ANNUAL REPORT SEPTEMBER 1, 1970-August 31, 1971
AEC AT(11-1)1469
PART A.   Software Systems Research

C. W. GEAR, Principal Investigator

Highlights of this years accomplishments

1. An initial version of the simulation system was completed. -

2. The Sparse matrix analyzer was rewritten, and now considers both numerical accuracy as well as sparsity preservation for pivot selection.

3. An extension to the differential equation integrator will solve steady state equations.

4. Two display terminals were interfaced to the PDP-8 system in a multiplexed fashion, and the software to drive them has been checked out

5. The disk controller was redesigned and rebuilt in order to improve reliability and ease software interfacing.

6. Our program packages for stiff equations and for the PDP-8 monitor system are now being used successfully by other groups.

This year has seen the completion of initial versions of all programs for the transient analysis of arbitrary networks and the linking together of these packages. A diagram showing the organization of the major parts of the software system is given in Figure 1. A brief description of the purpose of each package is given in section 2 below. (Many of these packages were ones started in the previous year.) Details of the techniques used in the packages that are new or have changed significantly since last years report are given in section 3 where the year's progress is related to the proposed program for this period. In section 1 we give some examples of parts of networks to illustrate the generability that has been achieved in the system.
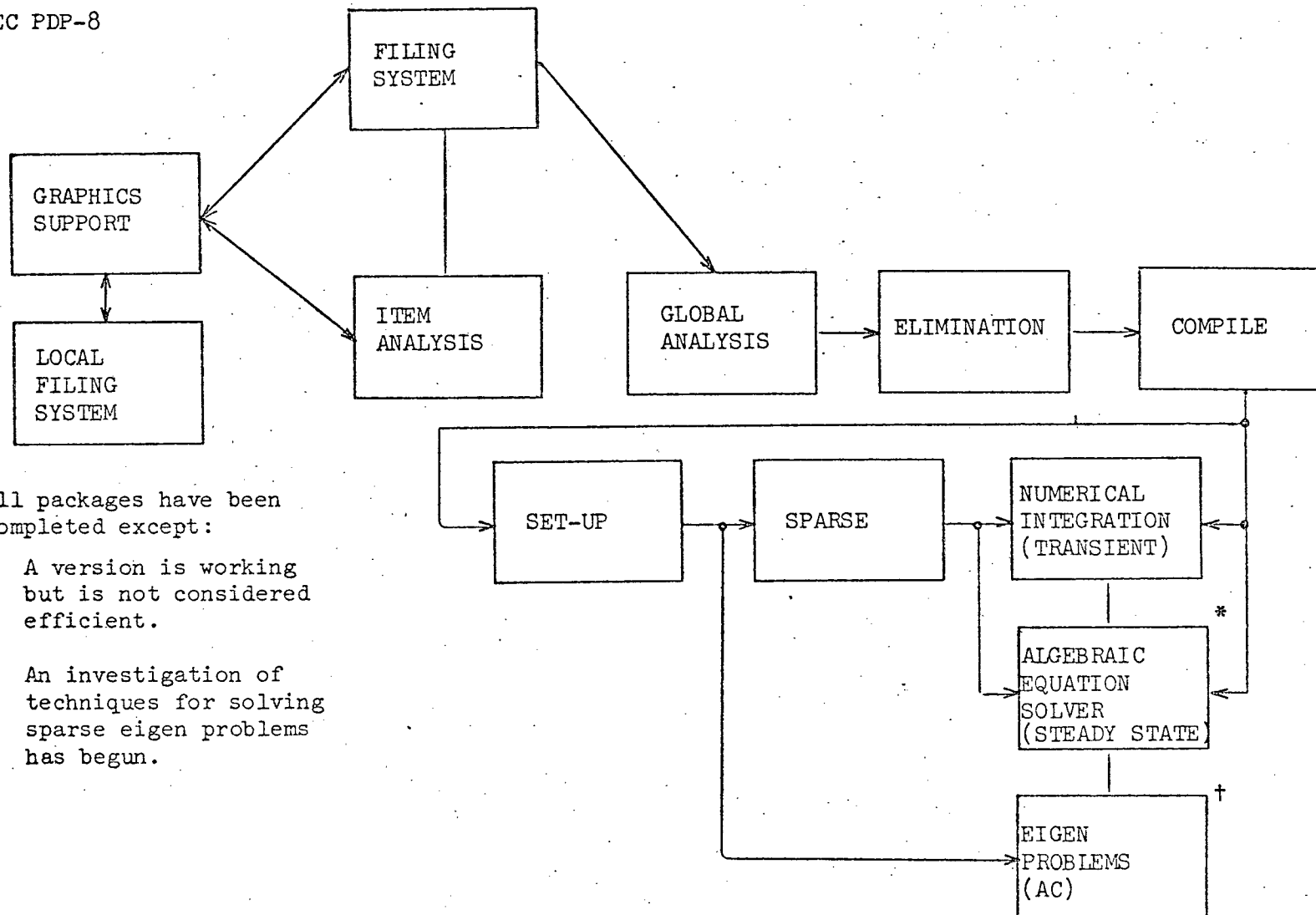
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IBM 360/75

DEC PDP-8

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                        ┌──────────────┐
                        │  FILING      │
                        │  SYSTEM      │
                        └──────────────┘

┌──────────────┐                              ┌──────────────┐   ┌──────────────┐   ┌──────────────┐
│  GRAPHICS    │                              │  GLOBAL      │──▶│ ELIMINATION  │──▶│  COMPILE     │
│  SUPPORT     │         ┌──────────────┐     │  ANALYSIS    │   └──────────────┘   └──────────────┘
└──────────────┘         │  ITEM        │     └──────────────┘
       ▲                 │  ANALYSIS    │
       │                 └──────────────┘
       ▼
┌──────────────┐
│  LOCAL       │
│  FILING      │
│  SYSTEM      │
└──────────────┘

              ┌──────────────┐   ┌──────────────┐   ┌──────────────┐
              │  SET-UP      │──▶│  SPARSE      │──▶│  NUMERICAL   │
              └──────────────┘   └──────────────┘   │  INTEGRATION │
                                                    │  (TRANSIENT) │
                                                    └──────────────┘

                                                    ┌──────────────┐
                                                    │  ALGEBRAIC   │  *
                                                    │  EQUATION    │
                                                    │  SOLVER      │
                                                    │ (STEADY STATE)│
                                                    └──────────────┘

                                                    ┌──────────────┐  †
                                                    │  EIGEN       │
                                                    │  PROBLEMS    │
                                                    │  (AC)        │
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All packages have been
completed except:

* A version is working
   but is not considered
   efficient.

† An investigation of
   techniques for solving
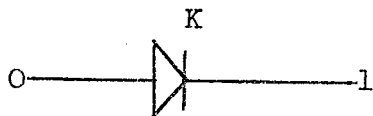   sparse eigen problems
   has begun.

Figure 1

1. Examples of Networks

The examples given below are part of some of the examples being used as test cases.

A. Electrical

A single terminal type ELECT was defined with an E-type variable E and an I-type variable I. Then the obvious definitions were given for resistors, capacitors, and current sources. A diode was also defined by:
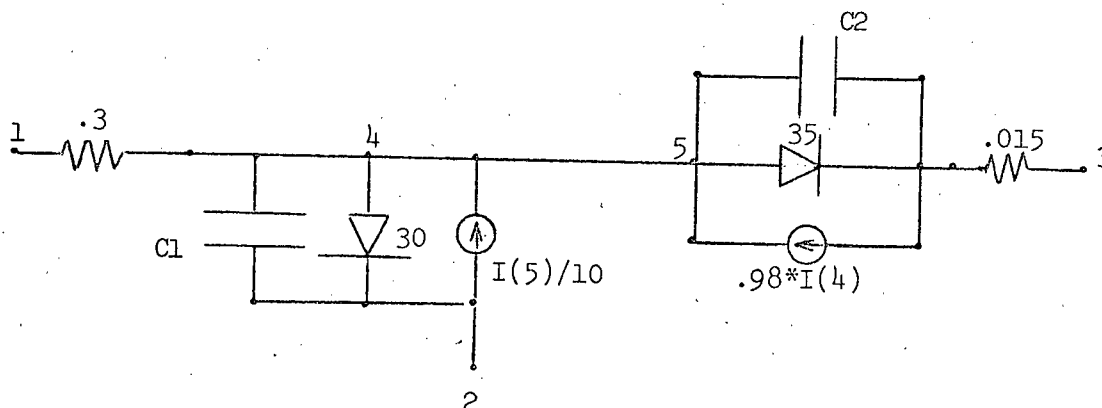

EQUATIONS

$$I(0) = -I(1), \quad I(0) = (EXP(K*(E(0)-E(1)))-1)/10000000$$

PARAMETER

K

This diode uses an exponential curve for the relationship between the current flow $I(0)$ and the voltage drop $E(0) - E(1)$. The slope of the exponential curve is given by a parameter K which can be specified each time that a diode is used. In particular, two different diodes with K values of 30 and 35 are used in a definition of a transistor by means of the equivalent circuit below:

NETWORK

EQUATIONS

$$C1 = .3 + 6*I(4)$$

$$C2 = .3 + 175*I(5)$$

The terminals labeled 1, 2, and 3 correspond to the base, emitter, and collector of a transistor. Since we obviously do not want to have to draw this large network each time we want to use a transistor in another network, we can give a mnemonic drawing such as the one below. It is a schematic symbol for a transistor and has three terminals numbered to correspond to the terminals in the defining network. Whenever this symbol is used, it is replaced by the equivalent network.
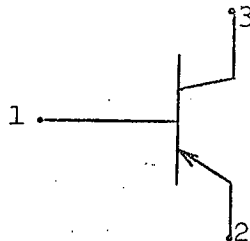
The definition of the transistor by the particular equivalent circuit given above is only one of many possible definitions. The important flexibility that our system offers is the ability to use any definition. The user can enter one at any time, and change it as he wishes.

In this particular example, two of these transistors were used in a larger network representing an amplifier.

B. Analog Computer

A single terminal type CONTROL was defined with a single E-type variable V. Standard elements for adders, potentiometers, sources and integrators were defined. An integrator, for example, was defined by
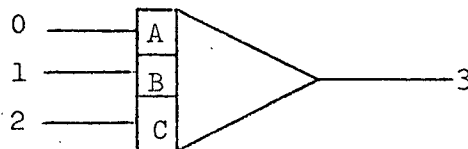
EQUATIONS
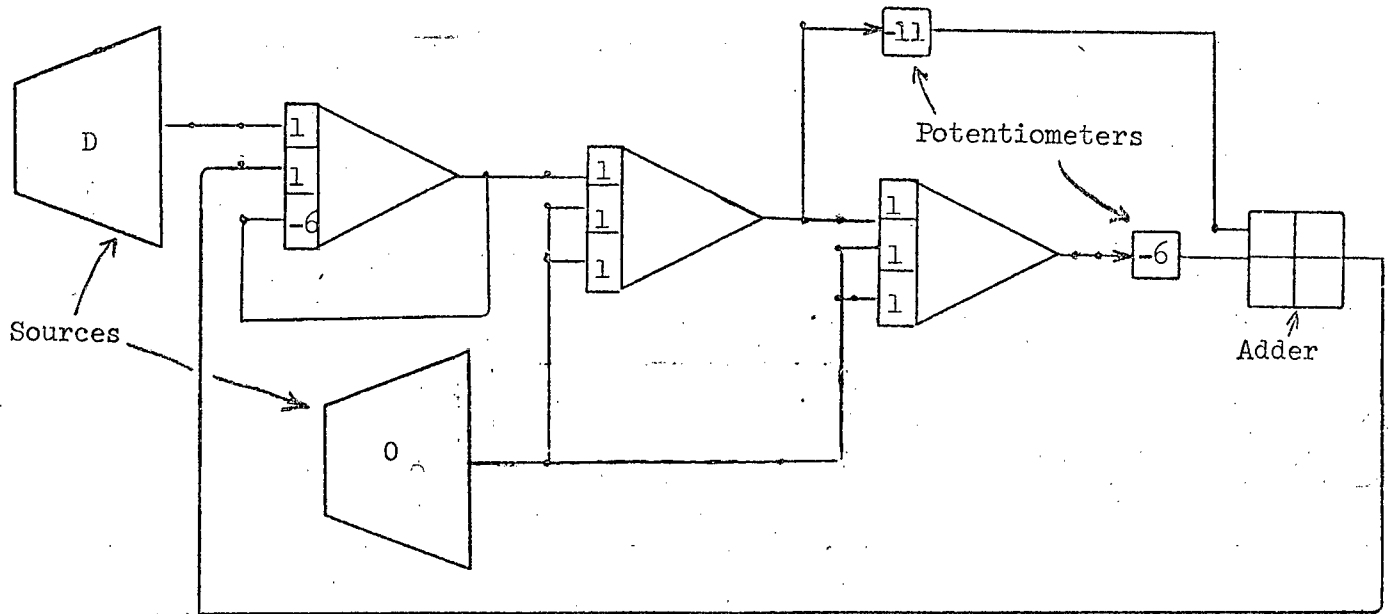
$$A*V(0) + B*V(1) + C*V(2) = V(3)'$$

PARAMETERS

A, B, C

The equation says that the derivative of the output signal (V(3)) is a weighted sum of the inputs. It is equivalent to saying

$$V(3) = \int (A*V(0) + B*V(1) + C*V(2))dt$$

This and other elements were coupled together in the network below:

LOCAL D

EQUATIONS

D = SIN(TIME/10)

If we label the outputs of the three integrators from left to right as w, x, and y, we have the equations

D - 6y - 11x - 6w = w'

w = x'

x = y'

D = sin(t/10)

We see that we are solving the differential equation

$$y''' + 6y'' + 11y' + 6y - \sin(t/10) = 0$$

C. "Air-Conditioning System"

This example is not supposed to be realistic as it has been simplified for test purposes, but it is designed to show that many different types of terminals can be involved. In this case, the system uses a power supply (terminal type POWER), a compressor, condensor, and evaporator using liquid refrigerant (terminal type LREFR) and gaseous refrigerant (terminal type GREFR), a chilled water system (terminal type WATER) and a control system (terminal type CONTROL). The refrigerants and the water type terminals all have one E-type variable (PRESSure) and two I-type variables (FLOW and HEAT). Thus when several pipes of the same type are connected together, the PRESSures of all are the same, while the total FLOW sums to zero at the connection, as does the total HEAT flow. The terminal types POWER and CONTROL both have a single E-type variable V, standing for the supply voltage in the case of POWER, and the control voltage in the latter case. The compressor, for example, was defined by
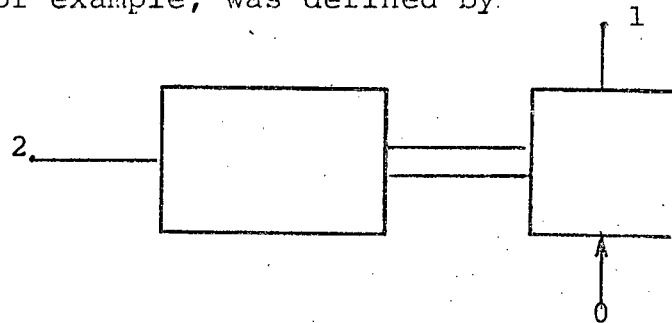
TERMINALS

    0 - GREFR

    1 - LREFR

    2 - POWER

EQUATIONS

    1000*FLOW(1) + FLOW(0) = 0

    PRESS(1) = PRESS(0) + V(2)/(1 + FLOW(0))

