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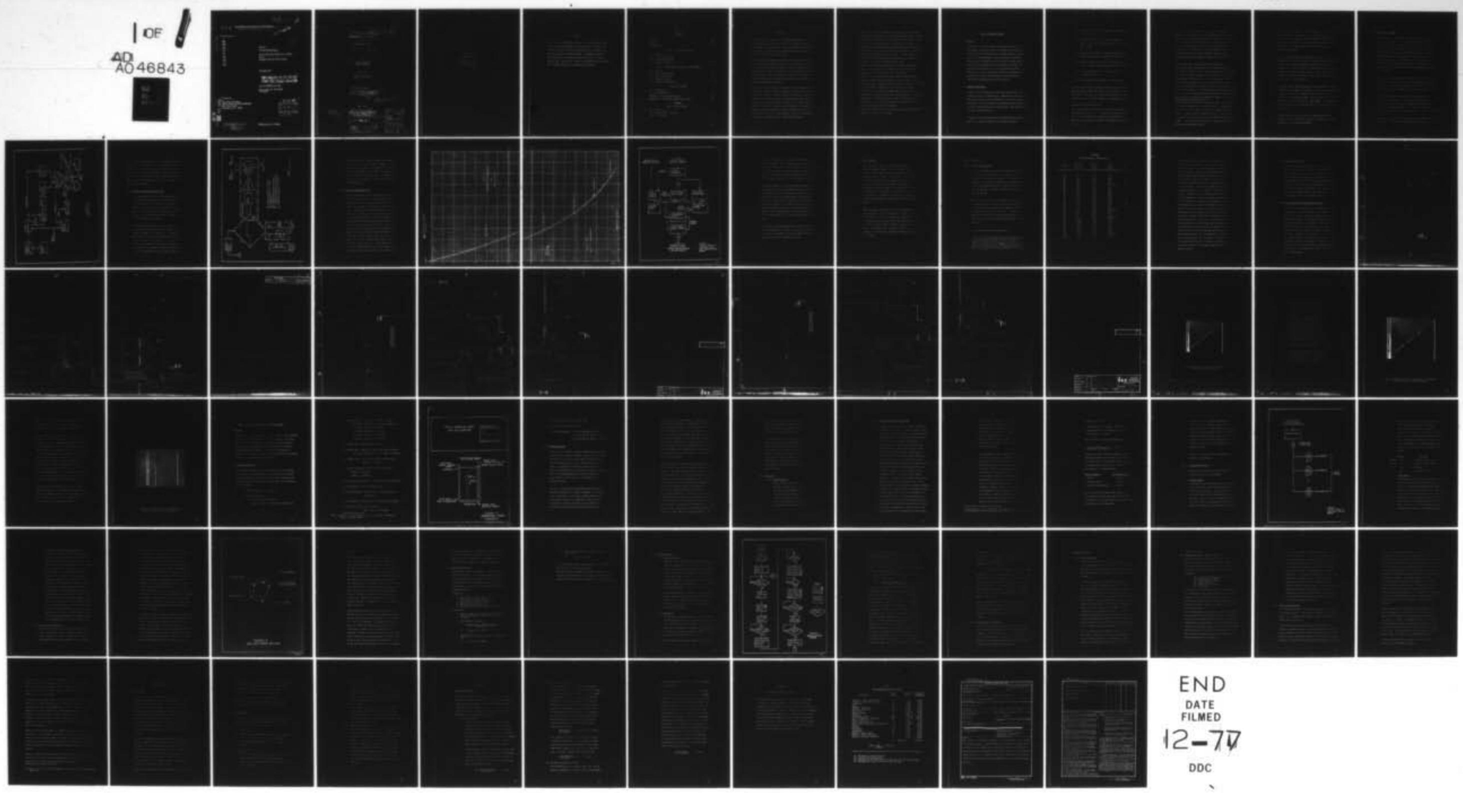

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Volume 1

Final Development Report

PHASE II: FEASIBILITY STUDY OF A FIBER OPTICS PLOTTER

12 October 1967

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Task 08631

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by

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VOLUME 1

TECHNICAL ASPECTS

FEASIBILITY STUDY
OF A
FIBER OPTICS PLOTTER

ABSTRACT

This study has established feasibility of a proposed fiber optics plotter system which produces bathythermograms on standard film aperture cards in both analog and digital form. Performance has been verified with a breadboard model. Outstanding features of the design are its all digital nature and the use of a new dry process film. Operational, reliability, production and cost aspects are considered based on a preliminary system design.

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PART III - SUMMARY

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INTRODUCTION

This study has been undertaken to establish feasibility of a proposed fiber optics plotter technique as applied specifically to recording data taken with an existing expendable bathythermograph (XBT) probe. The work has been performed under contract with the U.S. Navy, Naval Ships Systems Command.

The fiber optics recording principle is not particularly new, but the application described herein represents something quite different from existing recorder techniques. With this recorder data is plotted in both analog and digital form on film inserts in standard aperture cards. This is accomplished by moving the card under the optical recording head in small steps similar to that used in incremental digital tape recorders.

The most important feature of this device is its all digital nature wherein the inherent advantages of digital systems are realized, i.e., no stability or drift problems, high noise tolerances, simple and redundant solid state circuitry, no critical power supply requirements, ease of troubleshooting and repair, etc. Another important feature is the use of a new dry process film which is equivalent to standard silver halide films in quality, stability and cost, but which requires only heat for development. With this film finished records are available about ten seconds after exposure.

Phase I of the contract demonstrated feasibility of the recording technique through construction of a breadboard model which created simulated bathythermograms on the dry silver film. Phase II of the study involved two main areas: (1) demonstration of technical feasibility of digitizing and linearizing the probe data, and (2) investigating the technical and economic feasibility of producing fiber optics plotter systems in quantity. Volume I represents the body of the report wherein technical aspects of the study are discussed. The volume is divided into three parts.

Part I discusses modifications made to the Phase I breadboard model involving addition of a digitizer, digital linearization circuits and a new fiber optic head to the system.

Part II presents a preliminary system design, and this design is used to analyze operational, production and cost aspects of the proposed system. Included in this analysis is a reliability estimate and a discussion of additional capabilities of the system.

The results of this study are summarized in Part III where it is concluded that fiber optics plotter systems which meet the desired performance characteristics can be produced in quantity for a reasonable cost. Finally, recommendations regarding future areas of study and development are discussed.

Cost of the plotter systems in production quantities is estimated in Part IV, Volume 2 of the report.

PART I - BREADBOARD MODEL

1.1 Purpose

During Phase II of the study the breadboard demonstration unit was modified to provide a full scale model of the Fiber Optics Plotter System. This modification included design and construction of an Analog-to-Digital Converter, Digital Linearizing Circuitry, and a new full-scale Fiber Optic Recording Head. The film processing equipment was also augmented to provide automatically controlled hot air in in the developing chamber. In this manner a complete system was simulated in breadboard form permitting full-scale test and analysis and demonstrating feasibility simultaneously with practicability.

1.2 General Factual Data

In Phase I of the study, basic feasibility of the fiber optic recording concept was demonstrated. Digitized data was simulated with toggle switches and no linearization of the analog data was attempted. In this final phase the breadboard system was modified to include these functions and thereby permit study and demonstration of a full-scale system.

In general, the full-scale model was designed and constructed to demonstrate operation within the following constraints:

(1) Records are to contain both digital and analog presentations of the data.

(2) Temperature resolution in the digital domain is one part in 1024, i.e., ten binary digits, over the range 28° to 96°F.

(c) Temperature resolution in the analog presentation is ± 0.4°F with the plot linearized (1) within its resolution.

(d) Depth resolution is ± 10 ft. or better for a minimum range of 1500 ft., with a desired range up to 2500 ft.

(e) The recording medium is a dry process film mounted in standard aperture cards.

(f) Record time will correspond to the BT drop time.

In order to meet these constraints a new Fiber Optic Recording Head was fabricated with 183 fibers. One hundred seventy fibers were used for the analog plot, 10 for digital data and 3 were used for markers. The fiber diameter is approximately 5 mils.

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(1) Linearization was performed in accordance with "Resistance Vs. Temperature Values . . . ", Table 5-1 of the XBT vendor's manual: "R-467 Preliminary Instructions for Installation, Operation and Maintenance of Sippican Expendable BT System," pg. 5-9.

In consonance with our original proposal, the digitizer was designed to provide raw (i.e., non-linearized) data. Thus it was possible to use a relatively simple Wheatstone Bridge-type circuit for the "front end" of the system, as no non-linear resistors or other such compensating devices were required to obtain the desired output. Linearization of the analog plot was therefore placed completely in the digital domain avoiding all of the problems of stability and calibration common to analog circuits.

Two basic methods of linearization were considered,* i.e., a serial method and a parallel method. The latter approach was very desirable from the accuracy standpoint because it approximates the thermistor resistance-temperature curve with as many straight line segments as there are points on the analog plot. This is accomplished through decoding of the digital data with 170 multi-input and gates, each gate output connected to an individual lamp in the analog display. The alternate serial method involves the use of a non-linear digital counter which provides a somewhat less accurate output, as economic considerations limit the number of

---

* A third method, involving the spacing of fibers in the record head, was abandoned early in the project when it became apparent that the resulting analog plot would have a sliding resolution scale. In order to maintain desired resolution of about 0.4°F at one end of the scale, resolution at the other end would be about 0.08°F. This would require more fibers, lamps, etc., and is not considered economically feasible.

straight line approximations to the thermistor curve to about six or eight. (It was determined that an approximation involving six straight line segments would yield no more than ± 0.4°F error.) This method still requires the decoding and lamp driver circuits present in the original breadboard system in addition to the linearizing circuitry.

Since the parallel approach would require the purchase of a large number of gate circuits, and since the original breadboard system already had most of the decoding and lamp driving circuitry required for the serial approach, economy dictated the use of the serial approach for the Phase II demonstration system. The parallel approach has not been abandoned, however, and it is given consideration in Part II of this report.

To provide a more automated and repeatable film processing system, a blower, heating element and temperature controller were purchased for use on the Phase II breadboard system. This permitted control of the hot air developing chamber to within ± 0.5°F without manual intervention. This, combined with improvements in the mechanics of the film transport system, provided very consistent processing of the film.

Details regarding the structure of the modified breadboard system and results of tests utilizing a new high-contrast film are presented in the following paragraphs.

1.3 Detailed Factual Data

A block diagram of the modified breadboard system is presented in Figure 1. The bridge circuitry and Analog-to-Digital Converter provide a digital output directly proportional to the resistance of the thermistor sensing element in the BT probe. Thus, "raw" temperature data is recorded in digital form through the digital lamp driver circuits. This same data is processed by digital linearizing circuits and a decoding matrix to provide an analog recording which is linear within ± 0.4°F. The output of each lamp is coupled to the film surface through the Fiber Optic Recording head Assembly.

As in the original system, aperature cards are moved incrementally under the recording head by a rotary solenoid/lead screw arrangement. Gearing is provided to produce increments of about 6 mils; the aperture cards are stepped at a rate of about twice per second.

Each time the film is advanced, a "start conversion" pulse is coupled to the A/D converter. Upon receipt of this pulse the thermistor output is converted to digital form and the digital output is linearized for presentation on the analog plot. The digital logic portion has been implemented with integrated circuits.

On completion of the recording process, the aperture card is picked up by the film transport mechanism and passed through the

