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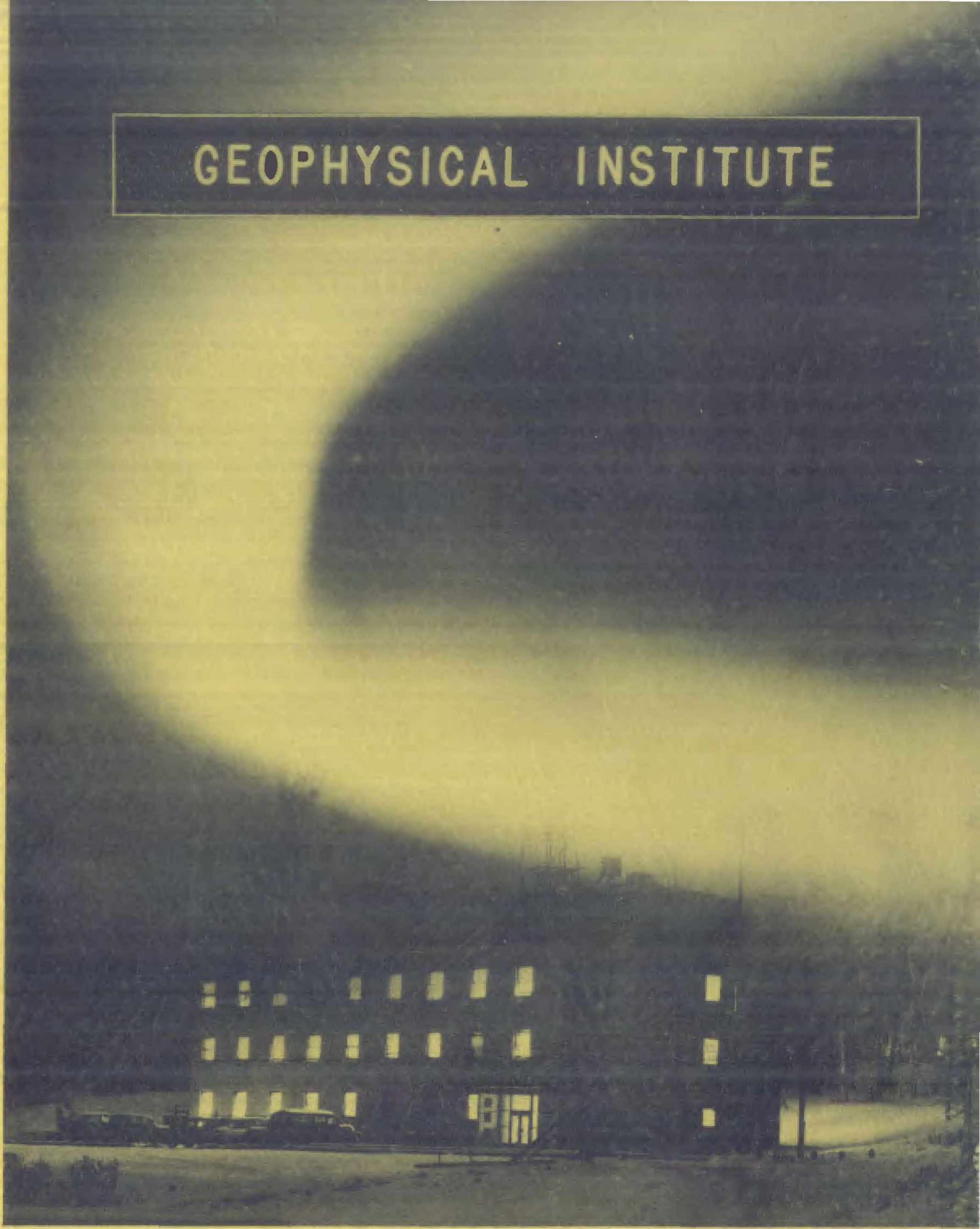

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Description of the All-Sky Camera, its Method of Operation; An Instrument (Ascagraph) for Measuring the Film

by

C. T. Elvey and Albert Belon

Scientific Report Number 1
IGY Project Number 1.1
NSF Grant Number Y/1.1/44

Principal Investigator: C. T. Elvey, Director

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PART I

INTRODUCTION

The primary objective of the auroral program for the IGY is a study of the development of the auroral display. This study is one phase of the more general problem of gaining a better understanding of the basic solar-terrestrial relationships concerning polar phenomena. In order to meet this primary objective, it is necessary to know the distribution of auroras over the globe at given times; in other words to have synoptic maps of the auroral displays. Since the aurora is a very active and rapidly changing phenomenon, it is not practicable to follow all of its changes in detail over the entire globe during the IGY, and, of course, the uses of complete descriptions of the auroral display is not yet known. Consequently, the primary objective may be conveniently divided into three secondary objectives or tasks, namely: (A) Macroscopic studies of the main features of the auroral display on a world-wide scale at 3-hour intervals throughout the IGY; (B) Detailed studies at quarter-hour intervals of the auroral display on a world-wide scale for the Special World Intervals and those days designated by the Aurora Committee of the International Association of Geomagnetism and Aeronomy together with representatives for the world data centers; and (C) Detailed studies of auroral displays for selected regions and selected times at one-minute intervals.

Task (A) above aims for a macroscopic view of the distribution of auroras over the globe eight times daily throughout the IGY. This method will answer many of the questions proposed by theoretical and laboratory studies since their inquiries concern only the distribution of the broader features of the auroral display, the general nature of the daily and seasonal variations, and the variations during disturbed conditions. These data would be obtained from visual observations, supplemented with photographic and radio observations, and presented as synoptic maps of auroral distribution. These synoptic maps will be extremely useful for Task (B) to assist the Aurora Committee in selecting days for special study.

PART II

DESCRIPTION OF THE ALL-SKY CAMERA

C. W. Gartlein[1] successfully used the combination of a camera and a spherical mirror to photograph auroras. This device, which we named "all-sky camera", has been used in Alaska during the past three years for routine observations of auroras. The all-sky camera to be used by the Technical Panel on Aurora and Airglow of the USNC-IGY is based on a design developed by W. Stoffregen in Sweden[2]. This model, built by Photomechanism Inc., N. Y., is more compact than the previous cameras used. The previous models, described by T. N. Davis and C. T. Elvey[3], evolved along the Gartlein system of mounting the camera above a convex mirror.

In the present model, the optical system (Fig. 1 and 2) consists of a plane mirror (B) horizontally mounted directly above a convex mirror (A) with a central aperture (1 5/16 in.) that allows the objective lens of the camera mounted below to "see" all of the plane mirror. The mirrors are front surfaced and protected with a coating of silican monoxide.

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[1] Carl W. Gartlein, "Unlocking Secrets of the Northern Lights," NAT. GEOG. MAG. 92 No. 5, 673 (1947).

[2] W. Stoffregen, "All-Sky Camera Auroral Research During the Third Geophysical Year 1957-1958," TELLUS 7, 509-517 (1955).

[3] T. N. Davis and C. T. Elvey, "Construction of an All-Sky Camera." (Geophysical Research Report 2.) College, Alaska: Geophysical Institute, 1957.

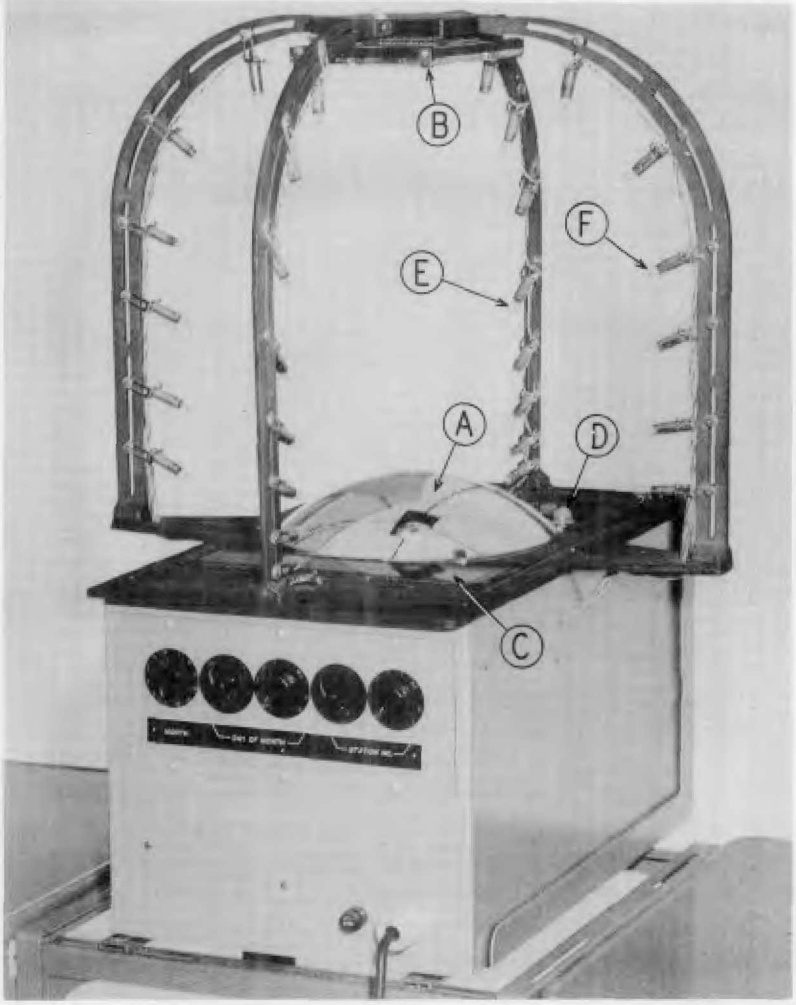


Figure 1 - The All-Sky Camera

A - Convex Spherical Mirror
B - Plane mirror
C - Coding lamps
D - Quarter hour lamp
E - Geomagnetic arc lamps
F - Zenith arc lamps

