BRL

REPORT No. 883

A Photogrammetric Instrumentation (PI) System for the Determination of Guided Missile Trajectories

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DEPARTMENT OF THE ARMY PROJECT No. 503-06-011
ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0538

BALLISTIC RESEARCH LABORATORIES

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B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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ECHenson/mjp
Aberdeen Proving Ground
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ABSTRACT

The present report describes a photogrammetric instrumentation (PI) system designed for the determination of trajectories of guided missiles and other projectiles.

The basic portion of the main instrument is a precision altazimuth mounted plate camera, originally designated as the Askania phototheodolite.

The modification of this instrument, the design and development of mechanical components and electronic instrumentation for exposure, 200 μs synchronization and auxiliary shutter coding are described.

The results of an analysis of shutter control and accuracy of synchronization are given.

I INTRODUCTION

The need for trajectory measurements of guided missiles by ground photogrammetry has been steadily increasing for the past several years.[1,2,3] Such methods not only provide positional measurements of an accuracy unobtainable by other means but also, in many instances are found to be suited to rapid reduction methods by means of optical-mechanical evaluation instruments.

In order to establish a high precision measuring system, it is necessary to meet the following requirements:

(a) precision geodetic reference data
(b) two or more plate cameras of high optical quality
(c) a method for precise synchronization of exposure
(d) instrumentation to record absolute and relative timing
(e) data reduction facilities.

This report deals only with the projects mentioned under (b), (c) and (d) since the baseline length measurement and data reduction methods are separate development programs.

The photogrammetric instrumentation (PI) system described here was designed and developed for two purposes. One of these was the demand for instrumentation to be used for experimental testing of newly developed methods of measuring guided missile trajectories. The other purpose, of no less importance, was the urgent need for precision positional data on current guided missile programs.

Two Askania phototheodolites (Fig. 1) were available to serve as the photographic instrumentation. Each phototheodolite consists of two major components: a plate camera, and a yoke mount providing an altazimuth movement. These instruments were selected because of their high mechanical-optical quality, and because of their immediate availability.

The original Askania system was designed to suit a specific short baseline condition. However, for the intended use on long baselines, the original system was inadequate. Therefore, it became necessary to design a new synchronization system applicable to long baselines, as well as mechanical components for adapting the cameras to a new control system.

II BASIC SYSTEM DESIGN

The basic photogrammetric instrumentation system consists of two slave stations and one master controlling station, interconnected by wire lines.

The system of synchronization is designed to force one camera exposure time to agree with that of another camera controlled by a frequency standard. Each camera employs a rotating disc shutter which indicates its actual mechanical shaft position by means of a brush and commutator (Fig. 2). The master station scope monitor (Fig. 3) indicates the accuracy of synchronization by displaying coincidence of the individual brush pulses. The time of exposure of the camera which is not controlled by the frequency standard is varied by changing the input power characteristics to the camera motor until synchronization is achieved.

The master station instrumentation consists of a phase shifting device to synchronize the two slave station cameras, a recorder to obtain the absolute and relative times of exposure, an automatic star trail shutter control instrument and a coder to operate the auxiliary capping shutters.

Each slave station consists of the Askania instrument (Fig. 1), a 60 cycle amplification system to drive the camera, a unit to control various dial and target lamps, and a power relay system to operate the auxiliary shutter. The Askania consists of two major parts: a plate camera in which the orientation of the lens with respect to the focal plane is fixed and determinable and a yoke mount to provide an azimuth and elevation movement. The azimuth and elevation angles are read directly from precision glass scales. Also incorporated in the instrument are various dial lamps, fiducial lamps and a target lamp, all of which are controlled at the slave station. An auxiliary shutter (Fig. 4) provided for coding purposes (Table 1) can be controlled from the master station, or either of the slave stations.

The PI instrumentation is designed to operate without additional equipment on baseline lengths up to 100 miles when the slave stations are connected by four standard telephone lines. The master station may be located at either slave station, or at some other desired position.

III MASTER STATION INSTRUMENTATION

The photogrammetric instrumentation control station (Fig. 5) performs two basic functions:

(a) the control and synchronization of cameras
(b) the recording of shutter exposures with respect to time.

The instrumentation which accomplishes these two functions consists of the following four assemblies:

(a) a phase shifting and monitoring system (Fig. 3)
(b) a coding unit to operate auxiliary shutters (Fig. 3)
(c) instruments for recording relative and absolute timing (Fig. 6)
(d) an automatic control for star trail recording (Fig. 7)

Each assembly performs a specific function and, with the exception of power supplies and line amplifiers, can be operated as a separate unit. The fundamental unit in the master station is the Gibbs 60 cycle frequency standard. This standard supplies the signal for all synchronization circuits and is also used in the star trail recording operation. The output of the frequency standard is fed directly to the line amplifier for PI-A station so that the "A" station camera shutter motor will follow the phase of the frequency standard. The synchronization system circuits were designed to operate in the following manner:

Each camera contains a brush and commutator which indicate the actual shaft position of the rotating disc shutters in the form of a pulse. This pulse signal is sent from both slave stations to the master station in order to indicate the time of exposure.

The synchronization system includes a dual beam Dumont oscilloscope to display the shutter pulses and also to indicate the phases of both the frequency standard and the multivibrator.

The camera driving frequency for PI-B station is the direct output of a multivibrator, suitably reshaped into a sine wave. This multivibrator may be either free-running, with frequency adjustable manually between 58 and 62 cycles per second, or it may be synchronized with the frequency standard at 60 cycles per second. In the latter case, a continuously variable phase shifter interposed between the multivibrator and frequency standard provides for manually delaying the phase of the multivibrator synchronizing pulse over a range in excess of 360 electrical degrees with respect to the phase of the frequency standard.

Synchronization of camera shutters may be achieved by - (a) speeding up or slowing down "B" camera motor by manipulation of the free-running multivibrator frequency until the "B" shutter pulse, as viewed on the monitoring scope at the Master Station, shows approximate coincidence with the "A" shutter pulse; (b) adjusting the phase of the multivibrator synchronizing pulse to make it coincident with the multivibrator switchover instant; (c) closing synchronizing circuit; (d) making final adjustment of phase delay to bring "B" shutter pulse into exact coincidence with "A" pulse.

Also included in the synchronization system is a mixing and monitoring circuit. By means of this unit the operator at the master station can observe the input and output characteristics of various circuits as well as the combined shutter pulses. The system not only allows complete monitoring, but also aids in locating component failures.

The output of the line amplifiers is of such capacity that a maximum of 50 miles of open wire line (as used at WSPG) or 20 miles of spiral four cable assembly may be employed between the master station and each slave station. Therefore, when the master station is located at the center of the baseline, the PI-AB system will operate a 100 mile baseline without additional equipment. Four wire line circuits are sufficient to operate the entire system since provision is made for simplexing the communication and shutter control circuits.

The original Askania system permitted picture repetition rates of 12, 9, 6, 3 and 1 picture per second, which in turn fixed exposure durations of 1/300, 1/225, 1/150, 1/75 and 1/25 second, respectively. Since the camera boxes and shutter discs were designed for these specific speeds, and the maximum possible speed is limited by bearing and vibrations effects, it was necessary to design instrumentation which would allow a choice of repetition rates independent of exposure duration. The selection of repetition rates for various exposure durations is called "coding", and the instrumentation to perform this operation is called the "Coder". This coder operates an auxiliary capping shutter which codes the synchronized disc shutters, and also operates in conjunction with a cam control for recording star trails.

For the operation of an auxiliary shutter the coder utilizes a delay circuit, a binary counting circuit and a gating circuit followed by a cathode follower. The combined shutter pulse is first fed to the delay circuit, where a new pulse is formed. This pulse is delayed to correspond with the maximum duration of shutter opening. The delayed pulse is then fed into a binary counter circuit which has a maximum count of 32. Each stage of this counter is provided with a take-off jack. The output of this take-off jack is followed by a gating circuit, the output of which is utilized to drive the cathode follower.

The coder operates as follows: The combined shutter pulses received from the mixer circuit are delayed and counted. After a predetermined number of disc openings have been counted, the gating circuit is triggered, and the auxiliary shutter is energized by the cathode follower, allowing the next disc opening to expose the camera plate. The same pulse which corresponds to the exposure also closes the auxiliary shutter so that the following disc opening will not expose the plate. The coder can be set to take a specific exposure in a series of disc openings or to drop an exposure in a series of disc openings. The coder can also be pre-set to combine the two preceding operations.

