requirements.

5. The feasibility to scan and record with differing system parameters extends the scope of experiments that can be performed using this system.

4 Design Details of the Experimental LBS System

The design relating to the hardware implementation of the basic dual channel Laser Beam Scanning System is shown in Figure 3. The components of the system shown in Figure 3 are numbered to permit easy identification and system description. The design of the system is presented in this section by describing the functions of each of the components shown in Figure 3.

1. Laser: The laser to be used in the system is a low power He-Ne laser (about 1 to 2 mw) and the laser beam output is polarized.

2. Laser Mount: The laser mount holds the laser onto the base plate. The laser mount includes pitch and yaw adjustment to permit angular alignment of the laser beam.

3. Base Plate: The base plate provides the reference plane on which all the components of the system are mounted.

4. Folding Mirror: This folding mirror permits the laser beam to be directed to the top side of the base plate. The pitch and yaw adjustments on the folding mirror permit the control of the laser beam direction.

5. Folding Mirror: This folding mirror is identical

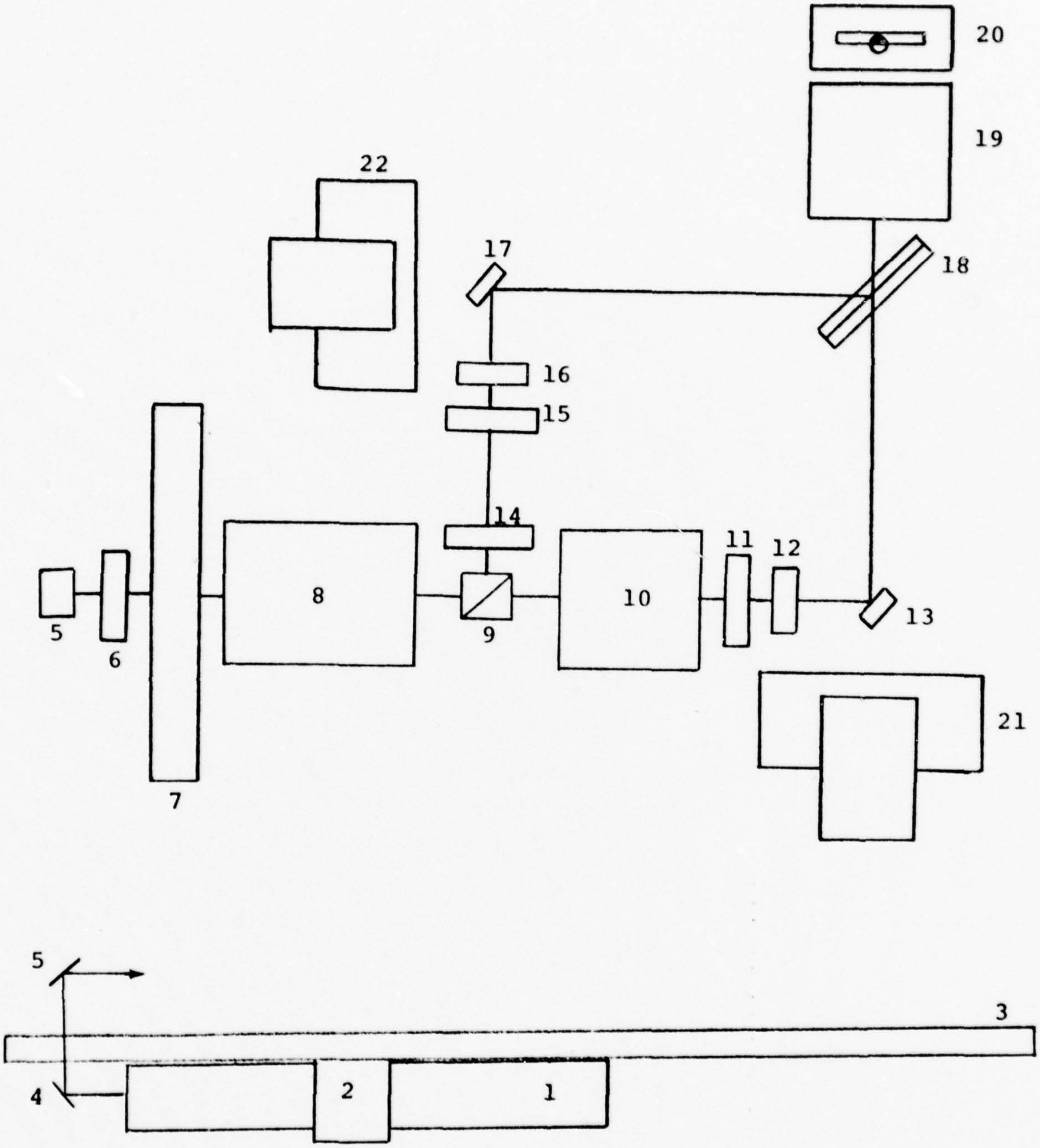


FIGURE 3. Design of the Dual Channel LBS System

to the folding mirror 4, and the pitch and yaw adjustments of this mirror in conjunction with those on mirror 4 permit one to align not only the direction of the laser beam but also the location of the beam with respect to the base plate. Hence using folding mirrors 4 and 5, the laser beam can be made to correspond to the optical axis of the optical system.

