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SUPPLEMENTARY REPORT

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Signalling and Detection

with

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Portable Equipment for the Amplification  
of Thermocouple Electromotive Forces.

ABSTRACT

An investigation has been conducted to determine the feasibility of indicating the electrical output of thermocouples by means of portable equipment of a type suitable for use at sea. A moderately satisfactory system has been devised which permits the detection and indication of electromotive forces as small as thousandths of a millionth of a volt. The equipment used in the experiments is described.

The apparatus described in this report replaces the galvanometer with a portable indicator which is connected to a portable thermocouple amplifier that can be distributed directly to the thermocouples of interest. It was found in tests that portable amplifiers which have not been previously described which will indicate the electromotive force of a thermocouple.

It should be noted that the portable indicator (that is, ordinary galvanometer) is to be replaced with a portable indicator which is connected to a portable thermocouple amplifier. This has been done by means of a portable amplifier. Experiments at this laboratory some years ago showed that the use of vacuum tubes in amplifiers of 200 voltages was the preferred for portable use because they required no such attention. Amplifiers were developed which could give an overall gain amplification of 100,000, but using only two tubes. The design diagram of such an amplifier is being prepared at this laboratory in view of their interest in their use in the field.

Since vacuum tube amplifiers are particularly adapted to amplify alternating currents, a preliminary attempt was made to intercept the I.C.F. from the thermocouple and amplifier using finally a photo-conductor in the plate circuit of the first tube. This method was abandoned although it is essentially the method used by the Signal Corps Laboratory at Fort Monmouth. There are three serious objections to the method:

- (a) Contact electromotive forces are usually large compared to that which is to be measured and consequently mask the desired quantity.

This report covers a single, but nevertheless an important, part of the problem of the detection of an enemy ship by means of infra-red radiation emitted from its hot stack.

The very serious practical difficulties that will be encountered in picking up the radiation from the hot stack of a hostile ship under service conditions and properly interpreting the observations will not be considered here.

So far as is now known, the only pickup device that will detect the heat radiation from such a hot object is the thermocouple. This device, made up of a welded junction of two suitable dissimilar metals, produces a very small electromotive force if it is slightly warmed. In general, the radiation from the hot stack of a ship is concentrated, by means of a suitable parabolic reflector, upon the thermopile. This radiation heats the thermopile slightly and a very small current or electromotive force is produced. Now, it is only possible to detect a hot stack on a typical ship at distances of two or three miles using the most sensitive laboratory equipment available, one element of which is a very sensitive galvanometer. Moreover, this galvanometer must be mounted on a concrete pier or other rigid mounting and this obviously makes the apparatus entirely unsuitable for shipboard use.

The apparatus developed and described in this report replaces the galvanometer with rugged apparatus and provides an indicator similar in construction to a portable voltmeter or ammeter that can be calibrated directly in thousandths of microvolts ( $10^{-9}$  volts). It seems fair to state that no reliable strictly portable apparatus has ever been produced heretofore which will indicate such small voltages.

It should be clear that if a portable indicator (like an ordinary voltmeter) is to be employed, some means must be devised to amplify the original  $10^{-9}$  volts up to a millivolt, say. This has been done by vacuum tube amplifiers. Experiments at this Laboratory some years ago showed that the use of vacuum tubes to amplify steady or D.C. voltages was impractical for service use because they required too much attention. Amplifiers were developed which would give an overall D.C. amplification of 100,000 using only two tubes (see circuit diagram of such an amplifier in Fig.1), but because of their inherent instability their use was abandoned.

Since vacuum tube amplifiers are particularly adapted to amplify alternating current, a preliminary attempt was made to interrupt the E.M.F. from the thermocouple and amplify this, using finally a microammeter in the plate circuit of the last tube. This method was abandoned although it is essentially the method used by the Signal Corps Laboratory at Fort Monmouth. There are three prime objections to the method:

- (a) Contact electromotive forces are usually large compared to that which is to be measured and consequently mask the desired quantity.

- (b) The input impedance to the amplifier changes periodically with the opening and closing of the circuit and the amplifier is correspondingly affected.
- (c) All amplifier noises are indicated on the meter.

In any satisfactory system these difficulties must be eliminated or at least minimized.