The coder may be used also in the recording of star trails. In this operation, the coder operates the auxiliary shutters by a one-per-second pulse. Since the WWV signal may fade or be indistinguishable because of interference, a one-per-second pulse simulator was designed and built. This unit is synchronized with WWV prior to the star-trail recording operation.[4)] The duration and sequence of opening of the auxiliary shutter is controlled by a cam. In order to avoid interpolation between full seconds for shutter openings, it is desirable to utilize the one second signal for gating the cathode follower. The coder performs this operation automatically and the results of the auxiliary shutter coding are recorded on a dual channel brush oscillograph.

Recording facilities in the PI master station consist of three assemblies: (a) a modified General Radio 35mm camera; (b) four R1130 cavity flash tubes; and (c) a 5 inch Dumont oscilloscope.

Modifications of the General Radio camera permit the use of 2000 ft. magazines and adapt the camera to synchronous motor drive. The synchronous motor is powered by a 60 cycle frequency standard causing the film to travel at a constant speed. This method permits the film sprocket perforations to represent a secondary time standard.

Each of the R-1130 tubes is used to record a different signal. One tube is used to record the time at which the auxiliary shutter is operated. A second tube records the WSPG binary and a third tube the superimposed 100 and 2 cycle timing codes. The fourth tube may be used for recording any additional signal needed for special problems.

The Dumont oscilloscope tube displays all combined shutter pulses and indicates the accuracy of camera synchronization. The pulses are displayed by means of a horizontal axis deflection, the sweep being provided by the film movement of the recording camera. Orientation of the four flash tubes on the same horizontal axis furnishes a common time base for all signals.

Another feature of the master station is the final output control. The circuitry allows all adjustments in the master station to be preset and tested without sending a command signal to the slave stations auxiliary shutters. Because of this control circuit, it is impossible to energize the auxiliary shutters without simultaneously starting the recorder.

IV SLAVE STATION INSTRUMENTATION

The slave stations are identical in design and construction. Either slave station may be controlled by the frequency standard or by the phase shifter. In order to describe the operation of the system, B station will be designated as the variable station and A as the one controlled by the frequency standard.

The slave station instrumentation (Fig. 8) consists of the following four assemblies:

(a) the Askania instrument (Fig. 1)
(b) a system of amplifiers to drive the camera motors (Fig. 9)
(c) an auxiliary shutter and its associated circuits (Fig. 4)
(d) fiducial, dial and target light circuits (Fig. 9)

As has been stated before, the Askania instrument consists of two major components: a plate camera of high optical-mechanical quality, and a yoke mount providing an elevation-azimuth movement. Orientation of the lens with respect to the focal plane is maintained through the use of a single casting. An auxiliary leaf shutter in the camera can be operated manually or by remote control from the master station.

The iris diaphragm is adjustable from f:5.5 to f:55. A precision glass circle to indicate elevation angles is located on the camera box. This circle is divided into 400 divisions (grad system) each of which can be set to 2-1/2 seconds of arc. Four fiducial marks are projected onto the focal plane. The elevation angle, focal length of the lens and two channels of numerical coding are also registered on the plate during the fiducial mark exposure. The rotating-disc-shutter assembly consists of two rotating discs, each driven by a separate selsyn receiver motor. One disc determines the picture repetition rate and the other disc determines the exposure duration. Mounted on each disc shaft are a brush and commutator (Fig. 2) which are connected in a series circuit so that a shutter pulse will be formed only when the openings in both discs are in a specific position. The selsyn receiver motors are driven from selsyn transmitters located in the slave station transmission assembly (Fig. 10).

The camera mount consists of two major assemblies. A yoke type azimuth mount supports the camera trunnion bearings. The yoke is in turn supported by a vertical conical bearing, which is contained in the yoke base casting. The camera mount is provided with a precision glass circle to indicate the azimuth orientation. This circle is also divided into 400 divisions each of which can be set to 2-1/2 seconds of arc. An azimuth orientation telescope is provided for orienting each instrument with respect to the baseline. Incorporated on the bottom of the mount is a target lamp, which together with the azimuth telescope, orients the cameras. Dial lamps for circle illumination are controlled by the slave station instrumentation.

The auxiliary shutters are of the venetian blind type. They are solenoid operated and have an operation cycle time of approximately twenty-five milliseconds. The shutter which is mounted externally on the camera, is counterbalanced for stability. Other accessories include a field-adjustment frame which is used for orientation of the camera with respect to the line-of-sight of the azimuth telescope, a striding level to measure the amount of tilt of the horizontal axis, and a focal plane level which is used to establish the optical axis horizontal. All of these leveling devices employ 5-second bubbles.

The sixty cycle amplification assembly for driving the camera selsyns is composed of the following five sub-assemblies:

(a) line distribution and monitor circuits.
(b) a 20 watt pre-amplifier.
(c) a Gates 300 watt power amplifier.
(d) an automatic starting circuit for the synchronous motor.
(e) a gear transmission assembly controlling exposure repetition rates.

The line distribution and monitor circuits provide a means of monitoring input and output signals for all major circuits. This feature is especially desirable for detection of component failures and maintenance problems. During normal operation of the cameras, the brush pulse is monitored enabling the slave station operator to detect immediately any irregularity. The simplex terminations of the intercom and the auxiliary shutter control circuit are made in the line distribution circuit.

A 20 watt pre-amplifier is used to drive the Gates 300 watt power amplifier. The pre-amplifier, of conventional design, employs two 807 tubes in a push-pull circuit. The Gates 300 watt amplifier employs four 810 tubes in a push-pull parallel circuit. This amplifier is internally regulated by a Sorenson 115 volt 60 cycle voltage regulator.

The output of the Gates amplifier provides the power to drive a 60 cycle single-phase 1/12 hp. synchronous motor. This motor is in turn used to drive the selsyn transmitters in the gear transmission assembly. Experimental results from testing different selsyn motors indicated the necessity for modification in order to adapt these units to high speed operation. Therefore, the selsyn rotor brush assembly was redesigned, the rotor bearings were changed, and a method was developed for slowly accelerating the synchronous motor to synchronous speed in order to permit the receivers to follow the transmitter signals. The slow acceleration technique is accomplished by use of the motor starter circuit. A series of time-delay relays is utilized to change the voltage applied to a 1/20 hp. universal motor. The universal motor, geared to the synchronous motor, is electrically disconnected from the amplifier circuit when synchronous speed is reached. Full voltage is applied to the synchronous motor before the universal motor is disconnected.

The gear transmission unit was designed and built to withstand desert operation conditions and to require a minimum of maintenance. The gears, fabricated from linen micarta, are lubricated with Standard Oil of California "Caluol" grease. Laboratory tests indicate that a periodic maintenance check after every 400 hours of operation is advisable. The overall gear train accuracy at 12 pictures per second is 30 μs, and during the first 400 hours of operation, no decrease in this accuracy was measurable. The gears are easily changed and are visible for inspection during operation. The selsyn transmitters were also modified in the same manner as the receivers.

The auxiliary shutter is energized by a power relay circuit. The coder pulse received from the master station is used to operate a 275-B Western Electric mercury relay which has an operation time of four milliseconds. The relay is used as a switch to connect 28 volts direct current to the shutter solenoid. It can be controlled by the slave station, or set to respond to the master station coder pulse.

All dial lamps and the target lamp are controlled and powered at the slave stations. The fiducial marks are exposed by an automatic timing circuit. In order to provide for variable exposure, the voltage applied to the fiducial lamp is changed by means of a variac. Reproducible results with this system were obtained from laboratory tests.

Intercoms provided in each slave station are simplexed with the 60 cycle signal line.

V OPERATIONAL PROCEDURE

The PI system instrumentation comprises a complete measuring system. After setting up the cameras, both are started and are brought into synchronisation by the master station. The coder is then set to perform a predetermined operation and the auxiliary shutter relay circuits in the slave stations are switched to respond to the coder pulse. Once the preceding steps are accomplished, the final switching to begin photographing and recording is controlled by the master station. For star trail recording (Fig. 11) the rotating disc shutters are locked in an open position[3].

At the present time, the PI system is being field tested and a detailed instruction manual for operation is being prepared.

