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BEYOND THE STATE-OF-THE-ART ILLUMINATION MEASUREMENTS

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APRIL 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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The invention of a direct method of obtaining candlepower has led to the development of a mathematical model of a simplified system for field testing illuminant items. In addition to obtaining the light intensity independent of the source distance, an innovation for assessing the atmospheric transmissivity is described. The light transmission is measured without employing special equipment other than that used for the basic candlepower measurements. The model configuration constraints are based on present field test practice.

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This technique will allow two or three people to set up and man a complete field test system. Test results which formerly required extensive data reduction and processing will be available on-site for instant readout. Besides increasing the reliability of data and on-the-spot readout, this system should reduce costs and generally enhance illuminant testing.

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SUMMARY

The system comprises a complete method for conducting field tests on illumination flares. The physical model (fig. 8) was selected for the general test requirements of artillery and aircraft flare tests. It is not specifically tailored to any individual test requirements. The physical test configuration can be optimized for specific test requirements while covering a specified flare drop area. In such cases, computer programs can be used to assess the accuracy of the configuration.

The cell's photometer reproducibility is a critical factor in obtaining accurate candlepower measurements. (Appendix B has the computer program for evaluating transmissivity error versus cell reproducibility for the configuration shown in figure 6.) Also the accuracy of obtaining candlepower is limited by the maximum field-of-view. The angle subtended by the cell's field-of-view should be kept to a minimum within test constraints. See appendix C for computer program to plot system error versus distance to the most remote cell.

The illumination falling on the cell is measured to the accuracy of the cell photometer itself, which will be as good as the system calibration. The accuracy of reading the candlepower will have a greater error because of the added effects of changes with distance and effective cell area vs angle. Candlepower reading will be limited to 10 to 20 percent for a practical system. Transmissivity measurements with a 2% photometer reproducibility will have less than 10% error.

There is also error associated with background illumination. Error caused by background illumination can be largely accounted for by measuring and subtracting from the test illumination levels because the flare subtends only a small part of the field-of-view angle of the cell. Even so, it is advisable to use a location and configuration having small illumination levels compared to the signal.

BACKGROUND

Candlepower measurements are not made directly, but are obtained by measuring the illumination and calculating the candlepower using the inverse square law. This requires that the distance between source and sensor be known with a degree accuracy. This has been the most difficult problem in the field testing of large flares because the parachute flares must be tracked as they are deployed and descend, drifting with the wind.

The results of tests of artillery- and aircraft-deployed illumination flares are reproducible when testing is conducted under controlled conditions. Test conditions are controlled by using tunnels or towers which are available from the tri-services and some contractors. These facilities are employed primarily in developing new systems. The typical information derived through testing is the flare's efficiency, intensity, burning time and spectral distribution of light in relation to the various factors affecting the intrinsic characteristics of the item as a light source. When deployed by aircraft or artillery, a descending flare produces spatial and time variations in ground area illumination.

One facility for conducting field testing is the Pyrotechnic Evaluation Range (PER) located at Yuma Proving Grounds (YPG). The PER records ground area illumination to preset levels, foot-candles. From this information, a computer is programmed to produce all required test data.

A major problem encountered in field testing is controlling or accounting for environmental factors affecting the test. Previous methods employed to overcome this problem have required many people to transport, locate, and man the equipment. The quality of the test data, which are often incomplete or unreliable, does not justify the cost of this method. For example, evaluating the flare's candlepower in the field requires that the flare's position be determined versus time. The PER uses three CINE theodolites for this purpose, and many people to operate them. Another field testing problem is correlating times and coordinating data systems with the firing of the flare. During field tests performed at Ft. Hood, manned photometers were deployed over large areas; stations were separated by thousands of meters.

New, ultrasensitive, prototype photometers were used with L-Band RF Links to record remote location information in a telemetry van. The flares were tracked by optical techniques. Typically, some data is lost during tests of this kind because the position of the item is lost temporarily during its burning. Also, flares descending and traversing with the wind occasionally saturate near stations and produce weak signals at distant stations.

To evaluate the light source intensity with any degree of accuracy, the atmospheric transmissivity of the test range environment must be assessed. In the past, weather reports provided crude estimates of visibility limitations. Also, since the varying configuration of a flame produces a flickering, nonisotropic light, source intensity can be determined reliably only when it is derived through spatial integration of candlepower, i.e., average light intensity when viewed from all directions.

The method described in this report uses an array of highly sensitive photometers incorporating automatic change of scale circuitry and automatic calibration to operate without a man in the loop.

DEVELOPMENT

System development involves two innovations to the state-of-the-art of flare testing. The first is a method of determining candlepower of the flare item without knowing its position or distance. The second is a means of assessing the transmissivity of the atmosphere over the test area to an accuracy better than 10%. The candlepower measurement is corrected by the transmission factor to yield the true field candlepower of the flare. The photometers record ground illumination. All other parameters are derived through data processing. These measurements are taken in real time as the item burns and descends by parachute.

The photometers have a fixed field-of-view and a position that is determined by the system equations and mathematical model. A restricted field-of-view and optimum angle-of-look are required to reduce system errors caused by background illumination and field test configuration. The field-of view for each cell will be designed through the use of a series of baffles to view only the region of operation of the item. The effects of background illumination will be further reduced by an automatic calibration and correction system.

Calibrating of the system is a three-step procedure. First, the optical equipment is calibrated with a laboratory standard. Second, equipment in the field is calibrated with an optical transfer standard. Third, the signal-conditioning electronics and RF link are electronically calibrated.

