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INVESTIGATION OF 10.6 MICRON PROPAGATION PHENOMENA

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The Ohio State University

ElectroScience Laboratory

Department of Electrical Engineering
Columbus, Ohio 43212

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13. ABSTRACT

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INVESTIGATION OF 10.6 MICRON PROPAGATION PHENOMENA

R. S. Davidson II

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116

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This technical report has been reviewed and is approved.

Raymond P. Urtz Jr.
RADC Project Engineer

ABSTRACT

This report summarizes the technical details of work performed at The Ohio State University ElectroScience Laboratory during the period 8 January 1972 to 8 April 1972.

The delivery and field testing of the Dual Channel Infrared Scanner System are reported along with details concerning the computer interface being constructed for the ElectroScience Laboratory data reduction facility. A description of the transmitting optics being supplied to RADC is also included in this report.

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TABLE OF CONTENTS

		Page
I.	INTRODUCTION	1
II.	DELIVERY OF IMAGING APPARATUS	1
III.	OSU DATA REDUCTION FACILITY	4
	A. Flow of Processed Data	4
	B. Interface System	5
IV.	ANALYTIC CONTINUATION	8
V.	TRANSMITTING APPARATUS	12
VI.	SUMMARY	13
REFERENCES		15

INVESTIGATION OF 10.6 MICRON PROPAGATION PHENOMENA

I. INTRODUCTION

This is the seventh technical report on Contract No. F30602-70-C-0003 entitled "Investigation of 10.6 Micron Propagation Phenomena." This report covers the period 8 January 1972 to 8 April 1972.

This program initially provided theoretical backup information to the RADC Atmospheric Optical Propagation Studies Program and is currently centered on the study of atmospheric imaging and the restoration of atmospherically degraded 10.6 micron images. The general aim is to provide initial attempts at image restoration, to determine potential problems, and to obtain data useful for preliminary systems design. For this purpose, a system has been completed, tested and delivered to RADC which will simultaneously sample with 40 x 40 resolution two 10.6 micron images at 200 frames per second and record these images in digital format on magnetic tape.

Primary effort during the past three months has been devoted to completing, delivering and field testing the Dual Channel Infrared Image Scanner Package and the Miller Code Magnetic Tape recording and playback system. Also effort has been applied toward completing an interface between the serial digital (Miller Code) recorder and the DC 6024/3 computer for reduction of data to be pre-recorded by RADC. Construction of the transmitting optics to be used at the Verona PATS test site has received emphasis during this period as has an investigation into performing analytic continuation, by computer processing techniques, on the recorded image spectrum to improve resolution in the restored image.

II. DELIVERY OF IMAGING APPARATUS

The ElectroScience Laboratory Dual Channel Infrared Scanner[1] has been completed and installed at the RADC Verona PATS test site. During the week of March 20, 1972, ElectroScience Laboratory personnel delivered the system consisting of the Dual Channel Infrared Image Scanner package, the control console and the Ampex FR1400 data acquisition magnetic tape recorder (see Fig. 1). After mounting the scanner package on the RADC telescope mount (see Fig. 2) and installing the necessary relay optics (see Fig. 3) to bring the telescope focus to the scanner input aperture, the entire system was field tested by recording and reproducing the 10.6μ turbulence degraded image resulting from transmitting a 10.6μ beam over the 1000 foot Verona propagation path. Two tapes, each containing approximately fifteen minutes of real time data, were recorded to check: the proper operation of the