VI SYNCHRONIZATION ACCURACY

Following a field simulated synchronization test the recorder film was analyzed for synchronization errors. For this test the slave stations were connected to the master station through line attenuators, which were designed to approximate a 100 mile baseline of open wire line (.128" Cu) as used at WSPG. A total of 3840 combined shutter pulses (Fig. 12) were measured for the synchronization error (Δt). The resulting frequencies observed over an operation time of about 5.3 minutes were as follows:

$\Delta t < 50\ \mu s$	$n = 3680$	or	95.8 %
$50\ \mu s \leq \Delta t < 100\ \mu s$	$n = 115$	or	3 %
$100\ \mu s \leq \Delta t < 150\ \mu s$	$n = 38$	or	1 %
$150\ \mu s \leq \Delta t < 200\ \mu s$	$n = 7$	or	0.2 %
$\Delta t \geq 200\ \mu s$	$n = 0$	or	0 %

where n is the number of pulses

After any of the above irregularities, the system became completely damped within 1/3 sec. Since all circuits were connected to commercial power lines, the local fluctuations tend to influence the system.

Whereas the original Askania synchronization control was capable of maintaining an accuracy of 1000 µs, the new PI system maintained an accuracy of 200 µs during the test period.

Another test was performed in order to analyze the venetian blind auxiliary shutters operation. For this purpose the auxiliary shutter was separated from the camera, and separate photocells were placed behind both the camera and the shutter. These two signals were mixed and the resultant signal was photographed on an oscilloscope. From Fig. 13, it is apparent that the auxiliary shutter opens before the selected disc opening, and closes before the next disc opening. This illustrates the lack of need for auxiliary shutter synchronization. Various coding patterns are shown in this figure.

In order to illustrate the effect of non-synchronization, a photocell was placed behind the lens of each camera and the phase shifter purposely varied to cause a separation between individual camera exposures. The output from these photocells was mixed and photographed on an oscilloscope. Fig. 14 shows both individual photocell signals as well as the effect of non-synchronization for errors of 1, 2, 3 and 4 milliseconds.

Since no modifications were made on the camera axis, the original accuracy should be maintained. Tests to determine the internal camera accuracy will be made at a later date.

VII SUMMARY

The PI instrumentation system provides a method for the determination of trajectories of guided missiles and other projectiles by means of two precision plate camera theodolites. These cameras, set up on an accurately measured baseline, are calibrated and oriented by means of photographed star trails or terrestrial reference points.[2]

The camera shutters are synchronized to an accuracy of 200 μs, and are coded by means of an auxiliary capping shutter. All events are recorded with respect to absolute and relative timing.

This method of recording trajectory data lends itself to rapid reduction by means of either optical-mechanical evaluation instruments or analytical methods using high speed calculating machines.

At the present time, the first PI system, designated PI-AB, is being tested under actual field conditions. New systems of PI instrumentation are being developed on the basis of the experience gained from this system.

ACKNOWLEDGMENTS

The author is indebted to Messrs. R. E. A. Putnam and R.L. Vitek for basic circuit designs for synchronization, coding, line transmission and recording, and to Dr. H. Schmid for his interest and suggestions throughout this work.

Messrs. Albert Ratush, Rolph Townshend and Ralph Wheeler deserve special mention for their valued assistance on engineering detail and construction.

Ellis C. Henson

TABLE 1 A

FREQUENCY OF DISC SHUTTER OPENINGS

Take code Pulses per Venetian Blind Shutter Opening	Exposures / Seconds: 12	9	6	3	1
1	12 / 1	9 / 1	6 / 1	3 / 1	1 / 1
2	6 / 1	9 / 2	3 / 1	3 / 2	1 / 2
4	3 / 1	9 / 4	3 / 2	3 / 4	1 / 4
8	3 / 2	9 / 8	3 / 4	3 / 8	1 / 8
16	3 / 4	9 / 16	3 / 8	3 / 16	1 / 16
32	3 / 8	9 / 32	3 / 16	3 / 32	1 / 32

Actual Exposures

Table 1 A lists the number of exposures per unit time for the different combinations of take code and disc shutter frequency. As an example, assume that the disc shutter is opening 12 times per second. If the Take code is set at 4 pulses per exposure, there will be three exposures every second.

TABLE 1 B

TAKE CODE

PULSES PER EXPOSURE

Drop Code Pulses per drop	1	2	4	8	16	32
1	-	-	-	-	-	-
2	1	-	-	-	-	-
4	3	1	-	-	-	-
8	7	3	1	-	-	-
16	15	7	3	1	-	-
32	31	15	7	3	1	-

Exposures between drops

The relation between the Take code and the Drop code is shown in Table 1 B. If pictures are being taken at a rate of one every fourth pulse (Take code 4) and the exposure that would occur on every sixteenth pulse is dropped (Drop code 16) there will be 3 exposures between each drop.

This coding would result in a repetition rate of 3 exposures per second with every fourth exposure dropped.

REFERENCES

1. L. A. Delsasso, L. G. deBey, D. Reuyl, Full-Scale Free-Flight Ballistic Measurements of Guided Missiles, BRL Report No. 660, January, 1948.

2. H. Schmid, Spatial Triangulation by Means of Photogrammetry, BRL Report No. 784, October 1951.

3. H. Schmid, An Analytical Treatment of the Orientation of a Photogrammetric Camera, BRL Report No. 880, (now being published)

4. John G. Schmidt, An Instrument for the Automatic Operation of Star Trail Recording Cameras, BRL Memo Report No. 732 (now being published)

