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SAMSO TR 69-125

3RD QUARTER FY69 APPLIED OPTICS RESEARCH REPORT

by

Optical Sciences Center Staff
The University of Arizona
Dr. A. B. Meinel, Director

April 1969

Prepared for the
Space and Missile Systems Organization
Air Force Systems Command
Los Angeles Air Force Station, California

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Optical Sciences Center
The University of Arizona
Tucson, Arizona 85721



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FOREWORD

This Status Report of the Optical Sciences Center, University of Arizona, Tucson, Arizona, under U. S. Air Force Contract FO-4695-67-C-0197 (P003), covers research progress, academic activities, and significant events for the period 1 January 1969 to 31 March 1969.

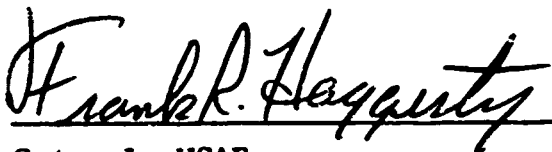
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Director
Optical Sciences Center



Colonel, USAF
SAMSO (SML)

ABSTRACT

The 3rd Quarter FY69 Status Report of the University of Arizona Optical Sciences Center presents the results of work and statements of research and academic direction in program areas supported entirely or in part by USAF Contract FO-4695-67-C-0197 (F003), during the period 1 January 1969 through 31 March 1969. Reference is also made to other activities being carried on at the same time, including status of construction of the new Optical Sciences Center building and academic activities. Research areas covered are atmospheric optics, geometric optics, image processing (both analog and digital), image tubes, lasers, massive optics, mathematical optics, optical design, optical testing, opto-mechanics (structural mechanics and lightweight mirror studies), remote sensing, and thin films. Technical reports published during the reporting period are listed and described.

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I. INTRODUCTION

This 3rd Quarter FY69 report of the Optical Sciences Center of the University of Arizona summarizes research activities and published technical reports for the period 1 January 1969 through 31 March 1969, in areas supported entirely or in part by USAF Contract FO-4695-67-C-0197 (P003).

General administration

The Optical Sciences Center steering committee is currently reviewing the activities that are supported under the basic USAF contract, in view of the several small contracts from other DOD sector groups. The original philosophy of using the basic contract support as the means of beginning work has proved very successful in enabling us to seek additional support to expand work in particular areas.

Services to other groups in USAF

Dr. Meinel has made several trips to review projects of interest to the USAF and to advise these groups of the services available to them in support of USAF tasks.

Construction progress

By the end of March, the brickwork on the exterior of the new building was nearly complete, windows were all in place, the interior walls were being put in, and plastering was completed to the fifth level. All of the air conditioning system is in, and utilities are nearly completed on Level 2. The elevator is currently being installed.

Because of problems of locating welders in the Tucson area, and problems of getting some building supplies, the completion date may have slipped another two weeks into the middle of September. A more definite assessment of this question can be made by the end of April.

II. STATUS OF ACADEMIC PROGRAM

Curriculum changes

The new catalog for the 1969-71 biennium is being prepared. Optical Sciences has received approval for 22 additional course offerings. Our growing student body and professional staff have made these new areas of study desirable and practical.

Two of these courses are cross-listed from the new offerings of the Department of Psychology in the areas of Color Vision and Visual Perception.

Six are laboratory courses allied with lecture courses already a part of our curriculum. The completion of our new building will make laboratory facilities available where none were before.

New students

At the beginning of the first semester four new students joined the Optical Sciences group. Three of these are assigned to us by the Air Force Institute of Technology. Two of them, James Darnauer and Ralph Haller, are in the Masters program, and Gordon Orme is working toward a PhD. The fourth student, Benjamin Platt, comes to us from the Texas Instruments Company. He is also working toward a PhD degree.

Student applicants for the 1969-70 academic year

In June of 1969, we expect three more Air Force Institute of Technology students. Two of these, Bruce Fiene and Thomas Hewlett, will be MS candidates. The third, James Gorrell, will be working toward a PhD.

The total number of inquiries received this year has been 63. Of these we have admitted 15 and a few others are still being considered.

As already noted, six new students are receiving support from the Air Force and three candidates will receive support from the Navy under the civilian laboratories educational program. We have been grateful to receive continued support from the Perkin-Elmer Corporation for a student fellowship.

III. STATUS OF RESEARCH PROGRAM

ATMOSPHERIC OPICS

J. J. Burke

Photoelectric measurements of the wavelength dependence of stellar scintillation continued during this quarter. Measurements were made during the first two weeks of January and the last two weeks of March. During February the instrumentation was modified with the incorporation of a beamsplitting arrangement designed and built at the Optical Sciences Center. Each of the two photomultipliers, with its own telescope and appropriate filters, now views the star through the same air mass. Because the beamsplitter is not dichroic, this modification has been at the cost of approximately half the available intensity. For the most recent experiments with Capella, therefore, we have returned to the use of broadband (50-90 nm) filters. Narrowband filters (20-30 nm) have been used with the bright star Sirius.

The data taken thus far do not show the $\lambda^{-7/12}$ dependence predicted by Tatarski's theory, which is based on the assumption of homogeneous, isotropic turbulence with a Kolmogorov spectrum. For the wavelength separation between the centers of the passbands of the pairs of filters we are using, the theory predicts that the scintillation at the shorter wavelength should be about 15% greater than that at the longer wavelength, both specified in terms of the normalized standard deviation of the intensity at these wavelengths. A representative set of data from runs made during the past quarter is shown below. Entries on the same line correspond to measurements made simultaneously.

		<u>Normalized σ of intensity</u>				
		420	449	580	600	$\leftarrow \lambda$ of peak transmission, nm
<u>Date</u>		<u>90</u>	<u>20</u>	<u>50</u>	<u>30</u>	\leftarrow Filter bandwidth, nm
March	28	.34		.31		
	28	.34		.32		
	28	.50		.56		
	26	.39		.35		
	24	.55		.51		
	21		1.02		1.07	
	21		.88		.87	
	19		.73		.69	
	18		.48		.48	
	17		.78		.66	
Jan.	7	.32			.31	
	7		.27		.28	
	6	.20			.20	

On almost all of the listed dates, runs were also made with both systems illuminated by light of the same spectral character. On the basis of these and other measurements, we can state that the above entries are generally accurate to at least 5%. Although the above data indicate that the blue scintillation is often greater than the red, it is not consistently so. Thus, more data are

required to establish whether or not the observed differences manifest a regular characteristic of scintillation. It is apparent, however, that the 15% difference is not generally present.

The surprising trend reported last quarter--that a narrowband red filter generally yielded stronger scintillation than a broadband blue filter--has been shown to be unreal. Extensive tests of the system, when it is exposed to nonvarying light signals of the same magnitude as those from stars, have shown that the differences were caused by signal-dependent shot noise. A theory has been developed to correct for this source of error in the measurements, and we are currently reducing some of the old measurements accordingly. The last three entries in the table represent such corrected data. Prior to the application of these corrections, these data showed the spurious trend reported previously.

