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U. S. NAVAL TECHNICAL MISSION TO JAPAN
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RESTRICTED

From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Japanese Infra-Red Devices, Article 2.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Article 2 of the report covering Target X-02 of Fascicle X-1 of reference (a), dealing with heat locator equipment, is submitted herewith.

2. The investigation of the target and the target report were accomplished by Maj. Wilhelm Jorgensen, AUS, assisted by Ma[illegible]. E.R. Ricker, Engineering Intelligence Section CE, AUS, and Sgt. Sperry Lea, AC, Air Technical Intelligence Group.

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JAPANESE INFRA RED DEVICES
ARTICLE 2
HEAT LOCATOR EQUIPMENT

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945
FASCICLE X-1, TARGET X-02

JANUARY 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

ELECTRONICS TARGETS

JAPANESE INFRA-RED DEVICES - ARTICLE 2
HEAT LOCATOR EQUIPMENT

Several research projects were carried on by the Japanese Navy, Air, and Army Technical Laboratories to obtain locator equipment which would detect ships, airplanes and other targets by the heat emitted from such objects. The researches were conducted almost independently, but the results were very similar, none particularly outstanding. Ships and other very strong heat sources could be detected at ranges of five to ten kilometers under most ideal conditions, but all equipments failed during slightly inclement weather and none of them had passed the experimental stage.

Research on heat sensitive elements was carried on by the Wartime Research Council, headed by Dr. KATO of the Kyoto Imperial University. Thermopiles were considered the best heat detecting elements, primarily for their simplicity and stability, and efforts were being made to improve these elements and to obtain suitable amplifiers. The results are essentially a summary of available published data but represent some of the most advanced thought on the subject.

In general, research was conducted on a qualitative basis only, and very little consideration was given to the compilation and study of quantitative data on which to base conclusive results. Although papers were presumably burned or destroyed, there is considerable evidence that most of the work was never recorded and that the results were merely absorbed as common knowledge by the research personnel concerned.

TABLE OF CONTENTS

REFERENCES

Location of Target:

a. Naval Airborne Heat Detector - Second Naval Technical Research Institute, ZUSHI.
b. Army Airborne Heat Detector - Fourth Air Technical Research Institute, TACHIKAWA.
c. Army Heat Locator Equipment - Seventh Military Technical Laboratory and the Yocho Machi Branch Ordnance Board.
d. Thermopiles and Thermo-Sensitive Elements - Prof. N. KATO - Wartime Research Council, Kyoto Imperial University.

Japanese Personnel who Assisted in Gathering Documents and Equipment:

a. Captain K. AOKI, IJN, Second Naval Technical Institute.
b. Lt. Col. T. TAKESHITA - Seventh Army Technical Laboratory.
c. Prof. N. KATO - Kyoto Imperial University.

Japanese Personnel Interviewed:

a. Second Naval Technical Research Institute, ZUSHI.
   (1) Tech. Capt. Kosaburo AOKI, IJN, - Chief.
   (2) Tech. Lt. Fumihiko SATO, IJN, - Project Engr.
b. Fourth Air Technical Laboratory, TACHIKAWA.
   (1) Lt. Gen. Takeo YAMAZAKI - Lab. Chief.
   (2) Engr. Mr. Noboru MIYOTA - Electrical.
c. Seventh Military Technical Laboratory.
   (1) Lt. Col. T. TAKESHITA - Optics and Tech. Chief.
   (2) Maj. Yoshio OJINO - Electronics and Television.
   (3) Capt. Tomoyuki HAMANO - Heat Radiation.
d. Yocho Machi Branch or Ordnance Board, FUJIMI.
   (1) Maj. M. KAGI - Mechanical & Electrical.
   (2) Maj. SHIRAKURA - Heat sensing units.
e. Wartime Technical Research Personnel.
   (1) Prof. N. KATO - Kyoto Imperial University. (Director - Wartime Research)
   (2) Assoc. Prof. Y. OTAMI - Heat Detection.

LIST OF ENCLOSURES

(A) Edited translation of report, "Japanese Army Heat Locator Equipment."

(B) Edited translation of report, "Japanese Navy Airborne Heat Detector."

(C) Notes, "Japanese Army Airborne Heat Locator Equipment."

(D) Edited translation of report, "Development of Thermosensitive Devices."

(E) Reprint, "Manufacture of Thin Film Thermopiles by the Evaporation Method and the Amplification of Alternating Current."

(F) Description, "Japanese Army Heat Detector Equipment (Personnel Detectors)."

(G) List of Equipment forwarded to NRL, Anacostia, D.C.

INTRODUCTION

This report consists of a compilation of information on Japanese heat locating equipment gathered at different times and in different localities by members of Air, Engineer, and Navy technical intelligence teams.

During the last five years the Japanese strove to perfect several military devices around an infra red sensitive pick-up element, capable of detecting a remote object of considerable heat concentration, such as a ship or plane. These projects included: airborne heat detectors, intended to locate ships or other planes; several heat location devices, for use in detecting ships or planes from the ground; a heat homing bomb, an air to ship high angle guided missile; and infra red sensitive noctovision, or image tube apparatus. This report is confined to heat detectors and locators.

LIST OF ILLUSTRATIONS

THE REPORT

1. Ground Located Heat Detecting Devices

Work on several types of heat locating devices was carried on at the Seventh Military Laboratory under the supervision of Lt. Col. T. TAKESHITA and the direction of Major Y. OGINO. The intended use of these devices was to detect ships or planes from a stationary position on the ground or from a vehicle. Experiments were made with both bolometers and thermopiles for the thermosensitive element, and with various methods of representation, including a cathode ray tube, a light box, and an output indicating meter. A complete record of experiments and systems tried, as furnished by Maj. OGINO, is given in Enclosure (A).

2. Air borne Heat Detectors

The Navy model of this device was mounted over a hatch in the belly of a bomber. At takeoff, the detector unit, a mirror box containing a thermopile pick-up element, was held retracted above the hatch. For operating, the mirror box was lowered manually by a worm gear until it protruded well below the under-surface of the plane. In the first trial model, cranks would move the mirror box in azimuth and elevation to accomplish scanning. Signals generated by the thermopile were amplified and fed to an output meter, movement of which showed a heat source had been found. The first trial model was claimed to have a range of up to six miles, but it was unsuccessful as the mechanical system used to rotate the mirror box was not powerful enough to overcome the force of the airstream. A new model was designed but never completed. It was to have had a 150 watt motor to move the pick-up unit, and a larger mirror and azimuth scan angle. Details of the Navy airborne heat detector, as furnished by Technical Capt. AOKI, IJN, are given in Enclosure (B). Photo and wiring diagram are included in this enclosure. Some details were obtained of a somewhat similar system developed by the Fourth Air Technical Laboratory (Army). This heat detector was bombed out before being flight tested. (See Enclosure C). The wiring diagrams were designed by Professor KATO of the Kyoto Imperial University and are essentially the same as those shown in Enclosure (D).

3. Research and Development of Thermosensitive Elements

Upon the request of interrogators, Professor KATO prepared a report on thermopile development which included information on research carried on with other types of thermosensitive elements. Professor KATO was head of the Wartime Research Council, which had somewhat the same function as the National Defense Council in the United States. He concentrated on theoretical studies and not all of his work was respected by the Army because often practical application of his theories was unsuccessful. The phenomena and systems described in Enclosures (D) and (E) were studied and developed by Professor KATO personally or under his direct supervision.

4. Other Devices and Associated Research

One other system which was discovered was called the Personnel Detector. It was developed by the Second Military Laboratory (Army). The range for detecting a single man was given at 100 meters (330 ft.). No equipment was found at the laboratory, but a similar apparatus was obtained from the YOCHO MACHI Branch of the Ordnance Board and has been shipped to the Naval Research Laboratory, Anacostia, D.C. (See Enclosure F). This apparatus employed essentially the same system as that developed by the Seventh Military Laboratory for ground heat locator equipment as discussed in Enclosure (E).

Associated developments, such as heat transparent window material, are covered in NavTechJap Report - "Japanese Infra Red Devices, Article 3 - Research, Development and Manufacture of Infra Red Equipment" - Index No. X-02-3.

ENCLOSURE (A)

JAPANESE ARMY HEAT LOCATOR EQUIPMENT

This is an edited translation of a report prepared by Maj. Y. OGINO, Seventh Military Technical Laboratory, project engineer, for the purposes of this investigation. It contains a brief description of equipment developed and tests conducted on a ship detector. Figures referred to follow the text of the report.

I. PURPOSE OF RESEARCH ON HEAT LOCATOR EQUIPMENT

To design equipment capable of locating a ship or an aircraft at night by the difference of temperature radiation from the object and its background. Period of research: Sept. 1944 to Aug. 1945.

II. EXPERIMENTS

A. To determine the value of heat radiations as a means of locating objects:

Three experiments were made on real ships with an apparatus consisting of a KAWANISHI's Moll type thermopile, a parabolic mirror (aperture 20cm., focal length 50cm.) and a galvanometer (current sensitivity 9.3×10^{-9}A). The results were as follows:

1. Operation at Night

The signals were small and the signal to noise ratio changed as a function of time, season, and object. However with best conditions a ship (for example a steamer of about 3000 tons) could be located at 4 km (2.5 miles) distance.

2. Operation by Day

The thermal radiation from the object was large, but the radiation from the background was also large. The signal to noise ratio was about equal to that at night.

3. Operation at Sunset or Sunrise

The contrast between the object and the background decreased at sunset and at sunrise, and in most cases a ship could not be located at all.

B. To determine the best thermo-sensitive element

The thermopile and bolometer were studied to determine the best type, form, and dimensions for a thermal element. Experiments were performed to compare the sensitivity of a Fe-Constantan thermopile (few micron) with amplifier to the sensitivity of a Ni bolometer (about two micron) with amplifier. The bolometer was found to be a few times more sensitive than the thermopile and to have a noise level of about 1/50°C., assuming the noise current to be the apparent temperature variation of the object. However, the bolometer had more long period noise than the thermopile (See Figures (A)1, part (b) and (A)1, part (c). Both require about two seconds to build up to saturation. Blackened cans, filled with hot water at different temperatures, were used as the heat sources for the experiments, and were located alternately for contrast (See Figure (A)1, part (a). The heat detector apparatus picks up cold and hot spots equally well, if the contrast to the background is the same.

ENCLOSURE (A), continued

1. The first study was of a system which consisted of an input selector scanning 21 elements of thermopiles in turn, and a cathode ray tube indicator synchronized with the input selector. The system was intended to give 21 spots on the cathode ray screen corresponding to the 21 thermal elements, but was unsuccessful because of the irregularity of each contact of the selector, electrically and mechanically, and of each element of the thermopiles (see Figure (A)2, part (a).

2. The second study was of a synchronously rectifying system with a rotating interrupter and rectifier for a thermopile (see Figure (A)2, part (b). Here the interrupter was used merely to furnish pulsating A.C. for ease of amplification, but the contacts soon wore down and caused considerable trouble.

3. The third study was of a five channeled amplifier which used five vibrating interrupters and five frequency relays (see Figure (A)2, part (c). This also was not successful because of the instability of the frequency relays. The design, however, was expected to furnish a general location of the heat target by showing a light in the center or in one of the four quadrants of the indicator system, corresponding to the particular thermopile that was picking up the signal. Its intended use was on vehicles or airplanes where the equipment would be fixed to the vehicle and could indicate relative direction of the target.

4. In the latest amplifier for thermopiles we interrupted the input D.C. current by a polar relay to make A.C., amplified the A.C. by a band-pass amplifier, rectified the A.C. synchronously back to D.C. by a polar relay similar to the input polar relay, and then applied the D.C. output to a direct reading meter (see wave forms, Figure (A)3). The wiring diagram of the Micro D.C. Amplifier is shown in Figure (A)2. The noise level of this amplifier was 5×10^{-9} volts when the input was terminated in a pure resistance of 10 ohms.

5. Amplifier for the Bolometer: As shown in Figure 4, the bolometer (Ni-strip) was put in one arm of a bridge. The output due to any unbalance was stepped up by a transformer and then connected to the grid of the first valve of the amplifier (6C6 in Figure (A)4). The output of the amplifier was rectified synchronously by a polar relay and applied to a direct reading galvanometer. The noise level of this amplifier was $\Delta R/R = 5\times10^{-8}$ (assuming the noise current as the apparent resistance variation at the input).

C. <u>To stabilize the equipment against disturbances of every kind</u>

1. <u>To stabilize the thermosensitive element</u>

a. The casing of the thermosensitive element must be airtight.

b. The thermosensitive element must be adiabatically shielded so that it will not be affected by the temperature variation of the atmosphere.

c. The contact points of the lead wires must be perfectly soldered and adiabatically shielded.

d. Loops in the lead wire must not be made.

ENCLOSURE (A), continued

e. The thermosensitive element must be kept free from vibration of the lead wires.

2. <u>To stabilize the amplifier</u>

a. The negative feedback circuit as shown in Figure (A)4 was used to stabilize the equipment against external disturbances. The disturbances were caused by the gradual variation of the background radiation or atmospheric temperature and by long period variations of the power supply battery voltage. The respective thermocouple heating arrangement in the input circuit that is affected by the feedback current is determined by the copper-oxide rectifiers and by the sign of the e.m.f. in the feedback circuit. The thermocouples in the input circuit are so connected as to oppose any change in existing conditions, (sensitivity 0.5v/m A feedback) but have a very long time constant, (approx. two minutes). This permits them to compensate for long period background variations in heat current but has very little effect on rapid heat changes resulting from scanning of the heat detecting head (see Figure (A)4). The thermocouple arrangement was used to isolate the input circuit from the output circuit, and to have a large time constant for the feedback effect. The same feedback circuit can be used for either the thermopile or the bolometer type detector, except that the pulsating or interrupted D.C. must be applied directly to the bridge circuit for the bolometer in place of interrupting the heat current for the thermopile. A compensating thermopile was generally used in the bolometer bridge, which made the feedback circuit unnecessary (see Figure (A)4).

b. The input transformer (1-100) must be the inner-core type and perfectly magnetically shielded.

c. The wave forms of the interrupter current (see Figure (A)3) must be stable, and the respective relays must have good contact surfaces or spurious results will be introduced. Also care must be taken to insure a good electromagnetic balance in the system to prevent induced currents from being generated.