    HEAT(1) + HEAT(0) + V(2)**2/10 + FLOW(1)*100 = 0

This element takes a gaseous refrigerant at terminal
0 and compresses it into liquid refrigerant at terminal 1.
Terminal 2 is the power supply. The first equation represents
the fact that the output flow is one thousandth of the input
flow because the gas has been liquified. (These are not supposed
to be realistic equations!) The second represents the fact
that the output pressure is determined by the input pressure,
the flow and the supply voltage to the compressor. It is thus
the conservation of momentum. The last equation is the
conservation of energy, and indicates that the amount of heat
flow out is the heat flow in, plus the latent heat from
condensation plus the energy from the power supply. (To be
realistic, we should also include differential equations
involving the change in the rotational energy of the compressor,
the heat storage in the compressor, etc.) After basic elements
had been defined, and a macro had been defined for a room
(consisting of a heat exchanger and a thermostat), the network
below was input for analysis. The function of the various
elements is indicated on that diagram. This network allows
the designer to see the effect of fluctuating power supplies,

PARAMETERS   T1, T2, VS

EQUATIONS   F = MIN(VS, TIME*VS)
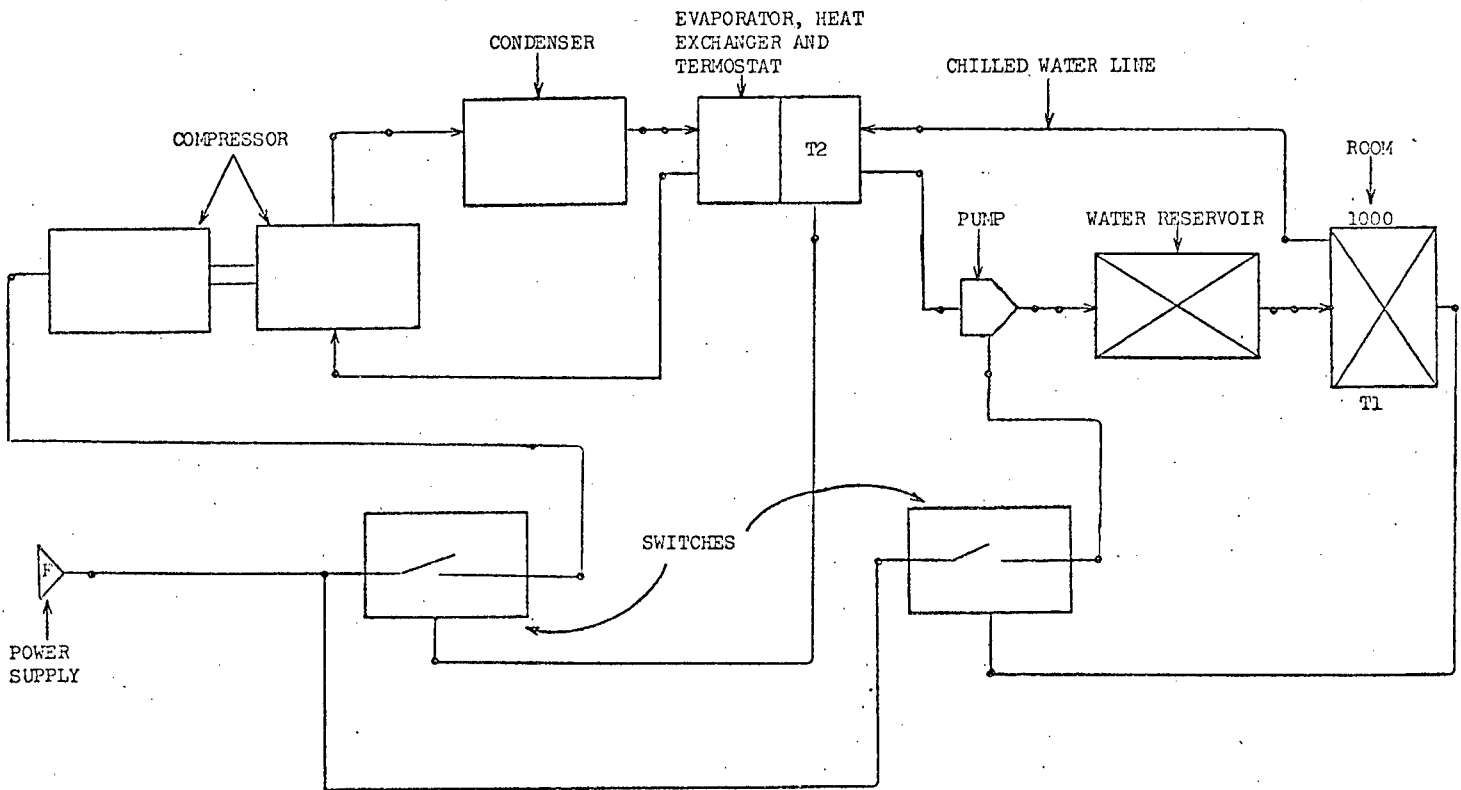
2. Description of the purpose of the software packages

The subsections below refer to the packages shown in Figure 1.

Graphics Support and Local Filing System

These are general purpose systems that enable sets of arbitrary line drawings to be constructed and stored in the local filing system. Associated text blocks can also be stored. Once a drawing has been constructed, a graphical mnemonic for the drawing can be entered and stored with the drawing. This mnemonic can be displayed as a menu item and selected to appear as an instance in another drawing. In our particular use of this general graphics support package, these mnemonics represent the element definitions or the networks that use these elements. When an element or a network has been completed it is handed across to the

Filing System

This is a special purpose filing system for storing the drawings and text blocks in the 360. It also stores the output of item analysis which is subsequently passed to global analysis. When a new drawing is added to the filing system it is also handed to

Item Analysis

This analyzes those text blocks that contain declarations and parses those text blocks that contain equations defining the elements. The output of the parser is a tree structure which is stored back in the filing system.

When a network is to be subject to numerical solution, control is passed to

Global Analysis

This fetches the network from the filing system
together with all subnetworks and elements which are used by
the original network. A system of equations is generated in a
tree structure form. These equations define the behavior of the
network and are a combination of algebraic and differential
equations. Because many of the equations that define elements
have parameters that are constants in instances of their use,
a lot of simplification is possible. Therefore the set of
equations output from the global analysis is input to

Elimination

This package performs as much constant computation and
simplification of the equations as reasonably possible. Whenever
equations can be reduced to "A = constant," "A = B" or "A = -B,"
the variable A is eliminated. The resulting equations are then
fed to the

Compiler

This produces 360 object code which evaluates the
expressions in the equations that by now have been converted to
"expression = 0." The object code is in the form of a subroutine
which is used directly by the numerical integrator and the
algebraic equation solver. However these processes require the
solution of the linear equation $Ax = b$ many thousands of times,
where A is essentially the Jacobian of the equations. Since this
is sparse, control is first passed to

Set-Up

This generates the entries of A by numerical differentiation.
They are stored in a doubly linked structure with chains going
through the rows and columns. Only the nonzero elements are
stored, and these are classified into three types: small
integers, floating point constants, and variables. (The latter
depend on the current value of the variables in the equations.)
This representation of the nonzero elements in A is passed to

Sparse

This program generates two straight line 360 machine language subroutines. MATMUL will process a vector b and produce an x which satisfies Ax = b. It represents the stages of a Gaus elimination-back substitution process for inverting A. It uses coefficients left in memory by the second subroutine MATINV. This subroutine takes the variable elements in A and performs the steps of a Gaus elimination process on them. Sparse attempts to find a pivot strategy which will minimize the length of the compiled MATMUL and MATINV programs. Finally control is passed to the appropriate numerical processing package.

Numerical Integration

Numerical integration is used for transient analysis. It can solve implicit differential and algebraic equations simultaneously. These equations are of the form $F(y, y', t) = 0$. The package requires a subroutine to evaluate $F(y, y', t)$ for any given vectors y and y' and scalar t. This is provided by the compiler. It also requires a package to solve

$$(\frac{\partial F}{\partial y} + \alpha h \frac{\partial F}{\partial y'}) \; x = b$$

where b is specified by the integrator. These subroutines are provided by sparse. The Jacobians are not re-evaluated very frequently, hence the two subroutines MATMUL and MATINV. The latter is called only when the Jacobian has been re-evaluated or h has changed. The methods are described in reference 11.

Algebraic Equation Solver

The steady state of the system described by $F(y, y', t) = 0$ is found by solving $F(y, 0, 0) = 0$. A technique that uses the differential equation package has been programmed, and further experiments are being made. It is described in reference 11.

Eigen Value Problems

The response to small perturbations can be understood by finding the eigenvalues and vectors of the problem

$$(\frac{\partial F}{\partial y} + \frac{\partial F}{\partial y'}) \; \underline{x} = 0$$

around a steady state of $F(y, y', 0) = 0$.

3. Details of progress this year

The proposal for this contract period listed the following new areas of investigation for the modeling system.

A. Software

(1) Diagnostic Input Output
(2) Tabular Input Output
(3) Graphical Input Output
(4) Procedural Control by Code

B. Theory

(1) Pivot Selection for Numerical Accuracy
(2) Source Language Diagnostics
(3) Detection of Singularities Symbolically
(4) Definition of Elements by Procedural Language Code
(5) Handling of Discrete Variables
(6) Steady State (DC) Analysis
(7) Small Signed Analysis
(8) Detection and Special Handling of Inactive Areas

C. Hardware

Additional display terminals and controller.

D. Applications

Study of use of system in typical applications.

Due to budget limitations and lack of suitable personnel, no effort was put into A(4), B(2), B(5), B(8) and D. Progress in the other areas is given below.

A(1) The programs shown in Figure 1 above translate the variables associated with element instances into internal names. A translation is performed from physical position to

terminal #/instance # by ITEM analysis, from that to a new form by GLOBAL, to yet another form by ELIMINATION, and finally into an actual machine location by the COMPILER. Tables of these transformations are generated and saved. Subroutines have been prepared which will perform the inverse transformations so that a machine location can be related to a variable in the original network. An interactive question-answer type of package will be prepared when the basic system has been checked out.

A(2) The standard IBM package for output has been modified so that executing programs can call the FORTRAN I/O package and transmit data exactly as if it were from cards or to the printer. This allows tabular input and output to be handled by the numerical packages. (It also permits other systems to use the graphic equipment in an interactive way.)

A(3) CalComp like subroutines have been prepared for the 360 which allow the user to draw arbitrary line figures on the display screens via standard subroutine calls. These can be used for graphical output from the numerical transient analysis package. They can also be used by other systems.

B(1) The program SPARSE has been rewritten so that it considers both numerical size and sparsity preservation in pivot selection. A number of test cases have been run in order to decide on the pivot selection strategy. They are described in reference 6. The program optimizes the register usage in the 360 in several ways. The fixed point registers are optimized as base registers. The floating point registers are optimized by keeping a row multiplier in register 2 when two or more elements in a row must be scaled. There is some additional optimization which will be added later.

B(3) Very little progress has been made on this hard problem partly because the half-time assistant pursuing this as a thesis topic was primarily engaged in finishing global analysis.

B(4) "User defined" functions have been added to the types allowed. This means that a user may input a function subprogram in FORTRAN (or other languages) and call on this as a function in an equation. This allows an element to be defined procedurally. At this time it is necessary to input the procedure via cards (or via a regular timesharing process). It is planned to make this more flexible later.

B(6) A working version of a steady state program has been written utilizing the ideas given in the proposal for

this year. It is described in reference 11. We have run a number of tests to determine the best strategy for step size selection and error control. These are described in the quarterly reports for October-December 1970, and January-March 1971. We are now implementing some of these strategies to see if improvement can be made.

B(7) The small signal analysis of the equations $\underline{F}(\underline{y}, \underline{y}', 0) = 0$ is done by linearizing to get

(1)
$$\frac{\partial \underline{F}}{\partial \underline{y}} (\underline{y}-\underline{y}_0) + \frac{\partial \underline{F}}{\partial \underline{y}'} \underline{y}' = 0$$

where the partials are taken at $\underline{y} = \underline{y}_0$ and $\underline{y}' = 0$ which are assumed to be a solution of $F(\underline{y}_0, 0, 0) = 0$. Equations (1) have solutions which behave like $\underline{x} \, e^{\lambda t}$ where $\underline{x}$ and λ are solutions of the generalized eigenvalue problem

$$(\frac{\partial \underline{F}}{\partial \underline{y}} + \lambda \frac{\partial \underline{F}}{\partial \underline{y}'}) \, \underline{x} = 0$$

We have started an investigation of methods suitable for sparse problems of this sort. Since the rank of $\partial \underline{F}/\partial \underline{y}'$ is normally small, a Gausian elimination by row and column to get

$$(P \, \frac{\partial \underline{F}}{\partial \underline{y}} \, Q + \frac{P \partial \underline{F}}{\partial \underline{y}_1} \, Q) \, Q^{-1} x = 0$$

where

$$P \, \frac{\partial \underline{F}}{\partial \underline{y}'} \, Q$$

has the form

$$\begin{bmatrix} 1 & 0 & \\ & & \bigcirc \\ 0 & 1 & \\ & \bigcirc & \bigcirc \end{bmatrix}$$

seems to be the best. The Gausian elimination can be done utilizing the sparsity. A study of techniques for pivot selection is in progress.

C. The Data Disk continued to give problems, so part way through the year the controller was redesigned and rebuilt. It now functions reasonably well as long as the temperature is carefully controlled, although on occasions it is necessary to change to spare tracks. Because of the unreliability of the disk, the display terminals now use storage tubes rather than disk refresh. During the year two storage tube terminals were interfaced to the system. A multiplexor was built and spares were constructed for these terminals so that a third terminal is about 90% complete. When this is finished we will have a third terminal except during maintenance. (The software is capable of handling eight terminals, although there are no plans to extend the hardware as far as the research goals are concerned. Two or three is adequate to investigate many problems of multiple users.)

Other Work

Work proposed in the previous period included cooperation with the stereo matrix project in Part B. This year an interface from our graphics controller has been designed and partially constructed. It will provide x, y, and z coordinates of figures for the three dimensional display.

In addition to the new areas of investigation covered above, work was continued on packages started in previous periods (those shown in Figure 1). Technical details of these programs are given in the quarterly reports. Important changes or additions during the year include:

a. The graphics support package allows general line drawings and text blocks to be created and transmitted to the 360/75. These are not specific to the simulation system, so the package can be used in conjunction with any interactive graphics work on the 360.

b. The filing system for the local disk has been made very general. It is not dependent on the particular disk used. Because of this, the package has been copied by a group at the Rome Air Development Center in New York. The system has also been extended to handle up to eight terminals simultaneously. It has been checked using two terminals now available. (This served to debug the hardware also.)

c. The global analysis package now requires two passes. It was found that item analysis should store its output in symbolic form (for example, element instance names) because we do not want to assign fixed internal names until we start

an analysis of a particular network. The first pass of global
extracts from the filing system all of the elements needed for
a particular network and builds symbol tables. The second pass
expands the networks. Global analysis will be described in
detail in a later report.

     d. The output of the compiler (which was initially
very simple minded) is now passed through an optimizing stage.
Optimizing the use of the fixed point registers as base registers
reduced the length of the object code by about 50%. Previously
the output consisted of a crude one address translation of a
three address code. Optimizing the use of floating point
registers to save unnecessary loads and stores saved another
50% to 70% of the resulting code, for an overall improvement
of 75% to 85% in length.

     e. The sparsity structure of the Jacobian matrix
$\partial F/\partial y + \partial F/\partial y'$ is now found numerically. A change was made
during the year which has resulted in finding more elements
of the Jacobian to be constants rather than variables. This
has shortened the output from sparse because the latter program
handles constants at compile time. (See report No. 443)

     f. The method for stiff equations has received wider
use during the year. The program has now appeared in CACM
(references 9 and 10). It has been used in further versions
of SCEPTRE (a network analysis program) by the United States
Air Force Academy in Colorado Springs, Colorado, in conjunction
with Kirkland Air Force Base. They quoted an improvement of
1200 fold in speed over previous methods (letter of Major
Schlicht, dated March 30, 1971). It has been used extensively
by people at LRL, Livermore (Creighton, Hindmarsh, and Gelinas)
in chemistry problems.

     g. Various levels of monitors have been completed
for the 360 part of the system. (They are described in the
recent quarterly reports.) The top level monitor which
supervises communication with the PDP-8 has been in operation
for several months. The second level monitor which handles
tasks assigned to different terminals has been in operation
correctly for most of the last quarter.