GEOMETRIC OPTICS

O. N. Stavroudis

Work on "modular design" continues satisfactorily. Some progress has been made in the problem of finding usable parameter domains--in fact, this aspect of the work appears very near completion. In addition, an attempt has been made to use "modular design" in the design of a simple catadioptric system. Moreover, conditions on the location of the stop position have been found. A report, "Two-Surface Optical Systems with Zero Third-Order Spherical Aberration," has been completed and will be published shortly as a Technical Report.

A paper entitled "Orthotomic Systems of Rays in Inhomogeneous, Isotropic Media" was presented to the Optical Society of America at its spring meeting in San Diego, March 11 to 14. After a little additional work, it is expected that a more extensive paper or report will be prepared from this talk.

IMAGE PROCESSING

Analog image processing

W. Swindell

During the past quarter a new modulator for the playback section of the analog image processor was completed, tested, and installed. Until recently, the neon-filled glow tube in the modulator was used in a conventional analog manner; that is, the light output was regulated by varying the continuous current flowing through the tube. There are two major disadvantages of this method of operation: (1) The tube is inherently nonlinear in its current-light output characteristic and, for linear operation, optical feedback is required. (2) In the low light output region, the operation becomes uncertain as a result of the finite current required to turn the tube on.

These problems are overcome in the new modulator design, in which the tube is driven in a digital mode. It is either turned fully off or turned on to a predetermined level, which is established by a constant-current power supply. The tube is switched at 1 kHz, and average intensity is controlled by varying the duty cycle. An analog-to-digital converter (designed by L. R. Baker) allows the light output to be controlled directly by a voltage input to the modulator. Tests show the functional relationship to be linear over at least $2\frac{1}{2}$ decades. Switching transients start to produce nonlinearity for duty cycles $\leq 0.2\%$.

The range of operation can be extended by adjusting the operating current of the tube. The 100% duty cycle intensity is variable over about three stops by this means.

Also during this quarter, a new mask-maker arrangement was completed, and the electronics were rehoused.

Some astronomical photographs have been processed with a view to reducing Gaussian blur. The results are presently being evaluated. We are also investigating the several different ways of using the playback system.

Test material is currently being produced for the program on the correction of motion degraded images. The computer program used for calculating the masks used in image correction is proceeding.

Digital image processing

L. R. Baker

A new test transparency of the letter R, which included a point spread function, was made by J. J. Burke. (The point spread is a necessary input to IMPROC program.) The transparency was scanned with a 96×96 element matrix. The accompanying photograph shows the new test transparency. At this writing, the tape is being processed by Dr. Frieden and Barbara Fell, using the IMPROC program.

During the tape recorder and control logic checkout, it was discovered that one of the important switching functions in the control logic had very poor rise time, and spurious signals. A transistor switch was added to the circuit, which improved the reliability of the scanner operation in both record and playback modes. The instrument has been used by Earl Nobles of Space Astronomy/Steward Observatory, the University of Arizona, to scan film density samples. Since the modification discussed above was incorporated, the operation in record mode is reported to be very good.

The operation of the tape recorder in incremental read mode is still unreliable. Tape recorder adjustments are being made, but the factory reports the setup of the recorder for incremental read is very touchy, and we are having difficulty getting it properly adjusted. Based on our conversations with the factory, it may be necessary to ship the recorder back to them for a complete checkout.

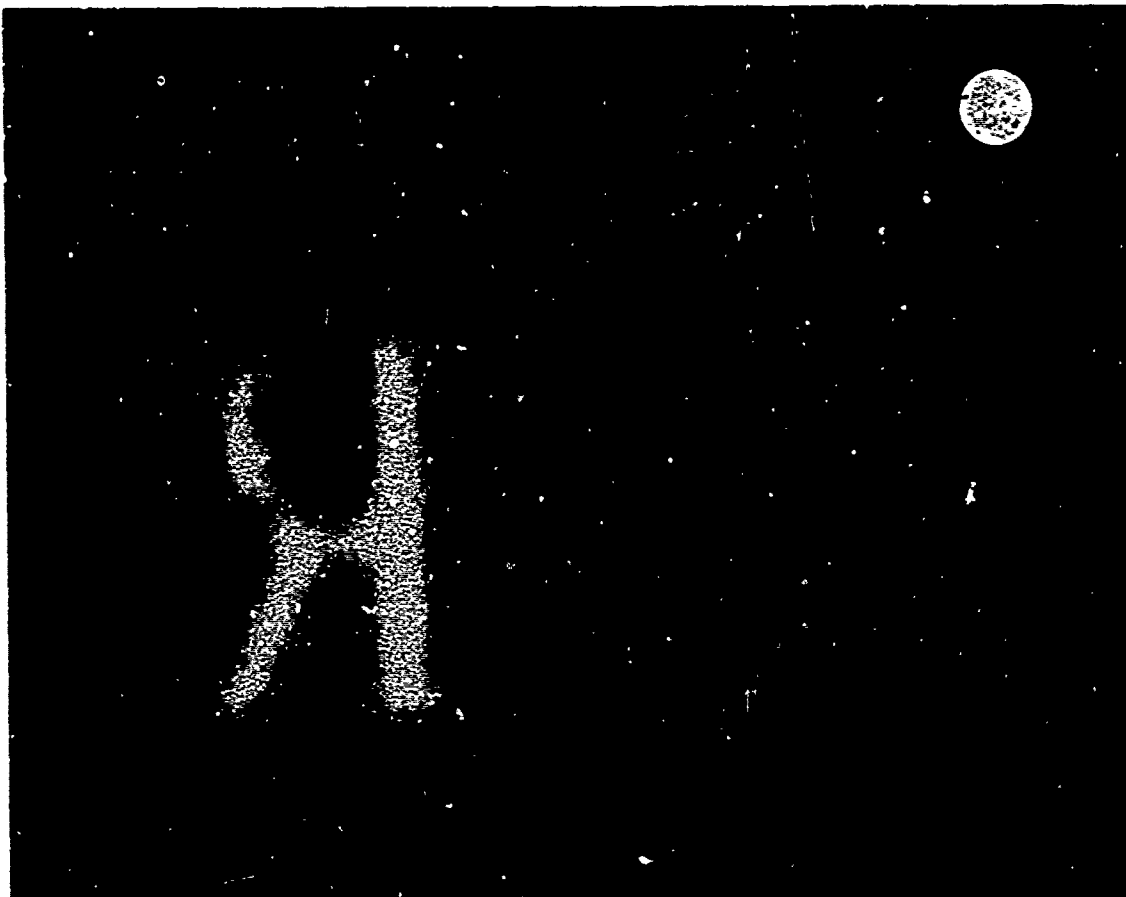


IMAGE TUBES

R. H. Cromwell

The Technical Report and dissertation entitled "Evaluation of Image Tubes for Use in Direct Photography of Astronomical Sources" is completed and will be available about the first of April. This report discusses the performance of the Carnegie image tube compared with the performance of unaided plates in several different applications to astronomical photography. Sky-limited photography of stellar images is discussed below.