ENCLOSURE (A), continued

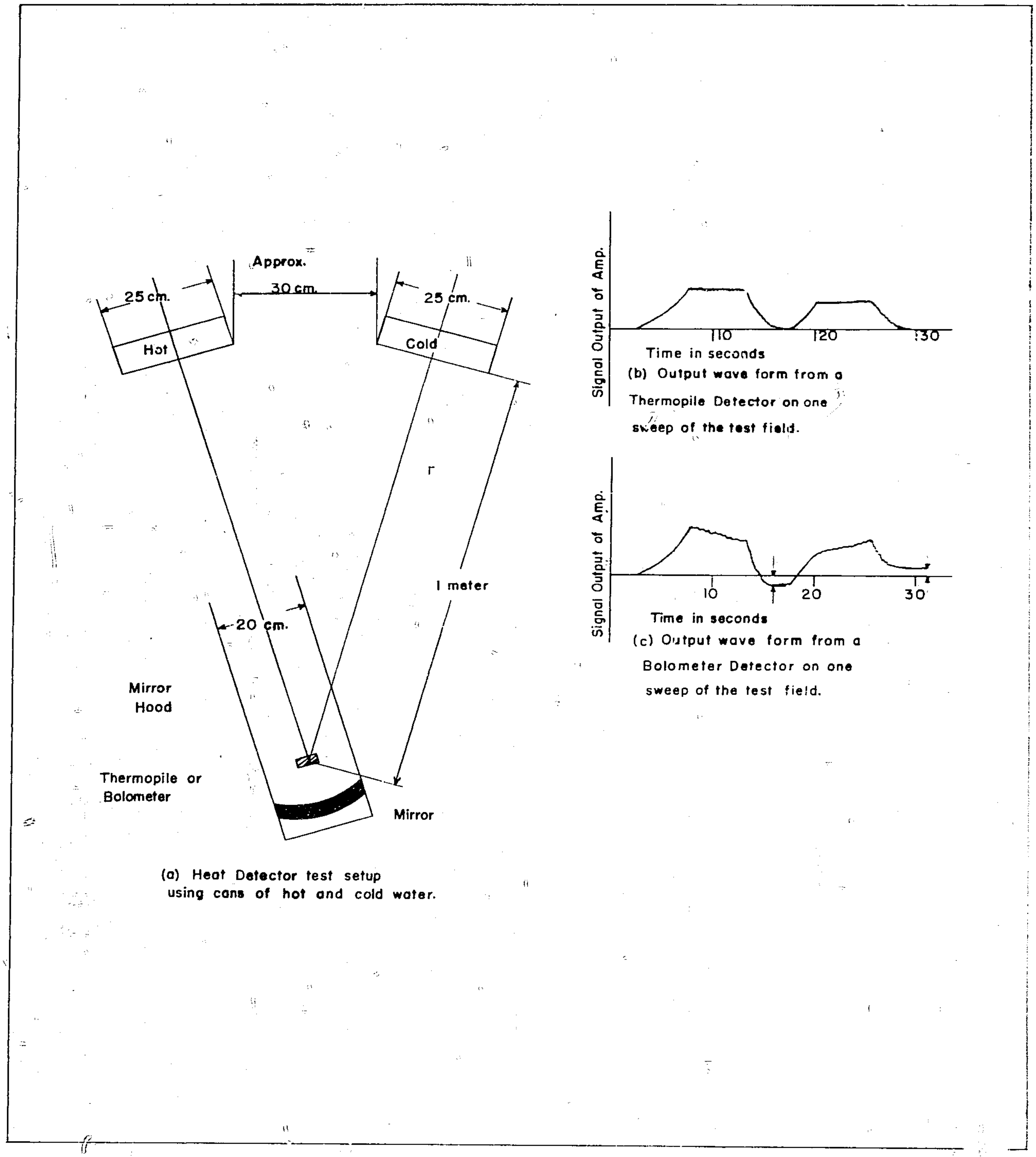


Figure (A)1
TESTING HEAT DETECTOR ELEMENTS FOR THERMAL SENSITIVITY

ENCLOSURE (A), continued

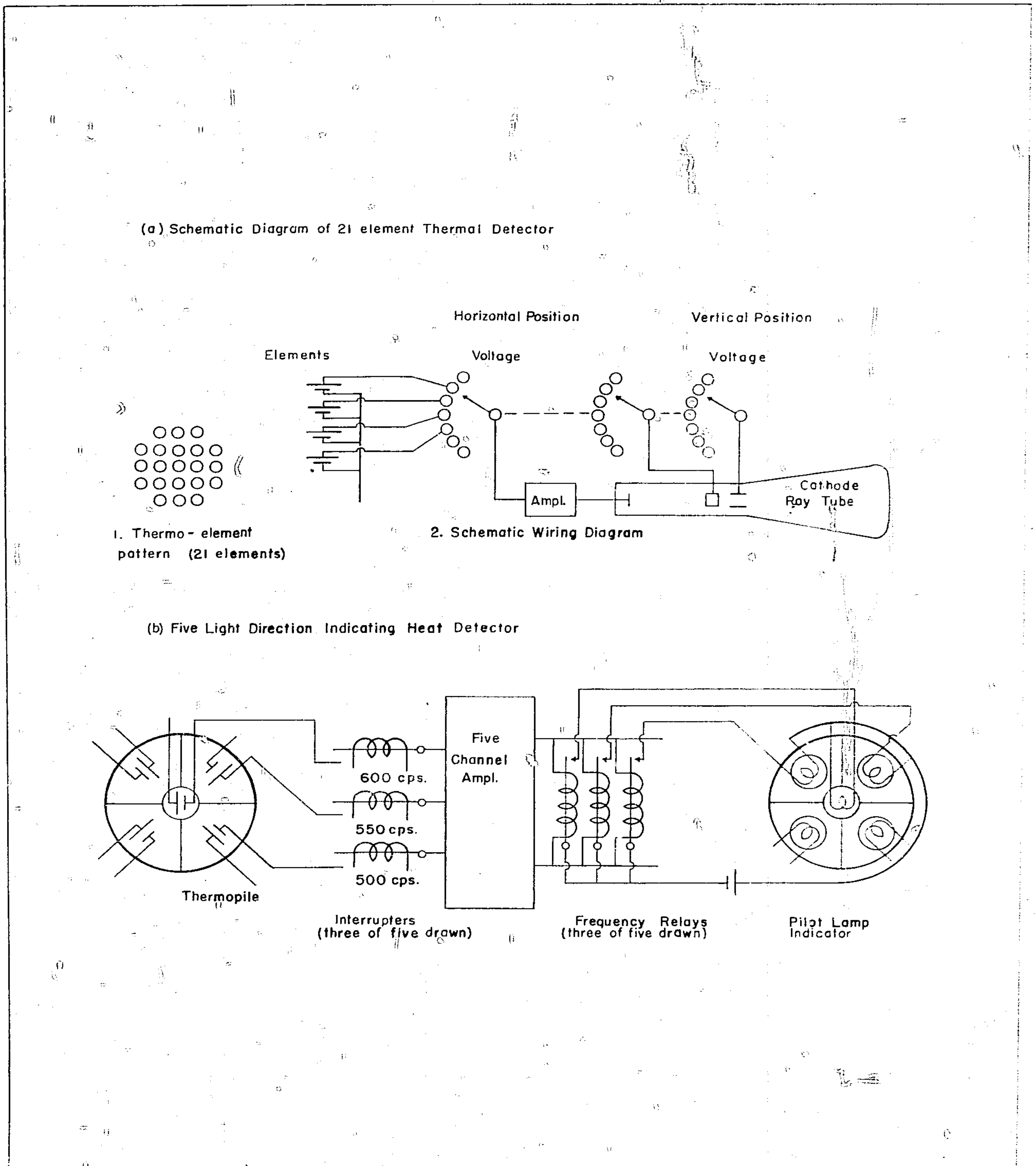


Figure (A)2

MULTIPLE ELEMENT THERMAL DETECTOR AND INDICATOR SYSTEMS

ENCLOSURE (A), continued

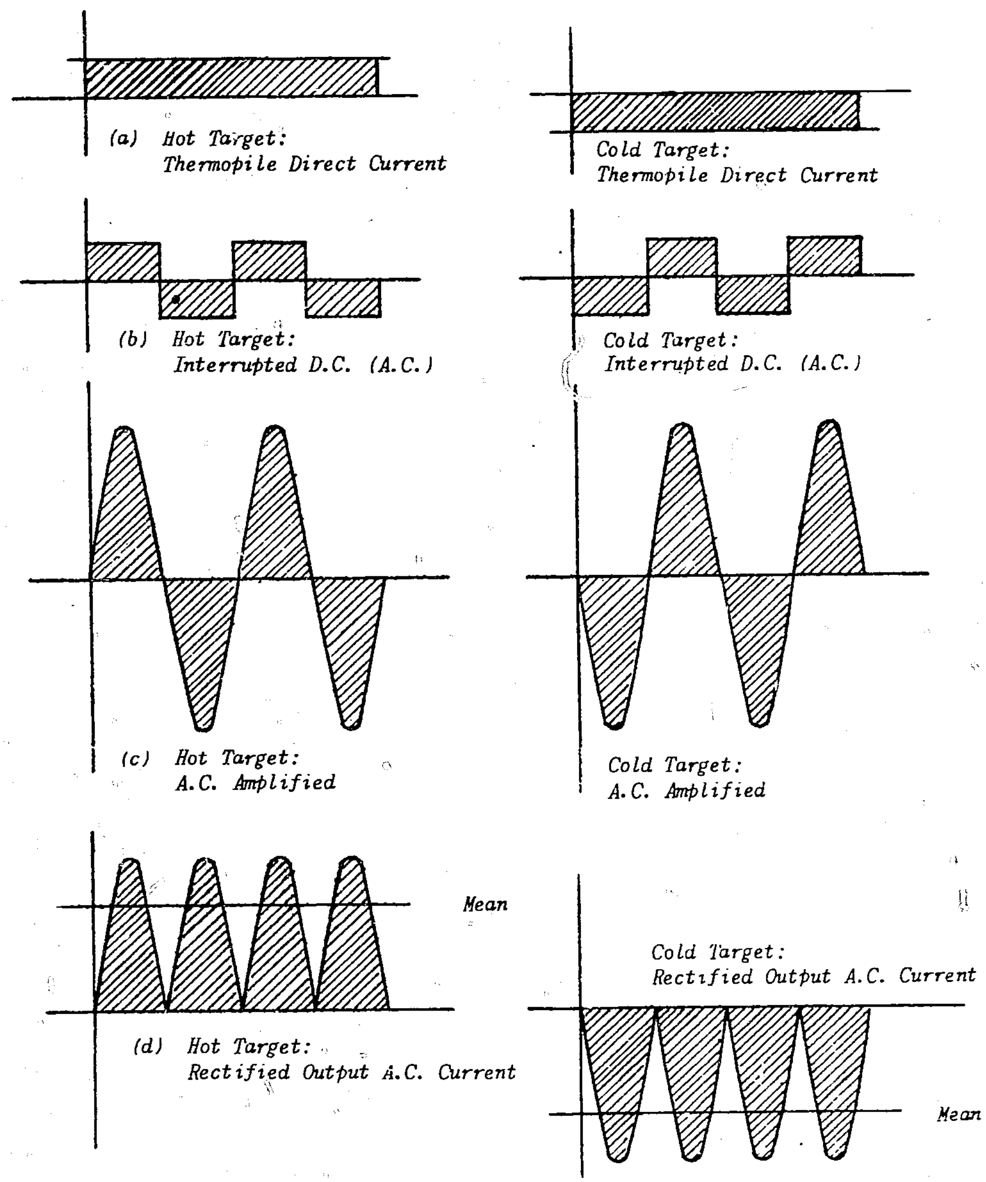


Figure (A)3: WAVE FORMS OF MICRO D.C. AMPLIFIER FOR THERMOPILES

ENCLOSURE (A), continued

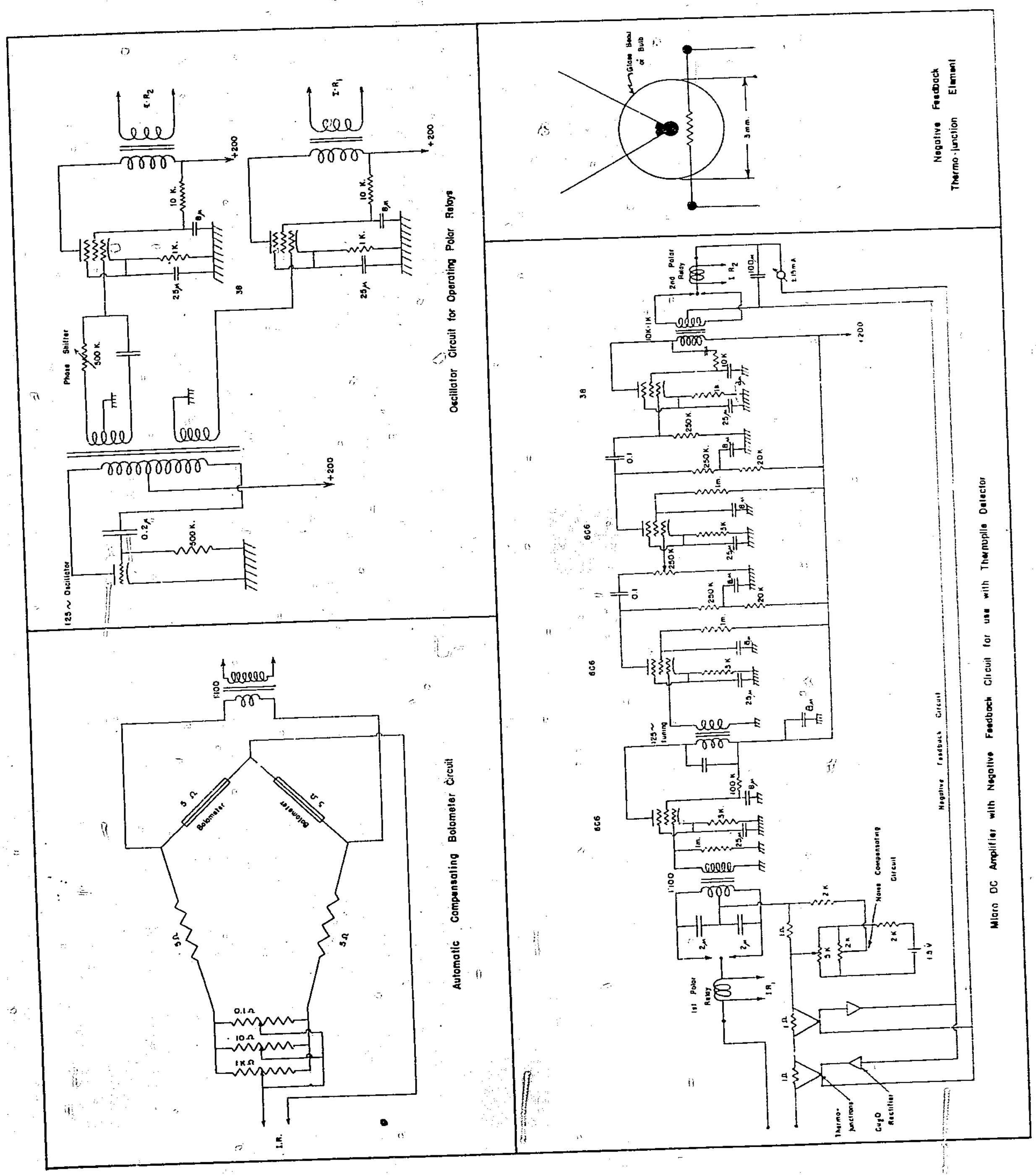


Figure (A)4
CIRCUITS TO COMPENSATE FOR BACKGROUND VARIATIONS

ENCLOSURE (B)

JAPANESE NAVY AIRBORNE HEAT DETECTOR

This is an edited translation of a report prepared by Capt. AOKI of the Second Naval Technical Institute for this investigation. It contains a brief description of the research and development conducted on the Airborne Heat Detector. Figures referred to follow the text of the report.

I. NAME

Navy Airborne Heat Ray Detector, Type 5. See Figure (B)1 for photograph of the equipment and Figure (B)2 for the wiring diagram.

II. PURPOSE

The apparatus was to be fitted in an aircraft and used to locate other airplanes or ships at night by detecting the heat radiation emitted from their engines or funnels.

III. PRINCIPLE

A collecting mirror focused the picked up heat image on a thermopile unit. The e.m.f. generated at the thermopile was fed to a tuned amplifier after being modulated by a constant frequency vibrator. Movement of an indicator meter showed that a heat source had been located.

IV. RANGE

Detecting range was 7 to 10 km (4.3 to 6.2 miles)

V. SCANNING

All movement of the mirror box was controlled by cranks, which lowered the pick-up head through a hatch in the belly of the plane and turned it in azimuth and elevation.

VI. DATA ON THE FIRST TRIAL MODEL

A. Mirror Box

1.	Rotating Speed	30°/sec
2.	Aximuth Scan Angle	180° (90° left and right of flight direction)
3.	Elevation Scan Angle	40°

B. Collecting Mirror

1.	Diameter	18 cm.
2.	Focal Length	10 cm.
3.	Surface	Evaporated aluminum

ENCLOSURE (B), continued

C. Thermopile

1.	Composition	36 Tellurium-Constantan thermopile elements connected in series.
2.	Receiver Surface	Gold-leaf blackened by bismuth
3.	Element Sensitivity	0.017uV/uW/cm^2(each)
4.	Resistance (total)	300 ohms
5.	Window Material (thermopile head)	Rock Salt

D. Window Screen

1.	Material	Chloride of rubber
2.	Thickness	0.03 mm

The first trial model failed because the mechanical system, used to rotate and reverse the mirror box was of insufficient power. A new model was planned.

VII. DATA ON IMPROVED MODEL (not produced)

A. Mirror Box

1.	Rotating Speed	10°/sec.
2.	Azimuth Scan Angle	200°
3.	Elevation Scan Angle	40°
4.	Motor for Mirror Rotation	150W.

B. Collecting Mirror

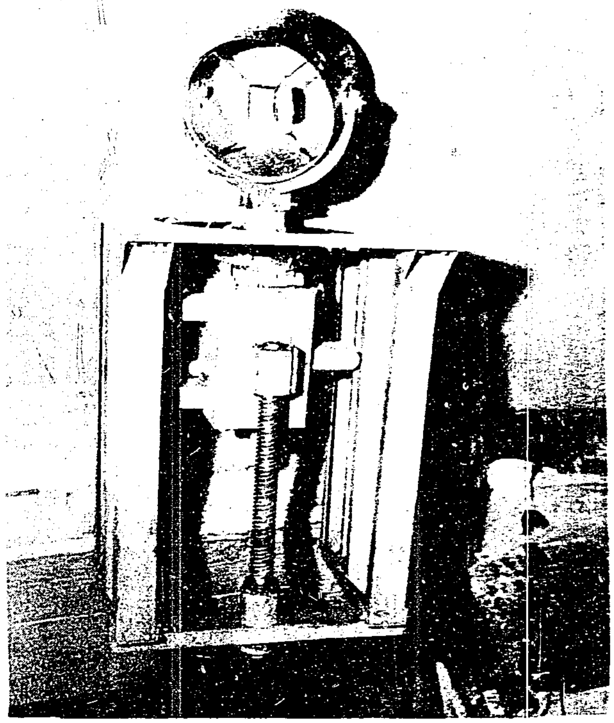
1.	Diameter	20 cm
2.	Focal Length	20 cm
3.	Surface	Evaporated aluminum