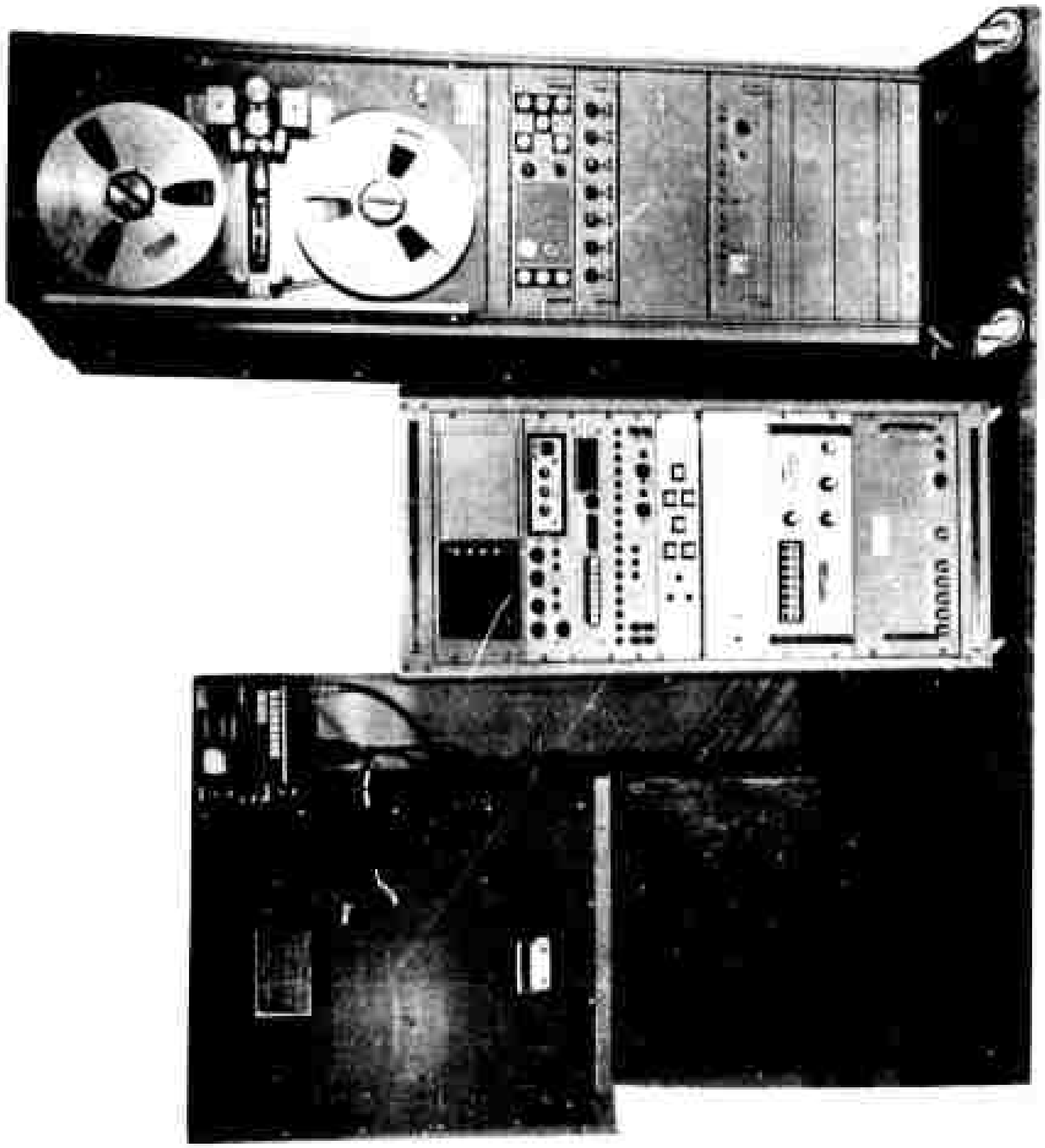

Fig. 1. Dual channel infrared image scanner system.

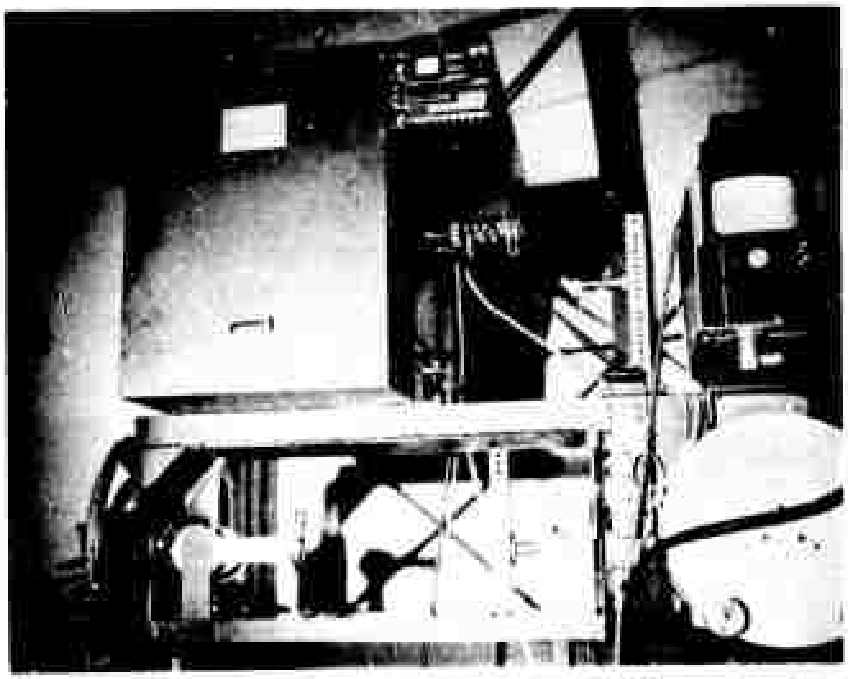

Fig. 2. Dual channel infrared scanner package mounted on RADC's telescope mount.

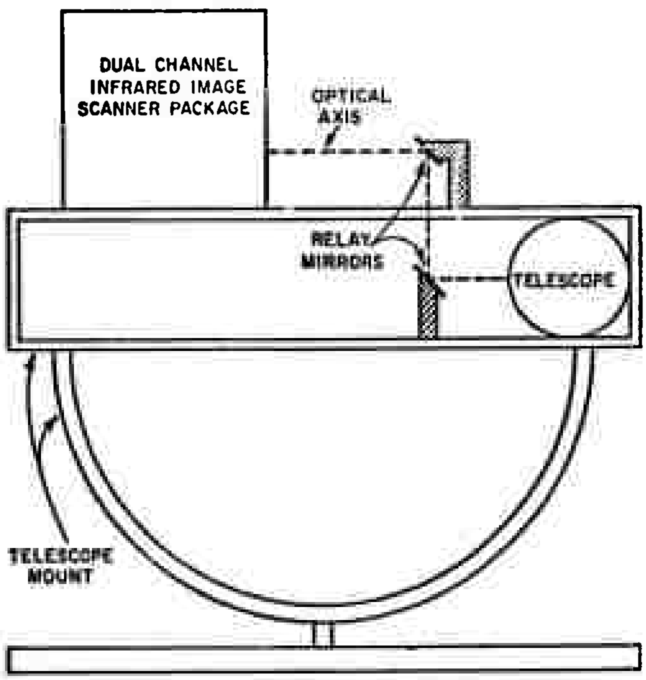

Fig. 3. Telescope mount detail showing relay optics.