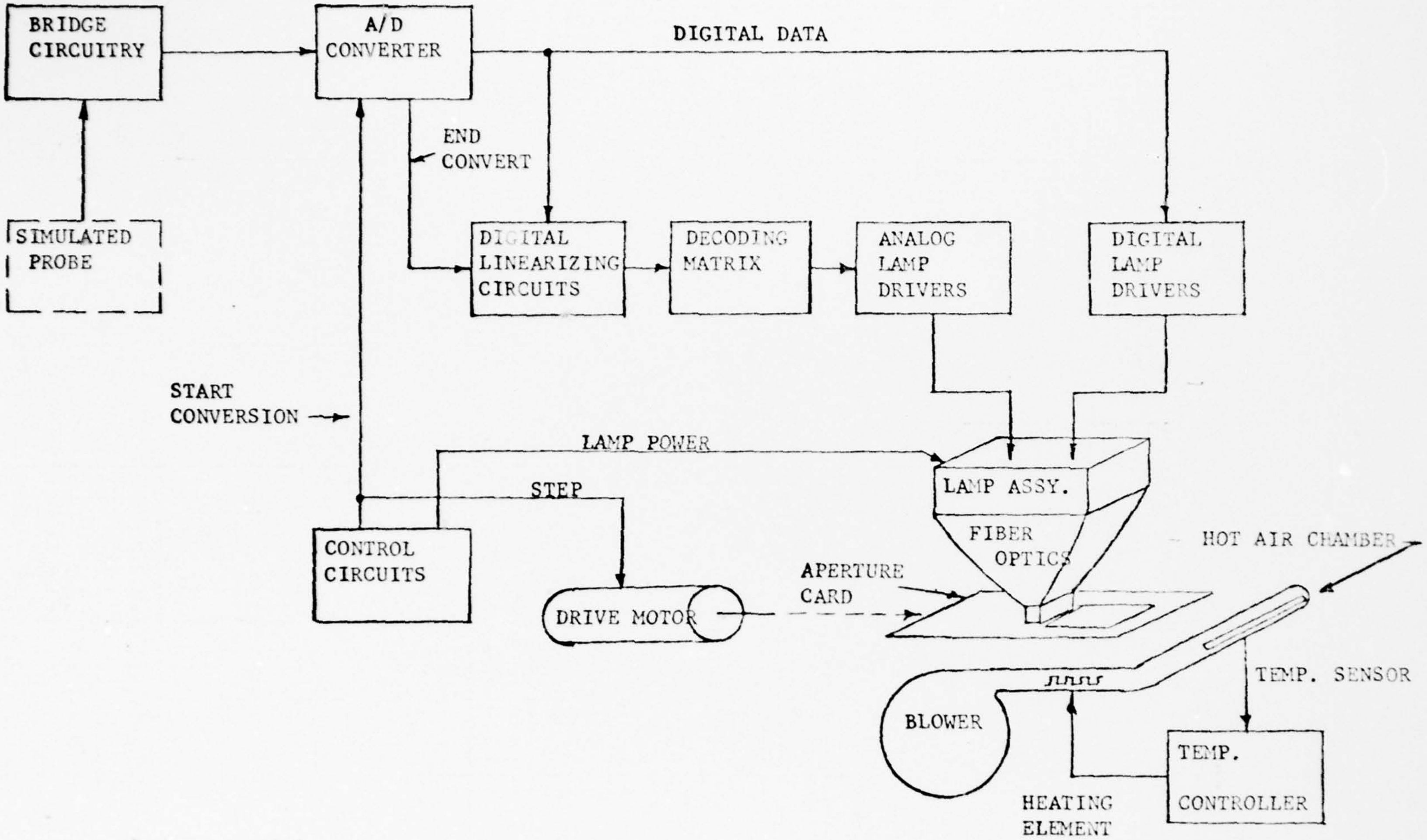


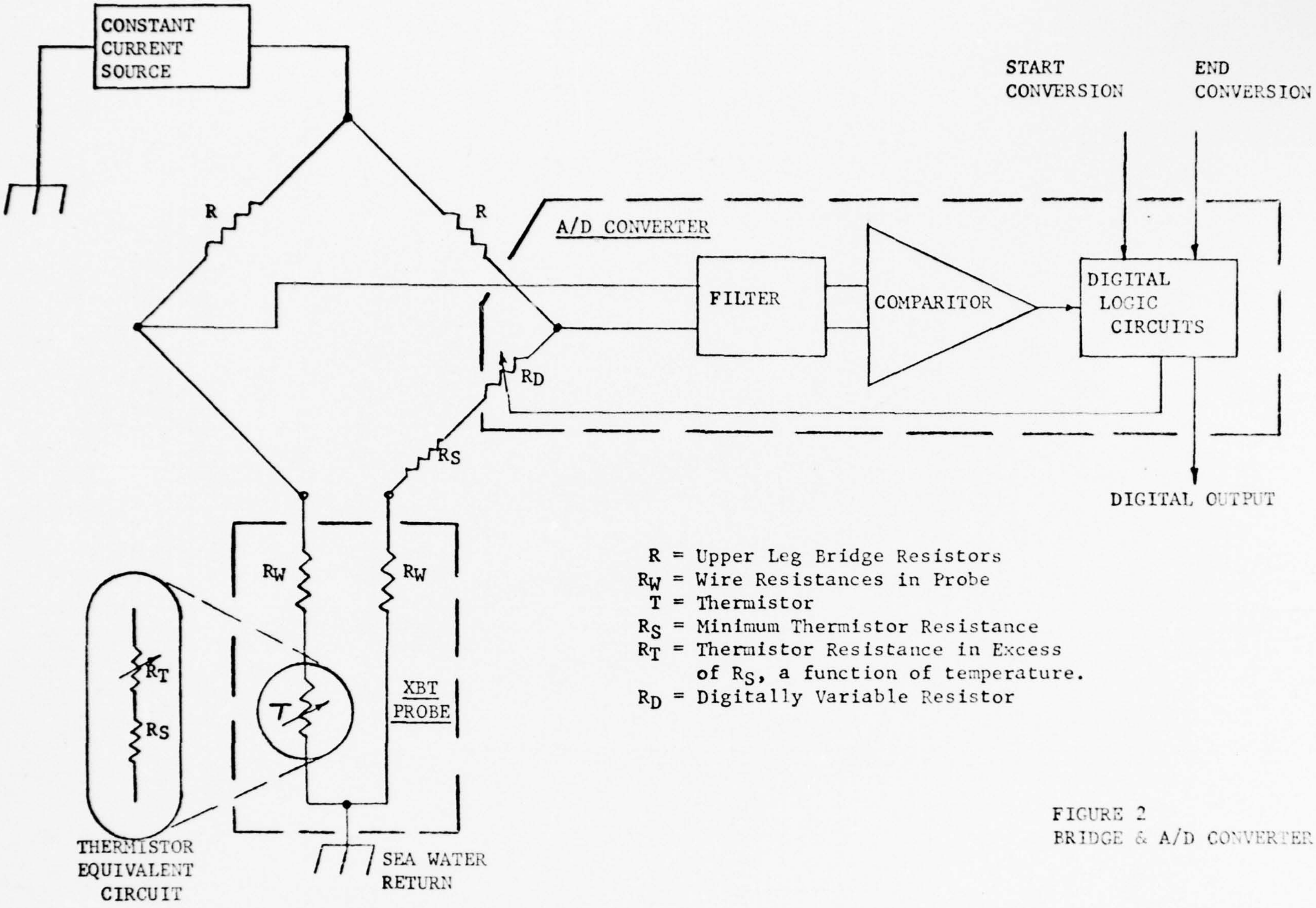
FIGURE 1
BLOCK DIAGRAM
BREADBOARD SYSTEM

hot air chamber for development. For experimental purposes the temperature of the chamber and the rate at which the card was transported through the chamber were under separate control. Since the only significant difference between the breadboard system outlined in the Phase I report and the current system are in the electronic and recording head areas, only those subjects will be covered in detail below.

1.3.1 Bridge Circuitry and A/D Converter

The general features of the Bridge and A/D Converter Circuitry are illustrated in Figure 2. This is basically a Wheatstone Bridge Circuit with exitation supplied by a constant current source. Note that the BT probe wire resistances, R_W, are in adjacent legs of the bridge and therefore eliminate any problems associated with differences in wire resistances from probe to probe.

The Bridge and A/D Converter act as a simple null balance system wherein the digitally-controlled resistor, R_D, is varied to produce a null condition at the comparitor input. R_D consists of a series of binary weighted resistors shunted by relay contacts. The relays are controlled by flip-flop circuits in the digital logic section. The digital logic was arranged in a standard successive approximation form to provide a minimum consistent conversion time of about



R = Upper Leg Bridge Resistors
R_W = Wire Resistances in Probe
T = Thermistor
R_S = Minimum Thermistor Resistance
R_T = Thermistor Resistance in Excess of R_S, a function of temperature.
R_D = Digitally Variable Resistor

FIGURE 2
BRIDGE & A/D CONVERTER

30 milliseconds. The digital functions were implemented with twenty-seven integrated circuit elements. Filtering was applied at the input to the comparitor to eliminate excessive bandwidth noise problems. (The comparitor used was an inexpensive integrated circuit type which was capable of operating at speeds well in excess of requirements for this application.)

1.3.2 Digital Linearizing Circuit

The thermistor Resistance Vs. Temperature curve for the probe is shown in Figure 3. This curve was plotted from data supplied by the manufacturer, and the straight line approximations used in this study are overlayed on the curve. The digital linearization scheme is illustrated in Figure 4. The Sync and Control circuits operate to reset the various counters and to synchronize the "end of conversion" pulse from the A/D Converter with the 100 kHz clock. Once this pulse is received, the various counters are reset and then clock pulses are gated into the 10-bit binary counter until a match is detected between the counter output and the A/D Converter output. At this point the comparitor provides an "equal" signal which terminates the clock input into the counter. In this manner "n" clock pulses are produced where "n" equals the number stored in the A/D Converter output register. These clock pulses are

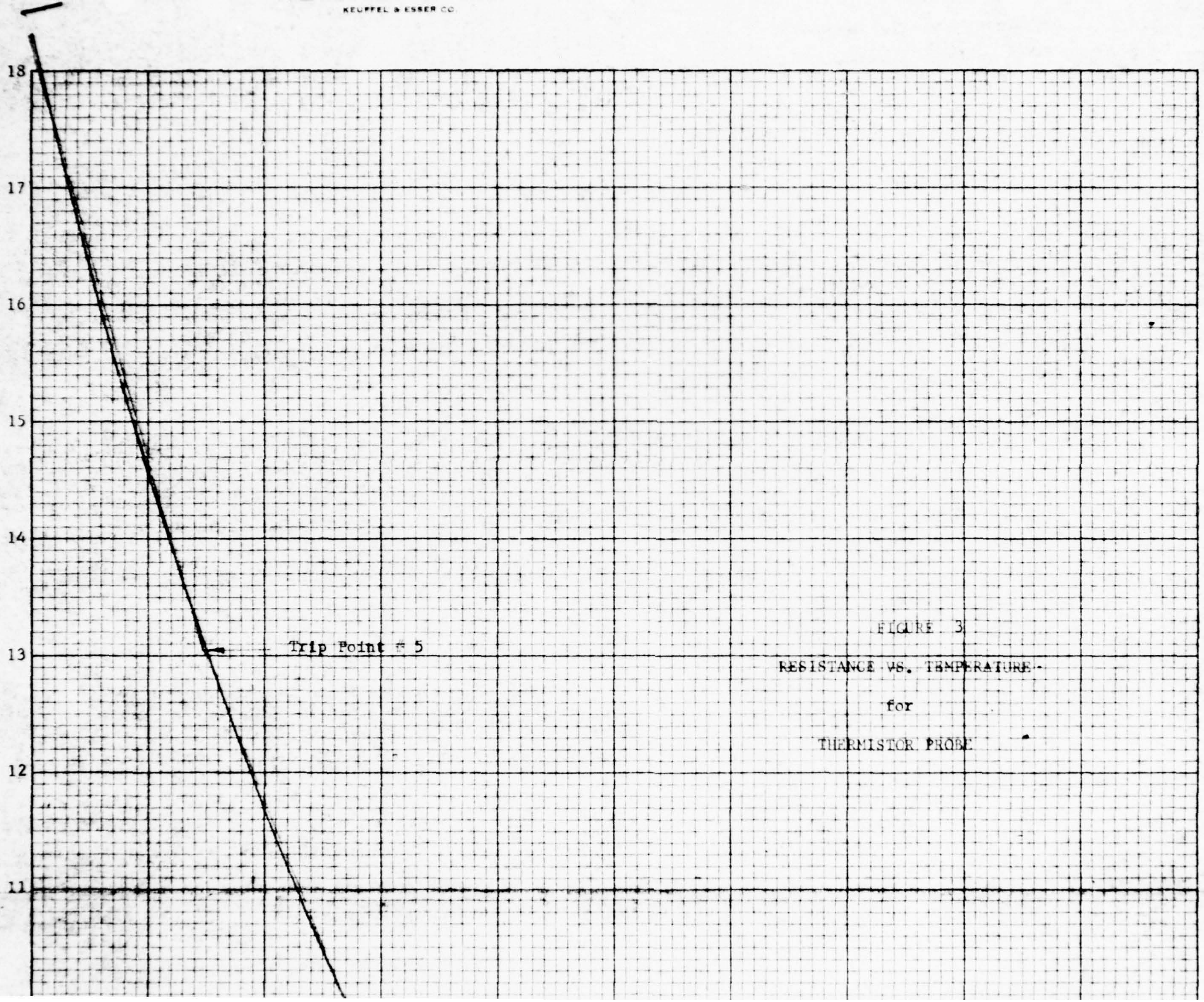
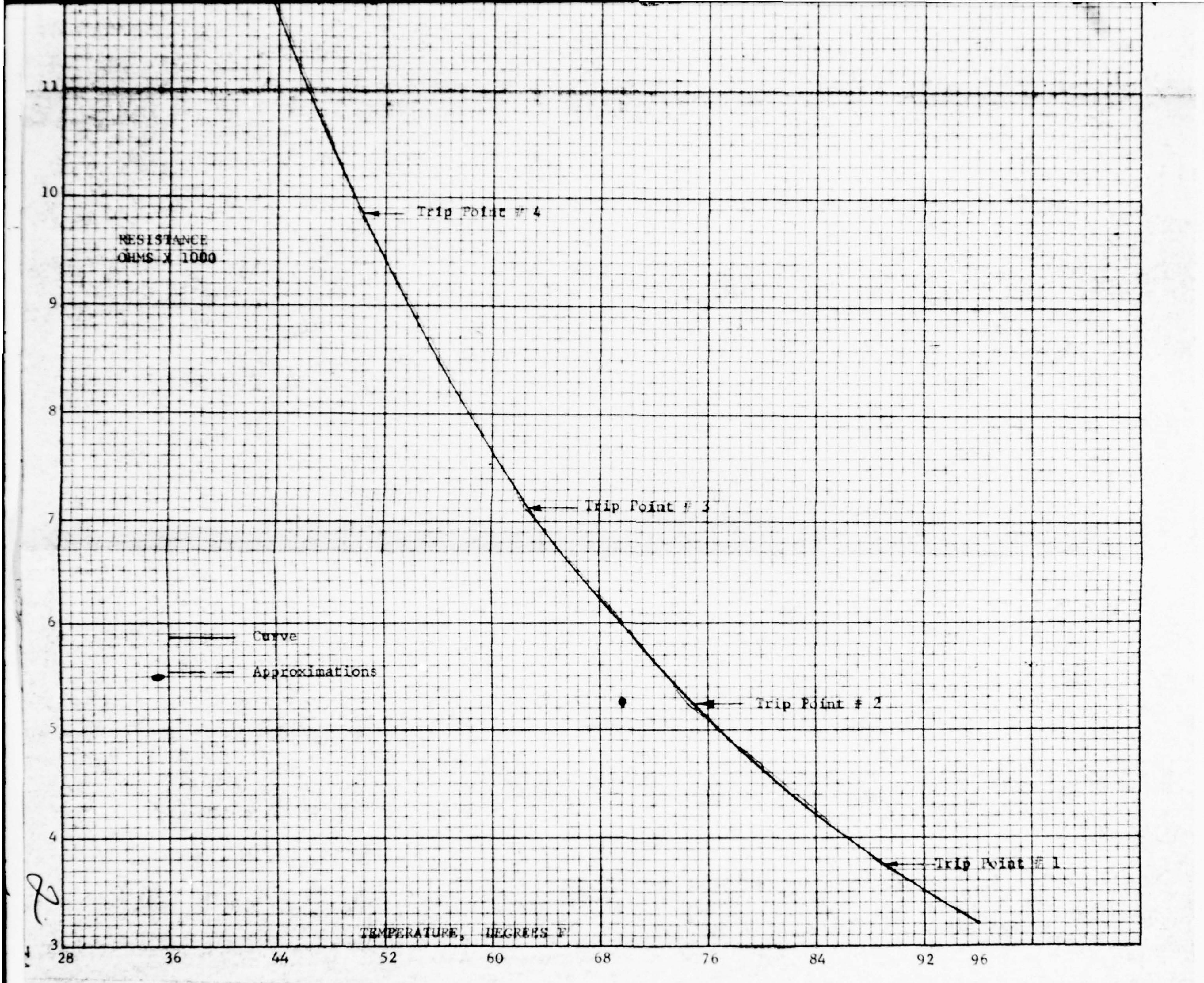


FIGURE 3

RESISTANCE VS. TEMPERATURE

for

THERMISTOR PROBE


RESISTANCE
OHMS X 1000
11
10
9
8
7
6
5
4
3
28
36
44
52
60
68
76
84
92
96
TEMPERATURE, DEGREES F
Trip Point # 4
Trip Point # 3
Trip Point # 2
Trip Point # 1
Curve
Approximations