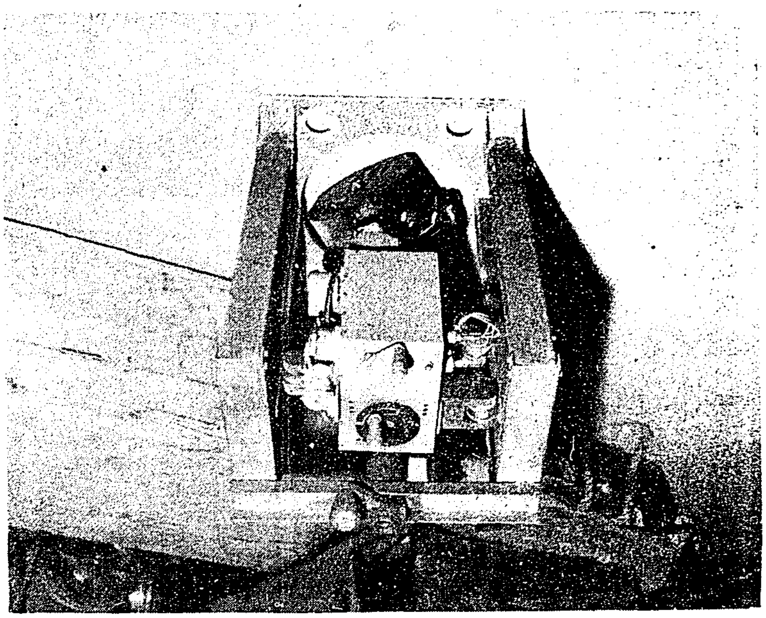
VIII. AMPLIFIER

The amplifier was an adaptation of that used on the Magnetic Ship Detector. The Controller Unit (including noise compensation rheostat, indicator meter, switch, etc.) was located 12ft. from the amplifier and was connected by a shielded cable. The amplifier was tuned to 675 cycles/sec and had a sensitivity of more than 5x10^{-7} V. The first ten sets were nearly completed.

ENCLOSURE (B), continued

(a) Scanning Head in Lowered Position





(b) Scanning Head in Raised Position

Figure (B)1
NAVY AIRBORNE HEAT DETECTOR

ENCLOSURE (B), continued

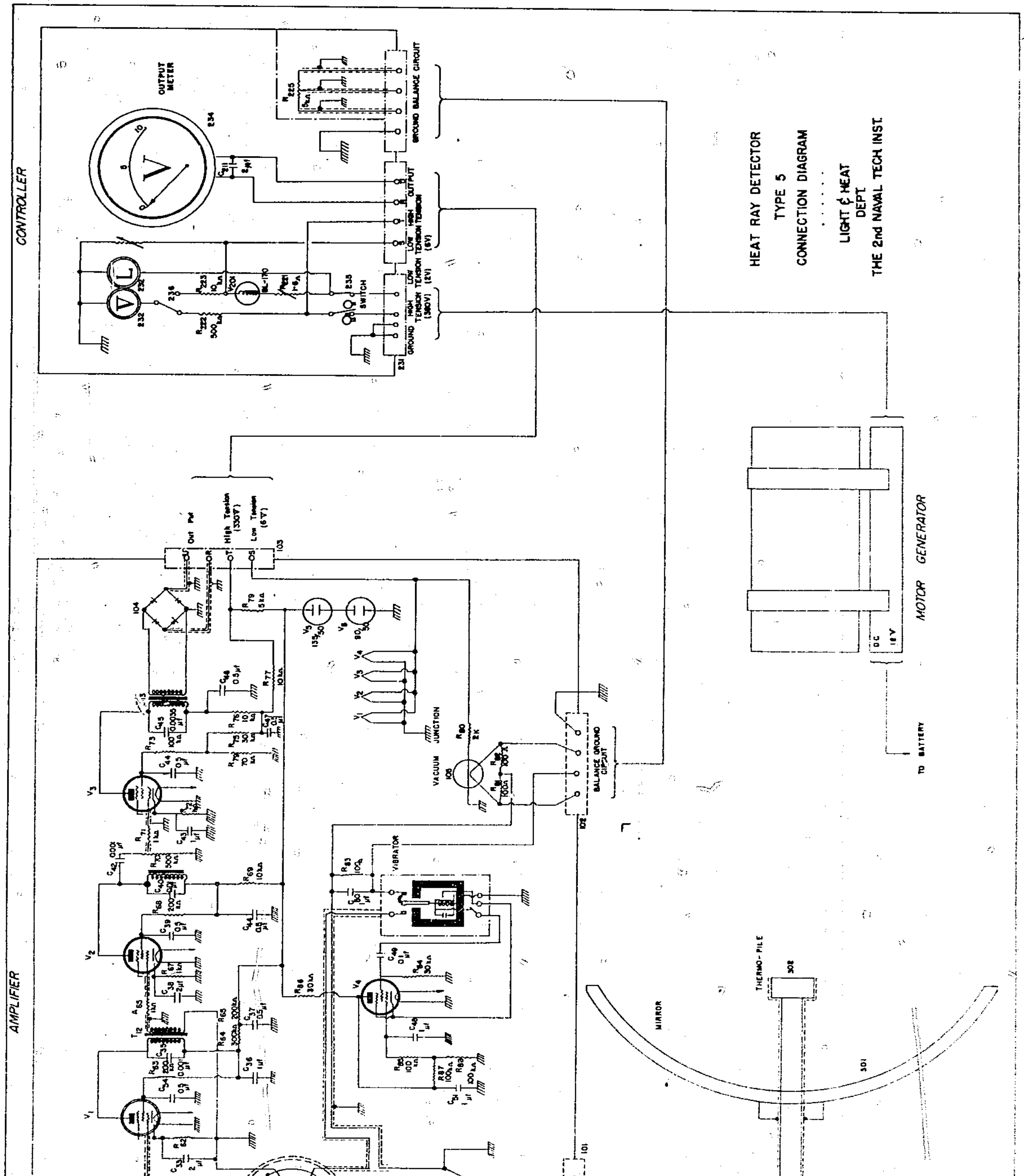


Figure (B)2
HEAT RAY DETECTOR TYPE 5
CONNECTION DIAGRAM

ENCLOSURE (C)

NOTES ON JAPANESE ARMY AIRBORNE HEAT LOCATOR EQUIPMENT

This is a summary of an interview with Lt. General YAMAZAKI and assistants, Fourth Technical Research Institute. It contains a brief review of the research conducted on the Army airborne heat detector.

I. GENERAL

The airborne heat detector was started in 1940 at the instigation of research personnel for the purpose of detecting ship and airplane targets from fighter-bomber aircraft. Technical direction and field tests were carried on by the Fourth Technical Research Laboratory. Research was conducted at Kyoto Imperial University by Prof. N. KATO, and development and manufacture of components by Kawanishi Seisakujo in KOBE, and Tokyo Shibaura Denki in KAWASAKI. The equipment was tested from ground stations on ship and plane targets on several occasions, but was never flight tested. The Fourth Air Laboratory was destroyed in an air raid, and no samples of the equipment were available. There was no coordination with similar projects conducted by the Army and Navy.

II. DESCRIPTION

The airborne heat detector employed a constantan-iron thermopile as a heat sensitive element, placed at the focus of a paraboloidal mirror of 40cm focal length and 20 or 30cm in diameter. The signal was amplified and presented as a meter indication. The various amplifiers used in the development operated on 600 to 1000 cycles/sec and the degree of amplification was 120 to 140 decibels. The power supply operated on 27v DC, and had an output of 200v DC. The angle or view was 1° horizontal and 13° to 20° vertical, with a 180° horizontal search. (It was planned to use supplementary narrow angle of view for accurate location of targets, but this proved too difficult). In later models, thermopiles were provided to compensate for background temperature. The angular rate of scan was 10°/sec. Sketches of the equipment and its intended installation are shown in Figures 1 and 2. The wiring diagram and the technical details are essentially the same as those developed by Professor KATO, Kyoto Imperial University (see Part IV of this report.)

