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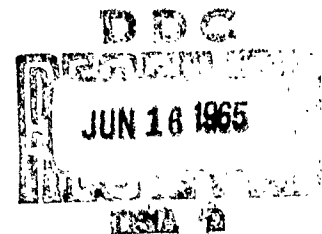# DESIGN INFORMATION FOR A NAVAL BHANGMETER [U]

BY

B. W. ALLWOOD

FEBRUARY 1965

IMPORTANT

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<u>DESIGN INFORMATION FOR A NAVAL BHANGMETER</u>

by

B. W. Allwood

<u>ABSTRACT</u>

The basic design features of the bhangmeter, an instrument for the recording of the yield of an air-burst nuclear explosion, are re-stated with special reference to the use of the most modern components, including a photo-sensitive detector of the semi-conductor 'solar' type.

The essential performance characteristics are described, and suggestions made for test equipment so that they may be determined independently of any operational check.

General principles of a circuit for the automatic compensation of variations in background illumination experienced by a ship-borne instrument are outlined.

20 pages
2 figures

- 1 -

C O N T E N T S

INTRODUCTION

With the possible introduction of a bhangmeter into Service use, it is considered advisable to gather together certain items of information gained from past experience and to present aspects of up-to-date electronic knowledge particularly relevant to the design of a modern instrument.

2. GENERAL DESCRIPTION

Although the general principle of the instrument is fully described elsewhere [1,2,3], a brief introductory description is given for completeness.

The instrument enables a measurement to be made of the time interval between the initiation and the first minimum of the light flash of a nuclear weapon, $T_{(min)}$, (to which the weapon yield, W, is directly related by an established formula; W increasing with $T_{(min)}$) The instrument consists of a photo-sensitive detector, mounted above decks in such a position as to have line of sight to the horizon at all times, and a console mounted below decks containing a photographically recording oscilloscope and its associated electronic circuits. On the occurrence of a flash, the output from the photo-sensitive detector is fed to the oscilloscope where the light-time characteristic, with superimposed timing marks for the measurement of $T_{(min)}$, is automatically displayed and recorded. To avoid unwanted operation of the instrument by extraneous light changes, the circuits are initiated by the characteristically rapid rise of the light pulse.

3. ELECTRONIC CIRCUITS

It is assumed that a modern instrument would employ transistors as far as is possible in order to reduce the bulk of the equipment, minimize heat dissipation and power consumption, and would employ components likely to be available in the future. As the A.R.L. experimental equipment employed valve electronics, it is therefore necessary, in some of the following paragraphs, to lay down certain parameters which specify the requirements whatever components are used.

4. THE LIGHT DETECTOR

Instruments in the past have employed a vacuum type Cintel VTA2 photoelectric cell in conjunction with an optical filter (Chance OY2) to bring the peak of the overall spectral response to 5,600Å with a bandwidth between wavelengths of half-maximum sensitivity of 570 Å. The main disadvantage of the vacuum cell in this application is its rapid deterioration when continuously exposed to sunlight. In order to maximize the life of the cell in the A.R.L. experimental prototype, its standing current had to be kept down to two microamps by the double sphere optical diffusing system and filter [1], but this imposed a limit to the sensitivity of the device.

There are several semi-conductor photo-sensitive devices currently available, of which the most suitable for the present application appears to be the silicon "solar" photovoltaic cells (such as the Ferranti MS11). The cell will withstand direct sunlight without deterioration, and

when in such a background will have a sensitivity much greater than that of a vacuum cell. However, since very successful determinations of the relationship between yield (W) and "time to minimum" $(T_{(min)})$ have been obtained in the waveband mentioned above, and are unlikely to be repeatable in any other waveband, it is necessary to employ the same spectral response characteristic in a Service instrument. Although the spectral response of the silicon cell peaks at 8,600 Å, combination with an optical filter to give the response prescribed above would still result in a detector with a sensitivity substantially greater than that of the vacuum photoelectric cell.