The field photometers consist of an ICI-Y photocell which is corrected to obtain spectral response equal to the average human eye, a filter, a cone, and electronics (fig. 1). A silicon photovoltaic barrier layer photocell is used for its stability and small temperature coefficient. The cell drives a low-noise operational amplifier which is used in its inverting mode to enhance the system's dynamic charge. Operating the cell into an effective zero impedance extends the cell's linear range. Three operational amplifiers (G1 thru G3, figure 1) measure resolution and dynamic range. The automatic circuitry selects the appropriate amplifier and outputs data to a conventional telemetry system. The photometer output is transmitted via an L-band PCM/FM/FM RF link from each remote field sensor to a central recording van where the data are processed and recorded. To improve system accuracy each photometer has a pulse code modulator (PCM) which digitizes before transmission. The PCM word length is set to reduce quantization errors to meet system requirements. Parity is used to detect transmission link errors. Each photometer incorporates a voltage controlled oscillator (VCO) which contains photometer scale information. An automatic change of scale is used to improve the system dynamic range. The outputs of the PCM and VCO modulate the L-band RF transmitter.

The automatic circuitry selects the appropriate system gain to optimize the output data, provides scale information on a separate VCO channel, and assures data calibration by an automatic calibration interrupt.

The transmitted signals from each field photometer are received by an L-band antenna and receiver at the central receiving station (fig. 2). The receiver output is applied to two discriminators. One discriminator contains the illumination data, in PCM format, and the other provides the automatic range information.

The processor operates on both the data and scale information from each remote photometer and outputs to a visual display the real time illumination levels (E) for each remote site.

A simplified general field test configuration, using three remote photometers and a source flare, is illustrated in figure 3. D_1, D_2, and D_3 represent the distance from the source flare to each respective photometer with E_1, E_2, and E_3 representing the levels of illumination they receive. These illumination levels are transmitted to the central recording site and impressed on the input of the processor. At the beginning and at the end of the test, the processor calculates the transmissivity (T) from E_1, E_2, and E_3. Using the transmissivity and any two of the illumination levels, the processor calculates the intensity of the source (I).

Candlepower Measurements

Candlepower is calculated from the difference of two photometer readings. A typical geometry is shown in figure 4. Photometers are located at fixed positions E_2 and E_3 with a fixed field-of-view and directed as shown.

This system uses an in-line array of two photometers to make the flare item appear as an isotropic radiator. Two photometers are placed in a line at a distance from the anticipated position of the flare's trajectory. Given these conditions, the candlepower of the test item can be determined by a relation of the two illumination levels recorded by the two photometers E_2 and E_3 and the fixed distance between them. This eliminates the need to track the flare and measures its distance, with respect to time, from the photometers.

Consider the simple case (fig. 5) where the flare (source) is at position 0. The expression for the illumination being seen by the photometers is:

$$E_3 = \frac{I}{D_3^2} \tag{1}$$

$$E_2 = \frac{I}{D_2^2} \tag{2}$$

$$D_3 = D_2 + d \tag{3}$$

To solve for the candlepower (I) of the flare, the following equations are used (distances D_3 and D_2 are unknown):

from equation 1

$$I = E_3 D_3^2 \tag{4}$$

from equation 2

$$I = E_2 D_2^2 \tag{5}$$

where E = Illumination

I = Intensity of source in candlepower

D = Distance.

Then

$$E_3 D_3^2 - E_2 D_2^2 = 0. \qquad (6)$$

Using equation 3 to eliminate D_3,

$$E_3 (D_2 + d)^2 - E_2 D_2^2 = 0. \qquad (7)$$

Solve for D_2 using quadratic

$$D_2 = \frac{-d\,(E_3 + \sqrt{E_2 E_3})}{(E_3 - E_2)} . \qquad (8)$$

Substitute D_2 to solve for I

$$I = E_3 (D_2 + d)^2 \qquad (9)$$

$$I = E_3 \left[d - \frac{d\,(E_3 + \sqrt{E_2 E_3})}{E_3 - E_2} \right]^2 \qquad (10)$$

Put in simplest form

$$I = \left[\frac{d}{\frac{1}{\sqrt{E_3}} - \frac{1}{\sqrt{E_2}}} \right]^2 \qquad (11)$$

Therefore, knowing the illumination levels E_2 and E_3 and the fixed distance, d, separating photometers #2 and #3, it is possible to compute candlepower I.

This simplified case does not represent a typical flare field test configuration because the flare in the field test is not directly in line with the photometers. Flares are deployed to burn from a height of approximately 2,000 feet to 800 feet and then extinguish. Measurement accuracy is improved by aiming the cells to view this region of operation (fig. 4) optimizing the angle at which the light rays impinge on the cell. This angle is critical because if it is not optimum, it will reduce the effective area of the cell which in turn reduces the illumination level that the cell experiences. A light incidence angle of 10° off cell axis normal would cause an error as high as 4%. To partially compensate for this error, the cells will be aimed at a point between the 800 ft and 2,000 ft elevation. For the test configuration of figure 4, cells E_2 and E_3 are set 9.93° and 7.25° respectively, above horizontal.

The computer program in appendix A computes the expected accuracy of the system and the optical separation between stations E_2 and E_3 for the configuration inputed. For the test configuration of figure 4, the optical separation, d, is computed using equation (3):

$$d = D_3 - D_2 \tag{12}$$

where $D_3 = 11088.73$ ft

and $D_2 = 8121.58$ ft

then $d = 2967.15$ ft

This value of d applies only to the configuration described in this report. A new value of d would be computed when the configuration is changed.

Besides eliminating the tracking equipment and the additional people needed to set up and man the tracking equipment, this method simplifies the data recording and evaluation. With the old method, extensive data processing was required; with this system the data are processed while the test is in progress. The ground illumination, E_2 and E_3, is being recorded and plotted in real time. The flare's intensity (I) is also being computed and plotted using the equation (11) and E_2, E_3 and the system constant, d. This requires a data processor consisting of three integrated circuit chips for generating the flare's intensity in real time analog form. In actual field tests more than one array of two photometers may be deployed depending on test requirements. There are no stringent requirements on the photometer/receiving station RF link; L or S band telemetry transmitters have been used with FM/FM modulation. Depending on system accuracy required, either FM/FM or PCM/FM can be used.