Both direct plates and image tube plates have been exposed in such a way that the photographic density of the sky background is at its optimum value. This assures that the faintest detectable stars have been recorded with the respective plates.

The globular cluster M13 was photographed at the Newtonian focus of the Steward Observatory 36-inch reflector, with both the image tube and a Ila-0 direct plate. Blue magnitude passbands were provided for both systems by use of filters. By appropriate selection of zenith distances, the difference in limiting magnitude for the several exposures due to the difference in night-sky radiation was kept to less than 0.2 magnitude. Atmospheric conditions were uniform throughout the night, and the seeing was average.

For the image tube plates, the nucleus of the cluster was masked off to avoid excessive light-induced background. Exposures were made with both Ila-0 and baked IIIa-J recording emulsions. Besides the optimum, sky-limited exposures, two additional image tube photographs were made with Ila-0 recording emulsion. One was exposed about 40% longer than the optimum exposure time, to demonstrate the effect of overexposure. The other was exposed for the same duration as the optimum exposure but with the nucleus of the cluster unmasked. This was done to determine the significance of the light-induced background arising from the nucleus.

Besides the above, an exposure was made with the image tube at the Cassegrain focus. (The Cassegrain focal length of this telescope is 3 times the Newtonian focal length.) This photograph was taken on a different night than those described above, but the observing conditions were similar.

Comparison of the image tube Ila-0 with the direct Ila-0 plate shows that the image tube record is adversely affected by a mottled pattern, due to nonuniformities in the phosphor screens of the image tube. The nonuniformities of the image tube stood out even more on the IIIa-J exposure but the star images were also brought out more clearly. The mottled pattern was considerably less significant when the image tube was used at the longer (Cassegrain) focal length. In fact, the sky background in that plate was the least noisy of all the M13 exposures.

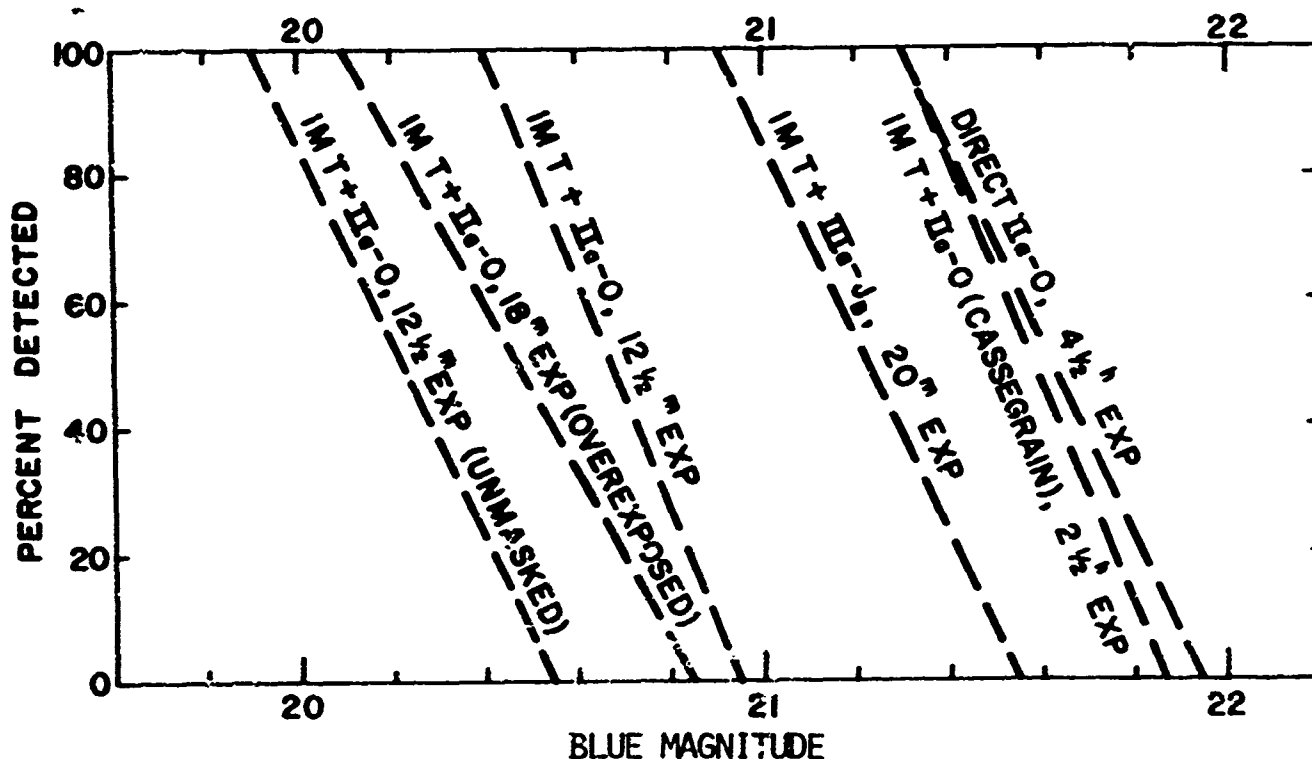
To the eye, the resolution of the most tightly grouped stars appeared slightly different on the different plates. In order from lowest to highest resolution, the four plates were as follows: image tube Ila-0, direct plate

Ila-0, image tube IIIa-J, and image tube Ila-0 (Cassegrain). The high resolution of the Cassegrain photograph was of course due chiefly to the greater image scale at the longer focus.

The magnitudes of the threshold star images on the several photographs were determined by comparing the photographs with a published identification chart and magnitude observations. To determine the limiting magnitude as accurately as possible, an average of 60 stars near the limiting magnitude for each particular plate were checked for their presence or absence. Graphs were then made of the resulting data from each plate by plotting the percentage of stars detected vs magnitude.

The several graphs could then be combined, as in the graph below, to compare the sky-limited magnitudes of all the plates. The mean curves for the plates are shown.

This graph indicates that, if a direct Ila-0 plate and an image tube Ila-0 plate are exposed at the same telescope focus, the limiting magnitude of the image tube record is about 0.9 magnitude less than that of the direct plate. However, if a baked IIIa-J recording emulsion is used with the image tube, about 0.5 magnitude of the loss is regained. This gain agrees with that



Sky-limited magnitudes for image tube and direct plates.

All plates were exposed at the f/5 Newtonian focus except for one image tube plate, which was exposed at the f/15 Cassegrain focus.

The loss of sky-limited capability is evident for the image tube plates exposed at the same focus as the direct plate. The effects of overexposure of an image tube (or direct) plate are demonstrated. For all but one of the image tube exposures, the nucleus of the globular cluster was masked from the photocathode. The effect of the additional light-induced background created by the nucleus is shown by the unmasked plate.

reported by Marchant and Millikan (J. Opt. Soc. Am. 55:907-911, 1965) in a paper discussing the theory behind the development of the new IIIa-J emulsion.

The detrimental effect of the light-induced background due to the cluster nucleus is clearly evident in the graph, for the unmasked image tube record shows an additional 0.5 magnitude loss. Microphotometer measurements of this plate indicate that the background intensity was effectively increased 60% by the light-induced background from the nucleus of the cluster. This in turn accounts for the loss in limiting magnitude.