ANNUAL REPORT PART B

UNCOMMON FORMS OF INFORMATION PROCESSING

SEPTEMBER 1, 1970 TO AUGUST 31, 1971

1. PREAMBLE, GENERAL REMARKS AND SUMMARY (PART B)

This year we shall abandon the characterization of projects by the "B + number" combination: These numbers are historical in nature, being the continuation of the numbers in the list of our contract in the mid sixties. At this point they serve little more purpose than to remind ourselves of the total number of ideas, and it seems easier to refer to each project by its acronym or codename.

We shall also replace the former system of dividing the report for Part B into a Summary Part and a Detail Part by the following arrangement: A Status Table will figure at the end of this section. It contains all the codenames of last year's proposal and indicates

   (a)   The present status (finished, paper design, parts ordered, etc.)

   (b)   The probable completion date (in months from Sept. 1, 1971)

   (c)   Reasons for deferment or cancellation if applicable.

Section 2 ("Details") will contain a slightly more concise description of the progress made than heretofore, and will rely heavily on photographs. This seems to be a more useful procedure because the Quarterly Progress Reports contain full details of all the work done, but very rarely material proof in the form of actual views of the equipment.

It should be noted that during the last contract period financial considerations entered the picture with considerable impact: increased salaries limited the total number of students supported to about 80% of that of the previous period. Similarly certain designs had to be delayed because of curtailed equipment funds and fast rising prices. Happily enough the main projects for the year, i.e. TRANSFORMATRIX, EIDOLYZER and STEREOMATRIX were not affected.

The most important piece of news is the completion of the stochastic picture processor TRANSFORMATRIX, at least as far as the original scope is concerned. This puts into our hands what is probably the world's most

parallel computer: It uses 1024 parallel arithmetic units! This, together with the stochastic form of the information signal, places TRANSFORMATRIX in the forefront of "uncommon computers" and gives us a powerful tool for on-line Fourier transformations, pattern recognition, etc. It is suggested to exploit these facilities fully in the next contract period!

A breakthrough of nearly equal importance is the successful operation of EIDOLYZER, the picture analyzer which gives appropriate names ("sky", "meadow", etc.) to colored (horizontal) bands, the names being stored in a "dictionary" called the world model. The apparent "cleverness" of the device is quite astonishing and proves the great value of the world model concept!

The 3D computer display, STEREOMATRIX, has progressed reasonably well, but being highly dependent on the collaboration of outside sources (e.g., Orlando Research Corporation) for certain advanced optical items, some delays were encountered. Also the scope of the project and the necessary interfacing between the four groups involved ("Transformer", "Coefficient Generator", "Position Detector" and "Laser Display") led to some redesign with accompany-ing loss of time.

Finally it should be recorded that successful efforts were made to com-municate with the National Laboratories (Argonne, Brookhaven, Livermore and Los Alamos) and that the new proposal reflects some of the interests of groups working in these laboratories.

The last three projects are revised projects from previous contract periods. Although they were actually terminated, certain refinements had not been put in! They were therefore used as a training ground for incoming students to acquaint them with the field of Uncommon Forms of Information Processing. It might happen that additional features will be added in the future for the very same reason!

Status Table: Summary of Hardware Projects on AEC 1469 for 1970/71

Name	Principle and Goal	Status	Remarks	Completion Date
BLAST	3D TV with special tube	About 70% complete	Synchronization difficulties	6 mos.
CERAVISION	Electrically controlled color filter TV	Shelved	Lack of personnel	-----
DOC	Magnetic bubble digital/optical converter	Cancelled	Lack of personnel and duplication	---
EIDOLYZER*	Picture analyzer using a "world model"	Completed	Very successful	0 mos.
LASCOT	Large screen color TV using vibrating mirrors	About 50% complete	Delayed because of cost	12 mos.
OLFT	Electro-optical Fourier transforms	Original design	New design in progress	18 mos.
RASER	Random/serial converter for displays	Hardware complete	Debugging remains	6 mos.
SCANTRIX	"Line freeze" LED display	Prelim. tests OK	Delayed because of cost	18 mos.
SEMANTRIX	Picture composer under "world model" control	Mechanical part complete	Needs on-line processor	12 mos.
STEREOMATRIX	3D on-line display of computer output	About 70% complete	Some optics necessary	12 mos.
TRANSFORMATRIX	Highly parallel stochastic picture processor	Completed	Very successful	0 mos.

* Sponsored jointly with ONR.

Name	Principle and Goal	Status	Remarks	Completion Date
ORBIT (Phase 2)	Add D/A-A/D Chain	Completed	Very satisfying	0 mos.
TRICOLOR CARTOGRAPH (Phase 2)	Add camera input	Completed	Acceptable	0 mos.
VISTA (Phase 2)	Add automatic BW adjuster	Completed	Acceptable	0 mos.

2. DETAILS OF ACHIEVEMENTS (PART B)

BLAST

The acronym, "Binocular Lenticular Autonomous Stereo Vision", contains
the key to the fundamental idea: a special CRT contains (inside) a plate with
vertical cylindrical lenses which throw the luminous information on the
phosphor into the left and the right eye respectively. Fig. 1 shows this tube
in principle. It had been hoped that the new tube with two "combs" would allow
us to pick up - via a difference amplifier - a signal (as the beam passed)
sufficient to synchronize the switching mechanism for the cameras. Unfortun-
ately the switching transient on the video signal produced more induced voltage
than the actual scanning of the beam: This is attributed to the fact that
the metal "fingers" are actually underneath the phosphor. Short of designing
a third tube (the first one with just one "comb" was burnt in an accident!),
it seems more attractive at this point to construct a highly linear sweep
generator and to hope for sufficient stability! It should be mentioned that
the system (see Fig. 2, note the two TV cameras on top!) has worked for smaller
areas of the tube. Fig. 3 shows a close-up taken off-axis: The two patterns
(for the left and right eye respectively) are clearly visible!

CERAVISION

This project aimed to explore a field-sequential color TV system in which
the ancient "color wheel" was to be replaced by a ferro-electric ceramic with
voltage-induced color changes. Our personnel being needed for such major pro-
jects as TRANSFORMATRIX, EIDOLYZER and STEREOMATRIX, it was decided to shelve
the project until further notice. This would also considerably reduce the
cost: right now a 2" × 2" filter costs about five thousand dollars ...

DOC (Digital to Optical Converter)

Here a collimated laser beam was to strike an array of magnetic bubbles
in an orthoferrite plate. The interference pattern could then have been con-
trolled by the digital pattern represented by the bubbles. Above and beyond
the lack of personnel, there was also a second reason for the cancellation:
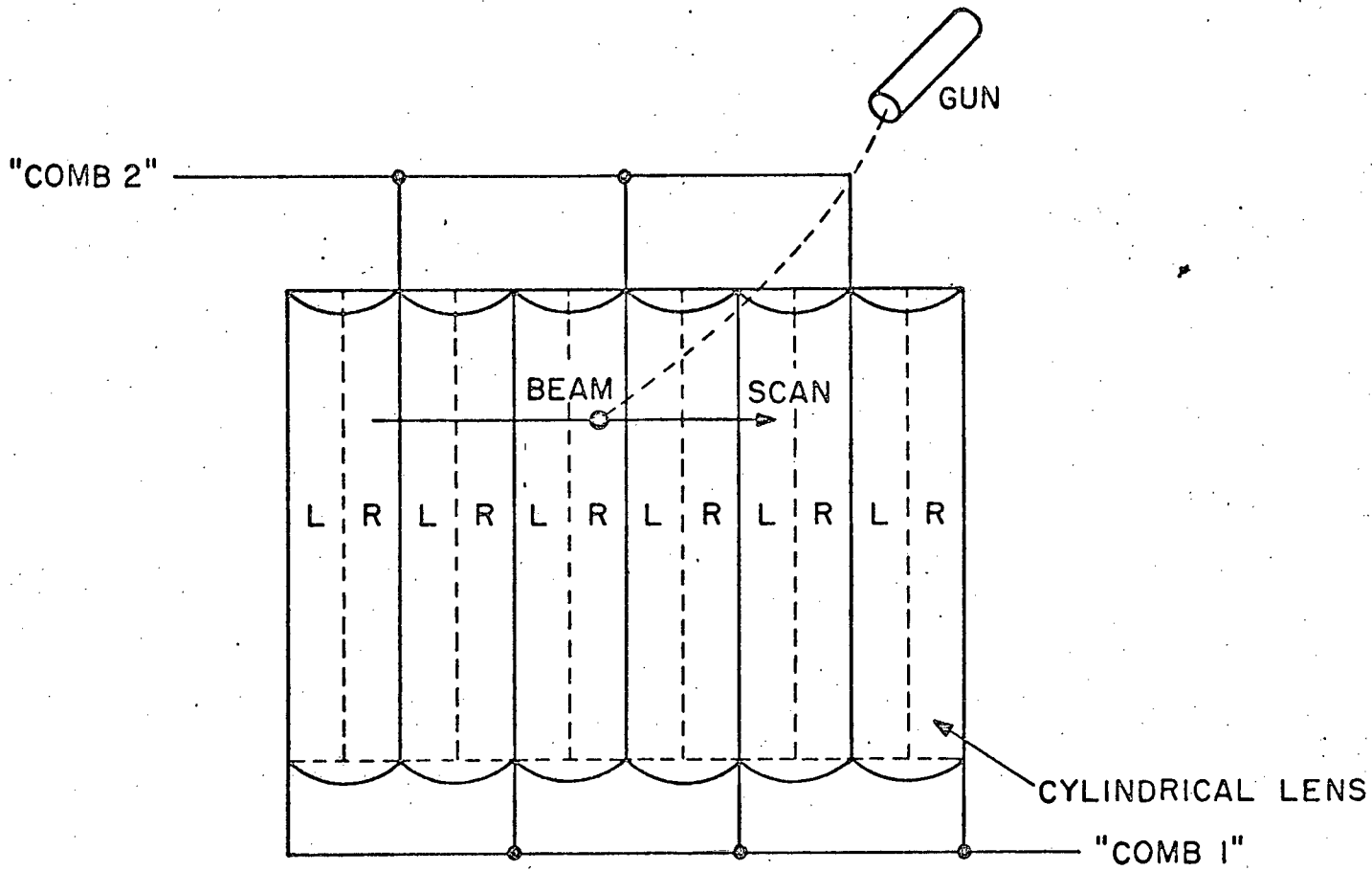BTL (where the "bubbles" were invented) was planning on similar research!
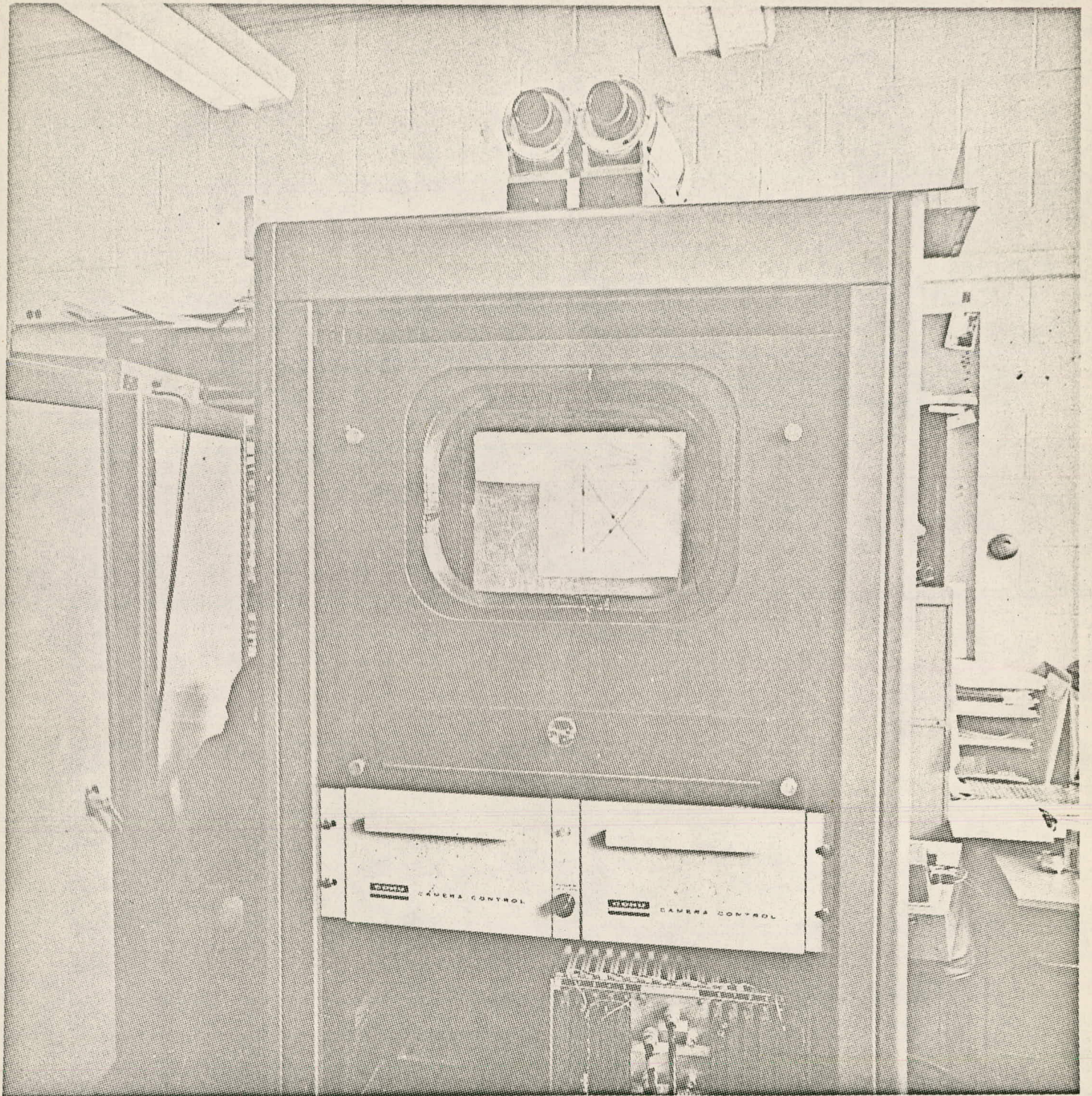
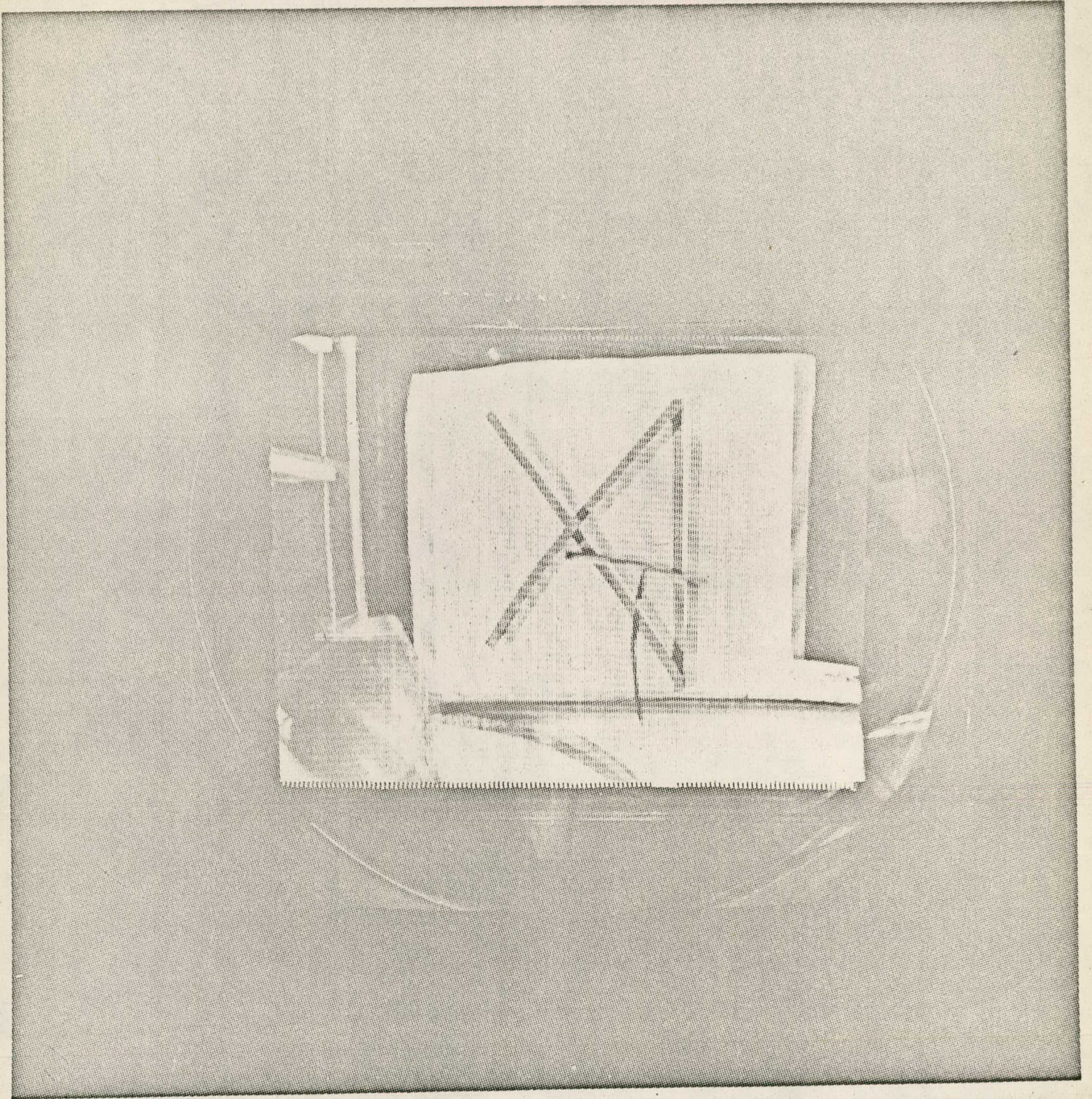Figure 1. Principle of BLAST Tube