6. Half Wave Polarization Rotator: The purpose of this component is to orient the polarization of the laser beam so as to obtain the desired laser powers in the two channels of the scanner. The rotation of the half wave plate rotates the polarization of the beam and hence alters amplitudes of the two orthogonal polarization components. The rotary mount requires that the half wave rotator can be positioned to an accuracy better than a degree.

7. Compensated Attenuator: The compensated neutral density beam attenuator is intended to reduce the laser power without introducing any gradients across the beam. Attenuation over a clear .5" aperture is provided with the neutral density being adjustable from .1ND to 4ND, with a resolution of .02ND per adjusting dial division.

8. Spatial Filter/Beam Expander Assembly: This spatial filter/beam expander assembly is mainly intended to clean up the laser beam and expand the laser beam to a suitable diameter to permit easy focusing and modulation downstream.

9. Polarization Beam Splitter: The polarization beam splitter not only splits the beam to form two channels, but also makes the polarization of the beams in the channels to be orthogonal to each other. The strength of the laser beams in the two channels depends on the orientation of the linear polarization of the beam with respect to the cube beam splitter, which in turn is determined by the half wave rotator.

10. Acousto Optic Modulator: This acousto optic modulator permits the modulation of the power of the laser beam in Channel I. The acousto optic modulator is capable of modulation at 1MHZ and must have a diffraction efficiency of at least 80%.

11. Focusing Lens: The focusing lens focuses the diffracted beam from the acousto optic modulator onto the spatial spot shaping mask. The purpose of the focusing lens is to increase the laser power density available to illuminate the spatial spot shaping mask.

12. Spot Shaping Mask: The spot shaping mask defines the size, shape and distribution of the scanning laser spot on the recording film. The mask can be made of photographic film and can be backed by a low angle scattering diffuser.

13. Folding Mirror: This folding mirror is used to fold the transmitted (and scattered) beam from the spatial spot

shaping mask towards the scan lens. The pitch and yaw adjustments on the folding mirror mount enables one to adjust the apparent position of the scan spot shaping mask as viewed from the scan lens.

14. Electronic Shutter: This electronic shutter is an electromechanical shutter which permits the beam channels to be either turned on or turned off.

15. Focusing Lens: This focusing lens is identical to the focusing lens (11) and it focuses the beam onto the spot shaping mask in Channel II.

16. Spot Shaping Mask: This spot shaping mask is identical in its functional characteristics as that of the mask (12) and it determines the size, shape and distribution of the scanning laser spot in Channel II.

17. Folding Mirror: This folding mirror is identical to the folding mirror (13) and has the same functions.

18. Polarization Beam Splitter: This polarization beam splitter reflects the beam from Channel II and transmits the beam from Channel I since it has a dielectric coating identical to the cube beam splitter (9).

19. Scan Lens: The purpose of the scan lens is to collimate the beam originating from the two scan spot shaping

masks (which are located at focal distance away from the scan lens) and also to focus the scanning beams onto the recording plane in Channel I or the scan plane in Channel II. The scan lens should provide a flat final image plane for the scan beams and should have minimum distortion.

20. Galvo Driven Scan Mirror: The collimated beam from the scan lens is retrodirected back through the same lens by the scan mirror 20. The scan mirror is rotated by the Galvanometer and the angle of the reflected beam changes correspondingly. The scanning beam from the Galvanometer mirror when focused by the scan lens (19) gives rise to the scanning spot in the back focal plane of the scanning lens. Since the Galvanometer mirror autocollimates the beam from the scan lens, the final scan spot represents a one-to-one image of the illuminated scan spot shaping mask.

21. Recording Film Plane/Translation Stage: This component defines the recording film plane. The translation stage is mounted on the reference base plate and carries the recording film cartridge. While the scanning beam gives the scanning of the spot in one dimension, the translation stage gives the scanning in the perpendicular direction to cover the second dimension. By using an adapter frame on the

translation stage several film cartridges can be used for recording the reconstructed image. This approach solves the problems of recording film handling, registration and film translation.

22. Scanning Film Plane/Translation Stage: This component is identical to translation stage (21) except for the fact that the film cartridge is modified to permit detection of the transmitted light. The cartridge carried the transparency followed by a condensor lens and a detector to permit generation of a video signal representing the information on the transparency.