The effect of increasing the exposure of a photographic emulsion beyond the optimum value is also evident in the graph, where a 0.2 magnitude loss in limiting magnitude is shown for the overexposed image tube plate. A similar effect, of course, would occur for an unaided plate.

Finally, we note that, when an image tube IIa-0 plate is exposed at the Cassegrain focus, the limiting magnitude is nearly the same as that of a direct plate exposed at the Newtonian focus. This is accomplished with a reduced exposure time--about half that of the direct plate. It should be pointed out that, because the Cassegrain focus of the present 36-inch telescope is not fully sky-baffled, scattered light from the nucleus of the cluster and direct radiation from the night sky were incident on the image tube photocathode during this exposure. Considering this fact, we conclude that a Cassegrain image tube photograph would normally reach a fainter limiting magnitude than a Newtonian unaided photograph. It can be argued, in fact, that the limiting magnitude of a Cassegrain image tube photograph should be at least 0.3 magnitude fainter than that of the present record.

A significant conclusion obtained from this study is that, in order to record the same sky-limited magnitude on a Carnegie image tube plate as on a direct plate, the image tube record must be made at a longer focal length. Under this condition, the exposure time by the image tube can be reduced to a half or a third. For certain areas of research, this relative exposure time may be the significant comparative figure of merit of the image tube over an unaided plate. It should be pointed out, however, that most of the star images have a higher signal-to-noise ratio on the image tube photograph. Only the threshold images, which are particularly affected by the nonuniformities of the image tube, have about equal signal-to-noise ratios on the two records. In applications that are concerned with more than just the threshold images, therefore, the gain of the image tube over an unaided plate is better than that suggested by the ratio of exposure times.

When an image tube plate and a direct plate are exposed at the same telescope focus, the image tube cannot record as faint a limiting magnitude as the direct plate. This may be important in certain astronomical investigations; however, the image tube can still provide useful observations of relatively faint stars and can do so with less exposure time than required by a direct plate. To reach a specified faint threshold magnitude, the ratio of exposure times may be estimated to be typically around 5:1, but the exact figure will depend on how close to the sky limit the image tube plate has been exposed.

The image tube laboratory has been relocated from Steward Observatory to the 22nd Street Annex. The Carnegie image tube system has been reassembled

and checked out. (Several parts of the Carnegie system, and the English Electric valve system as well, were recently returned from Boller and Chivens in Pasadena, where alterations had been made so that the image tubes could be used with the Steward Observatory 90-inch telescope Cassegrain spectrograph.)

New laboratory equipment is being assembled and designed for testing image intensifiers. The English Electric valve tube is scheduled for tests beginning in early April.

LASERS

Stephen F. Jacobs

Laser linewidth measurement

J. Hanlon has rebuilt the dual 3.39 μm lasers which had been used for preliminary measurements. This rebuilding was necessitated because of a virtual leak due to an epoxied repair which prevented isolated operation away from the gas filling station.

Although the University glassblowers have not yet repaired the original dual laser, Hanlon has made use of a similar structure which was on hand for backup purposes such as this one. He has attempted to eliminate glass blowing by redesigning for optical contacts and higher temperature epoxies. The new structure is now under vacuum and is being baked out prior to oscillation. By the end of April we will know whether this epoxied laser will be usable away from the gas filling station. If not, glassblowers will have to repair the all-silica system.

Stable lasers

Very little progress has been made on this project because the University glassblowers are unable to make the necessary graded seals. The job was subcontracted to a company in Berkeley, California, but came back mostly broken in transit. The University glassblowers have suggested a redesign which they feel they can make. We are awaiting their results.

He-Xe IR source

The He-Xe laser proved to have been incorrectly filled by Spectra-Physics. They refilled one laser and it now oscillates strongly at many wavelengths. It appears, however, that in refilling the tube, Spectra-Physics disabled the pressure-regulating valve. Without it the partial pressure of xenon depends on the temperature of a control point.

Preliminary investigation of the far infrared oscillation parameters will still be possible; however, we hope soon to be able to fill the He-Xe tube ourselves and install a new valve at that time.

A second, backup He-Xe laser was hand-carried to Spectra-Physics along with the incorrectly filled one. Spectra-Physics personnel accidentally smashed this tube and are now replacing it.

Ultraprecise measurement of thermal expansion coefficient

The method involves probing with a laser beam the resonances of a passive interferometer, spaced by the sample. Variable frequency sidebands are imposed on a stable laser beam which should sense the cavity resonance positions, and hence α to one part in 10^9 .

All the components for this measurement are now on hand. The environmental chamber has been modified to allow a beam of light to enter and leave. Also a vacuum line to the outside has been installed.

The interferometer works well, yielding a finesse of 250, or a frequency resolution of 6 MHz. The modulator also checks out, yielding sidebands whose power is $5 \times 10^{-5} P_{\text{carrier}}$. Carrier suppression (due to cross polaroids) is 4000, so the transmitted P_{carrier} is presently less than 5 times the P_{sideband} .

A preliminary scan through the interferometer was made by tuning the laser, which was also being modulated by impress sidebands. The expected triple peak was observed in the transmitted light (carrier plus two sidebands), and we are now in a position to take data by locking the laser (carrier) and tuning instead the sideband frequency.

Resonant sideband frequency vs interferometer (sample) temperature yields α .

Contributed paper to OSA

The author attended the OSA convention in San Diego on March 11 to 14 and gave a paper entitled "Quarter-Wave Plate for $\lambda = 3.39 \mu\text{m}$."

MASSIVE OPTICS

A. B. Meinel and J. Van Workum

Study of manufacturability of the 24-inch f/4.5 Meinel-Shack three-mirror system is completed. Preliminary layout of the system to be constructed has been started by N. A. Hochgraf. Three Cer-Vit blanks are being procured.

Before the shop work begins, the null correctors for optical testing must be designed.

It is anticipated that roughing out of the mirrors will start shortly.

An experimental lightweight Cer-Vit mirror of 70-inch diameter has been received from Owens-Illinois. This mirror will be used for fabrication tests and eventually will be used as a collimator in the 150-ft test tower.

MATHEMATICAL OPTICS

B. Roy Frieden

Digital processor program

The first computer run was made using actual data from the digital scanner. The output indicates programming errors, a few of which have been found. We hope to make many runs using this one set of data to sequentially eliminate all programming errors.

The extrapolating pupil

In previous reports we described a pupil coating $P_N(\beta)$ whose point image is arbitrarily close to a Dirac delta function. Some rather startling, and potentially useful, applications follow from this behavior. All are currently in the "thought experiment" stage:

(1) Optical signal extrapolator. We denote the pupil coating as $P_N(\beta)$, where β is the pupil coordinate and P is the amplitude transmittance. Suppose a voltage-vs-time curve is observed from time t_a to time t_b , and we wish to know what the voltage was before t_a and what it will be after t_b . We let this given voltage curve be physically coated upon the pupil of a diffraction-limited optical system, with the opposing edges of the optics corresponding to t_a and t_b . Upon this pupil we place $P_N(\beta)$, henceforth called the "extrapolated pupil." Then, by use of coherent illumination of the pupil, masking in the Fraunhofer plane, and reinversion by a larger diffraction-limited lens whose edges correspond to $t_1 < t_a$ and $t_2 > t_b$, the output amplitude distribution will be voltage vs time from t_1 to t_2 . Thus, the given voltage curve is extended beyond its initial boundaries, with arbitrary accuracy (in theory), and to any past or future times.