2

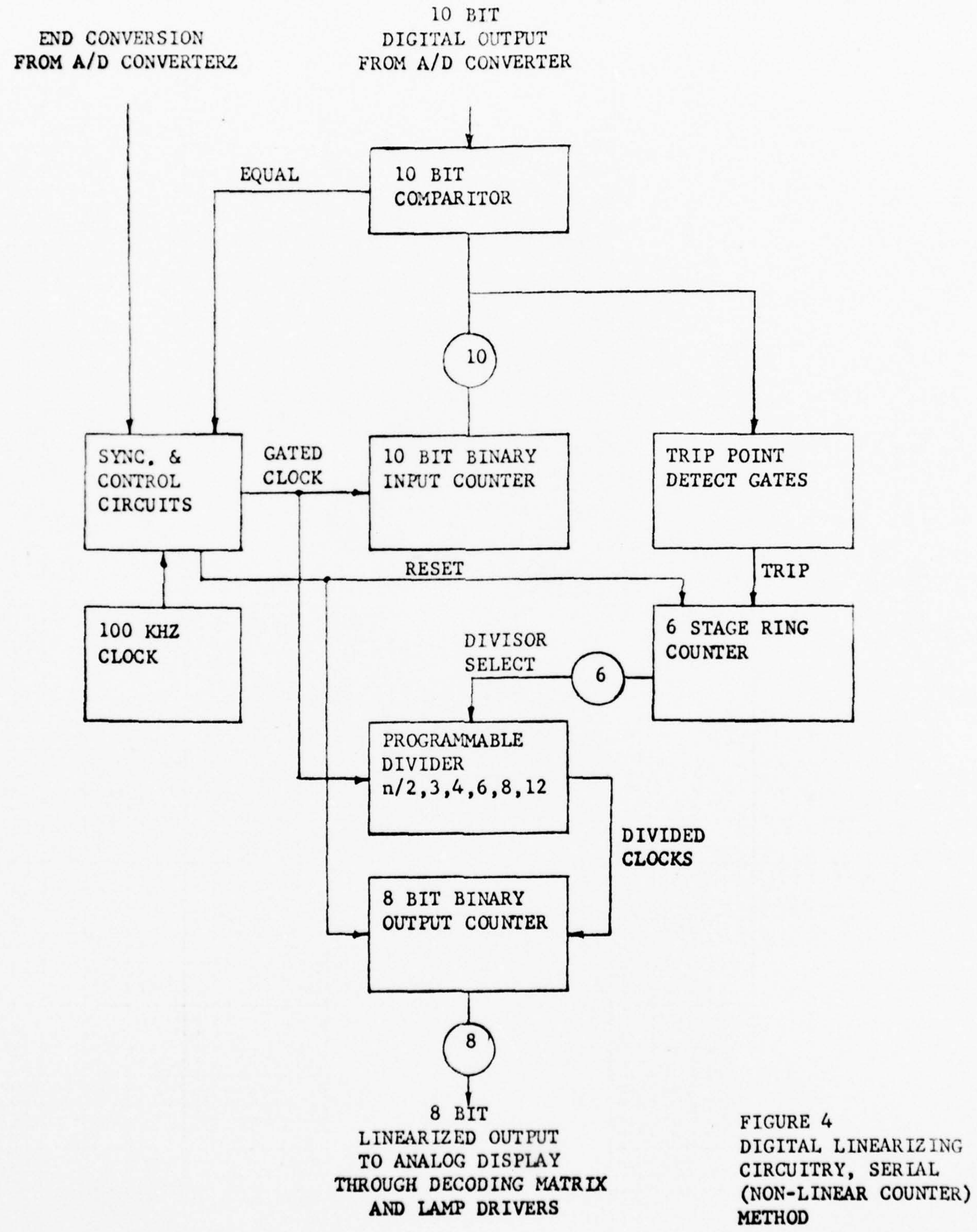


FIGURE 4
DIGITAL LINEARIZING
CIRCUITRY, SERIAL
(NON-LINEAR COUNTER)
METHOD

applied to the 8-bit binary output counter through a programmable divider circuit. The divider circuit is initialized to the n/2 condition such that one count is accumulated in the output counter for every two counts in the input counter. This creates a slope equivalent to that shown on the lower right hand section of the thermistor curve, Figure 5.

The divider remains at n/2 until the digital number equivalent to Trip Point No. 1 on the thermistor curve is reached. At this point one of five trip point gates shown in Figure 4 provides a "trip" signal which advances the Ring Counter one count. This output of the Ring Counter is coupled to the divider causing it to divide by three. The output counter therefore assumes the slope of the second straight line segment on the thermistor curve. This process is repeated up to four more times to provide linearization of the entire range.

In this manner the digitized thermistor data is linearized by approximating the resistance vs. temperature curve with six stright line segments. Fifty-four digital integrated circuits were used to implement this logic.

1.3.3 Recording Head

A new fiber optic recording head was provided for the modified breadboard system. This was necessary for a full-scale model, as the previous unit contained only 64 fibers for the analog plot. Also, smaller fibers (3 mil) were used in the new head to provide for a greater depth range, as the film could be stepped in much smaller increments between data samples. The new head was composed of 183 fibers - allowing for a full-scale presentation of the analog data in the form of 170 points. Ten fibers were reserved for the digital presentation and 3 were for margin marks.

Some difficulty in fabrication of the head assembly was experienced which resulted in breaking and bending several of the fibers. Most of the problems were related to handling the fibers, and it is apparent that a properly designed set of tools and fixtures will be required to produce recording heads in a reliable manner. Although some fibers were damaged, the head was still usefull for demonstration and test purposes.

1.4 Test and Results

1.4.1 Bridge and A/D Circuits

The bridge and A/D converter circuits were checked out by simulating the BT probe with a pair of precision 4.7K ohm resistors and a decade potentiometer. The resistors simulated the average wire resistances in a 1500-ft. probe, and the decade potentiometer was varied between about 3K ohms and 18K ohms to simulate the full-scale thermistor resistance change.

Table 1 presents test results showing the comparison between the digital output of the A/D converter and the digital value equivalent to simulated probe temperature for 2°F increments throughout the entire range. The maximum difference between actual and desired values was 3 bits which is well within the experimental limits for this test set up (*).

---

* Since a 0.1% decade potentiometer was used, errors due to this source alone represent one part in 1,000 which is nearly equivalent to the bit resolution (one part in 1,024). Thus, errors of at least ± 1 bit can be attributed to the potentiometer. This, combined with the ± ½ bit quantizing error inherent in all A/D converters, would account for nearly all the errors observed in the system.

TABLE I

BRIDGE AND A/D CONVERTER TEST DATA

(1) Temperature °F.	(2) Equivalent Thermistor Resistance, Ohms	(3) Equivalent Digital Value (Octal)	(4) A/D Converter Output (Octal)	(5) No. of Bits in Error |(3) − (4)|
96	3207	0000	0000	0
94	3350	0012	0012	0
92	3503	0024	0024	0
90	3666	0037	0037	0
88	3840	0053	0053	0
86	4024	0067	0067/0070	0/1
84	4221	0105	0105	0
82	4429	0123	0123	0
80	4694	0142	0145	3
78	4881	0162	0161	1
76	5126	0202	0202	0
74	5383	0224	0223	1
72	5656	0246	0246	0
70	5943	0272	0271	1
68	6247	0316	0316	0
66	6570	0344	0344	0
64	6912	0373	0373	0
62	7274	0424	0423	1
60	7657	0456	0455	1
58	8063	0511	0507/0510	1/2
56	8494	0547	0546	1
54	8950	0605	0604	1
52	9434	0646	0646	0
50	9948	0711	0707/0710	1/2
48	10496	0756	0756	0
46	11080	1026	1024	2
44	11699	1100	1077	1
42	12357	1154	1153	1
40	13057	1234	1231	3
38	13800	1316	1315	1
36	14591	1404	1401	3
34	15433	1475	1472	3
32	16329	1572	1567/1570	2/3
30	17287	1673	1670	3
28.07	18293	1777	1776	1

Tests on the conversion speed of the system revealed that speeds of up to 45 10-bit conversions per second could be attained. At this rate conversion time of the A/D converter was about 22 msec. However, these speeds were attained with the simple simulated probe described above, and it can be expected that dynamic effects in an actual probe will limit the minimum conversion time to something in excess of 22 msec. With no data available on these probe characteristics, one can only guess at a dynamic equivalent circuit. Certainly there are effects present such as wire-to-wire capacitance, wire-to-sea capacitance, inductance, etc. A limited test was made on the breadboard system to investigate what is probably the parameter with the greatest effect on conversion time, i.e., the wire-to-wire capacitance. This effect was investigated by shunting the simulated probe with a variable capacitance and determining the minimum conversion time in each case. The worst case occured when maximum probe resistance (18K ohm) was present, and here it was found that capacitances in excess of 0.5 microfarads produced conversion times greater than 0.1 seconds which seem intolerable for this application. At minimum probe resistance (3K ohms) capacitances in excess of 1 microfarad (the highest value used in this test) caused only slight increases in conversion time over the minimum described above.

1.4.2 Linearization Circuits

Performance of the linearization circuit is best illustrated by the record presented in Figure 5. Here the same equivalent resistance values used in the A/D converter test (Table 1) were used as input to the system, and the output was recorded on film. It is obvious that equal temperature increments at the input to the system produce equally spaced lines on the analog output record. (Note: Gaps in the plot were caused by broken fibers in the record head and not by malfunction of the linearization circuits.)

1.4.3 Recording Head, Film and Developing Process

Although the recording head, film and developing chamber are separate entities, the final result represents a combination of the three in which the separate functions are difficult to isolate. In general, the recording head performed as expected in that sufficient light was coupled to the film surface with the particular lamps used. The lamps produced a mean spherical candle power (MSCP) of 0.15, when operated at their rated 12 volts. It was found that sufficient light was produced at an operating voltage of 10.8 volts which is equivalent to a MSCP of about 0.10. Thus, no problems are anticipated in obtaining sufficient illumination of the film for the exposure time used in this test (0.5 sec.).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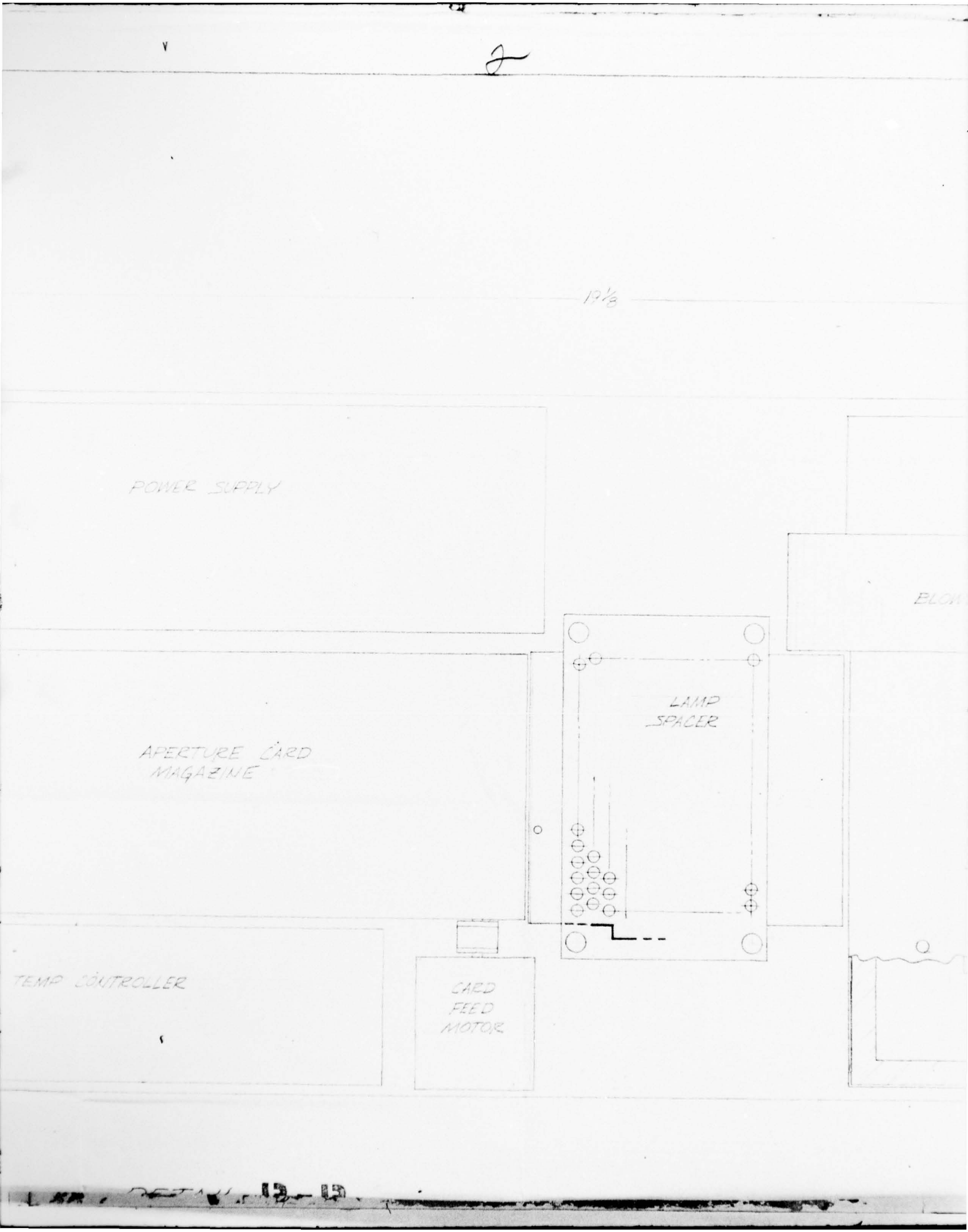
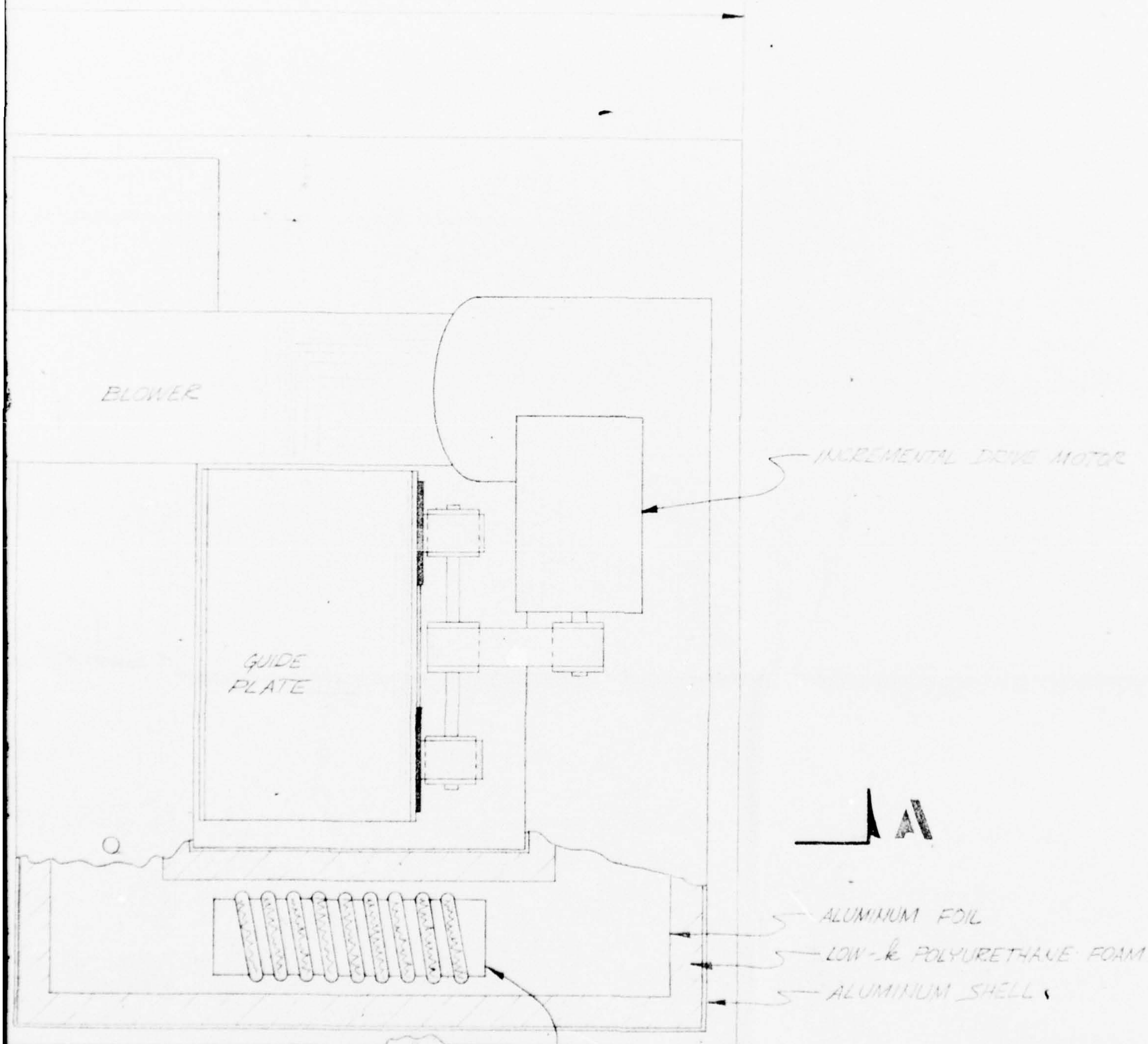
A
PO
A
TEMP CONTRO


