NEW LIMITATION CHANGE

TO
Approved for public release, distribution unlimited

FROM
Distribution authorized to U.S. Gov’t. agencies only; Test and Evaluation; 30 AUG 1976. Other requests shall be referred to Naval Air Systems Command, Washington, DC 20361.

AUTHORITY
USNASC ltr, 3 Aug 1978
THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.
FINAL REPORT for Period 30 September 1974 to 30 June 1976
Submitted

B. E. DOUDA, Manager
Chemical Sciences Branch
Pyrotechnics Division
Applied Sciences Department
**Title:** Photometric and Near Infrared Radiometric Measurement Systems

**Authors:** Forrest L. Burton, Carl E. Dinerman

**Performing Organization:** Naval Weapons Support Center
- Applied Sciences Department
- Crane, Indiana 47522

**Controlling Office:** Naval Air Systems Command (AIR-350E)
- Washington, D.C. 20361

**Report Date:** 30 August 1976

**Project Area & Work Unit Numbers:** 6226ON, WF53538, WF53538500

**Security Class:** Unclassified

**Distribution Statement:** Distribution limited to U.S. Government agencies only; Test and Evaluation: 30 August 1976. Other requests for this document must be referred to Commanding Officer, Naval Weapons Support Center, Applied Sciences Department, Crane, Indiana 47522.

**Supplementary Notes:**

**Key Words:**
- Pyrotechnics
- Radiometry
- Radiation
- Photometer

**Abstract:**

This report describes the details of calibration operation, and construction of a photometric, and a 0.73-0.97 μm near infrared radiometric measurement system, both constructed at NAVWPSUPPCCN Crane for measurements of flare plume candlepower and radiant intensities, respectively.
INTRODUCTION

In the improvement of existing flares and in the development of new flare concepts, it is necessary to measure candlepower and near infrared radiation. This report describes the details of calibration, operation, and construction of a photometric measurement system, and a 0.73-0.97 μm near infrared radiometric measurement system, both constructed at NAWPNUSUPPCEH Crane. The block diagram (Figure 1) is the same for both systems. The report describes each system separately. The description of each system is divided into two sections: (a) calibration and operation; and (b) construction details.

PHOTOMETER SYSTEM

Calibration and Operation

The photometer, details of which are described in the Construction Details section of this section, is calibrated against NBS Standard Lamp No. 9789, 1000 watt tungsten filament lamp rated at 1070 candlepower. An optical bench is used and the lamp is properly shielded. We use the relationship

\[
\frac{1070}{D^2} = E
\]

where \( E \) is the calculated illuminance in footcandles, and \( D \) is the distance in feet between the photometer and the standard lamp. For each distance, the irradiance \( E \) is calculated using equation (1) and plotted against the observed voltage at that distance. See Figure 2. The luminous intensity (candlepower), in candles, is calculated for a flare according to

\[
I(\text{cd}) = E \cdot D^2
\]

where \( E \) is the illuminance in footcandles, as determined from the observed voltage by using the calibration curve, and \( D \) is the distance in feet between the photometer and the flare. If the approximate candlepower of a flare is known beforehand, the photometer-to-flare distance is adjusted to keep the output in the linear region of operation.

\(^1\)General Electric Co., Cleveland, Ohio.
The output is recorded on a Moseley\textsuperscript{2} strip chart recorder, and can be integrated as well.

Construction Details

The photometer system and the radiometer systems were built on printed circuit boards for easy component replacement and troubleshooting. The systems use all solid state circuitry and precision components.

The photometer system uses a Weston 856 photocell\textsuperscript{3} corrected for eye response. An opal glass filter was inserted over the face of the photocell for uniform distribution of light. The field of view is ±12.5°.

The photometer detector/opal glass combination is mounted in a separate housing from the amplifier and the output signal is fed to an amplifier circuit through a coaxial cable. The input amplifier for the detector is also mounted on a printed circuit board in a precision current to voltage amplifying mode. The amplifier is a Burr Brown\textsuperscript{4} 3341/15C inverting field effect transistorized line driving operational amplifier. This amplifier has an extremely wide bandwidth with fast slewing and settling characteristics, along with high gain accuracy and linearity. This amplifier is designed to withstand input voltages as high as the supply voltage without damage. The output stage is internally current limited to withstand short-circuit to ground conditions.

The feedback resistor is a precision 10 turn variable resistor to give a linear 0 to 5 volts output. The output of this amplifier is then coupled to a BNC connector for input to the recorder or integrator.

Figure 3b and 3c show the electronic schematics.