(2) Image extrapolator. In the preceding, we replace the voltage-vs-time curve by the irradiance-vs-distance pattern for a piece of an image. The image extends from x_a to x_b . If used as described in (1) above, the output wave will be the image extended to $x_1 < x_a$ and $x_2 > x_b$.

(3) Analog band-unlimited restorer. A method of band-unlimited restoration was discovered and described in Optical Sciences Center Technical Report 18. By this method, the object scene may be arbitrarily restored from the image. We now are able to do such restoration (at least in principle) by an optical analog device. We use coherent, Fraunhofer processing with the addition of an amplitude mask $P_N(\beta)$ superimposed in the Fraunhofer plane. The reinverted wave is now the band-unlimited restoration.

(4) Image synthesis. Any required point amplitude distribution may now be produced by appropriate choice of a pupil function. If two functions $A(\beta)$ and $a(x)$ are Fourier transform mates, where $a(x)$ is a zero beyond x_0 , then the finite aperture $A(\beta)P_N(\beta)$ will physically give rise to an amplitude pattern $a(x)$, $|x| \leq x_0$.

(5) Producing an indefinitely narrow depth of focus. Instead of pupil $P_N(\beta)$, we now use a pupil

$$|\beta| P_N [c(\beta^2 \beta_0^2/2)]$$

where $c = \lambda/4\pi$ and β_0 is the pupil extent parameter.

(6) A superdirective, arbitrarily narrow laser beam. If only the even transverse laser modes are permitted to resonate, and with increasing energy as required, the output beam arbitrarily approaches a Dirac delta function. If diffraction losses are small also, the output beam would have an arbitrarily high power density.

(7) Use of sonar or radar with optical resolving power. Pupil $P_N(\beta)$ will work for any scalar wave, since the derivation is based solely upon the scalar wave equation. We also found that the resolution is arbitrarily good, independent of the wavelength employed as described in Technical Report 34 (see No. 1 on page 23). Hence, long wavelengths may now be used to produce pictures with optical resolution. This is important because sonar is much more penetrative of sea water, for example, than is light, and hence sonar may now be appropriate for use as an image-forming medium with optical quality.

Any attempts at actual implementation of items (1) through (7) above will probably meet with great difficulties. As described in Technical Report 34, there are very serious problems of field illumination and/or (depending upon the application) pupil fabrication. Let the user beware!

It may also be that the quantum nature of light, and in particular Heisenberg's uncertainty principle, rules out the ultimate use (high N , high resolving power) of pupil $P_N(\beta)$. This question is currently being investigated.

Contributed paper to OSA convention

The author attended the OSA convention in San Diego on March 11 to 14 and gave a paper entitled "Approaching Perfect Imagery."

OPTICAL DESIGN

R. A. Buchroeder

Massive relay system

Refractive relays, within the present physical and optical constraints, will be too massive and complex, requiring perhaps unrealistic advances in glass technology, to achieve the nearly diffraction-limited performance required in the wide-field 60-inch f/7 telescope.

Special off-axis reflecting designs appear capable of satisfying all requirements in difficult but not impossible physical structures. The design philosophy is complex, but following the lead of A. Kutter of Germany and A. S. Leonard of the USA, Buchroeder has designed a 10-inch f/19 reflective telephoto lens covering 0.5° , while Prof. Leonard has demonstrated that a 10-inch f/13 reflective Petzval is even better corrected. Modifications to the ACCOS package will enable Buchroeder to optimize a 60-inch f/7 three or four mirror reflector which, he expects, may be able to fully satisfy all requirements. Absence of color and absorption, plus the elimination of the central obscuration, are added advantages to a purely reflective system.

Cloudcroft satellite tracking station

Buchroeder has questioned the optical quality of the fixed relay systems now used on the 48-inch telescope. Mr. Tyson has shipped subject relays to Buchroeder for optical tests.

There are several areas in which improvements could be made. At present, parfocal relays are interchanged to allow four different speeds or plate scales. Because available space is unrestricted, Buchroeder proposed that the existing relays be replaced with one, or possibly two if necessary, zoom systems extending from f/6.5 to f/128. No sacrifice in optical quality is required; indeed, an improvement is to be expected over the present nonoptimized relays. A zoom allows a continuous, uninterrupted choice of power, allowing greater time for information acquisition. T. S. Byington has suggested that photodetectors could be coupled to the optical system to allow optimum power based on the detector in use, target size, orientation, and illumination. Degrading effects of the atmosphere could be considered in the choice of power.

A focal reducer to achieve a speed of f/3 or faster has been requested. One design is now being submitted for cost estimates and optical suitability.

In active optics, a relay system allows sensing and control of wavefront errors in the entrance pupil. This is an unexplored subject that may assume considerable importance, requiring some unusual designs.

Relay for the 90-inch Steward telescope

Prof. William Tifft requested a 1:1 apochromatic relay system permitting a stellar resolution of $\frac{1}{2}$ arc sec over a 25.4-mm image. While only narrow filtered bands were to be studied, an apochromat was required to minimize

refocusing requirements. Transmission in the violet restricted complexity and choice of optical materials.

A fluoride-short flint design of relative simplicity has been achieved, and it is now undergoing a thorough optical analysis. The system consists of a singlet field lens and two identical cemented doublets, plus a variety of plane plates that have negligible optical effect.

Consulting (inhouse)

Advice, simple design, and evaluation was given on a 20-inch Gregory-Maksutov site-testing telescope and a long-focus Dall-Kirkham. Buchroeder has also advised on the suitability of stock items for use in unusual photographic and testing situations.

R. V. Shack

Merit function design

Merit function design using orthonormalized aberration is continuing. A program is being prepared in which the input will simply be specifications on the character of the merit function desired. The output will be a set of cards which can be inserted into the ACCOS-GOALS design program so that it will design according to the specific merit function.

Delano y, \bar{y} diagram

Work on the application of the Delano y, \bar{y} diagram to optical design is continuing. We expect shortly to have a simplified version of the ACCOS program available which will incorporate the y, \bar{y} quantities as variables and the above merit function specification as built-in features. This simplified program will operate only with the Buchdahl paraxial estimates of the aberrations. This simplified program is intended primarily for experimental purposes.

Three-mirror study

The three-mirror parametric study is continuing. The first type of three-mirror system, that is, the type with a nominally plane secondary mirror, is virtually complete, and other types with different power distributions between the mirrors are being explored.

