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Name of the Inventors: Chester L. Smith and David N. Eversvick
Title of the Invention: A Direct Method of Measuring the Intensity of Light and Other Radiation Sources Without Knowledge of the Source Distance

Serial No.: 933,240
Filed: August 14, 1978
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ABSTRACT OF THE DISCLOSURE

The approximate intensity in candlepower of a burning parachute flare at a given point P in space is determined by measuring the illumination E_1 and E received from the flare at pc P_1 and P_2 located at distances D_1 and D_2, respectively, from the point P, where points P, P_1 and P_2 are substantially i line, and using the formula

$$I = \left[\frac{d}{\frac{1}{\sqrt{E_2}} - \frac{1}{\sqrt{E_1}}}\right]^2,$$

where d is the distance between points P_1 and P_2.

BACKGROUND OF THE INVENTION

Aircraft and artillery flares are tested at various proving ground and test areas. These tests are used to compare flares and flare systems and to evaluate optimum methods of deployment for tactical use. The two most signif cant parameters measured are the illumination produced by the item and its candlepower. The illumination produced by a flare source can be directly measured by means of photocell. However, to obtain candlepower it is necessa to know the distance from the source to the transducer. This is due to the inverse square law relation $E = I/D^2$, where E is illumination in terms of foot-candle, I is intensity in candlepower and D is distance in feet. In add tion, unless the cell is always aimed in the direction of the flare source it is also necessary to know the angle of the cell's active surface in relation to the flare's position. This is necessary to correct for the sensitivity du to loss in effective surface area.

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(2)

It has always been necessary to track the flare's position to determine the candlepower of the item, since the flare does not have an intrinsic candle power and is a time variant non-isotropic source.

In order to evaluate the effectiveness of a flare and compare it to other systems (as deployed in the field) it has been necessary to employ a system to track and determine space positioning (x, y, z coordinates) in time as the flare descends by parachute. This has been accomplished either by optical tracking (cine theodolite) or by radar. With optical tracking, theodolites have been commonly used with their attendant problems and costs. At least two stations are required and normally three are used to avoid loss of data. This has greatly increased the cost of the test (two people are required to man eac position and each station must be "surveyed in"). Setting up such a system is complicated and time consuming. In addition, the space positioning data must be synchronized and correlated with the illumination measurements in order to obtain meaningful candlepower records. These tests are, therefore, extremely costly and time consuming due to the complexity of such a test. The loss of data and usable results has been prevalent. These are systems that cost on th order of hundreds of thousands of dollars.

The previously utilized methods of measuring candlepower of field deploye items are much too costly and time consuming to set up and operate, requiring a large number of personnel to perform a field test and provide data evaluation. The data evaluation has also been time consuming, taking as long as several months before the flare project engineer has received his data. The data is typically manually transferred to a computer and is evaluated partiall by computer and partially by manual means.

BRIEF SUMMARY OF THE INVENTION

This invention will permit approximate on the spot real-time candlepower versus time records to be obtained at the test site. It will eliminate the need for tracking or space positioning equipment and greatly reduce associated time and manpower setup and operation. It will greatly simplify the data processing and evaluation. It will also simplify the field test procedure in that correlating and synchronizing the system will not be necessary. All of this will greatly reduce the loss of data and greatly reduce the cost and complexity of the test. The entire test system can now be set up and manned by two to three personnel rather than a crew of 20 to 30 people.

In accordance with the present invention, two sensitive photometers are mounted, at the same level, near the ground, in a line at a large distance from the anticipated position of the trajectory of the flare to be measured, with a relatively small spacing between the photometers. For example, the nearer photometer may be 8000 feet from the flare trajectory and 3000 feet from the farther photometer. By taking simultaneous measurements of the illuminations E_1 and E_2 received by the two photometers from a flare at a point in its trajectory, the approximate candlepower I of the flare at that point is calculated from the formula

$$I = \left[\frac{d}{\frac{1}{\sqrt{E_2}} - \frac{1}{\sqrt{E_1}}} \right]^2$$

where d is the known horizontal distance between the two photometers. The error in this approximation of the flare candlepower is small.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a schematic diagram of the arrangement of two photocells relative to the position of a flare whose candlepower is to be measured in accordance with the present invention.

Figure 2 is a schematic block diagram of a photometer circuit for each photocell with an associated transmitter.