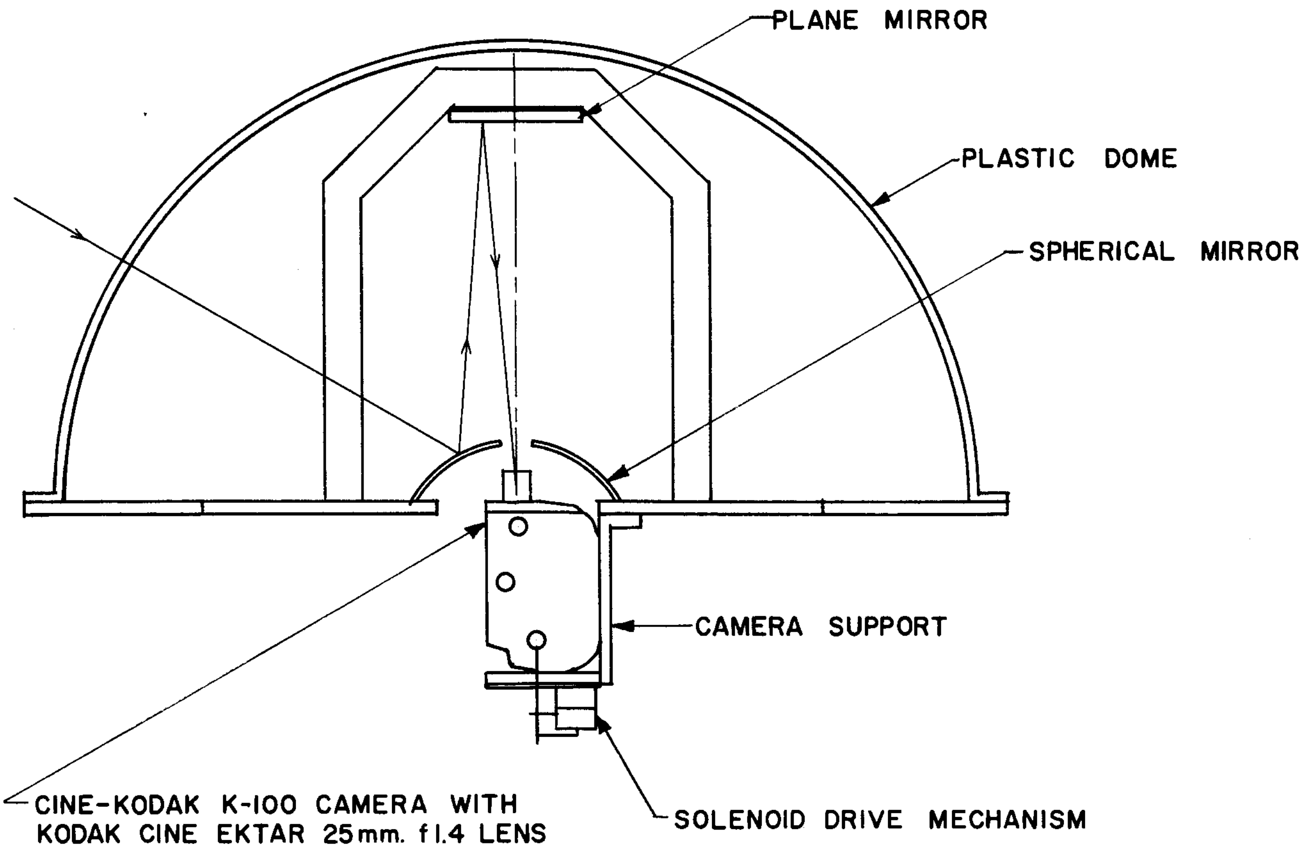


Figure 2 - Optical System

The camera is a 16 mm Model K-100 Eastman Kodak with a 25 mm f/1.4 Cine Ektar objective lens. During the past summer, investigations at the Geophysical Institute, College, Alaska, proved that Tri-X negative film developed for 10 min. with D-19 or D-11 (Eastman Kodak Company) produced best results. A 15 sec. exposure produces a detectable image of the night sky near midnight, leaving the entire contrast range for interpretation of auroral intensities.

The various lamps C, D, E, and F of Fig. 1, indicate the station number, date and time on each frame for that sky image (Fig. 3 and 4).

The station number and date are indicated by a binary code set up with 16 lamps mounted below a glass insert in the base. Lamp combinations are controlled by selection dials on the side of the camera base. Dial 1 has twelve positions and sets the month; Dial 2 has four positions and sets the tens of days; Dial 3 has ten positions for the unit of the day; Dial 4 has four positions for tens of the camera number; and Dial 5 has ten positions for units of the camera number; the following standard binary notation is used:

Decimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100

The time is read directly from the illuminated clock dials mounted on the side of the convex mirror opposite the binary coding lamps. A lamp mounted on the camera base next to the convex mirror is lighted to identify the 00, 15, 30 and 45 minutes frames.

Two arcs supporting the plane mirror (Fig. 1) above the camera are used to determine the azimuth and zenith angle measurements. One arc is oriented in the geomagnetic meridian with the north end designated on the base. Lamps mounted by clamps on this arc denote the zenith distance of the intersection of the geomagnetic latitude circles

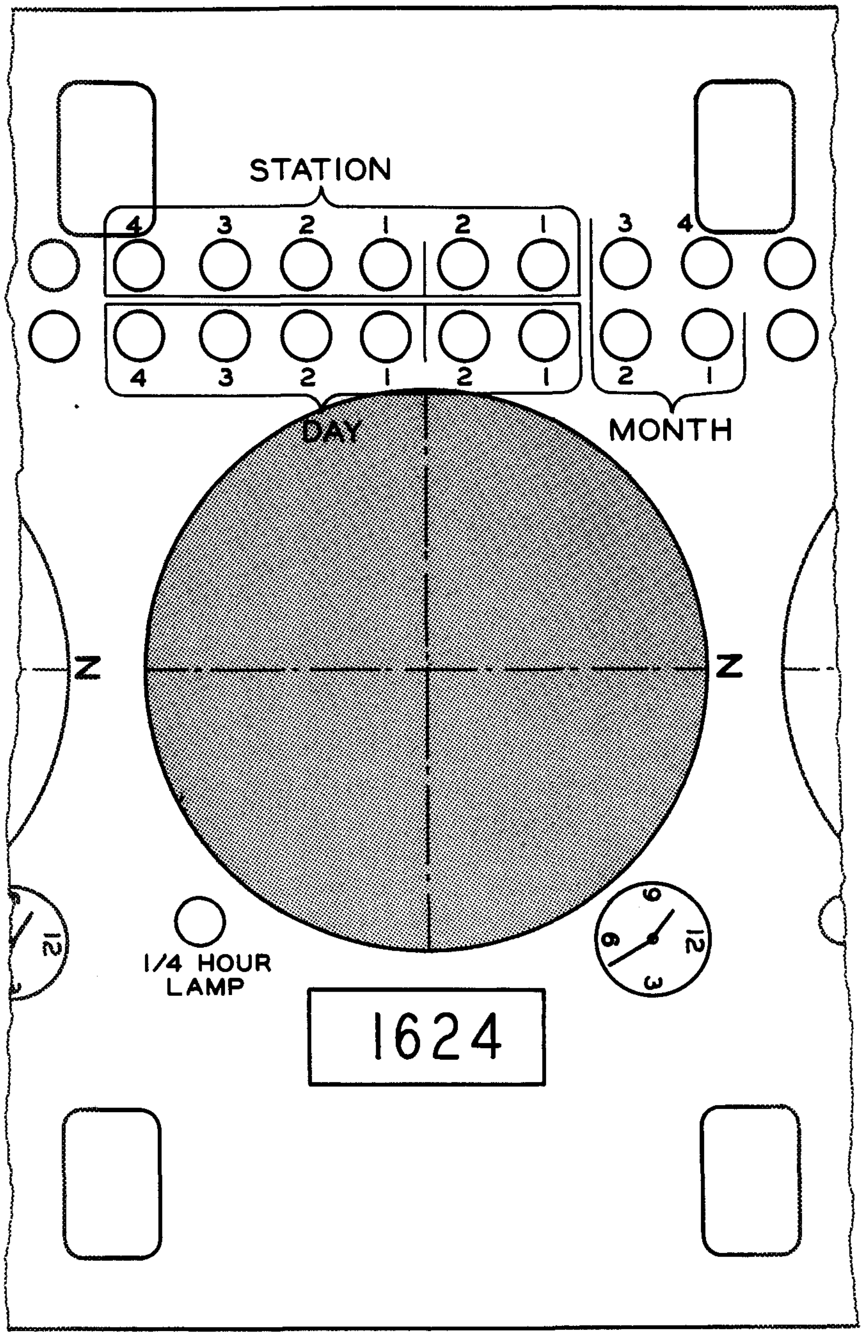


Figure 3 - 16 mm Frame Format

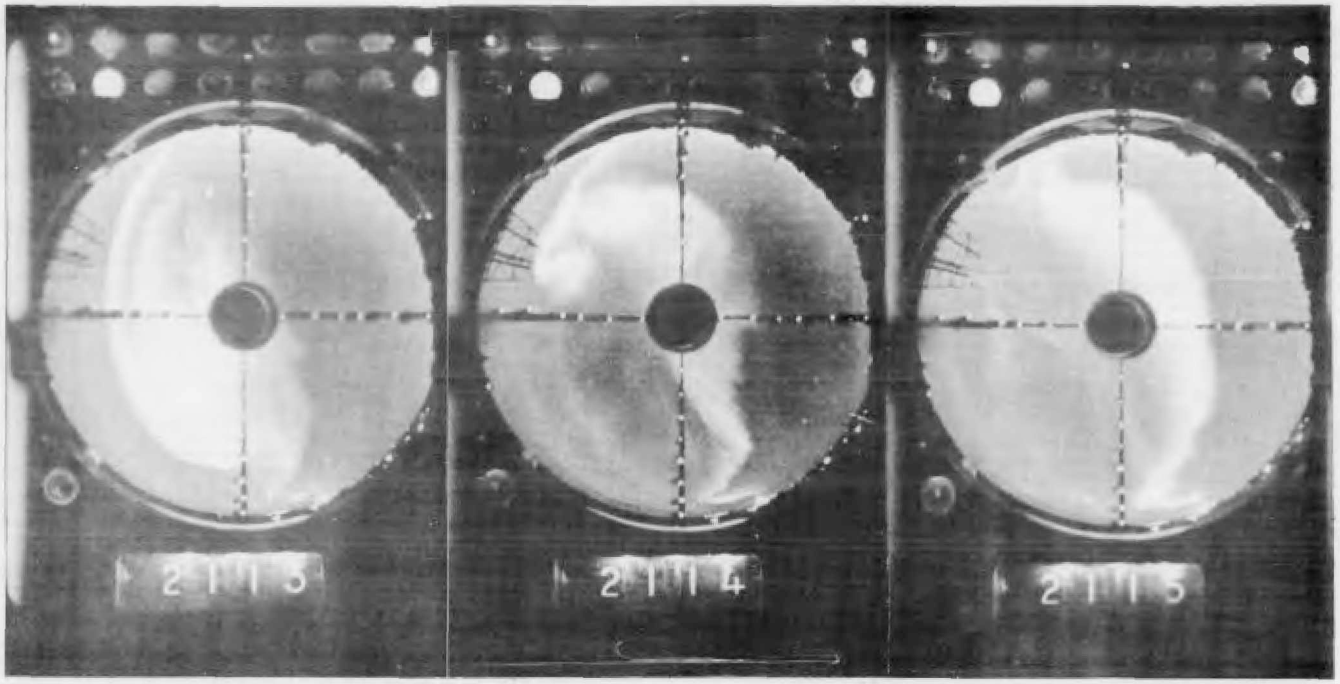


Figure 4 - All-Sky Camera Photographs

with the geomagnetic meridian at a height of 100 km above the earth's surface. The supporting arc at right angles to the meridian is marked at each 10° in zenith distance by lamps clamped on to the arc. The coding lamps and the arc lamps are interchangeable.

