RESEARCH REPORT

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RELATIVE SPECTRAL RESPONSE OF PHOTODETECTORS

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INTRODUCTION

The possible applications of a photodetector are subject to a number of factors. One of these is the detector sensitivity determined by the smallest input signal necessary to produce a useful output signal. As a rule, photodetectors do not respond with the same efficiency to radiation of all wavelengths. For this reason it is important to know the extent to which a given detector varies with the wavelength of the incident radiation. This variation is known as the spectral response of the detector.

Standard procedures for studying the properties of photodetectors have been published (References 1 and 2). The following report describes the instrumentation and procedures used to determine the relative spectral response of a detector to visible and near infrared radiation.

THEORY

Photon detectors are commonly defined in terms of a number of characteristics (Reference 3). The most significant of these are: the noise equivalent power (NEP), the noise equivalent input (NEI), the detectivity, D* (D-star), D** (D-double-star), the quantum efficiency, and the responsivity. Other factors which must be considered in the choice of a detector are: the time constant, the effect of operating frequency, and the spectral range over which it may be used.

This report deals with the relative spectral response of a detector. "The responsivity of a detector is defined as the output signal per unit input signal" (Reference 3) and thus has the dimensions of "volts per watt". Given an accurate voltmeter, it is a simple problem to measure the output of a detector. On the other hand it is much more difficult to determine the energy input into the same detector since it is necessary to have a standard source having an accurately known intensity and angular distribution. Assuming that this is known and that the dimensions and field of view of the detector are known, it is possible to determine the power incident on the detector and hence its responsivity. In order to determine the spectral response, the detector should receive a known amount of energy in a very narrow spectral range. An alternative would be to compare the spectral response of a detector with that of a detector of known spectral response when both receive the same energy in a narrow spectral range.

In contrast, it is a much simpler problem to determine the relative spectral response of a detector. Assuming that one has a "black" reference detector, that is, a detector having a response independent of wavelength, the outputs of the reference detector and of the unknown detector for the same energy input in a very narrow spectral range may be determined. These measurements should be made at frequent intervals over the wavelength range of interest. The ratio of the output of the unknown detector to that of the reference detector should be determined for each interval, and then normalized to unity at the wavelength at which the detector has its maximum response. An alternative would be to use a reference detector which is not "black" over the whole wavelength range of interest, but has a known spectral response, and calculate the corresponding ratios for a black detector.

INSTRUMENTATION

The optical system combines a Perkin-Elmer Double-Pass Monochromator, Model 99, with a beam splitter (dual beam chopper). The dual beam chopper consists of two two-sector chopper blades (see figure 1, M_8 and M_9) designed to be driven by a common synchronous motor operating at a speed which gives a 13 Hz output signal from each chopper blade. Both sectors of each chopper blade are covered by matching front-surfaced aluminum mirrors. The location and synchroniztion of the two blades are designed to divide the beam received from the reimaging optics (figure 1, M_6 and M_7) into two beams of equal intensity making 120^o with each other and with the incident beam.

Radiation from a mercury-xenon arc or from a globar is focussed on the entrance slit of the double-pass monochromator (see figure 2). After the second pass through the optical system of the monochromator, the radiation in a predetermined narrow spectral band, dependent on the monochromator drum setting and slit width, is focussed on the exit slit of the monochromator. This emerging beam is collected by the reimaging optics (figure 1) and directed toward the beam splitter (dual beam chopper). The beam splitter then sends one of the two beams to the reference detector (thermocouple), and the second one to the detector which is to be calibrated.