Figure 2. BLAST System

Figure 3. Close-up of BLAST Tube

EIDOLYZER

(Eidon = picture in Greek) The fundamental idea of this machine (shown in Fig. 4 in block diagram form) is to decompose a colored landscape into 16 horizontal bands and to determine the majority color for each row ("row analyzer"). Adjacent rows with the same color are collapsed into regions and a "world model" (in the form of a "dictionary") contains such information as "if the top region is blue, humans call that "sky". After assigning names to the regions, interruptions are analyzed. A white interruption of the sky is called "cloud", etc.! The operator can dial-in his personal prejudices by pushing buttons marked "hot" and "cold" and the like. What is called "sand" when "hot", might be called "snow" when "cold".

Fig. 5 shows EIDOLYZER from the front: on top is a (rear screen) projected version of the slide to be analyzed. The eight areas in the middle are the region indicators (left column) and the detail indicators (right column). The push buttons to the left of the indicators are those described above. Fig. 6 shows the rear of EIDOLYZER; the projector is visible on top. Fig. 7 shows a card containing (one row of) the input photocells. These are phototranistors with appropriate color filters incorporated in the can and arranged in triplets. Finding the majority color therefore simply amounts to comparing the sum of the outputs of the red, green and blue cells respectively ...

In actual operation the "intelligence" of EIDOLYZER is absolutely uncanny. All that proves, of course, is that humans use very simple clues when they interpret picture postcards of landscapes!

LASCOT (Large Screen Color Television)

The fundamental idea of the design (see Fig. 8) is to use (cheap) vibrating mirrors and a (cheap) TV receiver as a color buffer, scanned by the first set of mirrors while a second set deflects the (modulated) beam from an arc source. Electronic compensation is used to eliminate the phenomena due to the decay of the light intensity in the buffer ("Venetian Blind Effect") and those due to the nonlinearity of the deflection mirror movement.

The system was built except for the arc source. It proved impossible to obtain a high intensity (colored) beam of sufficiently small diameter to operate satisfactorily. Meanwhile, however, multicolor lasers of considerable power have appeared at reasonable prices (7K!), and the next contract period will see the substitution of such a laser for the arc source!
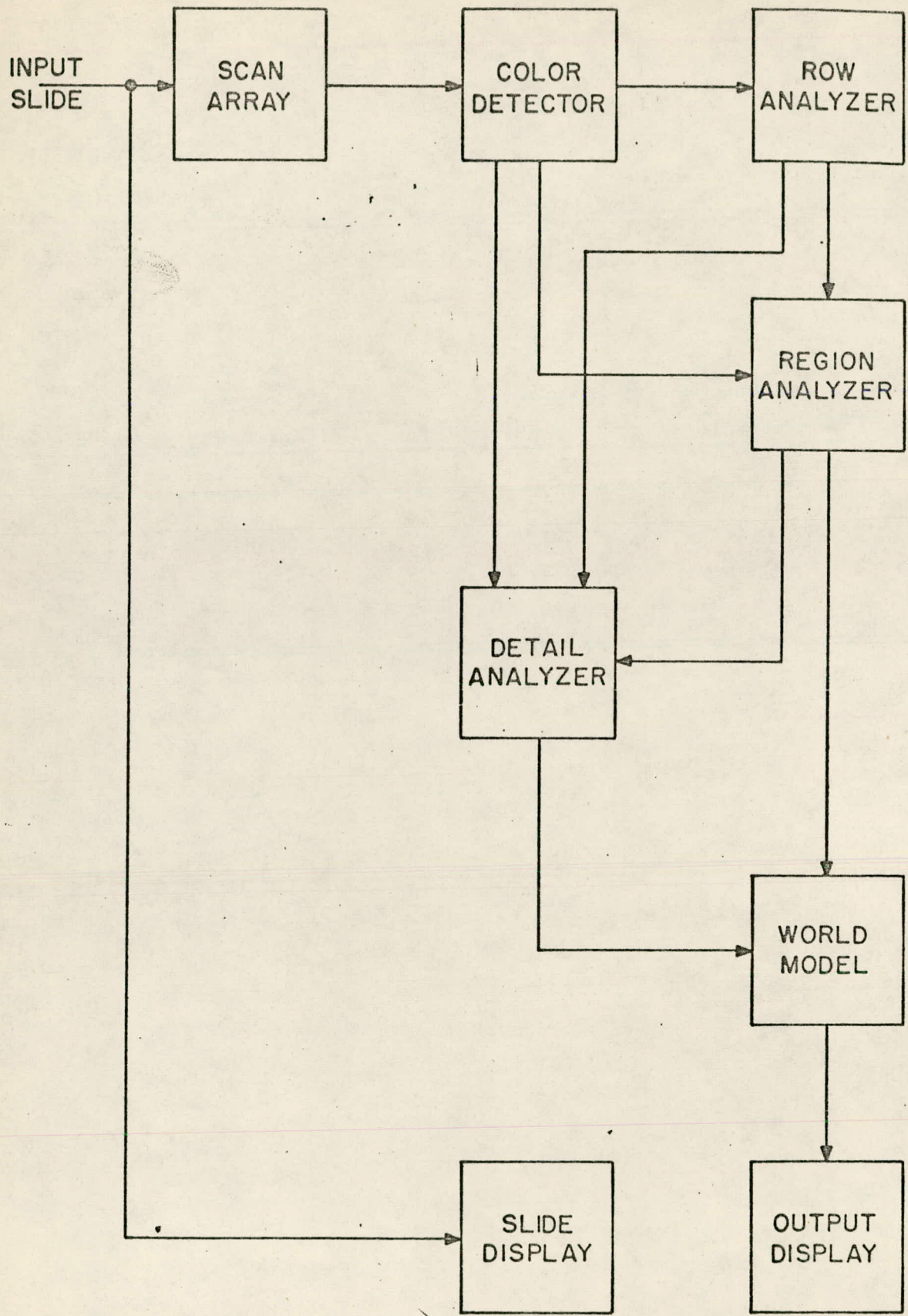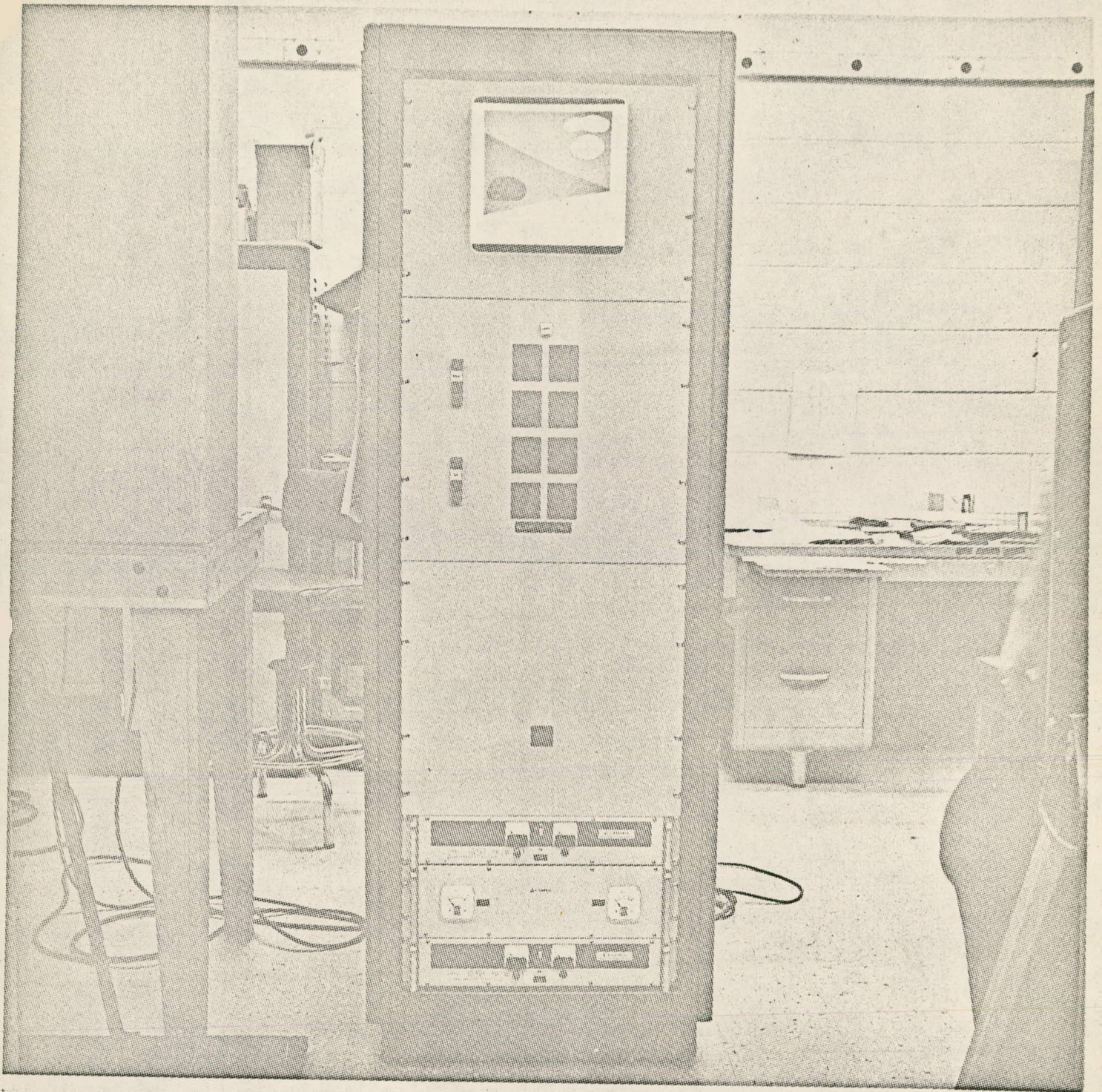
Figure 4. EIDOLYZER Block Diagram
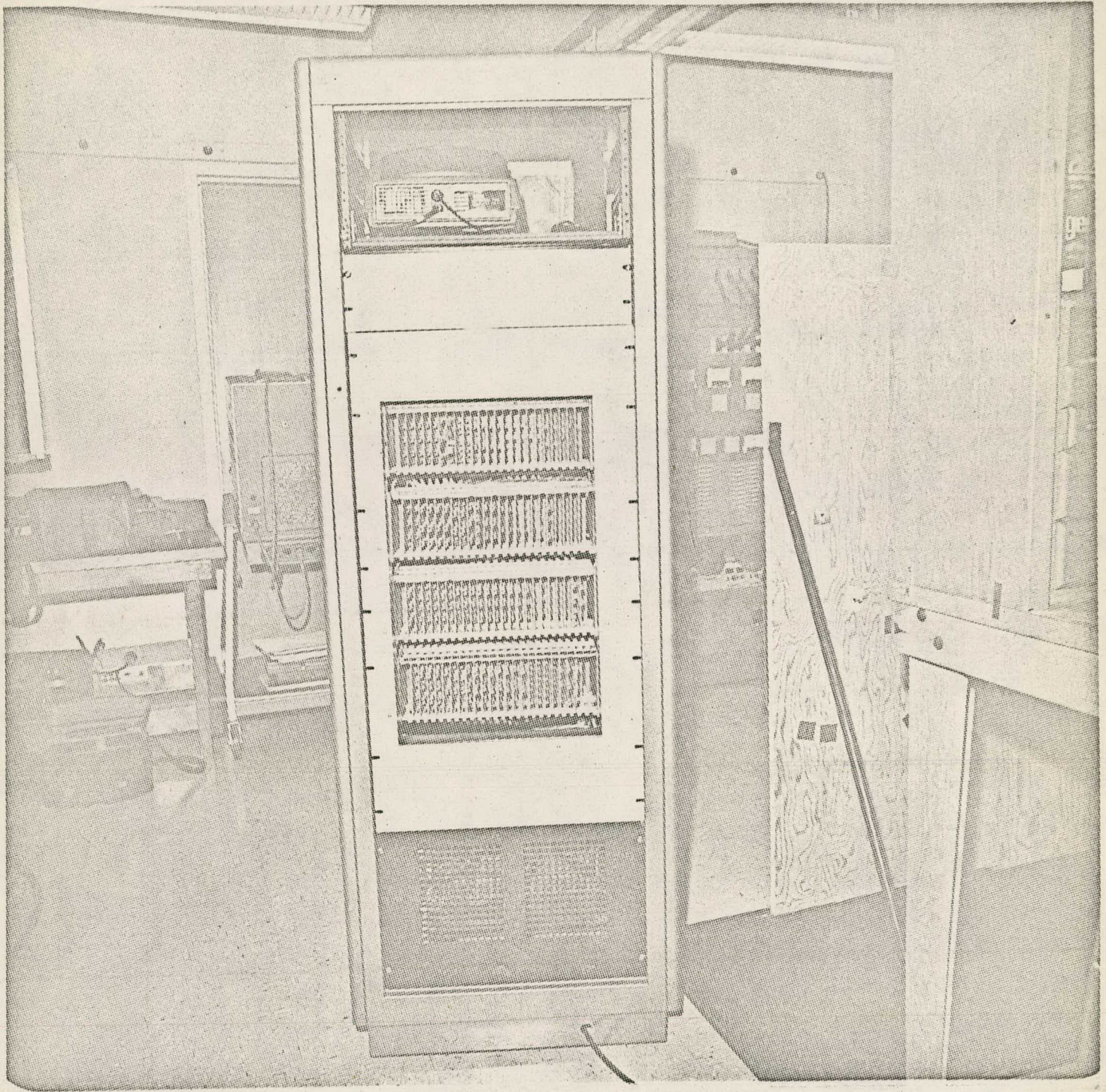
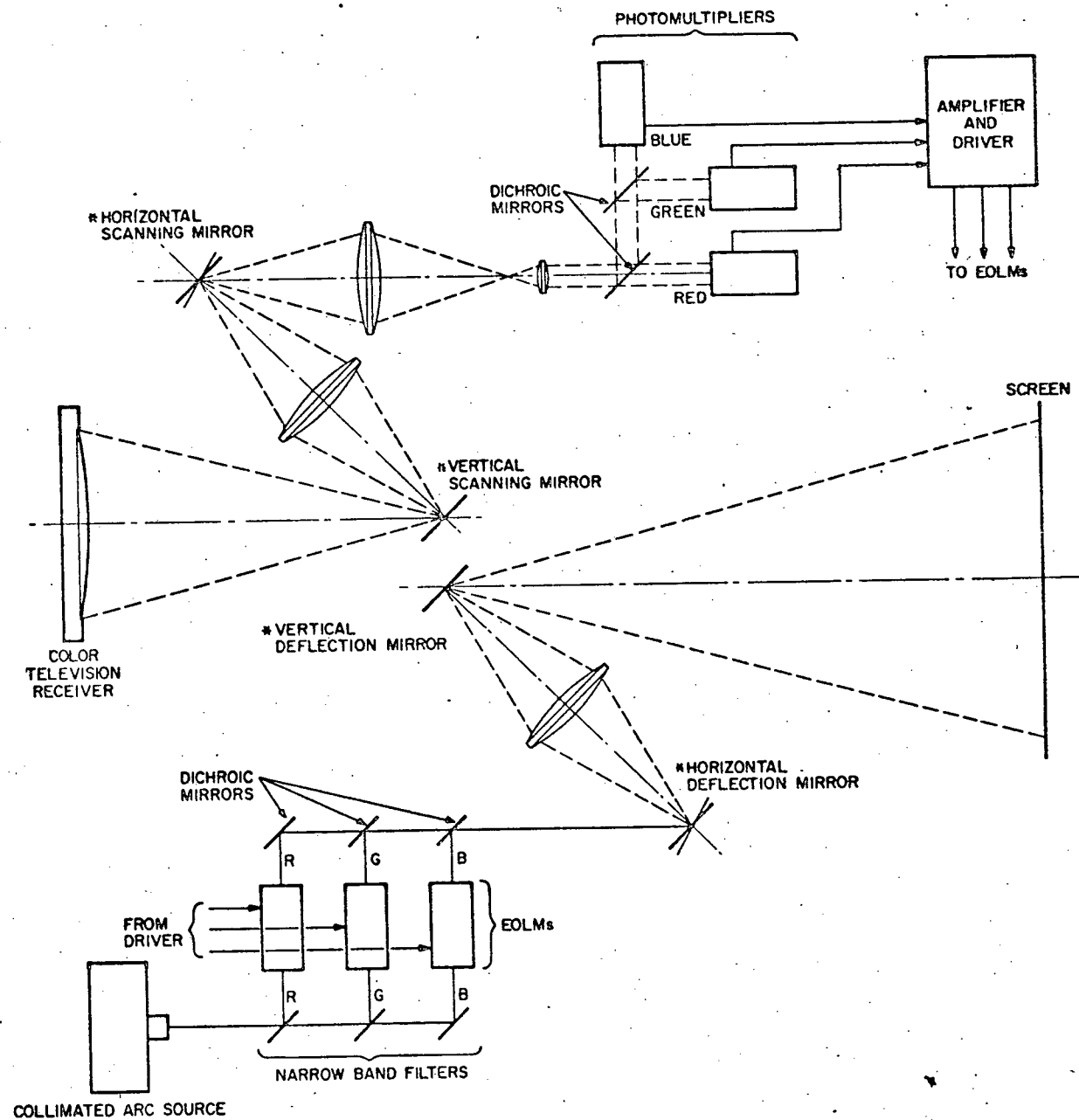Figure 5. EIDOLYZER Front View