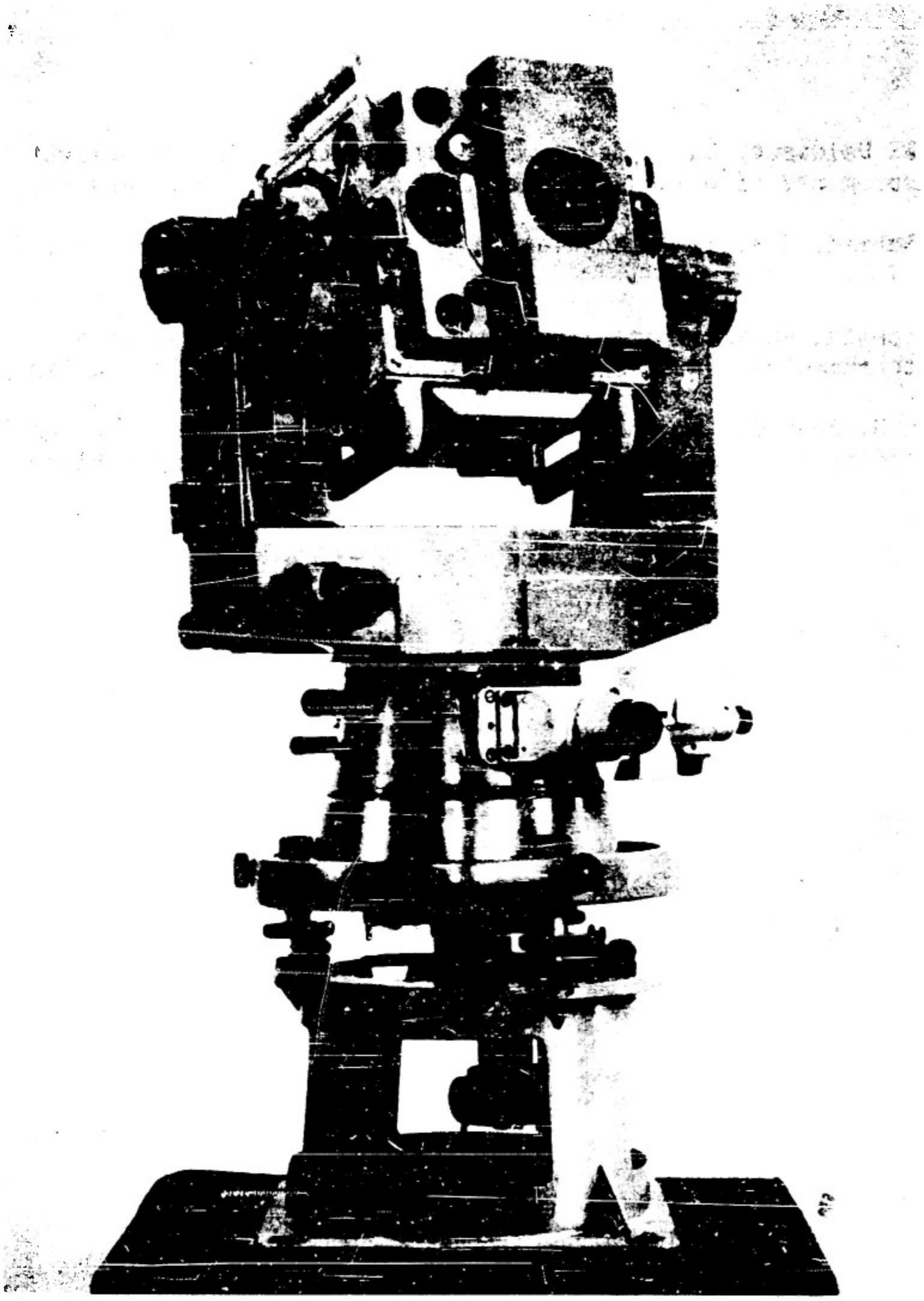
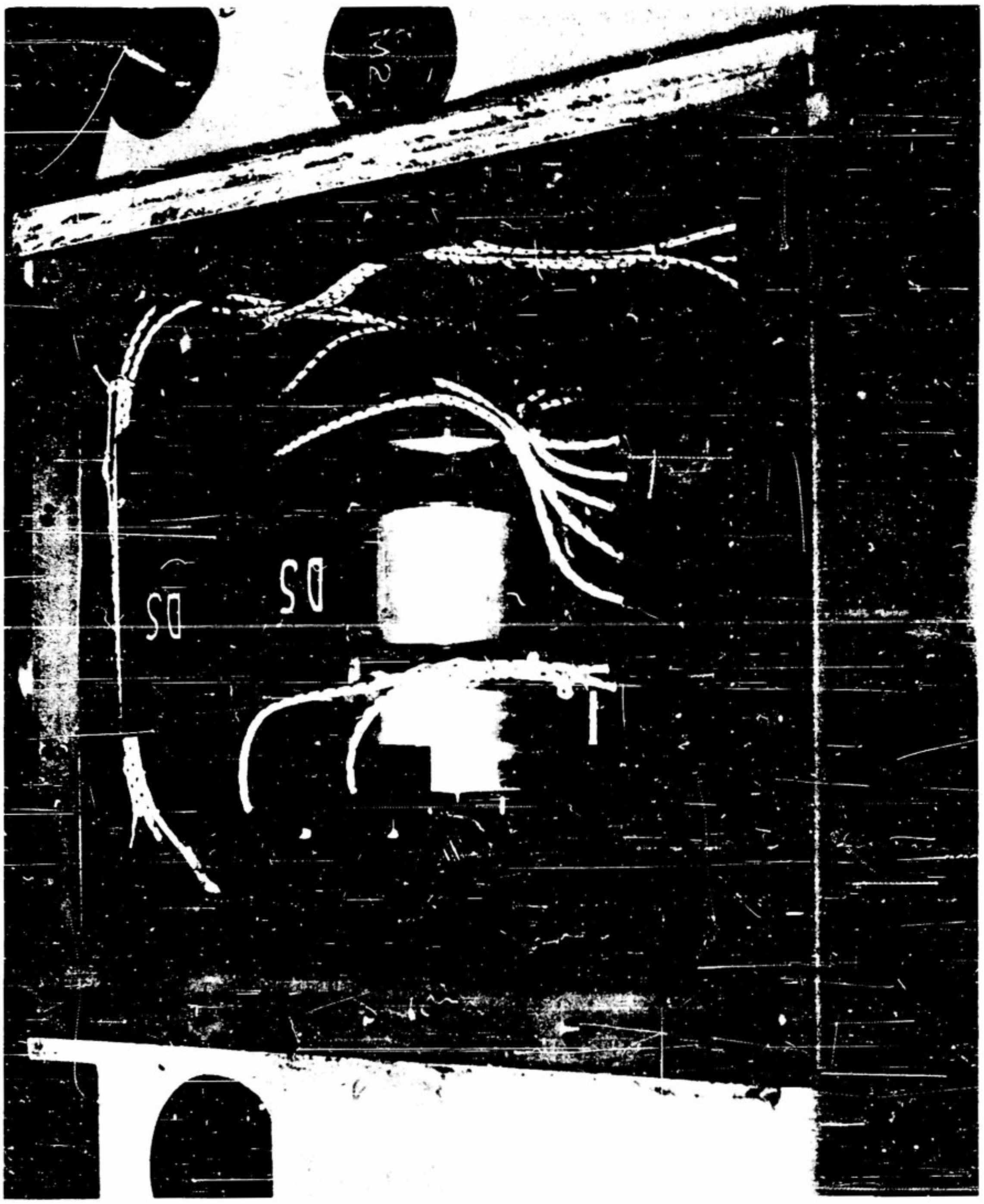
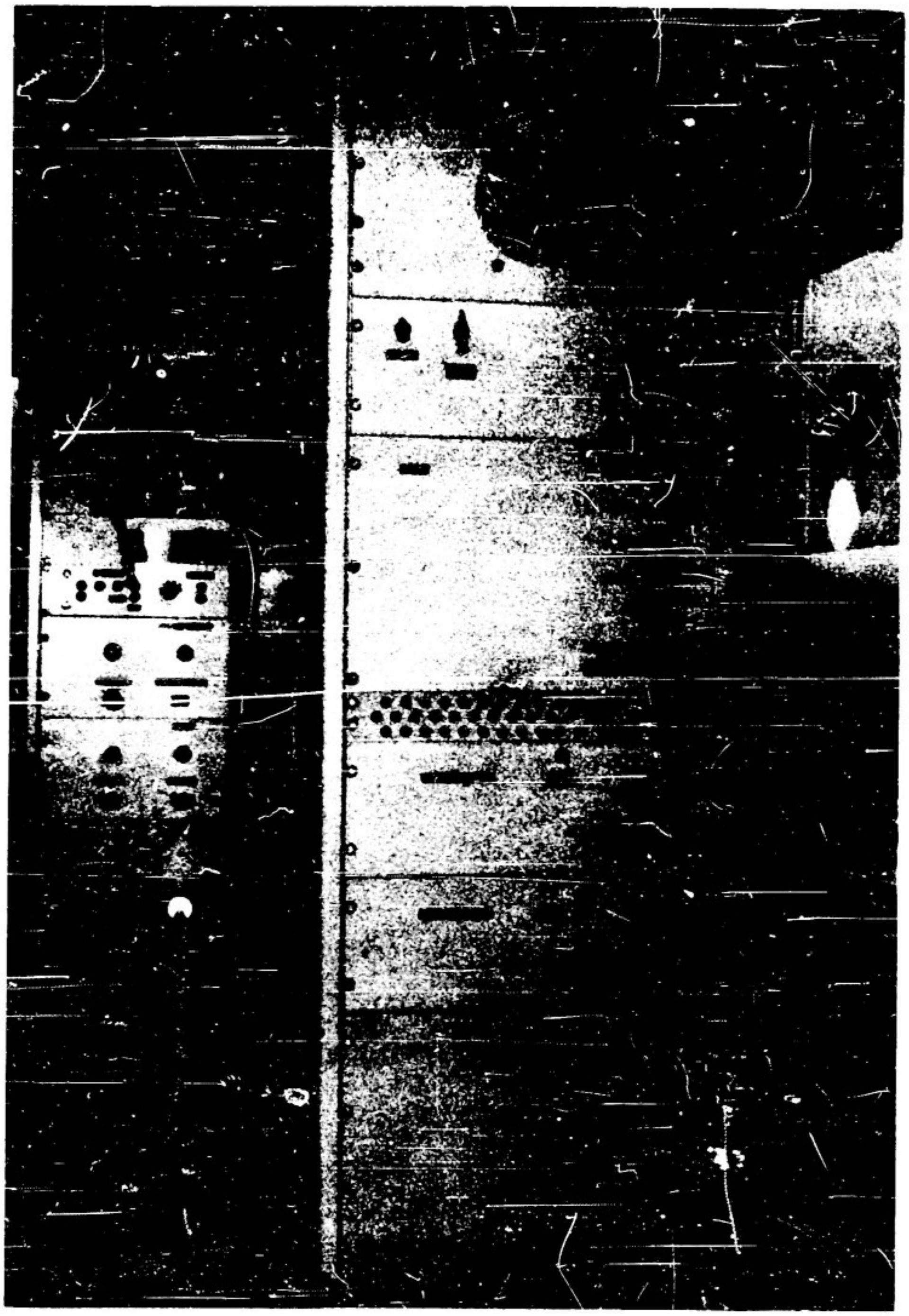


FIG. 1.