Figure 3 is a similar diagram of a remote station circuit for receiving and processing the signals from the two transmitters.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

In the diagram of Figure 1, P_1 and P_2 are the positions, near ground level, of two photocells on a straight line with a point P_0 in a transverse vertical rectangular region or area A-B containing the anticipated position in its trajectory of the parachute flare to be measured, at distances x_1 and from point P_0, and separated by a distance $d = x_2 - x_1$ which is small compare to x_1. The rectangular region AB has a height h_o and a width $2y_o$. In a preferred example, $x_1 = 8000'$, $x_2 = 11000'$, $d = 3000'$, $h_o = 2000'$, and $y_o = 1250'$. Also, preferably the measurement of flare illumination is limite to those located above $h = 800'$, in the dotted rectangle 3 shown in Figure 1.

Figure 1 shows, for example, a flare position P, at $h = 2000'$ and $y = 1250'$, at a distance D_1 from point P_1 and a distance D_2 from point P_2. The diagonal line s completes two triangles PP_0P_1 and PP_0P_2, having small angles α and β, respectively.

The illuminations E_1 and E_2, in foot-candles, from the flare, measured by the two photocells at P_1 and P_2, may be simultaneously converted into electrical signals and transmitted to a central receiving station by two conventional photometer circuits 1 and 2 such as that shown schematically in Figure 2.

In the case where the flare is at point P_0 (the ideal position), the equations for the illuminations being seen by the two photocells are

$$E_1 = \frac{I}{x_1^2} \tag{1}$$

$$E_2 = \frac{I}{x_2^2}. \tag{2}$$

From equation (1) and (2),

$$I = E_1 x_1^2 \tag{3}$$

$$I = E_2 x_2^2. \tag{4}$$

Adding (3) and (4) gives

$$2I = E_1x_1^2 + E_2x_2^2 .$$

Since $I = E_1x_1^2$,

$$E_1x_1^2 + E_2x_2^2 = 2E_1x_1^2 .$$

Substituting $x_2 = x_1 + d$, gives

$$E_1x_1^2 + E_2(x_1 + d)^2 = 2E_1x_1^2$$

$$E_2(x_1 + d)^2 - E_1x_1^2 = 0 . \qquad (5)$$

Using the quadratic equation,

$$x_1 = \frac{-d(E_2 + \sqrt{E_1E_2})}{E_2 - E_1} \qquad (6)$$

Substituting for x_2 in equation (4),

$$I = E_2(x_1 + d)^2$$

$$I = E_2\left[\frac{-d(E_2 + \sqrt{E_1E_2})}{E_2 - E_1} + d\right]^2 \qquad (7)$$

$$= \left[\frac{d}{\frac{1}{\sqrt{E_2}} - \frac{1}{\sqrt{E_1}}}\right]^2 .$$

Equation (7) gives the exact candlepower I of a flare at point P_0.

For a flare at any other point P, x_1 and x_2 in equations (1) through (6) must be replaced by D_1 and D_2, respectively, and the candlepower I becomes

$$I = \left[\frac{D_2 - D_1}{\frac{1}{\sqrt{E_2}} - \frac{1}{\sqrt{E_1}}}\right]^2 \qquad (8)$$

In accordance with the present invention, in order to avoid the necessity of measuring D_2 and D_1, the candlepower I of the flare is approximated by substituting $d = x_2 - x_1$ for $D_2 - D_1$, as follows:

$$I = \left[\frac{d}{\frac{1}{\sqrt{E_2}} - \frac{1}{\sqrt{E_1}}}\right]^2 . \qquad (9)$$

At $\alpha = 0°$, the illumination E_1 and E_2 at photometers 1 and 2 would be

$$E_1 = I/x_1^2$$

$$E_2 = I/x_2^2 .$$

Assume that $I = 10^6$ C.P.; then, in the preferred example given above,

$$E_1 = \frac{10^6}{(8,000)^2} = .015625 \text{ foot candle}$$

$$E_2 = \frac{10^6}{(11,000)^2} = .0082644 \text{ foot candle.}$$

Substituting these values in equation (9) gives

$$I = \left[\frac{3000}{\frac{1}{\sqrt{.0082644}} - \frac{1}{\sqrt{.015625}}}\right]^2 = 10^6 \text{ C.P.},$$

which is the value assumed.

Where the light source (point P) is at point P_o, in line with the two photocells at points P_1 and P_2 (zero angles α and β), the intensity I determined from equation (9) is accurate. Where the light source is at some poi P spaced laterally from point P_o (angles α and $\beta > 0$), the accuracy of the calculated value of the intensity I is reduced by at least two errors. One o these errors results from the use of the known distance d, between the two photocells, instead of the exact, but unknown, distance $D_2 - D_1$, in equation (9). As α and β increase, the difference between d and $D_2 - D_1$ increases, which increases the error in the calculated I. The other error in the calculated intensity I for α and $\beta > 0$ results from the combined effects of the reductions in the photometer outputs E_1 and E_2, due to the angles α and β between the light source directions and the common axis of the two photometers.