III. RESULTS

A range of 5km - maximum 10km (6.2 miles) was obtained at night on ships of 3000-6000 tons. Difficulties were encountered in the rusting of the iron of the thermopile, and constantan-manganin thermopiles were later tried, but were not as sensitive. Three types of window material were tested: fluorite, chloride of rubber, and rock salt. The rock salt was preferred. Attempts at coating the rock salt with protective materials were unsuccessful. No detailed target surveys were conducted, but it was generally agreed that ship signals were given off by the stack. The time constant of the thermopile was about o.3 sec. at 50% power, or 72% maximum voltage. The output of the thermopile was 4×10^{4} °C (and the smallest detectable reading of the galvanometer, 10^{-7} so that the maximum sensitivity was 2.5×10^{4} °C (Tokyo Shibaura) to 2.5×10^{3} °C (Kawanishi Kikai), measured at 0.5 sec.). Distinction of signals from background on the compensating type constantan-iron-constantan thermopile required a very delicate thermojunction. It was attempted to reduce the length of the iron strip to 0.3mm, but the smallest obtained was 0.5mm.

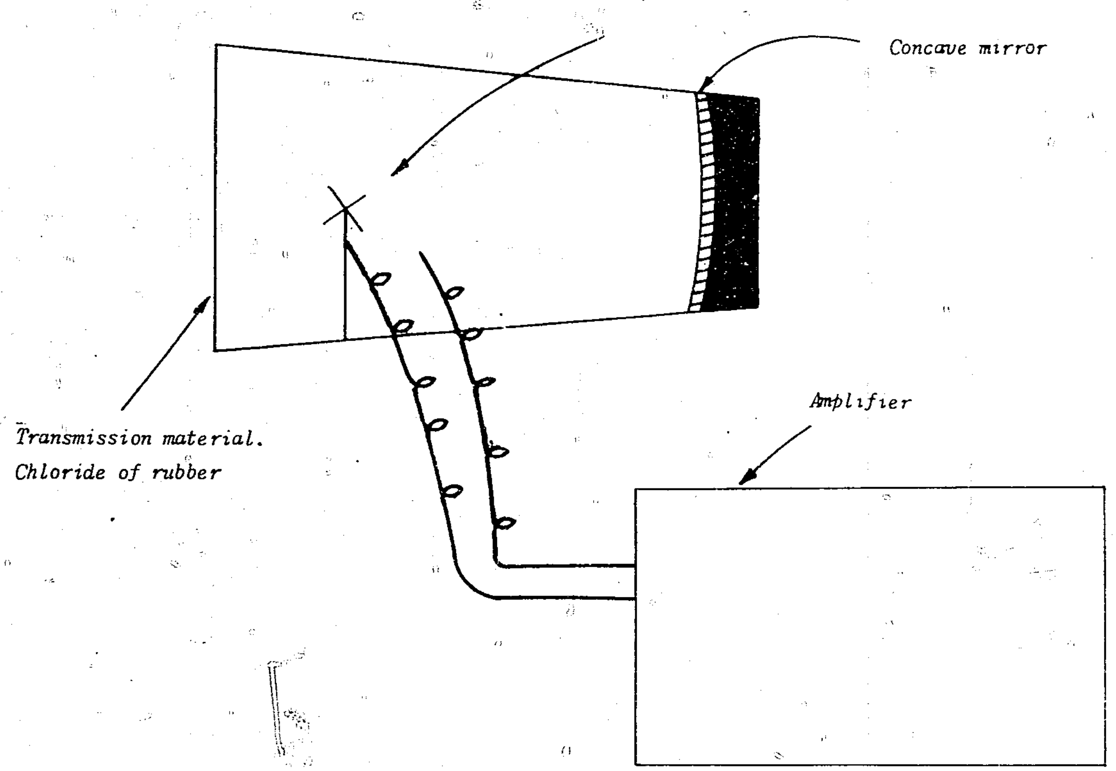
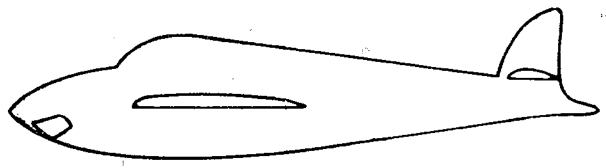
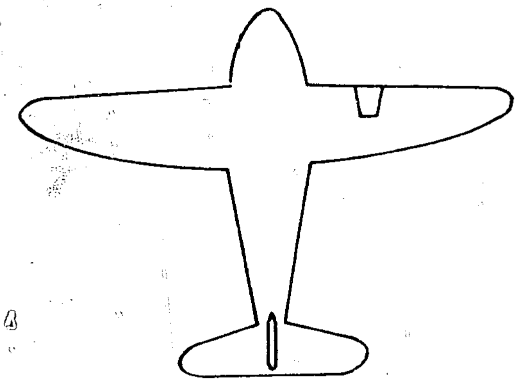


Figure (C)1
BLOCK DIAGRAM OF ARMY AIRBORNE HEAT DETECTOR

ENCLOSURE (C), continued



a. Nose Installation



b. Wing Installation

Figure (C)2
INSTALLATION OF HEAT DETECTOR ON AIRPLANES

ENCLOSURE (D)

THERMOSENSITIVE DEVICES

This is an edited translation of a report prepared for the purposes of this investigation by Prof. N. KATO, of KYOTO Imperial University. It contains a general review of heat-sensitive elements, and details of constantan-iron thermopiles and an associated amplifier developed for the Fourth Air Laboratory. Figures referred to follow the text of the report.

I. DEVELOPMENT OF THERMOPILES

A. Thermopile research was begun in May 1935 as a special project at the Army Physical Research Laboratory. It was carried on with the aid of Haye's electrostatic radiation detector, which was thought to be the most sensitive at that time. On March 8, 1939, a detection experiment was carried out at the city airport on a flying Type 88 reconnaissance plane, and detection was achieved at a range of about 4km (2.5 miles). The equipment consisted of a 150cm reflector with a 63cm focal length, a non-compensation Moll type thermopile, and a sensitive galvanometer that was made at the Physical and Chemical Laboratory. This was the first experiment of its kind and the problem of thermopile compensation had not yet been solved; hence the compensation type thermopile was not used. However, the fact that the sensitivity of the heat detector was increased, when the plane formed a screen against the background temperature, was accidentally discovered during Tachikawa Airfield tests in July 1939. This resulted in extensive research on background temperature compensation. This research produced the compensation type thermopile, which utilizes the contrast between the body of the plane and the background temperature radiation. The tests discussed below were made.

B. In October, 1939, a test of the heat detection equipment of the compensation type was carried out from the roof of the Electrical Engineering School, Science Dept., Kyoto Imperial University. Twin mounted identical reflectors were used. A Type 98 light bomber was detected at a range of about 3km (2 miles).

C. On March 8, 1940, another field test was held at the city airport which detected a Type 98 light bomber at a distance of about 7km (4.5 miles). The equipment used for this test was a compensation type heat detector. This equipment was composed of two Moll type thermopiles connected to a compensation type arrangement in the focus area of a 150cm aperture, large type reflector.

D. In July 1940 at the KANON SAKI testing grounds of the Army Physical Research Laboratory, another successful detection was made. Using a 65cm reflector with a compensation type thermopile, a 400 ton ship was detected at a range of about 4km (2.5 miles). The sensitive elements consisted of a Moll type thermopile connected to two compensators and a sensitive galvanometer made at the Physical and Chemical Research Laboratory. The galvanometer was connected to a compensation type thermopile made by Kawanishi, which had compensation distance of 3mm, 5mm, and 8mm. The basic heat detection research which utilized the galvanometer was done at the Seventh and Second Army Technical Research Laboratories; but in April, 1943, the Fourth Army Aerial Research Center began work on an amplifier which could be used on airplanes. The aim was to produce pulsed DC from the thermopile output with an interrupter, and amplify it to present the signal indications on a selective ammeter.

ENCLOSURE (D), continued

II. PRINCIPLES OF HEAT DETECTION

A. Simple Thermocouple Method

Heat radiation is changed into thermal e.m.f. by using a thermopile and galvanometer connected as shown in Figure (D)1.

B. Haye's Electrostatic Radiation Detector

The apparatus is shown in Figure (D)2. When the heat ray penetrates through the rock salt window and releases absorbed gas from the active carbon, the gas pressure displaces or moves the thin metal diaphragm of the moving electrode, causing the electrostatic capacity between the moving electrode and the static electrode to change. The heat ray can be detected, therefore, by detecting the change in electrostatic potential. The bridge connection used to detect this change in capacity is shown in Figure (D)3.

C. Bolometer Method

The bolometer is connected up as shown in Figure (D)4, using a thin resistance wire. The heat ray enters either arm A, or B. As the background temperature falls on both arms it is selfcompensating, and does not appear in the output. Since the heat ray strikes only one arm, it sets up a potential and can be detected. There are both metal type and di-electric type bolometers.

D. Photocell Method

A photocell compensation heat detector is made by using a special design of photo-cell with one anode and two opposing photo-cathodes, as shown in Figure (D)5. Figure (D)6 shows the wiring diagram. In this equipment the heat ray or infra-red ray is picked up on only one of the cathodes, and the photo current output is amplified and detected. The background temperature appearing on both cathodes, however, is self compensating and does not show in the output.

E. Thermopile Method

As shown in Figure (D)7, a large number of thermocouples are connected in series to form a thermopile. The heat ray strikes them, and a current is produces which may be amplified and presented through earphones. Similarly, the heat impulses can be presented and observed by means of a cathode ray tube when so desired.

F. Exhaust Gas Detection Phenomena

The pulses of heat from the exhaust gas of an engine have a certain frequency depending on the number of cylinders and the speed of the engine. This frequency is usually five or six hundred cycles per second. When the energy of this exhaust gas is received by a thermopile that has been produced by the sputter method or the evaporation method, and is then amplified for sound, the characteristic noise of the engine can be heard.

ENCLOSURE (D), continued

G. Compensation Methods

Many methods, such as the above mentioned, have been considered in heat ray detection; but the greatest problem is to distinguish between the heat ray from the target being detected and the heat radiation produced by the background temperature. The following considerations were employed to reduce the influence of background temperature.

1. Two thermopiles were connected as shown in Figure (D)8. Thus the background temperature heat ray strikes both thermopiles, and the heat ray strikes only one. The background radiation is cancelled, and the target can be detected.

2. Two-element thermopiles were designed. In the method shown in Figure (D)8, the distance between the thermopiles cannot be eliminated. But if a thermopile with two junctions in the element is used (as shown in Figure 9), the distance between the junctions can be shortened, and the effect of the background temperature can be decreased.

III. MANUFACTURE OF RADIATION DETECTORS

A. Electrostatic Radiation Detector

The details of this radiation detector were described in a special article, "New Type of Electrostatical Radiometer" which appeared in the Denki Tsushin Gakkai Magazine.

B. Rolled Foil Type Thermopile

The rolled foil type thermopile is used in making both Moll type and compensating type thermopiles.

1. The thermopile element is made by combining constantan and iron or constantan and manganin, rolled to 0.0005 - 0.007mm in thickness. As shown in Figure (D)10, constantan and pure iron are soldered together, passed through rollers, and made into foil. This is cut into strips about 0.5mm in width with a knife, and the strips are placed on a support constructed as shown in Figure (D)11. The ends of the brass support rods are made the same height and are levelled and polished. The strips are then soldered onto brass rods, connecting them in pairs, as shown in Figure (D)12.

2. In the Moll type thermopile there are about 18 elements, with an internal resistance of about 30 ohms. The surface of the box is blackened with camphor black and bismuth black. The area of the window which improves the absorption of the heat ray is eight sq. mm, and is made of fluorite. The sensitivity is 0.15×15^{0} uV/mW/cm^2. The compensation type thermopile is used to decrease the effect of backround temperature in heat detection. In order to produce an opposite electromotive force, an iron-constantan-iron block is made (as shown in Figure (D)13), and this is put through rollers. The compensation distance, that is, the width of the constantan after being rolled, is either 3mm, 5mm, or 8mm.

ENCLOSURE (D), continued

3. As a high degree of ductility is necessary in all the materials used in the rolled foil, materials of high purity are necessary. Thus good results are obtained by using metals and alloys purified by a "power melting" (TN metallurgical) process. Sometimes the iron is oxidised and breaks, but if the material is of high purity, and care is taken in the moisture-proofing of the soldered piece, this can be prevented.

C. Evaporation Type Thermopiles

Thermopiles made by evaporation in vacuum have the following characteristics:

1. The heat capacity is small with resultant small time lag.

2. Metals and semiconductors which cannot be rolled or wired, but which have good thermal e.m.f. or other characteristics can be used.

3. Apparatus used for evaporation is shown in Figure (D)14. There are two coiled filaments on an iron table and the metals to be evaporated are put in fuzed quartz pots which are heated by the coiled filaments. The material on which the metal is to be attached is mounted on a table over the filaments, and the table is rotated from outside. The apparatus is covered by a glass bell jar and sealed by vacuum compound. It is then evacuated to about 10^{-4}mm(Hg), and the metal is then evaporated. Bi and Te were used. The materials upon which these metals were condensed were celluloid, glass or mica, but generally celluloid. The details of the thermopile are shown in Figure (D)15. See Denki Hyoron, Bd. 29. 1941. "On Manufacturing of Thermopiles by Evaporation and A.C. Amplification".