At each one-minute cycle the following events occur:

1. The coding lamps, the clock dial lamps and the arc lamps turn on. The quarter hour lamp turns on at 00 min. and not again for 15 min.
2. The camera shutter opens and starts exposure.
3. All the lamps turn off.
4. The camera shutter closes and terminates the exposure.
5. The film in the K-100 camera advances one frame.

Two camera models have been produced: A synchronous model with an electric 24-numeral clock and a mechanical clock model.

1. Synchronous model (Fig. 5 and 6). A manually pre-set electrically driven 24-hour time clock (B-3) automatically turns the camera system on and off at predetermined times. The camera sequences and the recording lights flashes are controlled by two cams and microswitches on a single 1 RPM motor (B-1). Specified time exposures (5, 10, 20, and 40 sec.) are made by using the proper exposure cam on B-1. A third timing motor (B-2) with 1/15 RPM controls the quarter-hour lamp flashes.

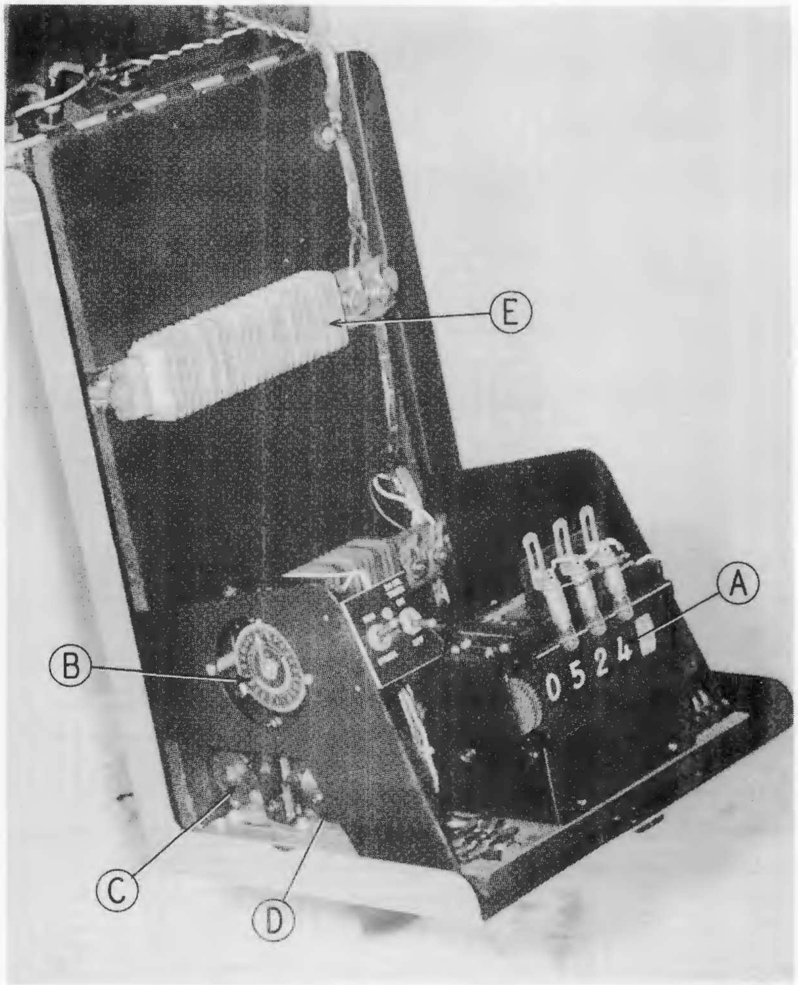


Figure 5 - Control Box of Synchronous Model

A - Numeral Clock
B - 24 hour timer B-3
C - Camera sequencing motor B-1
D - Quarter hour lamp motor B-2
E - Heating element

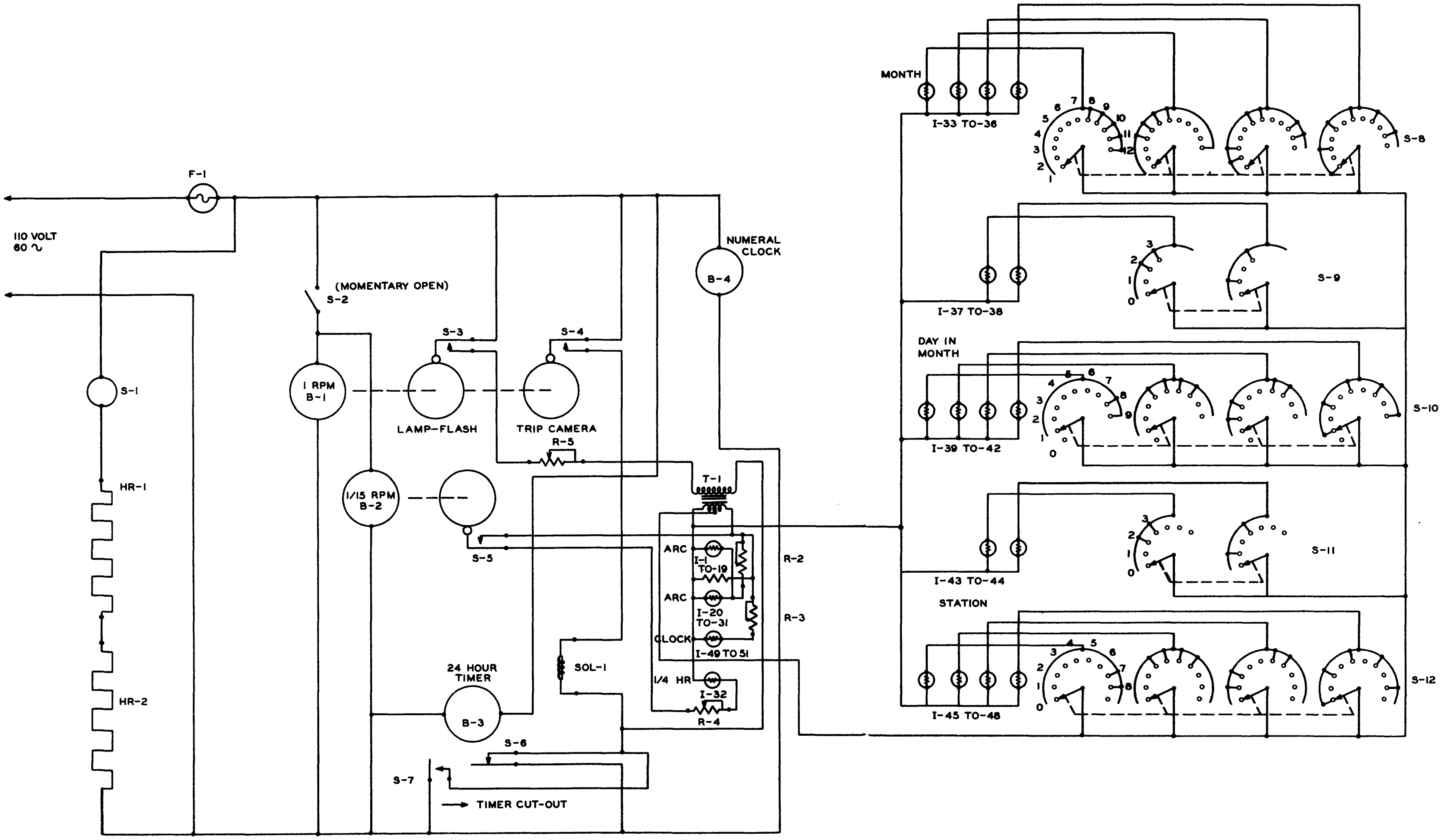


Figure 6 - Circuit Diagram of Synchronous Model

2. Mechanical clock model (Fig. 7 and 8). This model was modified to replace the electric numeral clock with a mechanical clock for use in areas where the 60 cycle power is unstable. An external pulse can be used to start B-5 which then controls the exposure. All other functions are the same as in the synchronous model except that the exposure and lamp-flash timer (B-1) is changed to a 1 1/3 RPM motor (B-5). A switch added to the 24-hour time clock (B-3) energizes the quarter-hour lamp with every exposure.

The control box houses the camera, the timing controls, the clock dials, the coding lights, and the thermostatically controlled heaters. This unit is on hinges and may be lowered for easy access.

The interior of the camera housing has been lined with insulation on 5 sides. A thermostat controls two 250 watt heaters in series (Fig. 5 and 6). The thermostat is adjustable between 40°F. and 100°F.

In the Antarctic the all-sky cameras are installed on the auroral towers which have four-foot plastic domes to protect the camera. The towers and the domes are heated so that the mechanism can be operated at room temperature.

For the cameras being placed throughout the United States and Alaska, a prefabricated wooden box, to be assembled at the observing site, has been designed and equipped with an electric heater and a fan to blow warm air against the inside of the dome (Fig. 9). This will be needed to prevent the formation of dew and frost on the outer surface.