In the preferred example,

$$x_1 = 8000'$$

$$x_2 = 11000'$$

$$d^2 = 3000'$$

$$h = 2000'$$

$$y = 1250'$$

$$S = h^2 + y^2 = 2358.5'$$

$$D_1 = x_1^2 + s^2 = 8340.4'$$

$$D_2 = x_2^2 + s^2 = 11250'$$

$$D_2 - D_1 = 2909.6'$$

$$\alpha = \text{arc tan } s/x_1 = 16.426°$$

$$\beta = \text{arc tan } s/x_2 = 12.1°$$

$$\text{Cos } \alpha = .95918$$

$$\text{Cos } \beta = .97778.$$

In this example, the actual outputs of the two photometers would be the light components normal to the photometer faces,

$$E_{1a} = \frac{10^6}{(8340.4)^2} \cdot \text{Cos } 16.426° = .0137887, \text{ and}$$

$$E_{2a} = \frac{10^6}{(11250)^2} \cdot \text{Cos } 12.1° = .0077256.$$

Substituting these values for E_1 and E_2 in equation (9) gives

$$I = \left[\frac{3000}{\frac{1}{\sqrt{.0077256}} - \frac{1}{\sqrt{.0137887}}} \right]^2$$

$$= 1{,}099{,}444 \text{ C.P.}$$

Thus, the net error in the intensity I resulting from the use of equation (9) at $\alpha = 16.426°$ is

$$e = \frac{1,099,444 - 1,000,000}{1,000,000} = .099444, \text{ or } 9.9\%.$$

If the two photometers are aimed at the light source,

$$E_{1b} = \frac{10^6}{(8,340.4)^2} = .0143756$$

$$E_{2b} = \frac{10^6}{(11,250)^2} = .0079012.$$

$$I = \left[\frac{3000}{\frac{1}{\sqrt{.0079012}} - \frac{1}{\sqrt{.0143756}}}\right]^2$$

$$= 1,063,104$$

$$e = \frac{1,063,104 - 1,000,000}{1,000,000} = 6.3\%.$$

Thus, the error in d is about two-thirds of the total error (9.9%).

In addition to eliminating the tracking equipment and the extra personne needed to set up and man the prior apparatus, the present method greatly simplifies the data recording and evaluation. The ground illumination E_1 and E_2 in foot-candles can be automatically recorded and plotted in real time, and t flare's intensity in candlepower can be calculated from equation (7) which requires only E_1, E_2 and the constant spacing d.

As shown in Figure 2, each of the photometers 1 and 2 may comprise a con 5, an ICI-Y filter 7, a photocell 9, at least one operational amplifier 11, at least one voltage-controlled oscillator 17, an S-band transmitter 23 and an antenna 25. The photocell 9 is preferably of the silicon photovoltaic barrier layer type which has a small temperature coefficient. The cell 9 operates into an effective zero impedance which extends the linear range of t cell.

The direct current analog voltage produced by the photocell 9 in respon to the light from the flare, amplified by amplifier 11, determines the frequency of oscillator 17, which frequency modulates the carrier of the transmitter 23. Preferably, the system's dynamic range is increased by using three amplifiers 11, 13 and 15 arranged as shown to feed the analog voltage from photocell 9 to three oscillators 17, 19 and 21, for frequency modulating the transmitter carrier at the three VCO frequencies.

The signal wave transmitted from each of the transmitters 23 of the photometers 1 and 2 is received at a telemetry van or portable ground statio by means of an antenna 27 and receiver 29 shown schematically in Figure 3. two carriers, e.g. 2300 megahertz, are demodulated and the two sets of modulations are applied to two sets of discriminators 31, 33 and 35 to produce two sets of signals E_1 and E_2 in analog form in real time. The E_1 and E_2 signals are fed to the input of a processor 37 which selects one of the scales for each signal and calculates the intensity I from equation (9), also in real time. E_1, E_2 and I are then recorded on one or more recorders 39 which may include magnetic, digital and/or paper recorders 39a, 39b and 39c.

