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DESCRIPTION AND OPERATION OF A FIELD RATED ERTS-BAND TRANSMISSOMETER

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Purdue University, West Lafayette, Indiana

1975

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Measurements Program

LARS-Purdue University

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ABSTRACT

This report describes a field rated instrument designed at the Laboratory for Applications of Remote Sensing (LARS), Purdue University, for the measurement of normal hemispherical transmittance at four wavelength bands: 0.5-0.6 μm, 0.6-0.7 μm, 0.7-0.8 μm, and 0.8-1.0 μm. The instrument consists of a detector system and a transmittance attachment comprised of an integrating sphere with collimator. The detection system is an Exotech Model 100 ERTS Ground Truth Radiometer which has four channels corresponding to the aforementioned spectral bands. The transmittance attachment is a 10 cm (4") diameter barium sulfate coated integrating sphere in which the detector port mates with the Exotech radiometer viewing optic for each of the four channels. A collimator, aimed at the solar disc, attached to the sphere causes the sample located at the entrance port to the integrating sphere to be irradiated normally. The ratio of the radiometer response with the sample IN to the response with the sample OUT provides a measure of the spectral normal hemispherical transmittance. Minimum sample stage aperture 3.2 mm (0.125 in) x 12.5 mm (0.50 in) permits use of the Transmissometer on small leafed vegetation. Preliminary performance data using glass filters and perforated screens plus typical results on two varieties of wheat leaves are presented. The principle of measurement permits direct comparison of field results with a laboratory spectrophotometer such as the Beckman DK-2A Spectrophotometer with integrating sphere attachment.

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EXOTECH/ERTS-BAND TRANSMISSOMETER

1. INTRODUCTION

This report describes a field rated instrument for the measurement of normal-hemispherical transmittance of small vegetation (leaves) at the four wavelength intervals which spectrally match the Earth Resources Technology Satellite (ERTS/LANDSAT) Multispectral Scanner (MSS).

The objectives in the design of the Transmissometer are first discussed. The measurement technique is described in sufficient detail to provide the experimenter with an appreciation of the advantages and limitations of the Transmissometer. Care has been taken in the design of the instrument to assure that the field measurement results will be properly comparable with conventional laboratory spectrophotometers normally available to remote sensing workers.

A complete description of the Transmissometer is presented, including schematics of the integrating sphere attachment with the solar collimator. Specifications of spectral wavelength intervals, sample aperture dimensions, and other essential features are tabulated for easy reference. Technical details on the detector system--Exotech ERTS Ground Truth Radiometer, Model 100--are briefly summarized, while the manufacturer's brochure is included as an appendix for a more complete treatment.

One of the purposes of this report is to serve as Instruction Manual for the Transmissometer. Operating procedures developed from the field and evaluation experiences at LARS are provided for the experimenter. Results of these experiences treating measurements on selected glass filter transmittance standards and perforated screens are summarized and discussed.

Typical measurements on two wheat leaf varieties are presented only to indicate the typical range of spectral transmittance values to be expected for green vegetation.

The final section of the report contains some precautionary notes as well as information on the applicability of the Transmissometer to field research in remote sensing.

2. DESIGN OBJECTIVES

The rationale for design of the instrument to provide the spectral transmittance field measurements of vegetation samples was based upon the following objectives:

i. The measured transmittance values should be obtained by a method that is directly and properly comparable with conventional laboratory spectrophotometers operating in the transmittance mode. It was especially desired to have the technique comparable with the Beckman DK-2A spectrophotometer with Integrating Sphere Reflectance Attachment. Other commercial spectrophotometers--such as the Cary 14--with proper accessories can also generate comparable results. Thus the instrument should measure spectral transmittance under the following geometric conditions: incident--normal collimated irradiation; viewed--hemispherically collected (sample) after the incident flux passes through the sample.

ii. The radiation falling on natural scenes contains a component due to direct sunlight and a component due to scattered sunlight (skylight). On reasonably clear days the intensity of the skylight (in the spectral bands of interest) can approach 15% of the intensity of the total radiation incident on a horizontal surface. Therefore, it is necessary to allow only the direct sunlight to fall on the sample.

iii. The instrument should provide measurements on small area samples, particularly slender elongated shaped leaves, typified by wheat.

3. PRINCIPLE OF THE MEASUREMENT TECHNIQUE

The Transmissometer is designed to measure the normal-hemispherical transmittance averaged over the spectral region corresponding to the band pass of the active channel of the ERTS Ground Truth Radiometer. The transmittance is defined as the ratio of the transmitted flux, ϕ_t, to the incident flux, ϕ_i, (solar irradiation), under prescribed geometric conditions and spectral conditions; that is,

$$\tau(0°,2\pi;\overline{\lambda}) = \phi_t(\overline{\lambda})/\phi_i(\overline{\lambda}) \qquad [1]$$

The geometric conditions for this Transmissometer signify that the sample is irradiated by a collimated source (the solar disc) and the flux transmitted through the leaf is hemispherically collected. It is important to recognize these geometric conditions when attempting to compare Transmissometer measurements with other instruments.

The spectral conditions for which the transmittance is measured depends upon the spectral distribution of the irradiating source (the solar disc) and the spectral responsivity of the detector system. The latter corresponds to the spectral characteristics of the Exotech ERTS Ground Truth Radiometer channels which have been designed to spectrally match the four spectral band of the ERTS-MSS. If it is desired to compare the Transmissometer results--averaged over a specified wavelength interval and denoted by $\overline{\lambda}$--with truly spectral transmittance values generated from the Beckman DK-2 Spectrophotometer with Integrating Sphere Reflectance attachment, it is necessary to perform this calculation:

$$\tau_c(0°,2\pi;\bar{\lambda}) = \frac{\int_{\lambda_1}^{\lambda_2} \tau(0,2\pi;\lambda)R(\lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2} R(\lambda)d\lambda} \qquad [2]$$

where $\tau_c(0°,2\pi;\bar{\lambda}_i)$ = calculated transmittance averaged over the wavelength interval λ_1 to λ_2 or represented by the averaged value $\bar{\lambda}_i$ where i corresponds to one of the four channels of the ERTS Radiometer

$\tau(0°,2\pi;\lambda)$ = measured spectral transmittance (with resolution 5 or 10 nm) by laboratory type spectrophotometer

$R(\lambda)$ = spectral responsivity of the ERTS Radiometer system over the wavelength interval λ_1 to λ_2.*

If the spectral transmittance, $\tau(\lambda)$, is monotonous over the interval λ_1 to λ_2, then of course the integration is not necessary and the spectrophotometer results and the Transmissometer are directly comparable.

