11. Roy Cason SH3

E82-10383

2. AgRISTARS

7. LARS-061182
SR-P2-04318
5. NAS9-15466
NASA-CR-167710

A Joint Program for
Agriculture and
Resources Inventory
Surveys Through
Aerospace
Remote Sensing

Supporting Research

6. June 1982

Technical Report

Performance Evaluation and Calibration of a Modular Multiband Radiometer for Remote Sensing Field Research

3. by B.F. Robinson, R.E. Buckley, and J.A. Burgess

4. Purdue University
Laboratory for Applications of Remote Sensing
West Lafayette, Indiana 47907

(E82-10388) PERFORMANCE EVALUATION AND CALIBRATION OF A MODULAR MULTIBAND RADIOMETER FOR REMOTE SENSING FIELD RESEARCH (Purdue Univ.) 15 p HC A02/MF A01 CSCL 02C
N82-32805
Unclas
G3/43 00383

SR-P2-04318
NAS9-15466
LARS 061182

PERFORMANCE EVALUATION AND CALIBRATION OF A MODULAR MULTIBAND RADIOMETER FOR REMOTE SENSING FIELD RESEARCH

B.F. Robinson, R.E. Buckley, and J.A. Burgess

Purdue University
Laboratory for Applications of Remote Sensing
West Lafayette, IN 47906-1399, U.S.A.

June 1982

Star Information Form

1. Report No. SR-P2-04318	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Performance Evaluation and Calibration of a Modular Multiband Radiometer for Remote Sensing Field Research	5. Report Date June 1982 6. Performing Organization Code
7. Author(s) B.F. Robinson, R.E. Buckley, and J.A. Burgess	8. Performing Organization Report No. LARS 061182
9. Performing Organization Name and Address Purdue University Laboratory for Applications of Remote Sensing 1220 Potter Drive West Lafayette, IN 47906-1399	10. Work Unit No. 11. Contract or Grant No. NAS9-15466
12. Sponsoring Agency Name and Address NASA Johnson Space Center Earth Resources Research Division Houston, TX 77058	13. Type of Report and Period Covered Technical 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

To develop the full potential of multispectral data acquired from satellites, increased knowledge and understanding of the spectral characteristics of specific earth features is required. Knowledge of the relationships between the spectral characteristics and important parameters of earth surface features can best be obtained by carefully controlled studies over areas, fields or plots where complete data describing the condition of targets are attainable and where frequent, timely spectral measurements can be obtained.

To meet the need for a standard instrument to acquire these spectral measurements, a multiband radiometer suitable for operation from helicopter, small plane, truck, or tripod platforms has been developed. The radiometer can be utilized by remote sensing field researchers to acquire the large numbers of accurate, calibrated spectral measurements needed.

The prototype of this instrument has been tested in the laboratory and field. The results of final laboratory testing are reported here.

17. Key Words (Suggested by Author(s)) Remote Sensing, Multiband Radiometer, Spectral Measurements	18. Distribution Statement

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA - JSC

Reprinted from SPIE Vol. 308—Contemporary Infrared Standards and Calibration
© 1982 by the Society of Photo-Optical Instrumentation Engineers, Box 10, Bellingham, WA 98227-0010 USA

Performance evaluation and calibration of a modular multiband radiometer for remote sensing field research

B. F. Robinson
Purdue University, Laboratory for Applications of Remote Sensing
1220 Potter Drive, West Lafayette, Indiana 47906

R. E. Buckley, J. A. Burgess
Barnes Engineering Company, 30 Commerce Road, Stamford, Connecticut 06904

Abstract

To develop the full potential of multispectral data acquired from satellites, increased knowledge and understanding of the spectral characteristics of specific earth features is required. Knowledge of the relationships between the spectral characteristics and important parameters of earth surface features can best be obtained by carefully controlled studies over areas, fields, or plots where complete data describing the condition of targets is attainable and where frequent, timely spectral measurements can be obtained.

To meet the need for a standard instrument to acquire these spectral measurements, a multiband radiometer suitable for operation from helicopter, small plane, truck or tripod platforms has been developed. The standard unit is equipped with the seven Thematic Mapper spectral bands with an added band from 1.15 to 1.30 μm; however, up to eight user specified spectral bands from 0.4 to 15 μm may be installed under clean field conditions. The radiometer, with available data acquisition systems, can be utilized by remote sensing field researchers to acquire the large numbers of accurate, calibrated spectral measurements needed.

The prototype of this instrument has been tested in the laboratory and field. Results of tests of the spectral responsivity of the detectors, the transmittance of the optical filters as a function of wavelength, the fields of view, and the system linearity, temperature stability, noise performance and dynamic range were evaluated. Minor modifications were made to the instrument and the results of final laboratory testing are reported.

All channels were stable in response to input flux changes; linear; adequately stable in response to ambient temperature changes; and all channels met or exceeded signal to noise ratio requirements. The optical coalignment and field of view definition as well as the spectral characteristics of the filters met or exceeded requirements.