Transmissivity Measurements

Transmissivity is calculated by finding the difference between illumination measurements. The difference between the two measurements in the array from the same source indicates the transmission of light on the optical path.

The system for measuring transmissivity uses highly sensitive photometers with automatic change-of-scale circuitry to extend the dynamic range without limiting instrumental accuracy. The in-line array of three photometers (fig. 6) yields a method of assessing the loss of light caused by atmospheric attenuation to within 10%. If a large flare is burned as shown in figure 6 before and after each test, the transmissivity of the test range environment can be measured. Figure 7 shows a typical test configuration.

The general expression for determining the intensity (I) of a flare with an in-line array of two photometers is

$$I^{\frac{1}{2}} = d/(1\sqrt{E_2} - 1/\sqrt{E_1}) \tag{13}$$

where d is the known optical separation between sensors II and I, and E_2 and E_1 are the illumination levels (fig. 6). This general expression can be modified to include atmospheric attenuation by scaling the illumination levels as a function of T (transmissivity) and distance from source.

$$I^{\frac{1}{2}} = d/\left(1/\sqrt{(E_2/T^{D}} - 1\sqrt{E_1/T^{D-d}}\right) \tag{14}$$

A similar equation can be obtained using the illumination data from sensors II and III.

$$I^{\frac{1}{2}} = d\left(1/\sqrt{(E_3/T^{d+D}} -1/\sqrt{E_2/T^{D}}\right) \tag{15}$$

Eliminating I in equations (14) and (15) yields

$$\left(1/\sqrt{E_2/T^{D}} -1/\sqrt{E_1/T^{D-d}}\right)$$

$$= \left(1/\sqrt{E_3/T^{D+d}} -1/\sqrt{E_2/T^{D}}\right) \tag{16}$$

By multiplying numerator and denominator by $1/\sqrt{T^D}$ and simplifying

$$\frac{2}{\sqrt{E_2}} = \frac{T^{d/2}}{\sqrt{E_3}} + \frac{T^{-d/2}}{\sqrt{E_1}} \tag{17}$$

Solve for T by changing variables and using quadratic equation.

$$T = \left(\sqrt{E_3/E_2} + \sqrt{\frac{E_3}{E_2} - \sqrt{\frac{E_3}{E_1}}} \right)^{2/d} \qquad (18)$$

The solution of T yields the transmissivity for the test range environment, which can be inserted in equation (14) or (15) along with the measured values of E_2, E_3, and the fixed value of d to obtain a more accurate field measurement of the flare candlepower. This system assesses the atmospheric transmissivity of the test range before a test is conducted. Test data are accurate to within 10%. Transmissivity tests are performed with the equipment provided for the basic illumination measurements, so the system is highly efficient and very economical.