The rotation of the half wave plate number 6 permits balancing of the total laser power in Channels I and II while the neutral density filter represented by number 7 permits the attenuation of the total laser power in both Channels I and II. By using the modulator number 10 and the shutter number 14, either of the two Channels can be selected. Scan spot shaping masks 12 and 16 permit independent control of the laser scanning spot shape for the two Channels. Because of the selectivity of the polarization beam splitter 18 to the direction of the incident laser radiation, it is anticipated that there will be less than 1% interaction between two

Channels. The block diagram corresponding to the control and process electronics of the dual channel laser beam scanning system is shown in Figure 4. Direct control of the translation stages 21 and 22 and the galvanometer mirror 20 are needed for the operation of the system. The modulation of the beam by the acoustic modulator 10 must be synchronized with the galvo mirror scanner 20. The specification details of each of the components used in the above design are given separately in Appendix A.

It is to be noted here that the component characteristics are illustrated by citing examples of commercially available units and this does not represent an endorsement of these vendors. The design of the system is shown in these selected components merely to illustrate not only the feasibility of the system concept but also to demonstrate the compactness of the system that can be achieved. Hence the material presented in Appendix A must be viewed in this context.

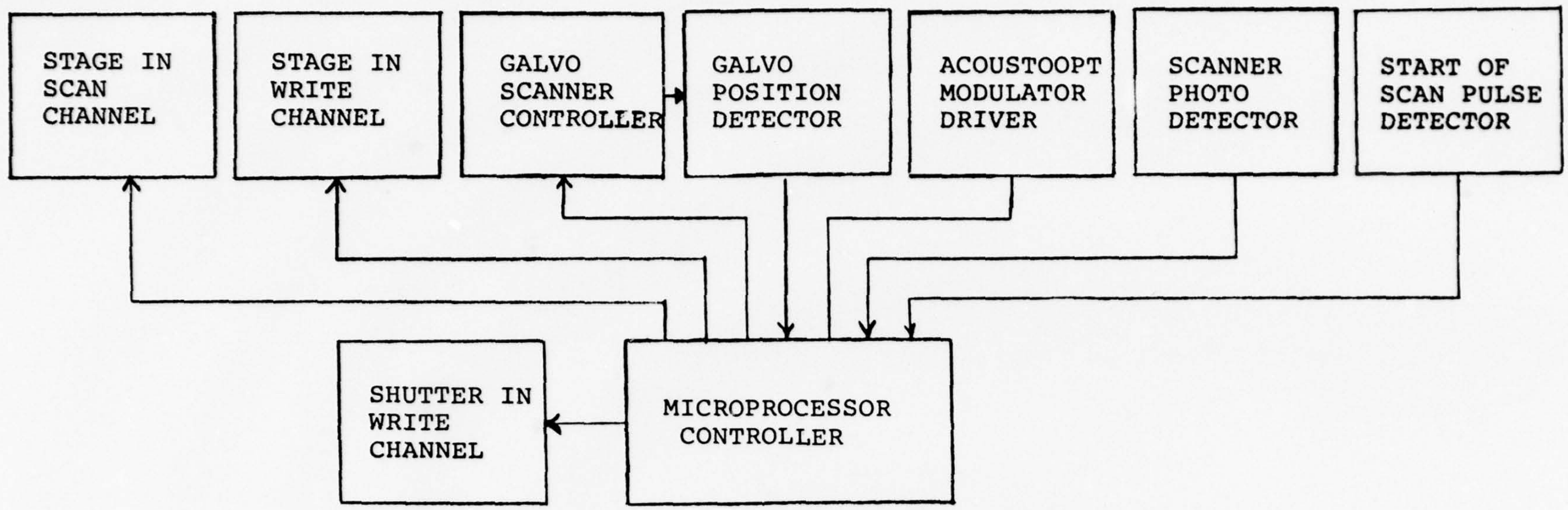


FIGURE 4. ELBS Electronic Control System

It is anticipated that the proposed design for the experimental LBS System will have the following characteristics:

SYSTEM CHARACTERISTICS:

Picture Format	50 x 50 mms
Spot Size	12.5 Microns Min 25 Microns Nominal
Line Scan Time	12.5 milliseconds
Write Window	10 milliseconds
Dwell Time per Spot	2.5 Micro seconds Min 5 Micro seconds Nominal
Modulation Rate	2 MHZ Max } at 256 grey levels 1 MHZ Min }
Time to Write Format	25 Seconds
Film Plane Translation	2 mms/second

LASER SCANNER CHARACTERISTICS:

Scan Field	Flat ($\pm$ 150 Microns)
Scan Linearity	0.5% of Scan Width
Scan Repeatability	10% of Spot Size
Start of Line Registration	4% of Spot Size

LASER SPOT EXPOSURE CHARACTERISTICS:

Total Laser Power on the Spot	2.5 Milliwatts
Spot Size (nominal)	25 Microns
Power Density	5 Watts/cm^2
Exposure Time (nominal)	1 Microseconds
Maximum Exposure	50 ergs/cm^2

FILM TRANSPORT/HOLDER CHARACTERISTICS:

Film stage stable during writing window

Film stage steps during flyback

Stage Step Resolution	2.5 Microns (10% of Spot Size)
Step Rate	4000 steps/sec
Line Spacing Accuracy	10% of Spot Size
Scan Line Registration	10% of Spot Size/inch of translation
Film Holder	Any Mamiya compatible back

5 Proposed Evaluation Program

The objective of this study is to design an experimental program to evaluate the effects of various system parameters on the performance of the LBR System. The performance of the LBR System depends on the "quality" of the output image. Various image quality investigations of the LBR output images based on subjective evaluation of photointerpretors have been carried out in the past. However no attempt has been made to develop quantitative means of evaluating the LBR output image. The "quality" of the LBR output image depends upon the particular application or use. In this section, three specific applications of the LBR output image are identified and experiments to evaluate quantitatively the "quality" of the output image within the context of the specific applications are described.

5.1 Pointing Ability and Geometric Fidelity

Many applications in mapping require manual measurement of distances in photographs between specific targets using mono or stereo comparators. The accuracy and repeatability of such measurements depends not only on the geometric fidelity (in terms of distortion) of the photograph or transparency used but also on the ability of the operator to point exactly on the target. LBR generated images will have characteristics that are likely to alter the operators ability to point at specific targets accurately and with precision. The significant system parameters that are likely to play a part in this application are (1) scan spot size (2) spot overlap and (3) jitter caused by vibration. The intensity distribution within the spot is also likely to have a greater impact on the ability of the operator to point on the image.

In the experiment to be performed, a high resolution aerial transparency with some specific and easy to identify targets is used as a reference. First measurements are made on the transparency using a monocomparator. The reference transparency is placed on the optical scanning channel of the dual channel experimental laser beam scanning system. The smallest possible scan spot size is used to scan the aerial transparency. The video signal generated is then used to generate the image on writing channel of the experimental LBS System. A number of images are reconstructed using various spot sizes, shapes and spot overlaps on the writing channel of the ELBS System. Measurements are made on each of the reconstructed images using the monocomparator to determine the error in pointing as a function of the varying system parameters.

5.2 Scan Artifacts and their Contribution to OPS Analysis

In recent years OPS analysis has shown considerable promise as a means of classifying and prescreening aerial transparencies. One of the possible applications of the output from the LBS Systems is to utilize it as an input for a conventional OPS Analysis System. Scan generated images exhibit many artifacts which may be acceptable from a "cosmetic" point view, but migh generate spurious intensity distributions in the Fourier planerendering them useless for any optical processing applications. The strength and the nature of the Fourier plane intensity distributions depend on the various system parameters described earlier. Hence experiments can be performed to empirically determine their impact on applications to OPS analysis.

In the experiment to be performed an aerial transparency with areas of low or zero spatial frequency is used as a reference transparency. This reference transparency is screened first on a ROSA type system to identify the boundaries and coordinate of areas of low spatial frequency. The reference transparency is then placed in the optical scanning channel of ELBS System. Various images are reconstructed on the writing channel by varying the system parameters (spot size, shape and overlap). Each of the reconstructed images is then screened individually on the ROSA type system under the same conditions as the reference transparency. Differences in power spectral measurements will provide significant and useful results for optimizing the LBR System for any future applications that involve optical data processing.

5.3 Scan Artifacts and Their Contributions to Optical Correlation

One of the many applications of LBR generated images in mapping is stereo compilation. All automated stereo compilation systems rely on image correlation to achieve matching of conjugate images and to measure the parallax automatically. The nature and shape of the image correlation function depends on the image structure in the two transparencies. Scan artifacts associated with LBR generated images are likely to interface with the correlation process and hence the "quality" of the LBR generated images must be evaluated from the point of view of correlation applications.

This experiment can be performed using an experimental optical correlator such as the HOC System. Identical copies of ELBS reconstructed images can be placed in the two channels of the HOC and the two dimensional correlation function generated. Several images can be generated with varying system parameters as described in 5.1 and 5.2 and they can be individually correlated on the HOC System to provde a measure of the width of the correlation function and the ratio of the primary correlation peak height to the secondary peaks (which relates to false correlation).

The experiments described above are only some of the many potential empirical studies that can be performed using the experimental LBS System to study the effects of various system parameters associated with LBR Systems.

6 Conclusions and Recommendations

The objective of this study is to design an experimental program for evaluating the LBR System from the viewpoint of mapping applications and to establish a basis for empirical investigation. During this study an experimental laser beam recorder system to be used during the course of the proposed investigation has been designed and its design evaluated. Some preliminary ideas on proposed experiments to be performed have been identified and the approaches documented. The results of this study support the following general conclusions:

(1) In order to establish a quantitative means of evaluating the "quality" of LBR image outputs, it is necessary to study the effects of system parameters on the usefulness of the output image for the many specific intended applications.