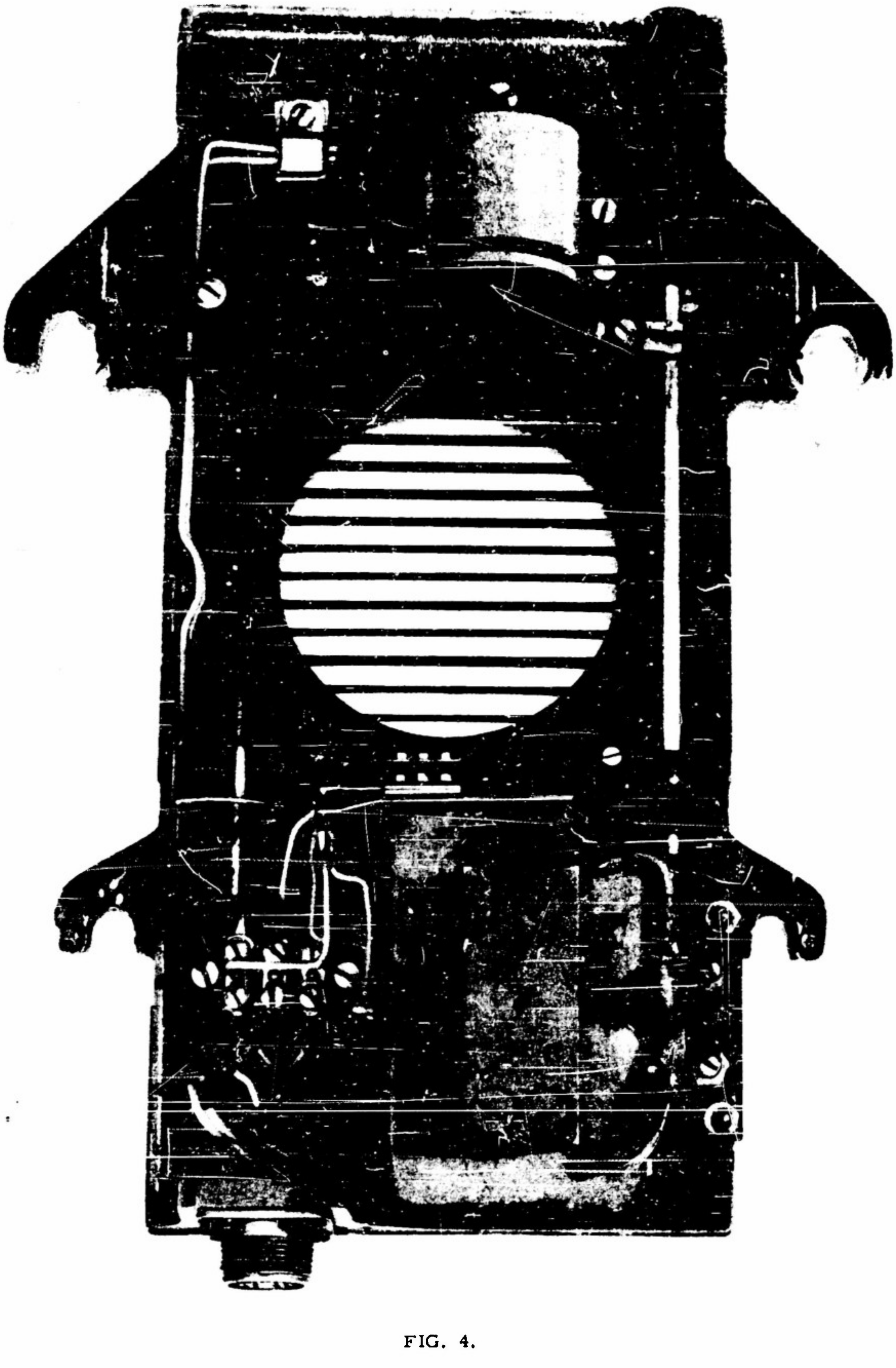
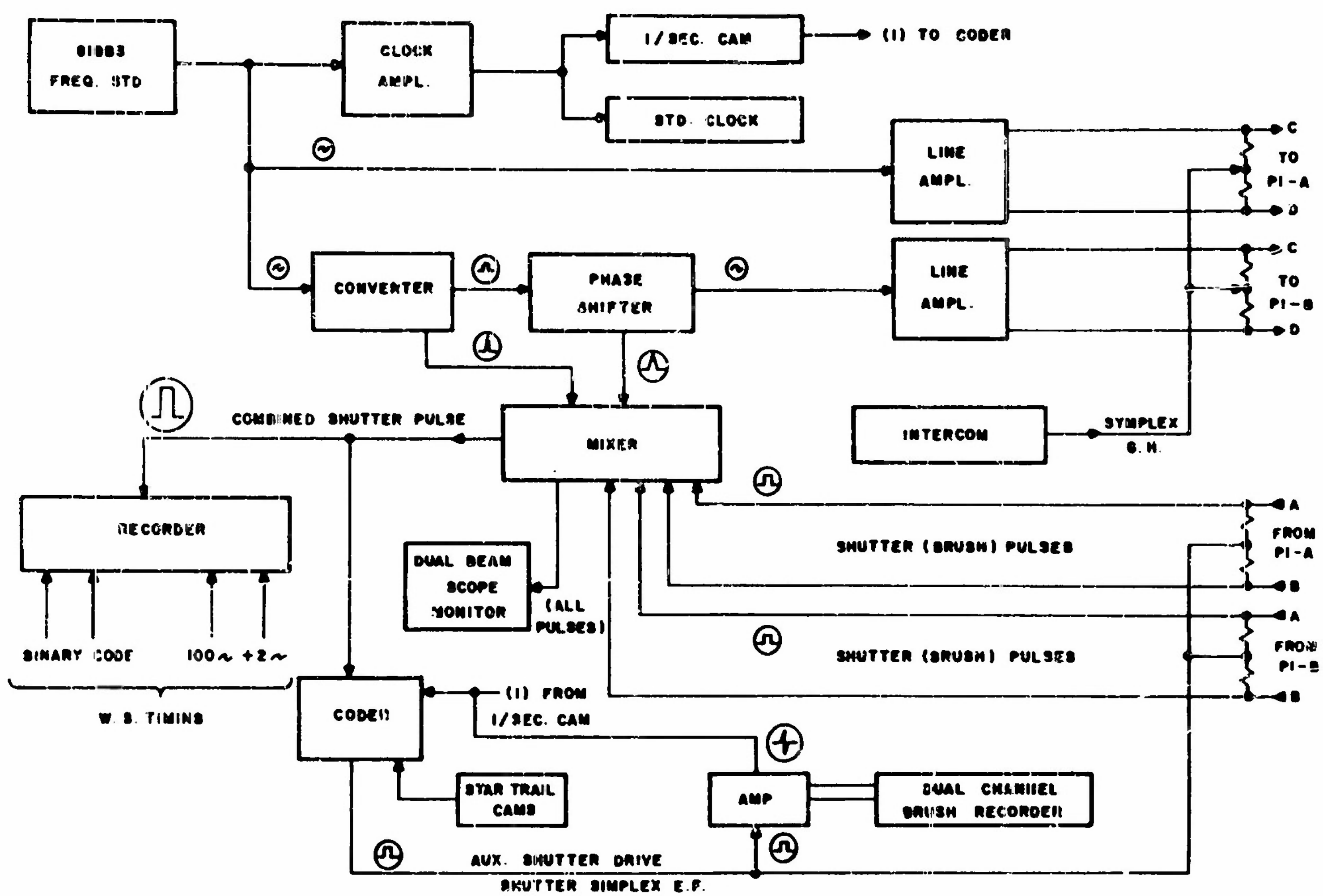


FIG. 4.