#### METHOD

The system finally adopted in the solution of this problem is shown schematically in Fig.2 and in the photograph, Fig.3. The thermocouple is indicated by "1"; one side connects to the center tap of a split primary, 20 to 1, step up ratio, input transformer. The other side of the thermoelement connects to a brush, 15, riding on a commutator having an even number of segments and having all alternate segments connected together. One group of segments goes to a collector ring, 5, and the other group to a collector ring, 4. It will be clear from Fig.2 that the rotation of the commutator by the motor, 2, will periodically interchange the connections in such a way as to produce an alternating flux in the primary of the input transformer. Examination will show, too, that contact electromotive forces at the brushes tend to produce opposing fluxes in the primary of the transformer so that contact difficulties become relatively small. It is further clear that the brushes can be arranged so that the primary of the transformer is always connected to the thermoelement or short-circuited through the brush resistance. Thus extraneous pulses that paralyze or disturb the operation of the amplifier are not produced.

The secondary 18 of the input transformer is connected to the grid of first tube in a high gain multi-stage amplifier which was particularly designed to amplify low frequencies. The alternating input from the thermocouple and commutator system is amplified to the desired extent and the alternating output from the output transformer 23, 24, 25 is passed through a synchronous rectifying commutator built exactly like the interrupting commutator and the resulting rectified direct current applied to the indicating meter 27. The ripple introduced by the rotating contact rectifier may be smoothed out to any desired extent by use of a choke 26.

The difficulties attendant the use of high gain audio amplifiers and their congenital tendency to break into oscillation have been successfully avoided by carefully isolating the input and output circuits. This was accomplished in the present experiments by driving the interrupting and synchronous rectifying commutator by a relatively long bakelite shaft. (See Fig.3) Thus the electrostatic coupling between the input and output circuits is kept at a minimum and stability is relatively easy to maintain.

Attention is drawn particularly to the fact that the rectifying commutator operates in strict synchronism with the interrupting commutator. Further, the internal resistances of these converting mechanisms are very low so that high electrical efficiencies are readily obtained.

## DATA

A resistance network was set up to supply known small voltages. The current read on a microammeter of 10 ohms was determined for numerous applied potentials. Tables of these data follow.

| <u>E applied<br/>volts</u> | <u>E out volts</u>   | <u>I out amperes</u> | <u>E out/E<br/>applied</u> |
|----------------------------|----------------------|----------------------|----------------------------|
| $5 \times 10^{-10}$        | $30 \times 10^{-6}$  | $3 \times 10^{-6}$   | 60,000                     |
| $10 \times 10^{-10}$       | $60 \times 10^{-6}$  | $6 \times 10^{-6}$   | 60,000                     |
| $50 \times 10^{-10}$       | $320 \times 10^{-6}$ | $32 \times 10^{-6}$  | 64,000                     |
| $100 \times 10^{-10}$      | $650 \times 10^{-6}$ | $65 \times 10^{-6}$  | 65,000                     |

The voltage amplification is about 60,000 and it is clear from the above table that 3 microamperes in the output indicating meter is equivalent to  $5 \times 10^{-10}$  volts at the input. This is about the upper limit of sensitivity that can be approached with the circuit due to the slight instability necessarily introduced by interrupting the input voltage.

Comparison of the results obtained with the instrument described and those obtainable with the most sensitive type of Leeds and Northrup high sensitivity galvanometer show that the amplifier is somewhat more sensitive than the galvanometer but, of course, very much more complicated in its operation.

## CONCLUSIONS

This investigation has shown that it is possible to build strictly portable apparatus which will successfully measure the very small voltages supplied by thermopiles. However, the apparatus is quite complicated and requires considerable attention. Therefore, the usual galvanometer is preferable where it can be used on a solid support. Clearly, the amplifier here described is the only device which offers promise for use on shipboard.