The Model P2.15.300 power supply\textsuperscript{5} features dual ±15VDC output with up to 0.01% regulation, automatic short circuit protection, and is encapsulated with hermetically sealed components and tantalum capacitors for full rated operation through +85°C.

\textsuperscript{2}Hewlett-Packard, Inc., Palo Alto, California.
\textsuperscript{3}Weston, Inc., Newark, New Jersey.
\textsuperscript{4}Burr-Brown Research Corporation, Tucson, Arizona.
\textsuperscript{5}Semiconductor Circuits Inc., Haverhill, Massachusetts.
The power supply is identical in the photometric and near infrared system. See Figure 4 for a schematic.

NEAR INFRARED (0.73-0.97 μm) SYSTEM

Calibration and Operation

The total relative system response (filter and detector) is shown in Figure 5. The wavelengths 0.73 and 0.97 μm were chosen since they are the points at which the relative response has fallen off to 0.5.

The equations regarding the calibration and operation of the radiometer are as follows:

\[ V = c \cdot A \cdot R^{-2} \int N(\lambda) \cdot s(\lambda) \cdot \tau(\lambda) \cdot \tau_a(R, \lambda) \, d\lambda \]  

(3)

where

\[ V \] is the volts observed on the meter or chart recorder

\[ c \] is a constant, in V/W·cm⁻²

\[ A \] is the area in cm² of the blackbody source aperture

\[ R \] is the source-to-detector distance, in cm

\[ N(\lambda) \] is the known radiance of a blackbody, in W·cm⁻²·sr⁻¹·μm⁻¹

\[ s(\lambda) \] is the (dimensionless) relative spectral response of the detector

\[ \tau(\lambda) \] is the (dimensionless) transmittance of the filter

\[ \tau_a(R, \lambda) \] is the (dimensionless) transmittance due to atmospheric constituents.

In the spectral region 0.73-0.97 μm, \( \tau_a = 1 \). Therefore,

\[ V = c \cdot A \cdot R^{-2} \int N(\lambda) \cdot s(\lambda) \cdot \tau(\lambda) \, d\lambda \]  

(4)

Since \( N(\lambda)A = J(\lambda) \), the radiant intensity in W·sr⁻¹, we can write

\[ V = c \cdot R^{-2} \int J(\lambda) \cdot s(\lambda) \cdot \tau(\lambda) \, d\lambda \]  

(5)
Calibration in this spectral region consists of placing the radiometer on an optical rail at a series of distances from a properly shielded and powered NBS-traceable lamp, of known spectral radiant intensity \( J(\lambda) \), and recording the voltages obtained. Plotting \( V \) against \( R^{-2} \) will allow \( c \) to be calculated in \( V/\text{W} \cdot \text{cm}^{-2} \). Figure 6 shows the results of a calibration, performed with a 1000 watt tungsten-halogen lamp (EG&G standard lamp serial number A163A, and their calibration test number 107019).

In order to determine the \( W \cdot \text{sr}^{-1} \) from a flare, (5) is used, except that \( J(\lambda) \) is now the unknown instead of \( c \). If we assume that \( J(\lambda) \) doesn't vary much in the 0.73-0.97 \( \mu \text{m} \) interval, then it can be taken out of the integral.

\[
V = c \cdot R^{-2} \cdot \int s(\lambda) \cdot \tau(\lambda) d\lambda
\]

(6)

where

\[
J' = \frac{J(\lambda) d\lambda}{\Delta \lambda} .
\]

(7)

Then

\[
J' = \frac{V}{c \cdot R^{-2} \int s(\lambda) \cdot \tau(\lambda) d\lambda}, \ W \cdot \text{sr}^{-1} \cdot \mu \text{m}^{-1} .
\]

(8)

Finally

\[
J'_{\text{band}} = J'_{\Delta \lambda} = J'(0.234), \ W \cdot \text{sr}^{-1}
\]

(9)

Construction Details

The radiometer system uses a PIN-10D silicon photodiode\(^7\) responding from about 0.35 to 1.1 \( \mu \text{m} \). A Corning 1-64 and 2-58 filter combination\(^8\) was selected to limit system response to the near infrared. The field of view is \( \pm 12.5^\circ \).

\(^6\)EG&G, Electro-Optics Division, Salem, Massachusetts.

\(^7\)United Detector Technology, Inc., Santa Monica, California.

\(^8\)Corning Glass Works, Corning, New York.
The output signal is fed to the amplifier circuit through a coaxial cable.

The input amplifier for the detector is mounted on a printed circuit board, in a precision current to voltage amplifying mode. The amplifier is an Intech A157 F.E.T. input operational amplifier. This amplifier has wideband, fast response characteristics and provides stable operation with capacitive loads up to 1000 pF. The feedback resistor is a handpicked precision 10 kΩ resistor to give a linear voltage output from 0-10 VDC. The output of the amplifier is then coupled to a BNC connector for input to the recorder or integrator.