4. DESCRIPTION OF THE TRANSMISSOMETER

(1) General Features

Figure 1 presents a series of photographs showing the two major systems of the Transmissometer--the Detector System and the Transmittance Attachment--separately and assembled for operation.

The technical details of the detector system, Exotech ERTS Radiometer, as provided in the manufacturer's brochure are presented in Appendix A. When operating with the Integrating Sphere Attachment in position, the signal output for that one channel no longer corresponds to the spectral irradiance

*See "Relative Response Curves" for the Radiometer in Appendix A.

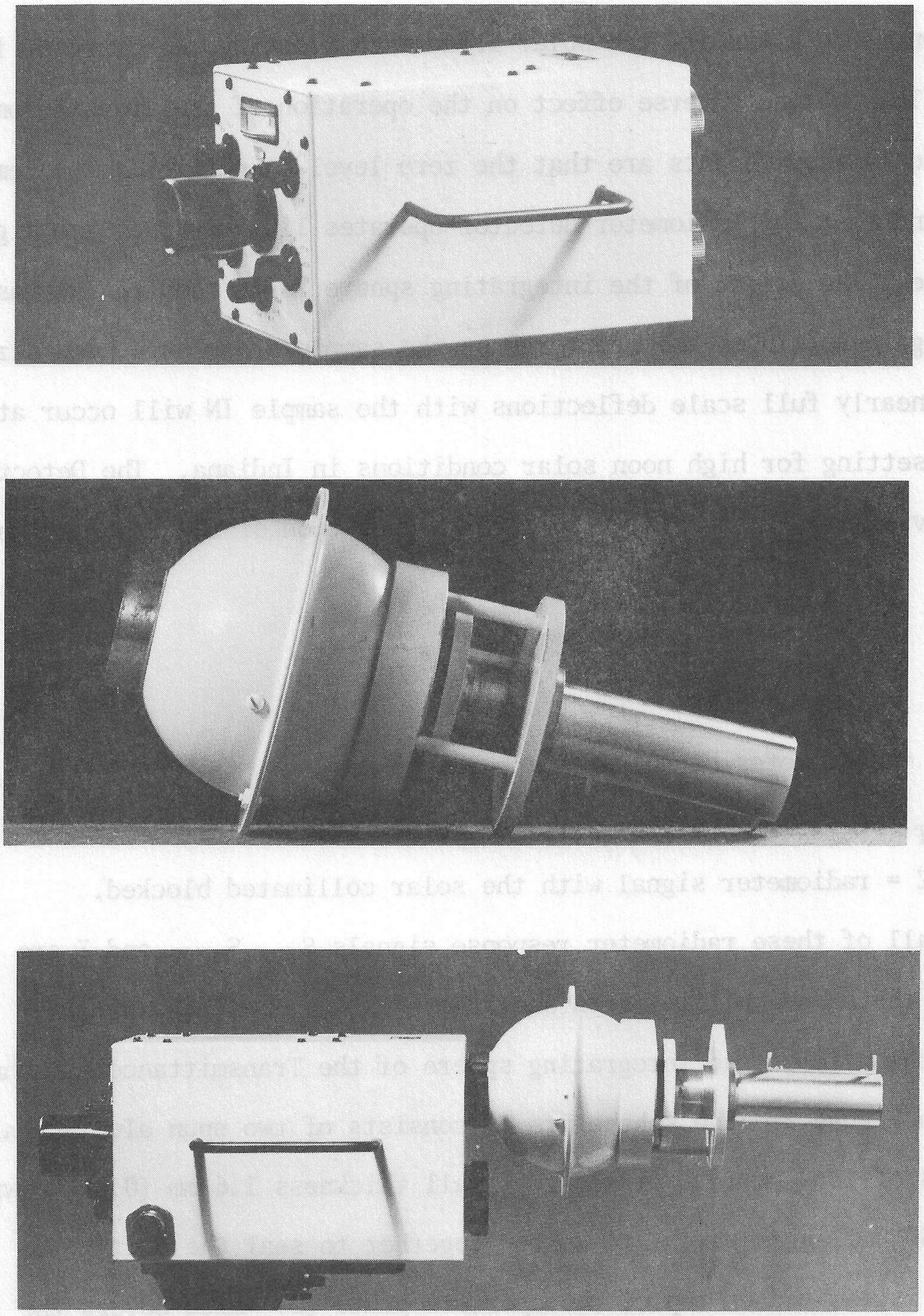


Figure 1. Photographs of the Transmissometer: (a) Exotech ERTS Ground Truth Radiometer, Model 100--The Detector System; (b) Integrating Sphere Attachment with Solar Collimator; (c) Transmissometer in Operating Configuration.

calibration curve provided with the instrument. That is, the effect of the integration is to attenuate the solar irradiance reaching the detector for the channel. This has no adverse effect on the operation of the Transmissometer since the only requirements are that the zero level (amplifier zero) remains constant and that the Radiometer detector operates linearly over the signal level range. The effect of the integrating sphere is to require increased amplifier gain settings; the apertures on the sample stage have been sized such that nearly full scale deflections with the sample IN will occur at the 125X gain setting for high noon solar conditions in Indiana. The Detection System provides three signals which allow computation of the transmittance:

$$\tau(0°, 2\pi; \bar{\lambda}_i) = \frac{S_{IN} - Z}{S_{OUT} - Z} \qquad [3]$$

where S_{IN} = radiometer signal with the sample IN,

S_{OUT} = radiometer signal with the sample OUT,

Z = radiometer signal with the solar collimated blocked.

Note that all of these radiometer response signals S_{IN}, S_{OUT}, and Z are taken with the same amplifier gain settings.