An important characteristic of any light detector used is that its frequency response characteristic should be sufficiently high for it to respond to the rapid rise of the leading edge of the flash. The time to first maximum intensity of a weapon flash is of the order of 200 micro-seconds, for which rate-of-rise the response of the cell is adequate. Also for a sharply falling light function, from a positive value to zero in ten microseconds say, the cell output will fall by a factor of 10^6 in 0.25 milli-seconds, a response which is adequate for recording the minimum of the smallest weapon required to be measured.

Other advantages of this type of cell are ruggedness, temperature independence over a wide range, low impedance and independence of any power supplies.

Perhaps the best way of employing such a device, since mast-head sites are difficult to obtain, is to use more than one cell so as to cover 360 degrees in azimuth free of all obstructions. A uniform polar response would be difficult to obtain in this way, but if the proposals of paragraph 8 were adopted, the degree of uniformity required could be relaxed. The electrical outputs from cells used in this way would need to be combined in a unit mounted as close as possible to the cells, containing such electronics as are necessary for providing an output which could be fed down 200 ft of cable with minimum distortion and attenuation, and without interference from local transmissions. The electronics would require to be substantially screened and the detectors covered with a metallic gauze of suitable mesh to prevent interference from high-frequency signals.

5.   DEFLEXION AMPLIFIERS

The two deflexion amplifiers, one of high and the other of low sensi-tivity, are located in the console containing the display and recording unit. They receive a common input from the detector head, and pass it to the two sets of Y plates of the double-beam cathode-ray tube.*

(a) Light sensitivity

The overall sensitivity, in terms of centimetres of spot deflexion per ft-candle of light received at the detector from a 3000°K tungsten filament source, of the A.R.L. prototype instrument is given in fig.17 of reference [1]. During a trial with the equipment the sensitivity of the device was increased by removing the inner polythene diffusing sphere of the detector head, leaving the outer sphere in place, and performing a minor circuit modification [2]. Tests with a flash tube performed at the trials site showed that this resulted in an instrument which had a triggering sensitivity to light six times greater than as originally designed and des-cribed in [1] (i.e. the sensitivity to an input voltage injected into the

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* Contrary to the statement in para. 2.2.1 of [1], it is now recommended that the two traces deflect in the SAME direction to avoid ambiguities of inter-pretation by unpractised observers.

FIG.1 REQUIRED AMPLIFIER RESPONSE CURVES.