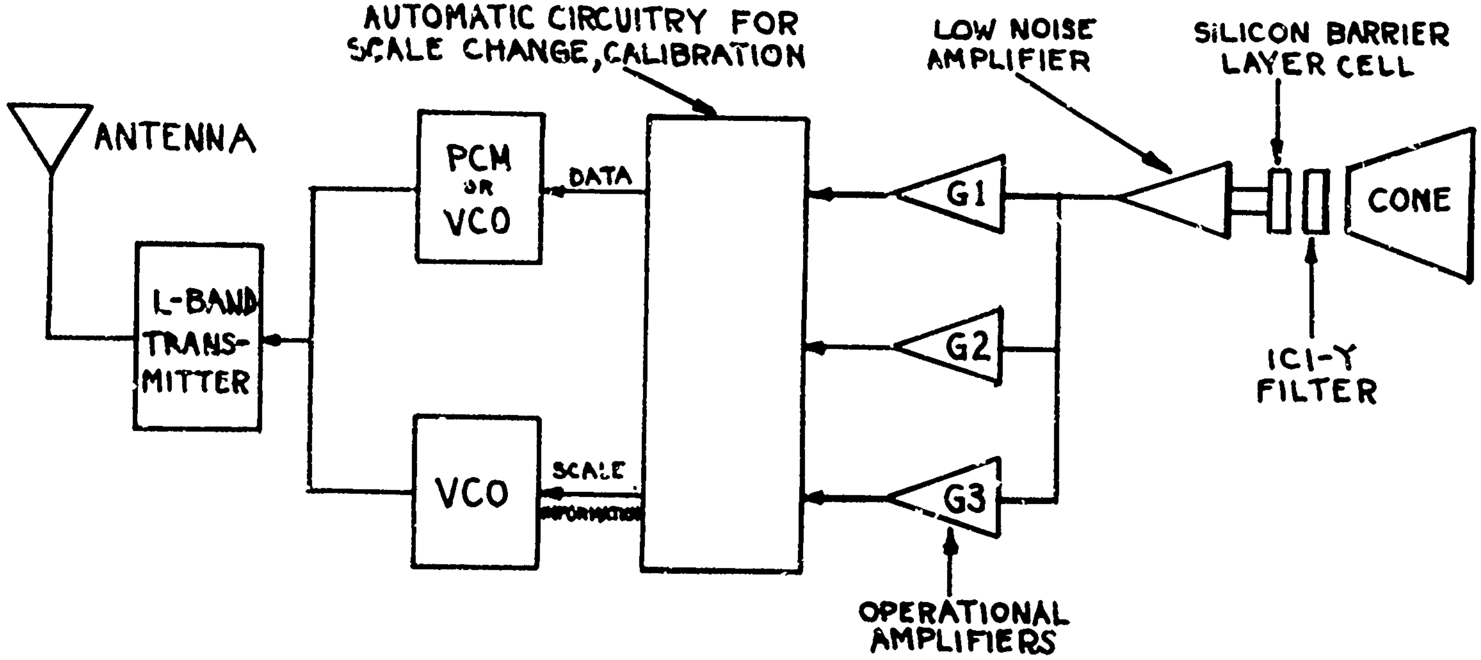

Figure 1. Field photometer block diagram

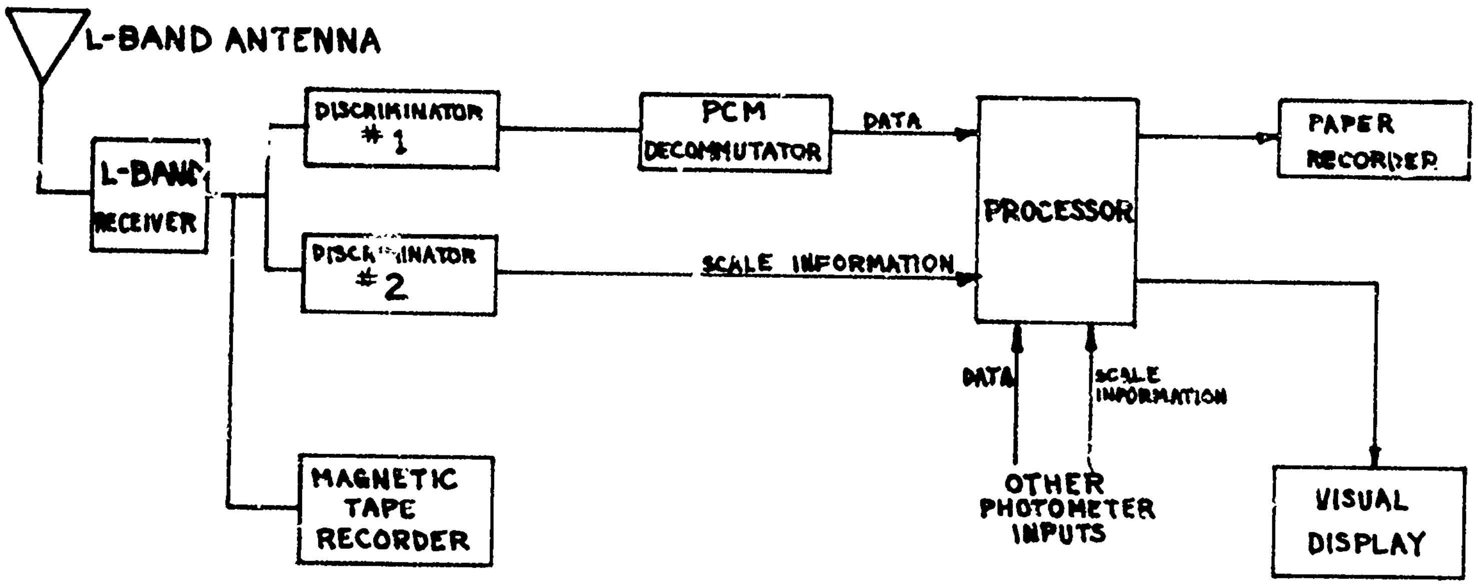

Figure 2. Receiving station block diagram (single channel)