(2) It is possible to design and fabricate a simple and flexible experimental laser beam recorder system that can be used in an empirical evaluation of the effects of the various system parameters on the quality of the output. It is possible to use clever system configurations to overcome the need for large data handling and data management digital hardware and hence permit the experimental hardware to operate in a stand-alone mode.

(3) Preliminary considerations of an empirical evaluation program suggest that the results of this investigation can have a significant impact in defining the specifications of future LBR Systems depending upon the intended applications.

The specific recommendations of this study are:

(1) The proposed dual channel experimental laser beam scanning system should be fabricated, since it would serve as a very useful experimental tool.

(2) The proposed experimental evaluation program should be carried out using the experimental laser beam recorder, since the results of such an investigation would be extremely useful for the specification and design of future LBR Systems.

APPENDIX A

Component Specifications

The list of components and the vendor sources presented in this appendix are only examples of what is available commercially as "off the shelf" units. The proposed design can easily be modified to accept similar components from other vendor sources and will require in most cases no more than mounting modifications. The inclusion of the specific vendor sources does not represent specific endorsement of these components over others.

(1) Laser
    Low Power He-Ne
    Power Output - 1 - 2mw
    Polarization - Linear
    Extinction Ratio - 500:1 or better
    Noise (below 1KHZ) - .5% or better
    Power Stability
      (Long Term) - 2% or better

Suggested Source:
    Spectra-Physics
    Mountain View, CA (Model 145P)

(2) Precision Adjustable Laser Mount

- to hold low power He-Ne Lasers such as Spectra Model 145
- requires pitch and yaw adjustment

Suggested Source:
    NRC
    Fountain Valley, CA (Model 810)

(3) Base Plate

Aluminum Tooling Plate
Size: 29" x 16.5" x .75"
Has to be custom fabricated

(4) Diagonal Mirror Mount

For Mounting Folding Mirrors

Adjustments: Pitch and Yaw
Resolution: 2 to 5 arc seconds
Mirror Flatness: 1/4 wave
Mirror Size: Greater than 5mm square

Suggested Source:
Daedal, Inc.
Harrison, Pa. 15636 (Model 3000)

(5) Diagonal Mirror Mount

Same as No. (4)

(6) Rotary Translation Stage

For Mounting Half Wave Rotator

Adjustments: 90° rotation
Resolution: $.1^{\circ}$
Aperture: Greater than 5mms
Mounting: Vertical

Suggested Source:
Daedal, Inc.
Harrison, Pa. (Model 20000)

(7) Compensated Attenuator

For Laser Power Control

Dynamic Range: .1 to 4ND
Resolution: .002ND
Beam Deviation: Less than 1% of Bead Diameter
Beam Angle Deviation: Less than 20 ArcSec
Beam Uniformity: No density gradients
5% uniformity
No spurious fringe patterns

Suggested Source:
Newport Research Corp.
Fountain Valley, Ca. (Model 925B)

(8) Beam Expanding Telescope

Purely for Spatial Filtering

Suggested Source:
Jodon
Model BET25

(9) Tilt Table

For Mounting Cube Beam Splitter

Adjustments: Tilt and Tip Adjustments

Suggested Source:
NRC
Fountain Valley, Ca. (Model - MM1, with Spacer)

(10) Acousto Optic Modulator

Acousto Optic Modulator Mat: Glass
Modulation Bandwidth: 2MHZ (Max)
Optical Aperture: 2mm
Wave Length of Operation: 6328 A^o
Diffraction Efficiency: 80% or better
Extinction Ratio: $>$ 1000:1
Polarization: Should be insensitive

Suggested Source:
Interaction Corp.
Bensenville, Ill. (Model AOM-40)

(11) and (12)
Focusing Lens Spatial Filter Combination

For Scan Spot Shaping

Focusing Lens: 5x Microscope objective
Spatial Filter: Scan spot mask with diffuser backing
Adjustments: X,Y adjustments on spatial filter
: Z adjustment on the lens

Suggested Source:
NRC
Fountain Valley, Ca. (Model 900)

(13) Folding Mirror

Aper: .1 inch

Suggested Source:
Daedal (Model 2000)

(14) Optical Shutter

For Closing and Opening Channel II

Optical Aper: 5mm
Response Time: 10 msec
Operation: Electronic control

(15) and (16)
Same as (11) and (12)

(17) Same as (13)

(18) Polarization Beam Splitter and Beam Splitter Holder

Aperture: 30mm
Extinction Ratio: 1000:1

Suggested Source:
Spectra-Physics
Mountain View, Ca.