2
13 1/8
POWER SUPPLY
BLOW
LAMP SPACER
APERTURE CARD MAGAZINE
TEMP CONTROLLER
CARD FEED MOTOR
DETAIL B-B

3


BLOWER
INCREMENTAL DRIVE MOTOR
GUIDE PLATE
A
ALUMINUM FOIL
LOW-k POLYURETHANE FOAM
ALUMINUM SHELL
HEATING ELEMENT
APERTURE CARD

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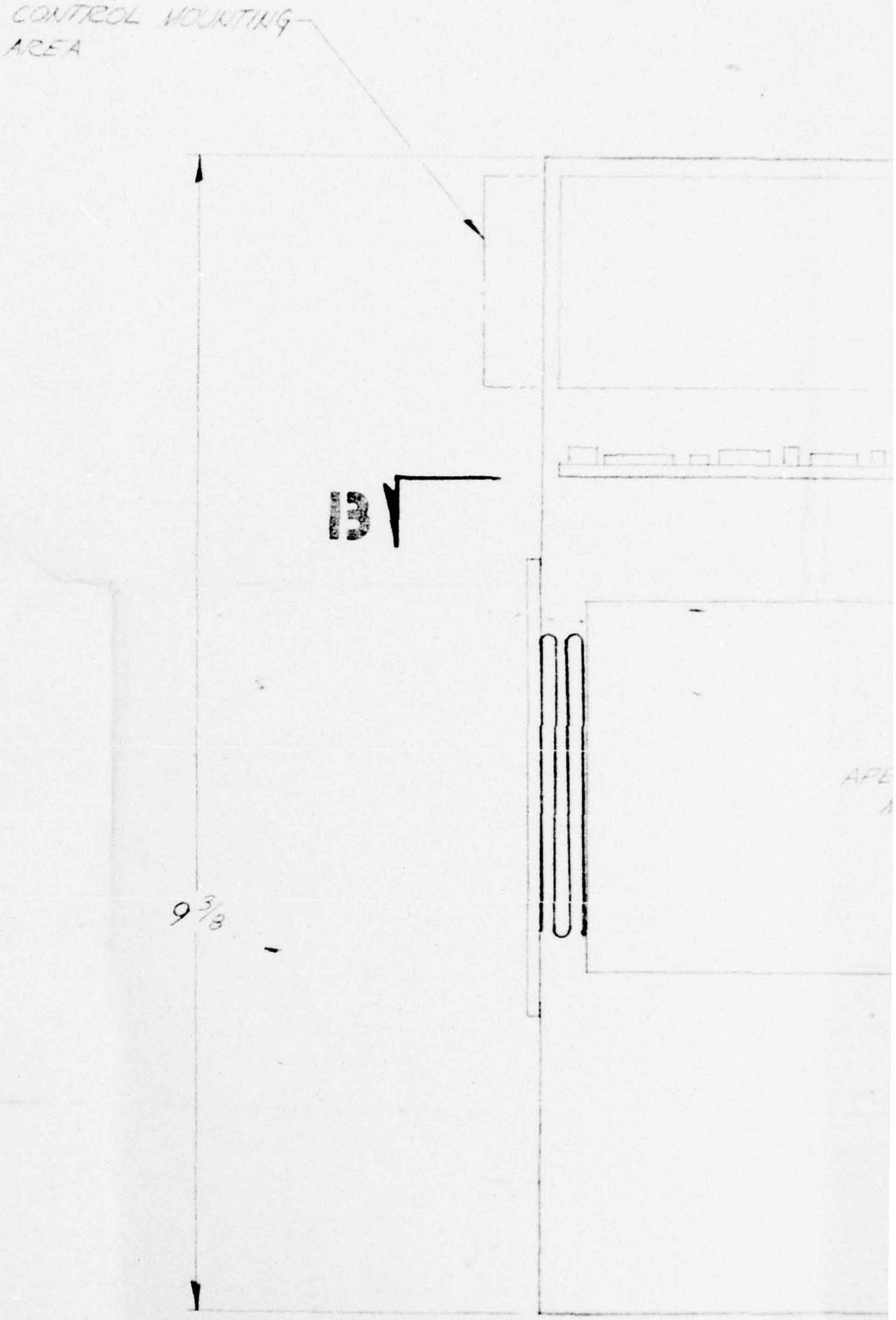
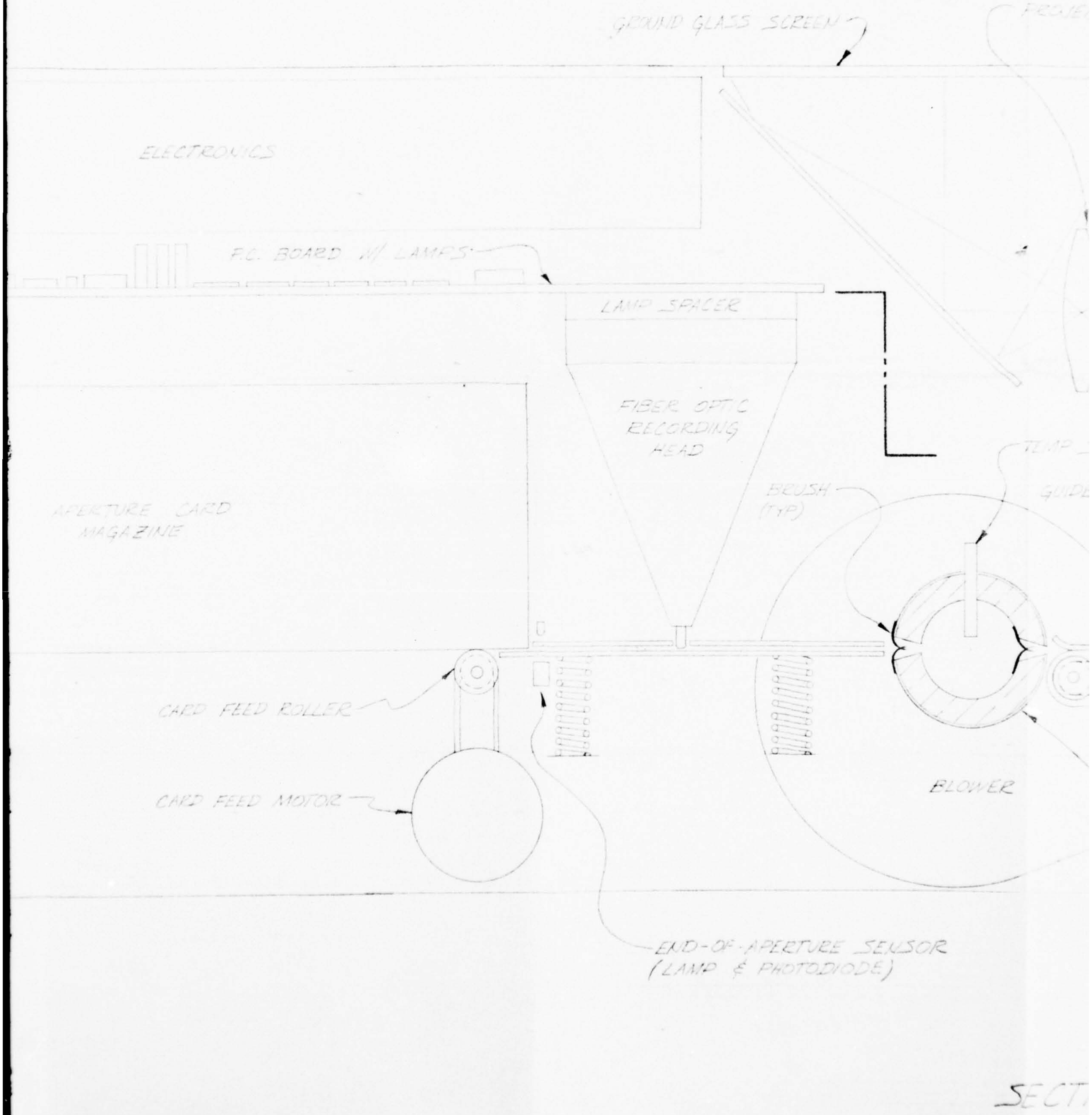
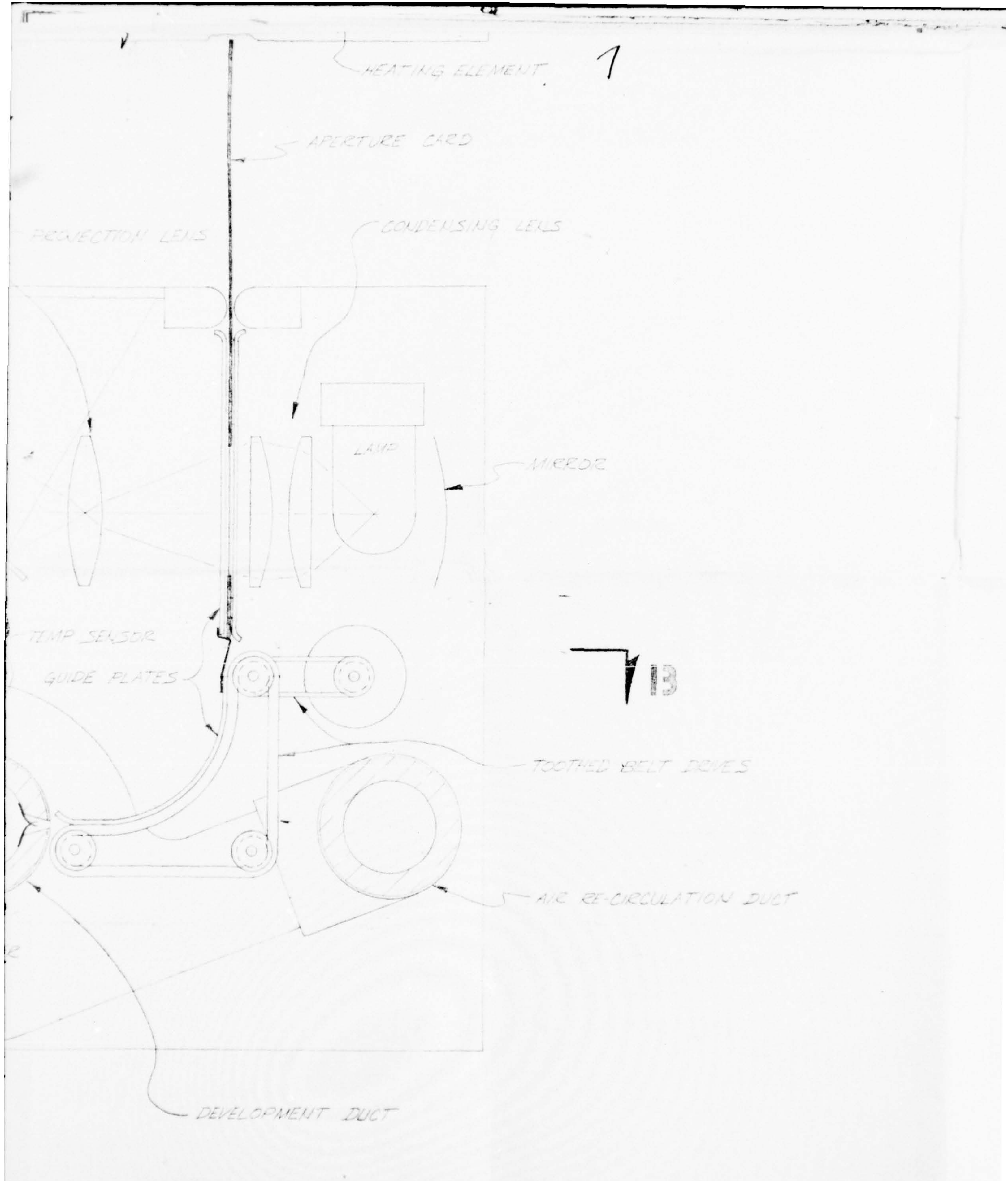