two record modes, (i.e., 8 bits or 7 bits plus parity), the three available image magnifications, (i.e. 1:1, 2:1, and 4:1), and the four CRT viewing modes, (i.e. analog, parallel in, serial in, and serial out)[1]. Each mode passed the field inspection tests and thus the entire system proved to be functioning as designed and is now ready to begin collecting data. The two tapes recorded during the field inspection were returned to the ElectroScience Laboratory where they will serve as the initial inputs to the data reduction facility described in the following section of this report.

III. OSU DATA REDUCTION FACILITY

A. Flow of Processed Data

The proposed flow diagram of the image processing steps at the ElectroScience Laboratory data reduction facility is shown in Fig. 4.

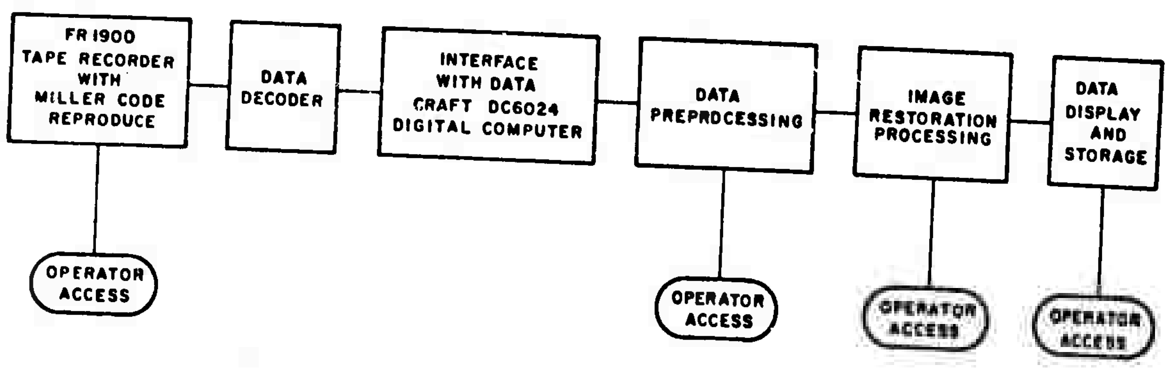

Fig. 4. Image processing flow diagram.

This flow diagram represents a significant change in the approach proposed in March 1971. At that time, the ElectroScience Laboratory proposed interfacing the SDS 920 computer with the IR scanner decoder unit to generate IBM compatible tapes. These tapes were then to serve as input data to the image restoration software program written for the OSU IBM 360/75 computer. However, in September 1971, the ElectroScience Laboratory installed an inhouse data processing facility centered around the Datacraft 6024/3 digital computer. As a result, effort applied toward a computer interface has been redirected toward a system compatible with the DC 6024/3. The first phase of this effort was the conversion of the existing IBM 360/75 restoration software to DC 6024/3 software. This phase has been completed and tested. The second phase, which is now receiving attention, is construction of the hardware interface components. With the completion and the installation of this hardware, the new ESL data reduction capability will have significant advantages over the one originally proposed. The key advantage, as shown in the flow diagram, is that the ElectroScience Laboratory image restoration personnel will have complete control over the data reduction steps from the time the data is read off the Miller Code tape to the time when a restored image is available from the DC 6024/3. Another advantage is the flexibility of the data output format. Numerical data will be available on the line printer, and various plots (contour, 3D, etc.) will be available on the X-Y plotter. A CRT display of degraded and restored images will be available for visual comparison and photographic recording purposes and digital tape will be available for efficient bulk storage of important results. Each of these options will be open to the system operator during a data run so that he can choose the best presentation of the restoration results.

B. Interface System

The purpose of the interface system is to convert the data obtained from the Ohio State University playback system into signals compatible with the Ohio State University Datacraft 6024/3 computer. After the data is converted into a computer compatible format, it will be written on a 9 track digital tape. This digital tape will then be processed using existing image restoration software programs.

The interface system has been designed to receive 24 signals from the Ohio State University playback system, which it converts into a 24 bit computer word. The 24 signals arriving from the Ohio State University playback system are actually 12 signals from each data channel. The 12 signals are: 8 data bits, 1 parity check, 1 mode select, 1 line sync, and 1 frame sync. These 24 signals are arranged so that the Datacraft computer word contains channel 1 information in bits 0-11 and channel 2 information in bits 12-23.

An additional function of the interface system will be to convert the 24 bit computer formated data into appropriate signals for use by the Ohio State University display system.

The Datacraft 6024/3 is a medium-scale, general purpose, digital computer featuring a cycle time of 1 microsecond. The computer has a fixed word length of 24 bits and uses a magnetic core memory with a maximum storage capacity of 32,768 words. It has five 24-bit general purpose registers, three of which may be used for indexing.

A brief discussion of the interface system operation is given below.