See Figure 3a for a schematic.

The power supply has been described in Construction Details in the Photometer System section.
<table>
<thead>
<tr>
<th>Designation</th>
<th>Catalog Number</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS-1</td>
<td>P2.15.300</td>
<td>Semiconductor Circuits, Inc., Haverhill, MA</td>
</tr>
<tr>
<td>F-1</td>
<td>AGC 1/2</td>
<td>Buss, fuses, St. Louis, MO</td>
</tr>
<tr>
<td>LS-1</td>
<td>36U2311</td>
<td>Allied Electronics, Elgin, IL</td>
</tr>
<tr>
<td>S-1</td>
<td>5222S</td>
<td>J.S.T. Instruments, Inc., New Haven, CT</td>
</tr>
<tr>
<td>Fuse Holder</td>
<td>HJM-H</td>
<td>Buss Fuses, St. Louis, MO</td>
</tr>
<tr>
<td>DT-1</td>
<td>856</td>
<td>Doystrom Inc., Newark, NJ</td>
</tr>
<tr>
<td>DT-2, DT-3</td>
<td>PIN-10D</td>
<td>United Detector Inc., Santa Monica, CA</td>
</tr>
<tr>
<td>Filter 1-64</td>
<td>1-64</td>
<td>Corning Glass Works, Corning, NY</td>
</tr>
<tr>
<td>Filter 2-58</td>
<td>2-58</td>
<td>Corning Glass Works, Corning, NY</td>
</tr>
<tr>
<td>Opal Glass</td>
<td>2149</td>
<td>Edmund Scientific Co., Barrington, NJ</td>
</tr>
<tr>
<td>B.N.C. Connector</td>
<td>UG254A/U</td>
<td>Amphenol Connector Div., Broadview, IL</td>
</tr>
<tr>
<td>C-1</td>
<td>CD7FD151J</td>
<td>Cornell-Dubilier Electronics Div., Newark, NJ</td>
</tr>
<tr>
<td>C-2, C-3</td>
<td>CD6CD100K</td>
<td>Cornell-Dubilier Electronics Div., Newark, NJ</td>
</tr>
<tr>
<td>R-1</td>
<td>RN55D1002F</td>
<td>Allied Electronics, Elgin, IL</td>
</tr>
<tr>
<td>R-2</td>
<td>3359P1K</td>
<td>Bourns, Inc., Riverside, CA</td>
</tr>
<tr>
<td>R-3, R-4</td>
<td>224P25K</td>
<td>Bourns, Inc., Riverside, CA</td>
</tr>
<tr>
<td>A-1</td>
<td>A-157</td>
<td>Intech Inc., Santa Clara, CA</td>
</tr>
<tr>
<td>A-2, A-3</td>
<td>3341/15C</td>
<td>Burr-Brown Research Corp., Tucson, AZ</td>
</tr>
</tbody>
</table>
Figure 3. Detector Circuits for Near Infrared Radiation (a), and Visible Radiation (b) and (c).