The schematic of the integrating sphere of the Transmittance Attachment is shown in Figure 2. The sphere itself consists of two spun aluminum alloy hemispheres of 10.2 cm (4") diameter of wall thickness 1.6 mm (0.062") with 1.3 cm (0.50") flanges which are bolted together to seal the unit. The sample (1) is located on top of the aperture plate (2) which covers the entrance port (3); various sized apertures as indicated in the Specifications, Table 1, are available to accomodate different solar irradiance levels and sample geometries. The solar collimator shown in a later figure causes the sample to be irradiated by collimated flux normal to the sample plane.

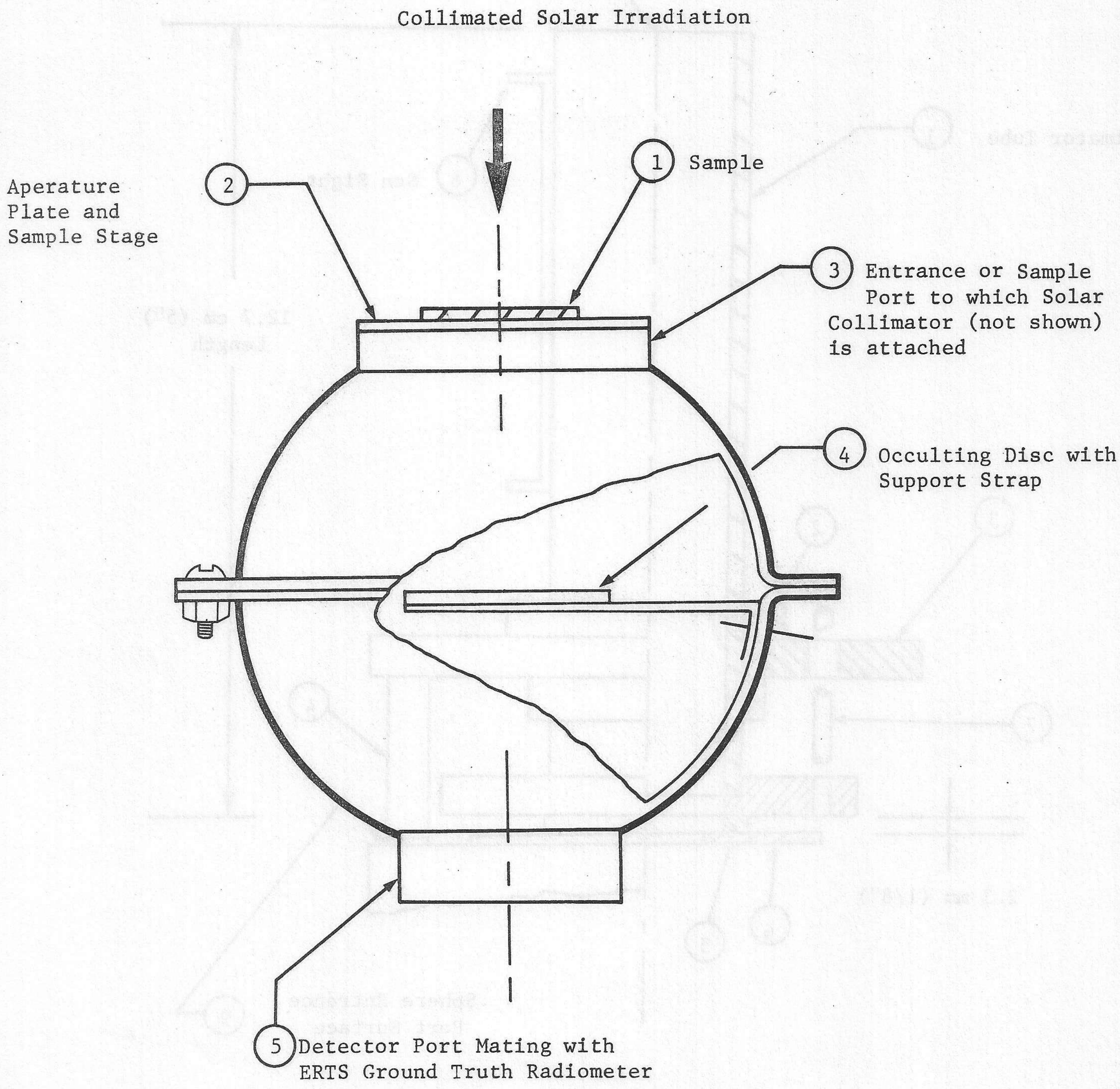


Figure 2. Schematic of the Transmissometer Integrating Sphere.