6

DETAIL B-B


GROUND GLASS SCREEN
PROJE
ELECTRONICS
P.C. BOARD W/ LAMPS
LAMP SPACER
FIBER OPTIC RECORDING HEAD
TEMP
GUIDE
BRUSH (TYP)
APERTURE CARD MAGAZINE
CARD FEED ROLLER
CARD FEED MOTOR
BLOWER
END-OF-APERTURE SENSOR (LAMP & PHOTODIODE)
SECT


1
HEATING ELEMENT
APERTURE CARD
PROJECTION LENS
CONDENSING LENS
LAMP
MIRROR
TEMP SENSOR
GUIDE PLATES
B
TOOTHED BELT DRIVES
AIR RE-CIRCULATION DUCT
R
DEVELOPMENT DUCT

SECTION A-A

8

	REV
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INTERSTATE ELECTRONICS CORPORATION
OCEANICS DIVISION


CONTROL MOUNTING AREA
B
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9 3/8
AREA
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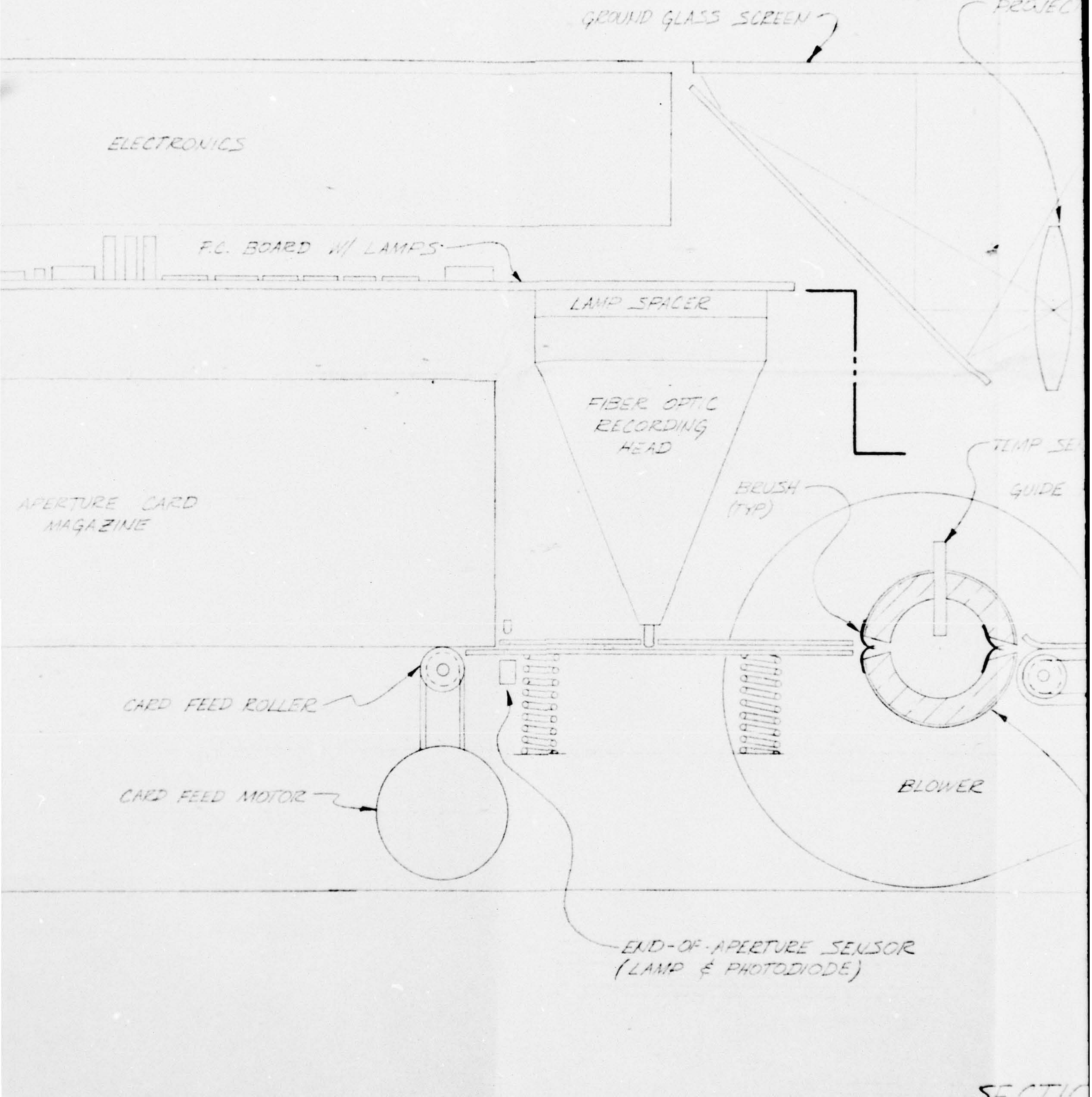
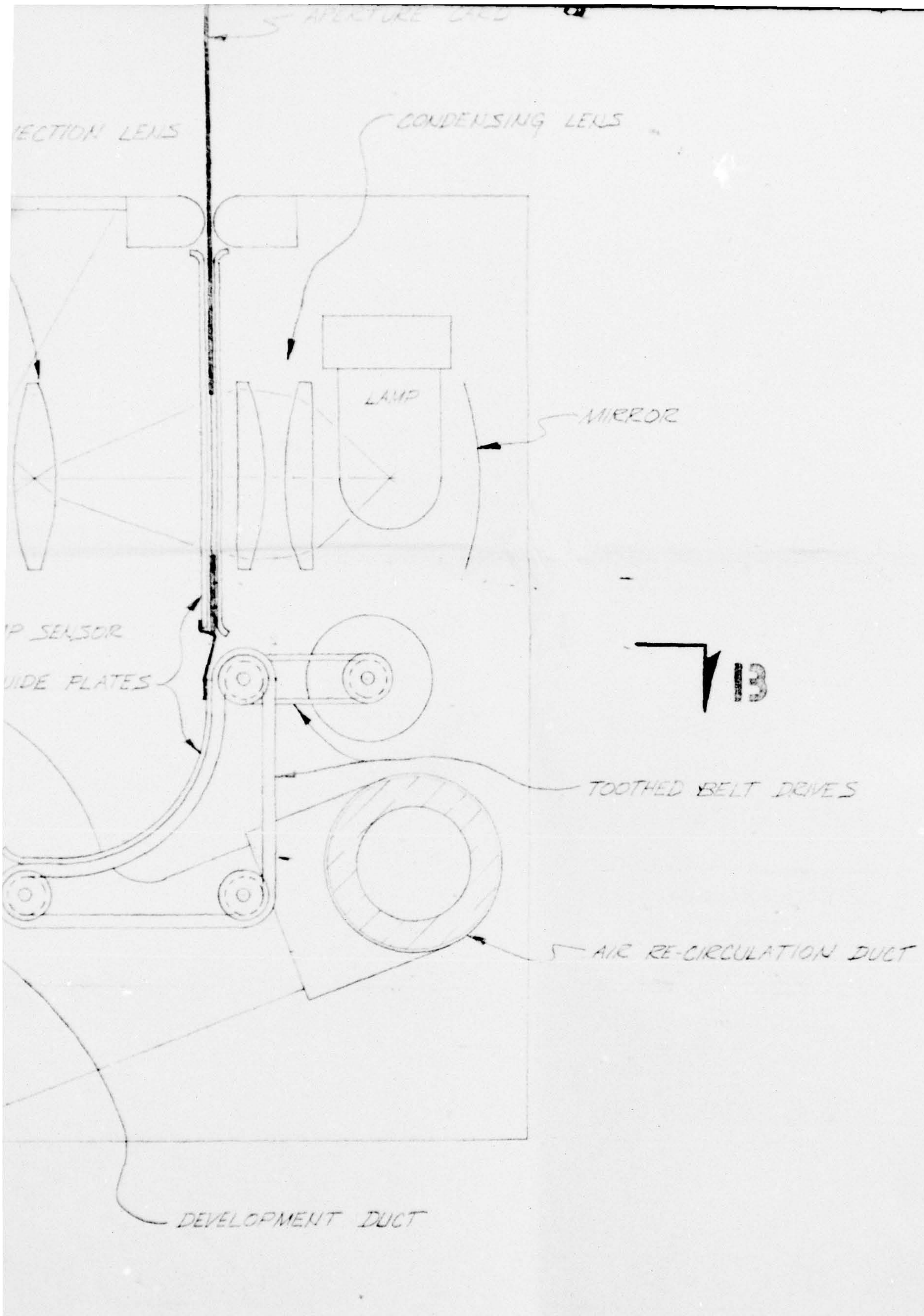
DETAIL B-B



SECTIO

3 10


APERTURE CARD
ECTION LENS
CONDENSING LENS
LAMP
MIRROR
P SENSOR
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TOOTHED BELT DRIVES
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DEVELOPMENT DUCT

CTION A-A

B

9992-8	REV A

A

DRAWN: PEPPER	DATE 29AUG67	TITLE PRELIMINARY LAY-OUT, FIBER OPTIC B.T. RECORDER.			INTERSTATE ELECTRONICS CORPORATION OCEANICS DIVISION
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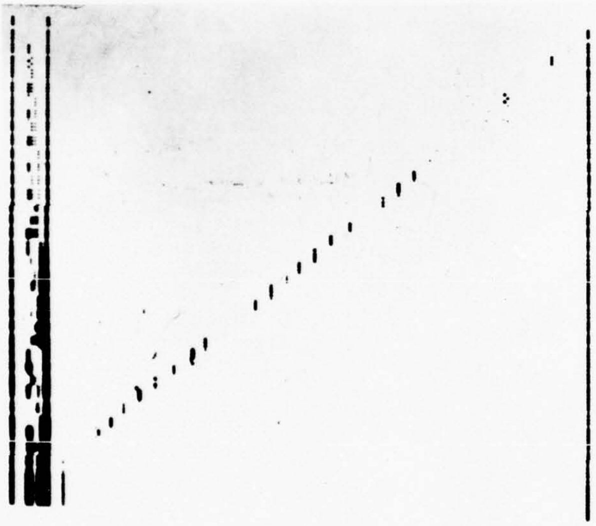

Figure 5. Linearity Check, 2°F Increments. Developed at 260°F for 10 Seconds (Enlarged Photo)

Resolution of the head and film is excellent as may be observed in Figure 6. The actual spot diameter is 1 mil, and individual points are readily observed on the records.

The film used in these tests is a high-contrast type which has proved to be vastly superior to the variable contrast film used in Phase I. Optimum development conditions for this film were found to be 250 to 260°F for approximately 8 to 10 seconds. This film provides a very good contrast ratio, and no background fogging or build-up was noted on any of the records as was the case with variable contrast film. In fact, a background problem has developed with the variable contrast film samples taken in Phase I, i.e., considerable fogging has been noted on these records which were processed about 3 or 4 months ago. However, no similar fogging has been noted with high contrast samples which were processed at about the same time.

An investigation of film sensitivity to high storage temperatures has shown that temperatures in excess of 180°F will cause background build-up. Other storage conditions such as exposure to ambient light, handling (fingerprinting, etc.) seem to have no detrimental effects.

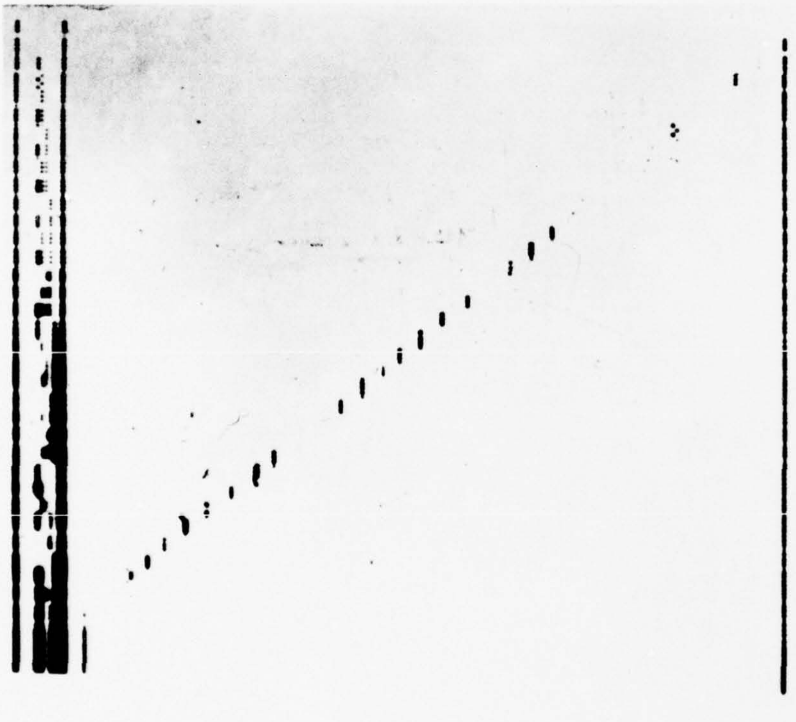

Figure 5. Linearity Check, 2°F Increments. Developed at 260°F for 10 Seconds (Enlarged Photo)

Resolution of the head and film is excellent as may be observed in Figure 6. The actual spot diameter is [illegible] mils, and individual points are readily observed on the records.

The film used in these tests is a high-contrast type which has proved to be vastly superior to the variable contrast film used in Phase I. Optimum development conditions for this film were found to be 250 to 260°F for approximately 8 to 10 seconds. This film provides a very good contrast ratio, and no background fogging or build-up was noted on any of the records as was the case with variable contrast film. In fact, a background problem has developed with the variable contrast film samples taken in Phase I, i.e., considerable fogging has been noted on these records which were processed about 3 or 4 months ago. However, no similar fogging has been noted with high contrast samples which were processed at about the same time.

An investigation of film sensitivity to high storage temperatures has shown that temperatures in excess of 180°F will cause background build-up. Other storage conditions such as exposure to ambient light, handling (fingerprinting, etc.) seem to have no detrimental effects.