Effective f/number of system with annular aperture

The specification of the equivalent f/number of an aberration-free system with a central obstruction in terms of image quality has been investigated and is reported in an article in the January-March Newsletter. In terms of performance of such a system, it is seen that there are essentially three equivalent f/numbers for a given system: one having to do with exposure, one having to do with depth of focus, and one having to do with image quality. The effective f/number for exposure is well known, and the f/number for depth of focus was reported in the previous Newsletter.

G. W. Wilkerson

Secondary dispersion and refracting materials

This project, which was begun in December and thoroughly described in the last quarterly report, is now over half complete.

This work is being done in the main by Gary Wilkerson, Andrew Hooper, and two undergraduate students (Brian Jones and John Waits) who are working part time.

In addition, the old NATO glass list is being reviewed by Mr. Richard A. Buchroeder and the author to see if it can be improved. It may be that more glasses can be deleted than need adding, but Buchroeder and the author definitely feel that some additional good secondary dispersion glasses need to be added to the list.

Status reached on computer programs for optical design and analysis

Our optical design programmer, Barbara Fell, has increased the ALTER routine in ACCOS-GOALS to include just about any conceivable alter situation that could be needed by the Optical Sciences Center optical design personnel. She has changed ACCOS-GOALS so that Buchdahl coefficients can be printed out and used in optical design. Buchdahl coefficients, transverse aberrations, or angular aberrations may now be used in a design run. Any of them may be used for analysis by simply changing the PARAX card.

Dr. Gordon Spencer, creator of ACCOS-GOALS, has sent us a routine that plots longitudinal aberrations. The other routines ordered as a result of the December conference in Tucson among Dr. Roland V. Shack, Mr. John D. Lytle, Mrs. Fell, Mr. Buchroeder, Dr. Spencer, and the author are expected to arrive from Dr. Spencer about the end of April. They will probably be put into good running order by Mrs. Fell by mid May.

Dr. Spencer has announced that he has a zoom lens design routine now for ACCOS-GOALS. That routine is available for a fee. It is not a generalized substitution parameter program like the substitution parameter routine in LASL which has often been applied to zoom lenses.

Dr. Spencer shortly will be sending us free a program that plots MTF as a function of focus for a given number of line pairs/mm.

For no charge, he has sent us a small FORTRAN routine that plots the interferograms for any given amount of spherical aberration as would be seen by a Twyman-Green interferometer. The program is written for an IBM 1130, a computer that is available to us, but it can also be easily adapted to the CDC 6400.

Mrs. Fell has adjusted PAGOS' MTF plotting routines to plot the phase and diffraction MTF as a function of frequency. The tangential and sagittal directions are done on separate graphs. Formerly, tangential and sagittal plots of τ_R and τ_I were all done on one single graph. She has also fixed the

plot routines so that they now automatically label the abscissa in nice round values of the frequency. Previously, the abscissa was labeled in fractions of the cutoff frequency.

Mrs. Fell has improved the design iteration printout format of the Jet Propulsion Laboratory (JPL) FORTRAN version of the LASL (hereafter referred to simply as LASL) lens design program, and she has begun adding to LASL some new changes in it sent to us by Mr. Paul Firnett of Informatics, Inc. (a JPL contractor). These changes should be completed this coming quarter.

Mr. Berlyn Brixner of the Los Alamos Scientific Laboratory has informed us that they are working at improving LASL's design process. They are adapting something very similar to a damped least squares process to it. It also uses a true derivative ("analytical derivative") instead of finite differences to set up the matrices. An "analytical derivative" greatly speeds up the design process. This new routine is still officially in an experimental stage, but the routine is working rather remarkably in a stripped down version of the LASL lens design code. It has caused optical systems to converge at Los Alamos that wouldn't converge for them in the current LASL program that both Optical Sciences Center and Los Alamos have from JPL. This new design routine will be available to us free as soon as it is in good running order.

We are supplying Brixner with the changes he wants from those that we make in LASL. We are also doing the same for Firnett and for Dr. Joe Rush of the High Altitude Observatory (HAO).

Travel

Wilkerson made a trip to Boulder at HAO's expense in early March to help Rush better learn to use LASL. In addition while there, the author aided in Rush's design work on improving the No. 2 HAO coronagraph. The trip was quite successful both with regard to the aiding of Rush with his LASL lens design techniques and with regard to getting the coronagraph design to a much better state.

Wilkerson attended the OSA meeting in San Diego in mid March. This trip was somewhat fruitful to the author in learning more about what is being done in optical design around the country and was quite fruitful for making new and valuable contacts and for gaining knowledge on optical quality glass.

Mariner '69 high resolution camera reports

Wilkerson submitted a brief article on the Mariner '69 high-resolution television camera for the January-March 1969 edition of the Optical Sciences Center Newsletter. This camera has gone in two spacecrafts to Mars this year and will also go to that planet in 1971. Wilkerson designed the optics for this instrument while consulting from Optical Sciences Center for JPL in 1966. L. R. Baker, at that time of JPL but now of the Optical Sciences Center, did the television and electronics design for this camera.

Wilkerson is presently writing a more detailed article on the optics of this camera for the next edition of the Newsletter. He is also writing a detailed technical report on the camera; the report will include a discussion of about a dozen other optical designs that he had considered.

OPTICAL TESTING*A. B. Meinel*

Testing and programming of the wire test have been completed. It has been confirmed that this test is valuable in a poor thermal and vibrational environment, but the accuracy is considerably less than interferometry, with an uncertainty of about $\lambda/10$.

R. V. Shack

The multiple-beam interferometer has been assembled and is in the process of being checked out. Some difficulty was found in aligning the system, and it appears that the reflectance of the reference surface can be reduced somewhat to aid in the alignment without seriously interfering with the multiple-beam capability.

The new interferometer for measuring the coherence function of the atmosphere is being designed. It is being tailored to be usable on the Cloudcroft telescope.

The image evaluator is being held up because the electronic equipment ordered for it has not yet been received. The mirror oscillating mechanism also has not yet been received. These are critical to the operation of the system.

A new interferometer has been conceived which, although it is a two-beam interferometer, will be in principle capable of competing in accuracy with a multiple-beam interferometer. It is based on a technique for converting optical path differences into local rotations of the plane of polarization of plane-polarized light emerging from the interferometer. Thus, for example, simultaneous interferometric photographs in quadrature can be produced, allowing more precise determination of optical path differences.

OPTO-MECHANICS

Structural mechanics

A. J. Malvick

Computer programs for obtaining mirror deflections are completed. A program has been developed to take the mirror surface deflection information and obtain the best focus, and surface deflection and slope components relative to the point of best focus. Analyses of the 60-inch sphere and 90-inch telescope mirror in existing and hypothetical mounts have been made, with recommendations.

Development of a computer program for analysis of lightweight, thin-shell mirrors is currently in progress.

Study of strap-and-point support combinations and their effect on mirror deformation is under way.

Lightweight mirror studies

N. A. Hochgraf

We have made a die and stamped several pyramidal core cells. This is easy to do, and we are able to make cores of 3 different heights with a 3-inch square base. These are being tested by moiré patterns for uniformity and flatness of the sides before structural testing. A jig is designed and will be built which will allow obtaining the shear and compressive stiffness of these pyramidal core cells.