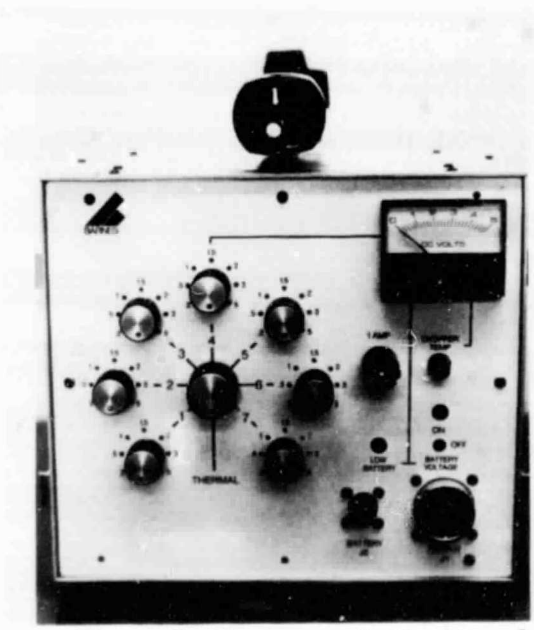


Figure 1. Front panel display of the Modular Multiband Radiometer

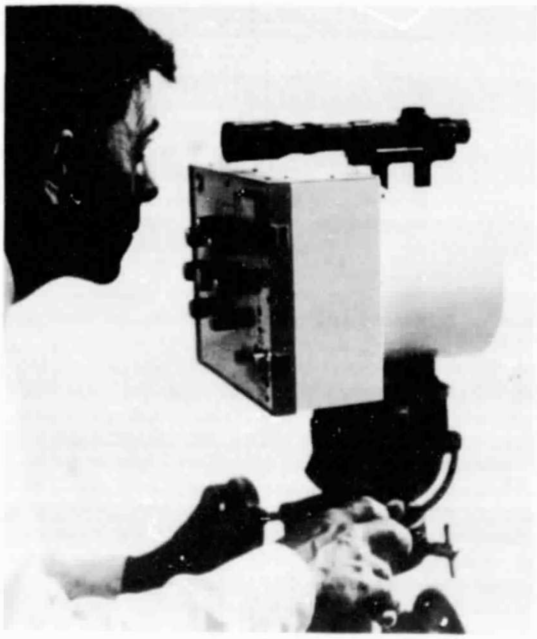


Figure 2. Operator viewing through the telescope sight of the Modular Multiband Radiometer

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Introduction

The need for a high quality field rated multiband radiometer with wide spectral coverage has increased with the growing interest in remote sensing field research.[1]

A practical means to obtain spectral data from a wider variety of subjects and to increase the number of researchers who can afford to acquire and analyze such data is to simplify the instrumentation and reduce the amount of data obtained for each observation. To achieve this, a field-rated multiband radiometer system (having a limited, yet sufficient number of wavelength bands) has been developed. It is:

- capable of complete spectral coverage (appropriate bands from 0.4 to 2.4 μm and a band at 10.4 - 12.4 μm);
- comparatively inexpensive to acquire, maintain, and operate;
- simple to operate, calibrate, and service;
- rugged, light weight, portable;
- complete with data handling hardware and software; and
- well-documented for use by researchers.

The following sections summarize the laboratory and field testing of the prototype of the Barnes Model 12-1000 Modular Multiband Radiometer and discuss its use with two types of data acquisition systems.

Description of the Modular Multiband Radiometer

The modular multiband radiometer[1] simultaneously produces analog voltage responses to the scene radiance in each of eight spectral bands. See Table 1. The radiometer, shown in Figures 1 and 2 is a stand-alone device suitable for operation with a variety of data acquisition systems (two are discussed below). The radiometer is capable of operation from 0° to 60° C, when mounted on a tripod, truck boom, helicopter, or small plane.

Key features of the radiometer are

- Chopped operation of all channels:
- Modularity - The coaligned fields of view (1° and 15°) may be exchanged and/or the entire self-aligning detector-preamplifier-module may be replaced under clean field conditions.
- Gain status signals. A remote TTL zero signal switches the outputs of the seven reflective channels to analog voltages characterizing the system gain. This feature enables instant checking of the operation of all electronics following the preamplifiers.
- System temperature signals. Sensors indicating the temperature of the chopper, detector and frame are imbedded in the radiometer. The response signals are in the 0 to 5 volt range and are all continuously available to the data logger.
- Dimensions. 26.4 x 20.5 x 22.2 cm
  10.3 x 8.07 x 8.74 in
  7.25 Kg (prototype)
  6.4 Kg (production).
- Power. The instrument may be powered by any 12 volt battery and is protected for vehicular operation. Two sealed lead acid battery sets (12 volt, 5 amp hour) were supplied with the prototype. These batteries (5 lb/set) may be easily carried in a "fanny-pack" and each set will operate the radiometer more than 10 hours. Battery charger: 110-220V, 50-60 Hz; recharge in 6 hours.
- Cables. Connecting cables of 1.2m and 15m were provided with the prototype for handheld and boom operation, respectively.

Laboratory Tests

Table 2 summarizes the results of radiometric response tests of completed prototype radiometer. Testing methods and results are discussed in the following paragraphs.

Response Stability. The instrument was tested for stable response by exposing each channel to a source of diffuse radiance of sufficient intensity to obtain a midscale reading. Then a 300K black panel was used to completely block the radiance. Following this the "dark level" response of each channel was monitored on a 40,000 count printing voltmeter and an oscilloscope. All channels settled immediately to the final dark level response and maintained that response indefinately. A similar test was performed using sunlit reflectance panels of 17% and "100%". The test showed that for each possible case the instrument settled immediately to its final value and stayed constant regardless of the past history of exposure to dark and "100%" radiation.

Linearity (at 300K). The instrument was tested using a sum of sources technique. This technique involved aiming four sources of irradiance at a diffuse white surface to simultaneously provide a view filling source of radiance for the seven "reflective" channels. Then the response, V_i, to the radiance, L_i, of each source (i) was determined for each channel while blocking the other three sources. Next, the eleven responses to sums of radiances, were regressed against the corresponding sums of responses to determine a standard error of estimate. The standard error of estimate, normalized to the response of the instrument to a diffuse 100% reflector normal to the solar direction on a clear day near noon, was taken as the measure of linearity. The voltage response of the channels was measured with a 40,000 count printing voltmeter. The procedure was initially tested using an Exotech Model 100A Landsat Band radiometer which uses four silicon PIN diodes operated (dc) in the photovoltaic current mode; it was determined that the precision of the procedures was less than 0.1% for the normalized standard error of estimate.