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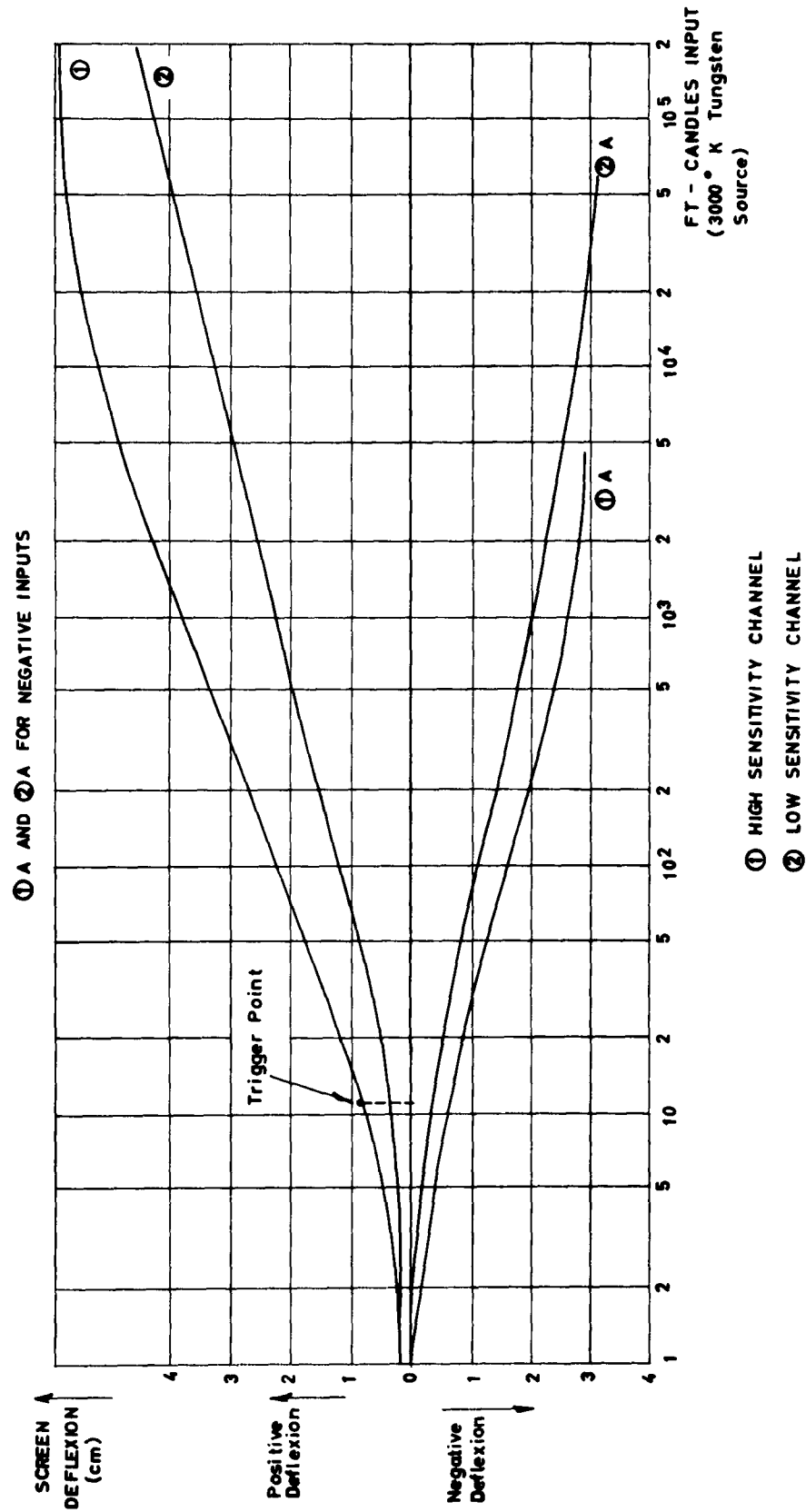
first valve of the mast head pre-amplifier remained the same as that shown in fig.17 [1], but the values of illumination on the ft-candles abscissa should be divided by six*). Results from nineteen rounds of the trial using the modified instrument showed this increased sensitivity to be near that required by an instrument used in practice. Any such improved sensitivity gained by increasing the transmission of the optical system, although it has been shown to be possible on trials, would be unacceptable operationally using a vacuum type photocell due to the deterioration of the cell after prolonged exposure (para.3). Use of the silicon solar cell would, however, allow a considerable increase of sensitivity without any risk of such deterioration. Accordingly it is recommended that any future instrument should have a triggering sensitivity of at least ten times that of the instrument described in [1]. The amplitude sensitivity curves of the deflexion amplifiers are replotted in this note (fig.1) to show the minimum sensitivity required. The absolute sensitivity should not be made so high, however, as to show interference from the natural background flicker of the sun, become unduly sensitive to false triggering, or saturate at the highest levels of light intensity which it may be necessary to record.

The deflexion sensitivities of the two compression amplifiers show a decreasing sensitivity with increasing applied voltage. The high and low sensitivity amplifiers are approximately logarithmic between 10 and 10^4 ft-candles and 50 and 10^6 ft-candles illumination of the detector head respectively, and approximately linear between 0 and 10, and 0 and 50 ft-candles, respectively. Also, the amplifier responds to negative excursions of electrical input.

(b) Pulse response

Laboratory experiments performed on the A.R.L. experimental instrument in 1963 showed that for an input step function of 8 µs rise time and input amplitudes corresponding to the full range of spot deflexions, the rise time to maximum output volts was between 0.5 and 1.0 ms. This response, together with a similar response for the fall time following the rapid removal of a voltage, is an adequate performance for an instrument required to give measurements in a yield range above one kiloton.

(c) Time constant

A time constant of not less than eight seconds over the linear part of the amplitude response curve is necessary. (A time constant applicable to other parts of the curve is difficult to specify since the impedance of some of the circuit elements changes according to the applied input voltage.)

6. TIME BASE

The time base should produce a single sweep of 700 ms duration (representing a 200 ms increase over the time base sweep of the A.R.L. instrument), the deflexion being approximately logarithmic with time between 2 and 700 ms. This increases the upper limit of the yield range to 50 megatons.