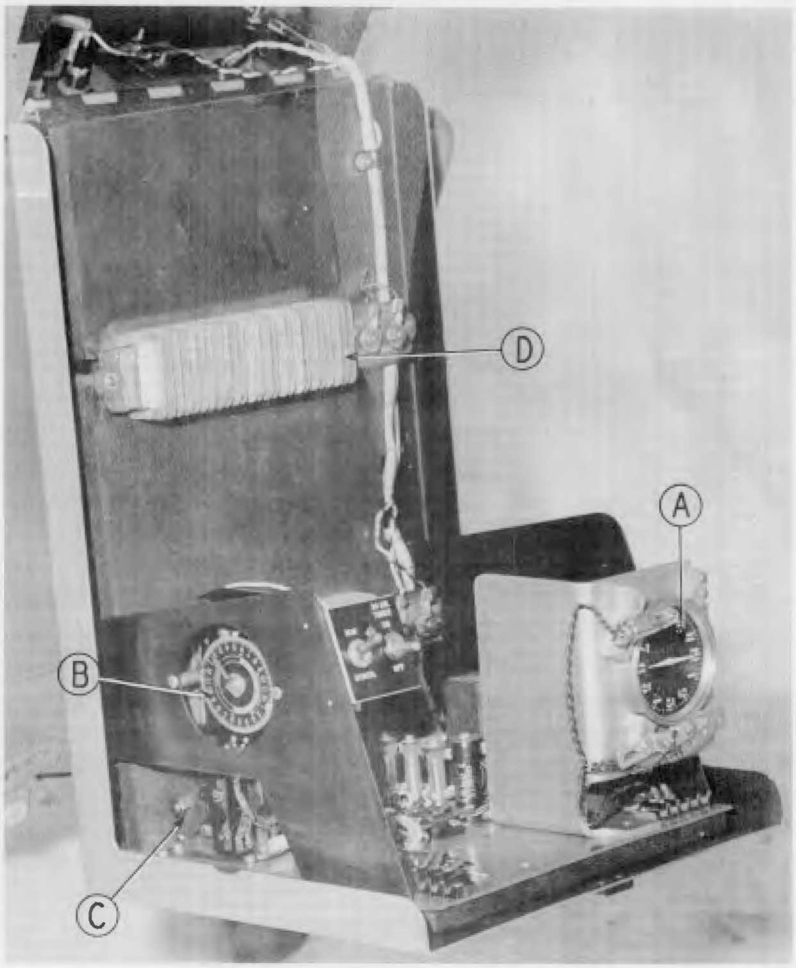


Figure 7 - Control Box of Mechanical Clock Model

A - Mechanical Clock
B - 24 hour timer B-3
C - Camera sequencing motor B-5
D - Heating element

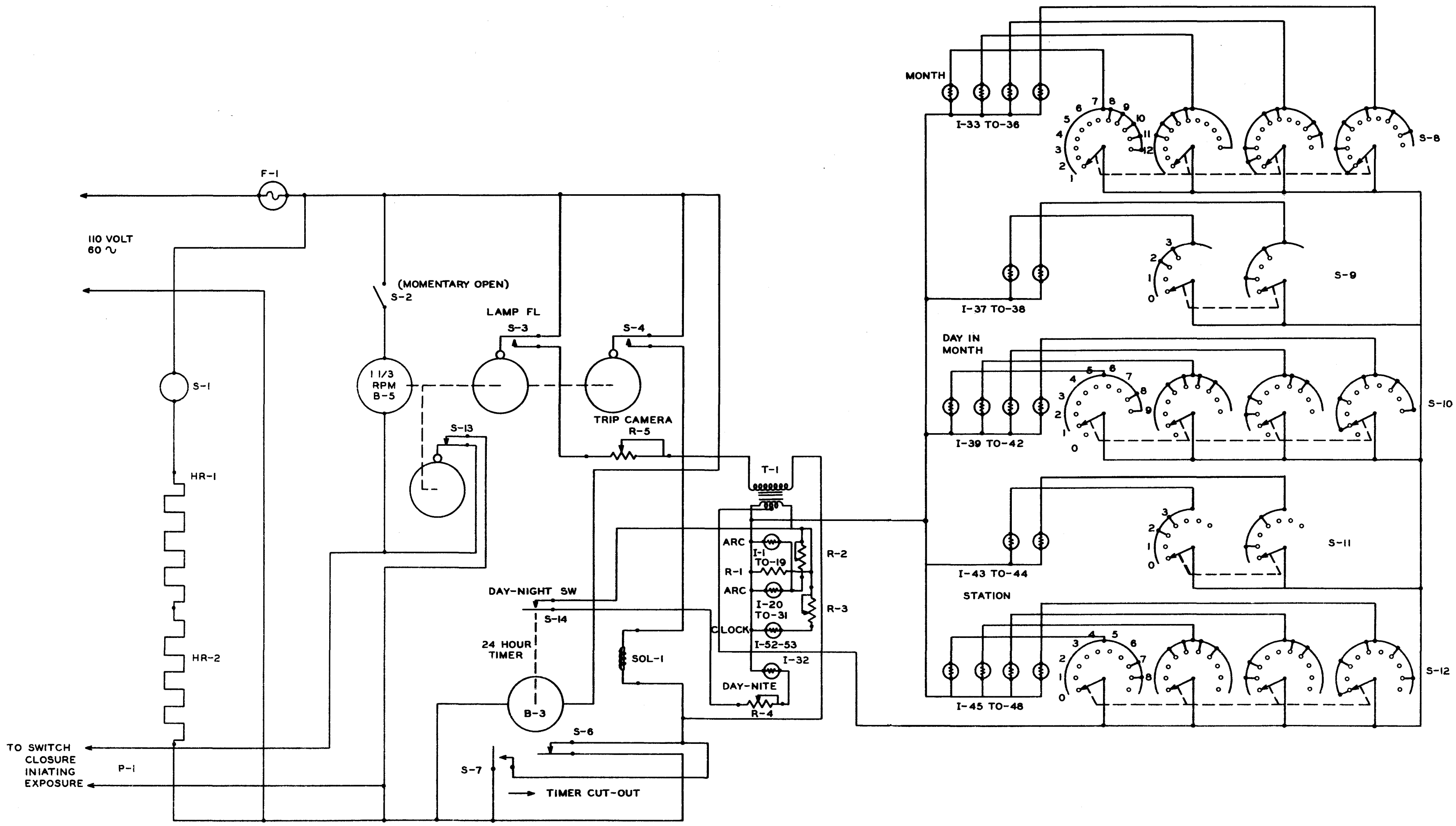


Figure 8 - Circuit Diagram of Mechanical Clock Model

ALL-SKY CAMERA HOUSING

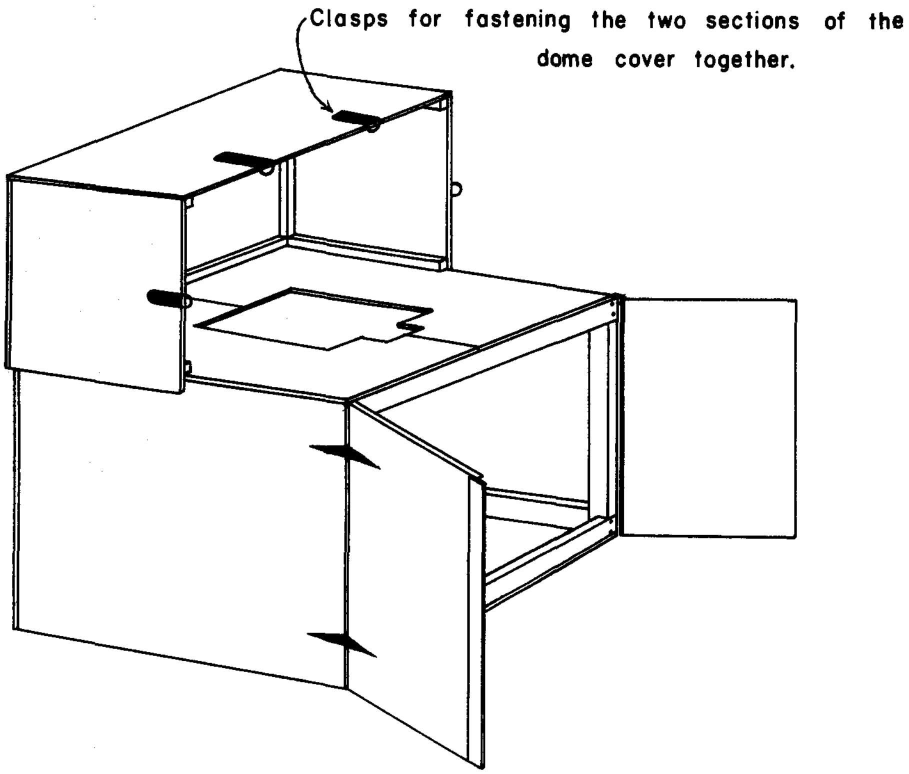


Figure 9 - Prefabricated All-Sky Camera Housing

The cameras are planned to operate automatically except for a daily check and to wind the driving motor of the camera (the Model K-100 Kodak camera will expose approximately 40 feet of film with one winding). At the same time, the clock corrections and other data will be entered in the log-book.

The all-sky camera requires for its operation 110 volt, 60 cycle alternating current. In the colder climates where all the heaters must be employed, the power consumption is one kilowatt. Virtually all of the power is required for heat.

The accessories and spare parts accompanying each camera are: 4 exposure cams (1 each of 5, 10, 20, and 40 seconds), 1 spare switch, and 10 spare minature lamps. In addition to these, each of the cameras at remote sites will have the following:

1 can of cement
1 SPDT toggle switch
1 SPST momentary toggle switch
1 spherical shell mirror
1 plane mirror

The following spare parts will be available at each of the three base sites, Little America, Antarctica; Cornell University, Ithaca, N. Y.; and Geophysical Institute, College, Alaska:

1 Modified K-100 camera

1 Spherical shell mirror

1 Synchronous 1 RPM timer

1 Set of 4 cams

1 Synchronous 1/15 RPM timer

1 Transformer, lamp supply

1 Solenoid, camera operating

1 Numeral clock

1 Heater, 250 watt

1 24-hour timing clock

1 Resistor, fixed 25 watt

1 Can of cement

1 Binary lamp matrix assembly

2 Thermostats

2 Sets of cover windows

2 Cam operated snap switches

2 SPDT toggle switches

3 SPST momentary toggle switches

4 Resistors, variable

30 Minature lamps

PART III

INSTALLATION AND OPERATION

The all-sky camera should be installed at a location free from artificial lights; but if a few artificial lights cannot be avoided the camera should be at a position above the ground so that the lights are below the horizon as seen from the camera. In this case, we have found it satisfactory at College, Alaska, to place baffles, with sides toward the camera painted black, in such a position that the light did not illuminate the plastic dome.