Select I/O Device

In order for the Datacraft computer to communicate with an I/O device, the I/O device must first be chosen by the computer. The selection of the I/O device, in our case the interface system, can be made with any one of the four I/O software assembly language commands available in the Datacraft computer. The software I/O command used designates from which I/O device the computer will receive information and to which device it will send information. This selection is accomplished in the interface by the unit decode matrix (see Fig. 5). The Datacraft computer sends to the unit decode matrix a 4 bit code, unit bits 0-3. After receiving this signal, the unit decode matrix then sends back to the Datacraft computer a unit connected signal, CNCT. Once the I/O interface system sends the Datacraft computer this CNCT signal, the computer is ready to input or output data. The Datacraft computer can at any time disconnect the interface system by sending a disconnect signal, DISC, to the unit decode matrix.

Input Data

The Ohio State University playback system supplies the interface system with 24 signals, as described previously, which are loaded into 24 flip-flops, located on 2 input logic boards of the interface system (see Fig. 5). These 24 flip-flops serve as the input register to the Datacraft computer. Once all 24 signals have been loaded into the flip-flops, the interrupt system (see Fig. 5) of the interface system sends an input data available from unit, DAVFU, signal to the Datacraft computer. Upon receiving the DAVFU signal, the Datacraft computer strobes the 24 bit word stored in the flip-flops into its I/O register (the A register). After the A register has been loaded, the Datacraft sends an input data accepted signal, DATU, back to the interface system. This DATU signal resets the 24 flip-flops of the input logic boards to zero. This procedure is repeated until all the data desired from the Ohio State University playback system has been transferred, via the interface system, into the Datacraft computer.

Display Digital Tape

In order to display a Datacraft 6024/3 9 track digital tape on the Ohio State University display system, the Datacraft sends to the interface system one standard 24-bit word (see Fig. 5), plus an output data here signal, ODH. The ODH is used by the interface system to generate, for the display system, an output data clock. The interface system upon receiving the 24-bit word and the ODH signal, sends to the Datacraft computer a data accepted signal, DACP, to inform the computer that the 24-bit word has been accepted. The display system upon receiving the 24 signals and the output data clock from the interface system selects the appropriate bits corresponding to the channel to be displayed on the CRT.

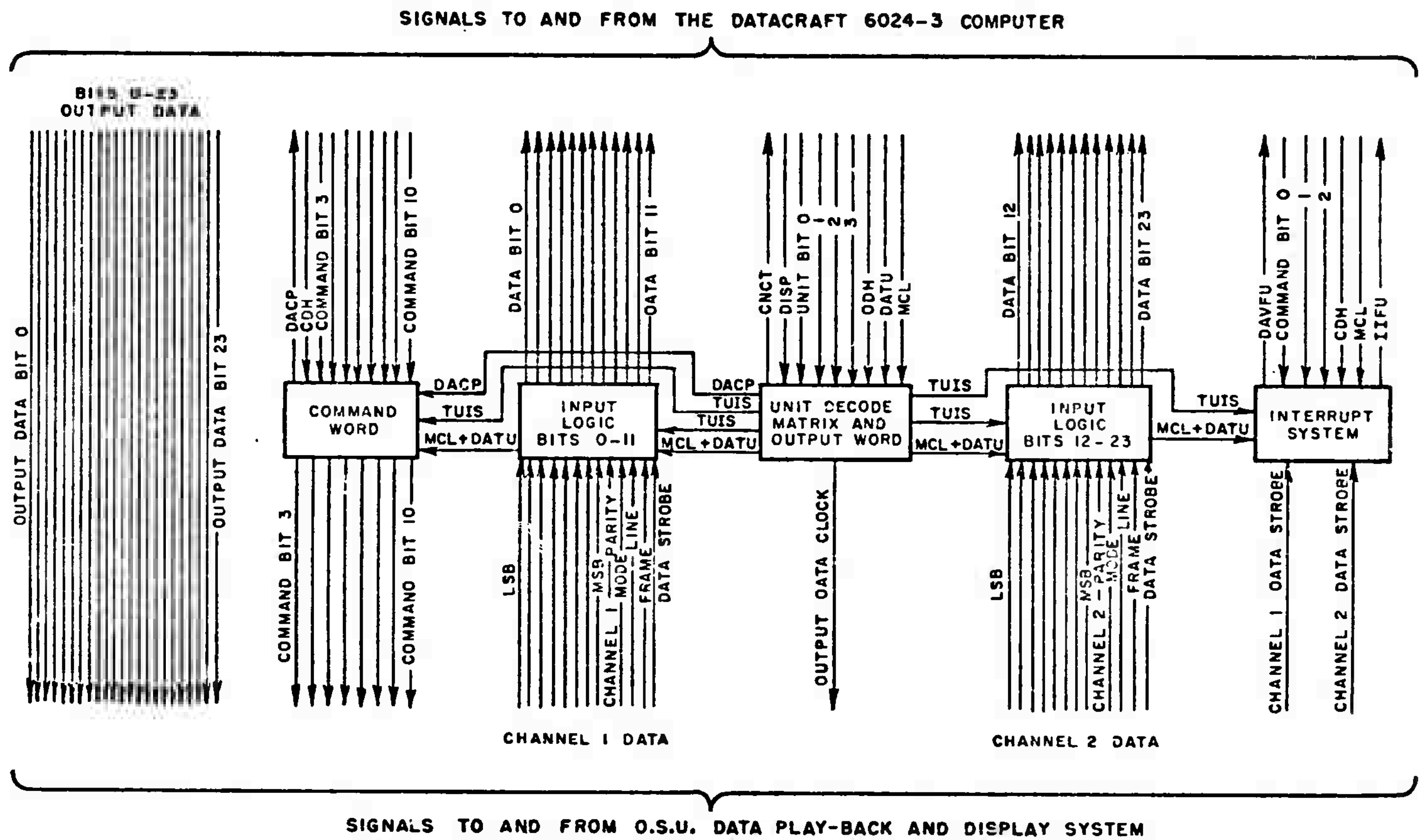

Fig. 5. Interface system.