(19) Scan Lens-See Specifications

(20) Galvo Scanner

For Scanning

Scan Angle: 2.755^{o}
Mirror Size: 25mm Diameter
2mm Thick
Angular Repeatability: 1 ArcSec
(1/5 of the spot size)

Suggested Source:
General Scanning, Inc.
Watertown, Mass. (Model 300PD)

(21) and (22)
Translation Stages

For Translation of Film Cartridge

Total Translation: 2"
Repeatability: .0001"
Resolution: .0001"
Step Rate: 200 steps/sec
Mounting brackets for film cartridges

Suggested Source:
Aerotech
Pennsylvania (Model ATS302M)

(23) Film Cartridges and Adopter Plates

Mamiya RB67

(See attached brochure)

APPENDIX B

Scan Lens Design

During the course of this investigation a scan lens was designed to demonstrate the characteristics that can be anticipated using a rather simple lens systems. An air spaced doublet was used to achieve the required performance. Only a third order optimization was used to design the lens and no elaborate attempt was made to achieve the best possible performance. The specifications and the characteristics of the lens designed are presented in this appendix.

The lay-out of the lens and the identification of the surfaces and thicknesses are shown in Figure (A-1).

Specifications:

Surface No.	Radius	Thickness	Index
-	-	Infinity (Object Distance)	1.0 (air)
1 (Scan Mirror)	-		
		10 mm	1.0 (air)
2	-32.207 mm		
		5 mm	1.515 (BK-7)
3	-40.906 mm		
		3.036 mm	1.0 (air)
4	-136.782 mm		
		5 mm	1.515 (BK-7)
5	-52.749 mm		
		281.671 mm	1.0 (air)
6 (Image Surface)	-		

Wavelength of Operation	.6328 microns
Aperture Stop Dia	20 mm

Lens Performance Characteristics:

Effective Focal Length	260.01039
Back Focal Distance	281.671 mm
F-Number	13.0
Scan Format	26 mm
Petzval Radius	-583.18676 mm

Spot Diagram Characteristics/Radial Energy Distribution:

Fractional Field FOB - 0.0

Fractional Energy	Spot Radius (in mms)
.1	.000196
.2	.000196
.3	.001258
.4	.002176
.5	.004317
.6	.005043
.7	.011599
.8	.011608
.9	.017049
1.0	.017049

RMS Radius - .009 mms

Fractional Field - .5

Fractional Energy	Spot Radius (in mms)
.1	.000231
.2	.000358
.3	.000491
.4	.001510
.5	.002455
.6	.005122
.7	.009361
.8	.011917
.9	.014384
1.0	.020845

RMS Radius - .0083 mm

Fractional Field - 1.0

Fractional Energy	Spot Radius (in mms)
.1	.000944
.2	.001161
.3	.001580
.4	.002015
.5	.002251
.6	.002624
.7	.003809
.8	.008437
.9	.015264
1.0	.022824

RMS Radius - .007 mm

It is clear from the characteristics listed above, the scan lens designed will more than adequately meet the needs of the ELBS System.

APPENDIX C

Laser Power Requirements

In this appendix, calculations are presented to show that a 2mw low power He-Ne laser is more adequate to meet the requirements of the experimental LBS System.

The various parameters are:

P_L	Laser power output
R_4	Reflectance of the folding mirror M_4
R_5	Reflectance of the folding mirror M_5
T_6	Transmission of the polarization rotator
T_7	Transmission of the attenuator
T_8	Transmission of the beam expander
T_9	Transmission of cube polarization beam splitter
T_{10}	Diffraction efficiency of the AO modulator
T_{11}	Transmission of the focusing lens
T_{12}	Transmission of the diffuser behind spot shaping mask
R_{13}	Reflectance of the folding mirror 13
T_{18}	Transmission of the beam splitter 2
T_S	Radiometric transfer function of the scan optics
P_S	The total power available in the scan spot

Now

$$P_S = P_L R_4 R_5 T_6 T_7 T_8 T_9 T_{10} T_{11} T_{12} R_{13} T_{18} T_S$$

Typically

$R_4 = .96$

$R_5 = .96$

$T_6 = .92$

$T_7 = .92$

$T_8 = .85$

$T_9 = .5$

$T_{10} = .8$

$T_{11} = .95$

$T_{12} = .8$

$R_{13} = .95$

$T_{18} = .95$

Hence

$$P_S = .182 \times P_L \times T_S$$

T_S depends on the scattering characteristics of the diffuser and the F-number of the scan lens (F).

$$T_S = \frac{2\pi}{n+1}\left[1 - \frac{2F}{\left[1 + 4F^2\right]^{\frac{1}{2}}}\right]^{n+1}$$

Where $\cos^n$ is the scattering distribution.

When $n = 1$, $T_S = 4.6 \times 10^{-3}$

$n = 10$, $T_S = 45 \times 10^{-3}$

When $n = 1$

$$P_L = \frac{P_S}{.182 \times 4.64 \times 10^{-3}}$$

$$= P_S \times 1.2 \times 10^3 \text{ watts.}$$

If S is the sensitivity of the film, T is the exposure time and A is the area

$$P_S = \frac{S \times A}{T} \quad , \qquad S - \text{Joules/CM}^2$$

A - CM^2

T - sec

When $S = 1 \times 10^{-6}$ Joules/CM^2 (max)

$T = 5 \times 10^{-6}$ sec

$A = 6.25 \times 10^{-6}$ CM^2 (26 micron spot)

$P_S = 1.25 \times 10^{-6}$ watts

Hence $P_L = 1.5$ mwatt (1.5×10^{-3} watts).