Figure 3 shows the linearity test results for Channel 3 (0.63-0.69 μm) and Channel 5 (1.55-1.75 μm) which typify the channels which use silicon and lead sulfide detectors, respectively. The data in Table 2 indicate the linearity for the normal operating range (100%) and the range extending from to three times the normal operating range (300%).

Linearity for the thermal channel was determined for chopper temperatures from 15° C to 30° C and target temperatures from 15° C to 40° C by assuming an equation of the form

$$V = a + bT_{CH} + cT_{BB}$$

where V is the thermal channel voltage response
T_{CH} is the chopper temperature
T_{BB} is the black body temperature
a, b, and c are regression coefficients.

The standard error of estimate for computing black body temperature from V and T_{CH} was 0.36° C.

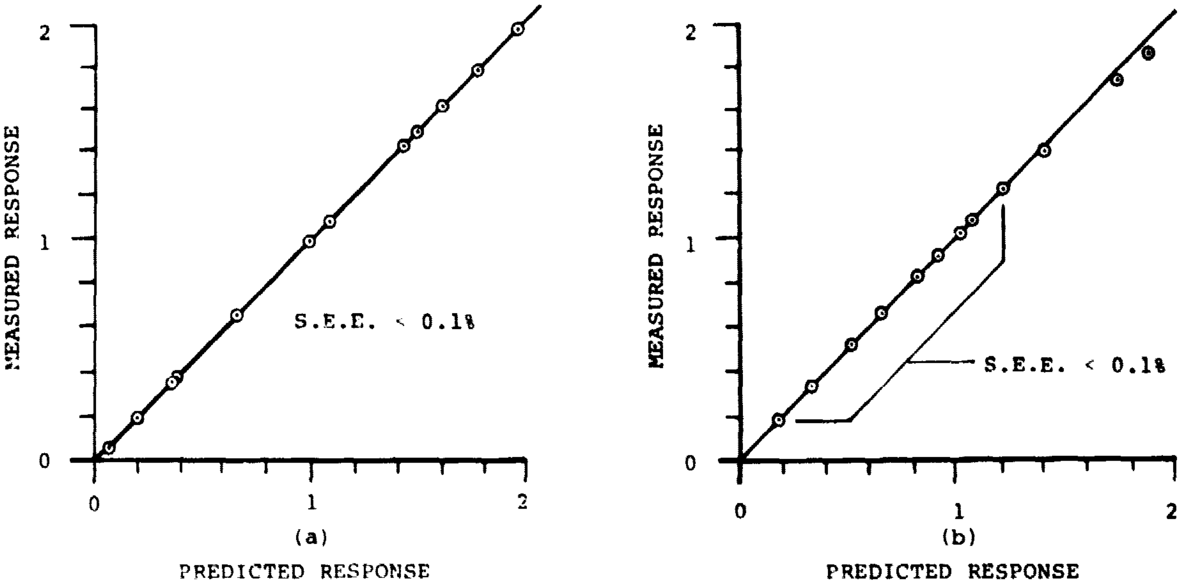


Figure 3. Results of the linearity test (a) for Channel 3 (0.63 - 0.69 μm) and (b) for Channel 6 (1.55 - 1.75 μm). Responses are normalized to "Nominal Maximum In-Band Radiance" (clear day--near noon--earth surface) for a painted barium sulfate reference surface normal to the solar irradiance.

Temperature stability. To typify reasonably severe field conditions, the design of the instrument was aimed at the following condition:

"Detector temperature shall be monitored; and analog compensation shall be used to limit the relative limit of uncertainty (maximum fraction error) in reflectance measurement to 1% (0.4 μm to 1 μm) and 2% (1 μm to 2.5 μm) for a 5 celsius degree step in temperature imposed for 20 minutes (20 Hz filter)."

Based on 10 years of experience with field measurement of spectral reflectance factors from truck booms and 5 years with helicopter measurements[2] of spectral reflectance factors, it was felt that this condition would be more than adequate. Futhermore, if accuracies better than 2% of value were required, the measured detector temperature could be used for changes in the channel responsivity.

The instrument was tested by mounting it securely on an optical table and enclosing it in a cardboard chamber. The front of the chamber was fitted with a cover which, when removed, exposed each channel of the radiometer to a view-filling source of stable radiance. See Figure 5. Attached to the rear of the cardboard chamber was an environmental chamber which contained two blowers which circulated heated or cooled air at a rate of about 40 cubic feet per minute around the mounted instrument. Two thermometers were used to monitor the blown air and stagnent air in the cardboard chamber. Dry nitrogen was used to lower the dew point to prevent condensation during tests at temperatures lower than 20C.

To obtain data for 5° C steps in temperature, the instrument was brought to equilibrium at 20C (about an hour and a half was required to reach equilibrium at most temperatures); then air, cooled to much less than 15C, was introduced. As the chamber cooled toward 15C, the temperature of the air was warmed to about 14.8C. The effect was a rapid step in air temperature which approximated a 5°C step in two to three minutes. With the blown air in the cavity at about 15C, the response of each channel was measured periodically with a 40,000 count printing voltmeter as the instrument cooled toward the new equilibrium temperature of 15C. Similar procedures were used to produce up and down steps of 5° C over the range 15C to 40C.