In the example considered above, the various distances are rather large (about 1/2 to 2 miles), and the two photocells are mounted on suitable fixed supports. In another application of the invention, two small sensors could b mounted, with a spacing d of one or two feet, on a suitable portable frame or bar hand-held by a soldier and aimed at a light source at a distance of the order of a mile or less. This apparatus could include a micro processor connected to the two sensors for calculating and displaying the intensity of a flare or other radiation source in the field.

For the purpose of this invention, the optical transmissivity (T) of the atmosphere is assumed to be 100%.

The foregoing disclosure and drawings are merely illustrative of the principles of this invention and are not to be interpreted in a limiting sens

We wish it to be understood that we do not desire to be limited to the exact details of construction shown and described, because obvious modifications occur to a person skilled in the art.

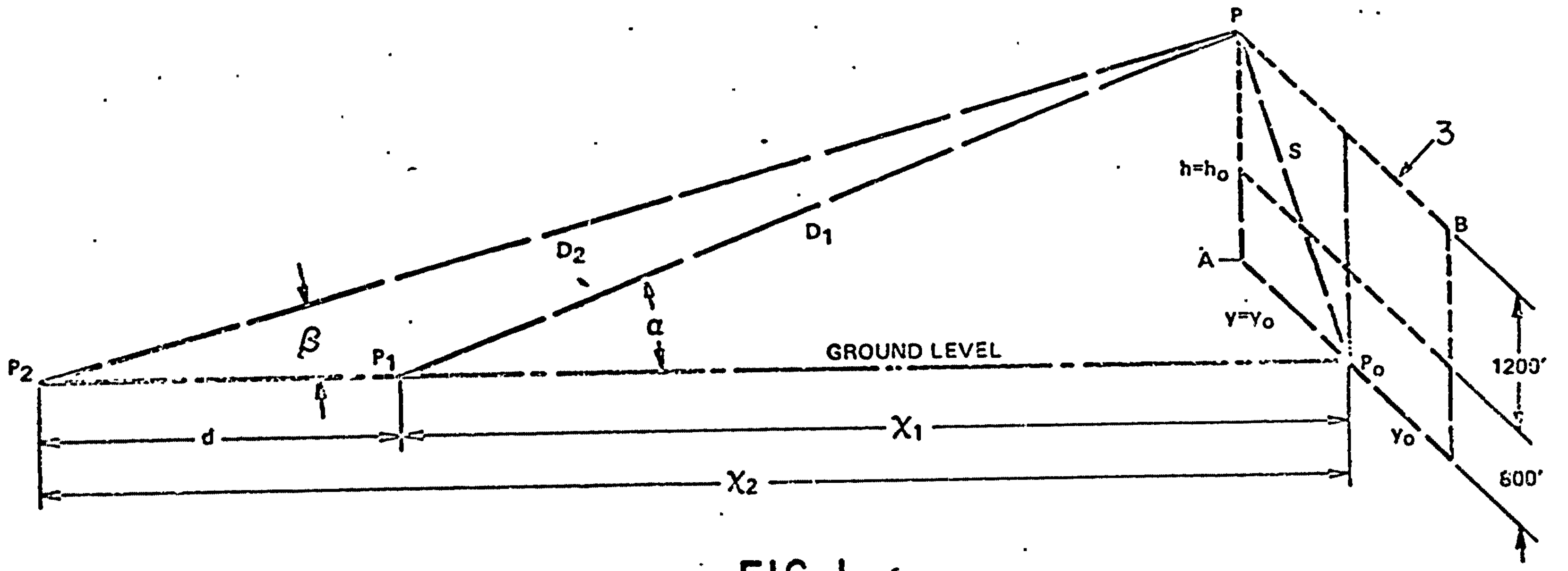

FIG. I

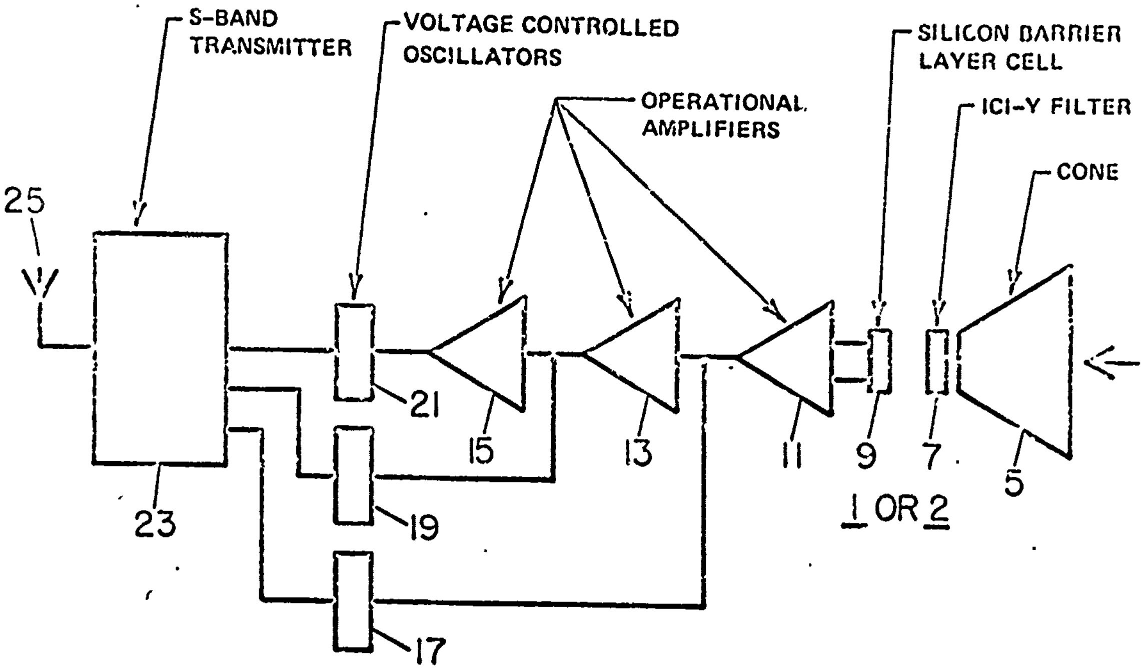
S-BAND TRANSMITTER
VOLTAGE CONTROLLED OSCILLATORS
OPERATIONAL AMPLIFIERS
SILICON BARRIER LAYER CELL
ICI-Y FILTER
CONE
25
23
21
19
17
15
13
11
9
7
5
1 OR 2

FIG. 2

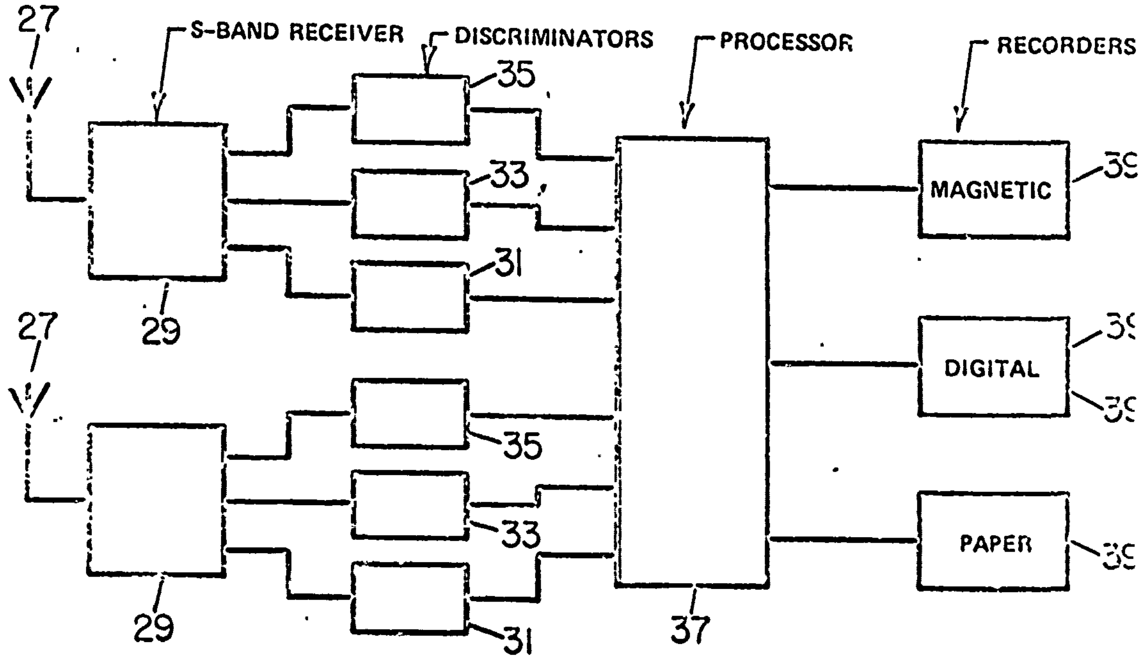
S-BAND RECEIVER
DISCRIMINATORS
PROCESSOR
RECORDERS
27
29
35
33
31
27
29
35
33
31
37
MAGNETIC
39
DIGITAL
39
39
PAPER
39

FIG. 3