The camera is oriented so that the plane of one of the structures supporting the flat mirror is in the geomagnetic meridian with the letter "N" toward the geomagnetic north point. Although orientation need not be more accurate than plus or minus one-half degree, an accurate sighting must be made on some distant object so that if the instrument is moved it can be brought back to the same orientation. The exact orientation, when required, for each camera will be determined from the photographs, making use of the positions of astronomical objects. A sketch is to be placed in the "Log Book" showing the location of the instrument and the azimuths of well known landmarks, especially those which project above the horizon (include poles, trees, mountain peaks, distant lights on the horizon, etc.). It is also very important that the all-sky camera is level. A bubble-type level will be provided with each camera. The final optical alignment of the camera will be determined from the photograph with the image of the camera objective centered on the photograph.

The operating procedures vary with the problem: thus to fulfill the requirements for Task (B), that is, synoptic maps each 15 minutes, much less accuracy is required than for Task (C), where detailed studies are being made at selected places and selected times. The accuracy required for Task (C) must be assessed and achieved by the individual investigator. The minimum requirements are those to fulfill Task (B).

The following recommendations as to procedures were adopted by the Arctic Conference of CSAGI meeting in Stockholm, 22-25 May 1956, and are to be followed by the operators for the all-sky camera under the jurisdiction of the Aurora and Airglow Panel of the USNC-IGY, except as noted:

1. All cameras should be operated from sunset to sunrise. Exception: The U.S. cameras will operate from the end of evening civil twilight to the beginning of morning civil twilight.

2. All installations, except those directed otherwise, will take an exposure every minute for detailed studies. It is recommended that all installations do this to determine the time of break-up of an arc to the nearest minute. However, if this exposure interval is impossible, then, since the data for the IGY program require an observation at 00, 15, 30, and 45 min. of each hour UT, three successive exposures at minute in-

tervals, centered at each of the above times, are highly recommended.

3. Exposures are to be centered at 0 secs. of the min., and the time should be correct to within 2 sec. for all cameras being operated in a network for determining the height of the aurora.

4. A date and time, as well as the station identification, should be placed on each frame of the film. However, if this procedure is not practical, the proper identification should be placed on the film at the beginning of each night's observation. Note: The U.S. cameras are designed to record automatically on each frame a binary coding with small lamps to give the serial number of the camera, the month and the day. The hours and minutes are also recorded on each frame by a numerical clock.

5. The recommendation of CSAGI that, as a minimum, observations will be made during Special World Intervals, is reaffirmed. It is desirable, however, to take observations daily. Note: The U.S. observers will operate the all-sky cameras every night except when the weather threatens damage to the equipment.

Log Book

A "log" or record will be kept of all data pertaining to the operation of the all-sky camera. The log books will be made in duplicate. One sheet is to be used for each roll of film. One of the record sheets will be perforated, and when the roll of film is removed from the camera, this record or log sheet will be removed also and sent with the film to the Area Center, or to the World Data Center to become a part of the permanent record of the IGY. The form of the log sheet is shown in Fig. 10.

ALL-SKY CAMERA LOG SHEET

STATION________________
STATION NO.____________
CAMERA NO._____________
OBSERVER_______________

DATES
from_______ to________

ROLL NO._____________________
EMULSION TYPE:________________
EMULSION NO:__________________

DATE	TIME SET FOR		Footage	Exposure	Camera Time	Correct Time	CHECK LIST					WEATHER	REMARKS (Malfunctions and corrections, unusual observations,) etc.
	Start	Stop					Wind Clock	Mirrors	Correct. Clock	Wind Cam.	Gen. Operation (check and sequence)		
1.													
2.													
3.													
4.													
5.													
6.													
7.													
8.													
9.													
10.													

Fig. 10. Sample of Log Sheet

PART IV

DEVELOPMENT OF FILM, INSPECTION, AND PRELIMINARY ASSESSMENT

To insure uniformity in the brightness of the auroras recorded, the choice of film, exposure time, and development must be such that a detectable image of the clear night sky without moonlight or twilight will be recorded. The details of some of the more intense auroras may be lost, but this is believed to be not serious for the IGY program. Furthermore, the exposure should be as short as possible and still maintain the above requirement. Uniformity throughout the program is to be maintained.

The U.S. observers will use the Kodak Tri-X negative film, 16 mm by 100 ft. The exposure time will be 15 sec. The films, whenever possible, will be sent to the Geophysical Institute, College, Alaska for uniform development (10 min. in developer D-19 at 68° F.). Note: A new emulsion, now known as S.O. 1177, recently developed by the Eastman Kodak Company, is reportedly 3 to 4 times faster than the Kodak Tri-X. Tests on this film are now being conducted at the Geophysical Institute and the preliminary results are very encouraging. The new film probably will be used if it becomes available in the 16 mm size.

The data centers will rapidly accumulate a large amount of all-sky camera film. Therefore, to facilitate handling and to expedite repairs in malfunctioning equipment, an inspection and preliminary assessment of the film will be made immediately after processing. The inspection and assessment will be in tabular form, an example of which is shown in Fig. 11. A copy of the inspection and assessment report will be sent immediately to the observer for his information concerning the performance of the equipment, and another copy to the World Data Center A (Dr. Carl W. Gartlein, Cornell University, Ithaca, N. Y., U. S. A.) for visual observations of aurora to be used in the construction of the 3-hourly synoptic maps of auroral distribution.

In order that all records and observations made during the IGY may be available to anyone, each station will send all film taken with the all-sky cameras, observing records, and pertinent data to the area center. The area center will scale the photographs which are required or needed for preliminary reports, copy all films and records, and will then return the original film to the investigator. Copies will be forwarded to the World Data Center for a permanent record of data for the IGY. The World Data Center will make duplicates of the data and forward it to the two other World Data Centers.

INSPECTION AND PRELIMINARY ASSESSMENT REPORT, ALL-SKY CAMERA

STA. NO. AND NAME__________ GEOG. LAT.__________ LONG.__________

CAMERA NO.__________ OBSERVER:__________ ROLL NO.__________ LOCAL DATE__________

LOCAL DATE__________ GREENWICH DATE__________

ZONE TIME (UT)	N_2 FORM (I)	N_1 FORM (I)	Z FORM (I)	S_1 FORM (I)	S_2 FORM (I)	REMARKS
0000						
0100						
0200						
0300						
0400						
0500						
0600						
0700						
0800						
0900						
1000						
1100						
1200						
1300						
1400						
1500						
1600						
1700						
1800						
1900						
2000						

NOTES:

Fig. 11. SAMPLE FORM FOR REPORTING INSPECTION AND PRELIMINARY ASSESSMENT OF FILMS FROM ALL-SKY CAMERAS.

PART V

PREPARATION OF SYNOPTIC MAPS

Observations taken with the all-sky camera will be reduced at the area data center to meet the requirements of Task (B) (detailed studies of the auroral display at 15 min. intervals during the Regular World Days and the Special World Intervals). The area center will prepare synoptic maps showing the distribution of auroras for that area at 00, 15, 30, and 45 minutes of each hour UT.

At College, Alaska, we have had a small amount of experience in preparing synoptic maps for observations with all-sky cameras located at College and Point Barrow. Two methods have been used and are described below.

Grid Matching Method

The all-sky camera photographs are examined by projecting them in a microfilm reader which enlarges the image 19 times. A grid was constructed to represent the geomagnetic latitude and longitude circles as projected on a spherical surface at an assumed height of 100 km and photographed with the all-sky camera. The lower edges of the auroral feature are located and the corresponding geomagnetic coordinates noted. These are sketched on an outline map of Alaska with geomagnetic coordinates printed on 8 1/2 x 11 in. paper. Since only one microfilm reader is available, separate maps are constructed for the

College and Barrow stations, and are combined later on a single map for the given time. With this technique, the incidence of auroras which are within 45° to 60° of the zenith distance may be located easily within 10 km and those at about 80° zenith distance may be located to within about 30 km. The zenith distance of 80° corresponds to an approximate radius of 500 km from the observer for the assumed height of 100 km. Arcs and other auroral features north or south of the observer cannot be located with sufficient accuracy if they occur beyond a zenith distance of 80° or a distance of 500 km. However, the arc often may be traced to either the eastern or western horizons and thus may be shown to be as far as 1000 km from the observer. Hence, the sphere of influence of an observer with an all-sky camera is approximately 500 km to north and south and 1000 km to east and west.

If two all-sky cameras are within 500 km of each other in the north-south direction, the height of the auroras between the two stations may be determined and a new grid computed to determine the location of the aurora for the synoptic map. A group of six projectors could be conveniently installed so that the photographs from six stations could be seen simultaneously. With a series of grids for assumed heights of say, 80, 90, 100, 120 km, etc., the person scaling the records could visually determine the height and thus, the correct grid to use. The resulting synoptic maps would be microfilmed for distribution to the World Data Centers.