MASTER STATION

FIG. 5

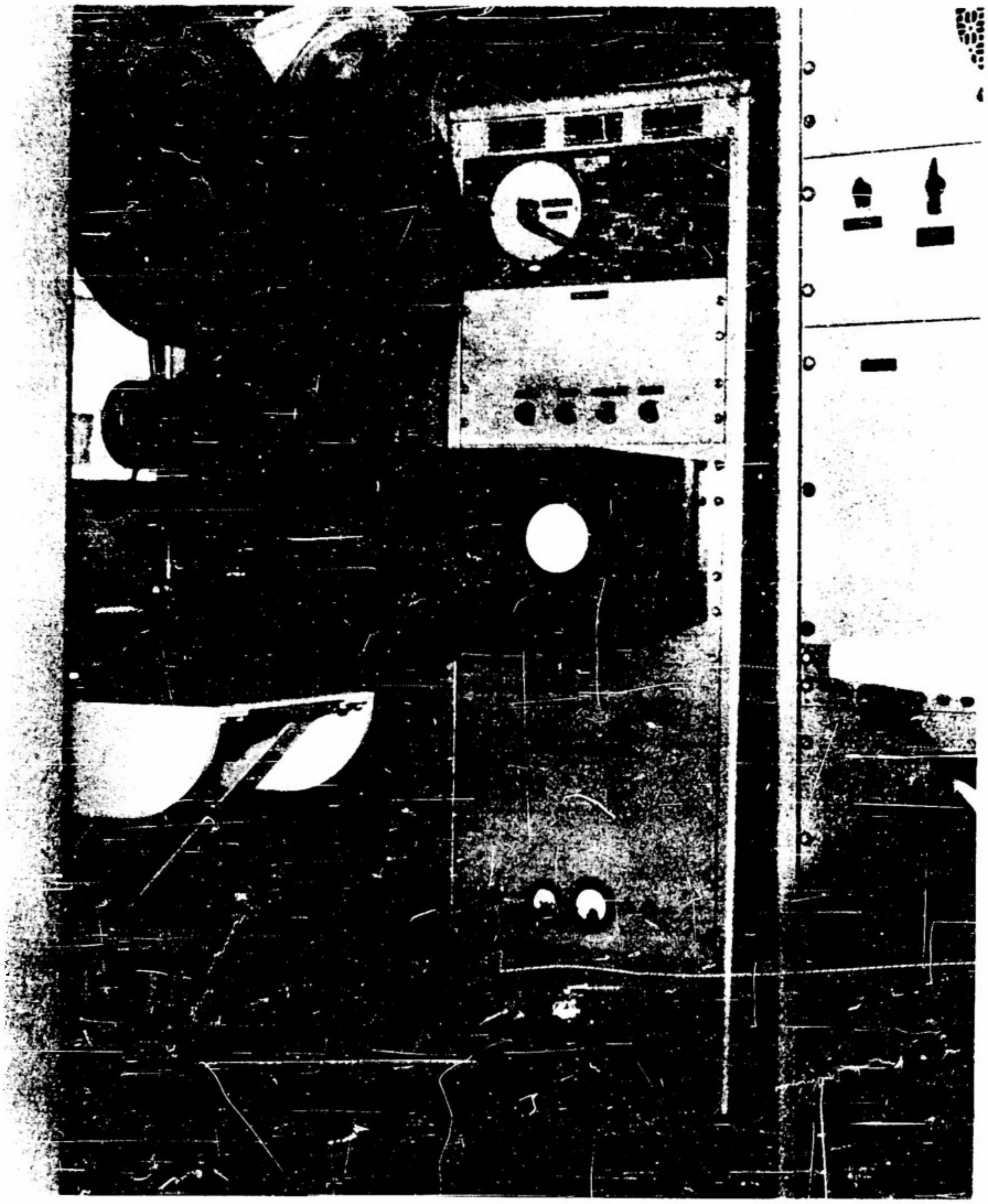


FIG. 6.

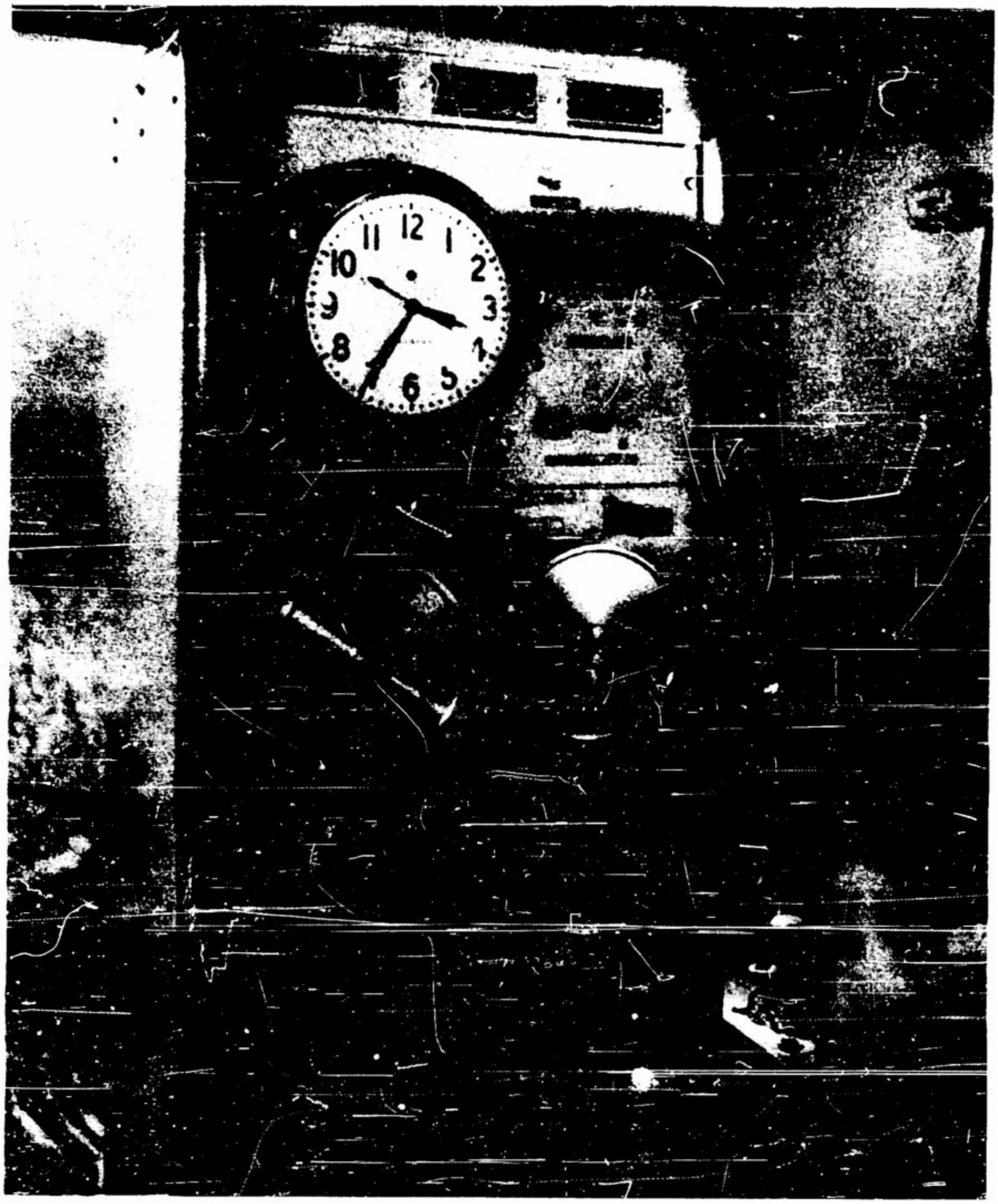
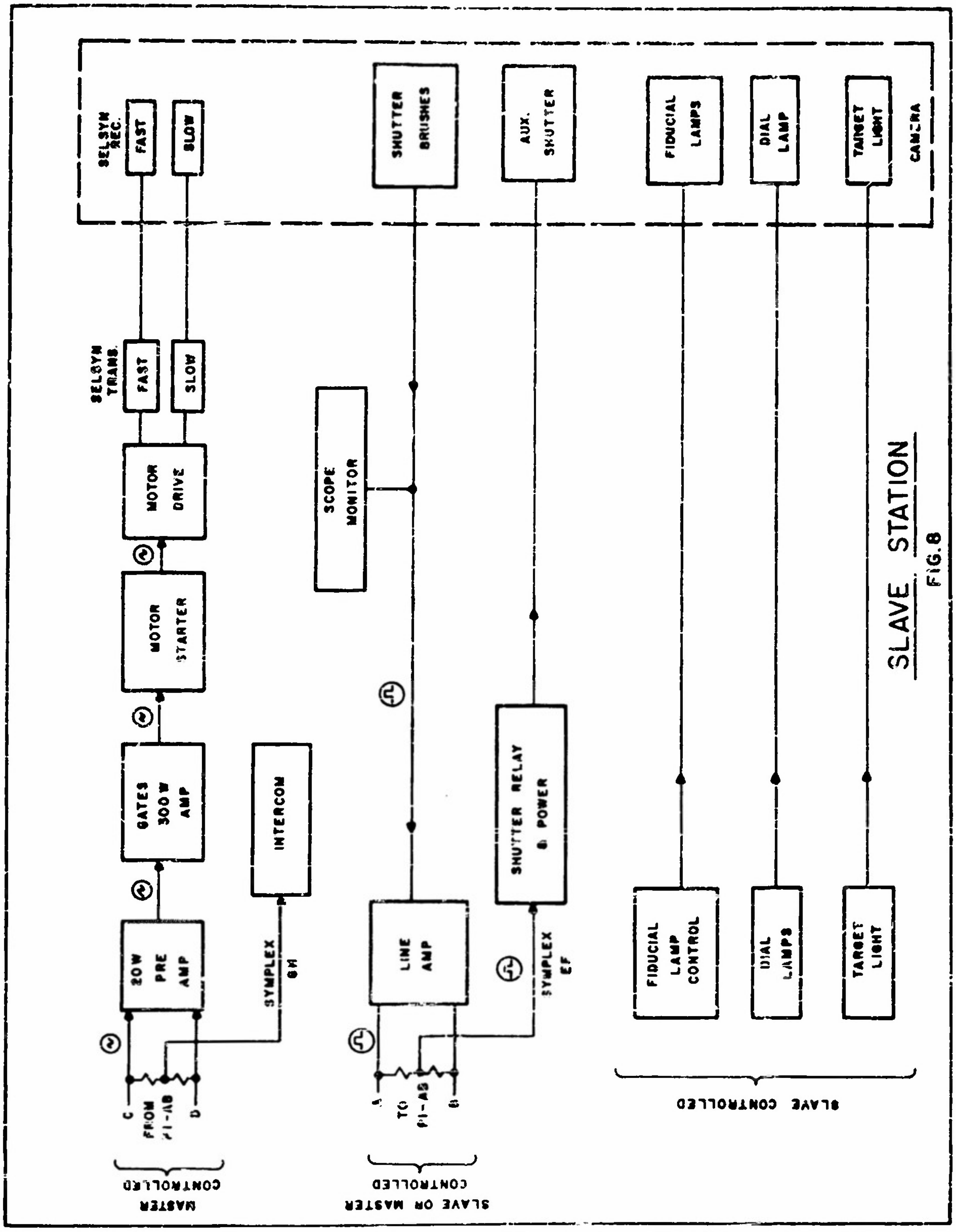