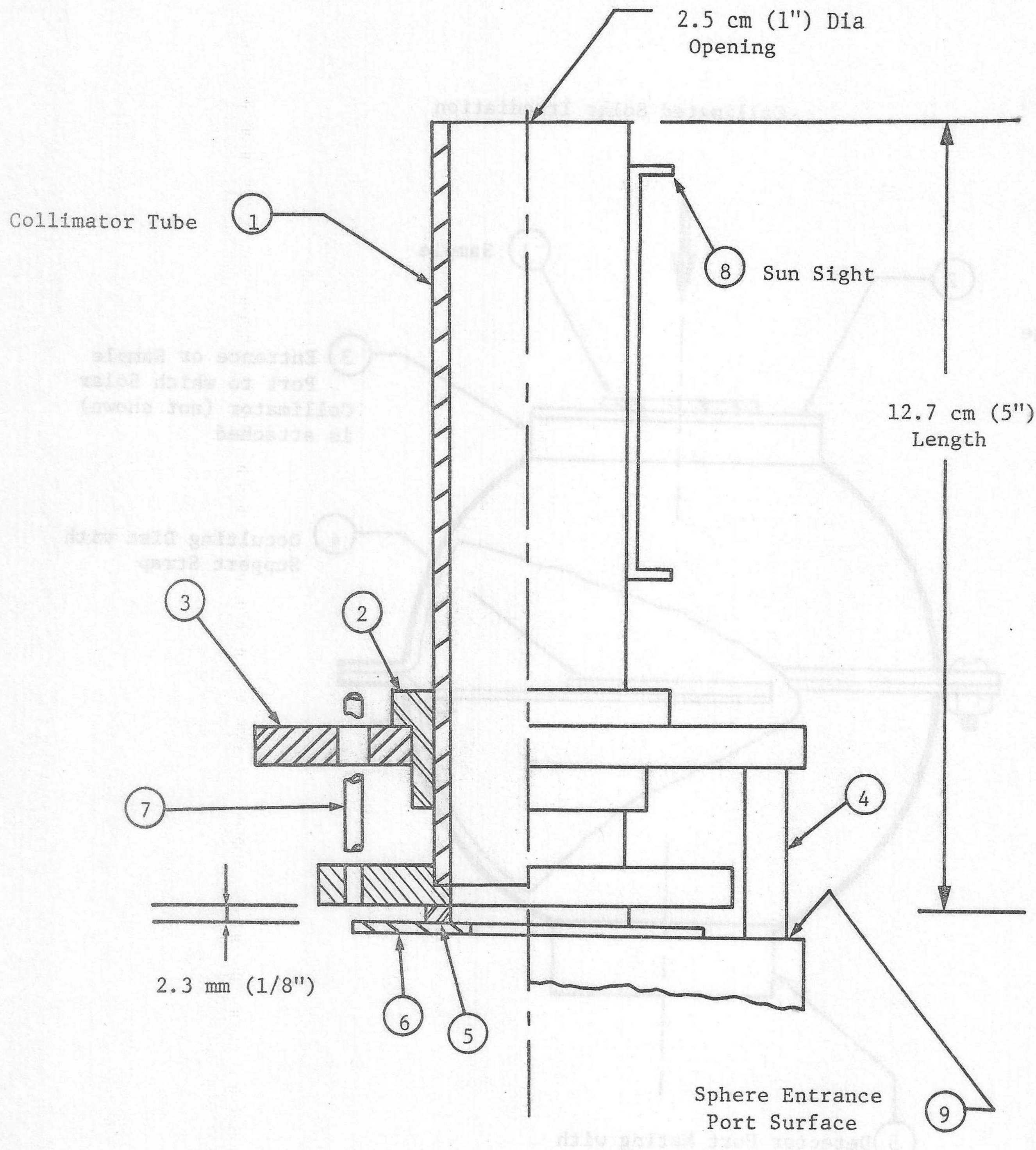


Figure 3. Solar Collimator Attachment to the Integrating Sphere Entrance Port Surface.

In the center of the sphere an occulting disc (4) of 2.54 cm (1") diameter, the transmitted flux (if the sample is IN) or the incident flux (if the sample is OUT) passing through the entrance port from falling directly on the detector at the detector port (5) which is located in a diametrically opposite position on the sphere. The optical function of the occulting plate is to insure that the detector will be insensitive to the degree of diffuseness of the flux passing through the entrance port. That is, the flux reaching the sphere entrance port is hemispherically collected in the proper manner. The inner sphere walls and occulting plate are coated with a barium sulfate paint.

The Solar Collimator attachment to the integrating sphere entrance port is shown schematically in Figure 3. The collimator tube (1) has a length-to-diameter ratio, 5 to 1; the inner diameter is threaded and painted black in order to increase its effectiveness. The collimator tube can slide in the brass sleeve bearing (2) afixed to the disc (3) which in turn is fastened to the entrance port surface by three standoffs (4). A soft rubber gasket (5) is adhesived to the flange of the collimator tube to serve as a light seal over the sample resting on the aperture plate (6). The guide rod (7) prevents the collimator tube from rotating. The sun sight (8) aligned axially with the collimator is used to align the Transmissometer directly with the solar disk.

(2) Specifications

The specifications for the Transmissometer are summarized in Table 1. Further technical specifications of the detector systems are provided in Appendix A.

Table 1. Specifications of the Transmissometer

Property Measured	Normal-hemispherical transmittance averaged over spectral bands specified
Spectral Bands	Four channels reproducing the ERTS MSS band passes

Channel No.	Wavelength Interval
1	0.5 - 0.6 μm
2	0.6 - 0.7
3	0.7 - 0.8
4	0.8 - 1.1

Sample Size	Various sized aperture plates control area of the sample measured and level of irradiation reaching detector system

Aperture	Size (Width×Length)
A	3.17×22.0 mm (0.125×0.866 in)
B	3.17×19.9 mm (0.125×0.783 in)
C	4.75×15.3 mm (0.187×0.602 in)
D	4.75×18.1 mm (0.187×0.713 in)

Detection System	Exotech ERTS Ground Truth Radiometer, Model 100
Integrating Sphere	Barium sulfate coated 10.2 cm (4") diameter aluminum spun hemispheres; entrance and detector ports located in diametrically opposed positions; occulting plate prevents direct radiation exchange between the two ports

5. OPERATING PROCEDURES

For best results it is recommended that the following steps be observed in order to properly operate the Transmissometer:

(1) Outfit each channel of the Exotech Model 100A with its 15° FOV optic. Do not allow 3/4° FOV optics to remain on unused channels.

(2) Mount the Radiometer on a tripod and turn the instrument on. Set gain settings to X125. Allow 5 minutes for warm-up. If external voltmeter is used, it may be desirable to turn it on at this time.

(3) Mount the transmissometer attachment on the channel 1 optic.

(4) Adjust the tripod so that the instrument is pointed toward the sun. The instrument will be pointed at the sun when the image of the sun falls on the lower spot of the sun sighting device.

(5) Connect metering cable to the signal output jack and set channel selecting device to channel 1; note reading. Meter reading should be similar to the readings presented in the Typical Results section.

(6) a. Insert the zero transmittance strip and allow the collimator sample holder to press the strip firmly over the slit. The slit should be completely covered by the strip. Record the output voltage. This is the voltage offset of the system, Z.

b. Insert sample and allow the collimator sample holder to press the sample firmly over the slit. The slit should be completely covered by the sample.

c. Ensure that the instrument is pointed at the sun.

d. Record the voltage output, S_{IN}, of channel 1.

e. Remove the sample (as quickly as feasible).

f. Allow the collimator sample holder to reset firmly.

g. Record the voltage output, S_{OUT}, of channel 1.