Figure 6. EIDOLYZER Back View
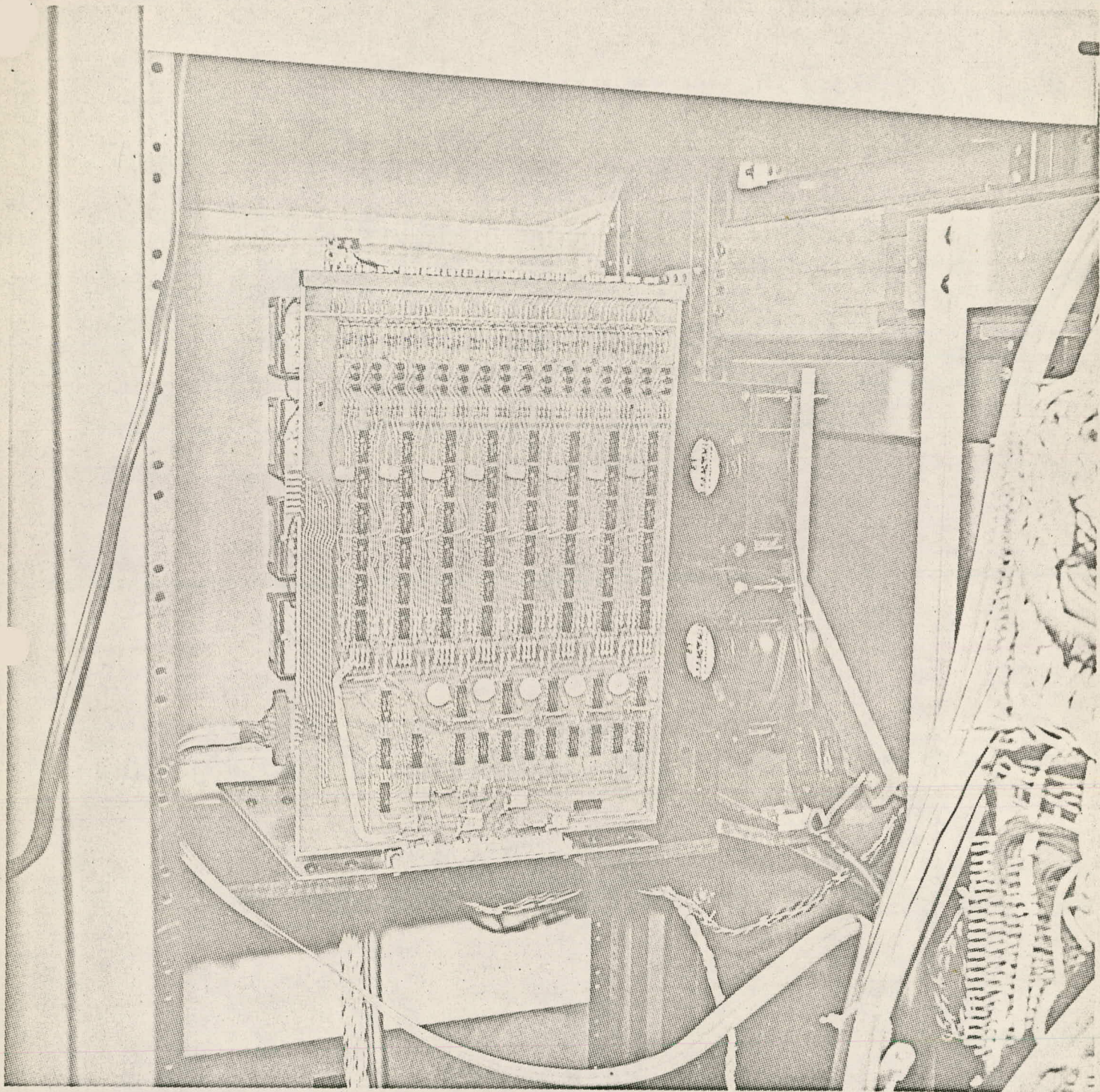
Figure 7. EIDOLYZER Photodiode Input Card

Figure 8. LASCOT Block Diagram

OLFT (On-Line Fourier Transform)

The beginning of this contract period saw the completion of a set of resolution tests on the existing, room temperature OLFT system. Resolution was almost exactly what we predicted theoretically, being about 200 TV lines (5lp/mm) for a 250 micron thick KD*P crystal, using a tube potential of 18KV. This figure is the best resolution obtained by anyone using a room temperature system. It can be shown that the crystal resolution is of the order of $(\epsilon_3/\epsilon_1)^{1/2}/\delta$, where ϵ_1 and ϵ_3 are respectively the transverse and longitudinal dielectric constants, and δ is the crystal thickness. For a crystal of given thickness the dielectric ratio increases by about a factor of ten as the KD*P crystal is cooled down to its Curie temperature of about -52°C, resulting in a resolution improved by a factor of 3 to 4.

We have worked out the detailed design of the "Cooled On-Line Fourier Transform And Reconstruction System" - COLFTAR. This work has encompassed the complete mechanical, electrical, thermal and optical design of the following system components: electron gun (by negotiation with manufacturer), thermoelectric module, chamber, crystal substrate and optical configuration. Construction is proceeding in two stages. The first, or intermediate stage is to test a cooled crystal assembly in the existing Ardenne tube. This measures the thermal efficiency of, and our theoretical predictions for the thermoelectric cooling devices that we are using. It cannot be a permanent arrangement because, in the first place, the existing tube geometry and electronics are designed for room temperature operation at a potential that is too high by an order of magnitude for Curie temperature operation and, secondly, COLFTAR has to be of a reflex design, so as to allow satisfactory erasure of the picture between frames. This work is almost complete.

RASER (Random to Serial Converter)

The crux of this system is a special encoding of incoming point coordinate information before it is put into a core memory: the y coordinates serve as addresses of 512 bit words, each storing the x coordinate as a "one" in a sequence of "zeros"! Fig. 9 shows the block diagram. A 4K × 18 bit core memory has been received and tested and most of the IN/OUT electronics have been built. There remains, however, the actual interconnection to be done and, of course, testing and debugging.
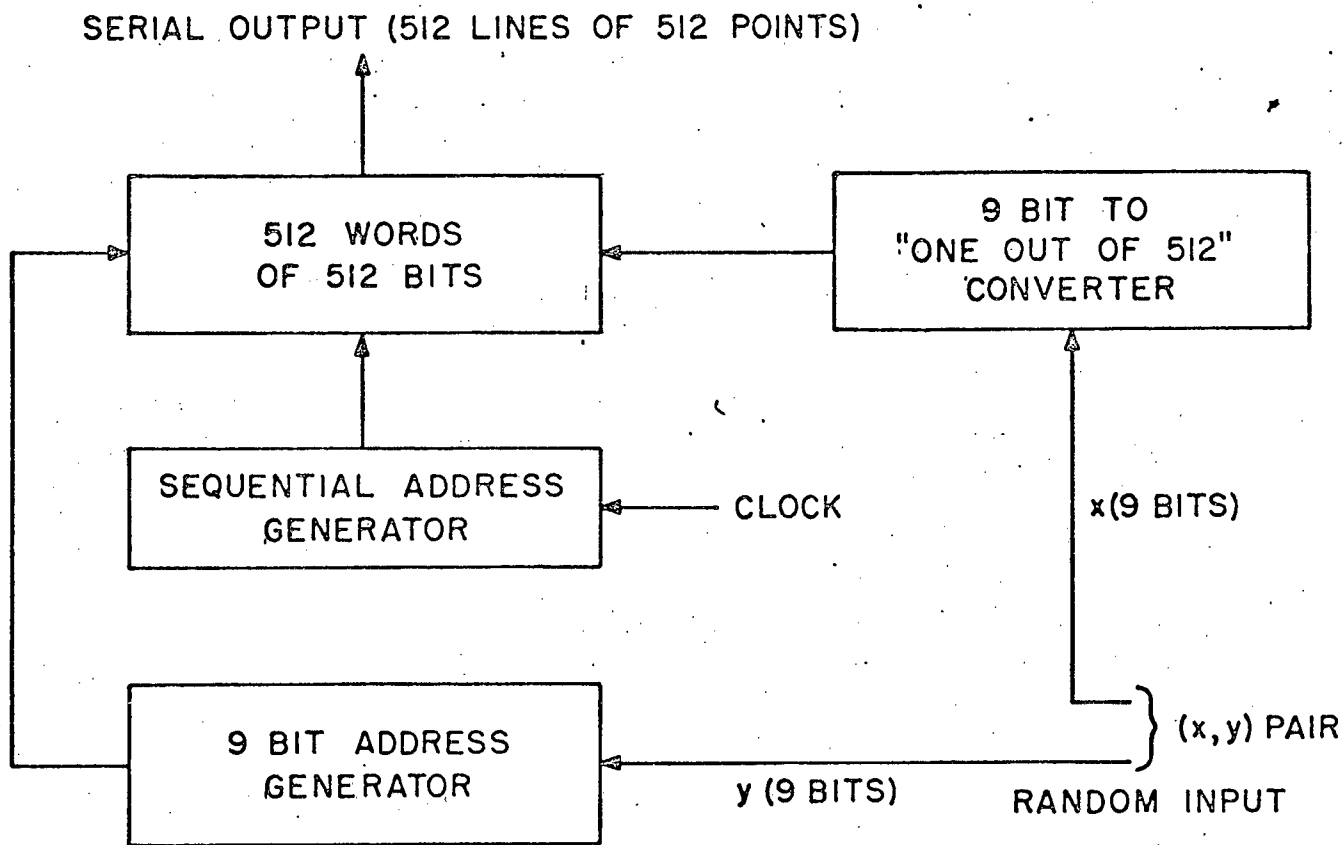
SERIAL OUTPUT (512 LINES OF 512 POINTS)

```
                                          ┌──────────────────────┐
┌──────────────────────┐                  │      9  BIT  TO       │
│    512  WORDS         │◄─────────────────│ "ONE OUT OF 512"      │
│    OF  512  BITS      │                  │     CONVERTER         │
└──────────────────────┘                  └──────────────────────┘
         ▲                                          ▲
         │                                          │
┌──────────────────────┐                       x(9 BITS)
│ SEQUENTIAL  ADDRESS   │◄──── CLOCK               │
│      GENERATOR        │                          │
└──────────────────────┘                          │
                                               ┐
┌──────────────────────┐                       │  (x,y) PAIR
│   9  BIT  ADDRESS     │◄──────────────────────┘
│      GENERATOR        │        y (9 BITS)   RANDOM INPUT
└──────────────────────┘
```

Figure 9.   Block Diagram of RASER

It might be useful to add that we count on the RASER system for STEREOMATRIX! Should tests show that the acoustic deflectors do not work with the large transients necessary for random access, we would convert the computer input into serial information and use raster scan!