FIG. 7.



SLAVE STATION
FIG. 8

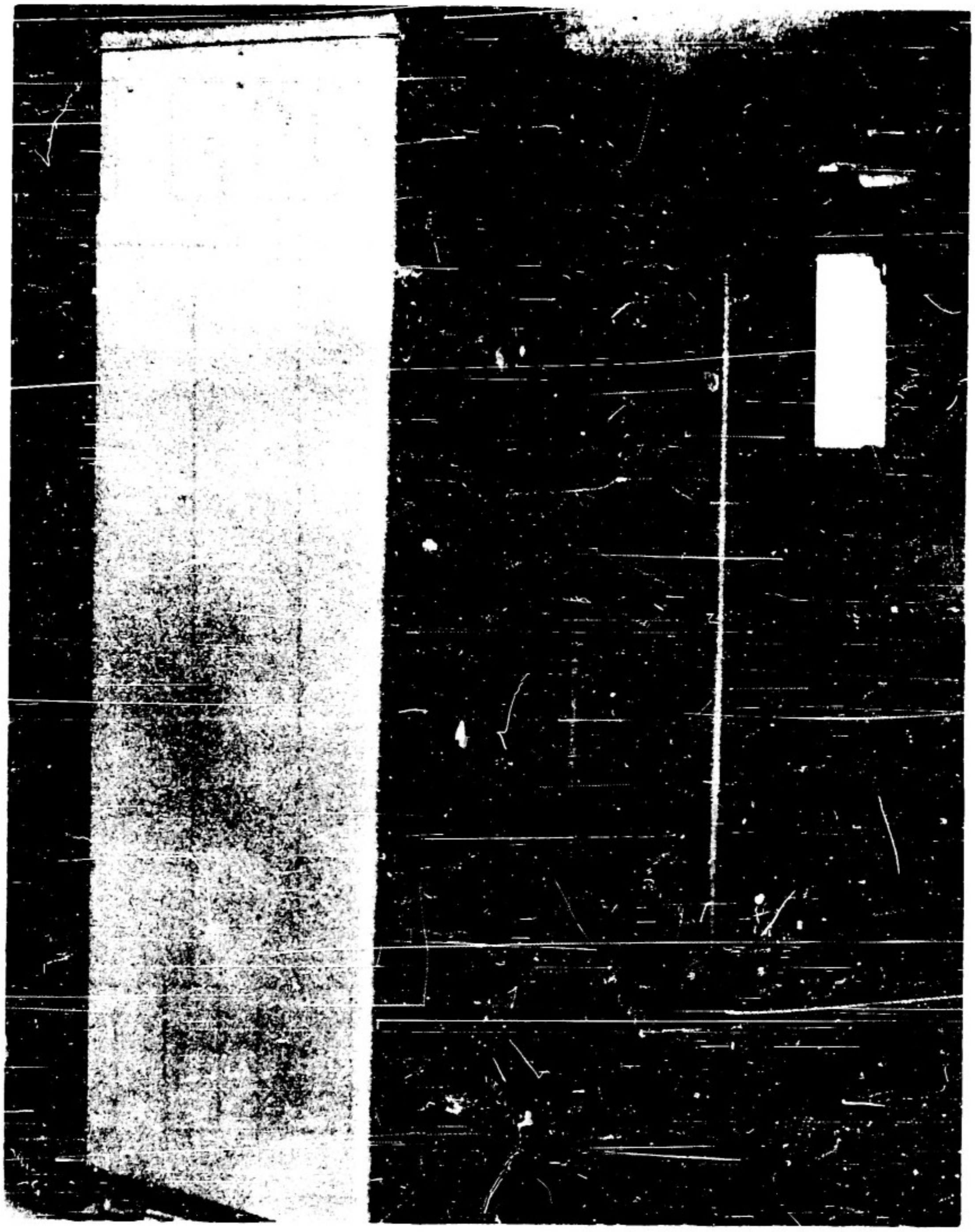


FIG. 9.