The power contained in the scanning spot is 1.56 mwatts. With that much power and using a silicon detector, it is possible to obtain a dynamic range of 100:1, which corresponds to a density of 2D at the transparency. When more sensitive films are used, more power can be diverted to the optical scanning channel using the polarization rotator.

However, when a proper diffuser is used behind the spot mask such that it has $\cos^{10}\theta$ scattering distribution (low spatial frequency diffuser such as the rear projection screen), the radiometric transfer function of the scan optics becomes 45×10^{-3}. Hence the laser power required for exposing the film is reduced by a factor of 10 and the power available in the optical scanning spot is correspondingly increased.

In summary, a 2mw He-Ne laser will permit using films with sensitivities as low as 10μ Joules/cm^2.

SINGLE-ACTION FOCUSING HOOD opens and closes with a touch. Interchanges with magnifying hoods and prism finders, including types with built-in CdS metering systems (will fit original RB67).

BREECH LOCK LENS MOUNT is designed for quick lens changing and secure locking. A safety device prevents the lens from being removed if the mirror is not cocked.

BELLOWS FOCUSING SYSTEM permits smooth rack-and-pinion focusing and allows close-up work without special attachments. For ultra-close photography, automatic extension tubes are available.

INTERCHANGEABLE LENS-SHUTTER COMBINATIONS give highest effeciency and matched performance. All shutters are identical with speeds from 1 to 1/400 second plus T and full flash synchronization at any speed. Lenses have multi-layer coatings, automatic diaphragms, depth-of-field scales, and common (77mm) filter threads.

FILM ADVANCE LEVER is conveniently located on the 120 and 220 roll film holders. A single movement or multiple strokes of the lever quickly advances the film. The double exposure prevention system has an intentional override.

UNIQUE REVOLVING BACK system enables horizontal or vertical format photography without changing the camera position. Red lines appear on the focusing screen to indicate when the back is set to the horizontal position.

FILM HOLDERS include those for 120 and 220 rolls, film packs, cut film and plates, and Polaroid film packs. With appropriate adapters, film holders for the Mamiya press camera as may also be used.

SHUTTER COCKING LEVER also cocks the mirror with a single quick motion. A safety device prevents the lens from being removed unless the mirror is down.

INTERCHANGEABLE BACKS allow complete film-use flexibility. Any back or film holder may be removed in mid-roll without frame loss.

FOCUSING KNOB is large and easy to use. Another focusing knob is on the opposite side of the camera for added convenience.

SHUTTER RELEASE is conveniently located for efficient exposures. A locking ring prevents accidental exposure.

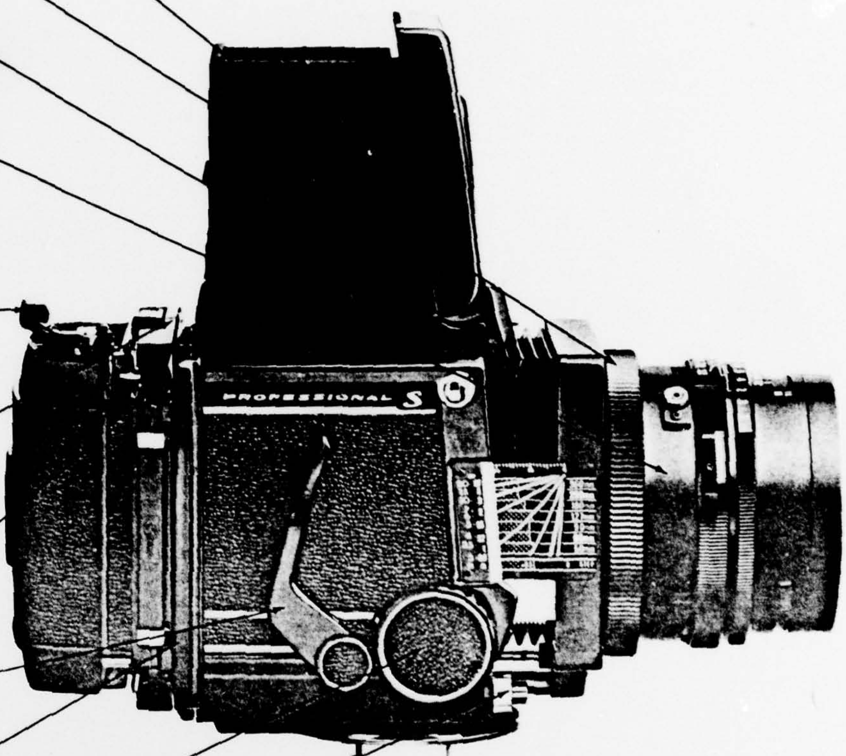
LOCK LEVER for the focusing knob secures the focus setting once it is made and prevents accidental movement.