Command Word

The command word section (see Fig. 5) of the interface system is not used at the present time, except to send the DACP signal to the computer. It may be used later to control certain functions of the Ohio State University playback and display system. Currently it is an optional feature of the interface system.

IV. ANALYTIC CONTINUATION

It is possible to extend the spectrum of a bandlimited signal beyond its cutoff frequency by applying the theorem of analytic continuation to the spectrum. For an incoherent imaging system, the image spectrum is bandlimited by the entrance pupil of the optics. This phenomenon limits the realizable image resolution which will have a pronounced effect when studying degraded images of objects known to be of finite size. These facts suggest that if a technique could be found to extend the region of known frequencies beyond the system cutoff frequency then improvements in image resolution would be obtained. Theoretically such an extension is possible by applying a theorem from complex variables, known as the Theorem of Analytic Continuation[2], to the band limited spectrum. It has been shown[3] that by applying this theorem in a situation where the object is of finite dimensions, an ambiguous image spectrum does not exist (an ambiguous image spectrum would exist if two distinctly different objects, when imaged, had the same image spectrum) and thus the resolving power is limited only by the inherent system noise.

A practical computer technique for applying analytic continuation to a band limited image[5] is being investigated at the ElectroScience Laboratory. The ideal goal would obviously be to extend the image spectrum throughout the entire frequency plane and thus realize the best possible resolution. Practically, of course, this is not possible but we would like to extend the region of known frequencies out to 1-1/2 or 2 times the system cutoff frequency, then Fourier Transform this extended spectrum to obtain a new image having improved resolution. To this end, some preliminary work has been undertaken at the Electro-Science Laboratory in applying analytic continuation to the band limited spectrum of a one-dimensional finite-sized object. This initial effort has been applied toward investigating an iterative technique for extending the band-limited spectrum as described below.

Suppose Fig. 6 and Fig. 7 represent the Fourier Transform relationship between the recorded image, known to be of finite dimension, (the dashed line in Fig. 6 represents the actual object) and its band-limited spectrum where $\pm B$ are the band limits imposed

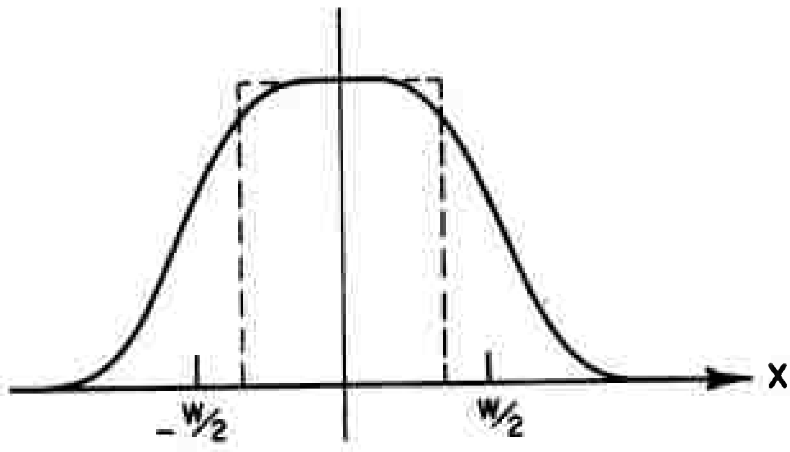

Fig. 6. Recorded image.

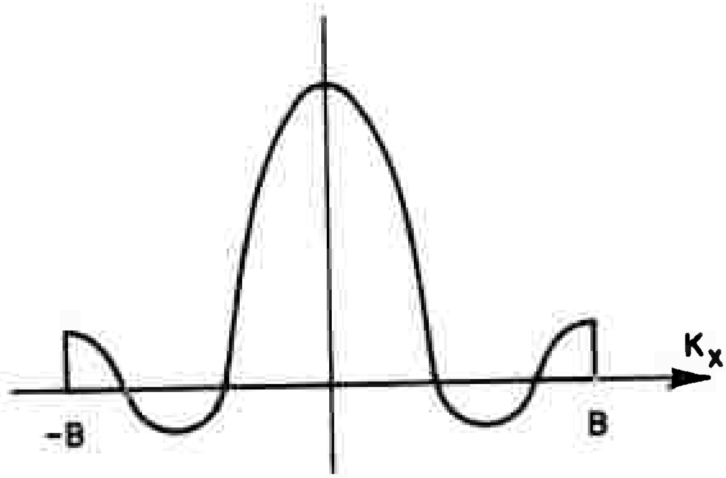

Fig. 7. Bandlimited spectrum of recorded image.

by an entrance pupil. Further suppose we know a priori that the object is of size $|X| \leq W/2$, that is, it is exactly equal to zero for $|X| > W/2$. Then in terms of the improved image that we are trying to find, we have the situation indicated in Fig. 8. Thus from Fig. 7 and Fig. 8 we know the object values for $|X| > W/2$ and the spectrum values for $|K_x| < B$ but we want to find the object for $|X| \leq W/2$ and the spectrum for $|K_x| > B$. These facts are summarized in Fig. 9 and Fig. 10.