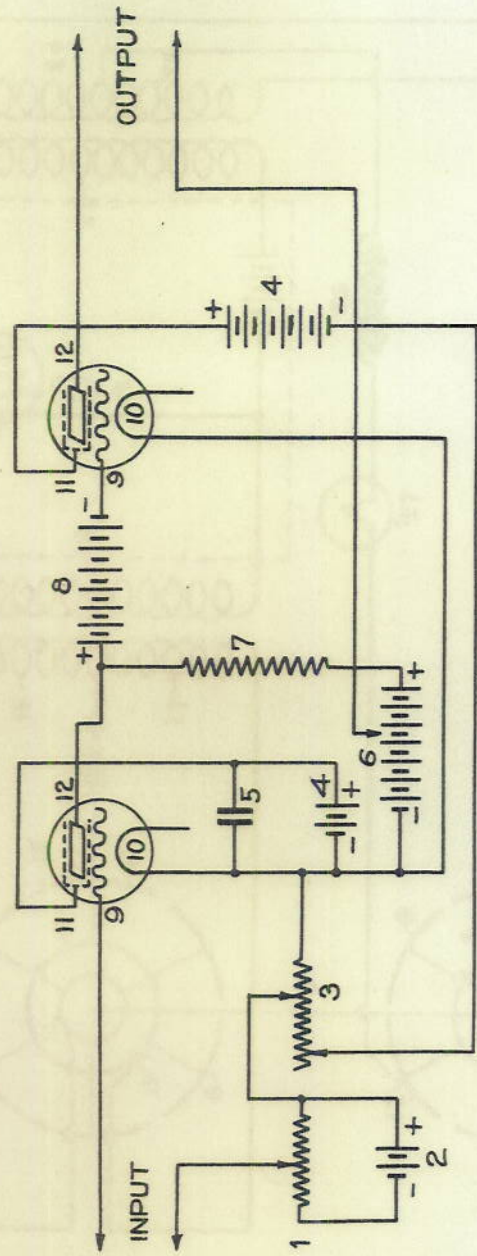


PLATE 1

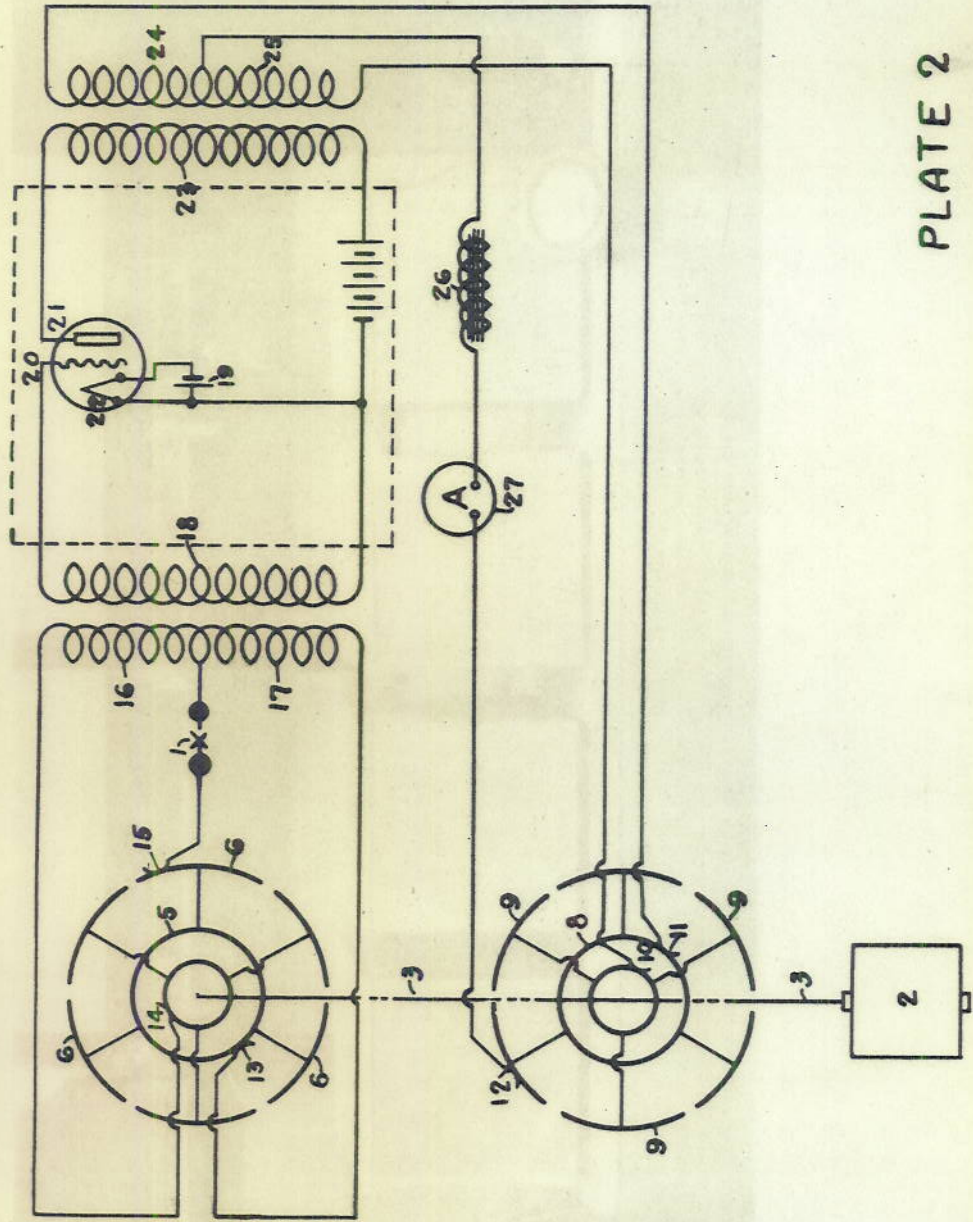