The equilibrium responses at 15C and 40C were used to compute equilibrium temperature coefficients for the silicon (0.6%/°C) and the lead sulfide (0.87%/°C) detector channels. The maximum changes in response for the 5° C steps of blown air for 20 minutes were determined to be 1.9% for silicon and 2.7% for lead sulfide detector channels. Subsequent minor modifications of the silicon channel circuits have yielded maximum changes on the order of 0.3%.

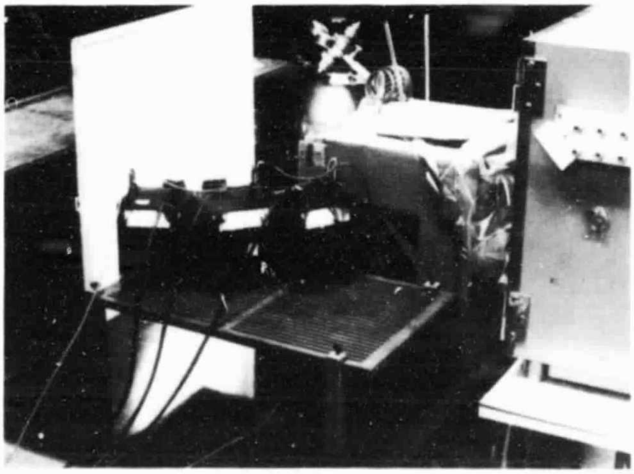


Figure 5. Test set-up for temperature stability tests. Shown from left to right are: the painted barium sulfate reference surface, the stable illumination sources, the cardboard chamber and the environmental chamber.

Noise. The noise in channels having silicon and lead sulfide detectors can be characterized as slightly fuzzy demodulation residuals for both low pass bandwidths. Therefore, the signal to noise ratio was essentially constant with gradual degraduation for target radiances corresponding to less than 3% reflectance measured under field conditions. During the linearity tests, the mean and standard deviation were determined for each channel response. The maximum observed standard deviations were determined for each channel response. The maximum observed standard deviations were 0.08% and 0.23% of the channel response for the 4 Hz and 20 Hz bandwidths, respectively. These limits correspond to values determined from observations of the noise on an oscilloscope. The noise in the lithium tantalate channel can be characterized as similar to low-pass filtered 1/f noise. The limits of deviation of apparent temperature were determined using a Tektronix 545B oscilloscope with Type D high-gain differential preamplifier which was operated dc using the balance control to subtract the average value of the signal. The scope display was monitored for about 30 minutes to determine the peak deviations from the signal average. The peak deviations were 0.71° C and 1.34° C for the 0.15 Hz and 1.0 Hz band widths, respectively. These values correspond to NEΔT values of about 0.3° C and 0.5° C.

Spectral Response. The spectral transmittance of each band-pass interference filter was measured by the filter manufacturer and the manufacturer of the radiometer. In addition to high resolution curves for the passbands, out of band transmittance was measured over the responsive ranges of the detectors. With increased out of band blocking added to band 3, all filters met or exceeded specifications. A comparison of the filter characteristics to the specifications is given in Table 1.

The relative spectral responsivity of each channel was predicted from the measured spectral responsivity of the detectors and spectral transmittance of the filters. The relative spectral responsivity (0.4 - 2.5 μm) was measured at a number of points in the passband using a Beckman DK-2A ratio recording spectrometer with fixed slit widths and a Leiss single pass monochrometer with a golay cell detector was used for Channel 8. Figure 6 shows the relative responsivities of channels 7 and 8.

Table 1. Major performance characteristics of optical filters.

	Specified			Measured			
	50% Response Wavelengths		Slopes	50% Response Wavelengths		Slopes	
Channel	Nanometers		%<	Nanometers		%	
1	450 ± 10	520 ± 10	4.5	453	505	2.9	2.6
2	520 ± 10	600 ± 10	4.5	515	595	4.5	2.2
3	630 ± 20	690 ± 10	4.5	623	695	3.5	4.2
4	760 ± 20	900 ± 20	4.5	775	890	4.0	2.2
5	1150 ± 20	1300 ± 20	4.5	1155	1306	2.3	1.1.
6	1550 ± 20	1750 ± 20	4.5	1578	1783	2.6	1.7
7	2080 ± 20	2350 ± 20	4.5	2094	2358	2.9	1.5
8	10.4 ± 0.1 μm	12.5 ± 0.1 μm	4.5	10.5 μm	12.6 μm	2.9	3.1