The scanning pentaprism has just been made operational, and final debugging and writing of alignment procedure has just been started by the author. The apparatus is simple and stiff, with every attempt being made to eliminate unnecessary adjustments to obtain reliable measurements at .1 sec accuracies.

The Optical Society meeting was attended in San Diego, and comprehensive discussions were held with displayees regarding our need for an auto-collimator working in the .1 to .01 sec accuracy and sensitivity area.

REMOTE SENSING*P. N. Slater*

Work described in the last quarterly report on interference filters for wide-angle lenses has been successfully completed and is briefly reported under "Thin Films" on page 21. Of the three lenses analyzed (the Geocon IV, Paxar, and Pleogon), the Paxar yielded the best result. With an accordion type interference filter on its second surface, there is no change in the spectral composition of the light incident on the film plane for field angles from 0° to 45°.

The Optical Sciences Center has recently received a \$37,800 contract from the NASA Manned Spacecraft Center for the post-flight testing and calibration of the Apollo 9 multispectral camera; this includes fabrication of a reflecting collimator facility suitable for the testing of this system and more advanced ones of the future. The equipment has provision for spectrophotometric and resolving power testing.

The multispectral camera used on Apollo 9 consisted of four Hasselblad cameras mounted on a frame, which was attached by an astronaut to the sides of the hatch window in the Command Module. The cameras are electrically powered for shutter operation and film wind. The lenses used are Zeiss 80-mm Planars. The film-filter combinations (all by Eastman Kodak) used on the flight were as follows:

- Panatomic-X (type 3400) with #25 Wratten filter
- Panatomic-X (type 3400) with #58 Wratten filter
- Infrared Aerial (type SO 246) with #89B Wratten filter
- Color Infrared (type 8443) with #15 Wratten filter

Coincident with a number of photographic passes of Apollo 9 over southern Arizona, there were a number of aircraft overflights. In all, seven aircraft were involved, flying at altitudes from 3,500 ft to about 60,000 ft. Five of the aircraft carried multispectral cameras using the same film-filter combinations as were being used from orbit. A target of considerable interest will be a special resolution and color panel (CORN) target that was laid out west of the Willcox dry lake area, 70 miles east of Tucson.

THIN FILMS

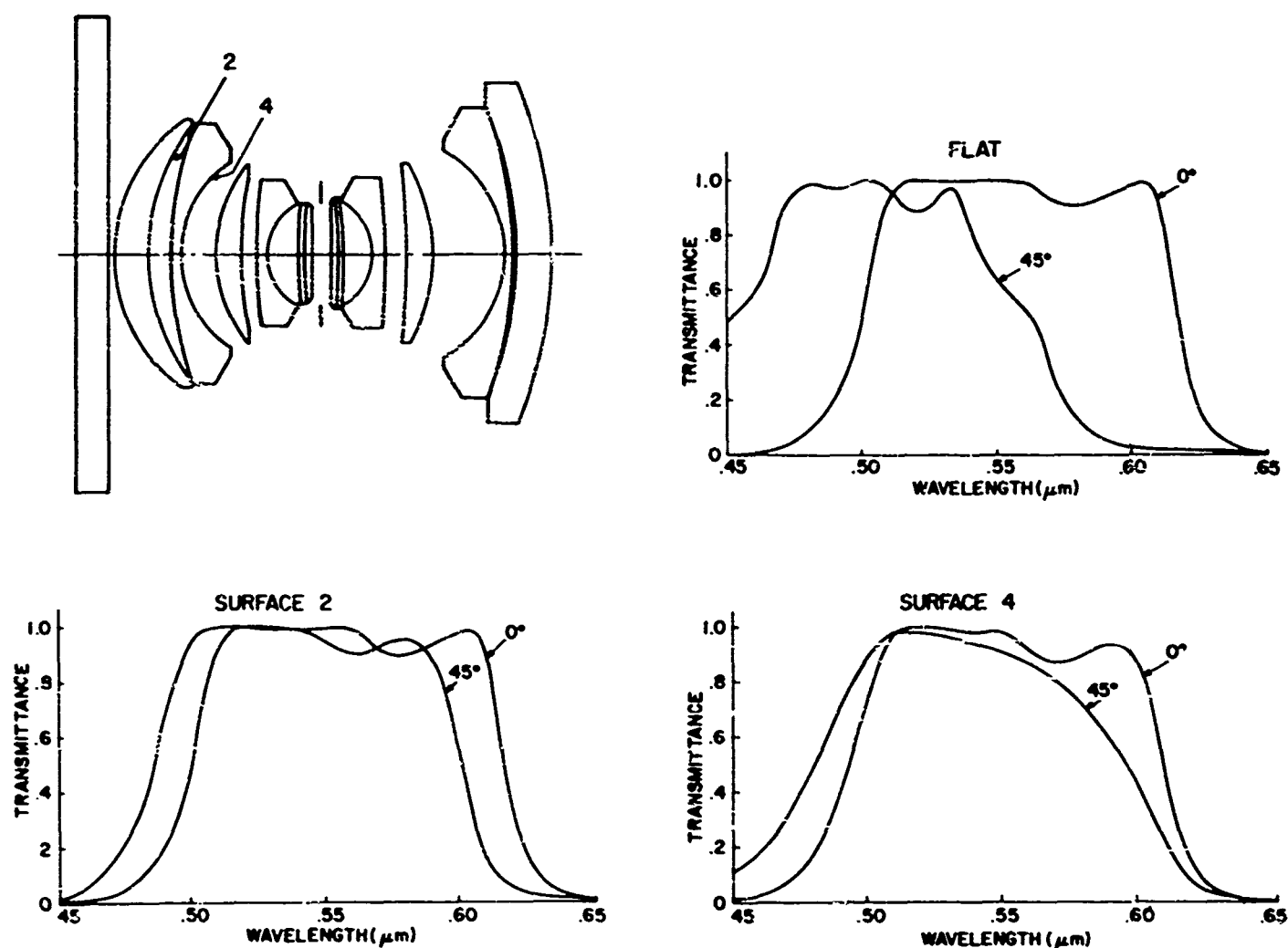
D. B. McKenney

Previously we reported some "ultrawide bandpass filters" for multispectral photography. (See Newsletter 1(5):7 and Tech. Rept. 25.) It would be useful to be able to use interference filters in multispectral photography, and yet, "as everyone knows," interference filters can't be used with cameras because the spectral transmittance characteristics of the filter change with the angle of incidence: As the angle of incidence increases, the passband shifts toward the blue.

With very wide passbands, considerable wavelength shifts could be tolerated for some applications before the change becomes appreciable with respect to the passband width.

Our computations indicate that coating an internal lens surface may be attractive for some specialized applications.

As an example, the lens sketched schematically below represents a Geon IV lens (Kollsman Instrument Corporation) with a before-the-lens filter (the flat plate) at the front.



The first graph, beside the diagram, shows the computed transmittance for unpolarized light at normal incidence and at 45° for one of the wide-passband filters on a plane substrate. This would correspond to a 90° full field lens with a before-the-lens filter.