SCANTRIX

Fig. 10 shows the block diagram of this TV line-freeze system: A TV line is sampled at 512 points and dumped (with 3 bit accuracy) into a register. This register drives 512 display lights. Since these are ON for 63 µs, a good light output can be obtained.

We started the project relatively late in the contract period. Preliminary investigations have, however, shown that quartz hologen lamps do not have the short time constants claimed by the manufacturers. At the same time the price of light emitting diodes has tumbled to 30¢ for a 1000 foot-lambert model! It appears therefore certain that the display of the "frozen" TV line will be done by LED's. It is even contemplated to forgo the rotating mirror for the vertical "movement" of the frozen line and to use a matrix of LED's (see proposal).

SEMANTRIX

This system uses a "world model" giving the rules for picture compositions (allowed color adjacencies, etc.), but here - in contrast to the "wired" memory of EIDOLYZER - the world model is kept inside the core memory of a general purpose computer. The mechanical portion involves the design of a servo-driven crane (under computer control), which moves colored blocks on a table after locating all those of a given color! An entirely passive block locator - using remote powering by induction - has been built and tested: It is shown in Fig. 11. The crane arrangement is designed but not built. A small general purpose computer is still sought for (see proposal).

STEREOMATRIX

Fig. 12 shows the general principle of this 3D-display for computer output. It consists of four subsystems:
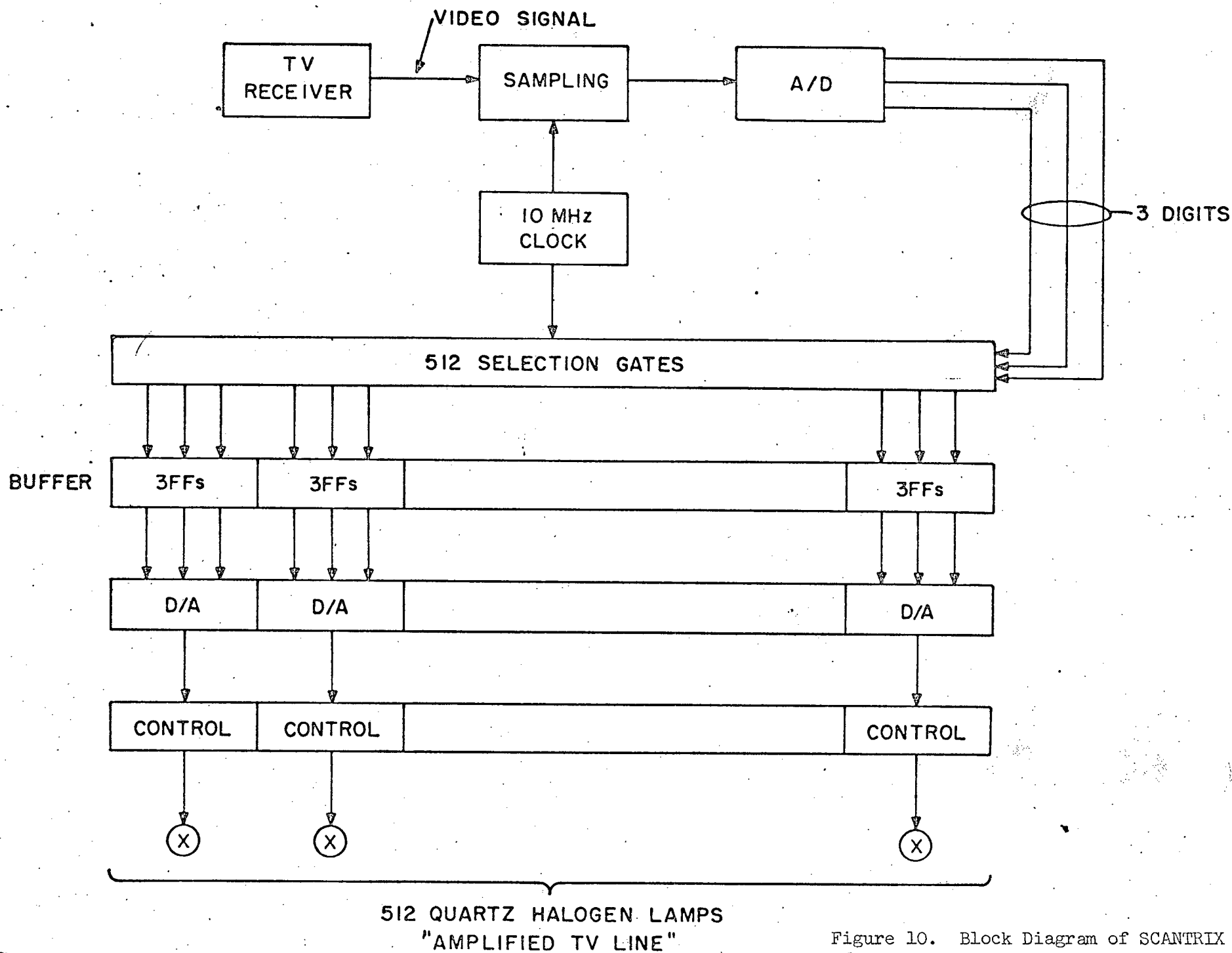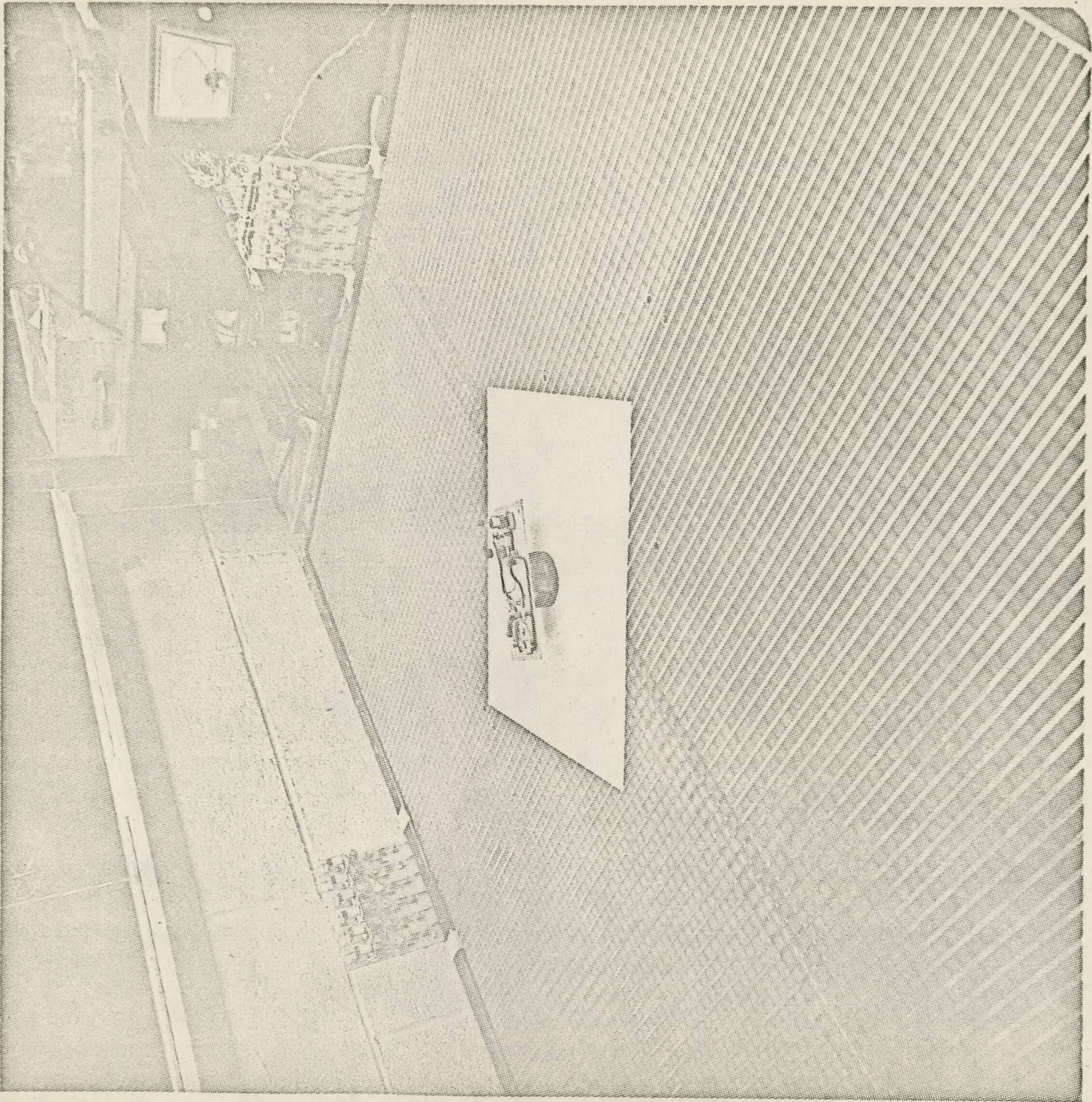
Figure 10.   Block Diagram of SCANTRIX

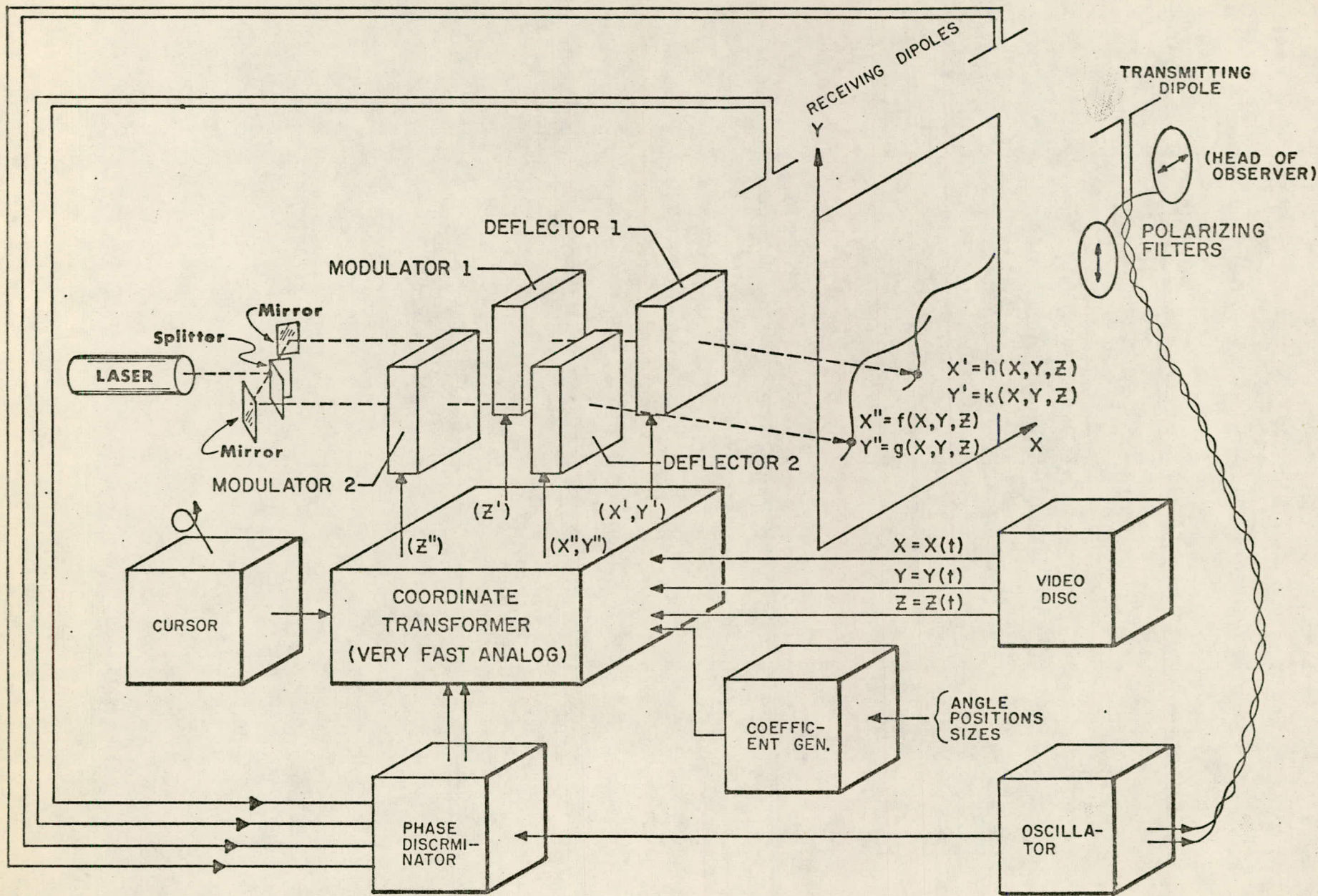Figure 11. SEMANTRIX Block Locator

Figure 12. STEREOMATRIX Principle

(1)   The Coordinate Transformer. This converts the x(t), y(t), z(t)
        triplets from the computer into the coordinates x'y' and x"y",
        the left and the right eye would see if xyz were in the space
        behind the display screen.

(2)   A Coefficient Generator and Cursor. This subsystem allows one to
        move the display as a whole (translation, rotation and magnifica-
        tion ...) by manipulating a control box. It also incorporates a
        cursor which can be moved inside the display.

(3)   The Laser System. This incorporates a laser (the output being split
        into two beams polarized at right angles to each other!), as well
        as modulators and deflectors for the two beams thus formed.

(4)   A Position Detector. This part measures the position of the observer
        and modifies the perspective when his head moves! This is necessary
        if spatial coincidence of a point (on a curve) with the cursor is to
        be assessed.