(7) Steps b through g of (6) above may be repeated for other samples or for other channels on the radiometer. Moving the transmittance attachment repeatedly may be more efficient than measuring each leaf on a given channel, then moving to a new channel. Speed is important.

(8) Step a of (6) above may be repeated occasionally.

(9) Just a reminder to turn the Model 100 A off when the data taking is complete.

6. TYPICAL RESULTS

(1) Transmittance Standards

In order to evaluate the performance of the Transmissometer a series of measurements were made on interference film type glass filters, Optics Technology Model 100, and perforated metal screens, Perforated Products Type 100. The nominal transmittance values of these spectrally flat filters were supplied by the vendors and have not as yet been confirmed by an independent LARS measurement.

Table 2 presents a summary of the measurements. For these tests the Transmissometer was operated with aperture C and at a gain setting of 125X. The radiometer output was recorded on a Fluke Model 8100A digital voltmeter.

The results for the perforated screens are consistent within 0.5% transmittance units for the four channels. The advantage of using these neutral screens is their spectral flatness and ruggedness which make them most useful for field use in periodically checking Transmissometer performance. The transmittance values of the screens in the second column--supplied by the manufacturer--can only be considered as nominal values and no detailed inferences should be drawn between these values and those measured by the Transmissometer.

The results using the glass filters were quite satisfactory for the 5, 25 and 50% transmittance levels and give an excellent check on the accuracy of the Transmissometer. For the range of transmittance values, 5 to 50%, this data would indicate the transmissometer has an accuracy in the range of ± 1%. No firm explanation is available for the very poor performance with the 80% glass filter, Trial #4. It is believed that this can be due to an interaction between the filter itself and the occulting plate. A systematic study in which the aperture sizes are varied would probably clarify this situation. However, for use on vegetation, transmittance values greater than 50% in this wavelength range are not anticipated and the Transmissometer can be used with confidence drawn from the favorable comparisons in Table 2.

(2) Wheat Sample Leaves

In order to gain experience in the field operation of the Transmissometer, a series of measurements reported in Table 3 were made on two varieties of winter wheat (10 May 1975) at the Purdue Agronomy Farm. The intent of the testing did not include characterization of the wheat leaves so at best the reported data can only be considered as representative of healthy green vegetation.

Table 2. Transmissometer Performance Evaluation--
Transmittance Standards

Trial	Filter		Ch 1	Ch 2	Ch 3	Ch 4
			Channel Values--S_{OUT}, S_{IN}, τ [1]			
---	Amplifier Zero Offset, Z [2]		0.00	0.02	0.01	0.02
Perforated Screens [3]						
1	9.1%	(S_{OUT})	2.68	3.49	2.52	3.62
		(S_{IN})	0.25	0.34	0.25	0.39
		(τ)	9.3	9.3	9.6	10.3
2	22.5		2.68	3.50	2.51	3.61
			0.71	0.96	0.70	1.03
			26.4	27.0	27.6	28.1
3	47.8		2.67	3.48	2.52	3.61
			1.36	1.79	1.29	1.85
			50.9	51.0	50.9	50.9
Glass Filters						
4	80		2.66	3.47	2.51	3.61
			2.41	3.11	2.20	3.10
			90.6	89.6	87.6	85.8
5	50		2.66	----	----	----
			1.36			
			51.0	----	----	----
6	25		2.38	----	----	----
			0.61			
			25.6	----	----	----
7	5		2.39	----	----	----
			0.12	----	----	----
			5.0	----	----	----

[1] S_{OUT}--sample OUT position and S_{IN}--sample IN position are radiometer response measured in volts; $\tau = (S_{IN} - Z)/(S_{OUT} - z)\times 100$. See Eq. [3].

[2] The stability of the Exotech Radiometer is sufficiently good that the zero signal level, Z, need only be periodically checked.

[3] Screens used with dull side facing incident beam.

Table 3. Representative Transmittance Measurements on Two Wheat Varieties

		Channel Values*--S_{OUT}, S_{IN}, τ			
<u>Wheat Variety</u>		Ch 1	Ch 2	Ch 3	Ch 4
Amplifier Zero Offset, Z		0.00	0.00	0.00	0.00
6941A3-4	(S_{OUT})	2.87	3.67	2.72	3.94
	(S_{IN})	0.59	0.55	1.47	2.64
	(τ)	20.6	15.0	54.0	67.0
Arthur		2.90	3.69	2.71	3.94
		0.39	0.36	1.35	2.54
		13.4	9.8	49.8	64.5

* See Footnotes 1 and 2 on Table 2.