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* The sentence in para. 4.2.1 line 18 of reference [2] beginning ("Otherwise, the electronic .... etc.) is misleading in this respect. Although the voltage sensitivity remained the same as in fig.17 [1] the light sensitivity was increased.

The triggering conditions used in the past, namely that the instrument should be just triggered by a pulse with a rise time of 200 microseconds and of sufficient amplitude to produce a spot deflexion of 8 mm on the high-sensitivity trace, still apply. In order to minimize false triggering from unwanted pulses having a long rise time, a 5 Kc/s acceptor parallel-T network was interposed between the detector output and the time base trigger circuit. A bandpass filter centred on this frequency and having a somewhat greater bandwidth, may be an improvement. A high pass filter is unsuitable, as the high frequency rejection of a bandpass circuit assists in eliminating electromagnetic interference.

7. **TIME MEASUREMENT**

Both traces are brightness modulated at the following intervals of time:-

at 1 ms intervals from 0 to 10 ms
at 10 ms   "   "   10 to 100 ms
at 100 ms   "   "   100 ms to the end of the trace (700 ms)

The spot is biassed off under quiescent conditions. The instant the time base commences its sweep is made to coincide with the beginning of a timing gap in the trace. Thus the end of the first millisecond is marked by the end of the first mark of the trace. The end of the first period of 10 milliseconds will be recognized as the point of the trace at which a break appears which is larger than those immediately preceding it. The mark space ratio is about 5:1 in time.

It is strongly recommended for a future instrument that the circuits for making the traces should be controlled by a 10 Kc/s crystal oscillator the shaped output from which should operate a series of divider circuits to provide three marker frequencies of 1 Kc/s, 100 c/s and 10 c/s. The arrival of the trigger pulse should operate a gate which allows 1 Kc/s pulses to modulate the spot brilliancy and so mark the trace. This gate should then be closed and another opened to pass nine 10 c/s pulses and so on until the trace is complete. The first pulse to be generated by the crystal oscillator after the arrival of the light pulse is allowed to pass to the first divide-by-ten circuit in order to produce the 1 Kc/s pulses. The maximum time difference between the beginning of the trace and the first time marker is therefore 0.1 ms, an error well within the maximum tolerable.

8. **COMPENSATION FOR SHIP MOVEMENT AND AMBIENT LIGHT FLUCTUATIONS**

Since the amplifier time constant is eight seconds or more, variations of the ambient light with periodicities of this order will produce corresponding deflexions of the cathode-ray tube spot. Also in so far as the detector(s) will not have (either singly or jointly) a uniform polar response, a variation of signal will also be produced in the absence of a variation in the ambient illumination simply as a result of ship pitch and roll with a periodicity of the same order.