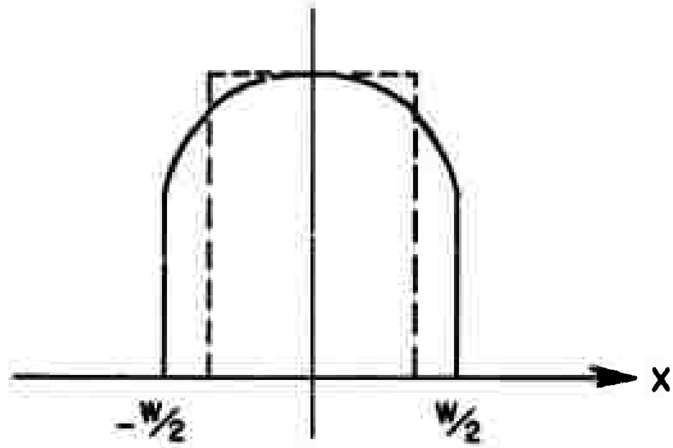

Fig. 8. Chopped version of recorded image.

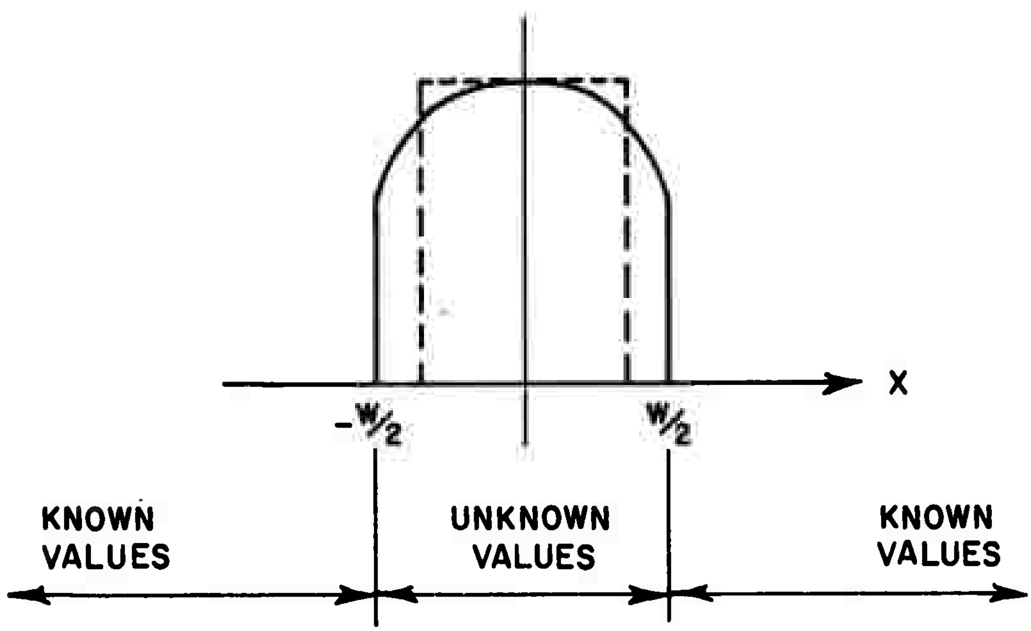

Fig. 9. Image information.

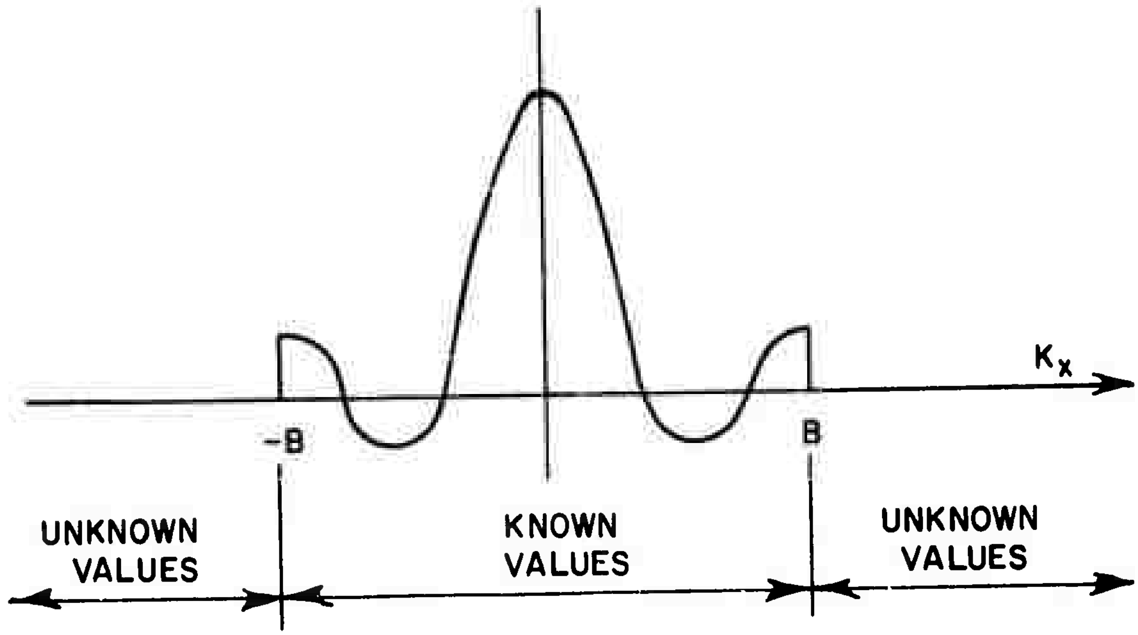

Fig. 10. Spectrum information.