The Ascagraph Method

Recently, we have designed and built a device which semi-automatically plots synoptic auroral maps from the all-sky photographs. This device, called an ascagraph, is discussed at length in Part VI of this report. It is suggested that synoptic maps prepared with the ascagraph be drawn not individually, but in groups. For instance, the 6 all-sky camera stations in Alaska could be placed on a single map of Alaska which would be part of a larger northern hemisphere map. This method would also provide a means of estimating the height of a given auroral display. Indeed, if the height assumed were not correct, corresponding auroral arc forms from two or more neighboring stations would not match on the map. Therefore by this method, the matching of arc forms would help the operator assume the approximate correct height of the display. Seven such maps drawn on standard 8 1/2 in. x 11 in. format would cover the entire northern hemisphere with sufficient detail (Fig. 12 and 13). The composite map would then have a radius of 10 inches. The stations could be grouped according to availability of the data. For instance, the data from the continental United States stations should be immediately available and could be grouped on the same map. On the other hand, the data from the extreme polar stations may be available only every 6 months. These last would then be grouped together. The synoptic maps from the 7 regions would be prepared by the area centers, which would then send 4 copies to their own World Data Center for the

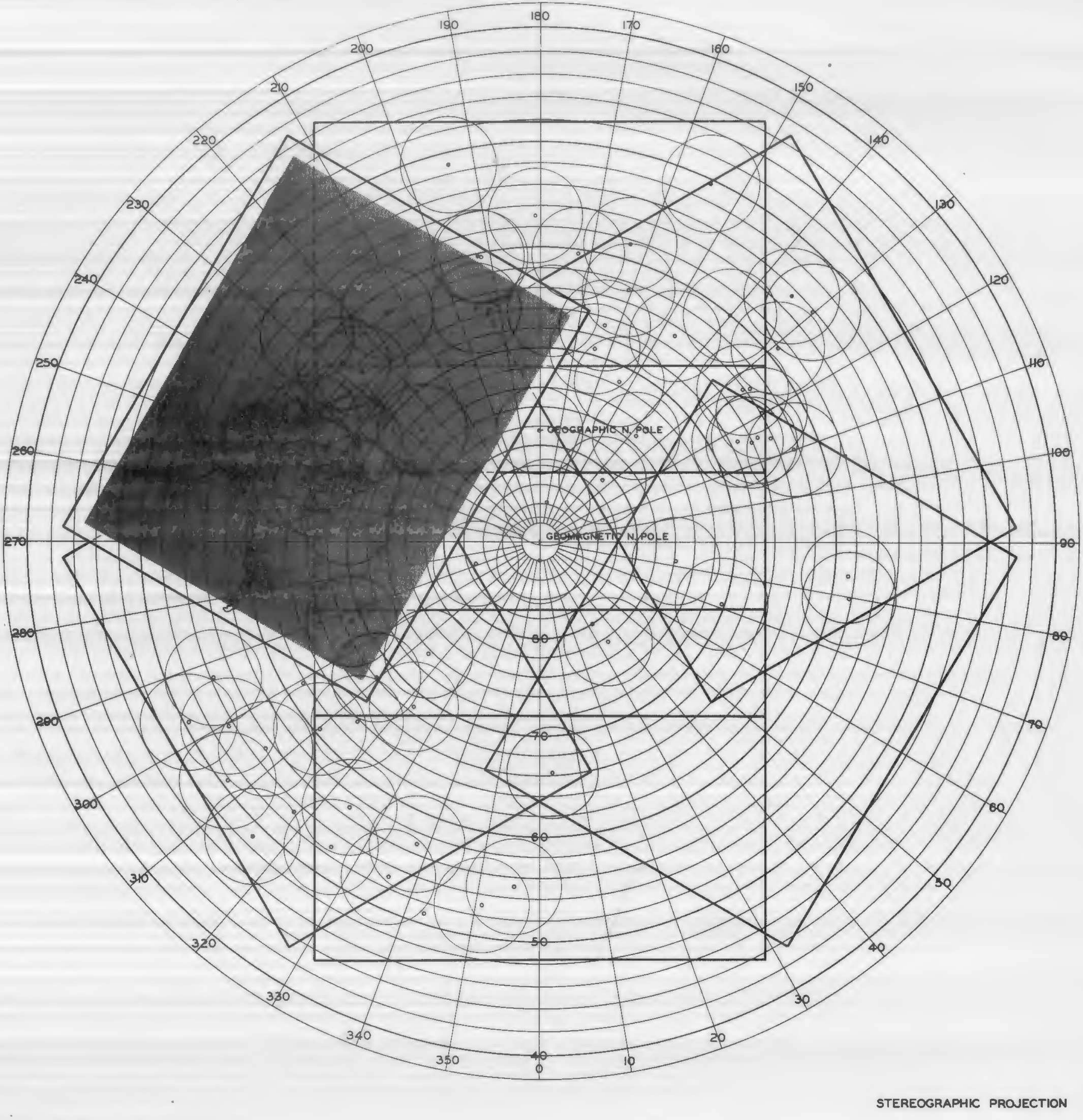


Figure 12 - Stereographic Projection Map

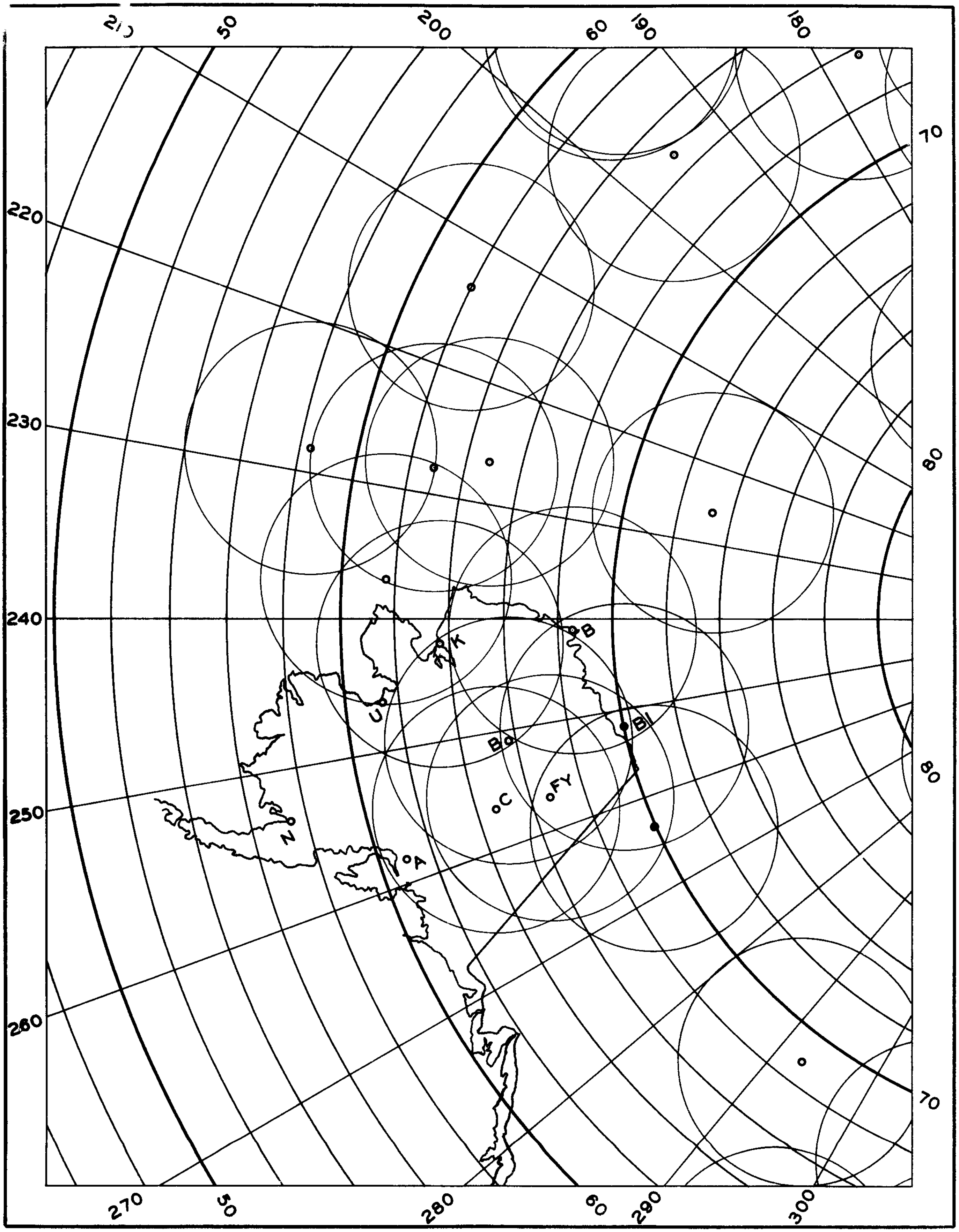


Figure 13 - Sample Regional Stereographic Map

Special World Intervals (WSI) at 00, 15, 30, and 45 min. of each hour GMT. The World Data Centers would interchange the synoptic maps and assemble them into the composite map. This assembly could be done in two ways:

(1) If the synoptic maps were on paper, they could be cut and glued onto a grid of the hemisphere, or

(2) If the synoptic maps were on microfilm, they could be projected through 7 properly arranged identical projectors aimed at a grid of the hemisphere and an operator could trace the auroral features on the grid. Small scale inconsistencies in the overlap between two regions could be adjusted by this method.

Once this assembly was completed for any given SWI, the composite synoptic maps could be microfilmed and redistributed.

To meet the requirements of Task C, (detailed studies of auroral display for local areas at one minute intervals) it is expected that individual investigators will make the analyses and present the results as scientific papers.

PART VI

AURORAL PLOTTER (ASCAGRAPH) FOR REDUCTION OF ALL-SKY CAMERA PHOTOGRAPHS

by

Albert Belon

One of the primary objectives of the IGY all-sky camera program is to construct synoptic maps of the aurora for determination of position, shape, and motion of the auroral zone. Probably, during the IGY, more than 30 miles of all-sky camera film will be accumulated in the United States alone. Consequently, as some process must be used for reducing this large amount of data, a simple recording device has been designed to transfer, semi-automatically, the data from the film to a map of the region over which the auroral display occurred.