D. Construction of Heat Detectors

Many types of construction were tried, the more recent of which are given in Table (D)1. The KTA Type is the same as the signal Moll Type thermopile. The KTB Types are similar to those shown in Figure (D)16, in which the center portion of the thermopile is used to locate the target direction accurately, whereas the outer boxes are used only to get broad angle vision for the initial finding of the target.

IV. EXPERIMENTAL RESULTS

A. Thermopile Sensitivity Data

1. Rolled or drawn metal (Moll Type No. 1109)

Sensitivity	13.2 $uV/W/m^2$
Time Constant	0.2 to 0.3 seconds

2. Evaporated metal type

Thickness	3x154mm
Width	2mm
Sensitivity	5.65 $uV/W/m^2$
Time Constant	0.01 to 0.1 seconds (Depends on Amplifier)

B. Thermopile Sensitivity Curves

The sensitivity curves of the Moll Type 1118 thermopile are shown in Figures (D)18 and (D)19. The sensitivity curve, Figure (D)18, represents the variation of the e.m.f. output as a small 3mm pencil beam of light is very slowly moved along the thermopile element. The peak e.m.f. represents the junction location. (The abscissa numbers are from an arbitrary zero). The sensitivity curve, Figure (D)19, represents the e.m.f. output as a light is moved crossways to the thermal elements along the line of junctions. If each junction were the same, each peak should be the same height. However inaccuracies in obtaining the data may contribute to the deviations. Figure (D)20 shows similar data taken along the length of an element of a compensation thermopile. The two peaks represent the two junctions.

V. AMPLIFIER CIRCUITS

A. The thermopile current or e.m.f. is interrupted for ease of amplifications. Light choppers or electrical switches must be used. Figure (D)21 shows a block diagram of such an interrupter. It utilizes a coil-type magnetic speaker magnet that oscillates longitudinally, making and breaking a platinum ruthenium alloy contact as shown in the diagram. The ruthenium rider slides back and forth on a bakelite peg that has a cross strip of platinum imbedded edgewise in it. In this manner the thermopile current is interrupted before it reaches the amplifier.

B. A single channel three-stage resonant amplifier is shown in Figure (D)22. The output current is rectified and observed on a DC meter.

C. Figure (D)23 shows a synchronous amplifier designed to amplify the output of a three section type thermal detector of the type shown in Figure (D)16a.

ENCLOSURE (D), continued

TABLE 1

CHARACTERISTIC DATA ON TEST MODELS OF HEAT DETECTOR THERMOPILES

NAME*	MODEL	CASE DIMENSIONS (mm)	WINDOW DIMENSIONS (mm)	WINDOW AREA (cm)	NO. OF COMPARTMENTS	COMPENSATION DIST.	NO. OF ELEMENTS **	FOIL MATERIAL	FOIL THICKNESS (mm)	FOIL WIDTH (mm)	INTERNAL RESISTANCE (ohms)
KTA-1-A	Moll Type	25 Circular	8 Circular	0.5	1		18	Fe-Constantan & Fe-Manganin	.003-.005	0.35	30
KTB-13	Comp.	25x23	12x12	1.44	1	3mm	17	Fe-Constantan	.003-.005	0.55-0.6	30
KTB-15	Comp.	25x23	12x12	1.44	1	5mm	17	Fe-Constantan	.003-.005	0.55-0.6	70-80
KTB-33	Wide visual range comp.	63x26	55x12	6.60	3#	3mm 3mm	35 each 15 each	Fe-Constantan	.003-.005	0.55-0.6	60 each 30
KTB-35	Wide visual range comp.	63x26	55x12	6.60	3#	5mm 5mm	35 each 15 each	Fe-Constantan	.003-.005	0.55-0.6	60 each 30
KTB-53	Wide visual range comp.	109x26	101x12	12.12	5##	3mm 3mm	35 each 15 each	Fe-Constantan	.003-.005	0.55-0.6	60 each 30
KTB-55	Wide visual range comp.	109x26	101x12	12.12	5##	5mm 5mm	35 each 15 each	Fe-Constantan	.003-.005	0.55-0.6	60 each 30

*Letter designations: K - Kawanishi Co.; T - Thermopile
A - Moll Type; B - Compensation Type

Number designations : first number indicates number of channels or heat detector compartments.
second number indicates distance in mm. between two junctions of a compensation type element.

**Moll Type element has one junction in the middle. Compensation Type has two junctions slightly separated.

(2 finding 1 aiming)
(4 finding 1 aiming)

ENCLOSURE (D), continued

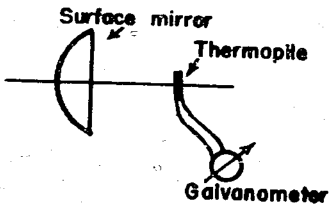


Figure (D)1
THERMOPILE HEAT DETECTOR

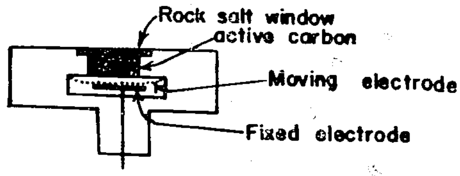


Figure (D)2
HAYE'S ELECTROSTATIC RADIATION DETECTOR

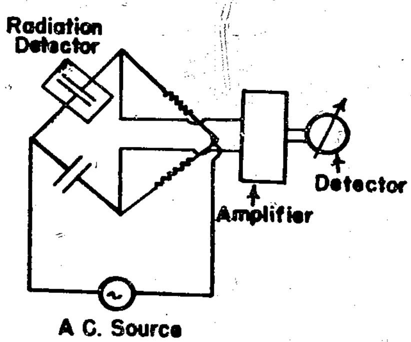


Figure (D)3
BRIDGE CIRCUIT FOR HAYE'S ELECTROSTATIC HEAT DETECTOR

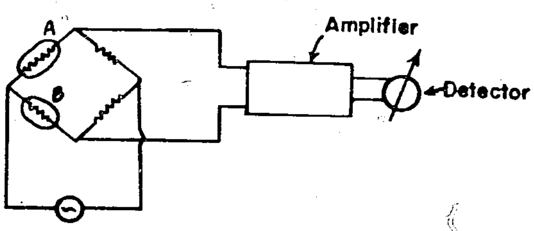


Figure (D)4
COMPENSATION TYPE BOLOMETER HEAT DETECTOR

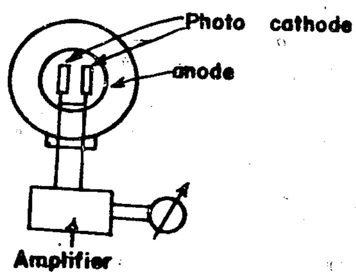


Figure (D)5
COMPENSATION TYPE PHOTOCELL HEAT DETECTOR

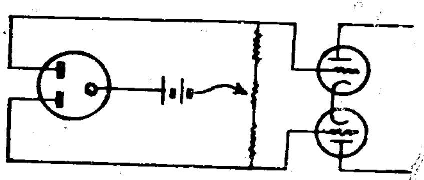


Figure (D)6
COMPENSATION TYPE PHOTOCELL WIRING DIAGRAM

ENCLOSURE (D), continued

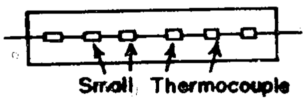


Figure (D)7
THERMOPILE

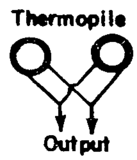


Figure (D)8
SIMPLE ELEMENT COMPENSATING THERMOPILE

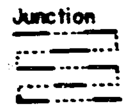


Figure (D)9
COMPENSATING ELEMENT THERMOPILE

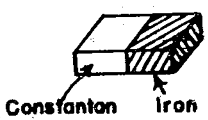


Figure (D)10
SIMPLE ELEMENT

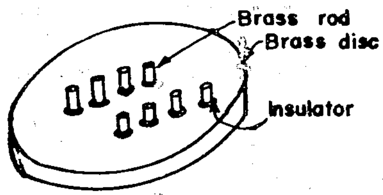


Figure (D)11
SUPPORTS FOR MOLL TYPE THERMOPILE

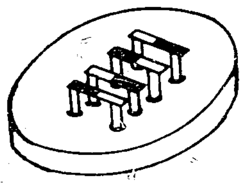


Figure (D)12
MOLL TYPE THERMOPILE

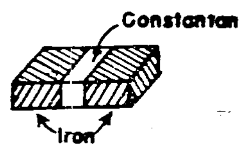


Figure (D)13
COMPENSATING TYPE ELEMENT

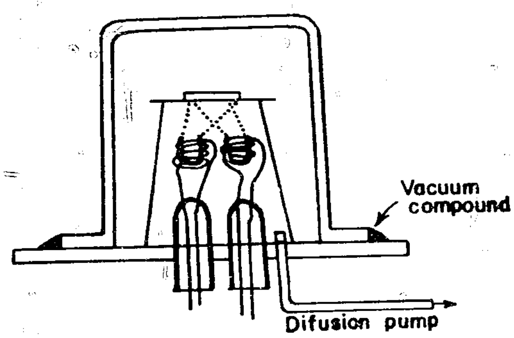


Figure (D)14
APPARATUS FOR MAKING EVAPORATION TYPE THERMOPILES

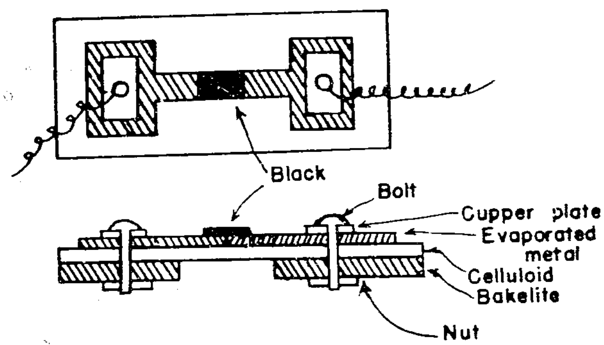


Figure (D)15
DETAILS OF EVAPORATION TYPE THERMOPILES

ENCLOSURE (D), continued

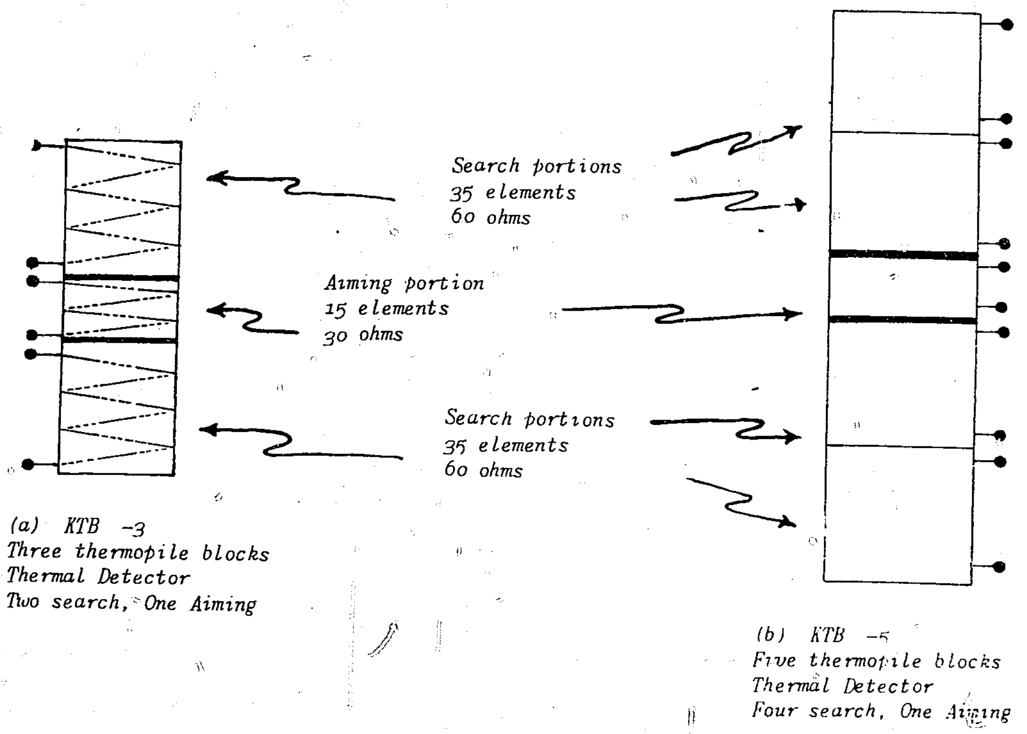
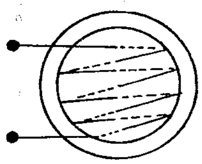


Figure (D)16

MULTIPLE BLOCKS OF THERMOPILES FOR SENSITIVE ELEMENT OF THERMAL DETECTORS WHICH PERMIT WIDE ANGLE BEAMS FOR SEARCH AND SMALL ANGLE BEAM FOR PRECISION AIMING



Vertical Direction. (Line of junctions)

Horizontal Direction. (Line parallel to an element of the thermopile).