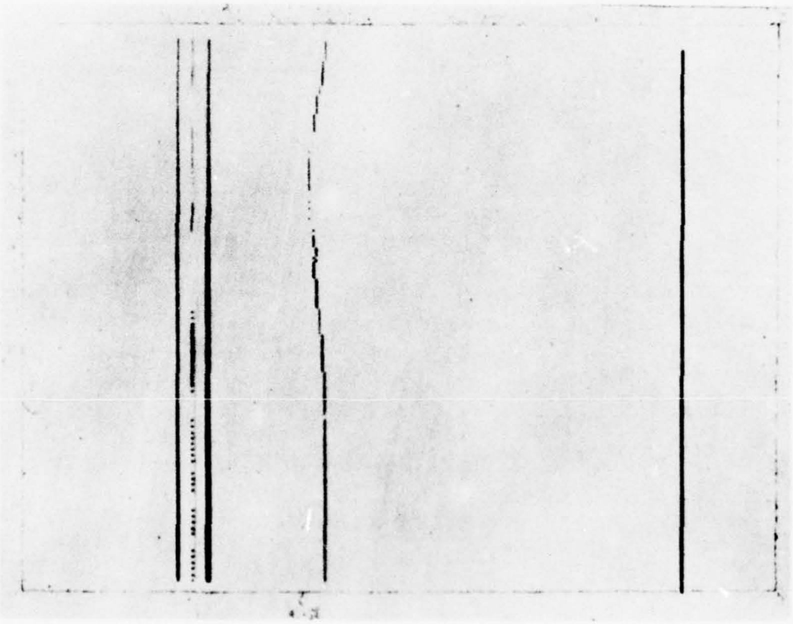

Figure 6. Simulated BT Trace. Developed at 259°F for 10 Seconds (Enlarged Photo)

PART II - OPERATIONAL, PRODUCTION & COST ASPECTS

2.1 Purpose

As part of this study, consideration has been given to the problems of producing fiber optic plotter units in quantity. Thus, this section of the report presents a preliminary system design and discusses the operational and production aspects of a plotter system based on this design. Cost aspects are presented in Volume 2 of the report. The section is concluded with a discussion of additional capabilities of the system.

2.2 System Specifications

The following tentative technical specifications are based upon our experience with the breadboard model and upon our presently available knowledge of the XBT probe interface; in general, the specifications are conservative, and improvement can be expected in a final design:

1. Temperature Range: 28° to 96°F.

2. Temperature Resolution:

   Digital: ± 0.1°F (raw data).

   Analog: ± 0.4°F (linearized; See Section 1.2)

3. Depth Resolution: to ± 6 ft. (for 1500 ft. range).

Depth range and resolution for various ranges are:

to 1500 ft. with 6 ft. resolution.

to 3000 ft. with 12 ft. resolution.

to 4500 ft. with 18 ft. resolution.

to 6000 ft. with 24 ft. resolution.

4. Sampling Time: Less than 0.1 seconds.

5. Sampling Rate: Dependent on depth range and resolution; max.rate is approximately 2 to 4 samples per second.

6. Gradient Error: Less than ± 0.1°F/ft. for a maximum gradient of 5°F/100 ft.

7. Gradient Resolution (at 10 ft. depth resolution): *

Digital: ± 0.01°F/ft.

Analog: ± 0.04°F/ft.

8. Digital Data Presentation: up to 10 binary or 12 BCD bits.

9. Spot Diameter: Less than 0.007 inches.

10. Recording Medium: Film mounted in aperture cards per MIL-C-9877B.

11. Film Format: A tentative layout is presented in Figure 7.

12. Film Processing: Type - Dry Process.

Time - Less than 10 seconds

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*NOTE: Based on ratio of temperature resolution and depth resolution - average over 100-ft. depth.

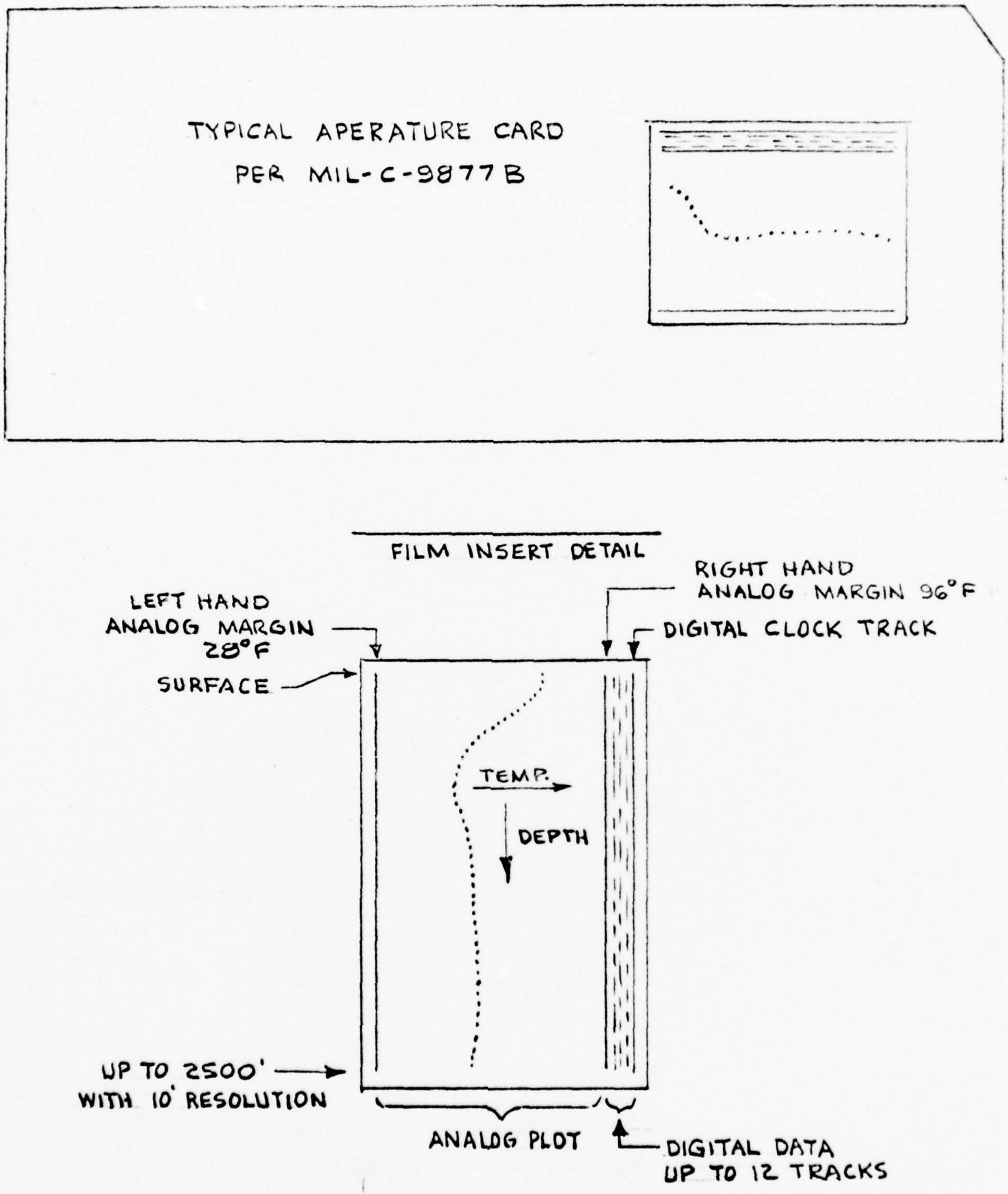

FIGURE 7
APERTURE CARD
LAYOUT

AL MALONE 9992-8

13. Size: Not to exceed 10" x 10" x 20".

14. Weight: Not to exceed 40 lbs.

15. Power Requirements: 115 VAC, single phase, 60 cps, at no more than 15 amps for a period of 100 seconds per 1500 ft. depth range.

2.2.2 Mechanical Layout

A first cut at a mechanical layout of the system is presented in the enclosed Drawing No. 9992-8. There are two outstanding features of this layout which differ considerably from the breadboard system, i.e., the aperture cards are provided in a magazine which holds up to 500 cards, and a projection mechanism has been included to provide an enlarged view of the bathythermograms once they are completed. Other features of this layout are very similar to the breadboard system.

The unit as conceived here is reasonably simple, assuring maximum maintenance with reliable performance. The aperture card is held captive at all times, yielding jam-resistant handling and capability of operation in severe vibration environments. Loading, unloading and card viewing are performed entirely from the top and front of the unit.

The mechanical system is primarily a card transport mechanism. The aperture card magazine is loaded into the front of the machine, and the card feed roller pulls one card at a time out of the magazine. The card is run aperture-last through the guide plates, the development duct and into the incremental drive mechanism. At this point the card feed roller stops and all further movement of the card is under control of the incremental drive. Positioning of the card relative to the record head is accomplished with a sensing device which detects the end of the aperture. The film is then positioned for exposure.

While recording,the incremental drive advances the card at a rate of about two steps per second for approximately 250 steps. The film is processed by drawing the card through the development duct at a high rate of speed until the card protrudes from the top of the machine. When the feed mode is actuated to start the machine, the development duct blower and heater are turned on to begin warm up. This will allow a minimum of 90 seconds for the duct to arrive at the proper temperature. The ducting is of low mass, low thermal conductivity design to permit fast warm up and to limit the amount of heat transferred to other components in the system. The finished bathythermogram may be viewed by pulling the card up about one inch then pushing it down against the stop. When the projection lamp is turned on the record is observed at about three times normal size on the ground glass screen. Note that previously recorded aperture cards may be projected by simply inserting them into the slot on top of the machine.

It is anticipated that the lamps and all electronic circuitry (except that associated with the power supply and pen motor [illegible] controller) can be mounted on a single, possibly multilayer, printed circuit board. Interconnections are thereby reduced to an absolute minimum, as only power, signal and a few control lines will be required to interface with the circuit board. This feature should enhance reliability and considerably ease manufacturing problems under a production setup.

2.2.3 Electronics

2.2.3.1 Control Circuits

Certain circuits will be required to control the operational sequence of the system. No particular problems are anticipated here, as the system requires only very simple control and interlock functions for applying power and operating motors and indicators. Standard relay or preferably solid state circuits may be used for these purposes.

2.2.3.2 Bridge Circuit and A/D Converter

A bridge circuit very similar to that outlined in Paragraph 1.3.1 would be utilized. Constant current exitation is highly desirable, as this will maintain bridge sensitivity at the comparitor input through any changes in the sea water return path. A "splash" detection circuit is required in series with the bridge exitation line to detect contact of the BT probe with the water and initiate the recording process. A lack of complete information regarding the probe and its performance during a drop (requested several times from the manufacturer) precludes any further detail regarding the bridge circuitry. However, it is anticipated that the bridge will have to be compensated for dynamic effects of the probe such as interwire capacitance, wire-to-sea capacitance, inductance, etc. None of these effects are considered to be major problems, as they can be compensated for in the bridge circuit. The main effect will be to reduce the maximum A/D conversion rate due to increased settling time at the comparitor input. Maintaining bridge stability and accuracy should also be relatively easy because most critical components are passive, such as precision resistors with low-temperature coefficients.

The main active component is the comparitor which should exhibit minimum drift when properly temperature compensated, since the input is differential and isolated from the rest of the system. With a bridge exitation on the order of one milliamp the comparitor threshold will have to be approximately ± 1 millivolt which is well within the state-of-the-art.

Several methods exist for controlling the digital resistor in the bridge. Two general methods are available, one uses counting techniques and the other uses some form of successive approximation. Variations on these general methods are covered extensively in the literature(2) and will not be discussed here. Without detailed knowledge of the probe/bridge characteristics it is somewhat difficult to establish design criteria for the digitizer. However, certain outside limits may be established and used as guides in the design. For instance, a limit on digitizer sample time may be estimated and used to help establish the optimum form of digitizer logic. If the following

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(2) For instance, see: F. D. Daley, Jr., "Analog-to-Digital Conversion Techniques," Electro-Technology, May 1967, pp. 34 - 39.

assumptions are made:

Maximum Temperature Gradient: $5^{\circ}/100$ ft.

Maximum allowable gradient error: $\pm 0.1^{\circ}F$.

BT drop rate: 20 ft/sec.

Then maximum sample time of the digitizer is:

$$\frac{0.1\ F^{\circ}}{5^{\circ}F/100\ \text{ft.} \times 20\ \text{ft./sec.}} = 0.1\ \text{sec.}$$

Appendix A presents an analysis of three common digitization methods with respect to their effect on settling time at the comparitor input assuming a maximum sample time of 0.1 sec. Results of this analysis are summarized below:

Type of Digitizer	Max. Settling Time
Counter	0.1 msec.
Tracking Counter	5.5 msec.
Successive Approximation	9.1 msec.

For the conditions assumed above, a successive approximation digitizer places the least stringent requirements on the system because it permits maximum settling time at the comparitor.

Although this type of digitizer requires more circuitry than the counting methods, it is not unduly complicated. In many respects it is simpler to maintain and troubleshoot because the successive approximation method follows a consistent timing sequence for each conversion; whereas the timing sequence in counting types varies depending on the accumulated count.

For these reasons the successive approximation digitizer is recommended.

2.2.3.3 Linearization Circuits

As discussed in Paragraph 1.3.2 two methods of linearization have been considered:

Parallel Method

The parallel method is illustrated in Figure 8, and for an analog plot with 170 possible points, 170 "And" gates are required. The gate inputs are driven by buffered outputs from the A/D converter. Decoding is set up such that each gate selects the A/D output states corresponding to a particular temperature increment (in this case 0.4°F increments).