In the second and third graphs, the before-the-lens filter is not present. Rather, the filter is assumed to be deposited on the second or fourth surface, respectively. These two surfaces were selected because they are concave (making it easier to provide a uniform coating) and they are near the front of the lens (hopefully minimizing the contribution of ghost images to the background illumination).

From the curves, it can be seen that the second surface would be a better one to coat. The shift of the passband is about 11% of its width, which would probably be tolerable for most photographic applications, and represents a vast improvement over the usual before-the-lens filter.

We have found that the task of producing the wideband filters mentioned above is not so easy as we originally thought. There are several possible sources of difficulty. First, we have been using cryolite and zinc sulfide as the two materials. For some applications these materials are best. The cryolite, however, is quite sensitive to evaporation conditions; small index changes can be the result of small substrate temperature variations. We have begun to work with chiolite, which is less sensitive and hopefully more repeatable. Another problem is that of thickness errors during deposition. The errors, however small, can often have large effects in some filter designs.

We have begun a study to learn whether it is possible to determine that thickness errors are the cause of discrepancies between measured and computed filter properties. Our method is to use a modified version of an automatic correction program, which tries to find a "design" to match the measured filter. Since nonunique solutions are possible, we use the restriction that there be a minimal difference in layer thickness between the ideal filter and the measured filter. Results will be available soon.

We shall use the error finding technique to produce some of the wide-band interference filters with the computed properties, locating the sources of error and hopefully eliminating them.

The work on ultraviolet reflection filter work is progressing well. We have been able to produce several varieties of filters that approach the specifications for a solar-blind mirror. A full report on the results of this research is being prepared. This work will continue in an effort to optimize the characteristics of these filters. We will center our efforts on reducing the background (visible) reflectance, and also try to maximize the potential transmittance when the mirrors are used as a Fabry-Perot narrow-band interference filter.

IV. PUBLICATIONS COMPLETED DURING REPORTING PERIOD

1. B. R. Frieden, *On Arbitrarily Perfect Imagery with a Finite Aperture*, Optical Sciences Center Tech. Rept. 34, 15 January 1969, 34 pp.

Despite its necessarily finite aperture, an optical system can theoretically be coated to produce arbitrarily perfect imagery over a limited field. When the object is of limited extent, this field can be made the optical conjugate to the object, so that the whole object is imaged with arbitrary precision.

The required pupil coating approximates low-contrast cosine fringes over its central region; toward the aperture edge the frequency and amplitude rapidly accelerate. The maximum occurs as a narrow spike.

The frequency near the central region varies directly with the total extent of the conjugate field and inversely with the required central core width Δ in the point amplitude response. As Δ is made arbitrarily narrow, the point amplitude response approaches the form of a sinc function over the field of view. This function is precisely the point amplitude for a diffraction-limited pupil with a magnified aperture of $1/\Delta$ times the given pupil aperture! The only image property that is not in compliance with this effective aperture magnification is that of total illumination. This is severely reduced from that of the original, uncoated aperture, and is the major restriction on practical use of the derived pupil.

2. E. L. Gieselmann, S. F. Jacobs, and H. E. Morrow, *A Simple Quartz Birefringent Quarterwave Plate for Use at $\lambda = 3.39 \mu\text{m}$* , Optical Sciences Center Tech. Rept. 35, 15 February 1969, 14 pp.

A thin plate of crystalline quartz has been fabricated for use as a quarterwave plate with He-Ne 3.39- μm lasers and has been used to determine the birefringence of the quartz at that wavelength.

With a single thin plate, first-order relative retardation is achieved without recourse to an air-spaced pair of thicker plates having opposing retardation. Compared with such thick, air-spaced plates, thin quartz plates are much less costly to make, and they allow use of this excellent optical material much farther out into the infrared region.

Because the birefringence at 3.39 μm had not yet been measured, an extrapolated value was used to determine an approximate thickness for the plate that was to be fabricated. Using the plate thus fabricated (0.128 mm thick), two methods were followed to independently determine the birefringence: First, with the plate normal to a linearly polarized 3.39- μm laser beam, the state of polarization of the transmitted beam was measured, yielding the relative retardation, and hence the birefringence, after determination of birefringence was obtained by measuring the plate tilt necessary to produce exactly circularly polarized light. The average of the 3.39- μm birefringence values obtained from the two methods was $.0065 \pm .0001$, corresponding to a quarterwave plate thickness of .1304 mm.

The possibility of using thin crystalline quartz for infrared waveplates is attractive. However, one must consider both anisotropic absorption and anisotropic Fresnel reflection, which vary with wavelength. Only if these anisotropic losses can be balanced or made negligible (as by antireflection coating) can a perfect waveplate be made.

3. R. G. Wilson, *Ionic Polishing of Fused Silica and Glass*, Optical Sciences Center Tech. Rept. 36, 15 February 1969, 31 pp.

It was reported in 1965 that an incident ion beam could be utilized to polish and figure optical surfaces. An f/6, 10-cm paraboloid has been figured in this manner. This paper reviews research in the erosion of fused silica and glass in an effort to gain a better understanding of the ionic polishing process as applied to optical materials. It is found that erosion rates depend on ion mass, ion energy, target temperature, angle of incidence, and target material, and may also depend on vacuum pressure. The paper also considers other effects that accompany ionic bombardment of insulators, such as nature of the eroded surface, contaminate films, surface layer alterations, secondary electron emission, and gas trapping and release.

4. O. N. Stavroudis, *Refraction of Wavefronts: A Special Case* (letter), J. Opt. Soc. Am. 59(1):114-115, Jan. 1969.

Wavefronts tend to be extraordinarily intricate surfaces, particularly in the neighborhood of a focus, and the analytic expressions that describe them are extremely involved. It is suggested that in a family of converging or diverging wavefronts there may be one with the property that the analytic expression describing it is relatively simple. If such an archetype exists, the properties of all other wavefronts in the family can be derived from it.

An example of such an archtypical wavefront has been found. Consider a point source and a plane refracting surface separating two media of refractive index N and N' . The wavefronts emanating from the point source are spherical. After refraction they are in general quartic surfaces. However, at one point the quartic surface degenerates into a quadratic surface, and at that point the wavefront becomes a conic section of revolution. If $N < N'$, this archtypical wavefront is a hyperboloid, if $N > N'$, it is an ellipsoid.

5. The following papers were presented at the 1969 Spring Meeting of the Optical Society of America in San Diego, California, 11-14 March 1969:

B. R. Frieden, *Approaching Perfect Imagery*.

S. F. Jacobs, E. L. Gieselmann, and H. E. Morrow, *Quarter-Wave Plate for $\lambda = 3.39 \mu\text{m}$* .

O. N. Stavroudis, *Orthotomic Systems of Rays in Inhomogeneous, Isotropic Media*.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Atmospheric optics Geometric optics Image processing Analog image processing Digital image processing Image tubes Lasers Massive optics Mathematical optics Optical design Optical testing Opto-mechanics Mirror deformation Lightweight mirror studies Remote sensing Structural mechanics Thin films Optical sciences						