Figure (D)17

MOLL TYPE NO. 1118 THERMOPILE

ENCLOSURE (D), continued

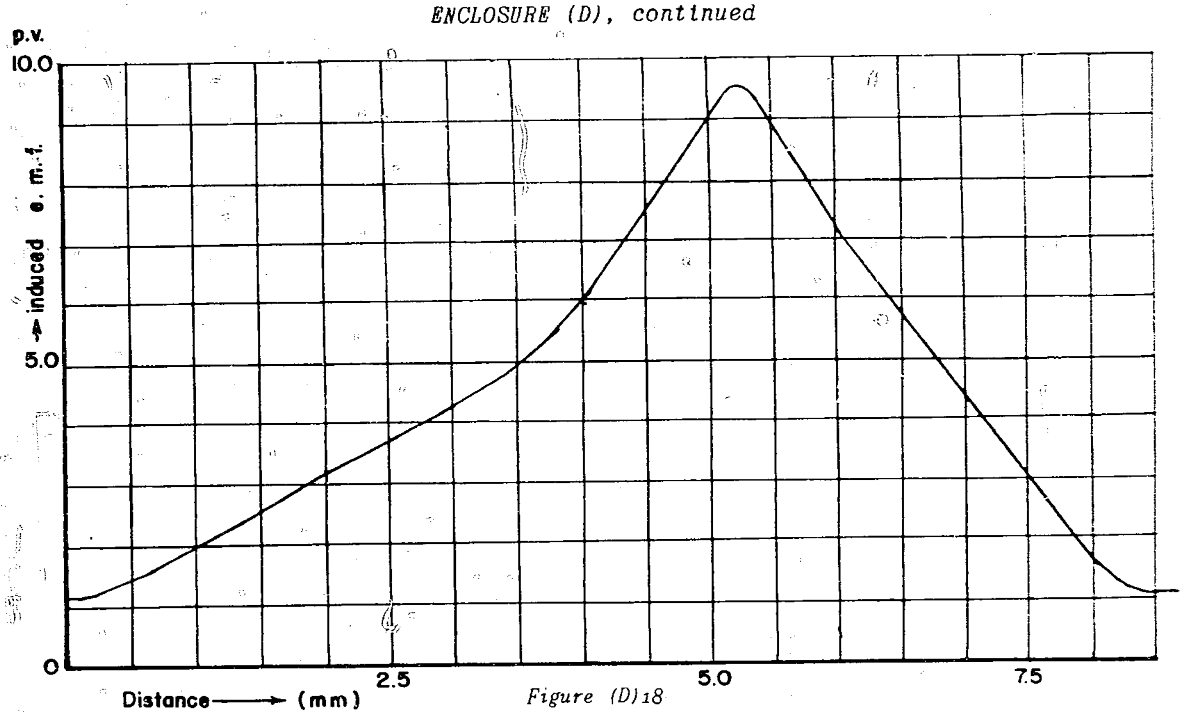


Figure (D)18

MOLL TYPE NO. 1118 THERMOPILE

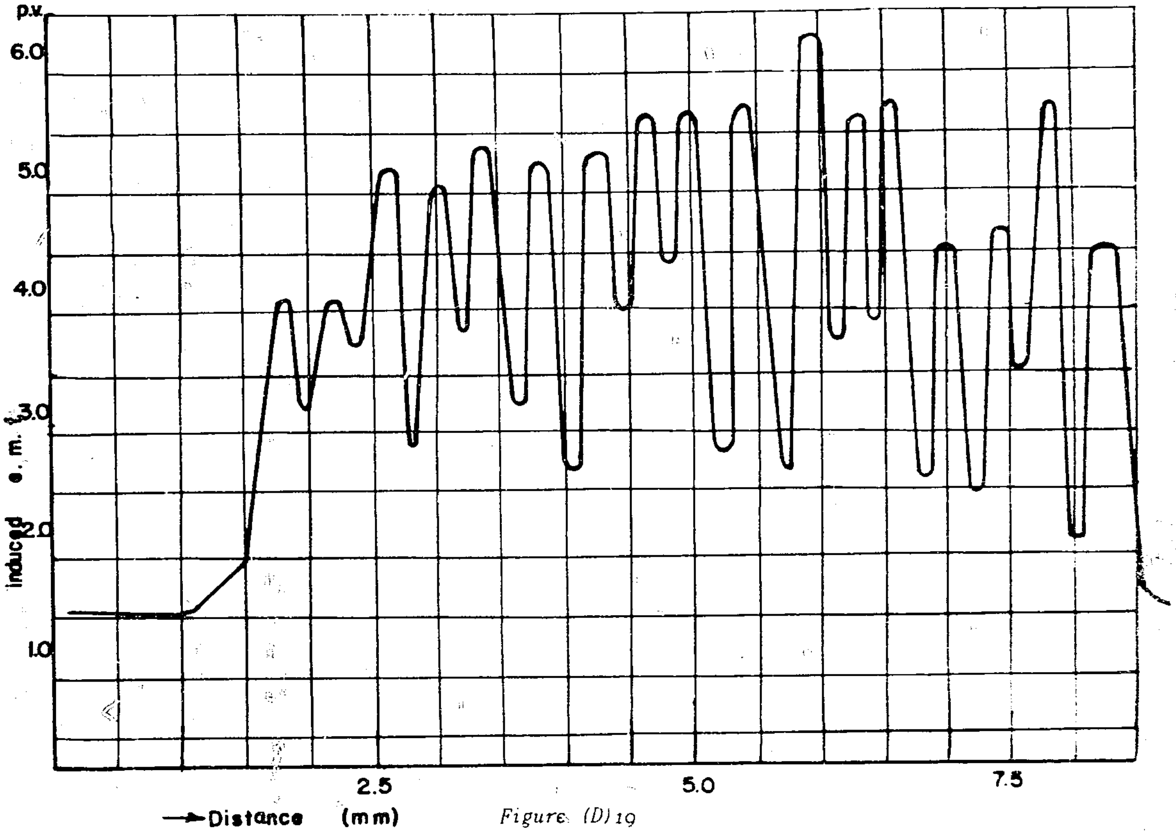


Figure (D)19

MOLL TYPE NO. 1118 THERMOPILE

ENCLOSURE (D), continued

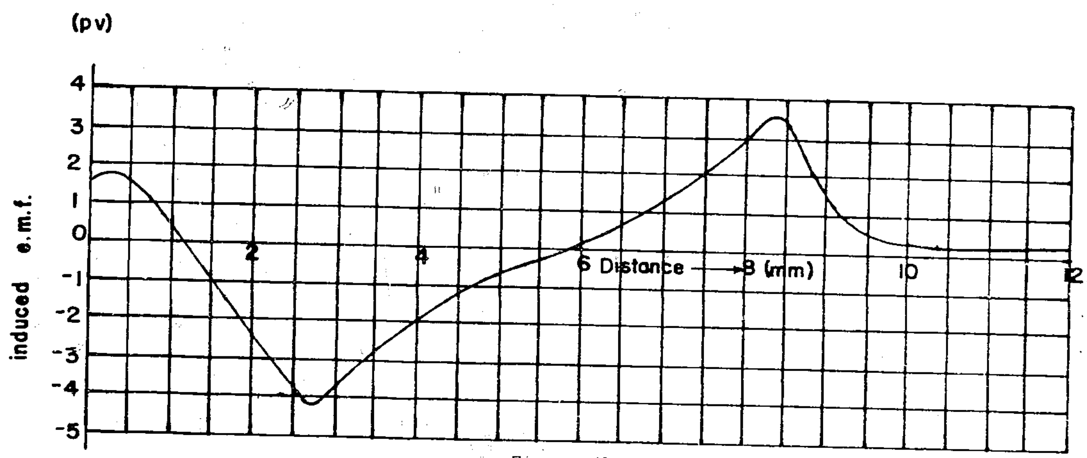


Figure (D)20

MOLL TYPE NO. 1118 THERMOPILE

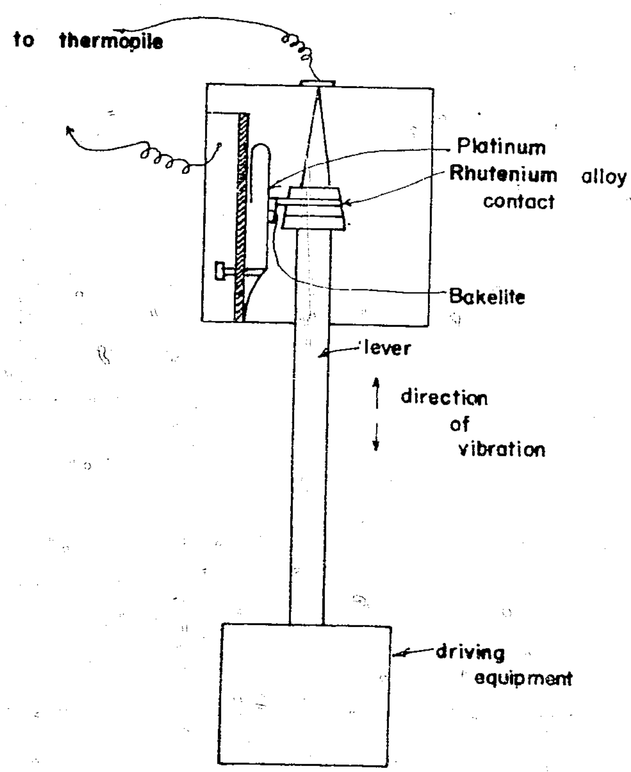


Figure (D)21

MOLL TYPE NO. 1118 THERMOPILE

ENCLOSURE (D), continued

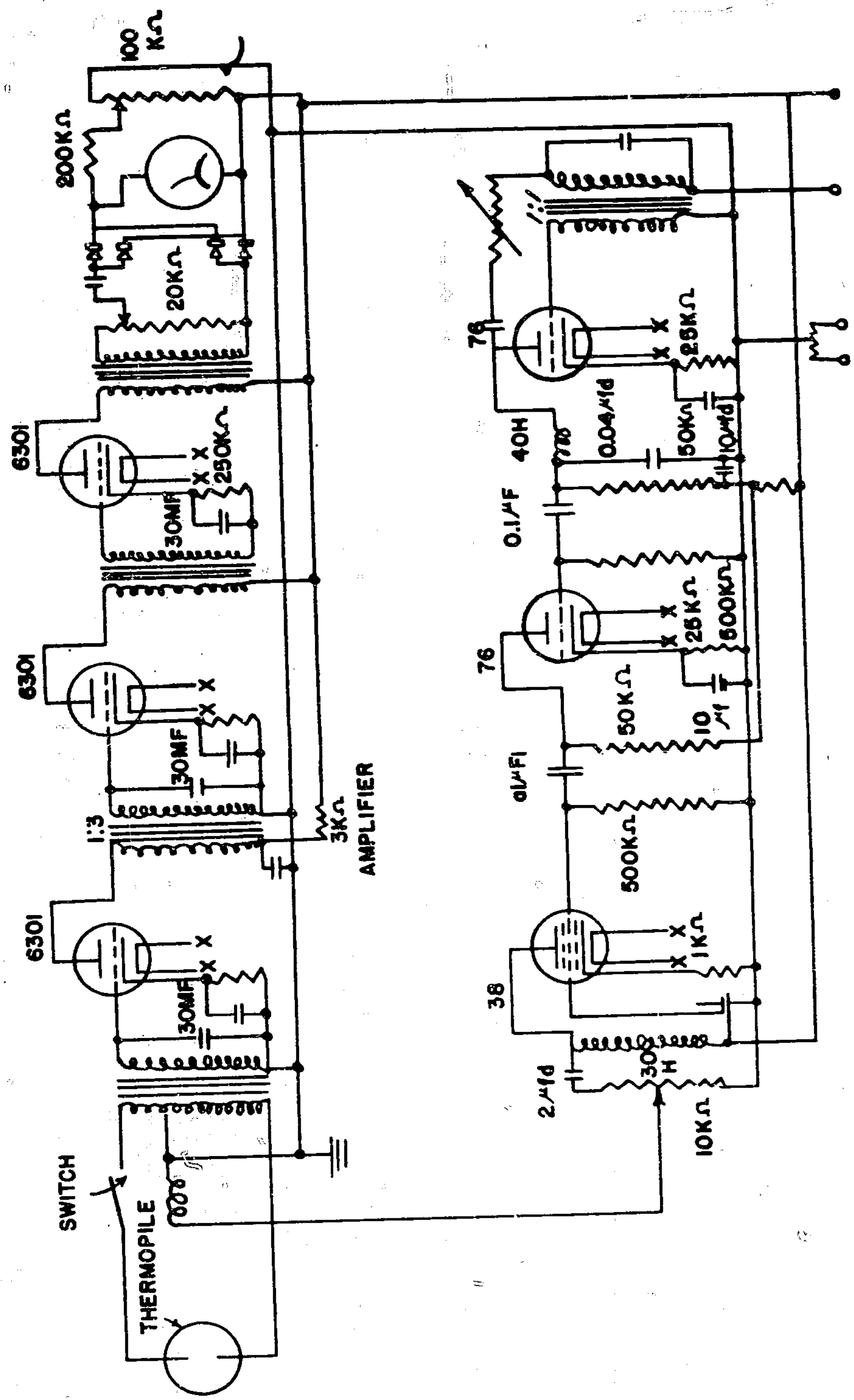


Figure (D)22
DRIVING OSCILLATOR

ENCLOSURE (D), continued

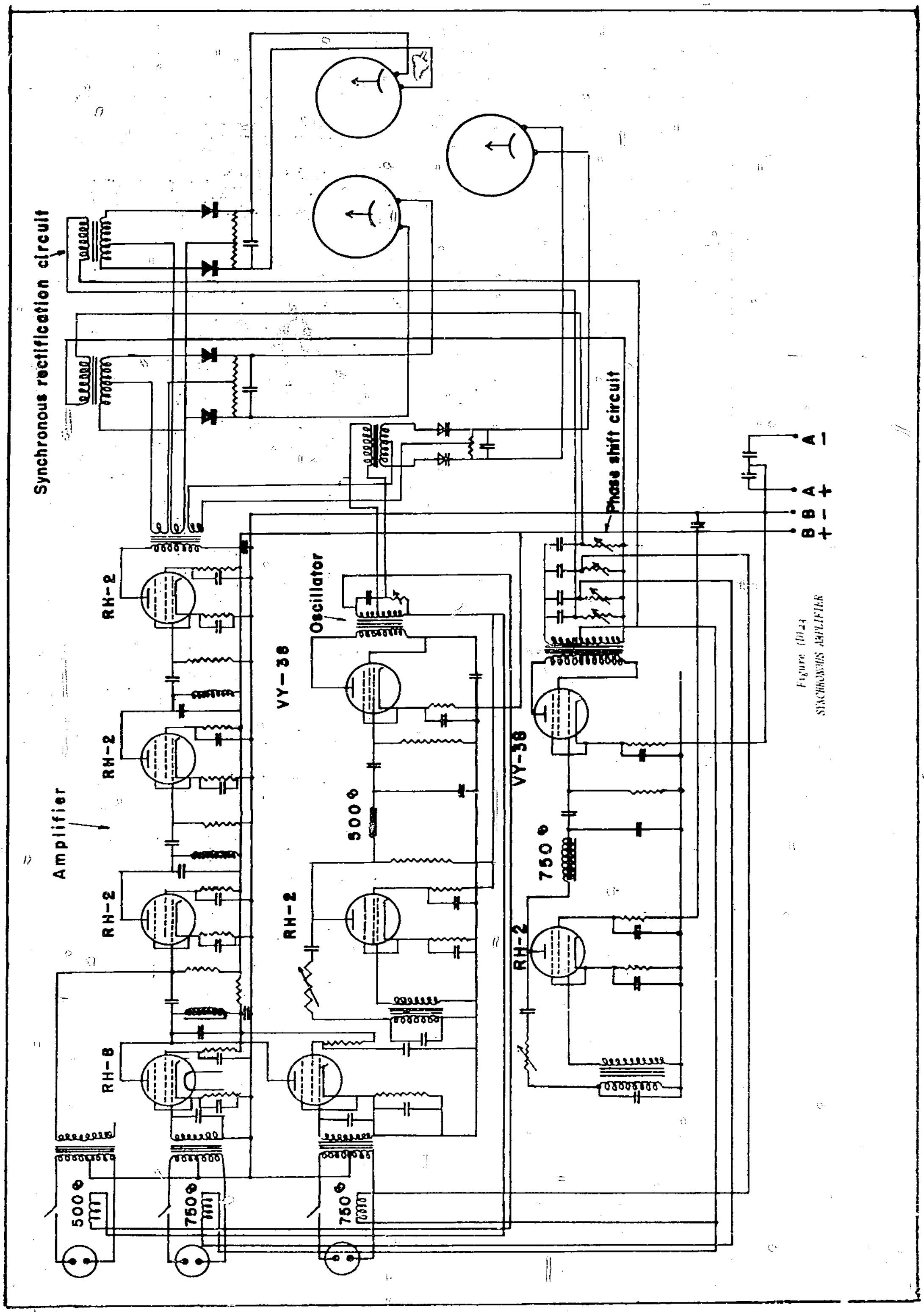


Figure (D)23
SYNCHRONOUS AMPLIFIER

ENCLOSURE (E)

Electrical Review

Section 29 1941

(Reprint)

MANUFACTURE OF THIN FILM THERMOPILES BY THE EVAPORATION METHOD AND THE AMPLIFICATION OF ALTERNATING CURRENT

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Electrical Review Editing Dept.

Kyoto Imperial University Engineering Dept.

Electrical Engineering Section.

ENCLOSURE (E), continued

Manufacture of Thin Film Thermopiles By the Evaporation Method and the Amplification of A.C.

Professor Nobuyoshi KATO of Kyoto Imperial University

* * *

1. General

Among the devices used to detect radiant energy produced by a heat source are the radiometer, radiomicrometer, bolometer, and thermopile, but considered from the point of view of minimum influence of surge and maximum usefulness, the thermopile is the best. Various methods have been studied with the aim of increasing the thermopile's sensitivity and quick response, but a metal foil type thermopile utilizing an element made of metal wires joined together and flattened into foil is commonly used. The Moll thermopile[1] is representative of this type. In order to improve its special characteristics, the metal foil must be made thinner. The difficulty of manufacturing an extremely thin metal foil out of a material possessing a high thermo-electromotive force has been eliminated by the development of the evaporation method and sputtering method. However, when the metal foil was made thinner, the use of a galvanometer to increase interior resistance became impossible, and it became expedient to couple it with a vacuum tube amplifier. By using an amplifier in this fashion the necessity of preventing interior resistance within the thermopile disappeared, and it became possible to use thin film manufactured by the evaporation method or the sputtering method, utilizing materials of great interior resistance and large thermo-electromotive power, such as bismuth-tellurium or bismuth-antimony.

In amplifying this electromotive force it is possible to use both DC and AC amplification, but, as steady amplification of small DC voltages is impractical, it is preferable to amplify AC. This may be done directly with heat rays that are varying in the manner of alternating current, but the electro-motive force generated in the thermopile is normally in DC voltage and so it is necessary to convert to AC first. To this end, an AC electromotive force must be produced by using a "light chopper" to interrupt at regular intervals the heat rays leading to the thermopile. Various research reports have been published on AC amplification[2] of thermo-electromotive force. L. Harris[3] recently stated that a thin film thermopile of high interior resistance coupled with a low resistance amplifier offered greater sensitivity than a thermopile of low interior resistance coupled with a galvanometer of great sensitivity.

The writer has been continuing his research previously reported[4] in

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[1]Moll: Proc. Phys., Soc. London, 35 257 (1923)

[2]L. Harris & E.A. Johnson: R.S.I., 5 143 (1934)
L. Harris & E.A. Johnson: R.S.I., 4 454 (1933)
L. Harris: Phys. Rev. 45 635 (1934)
E.A. Johnson: Phys. Rev., 45 641 (1934)
L. Harris & A.C. Scholp: R.S.I., 11 23 (1940)

[3]L. Harris & A.C. Scholp: J.O.S.A. 30 519 (1940)

[4]KATO and UCHIDA: Draft of the 13th session of the Rengo Taikai (Apr. 1938)
KATO and INOUE: Denki Hyoron (Electrical Review), January 1937.

ENCLOSURE (E), continued

producing thin film thermopiles of high sensitivity. As he has recently achieved some experimental success using highly efficient AC amplifiers, part of the results will be set down here in simple form.

2. Manufacture of Thin Film Thermopile

A thin film thermopile may be produced by the sputtering method, but the writer used the vacuum evaporation method instead. Figure (E)1 illustrates the method for the single element type (A) and the eight element type (B) thin film thermopiles.

The supporting stand is provided in the form of a mica plate 0.1mm thick. In the case of the single element type there is a round hole 5mm in diameter in the mica plate, while the many element type has a mica plate perforated by an oblong aperture $5x12mm^2$ in size. Over these apertures a thin film of some organic material is stretched to serve as a supporting membrane.

The method for making such a thin organic membrane is as follows: Using a dropper whose interior diameter is 1 to 3mm, fill with a solution of acetone and cellulose acetate. If this solution is dropped onto the surface of distilled water, it will spread, and a thin membrane about 10^{-5}cm thick will be formed. After some hours have passed, the solvent acetone will evaporate completely, and the membrane may be cut into suitable size with a pair of scissors. Then by bringing the aforementioned mica supporting plate up against the membrane from underneath, the hole in the center of the plate is thus covered. If the membrane is allowed to stand for twenty-four hours, it will dry of its own accord.

The thickness of the organic membrane is dependent on the density of the solution, volume dropped, type of solvent, temperature of the solution and the distilled water, etc., but, if a 10% solution is used with a dropper of 1.5mm interior diameter and the solution is at 15°C., a membrane of 10^{-4} - 10^{-5}cm can generally be obtained. Its thickness can be determined by weighing the amount of the solution at the beginning and by measuring the surface spread. Corroboration and correction can be obtained optically by interference colors.