The program has proceeded more or less according to schedule, except that
the supplier of the acousto-optical deflectors (500 points resolution, TV scan
rates!) was nearly 12 months late supplying these. The 2W laser (from the
same firm) caused enormous trouble until its power supply was rebuilt by us ...
The coordinate transformer and the coefficient generator are about 70%
complete, meaning that 70% of the circuits are actually installed and working.
A last minute change was made in the position detector: It turned out
that the phase-shift detection at UHF shown is Fig. 12 was too sensitive to
surrounding obstacles. Consequently a much simpler system was resorted to:
In this system the observer (who has to wear polarizing glasses anyway) indicates
his position by an infra-red source attached to the frame of the glasses. This
infra-red lamp is located by two rotating mirrors fixed to two optical encoders.
A special trick is to encode $\sin \theta$ and $\cos \theta$ rather than θ: The computation
of the observer coordinates then becomes a trivial exercise!
Fig. 13 shows the coefficient generator (on the left) with its control panel
(to the far left - on the stand!) and the transformer (on the right). Fig. 14
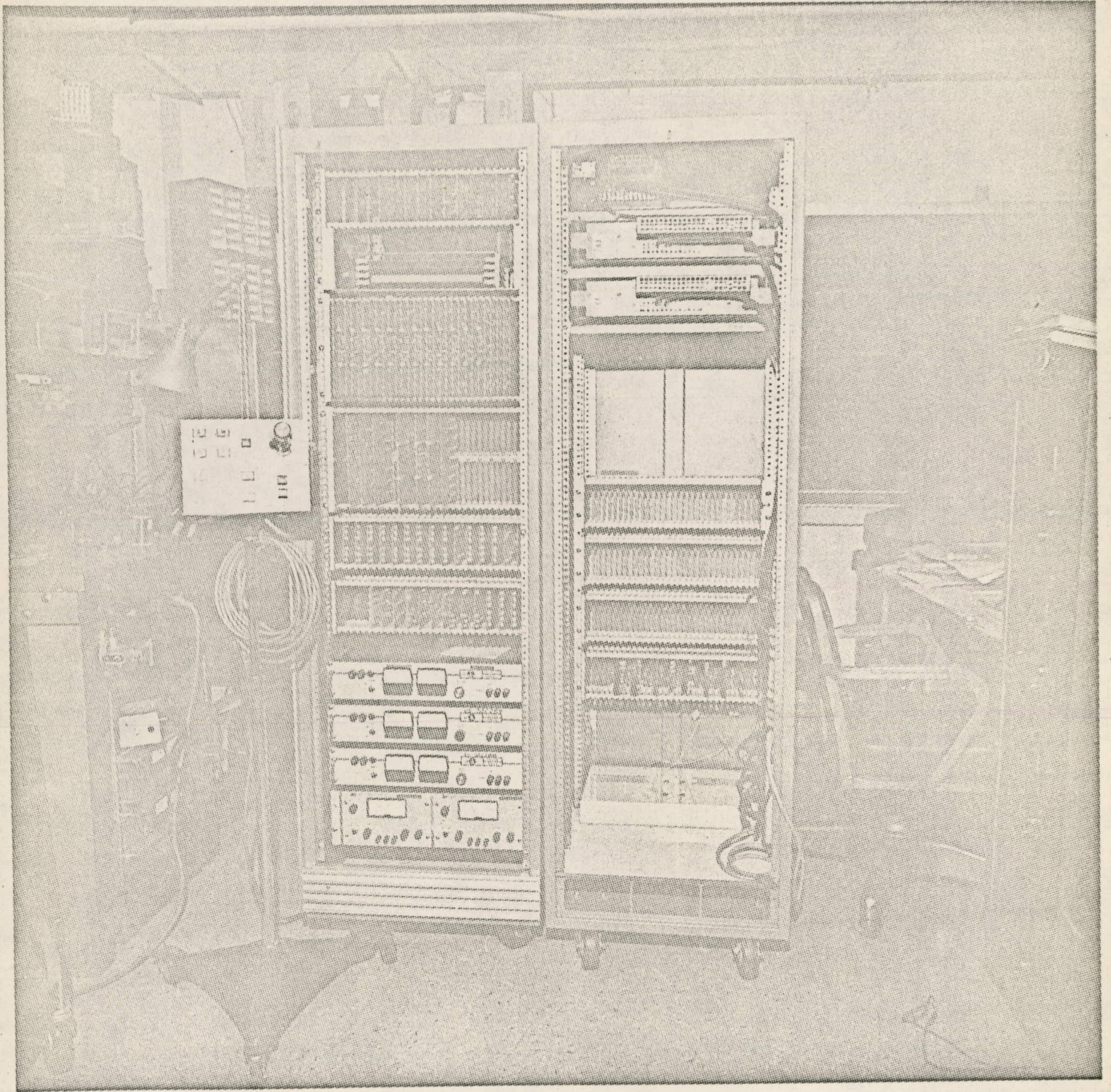shows the 2W laser and in the foreground one of the acousto-optic deflectors

Figure 13. Control Panel, Coefficient Generator
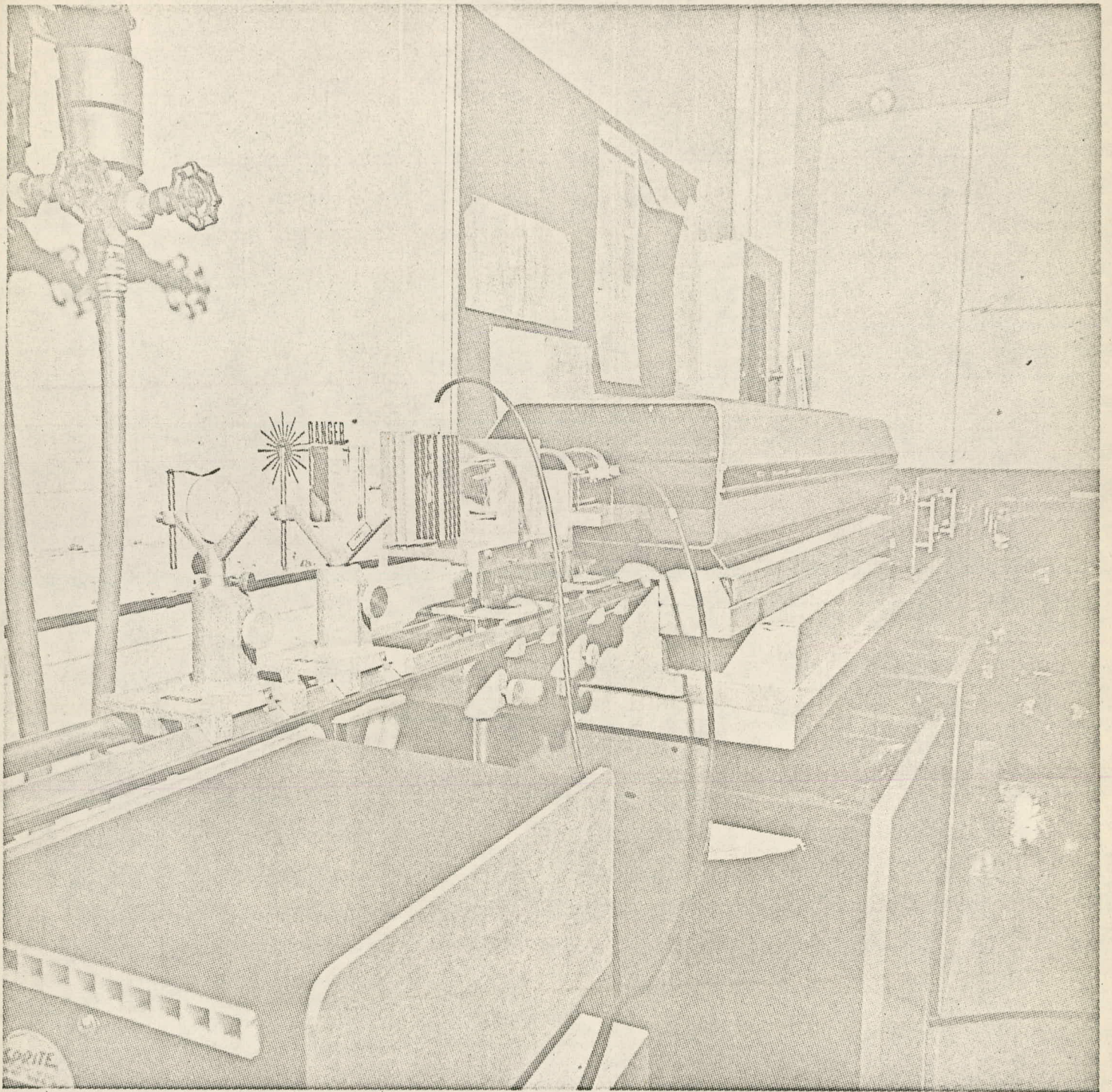and Transformer of STEREOMATRIX

Figure 14. STEREOMATRIX Laser, Modulator
and Deflector

(front cable) and a modulator (back cable). Fig. 15 finally shows the optical
encoder of the position detector.

TRANSFORMATRIX

Three years of hard work have finally paid off and the TRANSFORMATRIX
system has become operational! The crux of this system is the idea of map-
ping 32×32 input signals x_{ij} ($i = 0 \ldots 31$, $j = 0 \ldots 31$) into 32×32
output signals $y_{k\ell}$ ($k = 0 \ldots 31$, $\ell = 0 \ldots 31$) such that

$$y_{k\ell} = \sum_{ij} b_{k\ell ij} x_{ij}$$

i.e. each output signal is a linear combination of all input signals, the
actual matrix $(b_{k\ell ij})$ depending in the output point (k, ℓ). This general
linear transformation includes the rotation, translation and magnification
group, Fourier transforms and pattern recognition operations. Due to stochastic
processing (i.e. pulse sequences with the probability of appearance of a pulse
in a given time slot representing the information), it is possible to build
trivially cheap arithmetic units to perform 1024 multiplications in parallel.
Consequently it is possible to operate on-line at TV frame rates!

Although small noise problems remain to be smoothed out, the performance
of TRANSFORMATRIX is most impressive. At this point there seems to be no doubt
that stochastic processing is ideally suited to picture processing.

Fig. 16 shows a front view of TRANSFORMATRIX. To the left is the 32×32
photoelement matrix; this cabinet contains a projector (to give a choice of input
patterns) as well as a TV receiver coupled to a video recorder: This will allow
us to show on-line high speed operation in the near future. The center section
contains the 1024 arithmetic units as well as a 1024 word $\times$ 5 bit semiconductor
memory necessary for the coefficients. Above the processor are the controls
for pattern recognition (left 5×5 array to set-in the pattern), translation etc.
(center) and Fourier transforms (right). The right hand cabinet contains power
supplies. Fig. 17 shows the rear of the center section: The swing-out panel
contains the special purpose computer which calculates the coefficients for the
Fourier transform operation.

Fig. 18 shows the letter "E" after magnification and translation while
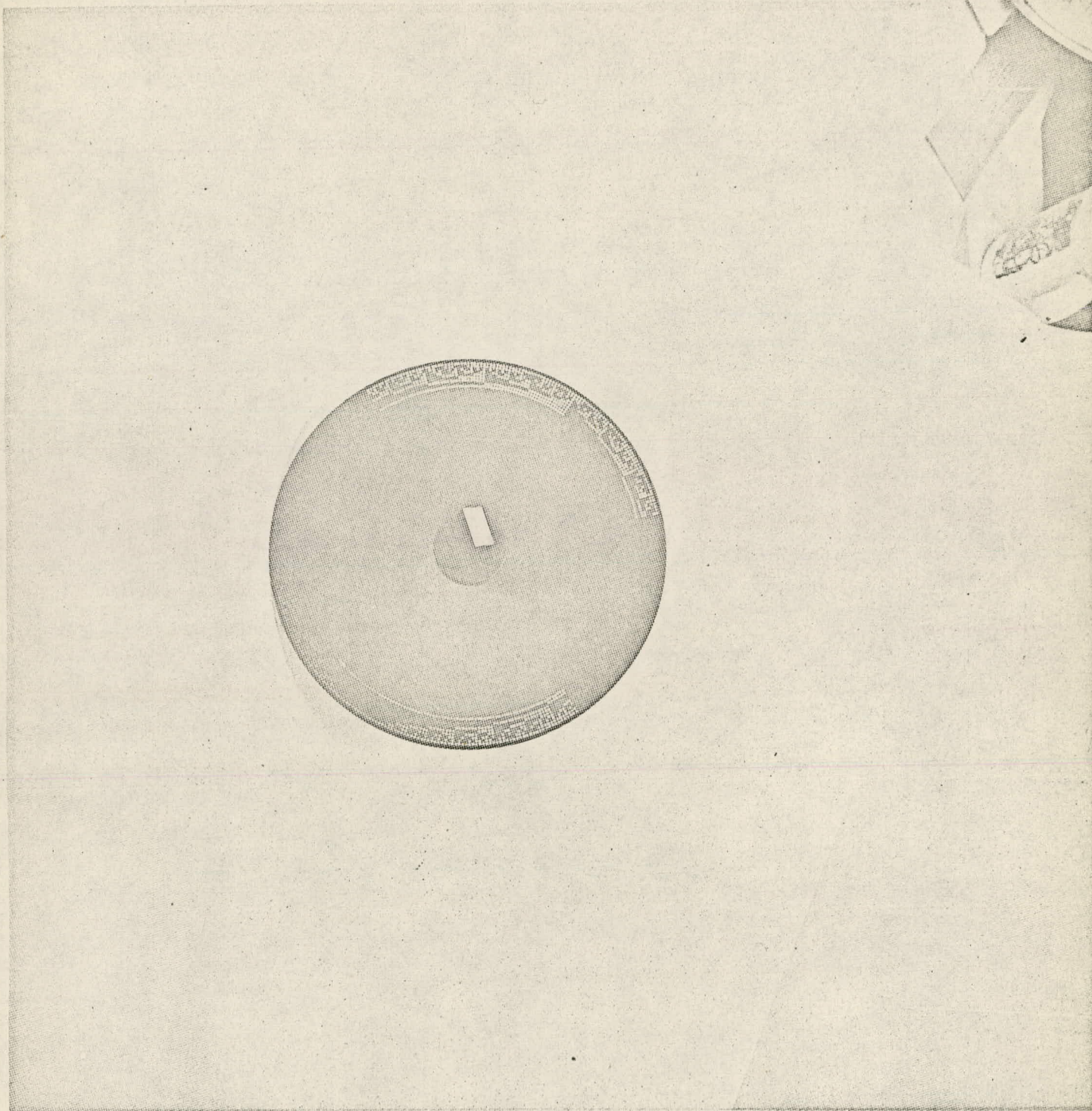Fig. 19 shows the real part of the Fourier Transform of the same letter!

Figure 15.   Encoding Disk for STEREOMATRIX
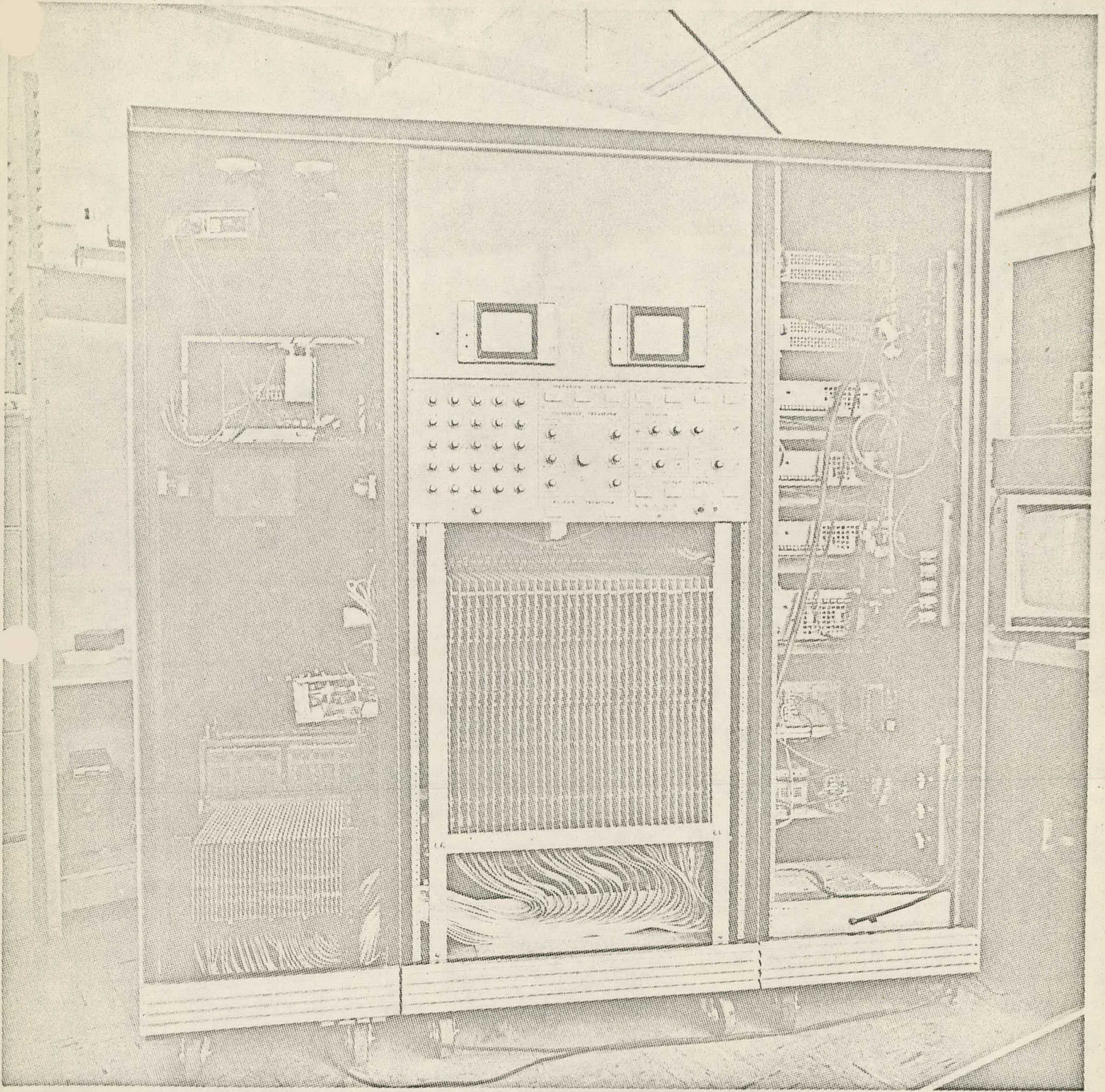   Position Detector