PLATE 2

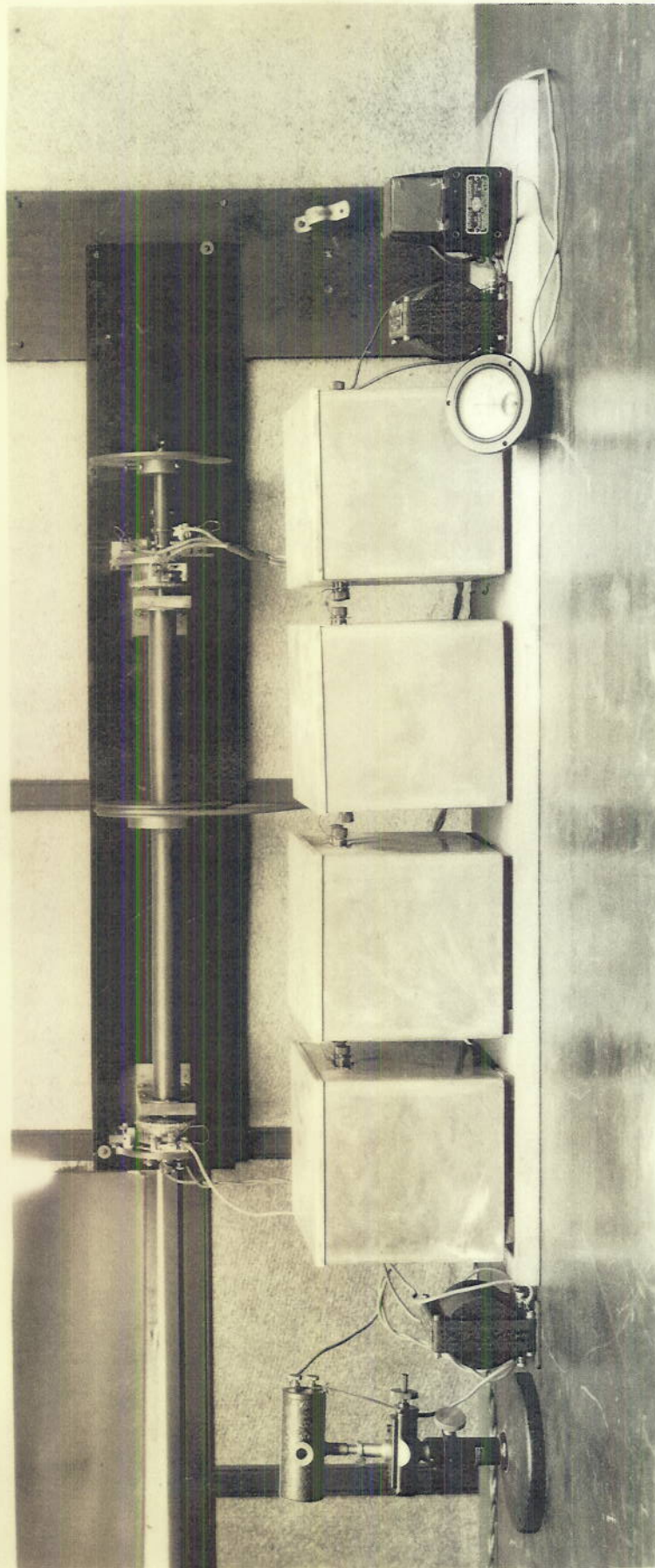


PLATE 3