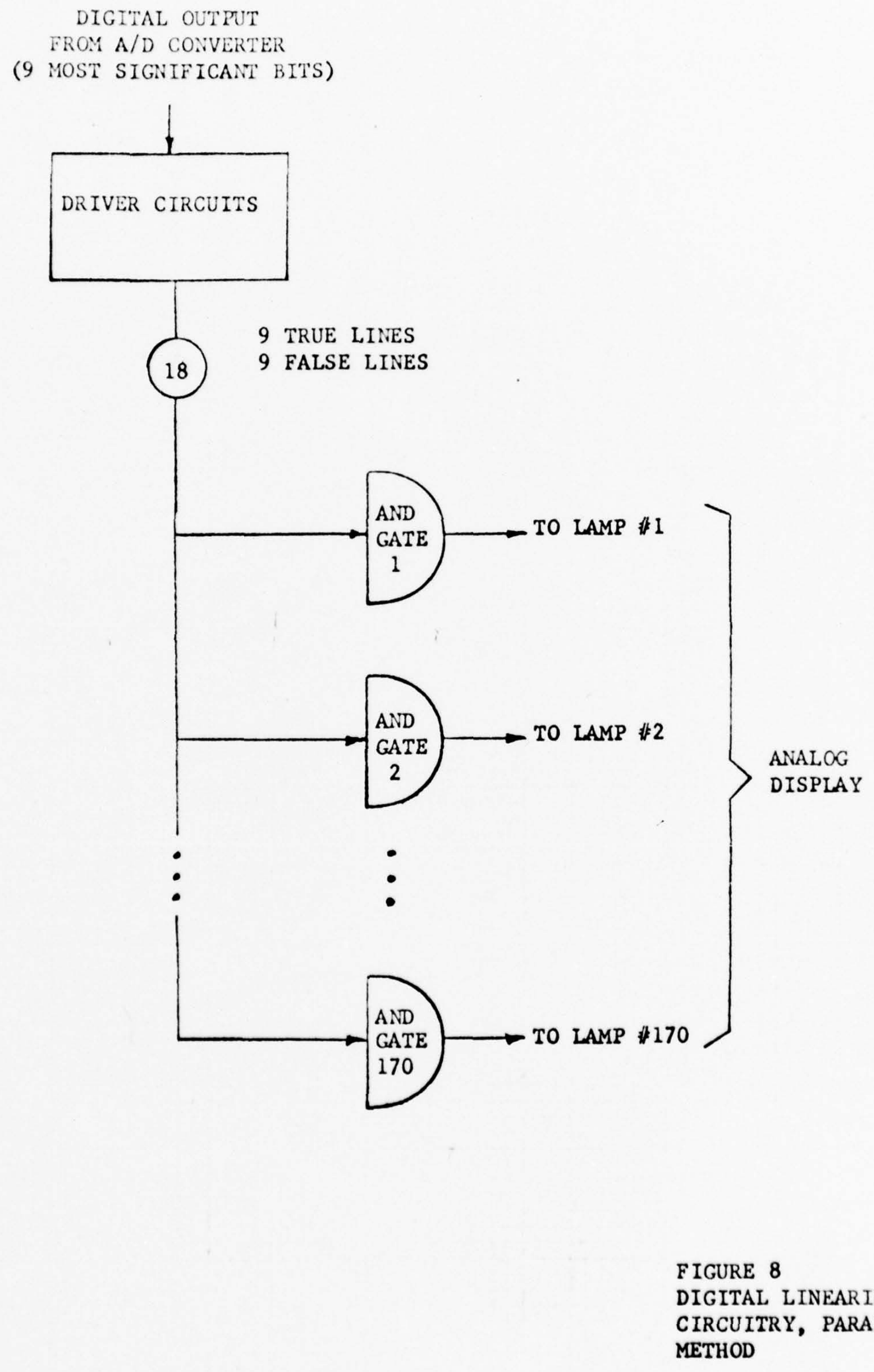

FIGURE 8
DIGITAL LINEARIZING
CIRCUITRY, PARALLEL
METHOD

With proper selection of circuitry, the total number of parts required with the parallel method may be minimized. For instance, integrated circuit "and" gates are currently available which contain an output stage capable of driving small incandescant lamps directly; thereby eliminating the requirement for individual lamp driver circuits. A parts count for the parallel method yields:

	Quantity	Part Type
Decoding:	170	Integrated Circuit Gates
Drivers:	18	Transistor, medium power
	54	Resistors
	242	Total parts count

Serial Method

A detailed explanation of the serial method has been presented in para. 1.3.2 excluding any discussion of the required decoding and lamp driver circuits. Although the decoding is less complicated than that in the parallel method, it still requires approximately the same number of gate circuits (or its equivalent in a diode decoding matrix and lamp driver circuits). Thus, no parts savings can be anticipated with respect to the parallel method.

Comparison of Parallel and Serial Methods

In addition to an increase in the number of parts required, the serial method has other features which are less desirable than the parallel approach. High speed circuits are required in order to perform the linearization in a reasonable length of time, and reliability is considerably reduced because the failure of a single circuit in the serial linearization process can cause total failure. Furthermore, troubleshooting is difficult causing an increase in mean time to repair a failure. On the other hand, a single gate failure in the parallel system is not catastrophic, and location and repair of the failure is relatively simple because each circuit is associated with an individual lamp. The only failure which can be considered catastrophic is that of one of the driver circuits, and location and repair of the failure is still relatively simple. For the reasons stated above, the parallel method is recommended for use in the final system design.

2.2.4 Film Developing Mechanism

The developing mechanism consists of four basic parts, i.e., the development duct, the blower, a heating element and a temperature controller. Based on tests with the breadboard system basic requirements for this mechanism are to maintain a flow of hot air over the film surface at approximately 30 cfm and 260°F. With the breadboard system an open end method was used where ambient air was heated to the required temperature, passed over the film surface and then exhausted. This method required a large heating element (on the order of 1000 watts) and a temperature controller capable of handling such power. If a recirculating system were used, the total power required would be significantly reduced, and there would be less dependence on ambient air temperature which would further reduce the maximum power requirements. Since there will undoubtedly be some air losses, a completely closed system is impossible. Thus, a recirculating system is recommended with partial intake of ambient air. The ratio of recirculated vs. outside air can only be optimized through detailed analysis and experimentation and is beyond the scope of this study.

An estimate has been made of the maximum power required to heat the ducting up to temperature in a reasonable amount of time and to maintain temperature after this time. To reduce convective heat losses an insulated developing duct has been assumed of the form illustrated in Figure 9. A thin, polished metal interior is used to reduce stored heat and provide minimum radiation losses. To allow for handling and fastening a metal exterior of reasonable

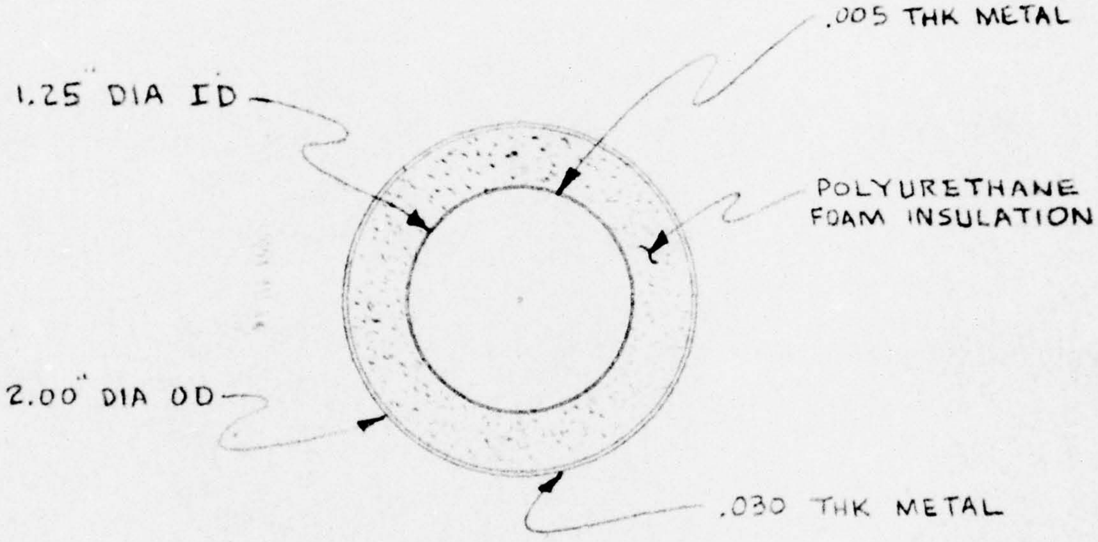

FIGURE 9

AIR DUCT CROSS SECTION

is used.

Two conditions are of importance: (1) Steady state heat losses, and (2) warm-up heat required. Both conditions will be maximized when the ambient temperature is the lowest required of the system. In this case, 32°F is assumed as the lowest ambient operating temperature. The duct operating temperature is about 260°F. From this data the steady state convective heat loss is calculated as 3.01 BTU/min (or about 50 watts). With the duct construction as shown either all aluminum, aluminum-steel or all steel can be used. The critical heat transfer diameter for a duct of this cross section is calculated to be 0.824 inches. Maximum heat transfer would occur at this diameter, and this is avoided with the two inch diameter shown in Figure 9.

During warm-up heat will be lost in three places: (1) heating the air, (2) heating the duct and blower assembly, and (3) convective losses as the outside of the duct warms up. Item (1) is negligible. By assuming the entire duct heats up to 260°F and taking one half of this value, a conservative estimate of the heat stored in item (2) is obtained. Similarly, assuming only one half of the steady state losses will occur during the warm-up period, a conservative value for item (3) may be established. If a 75 second warm-up period is assumed, the heat input required to bring the ducting up to temperature is 12.48 BTU/min. This will require a heating element rated at about 220 watts. Once up to temperature, the blower motor heat input alone may be sufficient to maintain temperature.

2.2.5 Projection Mechanism

The projection system is comparable to any standard slide projector mechanism. Of particular interest in this case is the power required by the projection lamp, as this affects the size of the lamp and the amount of heat to be dissipated. An estimate of the required lamp power is presented below:

Assumptions:

1. Screen Area: 3" x 5" or about 0.1 ft^2
2. Rear Projection Screen Gain: 2.5
3. Reflectivity of front of screen: 0.2
4. Ambient light on screen: 100 ft-cd
5. Desired Contrast Ratio: 20.1
6. Efficiency of lens, film and mirror system: 30%

Calculations:

1. Amount of ambient light reflected off front of screen = Reflectivity x Ambient or 0.2 x 100 = 20 ft-cd.

2. Required Rear illuminance =

$$\frac{\text{contrast ratio} \times \text{Reflected Ambient}}{\text{screen gain}}$$

or $\frac{20 \times 20}{2.5} = 160$ ft-cd

3. Required lumens at rear of screen = illuminance x area

or 160 x 0.1 = 16 lumens

4. Lumens required at lamp = Lumens at screen/efficiency

or $\frac{16}{.3}$ = 53 lumens

Since incandescant lamps typically produce 10 to 20 lumens/watt, about a 5 watt lamp would suffice.

The above estimate is rough, but it does indicate that the projection lamp requirement is very nominal and should not present any problems in power consumption or heat dissipation.

2.3 Operational Aspects

2.3.1 Operation Sequence

Figure 10 is a flow diagram illustrating the sequence of operations performed by the operator and the system to produce one record. Operator intervention is required in only two places, and once power is applied three basic sequences are involved: (1) Load the BT in the launcher and press the load switch on the plotter. This operation prepares the system for launch. (2) Launch the BT and record data. (3) Process the film.

The flow diagram also illustrates the interlocks which must be complete before each of the sequences are permitted to begin. At the end of the processing cycle the system is returned to its initial state and is ready for another BT drop.

2.3.2 Reliability

The reliability estimate presented in Appendix B yields and MTBF figure of 421 hours. This seems to be rather low for a "nearly all solid state" device, but, as will be seen from the discussion to follow, this figure represents an extremely conservative estimate. A more realistic figure has been estimated at 1,358 hours.

First, however, consideration is given to this worst

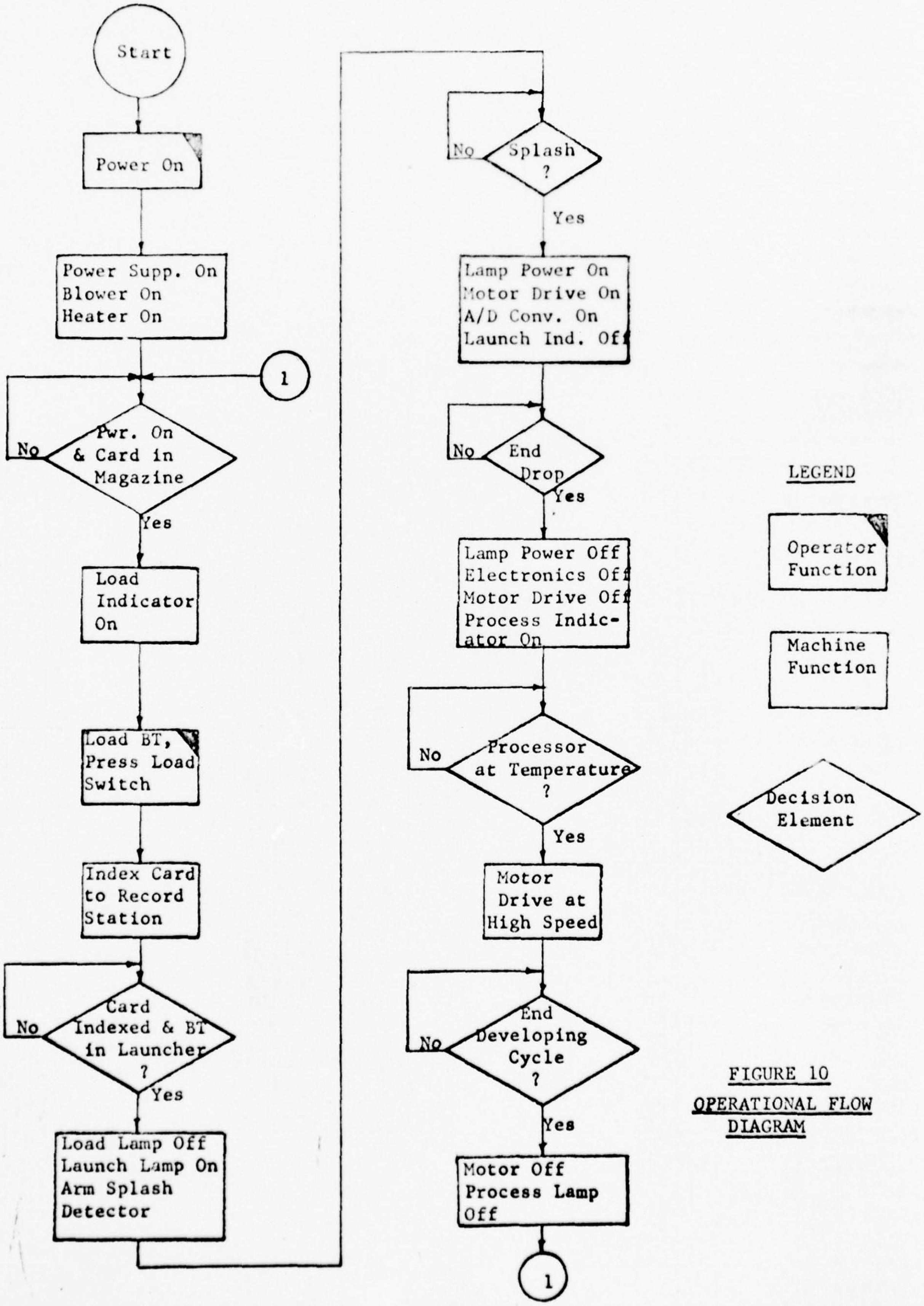

FIGURE 10

OPERATIONAL FLOW DIAGRAM

case estimate in relation to actual anticipated use of the equipment and in terms of its meaning to fleet personnel. If it is assumed that the average use of the system will mount to, say, 75 BT drops per month per ship, then the actual calendar time between failures may be estimated as follows:

Assuming average system operate time per drop is 3 minutes (0.05 hrs.),

$$\frac{421 \text{ hours between failures}}{0.05 \text{ hrs/drop} \times 75 \text{ drops/mo.}} = 112 \text{ months!}$$

Of course, this figure is very optimistic because a certain rate of component deterioration exists whether the system is operating or not, but it is indicative of what can be expected in terms of actual system use. A more realistic MTBF estimate results if consideration is given to the particular system design as it affects reliability. From Appendix B one observes that the incandescant lamps used in the record head assembly are by far the greatest contributors to the total failure rate. This is due to the large number of lamps involved. The majority (170) of these lamps are used in the analog plot where failure of a single bulb (or several bulbs if they are not adjacent to one another) would not be considered catastrophic, as the data may be easily interpolated over that point(s). Thus, usefulness of the record under such a failure condition is not impaired.