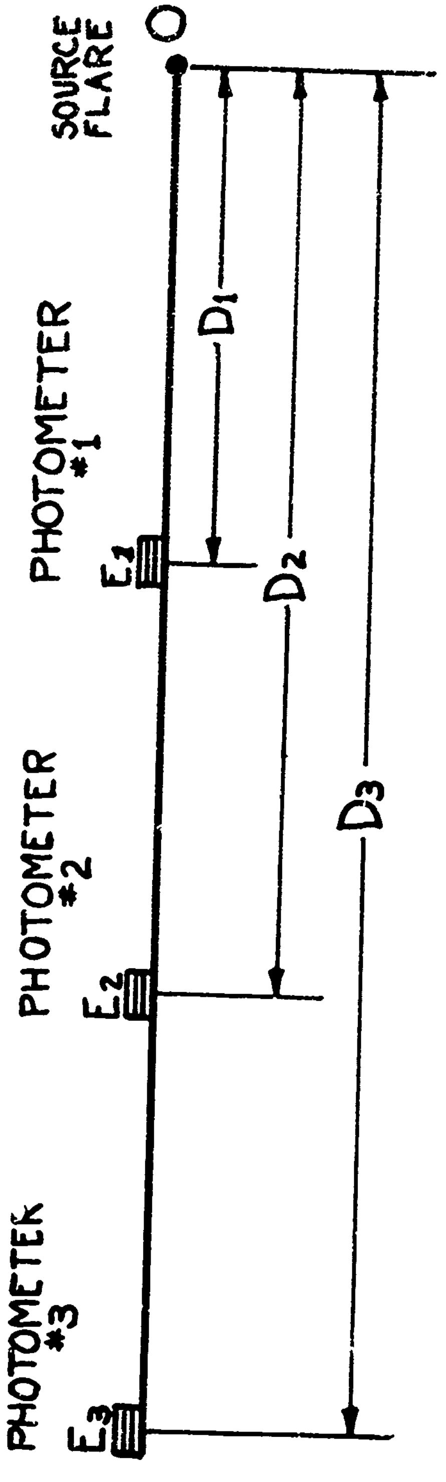

Figure 3. Simplified general test configuration

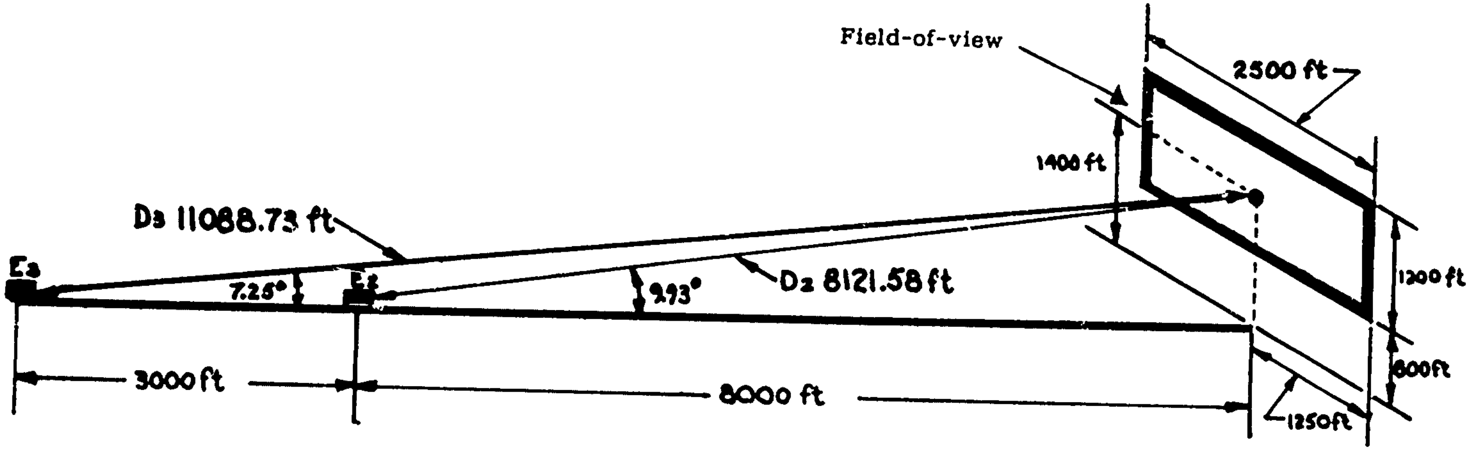

Figure 4. Test configuration for flare measurement

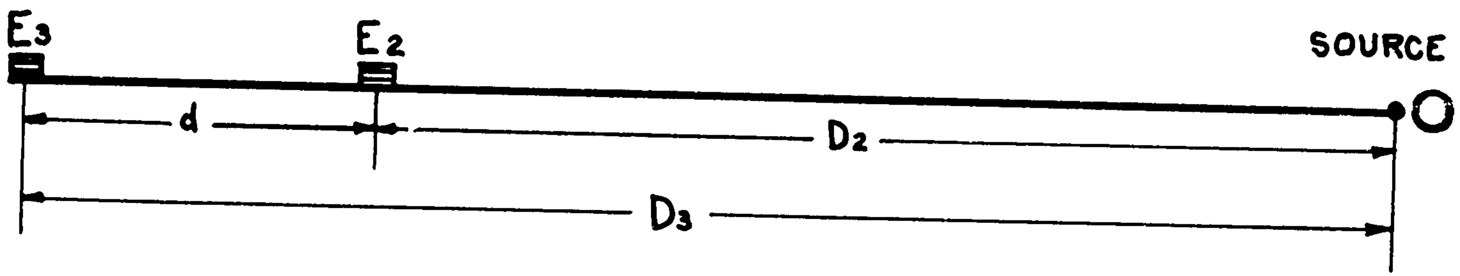

Figure 5. Simple test configuration

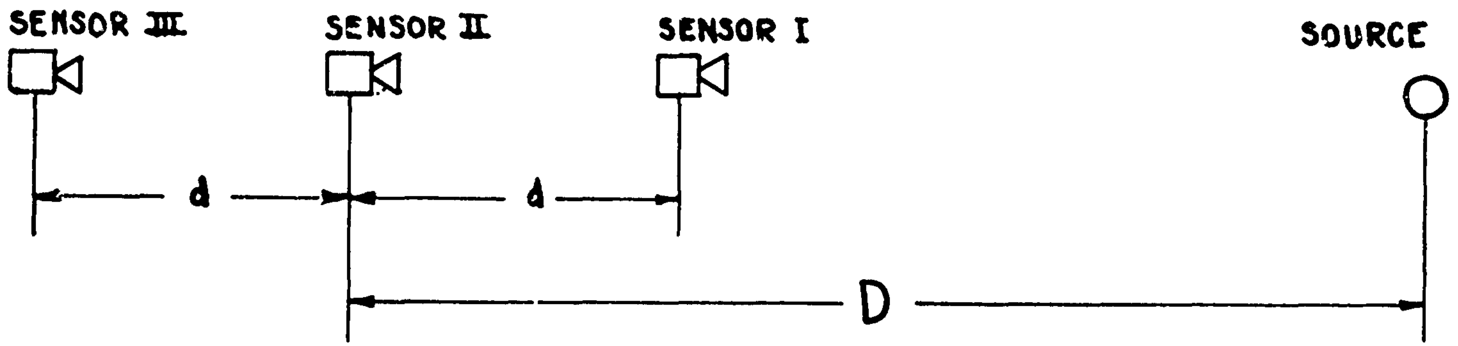

Figure 6. General test configuration

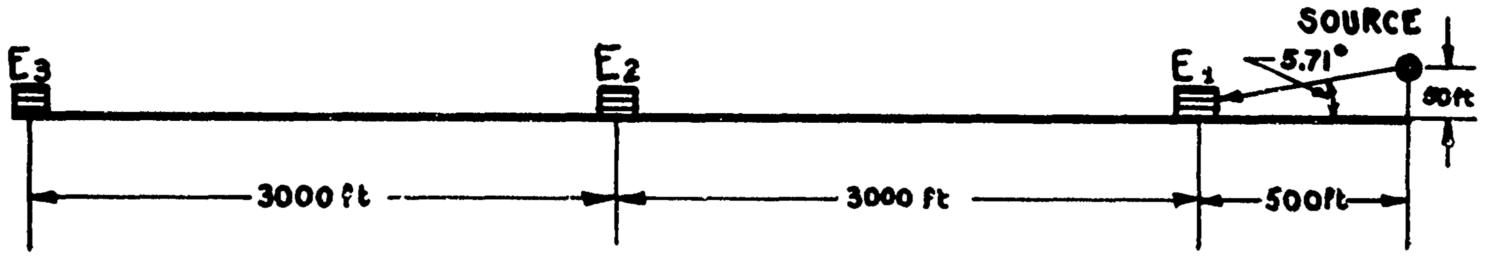

Figure 7. Test configuration for transmissivity measurement

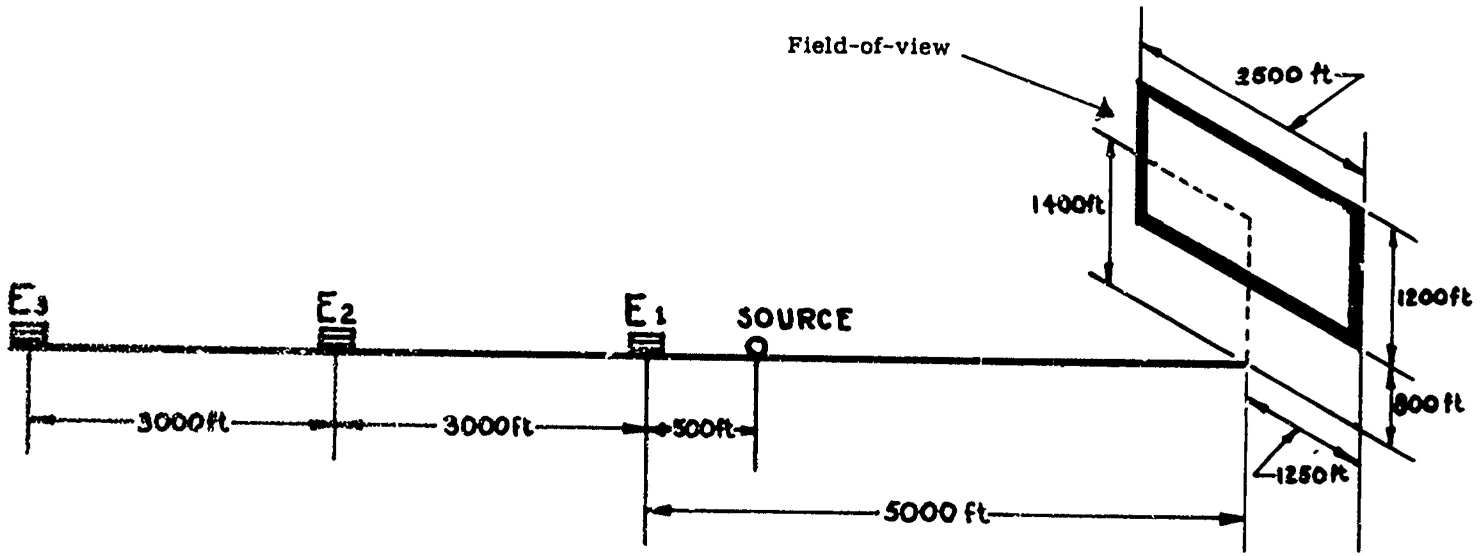

Figure 8. Typical test configuration

APPENDIX A

Program to Find Worst Case Error in Candlepower Calculations, Neglecting Transmissivity from Test Configuration as Shown in Figure 4

```
1 REM --- APPENDIX A
2 REM --- TITLE - PROGRAM TO FIND WORST CASE ERROR IN
3 REM ---          CANDLEPOWER CALCULATIONS,NEGLECTING
4 REM ---           TRANSMISSIVITY FROM TEST CONFIGURATION
5 REM ---          AS SHOWN IN FIG. 4
10  PRINT "************************************************************"
20  PRINT
30  PRINT
40  PRINT
45  PRINT "PRESS RETURN TO CONTINUE PROGRAM"
46  INPUT A
47 IF A<>0 THEN 570
50  PRINT "INTENSITY OF FLARE";
51  INPUT I
52  PRINT "MIDDLE OF CUBE (X-COORDINATE)"
53  INPUT X1
60  PRINT "ERROR OF CELLS IN DECIMAL FORM";
61  INPUT E
62  PRINT "CELL SEPARATION";
63  INPUT D
65 PRINT "PRESS 9 TO CHANGE VARIABLES,OTHERWISE PRESS RETURN"
67  INPUT J
68 IF J<>0 THEN 10
70  PRINT "DISTANCE IN X DIRECTION FROM FURTHEST CELLS";
71  INPUT X
72  PRINT "Y=";
73  INPUT Y
74  PRINT "Z=";
75  INPUT Z
80  LET D5=SQR(X1*X1+1.96000E+06)-SQR((X1-D)*(X1-D)+1.96000E+06)
81  LET T1=ATN(1400/(X1-D))
82  LET T2=ATN(1400/X1)
130  GOSUB 400
215  LET B=D
216  LET H3=H1
260 PRINT "INTENDED SEPARATION  'D' ="D5
270 PRINT "INTENSITY OF FLARE="I
280  PRINT "CELL ERROR="ABS(E*100)