Appendix A

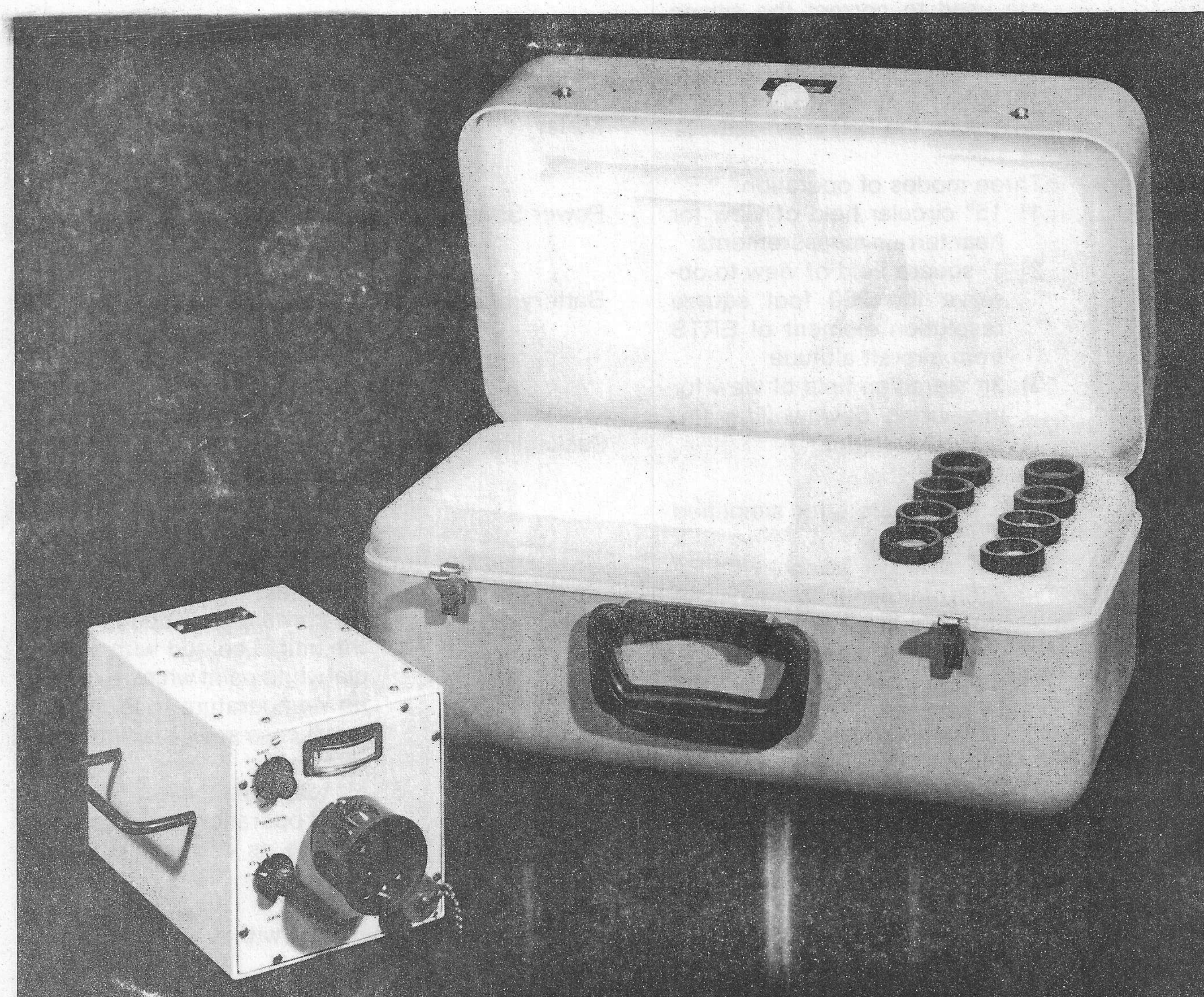
Technical Data

ERTS Ground Truth Radiometer

Model 100

Exotech Incorporated
1200 Quince Orchard Boulevard
Gaithersburg, Maryland 20760
301 948-3060
TWX 710-828-9746

Technical Data
ERTS Ground Truth Radiometer Model 100



The Model 100 is specially designed to supply an ERTS experimenter with either airborne or manually obtained Ground Truth data which matches spatially and spectrally the ERTS Multi Spectral Scanner (MSS) data. The instrument uses the four spectral filters employed in the spacecraft system to provide four simultaneous channels of accurately calibrated radiometric data of both downwelling (incident) and reflected radiation. The Model 100 system was designed by personnel who have extensive experience in remote field measurements and embodies the concepts of ruggedness and simplicity in a portable, precision instrument.

Detailed Description

Spectral Bands — Four channels reproducing the ERTS MSS bandpasses (0.5 to 0.6 microns; 0.6 to 0.7 microns; 0.7 to 0.8 microns; and 0.8 to 1.1 microns). Glass absorption filters are used to correct the silicon detectors to simulate the ERTS photomultiplier response curves. Thin film filters are then added to reproduce the ERTS bandpasses.

Field of View — Three modes of operation:
1) 15° circular field of view for near terrain measurements
2) 1° square field of view to observe the 260 foot square resolution element of ERTS from aircraft altitude
3) 2π steradian field of view for measuring downwelling (incident) radiation.

Controls — Only two controls for simplified field use.
1) Six position switch ("OFF," each of the four channels and "Battery Check" for display on the instrument meter)
2) Selector switch for Gain x1, x5, and x25.

Calibration — Each instrument is calibrated using precision light sources traceable to NBS standards. The instrument sensitivity is

gain x1=10 milliwatts/cm^2 full scale
gain x5=2 milliwatts/cm^2 full scale
gain x25=.4 milliwatts/cm^2 full scale.

Other gains available under special order.

Outputs — Four independent low impedance (1000 ohm), high level (5 volts full scale) outputs. Case isolation provided. May be shorted to ground or each other without damage to instrument. Electrical bandpass of 0-500 Hz ensures high data rate capability with low noise operation.

Sight — Precision 1.0 power, erect image scope with 15° field of view. Still and movie photography of the target area can be accomplished through this sight.

Co-alignment — All channels and the sighting scope are co-aligned.

Meter — Precision meter monitors four channels and battery condition.

Power Source — Burgess/Mallory 303314 replaceable battery.

Battery Life — 100 hours. Below -15 C° battery life is shortened considerably. An external 9V power source may be used.

Packaging —
1) The meter, controls and connector are all located on the rear panel. Adequate eye relief for the sight permits simultaneous sighting and reading of the meter.
2) All corners are rounded and the unit is coated with a special white paint which exhibits *no* temperature rise under worst case solar loading conditions.
3) Handles are located for one hand operation and sighting, as well as carrying convenience.

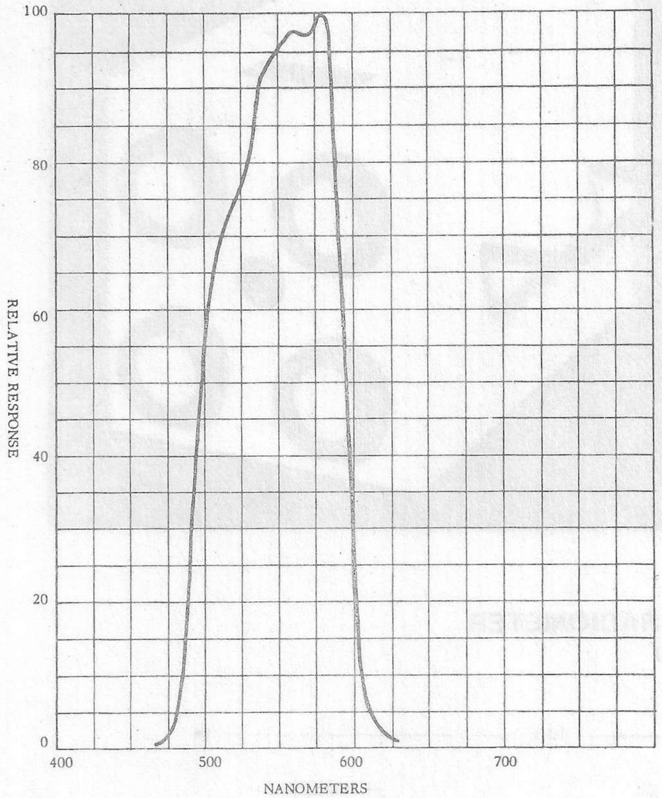
Environmental Conditions — Operable within specifications over
1) −20°C to +50°C
2) 0-95% relative humidity
3) shock and vibration as typical in the field and aircraft environments
4) 0 to 100,000 feet altitude.