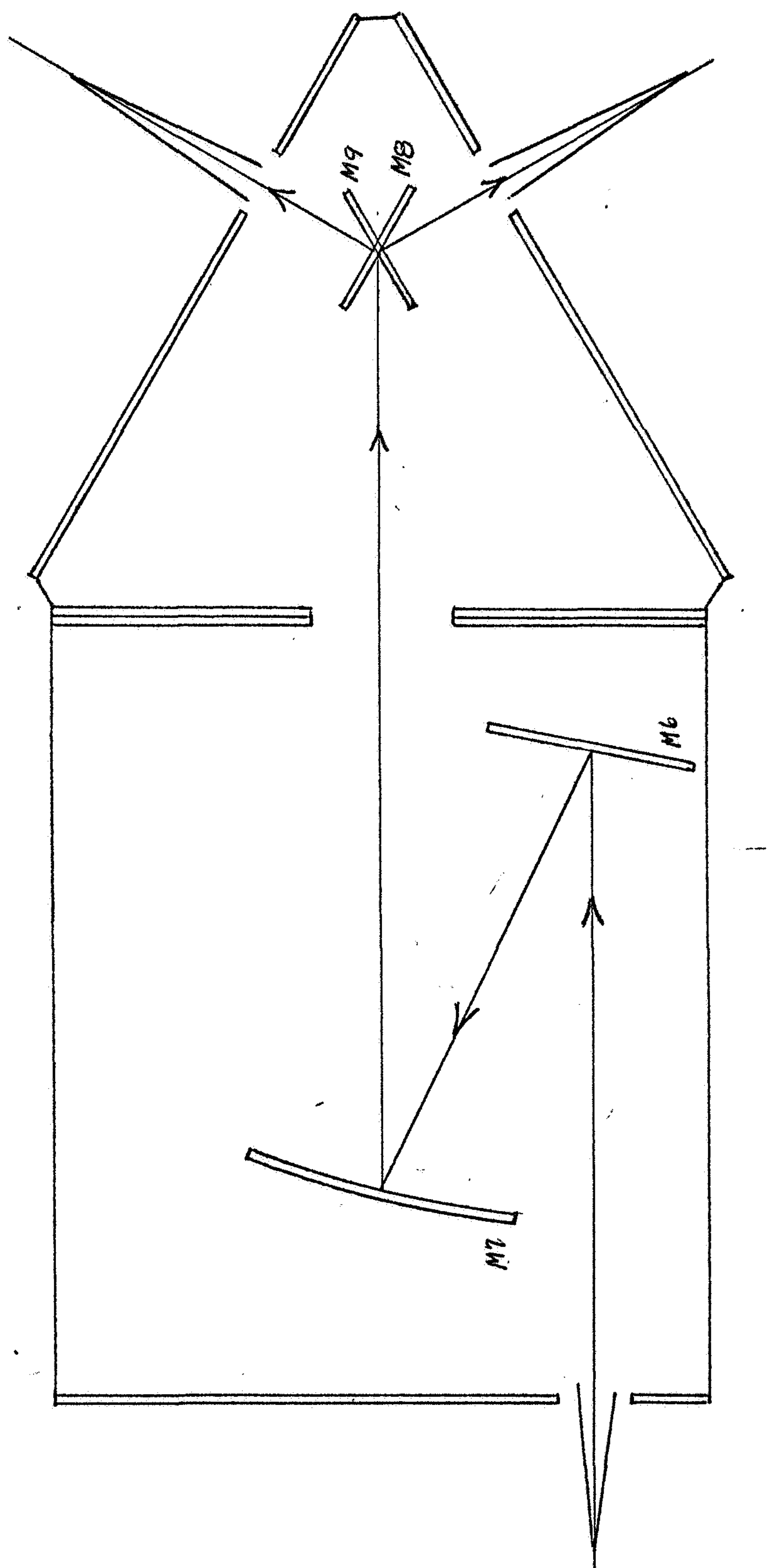


Figure 1. Reimaging Optics and Beam Splitter

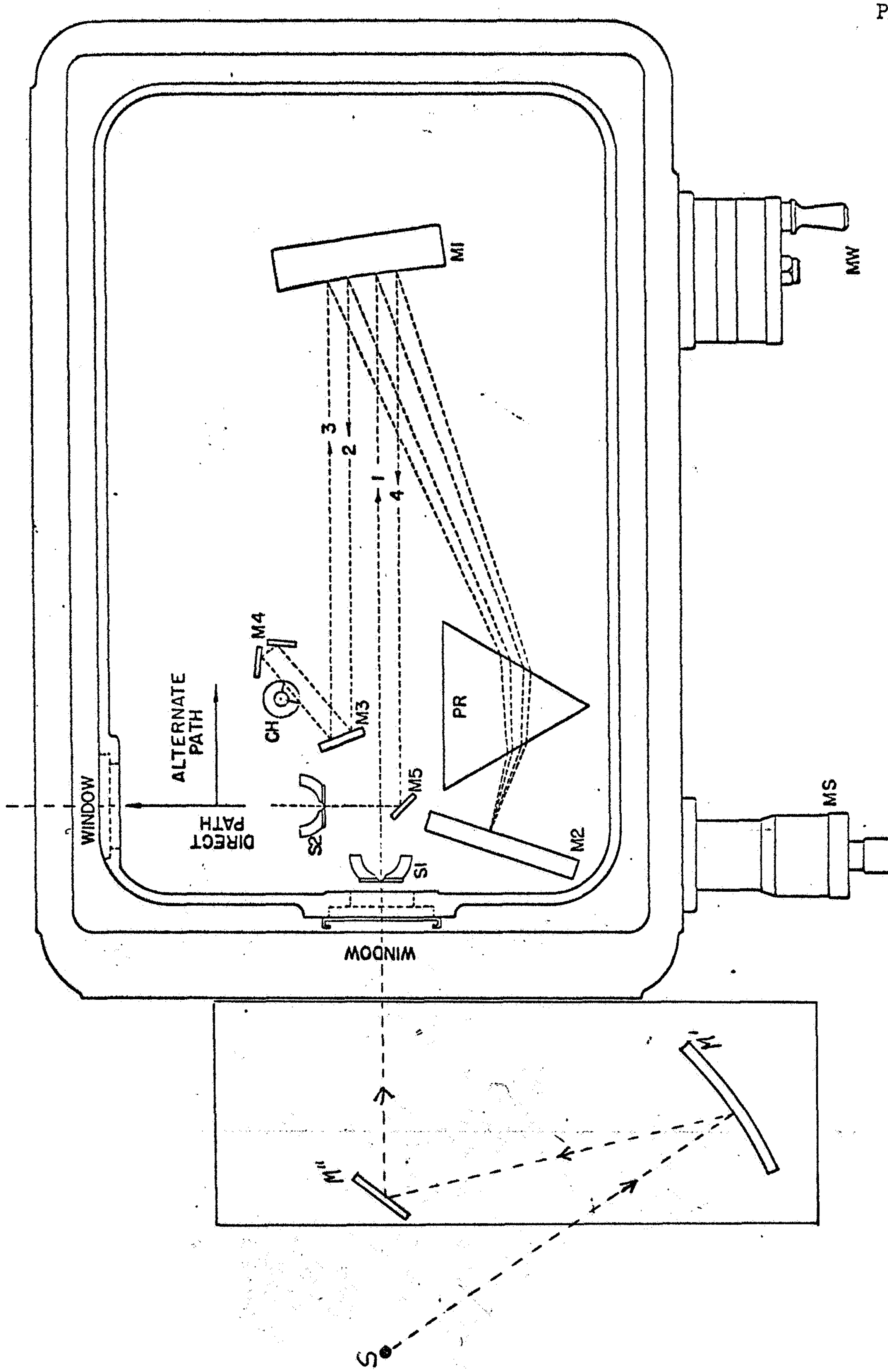


Figure 2. Optical Arrangement of the Monochromator

The signal from the reference thermocouple is fed, by way of a remote preamplifier, into a narrow bandpass A. C. amplifier and voltmeter. This meter locks its center frequency to the signal of interest. Since the radiation from the beam splitter is modulated at 13 Hz, and the lock-in meter is triggered by the same modulator, a high degree of noise rejection is achieved by this voltmeter. After the signal has been rectified by the voltmeter, the output from the reference thermocouple may be read directly on one of the twenty-four full-scale ranges of the read-out meter. Simultaneously a D. C. voltage appears on a pair of binding posts providing an output of 10 volts for full scale meter deflection regardless of the range used.

Similarly, the signal from the detector under study is fed into a second, but identical lock-in voltmeter. Thus the output of the unknown detector may be read on the appropriate range of this meter. In addition, a corresponding D. C. signal appears on the 0-10 volt outlet.

The D. C. output from each of the two lock-in meters is fed into a ratiometer. This meter has been designed to automatically ratio the outputs of the two lock-in voltmeters. This is possible if the reference input is between 0.1 and 10 volts and the ratio between the two inputs is between 0 and 1. This ratio may be read directly on a three-range meter calibrated to give the ratio of two incoming D. C. voltages.

EXPERIMENTAL PROCEDURE

In order to use the monochromator over the wavelength range 0.3 micron to 4.7 microns, it was necessary to make the following changes in the optics and the reference detector: In the range 0.3 micron to 1.0 micron a quartz prism was used in the monochromator and a reference detector with a quartz window was used to monitor the beam. In the range 1.0 micron to 2.0 microns, a quartz prism was used in the monochromator, while the reference thermocouple with a quartz window was replaced by one with a CsI window. Finally, in the range 2.0 microns to 4.7 microns, a rock salt prism was used in the monochromator, while the beam was monitored by means of a reference thermocouple with a CsI window.