ORIGINAL PAGE IS
OF POOR QUALITY

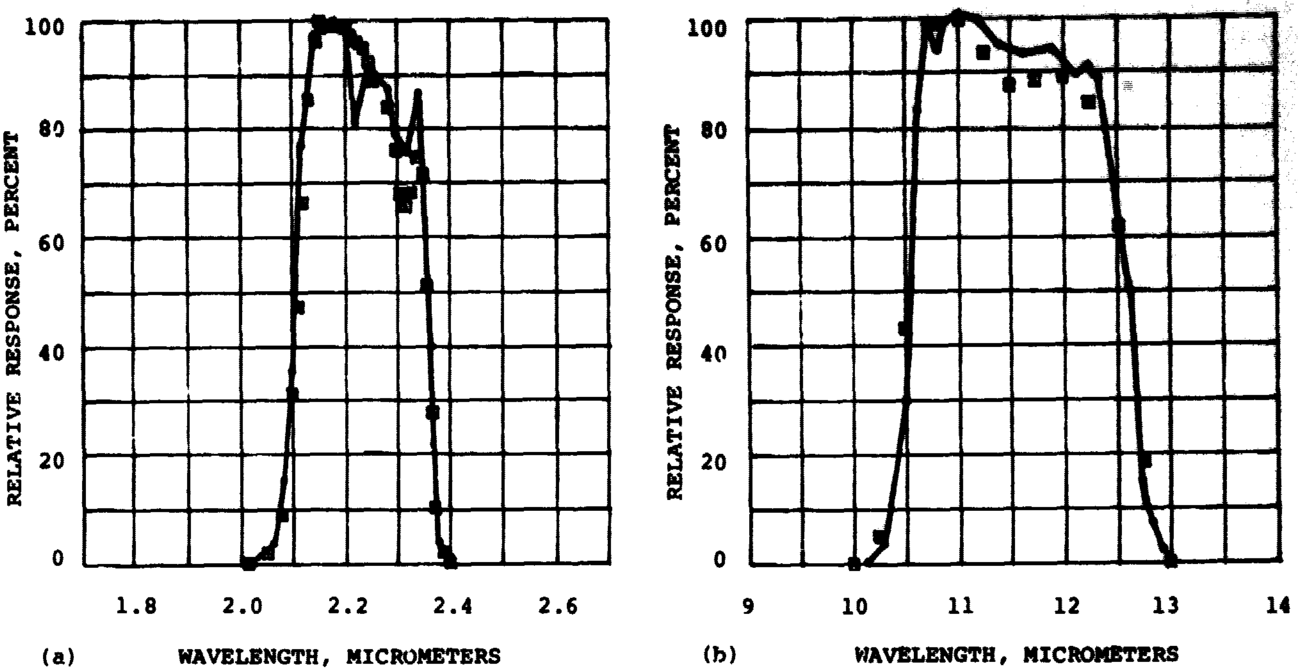
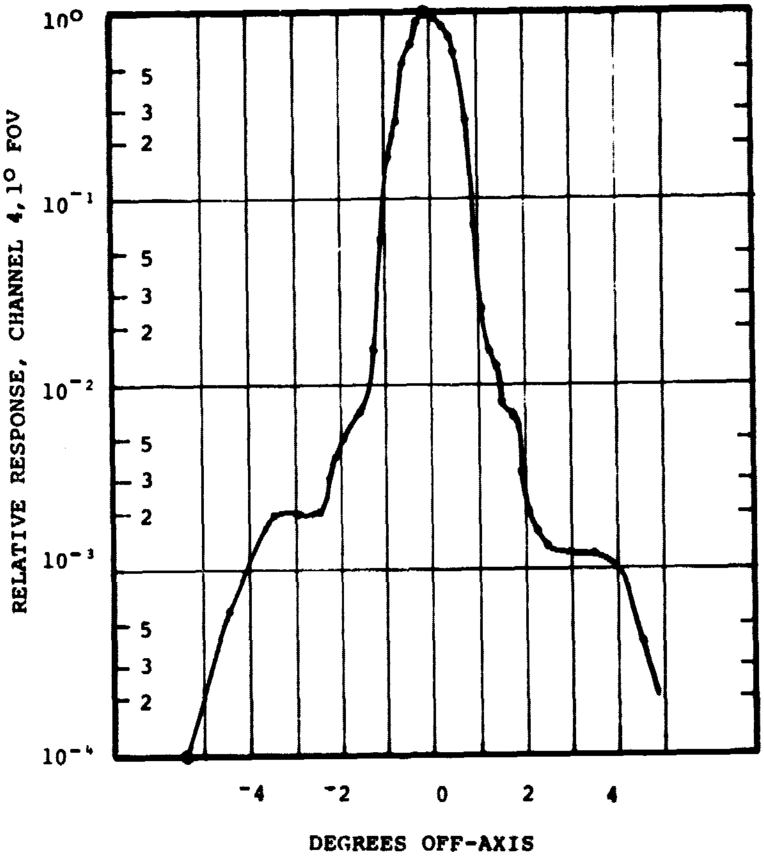


Figure 6. Relative spectral responsivity of (a) Channel 7 (2.08 to 2.35 μm) and (b) Channel 8 (10.4 to 12.5 μm). Solid curve is computed from measured detector spectral responsivity and filter and lens transmittance. Squares represent measured system spectral response.

Figure 7. Relative angular response for the 1° FOV of Channel 4 (0.76 to 0.90 μm).



Field of view. The angular response characteristics of the fields of view (FOV) were obtained by three methods: orientation of the radiometer with respect to a large collimator, orientation of the individual channels of the radiometer with respect to a point source (EG & G 590-21[3] housing with uncalibrated GE DXW lamp--stop full open for 15 FOV, 2.5 mm D for 1° FOV), and systematic search for spurious off-axis responses using a high intensity point source (uncalibrated solar constant lamp[4]).

For the point source transect technique, the source subtended 0.1° x 0.5° for testing the 15° FOV with the 0.1° arc in the direction of transit; for the 1° FOV; the source subtended a circular pattern of 0.05° diameter. Within the range of the collimater technique, the results of the techniques matched. Figures 7 and 8 show the angular response determined by the point source transect technique for channel 4 (0.76-0.90 µm). No spurious off-axis response was found in the completed prototype instrument.

The 1° fields of view are nearly circular with half response diameters which vary 1° to 1.2°. The 15° fields of view are also circular and half response diameters are approximately 14.4°.

Coalignment of the 1° fields of view was determined from the results of the collimeter technique. The centroids of the half response curves mapped into a pattern bounded by a circle 16 arc minutes in diameter resulting in coalignment within 0.13° for all channels. The sighting slope is adjusted to the centroid of the pattern.

The achromatic lens used in the reflective infrared channels of the prototype unit to attain the 1° FOV has been replaced with a single plane convex crown glass lens in the production units. This yields more uniform in field response and superior out of field rejection.