Mounting — Standard 1/4 - 20 tapped hole for tripod, etc. or for use with an airborne scanner accessory.

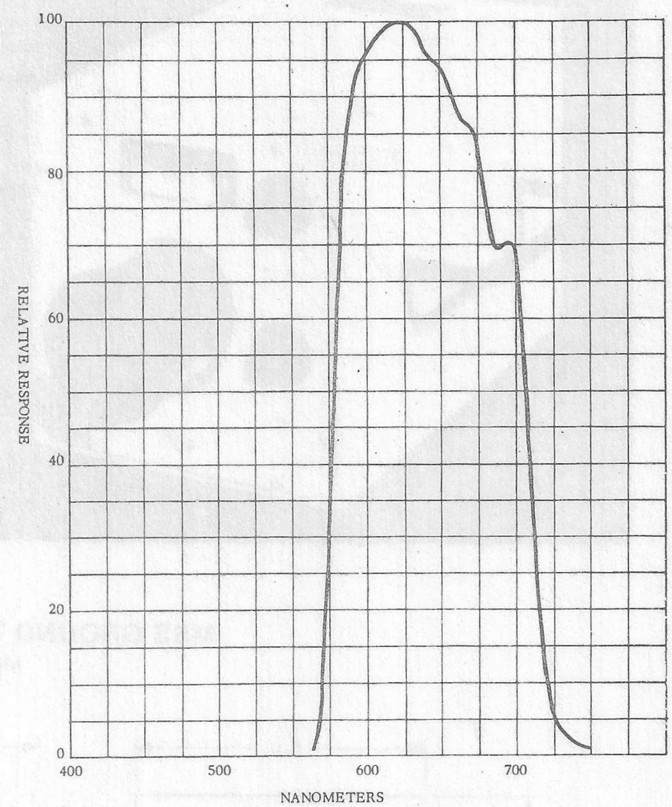
Size — 5" x 5" x 8 1/2"

Weight — Approximately five (5) pounds with battery.

RELATIVE RESPONSE CURVES



CHANNEL # 1



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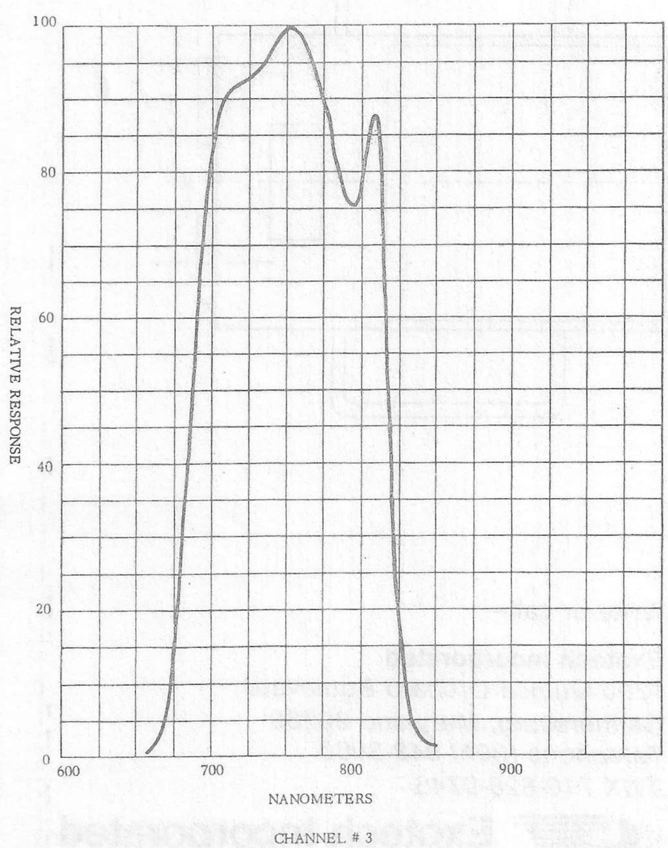

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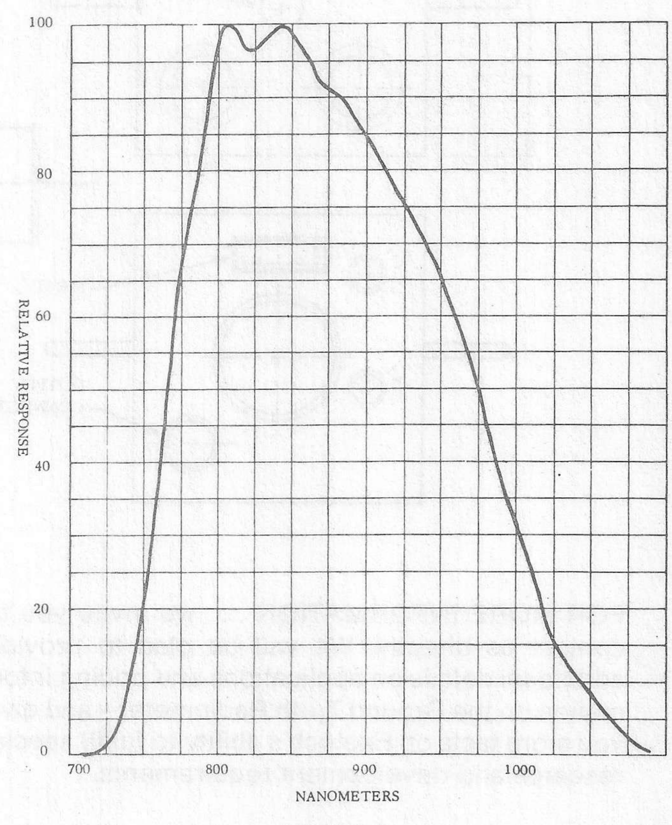