6x7cm FORMAT is considered ideal as the negative can be enlarged to 8x10 proportions with virtually no loss of picture area.

INTERCHANGEABLE FOCUSING SCREENS provide the desired view for every type of photographic application. Five different screens are available.

PLUS—
Film exposure counter • Film position indicator • Multiple exposure lever • Mirror release operating knob • Accessory shoe on camera body • Dark slide storing lug • Magnifier with interchangeable lenses • Distance scales for all lenses • Depth-of-field preview lever • [illegible] and more!

the ideal system for professional single-lens reflex photography

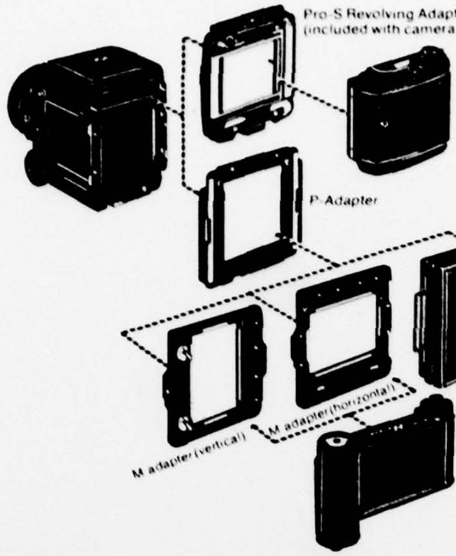


Mamiya RB67 Pro-S 6x7cm SLR

Designed with the professional in mind, this fine camera system provides the ultimate in quality, versatility, and photographic excellence. The superb precision and innovative features help to make the RB67 Pro-S the practical system for serious photographers. The ideal 6x7cm format is proportioned to the most common print sizes. The unique revolving back system, which accepts a multitude of film holders and adapters, provides convenience and efficiency. A fully interchangeable system of lenses with built-in shutters, viewfinders and screens for every application, and other accessories help to make the RB67 Pro-S the working photographer's dream.

CAT. NO. 4102A RB67 Pro-S Camera Body, 120 Roll-Film Holder, Single-Action Focusing Hood, Matte Focusing Screen (less lens)

COMPLETE INTERCHANGEABLE BACK SYSTEM...



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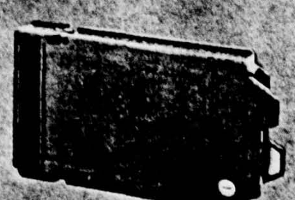

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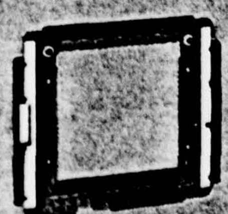

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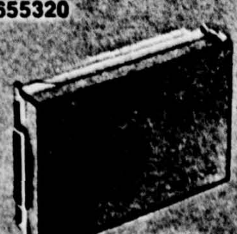

655322

CAT. NO. 655310 **Pro-S 120 Roll Film Holder** (10 exposures)
CAT. NO. 655311 **Pro-S 220 Roll Film Holder** (20 exposures)
CAT. NO. 655312 **6x4.5cm 120 Roll Film Holder** (16 exposures)
CAT. NO. 655313 **70mm Film Holder** (55 exposures maximum)
CAT. NO. 655316 **Double Cut Film/Plate Holder Type A** (film size 6x9cm)
CAT. NO. 655318 **Film Pack Adapter**
CAT. NO. 655321 **Polaroid Film Pack Holder Model 2** accepts Type 108 film for color prints (8) and Type 107 film for black-and-white prints (8). Image area 2⅞" x 3¼"
CAT. NO. 655322 **Polaroid Film Pack Holder M80** accepts Type 88 film for color prints (8) and Type 87 film for black-and-white prints (8). Image area 2¼" x 2⅞"
CAT. NO. 655320 **P-Adapter**
CAT. NO. 655187 **M-Adapter** (horizontal)
CAT. NO. 655326 **M-Adapter** (vertical)
CAT. NO. 655323 **Spare Dark Slide** for Pro-S Roll Film Holders

MAMIYA PRESS FILM HOLDERS AND BACKS
(use with P- and M-Adapters)

CAT. NO. 656180 **Roll Film Holder, Model 2** (6x9cm)
CAT. NO. 656181 **Roll Film Holder, Model 2** (6x7cm)
CAT. NO. 656182 **Roll Film Holder, Model K** (6x9cm, 6x6cm, or 6x4.5cm)
CAT. NO. 656190 **Cut Film/Plate Holder** (6x9cm)
CAT. NO. 656192 **Film Pack Adapter** (6x9cm)
CAT. NO. 656183 **Focusing Screen Holder**
CAT. NO. 656184 **Magnifying Focusing Back**
CAT. NO. 656185 **Right-Angle Focusing Back**

Spare dark slides for all above film holders are also available.