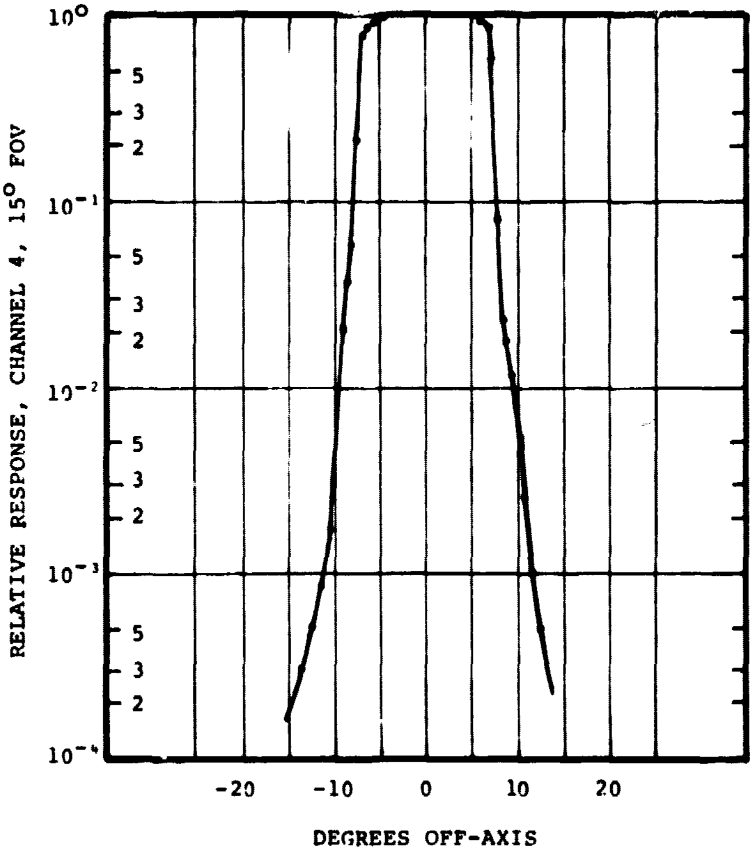


Figure 8. Relative angular response for the 15° FOV of Channel 4 (0.76 to 0.90 µm)

In-Band Radiance Calibration. To achieve reliability in reflectance measurement, a field calibration procedure is employed.[2] On site direct comparison with two reference black bodies at known temperatures is used for the most accurate measurement of thermal radiance.

To standardize instrument response (0.4 μm to 2.5 μm), 1000 watt standard of spectral irradiance and a calibrated barium sulfate reference surface were used to adjust the gain of of the reflective channels so that the radiance of a diffuse 100% reflecting surface, normal to the solar irradiance (clear day - near noon), will produce a response of 3 volts when the front panel gain setting is 1.0. Tests indicated responses within ± 10% of 3 volts. Calculation of in-band radiance was performed prior to evaluation of the filters and it is felt that this procedure can be improved slightly for production instruments and that it will provide a suitable means for performance evaluation of units in service as well as establishing a radiance scale of reasonable accuracy. A procedure for establishing a radiance temperature scale (10.4 μm to 12.5 μm) was discussed in the section on linearity.

Field Test

The radiometer was mounted on the pick-up truck boom (see Figure 9) and used at the Purdue Agronomy farm to measure the reflectance of five subjects of varying spectral reflectance. A data logger having 40,000 count precision was used to evaluate system performance. The standard deviations for the computed reflectances were less than 1% of value. The standard deviations for measurement of the calibration panel were less than 0.4%. Ambient conditions were nearly constant and the instrument was in equilibrium with the slowly moving air (about 25° C) and the solar irradiance conditions were typical for a reasonably clear day near noon. Since extensive instrumentation would be required to establish the temperature of a surface of suitable size, the thermal channel was not used; however, all laboratory environmental performance tests of the thermal and reflective channels used the 13 meter cable in a configuration identical to the field condition.

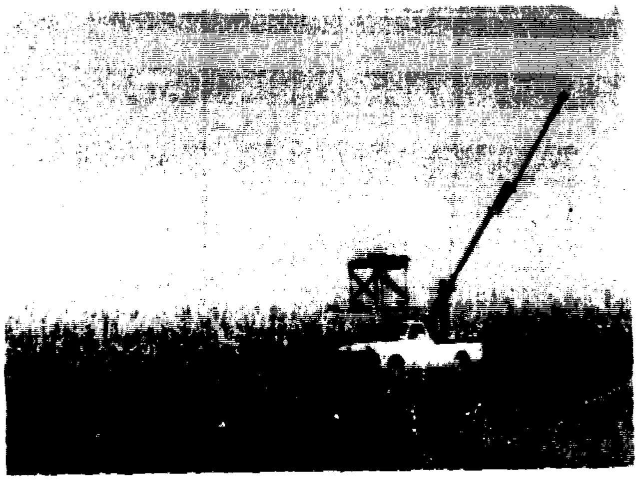


Figure 9. Field tests of modular multiband radiometer on pick-up truck boom at the Purdue University Agronomy Farm.