The all-sky cameras to be used in the United States are essentially 16 mm movie cameras directed on a spherical mirror. Consequently, the photographs which are obtained are radially distorted. Although the distortion is minor in terms of zenith distances, it becomes very severe when the film is calibrated in terms of the distance along the surface of the earth. This distortion is illustrated in Fig. 14 which shows a plot of radial distance on the film against the distance along the earth for assumed auroral heights of 100 km and 125 km. A useful feature of the curves shown in Fig. 14 is that one can be derived from the other simply by means of a scale factor. The error introduced by

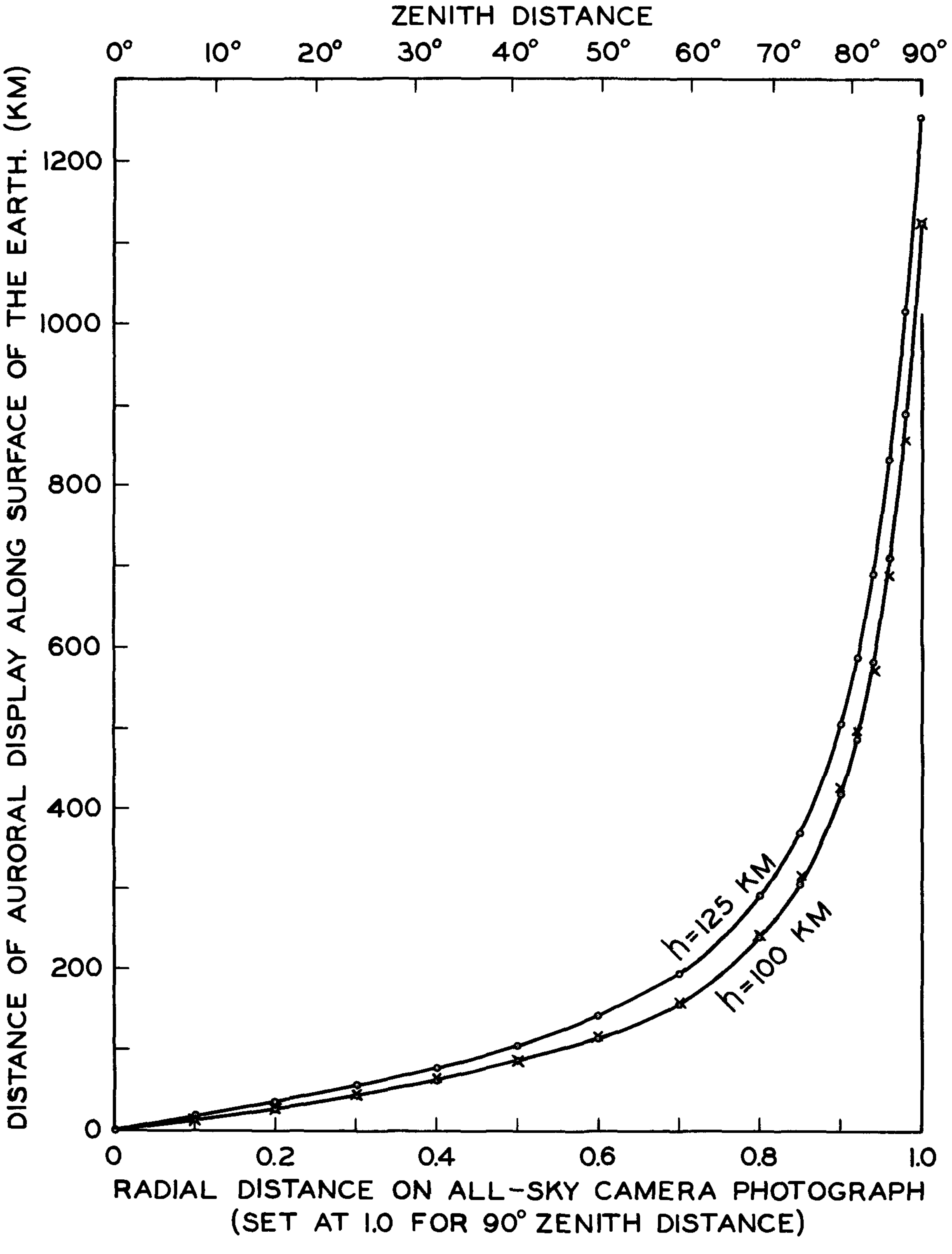


Figure 14 - Distortion Curve of All-Sky Camera

this approximation is less than 2.5% down to 80° zenith distance (less than 10% to 90°) and therefore is well within the film reading accuracy.

Auroral maps for widely separated stations will be eventually combined on a consistent map centered on the geomagnetic pole. On such a map it would be very advantageous and time-saving to retain the circular character of the individual all-sky camera ranges. Therefore a map of a hemisphere which would be both conformal and azimuthal is desired. The one that meets both of these specifications is the stereographic projection map. However, because the linear and areal scale increase away from the center of the projection, if this type of map is to be used for synoptic mapping of the aurora, this increase in scale must be taken into account.

The following paragraphs list several features which should be incorporated in the design of an auroral plotter to make it efficient as well as versatile:

1. The auroral features on the film must be traced manually from a projected image of the photographs because it is necessary to judge locations of the lower borders of auroral forms.

2. The two coordinates must be kept independent of each other because the azimuthal coordinate transformation (θ) is linear and the radial coordinate transformation (r) is not.

3. Both θ and r coordinates should be reversible at any time if the data are to be traced manually instead of scanned.

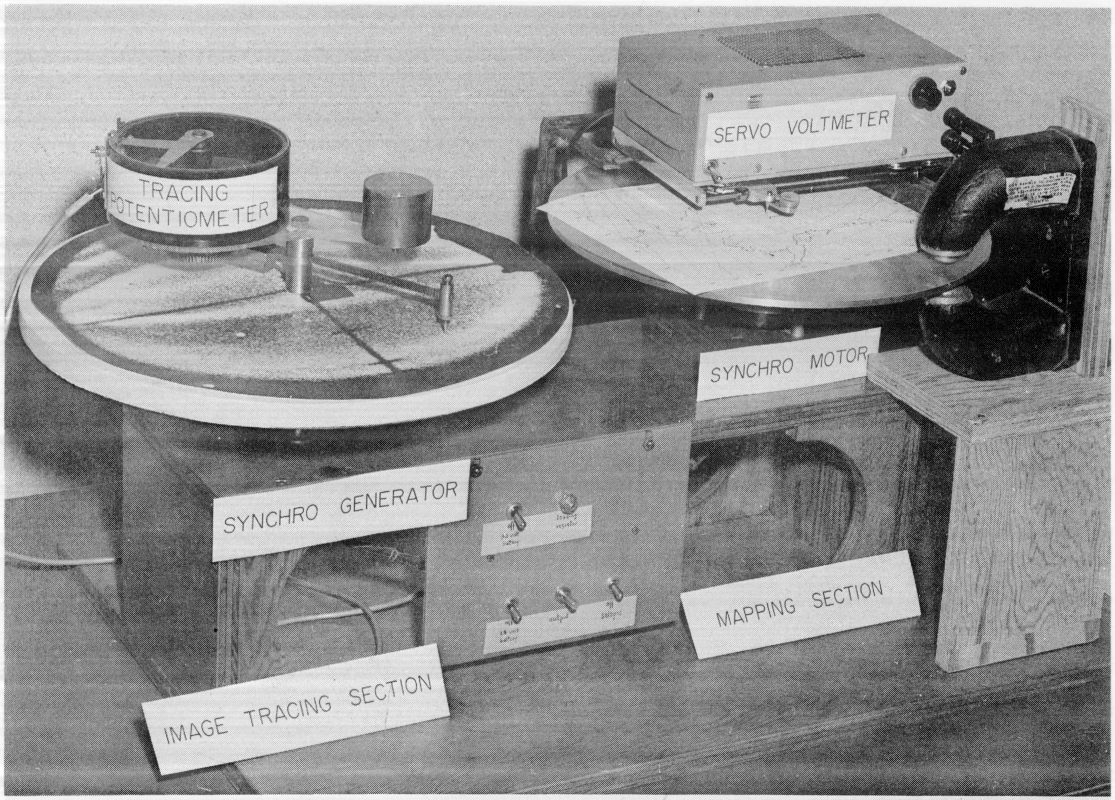
4. The recording span should be adjustable to correspond to different assumed heights of auroras, or to different stations because the scale of a stereographic projection slightly increases away from the center.

5. The device should be simple, rapid, and convenient to operate and generally suitable for operation and maintenance by non-technical personnel.

A preliminary model of an auroral plotter satisfying the above requirements was designed and built in January 1957, at the Geophysical Institute at the University of Alaska. It is named ascagraph from the initials of all-sky camera auroral graph. Although constructed only for testing purposes from locally available equipment, it is basically sound in design and operational procedure. In the following section, the system is first described; then planned modifications for improved performance and operation are discussed.

The prototype of the ascagraph is illustrated in Fig. 15. It can be considered as made of two sections: the image tracing section and the mapping section.

a. Image tracing section - An all-sky camera photograph is projected to a radius of 7 inches on a fixed table. A 3/4 inch aperture in the center of that table accommodates the shaft of a synchro generator fastened below. This synchro generator transfers azimuthal displacement to a corresponding synchro motor in the mapping section. Radial



THE ASCAGRAPH

Figure 15

motion on the tracing table is provided by a rack passing through a hole bored along a diameter of the synchro shaft. This rack engages a gear which in turn actuates a precision 100 K ohm potentiometer, so located that the shadow it casts on the tracing table is always situated in the area opposite to that where the operator is working. The operator then traces the auroral forms in the image by moving a pointer fastened to the rack.

Up to this point, the device is strictly linear and all that has been accomplished is the transfer of mechanical motion into electrical signals. A voltage proportional to angular displacement from an arbitrarily set zero position is generated in the stator of the synchro generator and a voltage proportional to a radial displacement is tapped off the potentiometer. Because the photograph exhibits no azimuthal distortion, the stator of the synchro generator can be connected to the stator of a corresponding synchro motor in the mapping section with a one to one transfer of angular displacement (Fig. 16). The photograph exhibits considerable radial distortion. Therefore, the radial tracing section should generate a voltage proportional not to the radial distance of the aurora on the film, but to the radial distance of that aurora along the surface of the earth. This can be accomplished by using a non-linear potentiometer with a response matching the distortion curve of the all-sky camera (Fig. 14). Of the various methods for constructing non-linear potentiometers, several are unsatisfactory because of the large