300  PRINT "DISTANCE BETWEEN CELLS="B
310  PRINT "ERROR OF SYSTEM="H3
320  PRINT "LIGHT INTENSITY SYSTEM FINDS="P
360  PRINT "------------------------------------------------------------"
370 GOTO 65
400  REM-------D=SEPARATION
402  REM -------D5=INTENDED SEPARATION
405  REM-------X,Y,Z=COORDINATES
410  REM-------I=INTENSITY
415  REM-------E=ERROR OF CELLS
420  REM-------SUBROUTINE TO CALCULATE ERROR
421  LET V1=SQR(X*X+Z*Z)
422  LET V2=ATN(Z/X)
423  LET V3=V2-T2
424  LET V4=V1*COS(V3)
425  REM-------H1=ERROR OF SYSTEM
426  LET V6=SQR((X-D)*(X-D)+Z*Z)
427  LET V7=ATN(Z/(X-D))
428  LET V8=V7-T1
429  LET V9=V6*COS(V8)
430  GOSUB 500
440  LET H2=H1
445  LET PS=P
450  LET E=-E
455  LET D5=D
460  GOSUB 500
470  IF H1 >= H2 THEN 560
480  LET H1=H2
485  LET P=PS
490  GOTO 560
500  LET D1=(X-D)*(X-D)+Y*Y+Z*Z
510  LET D2=X*X+Y*Y+Z*Z
520  LET E1=(I/D1)*(V9/SQR(D1))*(1+E)
530  LET E2=(I/D2)*(V4/SQR(D2))*(1-E)
540  LET P1=D5/(1/SQR(E2)-1/SQR(E1))
545  LET P=P1*P1
550  LET H1=ABS(((P-I)/I)*100)
560  RETURN
570  END
READY
```

```
RUN
********************************************************



PRESS RETURN TO CONTINUE PROGRAM
?
INTENSITY OF FLARE?1000000
MIDDLE OF CUBE (X-COORDINATE)
?11000
ERROR OF CELLS IN DECIMAL FORM?.02
CELL SEPARATION?3000
PRESS 9 TO CHANGE VARIABLES,OTHERWISE PRESS RETURN
?
DISTANCE IN X DIRECTION FROM FURTHEST CELLS?11000
Y=?0
Z=?1400
INTENDED SEPARATION  'D' = 2967.157
INTENSITY OF FLARE= 1000000
CELL ERROR= 2
DISTANCE BETWEEN CELLS= 3000
ERROR OF SYSTEM= 14.29149
LIGHT INTENSITY SYSTEM FINDS= 1142915
---------------------------------------------------------
PRESS 9 TO CHANGE VARIABLES,OTHERWISE PRESS RETURN
?9
********************************************************



PRESS RETURN TO CONTINUE PROGRAM
?9

STOP AT LINE  570
READY
```