The iterative technique programmed at the ElectroScience Laboratory on the Datacraft DC 6024/3 computer takes the restricted image (Fig. 8), Fourier transforms it and adds those frequency components, from this new spectrum, which are outside the passband $|K_x| \leq B$ to the spectrum in Fig. 7. An inverse transform is performed on this extended spectrum to obtain a new image which is set equal to zero for $|X| > W/2$ and the same sequence of steps is then performed on this new image. The goal is, after a number of iterations for the values of $|X| < W/2$, to converge to the actual object and for the frequency components $|K_x| \geq B$ to converge to those values not passed by the entrance pupil. At the present time; however, after as many as 40 iterations the technique does not show satisfactory convergence. Hence, effort is now being applied toward matching boundary conditions in the frequency domain in hopes of improving the convergence of this technique.

Effort has also been applied toward finding a better technique for performing analytic continuation of the spectrum. The most promising is the use of prolate spheroidal wave functions. It has been suggested[4] that a signal to noise ratio of 30 dB is necessary when applying this method to reduce the severe errors introduced by noise. This signal to noise ratio is the minimum figure expected from the ElectroScience Laboratory digital recording apparatus thus we are optimistic about the use of prolate spheroidal wave functions in our analytic continuation work and intend to investigate this approach further.

V. TRANSMITTING APPARATUS

One of the major aims of this project is to measure the isoplanatic patch size within which a degraded point image can be used to restore an extended degraded image. There are two general pieces of apparatus required for this experiment, an imaging receiver capable of recording two simultaneous images and a transmitting apparatus providing two point sources with adjustable separation. The imaging detector has been completed and delivered. The transmitting apparatus has been designed and is now under construction. The design will now be discussed.

Several criteria entered into the design of the transmitting apparatus:

1. The apparatus should provide two identical waves with spherical wavefronts and intensities of the undegraded beams constant to within five percent over the receiving aperture.

2. The transmitter should be adjustable so that the beam is provided as described at the receiver for ranges of 1000, 3000 and 5000 feet.

3. The transmitting operator should have the capability of pointing the beam at any preselected receiver.

4. The transmitting apparatus should provide boresighted 10.6 micron and 0.6328 micron beams.

5. The transmitter spacing of the two beams should be variable up to six feet with the possibility of larger separations being added if necessary.

Thus three different sets of optics corresponding to the three different ranges had to be designed to provide the proper transmitted beam sizes for both visible and infrared at the three ranges. At each range it was desirable not to have the beam any larger than necessary at the receiver so as to provide maximum signal-to-noise ratio at the receiver.

A schematic layout of one system for one wavelength and one range is shown in Fig. 11. The beam emitted by the laser is first reduced in size, then again modified in size to compensate for the particular range and finally applied to the output mirror. The output mirror then radiates a Gaussian beam with flat wavefront and spot size adjusted to provide the desired beam size at the receiver. The beam reducer was employed to simplify the design of the range size compensator. It provided a sufficiently small spot that Gaussian

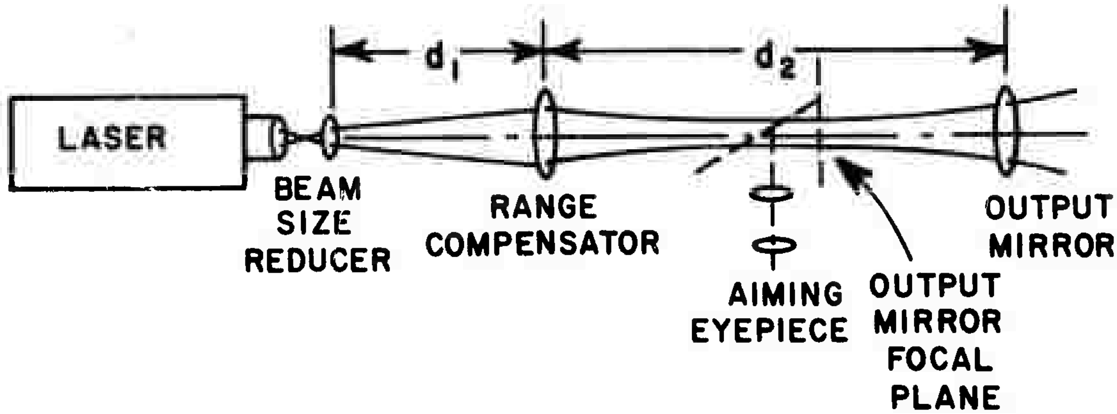

Fig. 11. Transmitter optics.

optics calculations could be used to specify the distances d_1 and d_2 of the range compensation mirror.