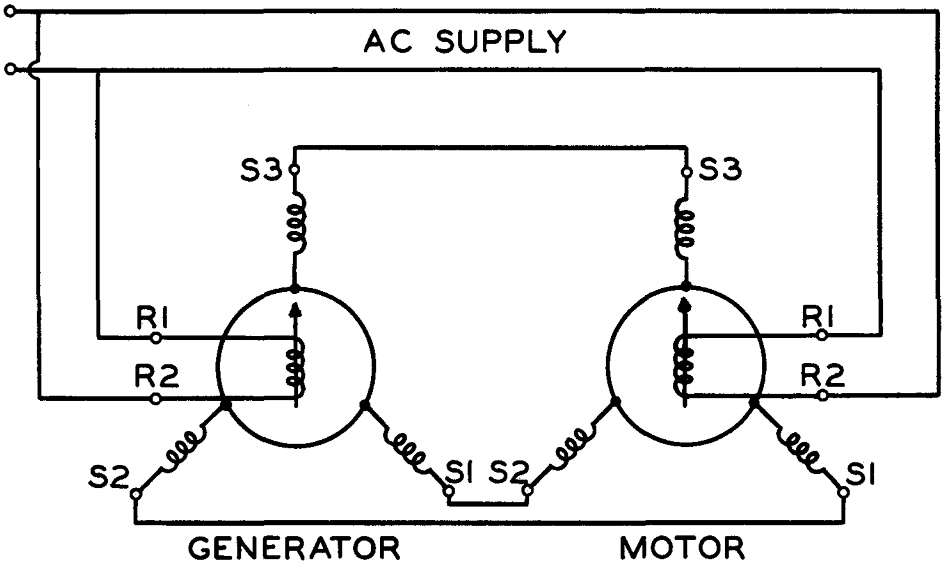


Figure 16 - Circuit Diagram of Synchro Generator-Motor System

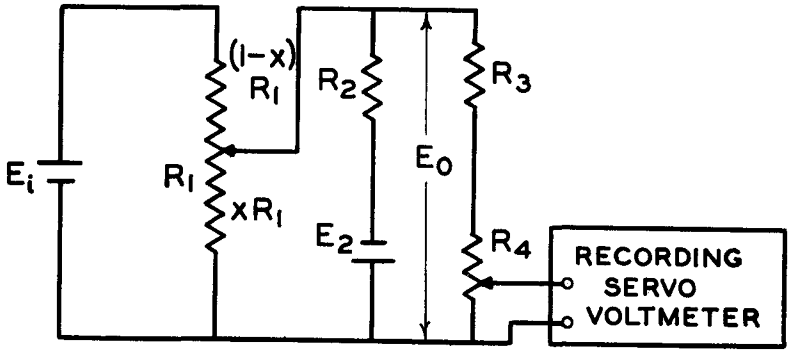


Figure 17 - Circuit Diagram of Tracing Potentiometer System

variation in the slope of the curve. A method that made use of standard locally available parts was found to be satisfactory. It consists of loading the tracing linear potentiometer by means of a resistor (Fig. 17). The function of this loading resistor connected to ground is to drag down the output voltage and to give a positive curvature to a previously linear characteristic. The response of such a loaded potentiometer system is:

$$E_o = \frac{X \dfrac{R_2}{R_1} E_i + (1 - x) E_2}{\dfrac{R_2}{R_1} + x (1 - x)}$$

where R_1 is the tracing potentiometer and R_2 is the loading resistor. R_3 and R_4 in Fig. 17 are a voltage divider. By properly adjusting the parameters and by adding a battery in the loading circuit, it is possible to match the distortion curve of the all-sky camera (Fig. 14) quite satisfactorily down to about 83° zenith distance. Because the curves are made to match at 90°, there is no error at that point. The error between 83° and 90° is again within the film reading accuracy in that severely distorted region.

b. Mapping section - Because the voltages derived from the tracing section are directly proportional to the quantities desired, the mapping section simply transfers these electrical signals to mechanical motion. Transfer of angular displacement is accomplished by a synchro motor. Its shaft is fastened to a 7-inch radius aluminum turntable carefully machined for dynamic balancing. The stators of the two synchros are so interconnected that a given motion of the rotor of the synchro generator causes an equal motion of the turntable in the opposite direction.

A servo-voltmeter (Varian Associate Model G-10) with a one-second full scale response is placed in a fixed position above the turntable so that its recording pen rides on the turntable along a radius. A map of the region over which the auroral display occurred is attached to the turntable. The station location is placed at the center of the turntable with the magnetic meridian through the station as the reference zero azimuth. For zero input, the pen of the servo-voltmeter is adjusted to rest at the center of the turntable. For maximum input (90° zenith distance) the span of the recording pen is adjusted to correspond to the given assumed height of the aurora and to the given station, by means of a voltage divider located at the output of the loaded potentiometer circuit.

The instrument in its present crude state successfully mapped a number of specified graphical patterns. A sample synoptic map drawn by the ascagraph is illustrated in Fig. 18, along with the all-sky camera photograph from which the data was traced. This testing work indicated several defects. Although angular motion in the image tracing section was very smooth and effortless, radial motion offered resistance. When the 2 motions were combined in the tracing of a pattern, the resultant

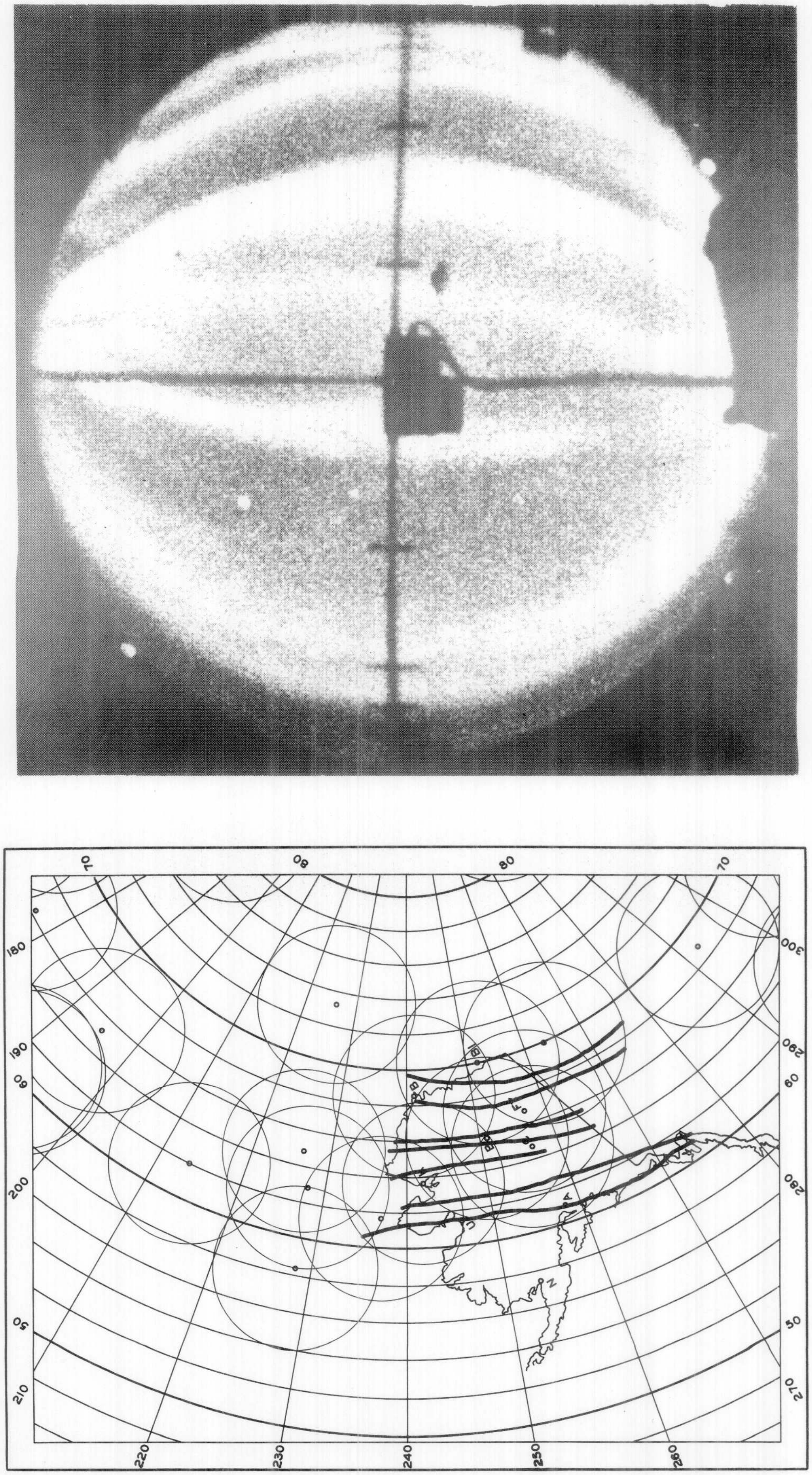


Figure 18 - All-Sky Camera Photograph and Corresponding Synoptic Map

motion was somewhat jerky as the operator could not successfully control simultaneously these unequal frictional resistances in the r and Θ directions. This effect was most pronounced below 80° zenith distance because of the small dispersion of the all-sky camera in that region. This defect will probably be removed by replacing the circular potentiometer and its rack and pinion arrangement with a precision translatory type potentiometer whose center-operated actuating arm is mounted on ball bearings. This system would keep radial frictional resistance to a minimum, comparable to the angular one, and would have the additional advantage of being much more compact so that a smaller shadow would be cast on the screen plane. This potentiometer can be either linear and operated as a loaded potentiometer or it can be non-linear and made to match the distortion curve of the all-sky camera. Both are commercially available.

In the mapping section, due to the inertia of the turntable, the synchro motor had a tendency to overshoot for large angular motion and subsequently would "hunt" about for the correct position. Felt pads pressing against the bottom of the turntable did not help because suitable drag for large motions was too much drag for smaller motions. This problem was satisfactorily resolved by inserting the edge of the aluminum turntable between the magnetic field opposite to that of the magnet. The resultant effect is a velocity damping of the turntable.

A more serious problem was that both the synchro system and the servo voltmeter exhibited "dead zones". That is, the operator did not reach the correct position whether that position was approached from the right or from the left. In the synchro motor, that dead zone has a half-width of about 1 1/2°. In the servo voltmeter, it is approximately 1 1/2% of the recording span. These are inherent limitations in the sensitivity of the instrument. As far as the synchros are concerned, it is possible to increase the sensitivity by gearing up the synchro generator so that it turns faster than the driving shaft and to gear down in the same ratio from the synchro motor. For instance, if a gear ratio of 3:1 is used, the overall accuracy of the system is tripled and the motor should have a dead zone of only 1/2° half-width. For the servo voltmeter, all we can hope for is to obtain an instrument of good sensitivity. The specifications for the Varian Model C-10 recording servo-voltmeter gives a sensitivity (dead zone) of 0.5% of the recording span. It is hoped that with careful adjustment of the servo-voltmeter, this acceptable figure for the sensitivity can be reached.

The tests made with this design indicate that the method is feasible. The few defects present in the preliminary model can be reduced considerably with little modification. After a little experience, skilled personnel should be able to operate the instrument easily, rapidly, and efficiently. One would also expect increased personnel efficiency as it requires much less concentration than the laborious grid-matching method. It is estimated that this method would speed up the process of constructing synoptic maps by a factor of about 20, and with comparable accuracy.