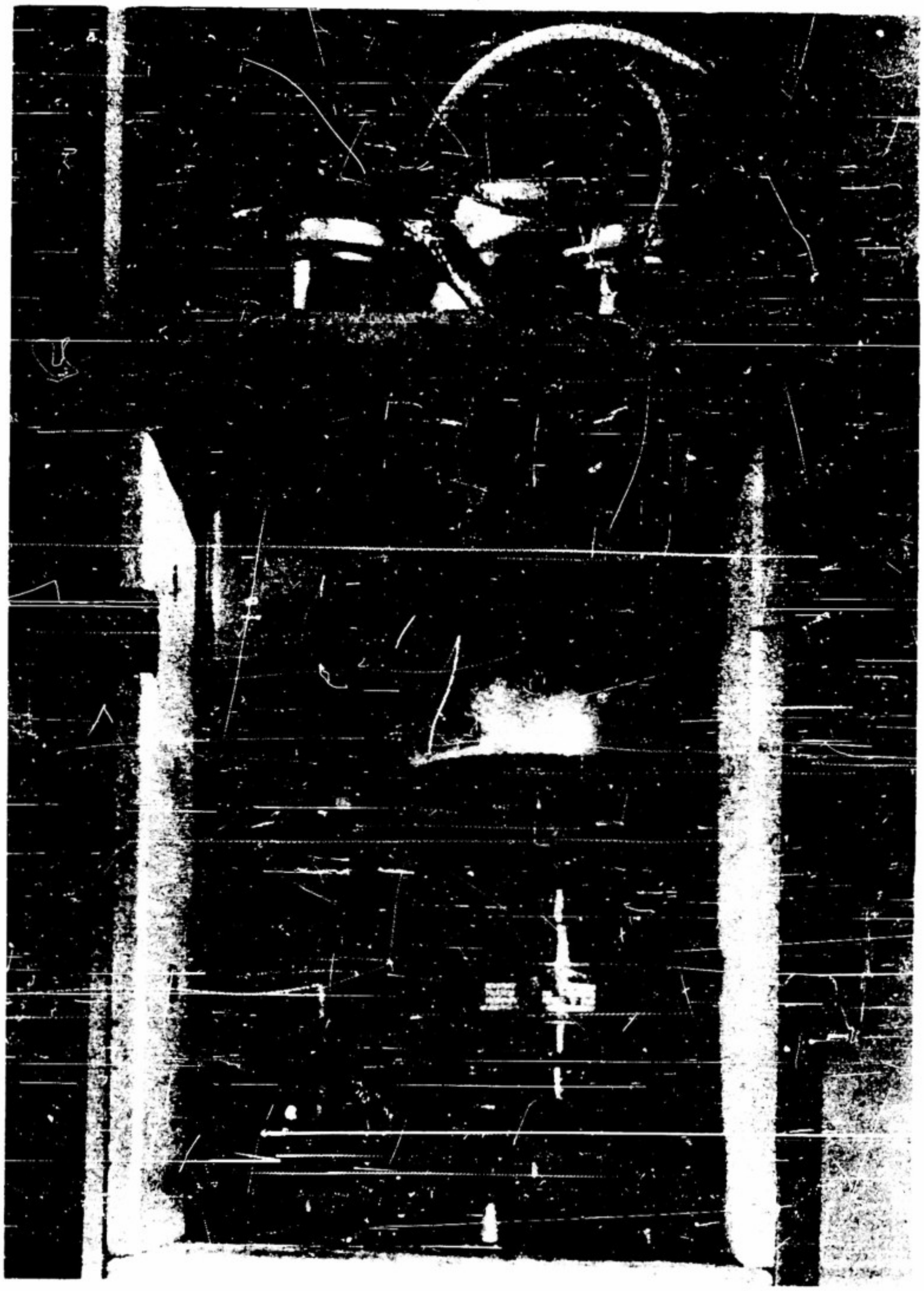


FIG. 10.

Fig. 12. Showing Superimposed Shutter Pulses and an Auxiliary Shutter Cycle. The Timing Marks in this Test are from the 60 Cycle Frequency Standard Used in Place of the Normally Recorded Coded Timing Signals.

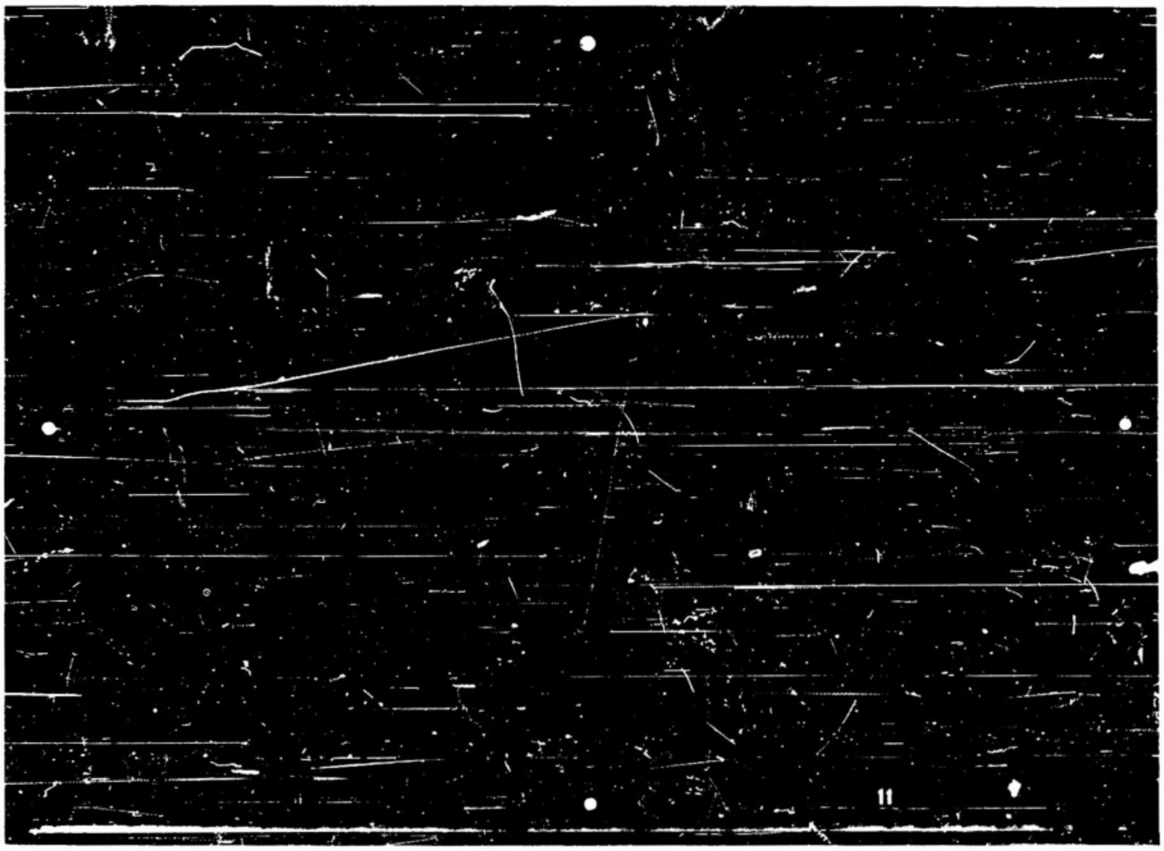
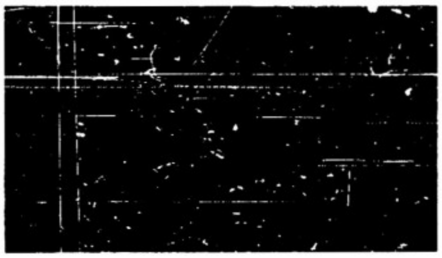


Fig. 11. Star Trail Recording from "B" Camera with Successive Aperature Settings of f:5.5, f:8 and f:11



CODER SETTING TAKE 2
DROP 0. EVERY 2ND. SHUTTER DISC OPENING IS USED BY THE AUXILIARY SHUTTER.

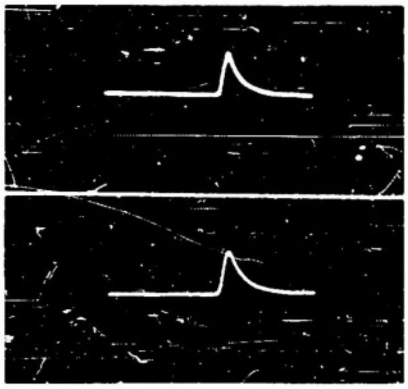
CODER SETTING TAKE 4
DROP 0. EVERY 4TH. SHUTTER DISC OPENING IS USED BY THE AUXILIARY SHUTTER.

CODER SETTING TAKE 8
DROP 0. EVERY 8TH. SHUTTER DISC OPENING IS USED BY THE AUXILIARY SHUTTER.

CODER SETTING TAKE 16
DROP 0. EVERY 16TH. SHUTTER DISC OPENING IS USED BY THE AUXILIARY SHUTTER.

FIG. 13

SHOWING OPERATION OF THE AUXILIARY SHUTTER IN RELATION TO THE DISC SHUTTER.



"A" CAMERA

"B" CAMERA

INDIVIDUAL SHUTTER PULSES FROM EACH CAMERA.

DISC SHUTTERS SYNCHRONIZED (INDIVIDUAL PULSES SUPERIMPOSED)

1 M.S. ERROR IN DISC SHUTTER SYNCHRONIZATION.

2 M.S. ERROR IN DISC SHUTTER SYNCHRONIZATION.

3 M.S. ERROR IN DISC SHUTTER SYNCHRONIZATION.

4 M.S. ERROR IN DISC SHUTTER SYNCHRONIZATION.

FIG. 14

SHOWING DISC SHUTTER SYNCHRONIZATION WITH VARIOUS DEGREES OF ACCURACY.

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