Although changes of such long periodicities will not cause triggering, and the variation of the position of the spot will not be observed in the quiescent cut-off condition, triggering of the equipment at any time is likely to produce in the absence of any compensating arrangements, a trace sufficiently far to the top or bottom of the screen to prevent reliable determination of $T_{(min)}$. Circuit arrangements must therefore be adopted to compensate for any spot wandering under quiescent conditions.
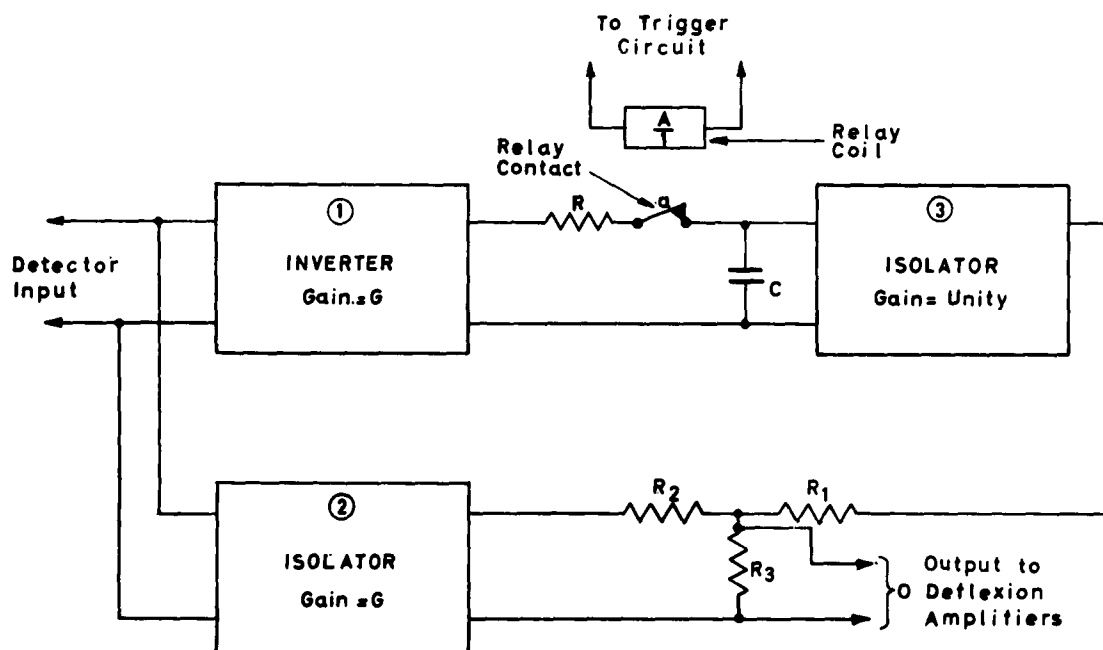
FIG. 2 SCHEMATIC OF BACKGROUND NOISE
COMPENSATION CIRCUIT

A.R.L. / C / N6

One such possible circuit arrangement makes use of a high-speed relay with an opening time of approximately 0.5 ms, much less than the time to the earliest minimum required to be measured. This relay in its normal closed position allows the application to the deflexion amplifiers of the inverse of the detector output so that the net spot movement is zero. On receipt of the trigger pulse, the relay opens, the inverse voltage at the deflexion amplifier input is clamped at a value corresponding to the immediately preceding level of the ambient light, and the spot is allowed to deflect from a fixed zero position. The method is illustrated in fig.2. The inverter (1) provides at its ouput a negative replica of the photo-detector output variation with a gain G. The isolator (2) provides a non-inverted replica with the same gain. The outputs from (1) and (2), if added in a resistor network (such as R_1 R_2 R_3 in the diagram) would, of course, produce a non-varying output at all times. It is required, however, that the output should follow the light changes after the receipt of a weapon triggering pulse. For this purpose there is an intermediate stage, the isolator (3). This unit produces at its output a non-inverted replica of its input with unity gain, and has a high input resistance. The output of unit (1) is applied to the input of (3) through the normally closed relay contact (a) and the resistance R. Shunting the input terminals of (3) is the capacitor C which has a high leakage resistance. The outputs of units (2) and (3) are added in the resistor network R_1 R_2 R_3 and the output at O is fed to the input stage of the deflexion amplifier. The coil of the relay (A/1) is in the triggering circuit. The time constant RC is sufficiently high to prevent a pulse, which is steep enough to trigger the instrument, from reaching the condenser C before the relay contact opens, and sufficiently low to allow the voltage across C to follow the slower ambient variations. On receipt of a trigger pulse the relay contact (a) opens, and the capacitor C retains the voltage which it had immediately prior to the breaking of the contact, a voltage which represents the existing level of ambient illumination. From this time onwards the output from isolator (3) will be a steady D.C. voltage, while the output from isolator (2) will be a replica of the weapon pulse developed within the photosensitive detector. The summed output at O will therefore vary as the weapon light pulse above a permanent D.C. level.

In practice it may well be possible to combine inverter (1) and isolator (2) in a single transistor stage employing resistor loads of equal value in both the emitter and collector circuits. The gain G need not be large, and indeed may be acceptable at a value of a little less than unity. The isolator (3) should have a high input resistance and the compensator, since it is located at the amplifier input, should have a low noise output. Field effect transistors, which have these characteristics, may therefore be suitable for this part of the circuit, although other circuit techniques for producing a high input impedance are now readily available. It is suggested that the relay should be a reed relay type, which has high operating and breaking speeds, low contact resistance after many operations, and low contact bounce.