The mica plate with its membrane is then placed in a bell-jar of suitable size and a vacuum of 10^{-4} - 10^{-5}mm (Hg) is produced. The metal introduced previously onto the tungsten filament is then heated and evaporated in part M_1. The other metal is treated in the same way to effect evaporation in part M_2. In evaporating the metal in parts M_1 and M_2 it must be covered with a thin metal and mica plate to keep it from adhering to other parts.

The thickness of the metallic membrane is governed by the amount of metal evaporated and by the relative positions of the tungsten filament and the surface plated through the evaporation process, but in general it will be 10^{-4} - 10^{-5}cm. At the juncture of M_1 and M_2, that is, in the central part of the organic membrane, it is contrived to double the thickness of the metal for an overlap of 0.3 - 1mm. After this method has been used to make a single or multiple element type thermopile with bismuth antimony and bismuth tellurium, the sensitivity is further increased by "blackening", whether it be by evaporating the bismuth antimony and other metals or by some other means. An exterior view of this may be seen in Figure (E)2, where it is shown enclosed in a brass case. A piece of fluorspar 6x14mm is used for a window.

ENCLOSURE (E), continued

3. Experimental Apparatus for Amplifying Alternating Current

Experiments with the thin-film thermopile constructed in the above described fashion were carried on as follows. As a source of heat, a projector was used with an automobile headlight bulb backed by a reflector, a "light-chopper" made of an aluminum disk 1m in diameter, about the circumference of which were cut at regular intervals twelve round holes 10cm in diameter. The disk was directly connected to a DC motor and, in revolving, intermittenly cut off the heat rays. Adjusting the revolutions gave a band of frequency ranging from 0 to 300 cycles. Figure (E)3 gives a photograph of this heat source. The heat rays from this source are focused by the small reflector upon the thermopile. The AC electromotive force thus created in the thermopile is raised by a five-stage low-resistance amplifier, and the electric output is measured by vacuum tube voltmeter, oscillograph, etc. The various detection devices are illustrated in Figure (E)4. Figure (E)5 shows the wiring layout for the amplifier. In the first stage a low hum vacuum tube UY-3601 was purposely used and in all parts special pains were taken to cut out, as far as possible, the effects of leakage, external electro-magnetic fields and mechanical vibration. Under such circumstances the amplification factor rose to several million times.

Table 1. Characteristic Data of Evaporated Type Thermopiles

Thermopile No.	Metal	Number of Elements	Internal Resistance (52)	DC Electromotive Force(V) with Heat Radiation Density $2.0x10^{-4}$ watt/cm^2
4	Bi-Sb	1	25,000	0.21×10^{-4}
5	Bi-Sb	1	13,000	0.25×10^{-4}
5	Bi-Sb#	1	13,000	1.1×10^{-4}
7	Bi-Te	1	36,000	0.87×10^{-4}
8	Bi-Te	1	11,000	1.48×10^{-4}
8	Bi-Te#	1	12,000	4.44×10^{-4}
9	Bi-Te	1	24,000	1.30×10^{-4}
9	Bi-Te#	1	24,000	3.20×10^{-4}
10	Bi-Te	4	300,000	1.8×10^{-4}
11	Bi-Te	4	65,000	2.0×10^{-4}
15	Bi-Te#	8	1,000,000	7.0×10^{-4}
16	Bi-Te	8	300,000	5.2×10^{-4}
16	Bi-Te#	8	310,000	18.0×10^{-4}
17	Bi-Te	8	230,000	4.5×10^{-4}
17	Bi-Te#	8	230,000	11.0×10^{-4}

#(blackened)

ENCLOSURE (E), continued

4. Results of Experiment

The above described means were used to measure the special frequency characteristics of various experimental thermopiles. Figure (E)6 shows as an example the characteristics of No. 8 single-element type thermopile of the bismuth-tellurium class. Vertical lines mark the voltage (V) of the amplifier output margin and horizontal lines mark the frequency of the alternating heat waves which were projected.

Table 1 shows the internal resistance of various experimental thermopiles and also direct current sensitivity (in the latter case electromotive force generated by the projection of fixed heat rays was measured by a high internal resistance, high sensitivity galvanometer.) In general, with an increase in frequency there was a decrease in amplifier output and, hence, in AC electromotive force within the thermopile. This decrease is in keeping with the thermal inertia of the thermopile. Thus, in order to get a large AC electromotive force with a high frequency, it is necessary to have a thin metallic film with a thin organic membrane for support. The combined thickness of these in the No. 8 thermopile, averaged 10^{-4}cm, but with further experimentation to make it thinner, one of 10^{-5}cm was produced. The result of this was lowered sensitivity, but amplification by still higher frequencies was made possible. Furthermore, Table 1 makes clear that, by blackening, DC sensitivity increased two to three times and internal resistance also rose. In order to diminish loss by heat conduction the thermopile may be placed in a vacuum container, which is then exhausted to 10^{-4}mm (Hg) or is filled with a vapor of CCL_4 and operated at a low temperature. In this way sensitivity can be increased.

5. Conclusions

I have set forth above the processes for making a high sensitivity thin film thermopile by the evaporation process and also some experimental results in AC amplification of its electro-motive force. If the results are to be evaluated by the degree to which the frequency of interruption of heat rays is audible, by using good amplifying equipment it is possible to make AC amplification with a sensitivity that would convey sound to the ear. When the heat rays are radiated steadily it is necessary to interrupt them with a chopper, but when they are varying in the manner of alternating current, they may be amplified directly and then measured.