The aiming capability was provided by using the output mirror as the objective of a telescope aimed at the receiver. The receiver was centered on an aperture placed in the image plane of the output mirror, and the transmitted beam was put through the center of the same aperture. A secondary mirror is inserted to allow observation of the aperture when pointing the output mirror towards the receiver.

The actual layout for both wavelengths and all three ranges is shown in Fig. 12. The basic optical operations are identical with those of Fig. 11. There are, in addition, the beam splitting and combining unit in front of the two lasers which is not shown in Fig. 11 and the apparatus for sidestepping the output beams. The optical systems are symmetric from point A and A' to the output. Further, the paths in the beam separating and combining unit from each laser to points A and A' are identical. In switching from one range to another only the range compensator mirror need be changed, resulting in a minimum of adjustment. The system has been designed, materials purchased, and is now under construction.

VI. SUMMARY

Delivery, installation and successful field testing of the Dual Channel Infrared Image Scanner are reported. Work in progress includes the design and construction of a serial digital (Miller Code) recorder - DC 6024/3 computer interface system and a laser beam transmitting apparatus providing two point sources with adjustable separation. Initial studies of computer techniques for improving image resolution through analytic continuation of bandlimited spectrum are described. The computer interface will be completed and actual image restoration using the existing ElectroScience Laboratory software capability will be demonstrated during the next quarter of this contract.

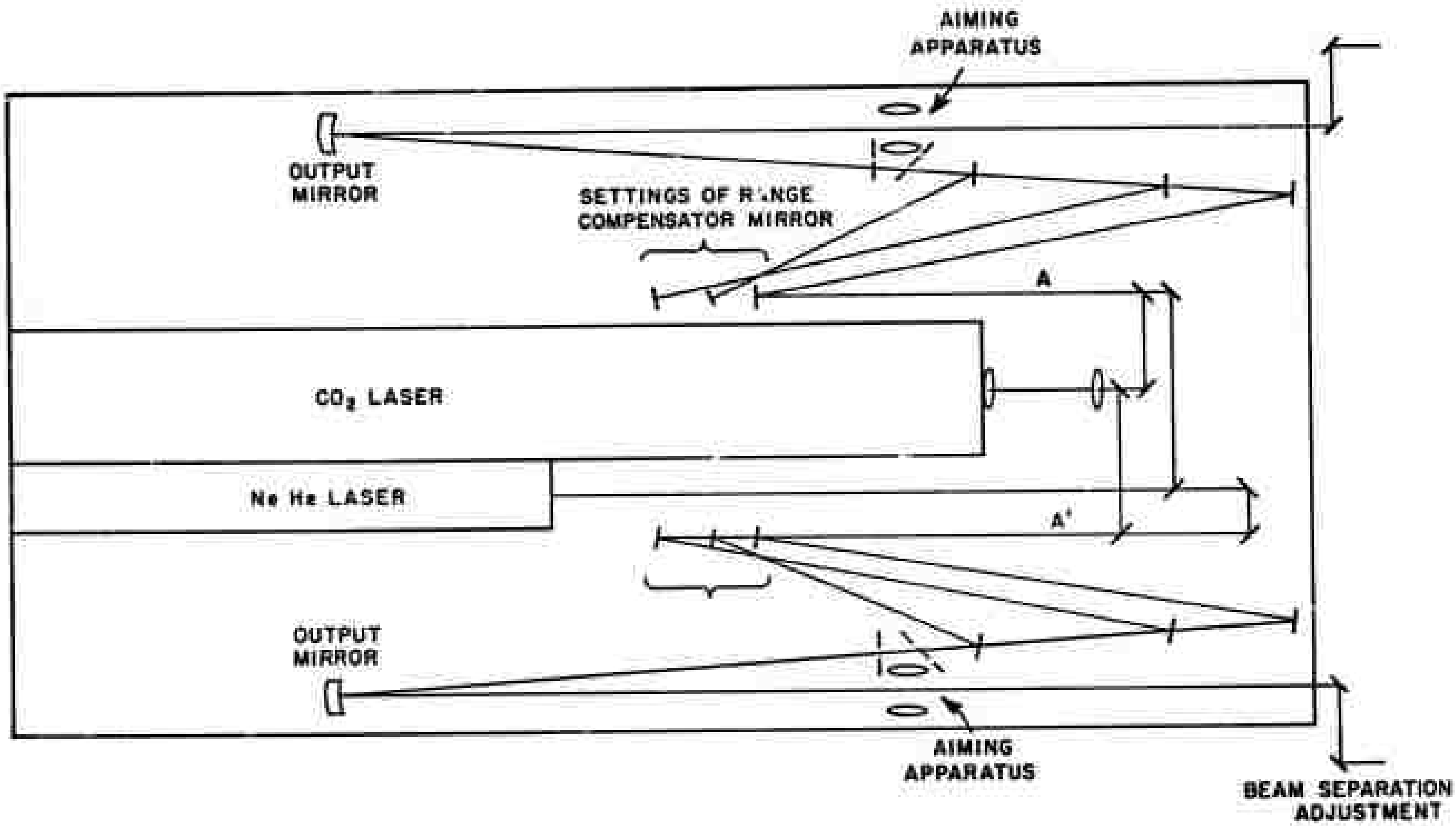

Fig. 12. Dual beam transmitting apparatus.

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