NOTE:
2. A2 & A3 - BURR-BROWN 3341/15C
Figure 4. Power Supply for Both Photometric and Near Infrared Radiometric Systems
Figure 5. Relative System Response for the 0.73-0.97 μm Radiometer. This curve results from multiplying the detector response by the filter response and normalizing to 1.0.
Figure 6. Calibration Curve for the 0.73-0.97 μm Radiometer
<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>COPIES</th>
</tr>
</thead>
</table>
| Commander  
Naval Air Systems Command  
Department of the Navy  
Washington, D.C. 20361  
Attention: Code AIR-954, Technical Library  
Code AIR-53235, Mr. R. Szypulski  
Code AIR-350, Mr. E. Fisher  
Code AIR-310C, Dr. H. Rosenwasser | 1 |
| Commander  
Naval Sea Systems Command  
Naval Sea Systems Command Headquarters  
Washington, D.C. 20362  
Attention: Code SEA-09G3, Technical Library  
Code SEA-033, CDR J.R. Gauthey  
Code SEA-0332, Dr. A.B. Amster  
Code SEA-0332B, Mr. G. Edwards  
Code SEA-9921, Mr. W. Greenlees | 1 |
| Administrator  
Defense Documentation Center for Scientific and Technical Information (DDC)  
Building 5, Cameron Station  
Alexandria, Virginia 22314 | 2 |
| Commander  
Naval Weapons Center  
China Lake, California 93555  
Attention: Code 6082, Mr. J. Eisel  
Code 533, Technical Library  
Code 454, Mr. D. Williams  
Code 45403, Mr. H. Larsen  
Code 4544, Dr. M. Nadler  
Code 45401, Dr. R. Reed  
Code 454A, Mr. E. Allen | 1 |
| Commanding Officer  
Naval Avionics Facility  
Indianapolis, Indiana 46218  
Attention: Code PC-010, Mr. P. Collignon | 1 |
| Commander  
Naval Surface Weapons Center  
White Oak Laboratory  
Silver Spring, Maryland 20910  
Attention: Code WR, Research & Technology Dept.  
Code WX-21, Technical Library  
Code WR-12, Mr. B. White | 1 |
<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>COPIES</th>
</tr>
</thead>
</table>
| Commander  
Naval Surface Weapons Center  
Dahlgren Laboratory  
Dahlgren, Virginia 22448  
Attention: Code DG-50, Mr. R. Morrissette | 1 |
| Commander  
Naval Ordnance Station  
Indian Head, Maryland 20640  
Attention: Code 5232V, Mr. W. Vreatt  
Code 5111A, Mr. F. Valenta | 1 |
| Commanding Officer  
Frankford Arsenal  
Philadelphia, Pennsylvania 19173  
Attention: Code SARFA-MDP-Y, Mr. W. Puchalski | 1 |
| Commander  
Edgewood Arsenal  
Aberdeen Proving Ground, Maryland 21010  
Attention: Code SAREA-DE-MMP, Mr. M. Penn  
Code SAREA-DE-MMP, Mr. A. Deiner | 1 |
| Commander  
Ballistic Research Laboratories  
Interior Ballistics Laboratory  
Aberdeen Proving Ground, Maryland 21005  
Attention: Code DRXBR-IB, Mr. J. R. Ward | 1 |
| Commanding Officer  
Picatinny Arsenal  
Dover, New Jersey 07801  
Attention: Code SARPA-FR-E-L, Mr. T. Boxer  
Code SARPA-FR-E-L-C, Dr. F. Taylor  
Code SARPA-TS-S, Technical Library  
Code SARPA-AD-D-R-4, Mr. A. Neigh  
Code SARPA-FR-E-L-P, Mr. J. Tyroler | 1 |
| Commanding General  
U.S. Army Missile Command  
Redstone Arsenal  
Alabama 35809  
Attention: Code DRSMI-REI, Mr. T. Jackson  
Code DRSMI-REQ, Mr. G. Widenhofer | 1 |
| Commander  
Army Aviation Systems Command  
Avionics and Weaponization Division  
St. Louis, Missouri 63166  
Attention: Code DRSAV-EVW | 1 |
<table>
<thead>
<tr>
<th>ADDRESS</th>
<th>COPIES</th>
</tr>
</thead>
</table>
| Commander  
U.S. Army Material Systems Analysis Agency  
Aberdeen Proving Ground  
Maryland 21005  
Attention: Code DRX-SY-RE, Mr. J. Sheldon  
Code DRX-XY-T, Mr. P. Topper | 1 |
| Commanding General  
U.S. Army Tank Automotive Command  
Warren, Michigan 48090  
Attention: Code DRSTA-RHFL | 1 |
| U.S. Army Foreign Science and Technology Center  
220 Seventh Street, N.E.  
Charlottesville, Virginia 22901  
Attention: Code DRXST-CSI, Mr. J. Jacoby | 1 |
| Commander  
Wright-Patterson Air Force Base  
Ohio 45433  
Attention: Code AFWAL/DO, Technical Library | 1 |
| Commander  
Aeronautical Systems Division (AFSC)  
Wright-Patterson Air Force Base  
Ohio 45433  
Attention: Code ASD/ENAMC, Mr. M. Edelman  
Code ASD/AEWE/ENADC, Mr. R. Sorenson  
Code ASD/ENADC, Mr. H. Wigdahl  
Code ASD/ENAMC, Mr. G. Runseiman | 1 |
| Commander  
Air Force Avionics Laboratory  
Wright-Patterson Air Force Base  
Ohio 45433  
Attention: Code AFAL/CC  
Code AFAL/WRW-3, Mr. F. D. Linton  
Code AFAL/RWI, Dr. B. Sowers | 1 |
| Commander  
Armament Development and Test Center  
Eglin Air Force Base  
Florida 32542  
Attention: Code ADTC/SD-3, Mr. S. Lander | 1 |
| Commander  
Air Force Armament Laboratory  
Eglin Air Force Base  
Florida 32542  
Attention: Code AFATL/DLJW, Mr. A. Beach | 1 |