Since this is a fail-unsafe type of circuit, it may be necessary to duplicate the relay coil operating circuits and to provide two relay contacts in series. In any case it is suggested that a manually operated switch in a not-too-accessible position is placed in series with the relay contact in order that the compensation system may be temporarily immobilised if routine tests show that the relay is not operating.

9. BUILT IN TEST FACILITIES

The modern tendency in naval practice is to make an instrument as self-contained as is reasonably possible by building test facilities into it. The facilities which are necessary for this instrument are as follows:-

(a) A small flash unit, such as a semi-conductor or other type of flasher lamp, capable of remote operation from the display unit, built into the detector head. The light flash from this unit must possess the necessary rise-time and amplitude characteristics to trigger the instrument. This facility would provide a check on the time base, time markers, triggering, deflexion circuits and photosensitive detector.

(b) A push-button operated circuit for injecting an electrical pulse into the trigger circuits and amplifiers at the display unit. This pulse should be a steep-edged square function of about 5 ms duration. This would be for use if (a) above failed to cause triggering, and would thus determine whether the fault lay in the detector head or elsewhere. The trigger, time marker, time base and the part of the deflexion amplifier circuits situated in the display unit would be tested by this means.

(c) Provision for checking and setting the brilliance of the trace, X and Y shifts and focus, and a repetitive time-base sweep of about 1 to 10 c/s. The latter might most conveniently be obtained by repetition of the pulse required for (b) above.

(d) Monitoring points for checking the operation and frequency of the crystal oscillator and divider timing circuits. Check points for monitoring the associated gates should also be readily accessible.

(e) A panel meter which may be switched, with suitable shunting and series components, to measure all the internal power supply voltages (of both detector head and display unit), including the c.r.t. supplies and the mains. There should be provision on the same meter for the measurement of the quiescent output D.C. voltage of the detector head unit. This latter facility has proved invaluable in the experimental instrument for checking the operation of the detector unit.

10. OVERALL PERFORMANCE TEST

A test waveform representing an idealised weapon flash, illustrated in fig. 9(a) of reference [3], has proved to be a good overall check of the performance and accuracy of a given instrument. This waveform may be varied in respect of 'time to minimum' $T_{(min)}$ and the ratio of amplitude at first maximum to amplitude at first minimum (C). The deflexion amplifier design should be such that with values of C between infinity and 10, and with the full range of inputs specified in paragraph 5 (above), the output waveform presents a measurable minimum for values of $T_{(min)}$ from 3 to 500 milliseconds. This test waveform should be applied to a suitable light source (e.g. the Ferranti linear light source, Type CL 52 or a semi-conductor light flasher) and the instrument tested as a whole, and also directly as an electrical signal to the detector pre-amplifier. Values

of $T_{(min)}$ above 4 ms should be obtainable from the record within $\pm 5\%$ of the true value, with C ranging from 10 to infinity.

11. CONCLUSIONS

The recommendations contained in this note may be summarized as follows:-

(a) Semi-conductor circuits, using approved Service components, should be used as far as possible in order that spares may be readily available, and size and heat dissipation minimized.

(b) A semi-conductor photo-sensitive detector should be employed, the most suitable type currently available appearing to be a "solar" photovoltaic cell.

(c) More than one photo-sensitive detector device should be used to cover 360 degrees in azimuth.

(d) The minimum overall sensitivity, in terms of cathode-ray tube spot deflexion per unit light intensity at the detector, is specified in paragraph 5 (and fig.1) together with a desirable response function of the deflexion amplifiers, their rise time and time constant.

(e) An increase in time base sweep time to 700 ms is required in order to accommodate weapons of 50 megaton yield.

(f) The time-marker circuits should be controlled by a 10 Kc/s crystal master oscillator.

(g) The two traces of differing sensitivities should deflect in the same direction.

(h) A circuit should be employed to compensate for changes of ambient illumination and the fluctuations caused by the ship's pitch and roll. The principle of such a circuit is given in paragraph 8.

12. ACKNOWLEDGEMENTS

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B. W. Allwood (P.S.O.)

BWA/JER

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