Determination of Maximum Fractional Error

The field measurement of reflectance factor R_F, is accomplished as follows:

$$R_F = \frac{T^* - D}{S^* - D} \times R_s \qquad (1)$$

where T*, S*, and D are the voltage readings of the radiometer in response to the reflecting target, the reflectance reference surface, and the dark level (all incoming flux blocked), respectively; and R_s is the reflectance factor of the reference surface. Then to simplify,

$$R_F = \frac{T}{S} \times R_s \qquad (2)$$

where $T = T^* - D$ and $S = S^* - D$ are observations of the system response to the flux from the target and reference surface. Then the fractional uncertainty in the measurement of reflectance factor maybe expressed.

$$\frac{\Delta R_F}{R_F} = \frac{\Delta R_s}{R_s} \oplus \frac{\Delta T}{T} \oplus \frac{\Delta S}{S} \qquad (3)$$

Where the procedure for addition, $\oplus$, depends on the nature of the errors; $\Delta R_s/R_s$ stems from the uncertainty for the reflectance of the reference surface (this error is not due to the radiometric performance of the instrument and will be omitted); $\Delta S/S$ and $\Delta T/T$ are the fractional uncertainties for the observations of the reference surface and target, respectively. Then

$$\Delta S = \Delta S^* \oplus \Delta D = \Delta S^* \oplus 1q \qquad [v] \qquad (4)$$

and

$$\Delta T = \Delta T^* \oplus \Delta D = \Delta T^* \oplus 1q \qquad [v] \qquad (5)$$

For this instrument, because the noise consists mainly of demodulation noise, the noise is proportional to the signal; therefore, except for the quantization error associated with reading the dark response, D, ΔD is approximately zero.

The uncertainties for the observations S and T are obtained by adding the partial uncertainties

$$\Delta S = (\sqrt{2} \cdot S \cdot (S/N)^{-1} \oplus 1q \oplus N_s) \oplus 1q \qquad [v] \qquad (6)$$

$$\Delta T = (\sqrt{2} \cdot T \cdot (S/N)^{-1} \oplus 1q \oplus N_t) \oplus 1q \qquad [v] \qquad (7)$$

where S* and T* are assumed to be equal to S and T and the additional quantization unit is for the readings of S* and T*; where S/N is the dc to rms signal to noise ratio which is, for this instrument, approximately constant (the rms noise, $S \cdot (S/N)^{-1}$ is multiplied by $\sqrt{2}$ to obtain the peak deviation); and where N_s and N_t are net systematic errors associated with procedures for obtaining the readings from the panel and target, respectively, and include the effects of changes in ambient temperature. Then, the <u>maximum fractional error</u> due to the radiometric performance of the instrument may be expressed

$$\begin{aligned}\frac{\Delta R_F}{R_F} &= \frac{\Delta S}{S} \oplus \frac{\Delta T}{T} \\ &= \left[\sqrt{2}\ (S/N)^{-1} + \frac{2q + N_s}{S}\right] + \left[\sqrt{2}\ (S/N)^{-1} + \frac{2q + N_t}{T}\right] \qquad (8)\end{aligned}$$

where the limit is estimated by adding the terms algebraically (the maximum absolute values of N_s and N_t are used.) This result may be rearranged and, using $R_F = (T/S)\ R_s$, the limit of fractional error can be expressed as a function of the reflectance level being measured:

$$\frac{\Delta R_F}{R_F} = 2\sqrt{2}\ (S/N)^{-1} + \frac{2q}{S}\left(1 + \frac{R_s}{R_F}\right) + \frac{N_s}{S} + \frac{N_t}{T}. \qquad (9)$$

If procedural errors are omitted, N_s and N_t are mainly due to temperature effects. If a 10% (0.1) reflector is observed 20 minutes after the reference panel and if a 5° C step in temperature is introduced following the reading of the reference panel, then the <u>limit of fractional error</u> for the measurement by a lead sulfide channel (20 Hz bandwidth) is

$$\frac{\Delta R_F}{R_F} = 2\sqrt{2}\ (0.0023 + \frac{2(0.00122)}{3}\left[1 + \frac{1.0}{0.1}\right] + 0.027$$

$$= 0.0065 + 0.0089 + 0.027$$

$$= 0.0424 \tag{11}$$

where the $(S/N)^{-1}$ term is the maximum observed value discussed in the section on noise; q = 5 volts ÷ 4096; R_s is assumed to be 100% (1.0); S is the 3 volt response to the flux from the reference surface; the temperature error at the time of observation of the reference surface is 0; and the 2.7% error is caused by the 5° C shift in blown air temperature discussed in the section on temperature stability. Then, the measured result would be within the limits:

$$R_F = 0.100 \pm 0.004 \tag{12}$$

Data Acquisition Systems

<u>High Speed Data Logger</u>. Portable low power data loggers developed at the Purdue University Laboratory for Applications of Remote Sensing are being constructed for operation from all platforms, particularly for helicopter and small plane platforms. These 12 volt battery powered units operate at temperatures from 0C to 60C. All data is recorded in a 0.8 millisecond interval: Year; Day of Year; a six digit observation number; time (hour, minute and second); and a one digit data type code are recorded prior to recording the 12 bit radiometer data which is identified by a four bit channel code. Up to 15 channels of analog data may be digitized and stord.

Data is stored in a 128K byte CMOS memory module with data retention battery. The capacity of each memory module is sufficient to store the 60,000 target observations and 5000 calibration observations which are gathered in a typical helicopter mission. When full, the memory module may be disconnected and another module connected. The data logger provides a 16 bit parallel interface with handshake system suitable for many microcomputers and minicomputers. The contents of the memory may be examined on a front panel data display. In the field, the contents of the memory may be transferred to a HP 85A microcomputer for storage on the data cartridge. In the laboratory, data is entered directly to a DEC PDP 11-34 minicomputer. As well, completely portable operation may be maintained using the interface to a H.P.97S calculator which interrogates the logger to determine proper operation and may also be used to process and print the data stored in the memory.

The data logger provides complete interface to the radiometer and on command will query the "status" function mentioned above. A panel indicator responds to a "low battery" signal from the radiometer.