APPENDIX B

Special Program for Finding Worst Case Transmissivity Error vs Cell Reproducibility Using Configuration Shown in Figure 6

```
1 REM --- TITLE - SPECIAL PROGRAM FOR FINDING WORST CASE
2 REM ---         TRANSMISSIVITY ERROR VS. CELL REPRODUCABLITY
3 REM ---         USING CONFIGURATION SHOWN IN FIG.6
12  PRINT
13  PRINT
14  PRINT "                 TRANSMISSIVITY PROGRAM I"
15  PRINT
16  PRINT
17  PRINT "INPUT THE FOLLOWING; T,H,E";
18  INPUT T,H,E
19  IF T<0 THEN 17
20  IF H<0 THEN 17
21  IF E<0 THEN 17
22  PRINT
23  PRINT
24  PRINT "                    TEST CONFIGURATION"
25  PRINT
26  PRINT
27  PRINT "                                                       !";H"FT"
28  PRINT "                                                       !"
29  PRINT "                                                       !"
30  PRINT "                                                       !"
31  PRINT "                                                       !"
32  PRINT "     !--D3--!--D2--!----------------D1----------------!"
70  PRINT
71  PRINT
72  PRINT "T=";T;",CELL ERROR=";E
75  PRINT
80  PRINT "          D3 AND D2 MUST BE EQUAL"
85  PRINT
90  PRINT "TYPE 0 FOR D1,D2,D3 TO RESTART PROGRAM"
95  PRINT
105  PRINT "INPUT D1,D2,D3";
110  INPUT D1,D2,D3
111 IF D2<>D3 THEN 105
112  IF D1<0 THEN 105
113  IF D3<0 THEN 105
114 IF D1<>0 THEN 119
115IF D3<>0 THEN 119
116  GOTO 10
119  LET R=0
120 LET L3=(D1+D2+D3)↑2+H*H
130 LET L2=(D2+D1)↑2+H*H
140 LET L1=D1*D1+H*H
150  FOR X=-1 TO 1 STEP 2
160  FOR Y=-1 TO 1 STEP 2
170  FOR Z=-1 TO 1 STEP 2
180  LET A=E*Z
190  LET B=E*Y
200  LET C=E*X
210  LET E1=100000./L1*T↑(SQR(L1)/5280)*(1+A)
220  LET E2=100000./L2*T↑(SQR(L2)/5280)*(1+B)
230  LET E3=100000./L3*T↑(SQR(L3)/5280)*(1+C)
240  LET T1=SQR(E3/E2)
250  LET T2=SQR(E3/E2-SQR(E3/E1))
260 LET T3=(T1+T2)↑(2/(D3/5280))
270  LET R1=(T3-T)/T*100
280  IF ABS(R1)>ABS(R) THEN 00
290  NEXT Z
300  NEXT Y
310    NEXT X
320  PRINT
330  PRINT
340  PRINT "-------------------------"
350  PRINT "D1=";D1;"D2=";D2;"D3=";D3
360  PRINT "ERROR OF T=";R
370  PRINT "-------------------------"
390  GOTO 95
400  LET R=R1
410  GOTO 290
420  END
```