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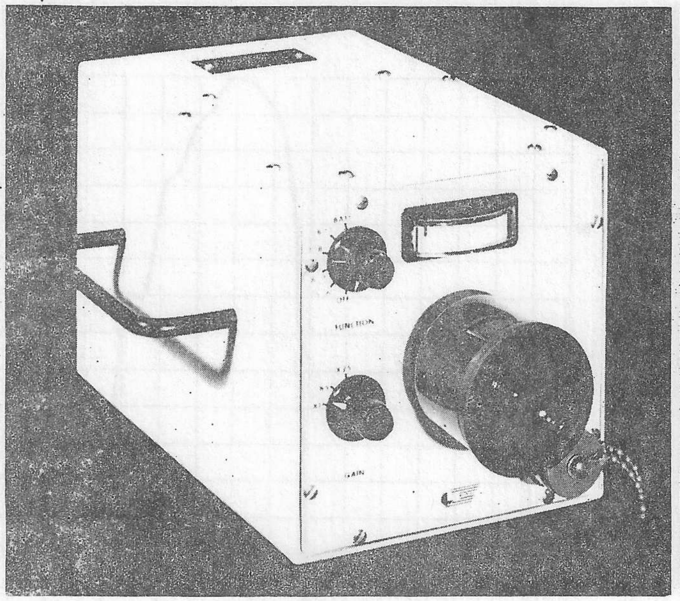
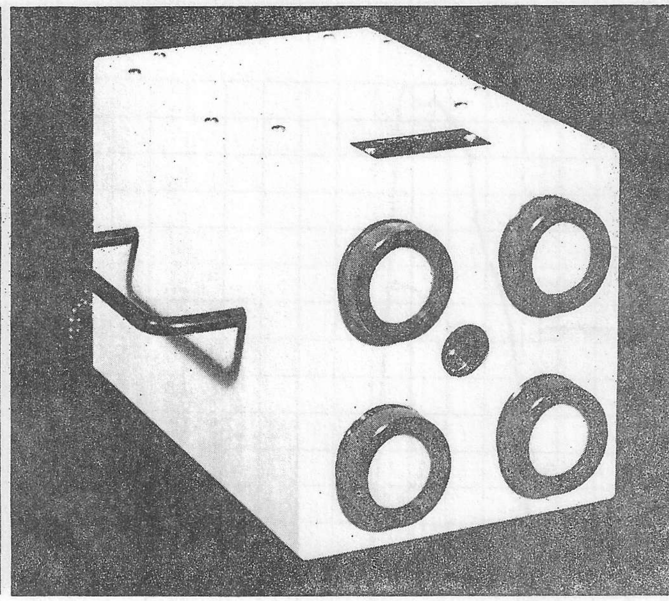
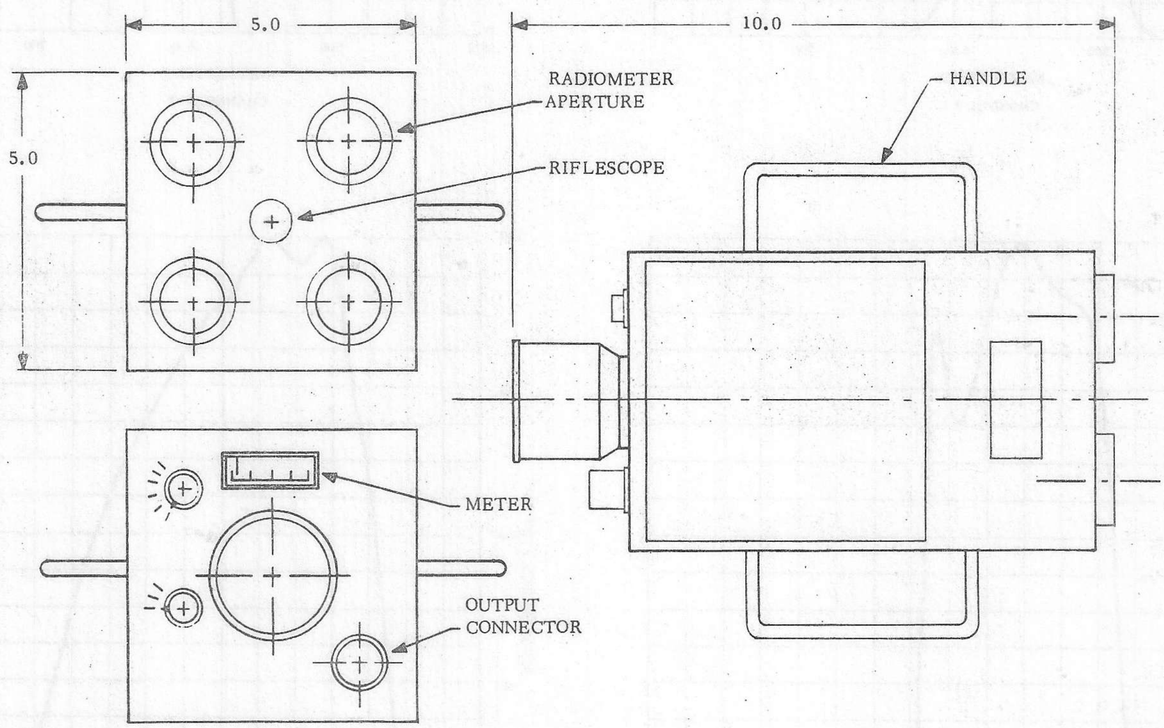




MSS GROUND TRUTH RADIOMETER

MODEL 100



FOR MORE INFORMATION . . . we invite you to contact us directly. We will be glad to provide additional details on applications and pricing information on the Ground Truth Radiometer—and give you more facts on Exotech's ability to fulfill special research and development requirements.

Write or call—

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