<u>Medium Speed Data Logger</u>. For applications where medium speed acquisition and moderate numbers of observations are required, the Omnidata International, Inc., Model 516 Polycorder is being used.[5] This unit is suitable for operation from all platforms. For 12 bit accuracy the acquisition interval is about 20 milliseconds per channel which, for the eight radiometric channels, requires 0.16 seconds. In addition to time (to 0.01 second if needed) and observation number, other information may be automatically (or manually) entered prior or subsequent to the acquisition of up to 10 channels of radiometric data. The unit memory which holds about 350 observations (depending on format), may be interrogated at its front panel.

The data logger, which is suitable for a variety of applications, is 8" x 4.5" x 3" and weighs 3.2 pounds with batteries. Interface to a cassette recorder and a standard RS-232 port are standard, built in features. Because of its versatility the unit must be programmed. This is accomplished, manually, by a prompting format which is resident in the logger. Alternatively, the logger may be programmed by a development system or an assembler resident in another computer. The manufacturer of the modular multiband radiometer will provide a special purpose version of the Polycorder equipped for turn-key operation with the radiometer.

The Polycorder provides a signal to initiate the status function in the radiometer and responds to a low battery signal from the radiometer. Data and format programs are retained up to 4 months by two sets of rechargeable batteries (8 penlight cells and one 9 volt sytle battery). Line power operation is possible using the battery charger.

Discussion

The spectral responsivity of the instrument closely matches the thematic mapper satellite scanner (with an additional band at 1.15 to 1.30 μm) and the out of band blocking is effective in all channels. Results of the radiometric tests indicate the potential use of narrow, user defined, pass bands in the range from 0.4 to 2.4 μm.

The fields-of-view are well suited to remote sensing field research. The acceptance of radiance from the well defined 15° cone enables spatial "averaging" while limiting the off-axis rays to less than 7.5°. The 1° field of view may be used for more detailed measurements from terrestail platforms or for spatial averaging from an airborne platform. Of particular importance is the absence of spurious off-axis responses, which can completely invalidate many measurements.

The Radiometric Performance is summarized in Table 2. The maximum fractional errors indicated in the table represent limits of error (not standard deviations) and it can be expected that the field performance will be well within those limits. (In the field test, the reflectances ranged from 2.9% to 48% with a maximum fractional error of less than 1% of value. In laboratory tests (25° C) the temperatures of black body targets from 12° C to 38° C were measured to within $\pm 0.3^{\circ}$ C using the simple algorithm discussed in the section on linearity. In normal field operations, the instrument is in equilibrium with the solar irradiance and the ambient air (in helicopter operations, the instrument is enclosed in a cowl) and typical time to calibration is 10 minutes. Thus, it is unlikely that a 5° C (9° F) step of blown air will be imposed for 20 minutes, but not impossible. In this event, the performance is still well suited to most field measurement applications. Futhermore, if superior accuracy is required, the response may be compensated using the detector temperature signal. This approach will be used to improve the temperature measurement algorithm for the thermal channel (which has a detector temperature coefficient of about $0.1\%/^{\circ}$ C), since the accuracy is limited by the algorithm as well as the noise.

System Performance. Using available 12 bit data loggers, the radiometer is well suited to the needs of remote sensing field researchers who require portability, spectral accuracy, well defined fields of view, appropriate dynamic range, and excellent radiometric performance in the ranges 0.4 μm to 2.5 μm and 10 μm to 15 μm.

Table 2. Summary of Radiometric and System Performance

Test	Response Range or Bandwidth Range	Detector		
		Silicon (0.4 μm - 1.0 μm)	Lead Sulfide (1.0 μm - 2.5 μm)	Lithium Tantalate (10.4 μm - 12.5 μm)
Linearity	0-100% 0-300%	0.1%< 0.2%	0.1%< 2.0%	(See Linearity)
Instability	0-100%	None	None	None
Maximum Relative Noise 10° C to 45° C	Lo Hi	0.08% @ 4 Hz 0.23% @ 20 Hz	0.08% @ 4 Hz 0.25% @ 20 Hz	0.18° C @ 0.15 Hz 0.73° C @ 1.0 Hz
Maximum Relative Error $\Delta R_F/R_F$ @ $R_F = 10\%$ 5° C step; blown air x 1 gain range; 12 bits = 5 volts	Lo Hi	1.4% @ 4 Hz 1.8% @ 20 Hz	3.8% @ 4 Hz 4.2% @ 20 Hz	(See Discussion)

ORIGINAL PAGE IS OF POOR QUALITY

Acknowledgements

The authors wish to thank Richard Juday, EOD, NASA Johnson Space Center for his assistance in defining the tests and for suggesting the sum-of-sources technique for determining linearity. This work was performed under NASA contract NAS-9-15466.

References

1. Robinson, B.F., M.E. Bauer, D.P. DeWitt, L.F. Silva, and V.C. Vanderbilt, "Multiband Radiometer for Field Research," Proceedings of the Twenty-Third Annual International Technical Symposium, SPIE, Bellington, Washington, 1979.

2. Robinson, B.F., and L.L. Biehl, "Calibration Procedures for Measurement of Reflectance Factor for Remote Sensing Field Research," Proceedings of the Twenty-Third Annual International Technical Symposium, SPIE, Bellington, Washington, 1979.

3. EG & G, "Model 590 Calibrated Lamp System," Data Sheet 5902, 35 Congress St., Salem, Massachusetts, 01970.

4. Optronic Laboratories, "One Solar Constant Standard Lamp," Bulletin B-3, 730 Central Florida Parkway, Orlando, Florida, 32809.

5. Omnidata International Inc., "Model 516 Polycorder," Operators Manual, P.O. Box 3489, Logan, Utah, 1981.