APPENDIX C

Program to Plot System Error vs Distance to Farthest Cell

```
1   REM  APPENDIX C
2   REM  TITLE  PROGRAM TO PLOT SYSTEM ERROR VS
                DISTANCE TO FARTHEST CELL
```

```
LIST
3  LET G=1250
10  LET J=2000
15  LET E=100000.
17  LET M=-2.00000E-02
20  LET L=3000
25  DEF FNX(X)=(X-L)↑2+G↑2+J↑2
30  DEF FNY(X)=X↑2+G↑2+J↑2
35  DEF FNZ(X)=SQR((X-L)↑2+J↑2)
40  DEF FNW(X)=ATN(J/(X-L))-ATN(1400/(X-L))
45  DEF FNT(X)=FNZ(X)*COS(FNW(X))
50  DEF FNM(X)=SQR(X↑2+1.96000E+06)-SQR((X-L)↑2+1.96000E+06)
55  DEF FNS(X)=SQR(X↑2+J↑2)
60  DEF FNR(X)=ATN(J/X)-ATN(1400/X)
65  DEF FNQ(X)=FNS(X)*COS(FNR(X))
70  DEF FNP(X)=(E/FNX(X))*(FNT(X)/SQR(FNX(X)))*(1+M)
75  DEF FNO(X)=(E/FNY(X))*(FNQ(X)/SQR(FNY(X)))*(1-M)
80  DEF FNN(X)=(FNM(X)/(1/SQR(FNO(X))-1/SQR(FNP(X))))↑2
100  DEF FNF(X)=(FNN(X)-E)/E*100
150  DIM Z[10]
400  LET R1=0
500  LET L1=0
600  LET Q1=0
700  PRINT "PLEASE INPUT THE FOLLOWING PARAMETERS:"
800  PRINT "LEFT X-ENDPOINT";
900  INPUT A
1000  PRINT "RIGHT X-ENDPOINT";
1100  INPUT B
1200  PRINT "X-SPACING";
1300  INPUT D
1400  PRINT "THE NUMBER OF UNDEFINED POINTS (IF NONE,ENTER 0)";
1500  INPUT N9
1600  IF N9=0 THEN 2100
1700  PRINT "ENTER THE UNDEFINED POINTS, FOLLOWING EACH WITH A RETURN"
1 800  FOR K7=1 TO N9
1900  INPUT Z[K7]
2000  NEXT K7
2100  DEF FNG(X)=INT((Y7-L1)/D1+.5)+15
2200  LET L2=R2=FNF(A)
2300  FOR X=A TO B STEP D
2400  FOR I=1 TO N9
2500  IF X=Z[I] THEN 3100
2600  NEXT I
2700  IF FNF(X)>L2 THEN 2900
2800  LET L2=FNF(X)
2900  IF FNF(X)<R2 THEN 3100
3000  LET R2=FNF(X)
3100  NEXT X
3200  IF L2<0 THEN 3500
3300  LET R1=R2
3400  GOTO 3900
3500  IF R2>0 THEN 3700
3600  GOTO 3800
3700  LET R1=R2
3800  LET L1=L2
3900  LET D1=(R1-L1)/50
4000  IF L1<R1 THEN 4300
4100  PRINT "THIS IS THE FUNCTION Y=CONSTANT."
4200  STOP
```

```
4300  PRINT "THE MINIMUM VALUE OF THE FUNCTION IS";L2
4400  PRINT "THE MAXIMUM VALUE OF THE FUNCTION IS";R2
4500  PRINT "THE SPACING ON THE Y-AXIS IS";D1
4600  PRINT ""
4700  LET F=INT(-L1/D1+.5)+15
4800  IF A <= 0 THEN 5900
4900  IF A/D>6 THEN 5900
5000  LET Q1=1
5100  IF L1=0 THEN 5300
5200  PRINT TAB(F);"+"
5300  PRINT
5400  GOTO 7800
5500  FOR I=1 TO INT(A/D-.5)
5600  PRINT TAB(F);"+"
5700  NEXT I
5800  LET Q1=0
5900  FOR X=A TO B STEP D
6000  IF D<1.00000E-04 THEN 6300
6100  IF ABS(X)>1.00000E-05 THEN 6300
6200  LET X=0
6300  PRINT X,
6400  FOR P=1 TO N9
6500  IF X#Z[P] THEN 7500
6600  IF X#0 THEN 7300
6700  FOR I2=1 TO 50
6800  PRINT "+";
6900  NEXT I2
7000  LET Q=1
7100  PRINT "Y"
7200  GOTO 9907
7300  PRINT TAB(F);"+"
7400  GOTO 9907
7500  NEXT P
7600  IF X*(X+D)>0 THEN 9600
7700  IF X<-D/2 THEN 9600
7800  FOR I=0 TO 50
7900  IF Q1>0 THEN 8200
8000  LET Y7=FNF(X)
8100  IF FNG(X)=I+15 THEN 8500
8200  IF I+15=F THEN 8700
8300  PRINT "+";
8400  GOTO 8800
8500  PRINT "*";
8600  GOTO 8800
8700  PRINT "O";
8800  NEXT I
8900  IF I+15#F THEN 9100
9000  PRINT "+";
9100  PRINT "Y"
9200  LET Q=1
9300  IF (Q1+1)=1 THEN 9907
9400  IF (Q1+1)=2 THEN 5500
9500  IF (Q1+1)=3 THEN 9916
9600  IF X*(X-D)>0 THEN 9800
9700  IF X <= D/2 THEN 7800
9800  LET Y7=FNF(X)
9900  IF FNG(X)>F THEN 9906
9901  IF FNG(X)=F THEN 9904
9902  PRINT TAB(FNG(X));"*";TAB(F);"+"
9903  GOTO 9907
9904  PRINT TAB(F);"*"
9905  GOTO 9907
9906  PRINT TAB(F);"+";TAB(FNG(X));"*"
9907  NEXT X
9908  IF X >= 0 THEN 9917
9909  IF -X/D>6 THEN 9917
9910  FOR I=1 TO INT(-X/D-.5)
9911  PRINT TAB(F);"+"
9912  NEXT I
9913  LET Q1=2
9914  PRINT
9915  GOTO 7800
9916  PRINT TAB(F);"+"
9917  PRINT TAB(F);"X"
9918  IF Q=0 THEN 9920
9919  STOP
9920  PRINT
9921  PRINT
9922  PRINT
9923  FOR I=0 TO 50
9924  PRINT "+";
9925  NEXT I
9926  PRINT "Y"
9927  PRINT
9928  PRINT
9929  PRINT "                    SINCE THE REAL Y-AXIS IS OFF THE GRAPH."
9930  STOP
9931  END

READY
```

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