Figure 16. Front View of TRANSFORMATRIX
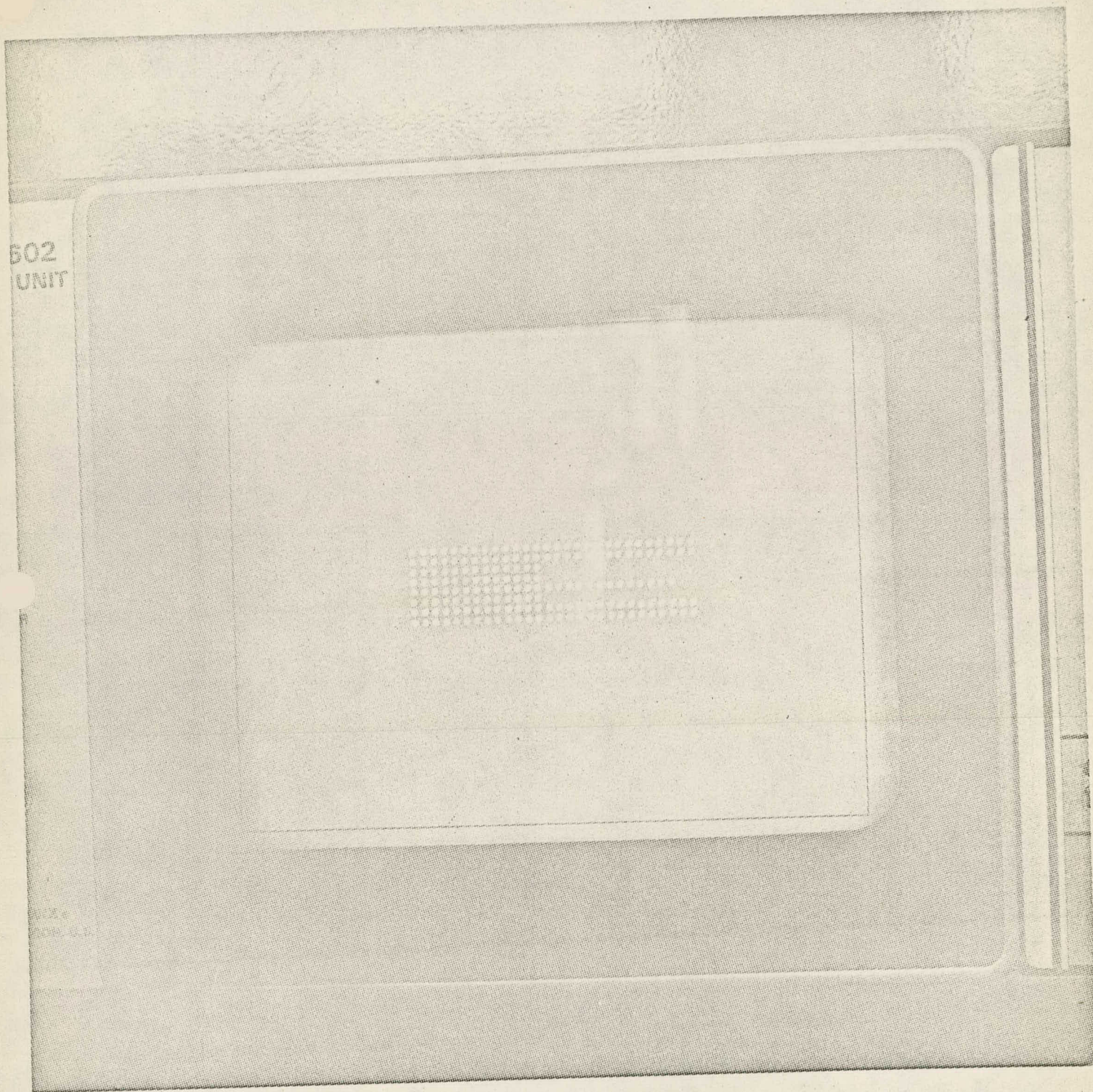
Figure 17.   Rear View of TRANSFORMATRIX

Figure 18. Translation and Magnification
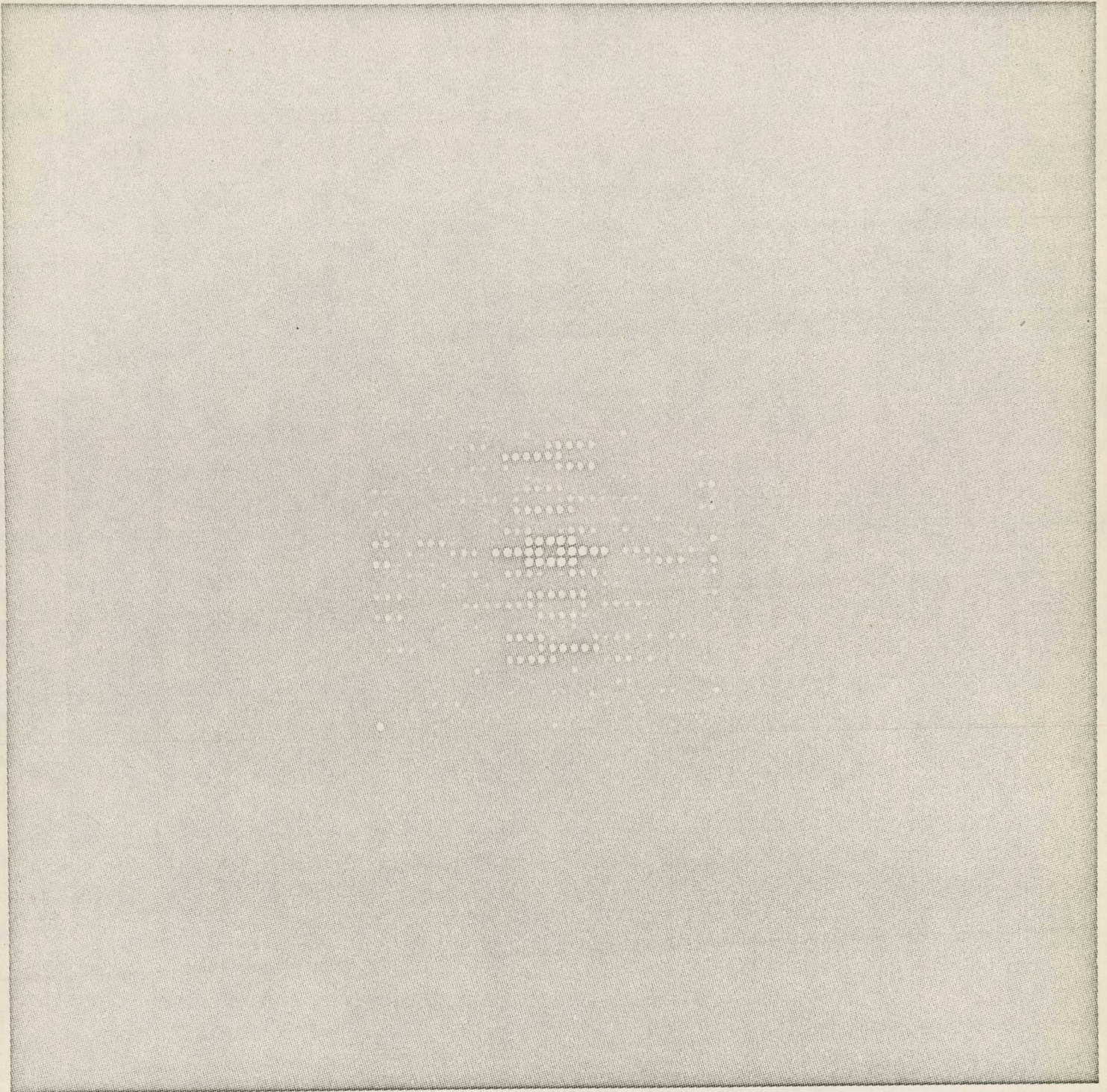on TRANSFORMATRIX

Figure 19. Real Part of a Fourier Transform
on TRANSFORMATRIX

ORBIT, TRICOLOR CARTOGRAPH, VISTA

The work on these three projects was more in the nature of student training and the modifications relatively slight. Details will be found in the Quarterly Progress Reports.

BIBLIOGRAPHY--PART A

<u>REPORTS</u>

1. Fleck, R. "Multiple Precision Computations of Legendre Assumptions," Department of Computer Science Report No. 404, University of Illinois, Urbana-Champaign, 1970.

2. Fosdick, L. and Kim, Y. "Test Matrices I," Department of Computer Science Report No. 403, University of Illinois, Urbana-Champaign, 1970.

3. Frazao, J. "WEED--A Wonderful Equation Elimination Device," Department of Computer Science Report No. 344, University of Illinois, Urbana-Champaign, 1971; also, Master's Thesis. (Available June 30, 1971)

4. Jain, M. K. and Srivastava, V. K. "Optimal Stiffly Stable Methods for Ordinary Differential Equations," Department of Computer Science Report No. 402, University of Illinois, Urbana-Champaign, 1970.

5. Levin, H. and Lopeman, H. "PDP-8/I to PDP-8 Interface," Department of Computer Science File No. 843, University of Illinois, Urbana-Champaign, 1970.

6. Levin, H. "Local Information Retrieval for the Simulation and Modeling System," Department of Computer Science Report No. 409, University of Illinois, Urbana-Champaign, 1970; also, Master's Thesis.

7. Lopeman, H. "PDP-7/I CPU to Expanders and IOT Instruction Decoders, GRAPHICS--1469-Gear," Department of Computer Science File No. 842, University of Illinois, Urbana-Champaign, 1970.

8. Ratliff, K. "Sparse Matrix Inversion," Department of Computer Science Report No. 443, University of Illinois, Urbana-Champaign, 1971. (Available June 30, 1971).

PAPERS

9. Chawla, M. M. "Estimating Errors of Numerical Approximation for Analytic Functions," Numer. Math., 16, pp. 370-374, 1971.

10. Chawla, M. M. "Approximation by Non-Negative Algebraic Polynomials," BIT, 10, pp. 243-248, 1970.

11. Gear, C. W. "Rational Approximations by Implicit Runge-Kutta Schemes," BIT, 10, #1, pp. 20-22, 1970.

12. Gear, C. W. and Dill, C. "A Graphical Search for Stiffly Stable Methods for Ordinary Differential Equations," JACM, 18, #1, pp. 75-79, 1971.

13. Gear, C. W. "The Automatic Integration of Ordinary Differential Equations," CACM, 14, #3, pp. 176-179, 1971.

14. Gear, C. W. "Algorithm DIFSUB," CACM, 14, #3, pp. 185-190, 1971.

15. Gear, C. W. "Transient and Steady State Numerical Solution of Differential-Algebraic Equations," IEEE Conference Proceedings, Oaxtepec, Mexico, 1, pp. 384-386, 1971.

16. Gear, C. W. "The Simultaneous Numerical Solution of Differential-Algebraic Systems," IEEE Transactions on Circuit Theory, 18, #1, pp. 89-95, 1971.

BOOKS

17. Gear, C. W. NUMERICAL INITIAL VALUE PROBLEMS IN ORDINARY DIFFERENTIAL EQUATIONS, Prentice-Hall, Inc. New Jersey, 1971.

OTHER REFERENCES

18. Gear, C. W. "An Interactive Graphic Modeling System," Department of Computer Science Report No. 318, University of Illinois, Urbana-Champaign, 1969.

19. Gear, C. W. et.al. "The Simulation and Modeling System-- A Snapshot View," Department of Computer Science File No. 824, University of Illinois, Urbana-Champaign, 1970.

Bibliography for 1469 - Poppelbaum

Papers Published

Poppelbaum, W. J. Computer Oriented Texts or Computer Aided
Instruction: Proceedings of the 1971 Symposium on Application
of Computers to Electrical Engineering Education. Purdue
University, Lafayette, April 1971.

Kubitz, W. J. and Poppelbaum, W. J. Stereomatrix - A Three
Dimensional Display. Proceedings of the 1971 Symposium of the
Society for Information Display, Philadelphia, May 1971.

MS Theses Completed

Lin, C. Design Factors for a Transition Temperature Pockels Tube,
Department of Computer Science Report No. 413, University of
Illinois, (August 1970).

Olsen, D. L. Remote Power Supply for the APE System, Department of
Computer Science Report No. 410, University of Illinois,
(August 1970).

MS Theses in Preparation

Carr, Edward. A Synchronization System for a Television Bandwidth
Compression Scheme.

Hanson, D. Outline Generation and Variable Shading for an Automatic
Coloring System.

Partridge, Richard. PAGAN - A Three Dimensional Analog Pattern Generator.

Ph.D. Theses Completed

Oberbeck, P. ORBIT - Online Reduced Bandwidth Information Transmission, Department of Computer Science Report No. 430, University of Illinois, (February 1971).

Ryan, L. System and Circuit Design of the Transformatrix Coefficient Processor and Output Data Channel, Department of Computer Science Report No. 435, University of Illinois, (March 1971).

Simons, A. EIDOLYZER: A Hardware Realization of Context-Guided Picture Interpretation, Department of Computer Science Report No. 448, (June 1971).

Ph. D. Theses in Preparation

Cheng, Tien-Ren. The Stereomatrix Cursor and Coefficient Generator.

Cooper, M. LASCOT - A Large Screen Color Television Design.

Katoh, Tak. RASER - A Random to Serial Scan Converter with Processing.

Pirnat, Charles. The Stereomatrix Operator Position Detector.

Verma, Shiv. The Stereomatrix Transformer.

Wallman, Larry. BLAST: A Xographic Stereoscopic Television System.

Whiteside, Stephen. The Stereomatrix Modulation, Deflection and Projection System.

Papers to be Published

W. J. Kubitz and Poppelbaum, W. J. Stereomatrix - An Interactive Three-Dimensional Display System. 1972 fall issue of The Proceedings of the SID.

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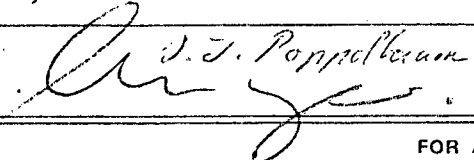- [ ] c. Make no announcement or distrubution.

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