ENCLOSURE (E), continued

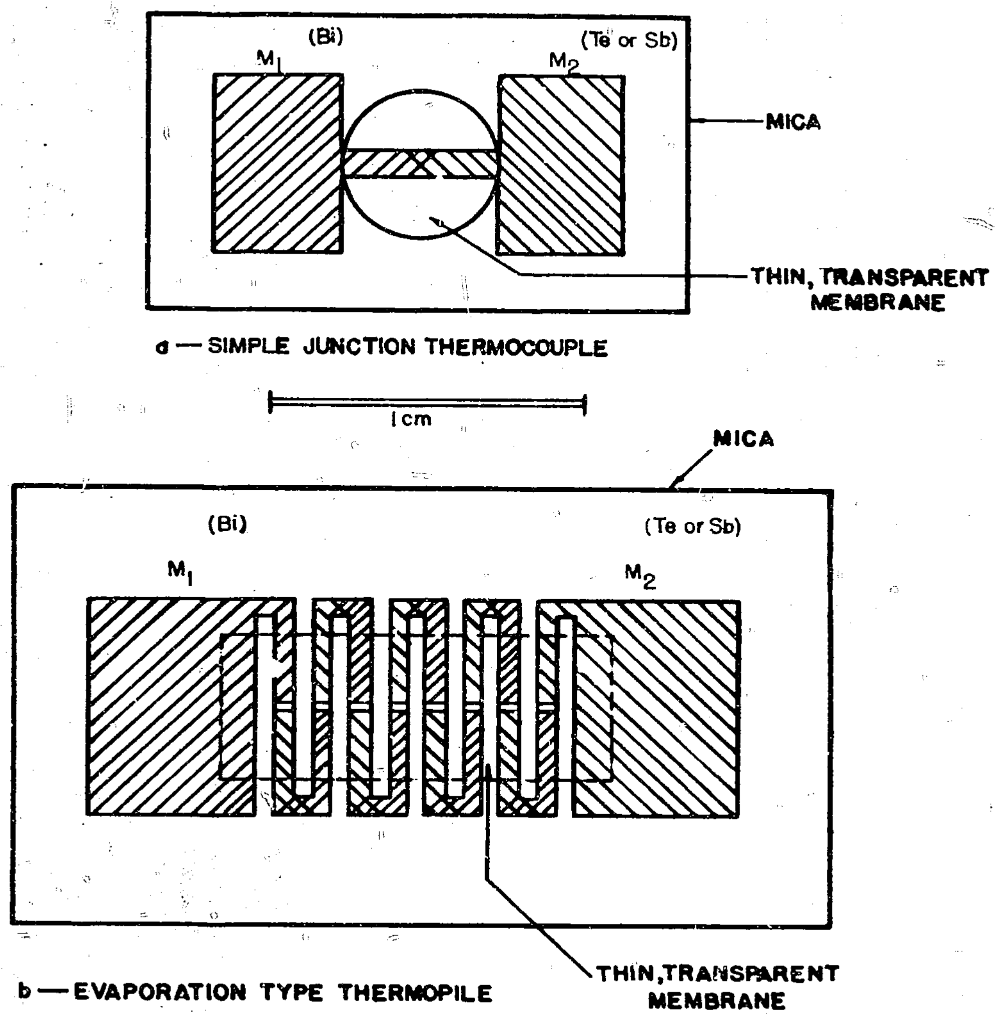


Figure (E)1

EVAPORATION METHOD FOR MAKING THERMOPILES

ENCLOSURE (E), continued

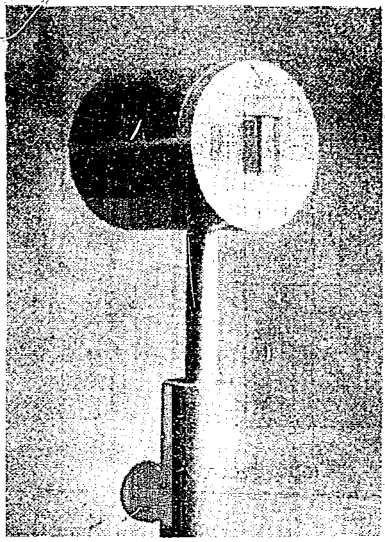
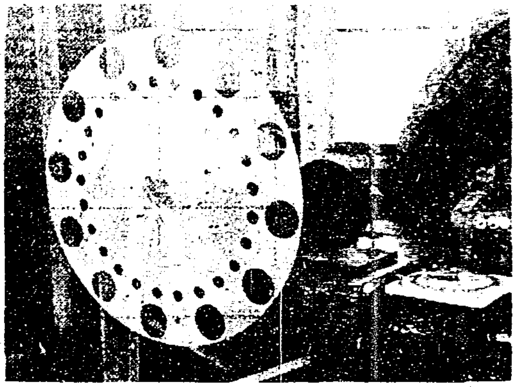


Figure (E)2
EVAPORATION TYPE THERMOPILE IN CASE

Figure (E)3
LIGHT CHOPPER



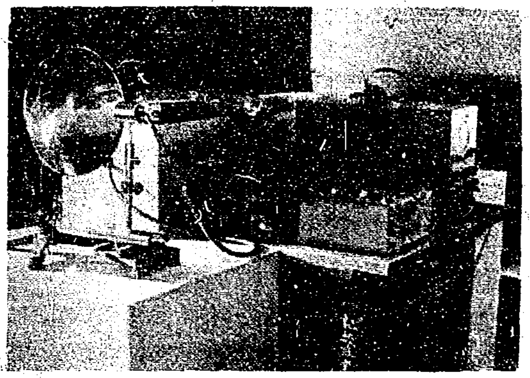


Figure (E)4
INDICATOR DEVICES

ENCLOSURE (E), continued

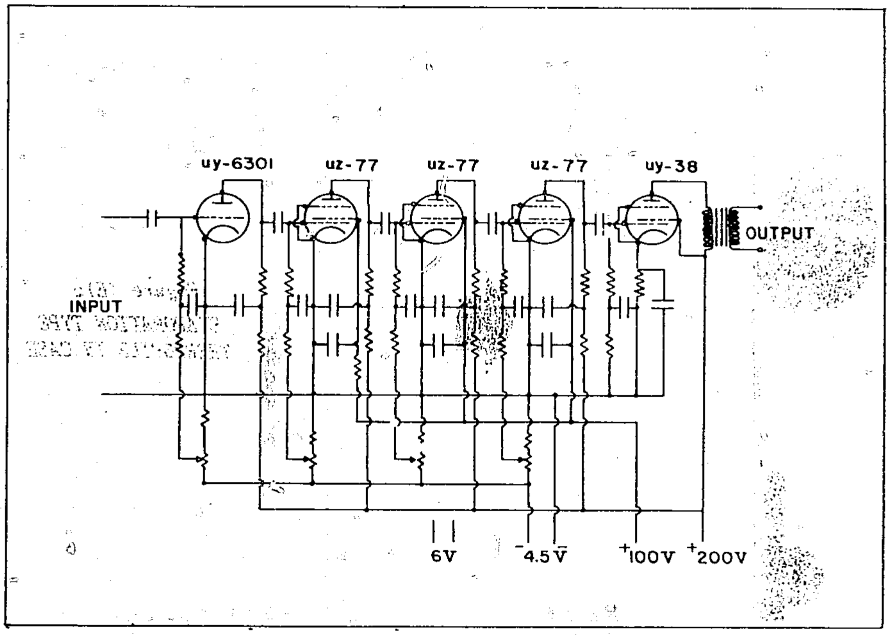


Figure (E)5
AMPLIFIER CIRCUIT

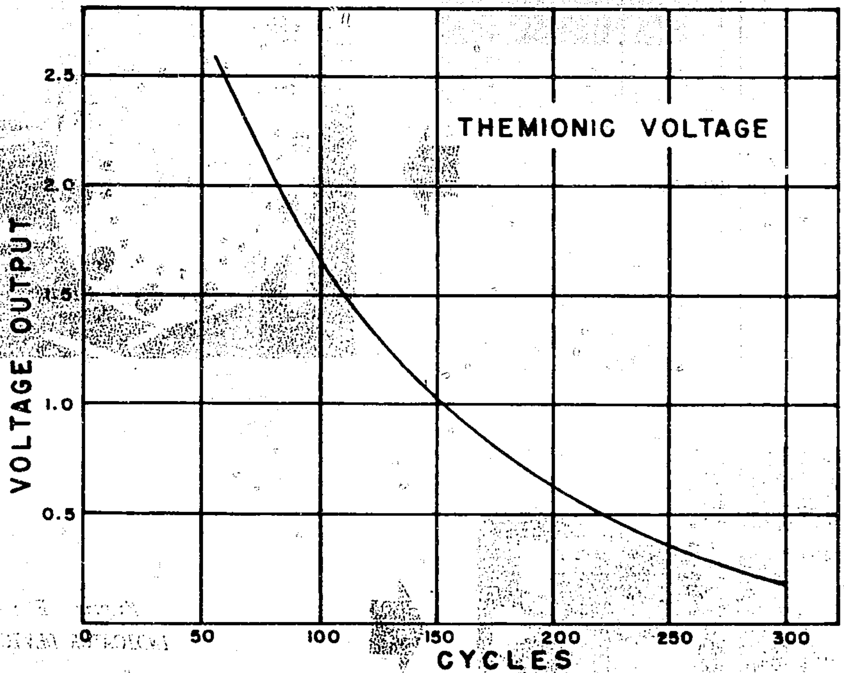


Figure (E)6
EVAPORATED THERMOPILE OUTPUT VERSUS CHOPPING FREQUENCY

ENCLOSURE (F)

JAPANESE ARMY HEAT DETECTOR EQUIPMENT
(Personnel Detectors)

(Second Military Technical Laboratory)

A heat locator equipment (see Figure (F)1) was found at the Yocho-Machi Branch of the Ordnance Board, which had been used by the Second Military Laboratory in personnel locator tests. The range of detection of a single man was about 100 meters under most ideal conditions, using a nickel bolometer for the sensitive element, but the difficulties were great and the work was discontinued. No equipment or material was obtained from the Second Military Laboratory, but personnel of the Seventh Military Laboratory and the Yocho-Machi Branch of the Ordnance Board were familiar with the problem. The equipment was essentially the Seventh Laboratory Heat Locator (see Enclosure A) somewhat improved by the Second Laboratory for the personnel detection tests. The results were not considered to have outstanding significance or success, but, when the tests were stopped at the Second Military Laboratory, the equipment was given to the Yocho-Machi Branch of the Ordnance Board for further investigation. Some qualitative observations had been made by the Ordnance Board and the experiments stopped.

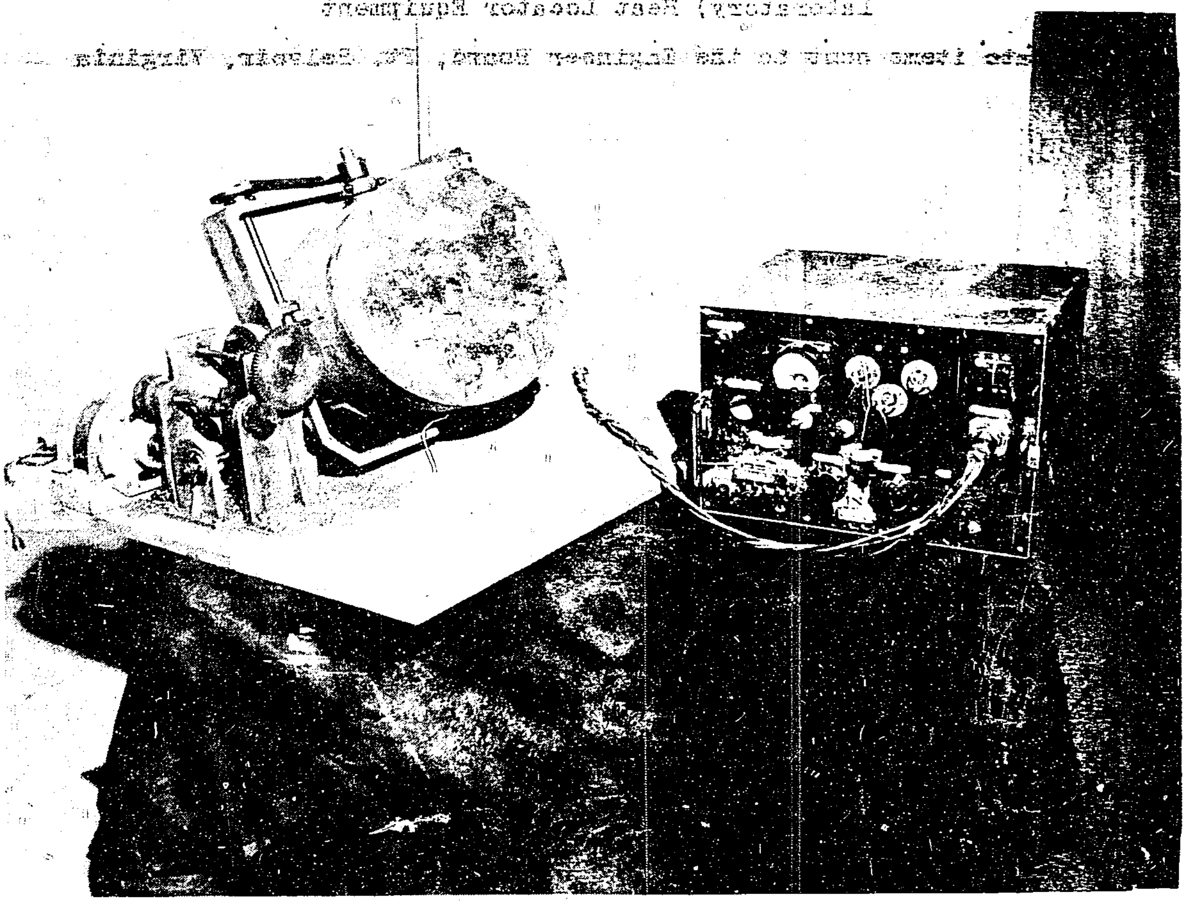


Figure (F)1
ARMY TYPE HEAT DETECTOR

ENCLOSURE (G)

EQUIPMENT FORWARDED TO THE NAVAL RESEARCH LABORATORY, ANACOSTIA, D. C.

NavTechJap Equipment No.	Item
JE 21-6330	#Scanning Support - Naval Airborne Heat Detector, Mk 5.
JE 21-6331	#Motor Generator - Naval Airborne Heat Detector, Mk 5.
JE 21-6332	#Amplifier - Naval Airborne Heat Detector, Mk 5.
JE 21-6333	#Detector - Naval Airborne Heat Detector, Mk 5.
JE 50-5020	Amplifier (Seventh Military Laboratory) Heat Locator Equipment
JE 50-5018	Detector Head - Yocho-Machi Branch of Ordnance Board (Second Military Laboratory) Heat Locator Equipment
JE 50-5019	Yocho-Machi Branch of Ordnance Board (Second Military Laboratory) Heat Locator Equipment

#Duplicate items sent to the Engineer Board, Ft. Belvoir, Virginia