If random failure of up to 5% of the total number of analog lamps (about 8 lamps) is considered non-catastrophic, then the effective number of lamps for reliability estimation becomes:

$$\frac{170}{8} \text{ analog} + 10 \text{ digital} + 3 \text{ marker} = 34 \text{ lamps.}$$

Furthermore, operation of the analog display is such that only one bulb at a time is turned on. The digital lamps have a nominal duty cycle of 50%, and, if this duty cycle is assumed for all of the lamps except the three markers, then the effective number of lamps is further reduced to 19. Using this number to estimate reliability yields an MTBF of 1,358 hours.

Although these arguments cannot be considered rigorous, their development is also not overly optimistic. Thus, it is certainly reasonable to expect an actual MTBF figure that is well in excess of that developed in the Appendix.

2.3.3 Environmental Considerations

In our opinion, there is nothing inherent to the system which would negate compliance with the environmental requirements of MIL-E-16400F, Class 4. The extensive use of solid state devices in the equipment assures high reliability and eases the design/fabrication task related to meeting the environmental specifications.

2.4 Production Aspects

2.4.1 General Discussion

The production of fiber optic plotter systems as conceived and described in the report will be a relatively simple task for an organization which is well acquainted with and equipped for fabrication of military electronic equipment.

The plotter system consists mainly of standard parts common to commercial and military electronic and data processing equipment, and no unique or special fabrication, assembly or quality assurance procedures are required for production. The only element in the system which represents a new and somewhat delicate production problem is the fiber optic recording head. Based on our experience in the fabrication of two different head assemblies for the breadboard system, this problem can be greatly simplified with a few properly designed tools and fixtures which would permit the head to be assembled and cast in epoxy without the extensive handling required by the multi-step manual process used in our first efforts.

Thus, no severe production problems are anticipated. Furthermore, there are many aspects of the design which tend to simplify production as compared with similar equipment. Some of these features are discussed in the following paragraph.

2.4.2 Design Features Which Simplify Production

Certain features of the design contribute to the reduction of production problems and result in less expensive and more reliable equipment. As an example, the system is easily broken down into six major sub-assemblies:

(1) Printed Circuit Board/Optics Assy.
(2) Blower and Duct Assembly.
(3) Card Transport Assembly.
(4) Viewer Assembly.
(5) Temperature Controller.
(6) Power Supply.

Each of these sub-assemblies may be fabricated and tested on an *individual* basis prior to installation in the main chassis. This will greatly facilitate production, as these several operations may be performed simultaneously rather than having to complete one assembly before work can begin on another.

An outstanding feature of the design is the single printed circuit board which houses nearly all of the electronics. By using only one board the production process is greatly simplified because "back panel" wiring is eliminated, and fabrication is reduced to stuffing components on the board and dip soldering. Reliability is also enhanced, as the many connectors and wiring harnesses associated with a multi-board system are not required.

It is also planned that the card transport mechanism will be self-contained, i.e., it will be mounted on its own sub chassis and will not be dependent on main chassis mounts for dimensional stability. This scheme may cause some slight increase in parts cost, but it will facilitate construction, alignment and test during production. It also eases the requirements on dimensional tolerances in the main chassis. This is a definite advantage, as the main chassis is perhaps the most difficult mechanical part in which to hold tight tolerances. These same features are also important with regard to maintenance and repair of the equipment once it reaches the field because this modular construction simplifies the location and repair of faults.

2.5 Additional Capabilities

One outstanding feature of the plotter system is its capability of providing outputs to other mediums in addition to the aperture cards, i.e., telemetry links, magnetic or paper tape recorders, direct computer input, etc.

Of particular interest here is the possibility of recording BT data on punched paper tape in a form compatible with requirements layed down by the Fleet Numerical Weather Facility. These records could be prepared on standard 5 or 8 level teletype tape suitable for transmission over existing Navy communication circuits.

A relatively small amount of additional digital circuitry would be required to interface with a standard paper tape punch. In this case, however, it would be most advantageous to have the A/D converter provide a BCD (binary coded decimal) output rather than the natural binary type previously discussed, as it would be directly compatible with the teletype code. Temperature would then be recorded as three digits representing tens, units and tenths of a degree. This would add some complexity to the A/D converter, but it would not be excessive. The interface circuitry would then consist simply of a digital multiplexer capable of sequentially scanning three BCD characters onto a common output buss for presentation to the tape punch mechanism. This could be accomplished with as few as 10 integrated circuit chips assuming the tape punch contains its own solenoid driver circuits.

As envisioned here, the tape would be punched while the BT drop is taking place. Each time the A/D converter makes a conversion the interface unit would scan three characters out to the punch. Timing is no problem because about 0.4 sec. is available between conversions, and even the slowest paper tape punches (about 20 char./sec.) can record up to eight characters in this time. This same scheme could be applied to any other device capable of receiving or recording digital data.

In our opinion there is no question as to the technical feasibility of this added capability.

Up to this point in the study no consideration has been given to the problem of transcribing the filmed digital data records onto more useful media such as magnetic tape for computer entry. To fully utilize the aperture card concept, some type of film "reader" equipment will be required at the central depository for BT slides.

One very obvious method of reading the aperture card consists of simply reversing the recording process, i.e., use a fiber optic head, a common light source behind the film and individual photo cell sensors to read out the digital data on film. However, this method would require extremely close mechanical tolerances between a common card reader and several hundred recorders scattered all over the world in order to maintain the required registration, and the problems of maintenance, calibration and stability would be overwhelming.

A more ideal method would involve an adaptive reader wherein variations in registration could be easily accommodated. Such equipment does exist in the form of flying spot scanners which are currently used in applications similar to this one. These systems are adaptive, have a resolving power in excess of that required here(3), and are capable of producing computer compatible outputs.

Thus, the flying spot scanner would seem to be an ideal reading mechanism for BT aperture cards. It is recommended that consideration be given to this method in future plans for aperture card plotter systems.

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(3) Brown, C.J., "Resolution of Flying Spot Scanner Systems," IEEE Spectrum, August 1967.

PART IV - SUMMARY

3.1 Conclusions

Phase I of this study established technical feasibility of the fiber optic recording technique and demonstrated the use of a completely new dry process film. Phase II has expanded upon this previous work to demonstrate the technical feasibility of digitizing expendable BT data and linearizing this data in the digital domain for presentation in an analog plot. Furthermore, economic feasibility of the proposed fiber optic plotter system has been established through a preliminary design and cost estimate which indicate that these units can be produced for the Navy at reasonable cost as shown in Volume II of the report.

The plotter system will produce bathythermograms on standard aperture cards with both analog and digital presentations of the data. The system is relatively simple and, therefore, reliable due to the extensive use of digital integrated circuits, a conservative mechanical design, and the simplicity of the film processing mechanism. There are no extremely critical areas in the system, as the technology and parts required are all well within the state of the various arts.

Additional capabilities of the system may be exploited through the addition of inexpensive interface units which would permit direct recording of the data on paper tape or other mediums. A direct interface with telemetry links or a computer is also possible at very minimum expense and complication.

The system as conceived herein is very flexible, it can be produced economically, and it should provide many years of troublefree operation under fleet operating conditions.

3.2 Recommendations

There are five prime areas where additional study or development would be desirable and profitable prior to considering production of these systems in quantity:

(1) Probe Interface

Although no major problems are anticipated, some testing of Federal stock XBTs will be required to establish finalized tolerance limits of the recorder input circuitry.

(2) Recording Head

Since some difficulty can be anticipated here, an investigation should be made into the problems of procedures, tools and fixtures required to produce these items in quantity.

(3) Improved Reliability

It is our opinion that the reliability figure, especially as regards the incandescent lamps, can be improved. Some concentrated effort in this area would result in dramatic improvement in reliability due to the large number of lamps used in the system.

(4) Film Stability

The dry silver film used on this project is still relatively new, and, although the manufacturer claims near archival quality, we feel that further investigations should be made into stability of the film under anticipated storage conditions.

(5) Additional Capabilities

Prior to solidifying the design of this system the possibility of interfacing with other equipments should be considered and at least allowed for in the system design. In order to do this, some effort should be expended to identify and define such possible interfaces and to determine both technical and economic feasibility of these added features. Such an effort would be very rewarding if it avoids a costly and time consuming modification and refit program at some later date.

APPENDIX A

Digitization Methods

Since the conversion speed required in this system is very nominal, consideration has been given to only three relatively simple digitization methods. These methods are considered with respect to their effect on settling time at the comparitor input. In other words, the bit or clock rate of the digitizer has been determined in each case.

(a) Counter Method

One of the simplest digitizers utilizes a counter to drive the digitally controlled resistor in such a manner as to create a ramp function. The resistor increases linearily with time until it compares with the thermistor resistance. The counter is then stopped, and the resulting number stored in the counter is a digital equivalent of the thermistor resistance.

The sample-time is therefore proportional to the count, n, and it requires n clock pulses to reach the balance condition. The worst case sample-time occurs when a full count of 1,024 is accumulated. Maximum settling time is estimated as follows:

$$\frac{0.1 \text{ sec. sampling time}}{1024 \text{ counts}} = 0.1 \text{ msec.}$$

(b) Tracking Counter Method

This is a variation on the counting method wherein an up/down counter is used. The counter does not reset at the beginning of each conversion as with the simple counter method. It merely holds the previous count and then counts up or down as required at each conversion time. Thus, the maximum number of counts is a function of the gradient, i.e. it depends on how far the parameter has shifted from one conversion to the next. At the cold end of the temperature scale where the worst case temperature/resistance rate exists (510 ohms/°F) we may calculate the worst case bit rate of change:

$$\frac{510 \text{ ohms}/^{\circ}\text{F}}{14.75 \text{ ohm/bit}} = 34.6 \text{ or about } 35 \text{ bits}/^{\circ}\text{F}$$

With a gradient of 1°F/sec. the equivalent bit rate of change is 35 bits/sec. Now, if samples are taken twice per second, the maximum number of bits accumulated between samples is 35 bits/sec /2 or about 18 bits (or counts). Maximum settling time is then

$$\frac{0.1 \text{ sec/sample}}{18 \text{ counts}} = 5.5 \text{ msec.}$$

(c) Successive Approximation Method

This method results in a constant sample time, but it requires somewhat more circuitry than counting methods.

Sometimes termed "put and take" this method operates as described below.

First, the most significant bit is set which places half of the total possible resistance in the bridge circuit. The comparitor determines whether this is greater or less than the thermistor resistance. If greater, the most significant bit remains set. If less, it is reset, and, in either case, the next most significant bit is set placing ¼ of the total resistance in the bridge. The process is repeated through the least significant bit (1/1024 of total resistance). Thus, allowing one clock period to initialize the circuitry, the total number of clock periods required per conversion is equal to the number of bits plus one. For a 10 bit digitizer 11 clock periods are required. The maximum clock period (which is equivalent to settling time) may then be calculated as follows:

$$\frac{0.1 \text{ sec time}}{11 \text{ clock periods}} = 9.1 \text{ msec.}$$

APPENDIX B

PRELIMINARY RELIABILITY ESTIMATE

The reliability estimate given in Table 1 conforms, inasmuch as possible, to the procedures outlined in NAVSHIPS 93820 "Handbook for the Prediction of Shipboard and Shore Electronic Equipment Reliability". Method C "Equipment or Circuit Prediction from Average Parts Failure Rates." Component failure rates not tabulated in NAVSHIPS 93820 have been estimated or taken from manufacturer's data. The parts list represents a best estimate based on the system design outlined in this report and on experience gained through this Feasibility Study.

TABLE 1

PRELIMINARY RELIABILITY ESTIMATE

Part Type	Quantity Used	Failure Rate	Failures Per 10^6 Hours
Capacitor, Fixed, Electrolytic	12	2.48	29.76
Capacitor, Fixed, Mica or Equiv.	19	0.46	8.74
Connectors	4	0.058	0.23
Diode	26	2.98	77.48
Hardware, Electrical	50	0.033	1.65
Hardware, Mechanical	100	0.092	9.20
Belt, Drive	2	63.56	127.12
Heating Element	1	5.00 (1)	5.00
Inductor	2	0.28	0.56
Integrated Circuit	185	0.25 (2)	46.25
Lamp, Incandescant, Miniature	183	10.0 (3)	1830.00
Motor, Blower Type	2	2.85	5.70
Motor, Incremental Type	1	5.43	5.43
Power Supply, Dual Output, Solid State	1	25.0 (4)	25.00
Relays	12	2.03	24.36
Switches	5	0.48	2.40
Transistors	45	1.60	72.00
Transformer	2	1.16	2.32
Resistor, Fixed, Carbon	220	0.39	85.80
Resistor, Fixed, Wirewound	10	1.40	14.00
Resistor, Variable, Wirewound	4	0.84	3.36
		Summation	2,376.36

$$\text{MTBF} = \frac{10^6}{2,376.36} = 421 \text{ Hours}$$

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(1) **Estimated.** No data available.
(2) Obtained from manufacturer.
(3) **Assuming** MIL STD 24367-715-AS15 lamp operated at 80% rated voltage.
(4) **Estimated** at ½ that of similar vacuum tube type.

Unclassified

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Washington, D.C.

13 ABSTRACT

This study has established feasibility of a proposed fiber optics plotter system which produces bathythermograms on standard film aperture cards in both analog and digital form. Performance has been verified with a breadboard model. Outstanding features of the design are its all digital nature and the use of a new dry process film. Operational, reliability, production and cost aspects are considered based on a preliminary system design.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fiber Optic Recording						
Bathythermograph Recorder						
Dry Silver Film						
Aperture Cards						

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