Initially the optical system was aligned with care in order to obtain a maximum output signal from the detectors. In order to obtain radiation in a narrow spectral band, the wavelength drum of the monochromator was set so that a known spectral band was focussed on the exit slit of the monochromator. Similar drum settings were made every tenth of a micron or less from 0.3 micron to 4.7 microns.

The radiation from the exit slit of the monochromator, for a given wavelength setting, was refocussed by the reimaging optics and divided into two beams of equal intensity. The two beams were received respectively by the reference detector and by the detector being studied.

The output signal from each detector, corresponding to a given wavelength, was monitored by means of its lock-in voltmeter tuned to 13 Hz. The signals from the two lock-in voltmeters were then ratioed by the ratiometer. The resulting apparent ratio as well as the scale range of both meters were recorded. This was repeated at each drum setting.

As a rule the spectral response of the unknown detector is different from that of the reference detector. This means that it may be necessary to change the meter range of one lock-in voltmeter but not of the other. Hence the ratio given by the ratiometer is an apparent one which must be corrected for any change in meter range. Thus the corrected ratio is equal to the product of the apparent ratio times the range of meter A divided by the range of meter B, where meter A monitors the unknown detector and meter B monitors the reference detector.

The unknown detector used in the present study was the detector in the solar channel of the Tiros Five-Channel Radiometer #303. Each channel in the radiometer has its own optical system and amplifier. Thus each "detector has filters and lenses to spectrally limit and focus the energy onto the detector flake" (Reference 4). The output signal from the solar channel was taken directly from the detector. Hence the spectral response of the detector which was obtained in the measurements is the effective response of the detector as modified by the associated filter and optics.

After obtaining the corrected ratios of the solar channel output to that of the reference detector, they were normalized by taking the maximum ratio as unity. These normalized ratios represent the relative spectral response of the solar channel of radiometer #303 over the range 0.3 micron to 4.7 microns.

EXPERIMENTAL RESULTS

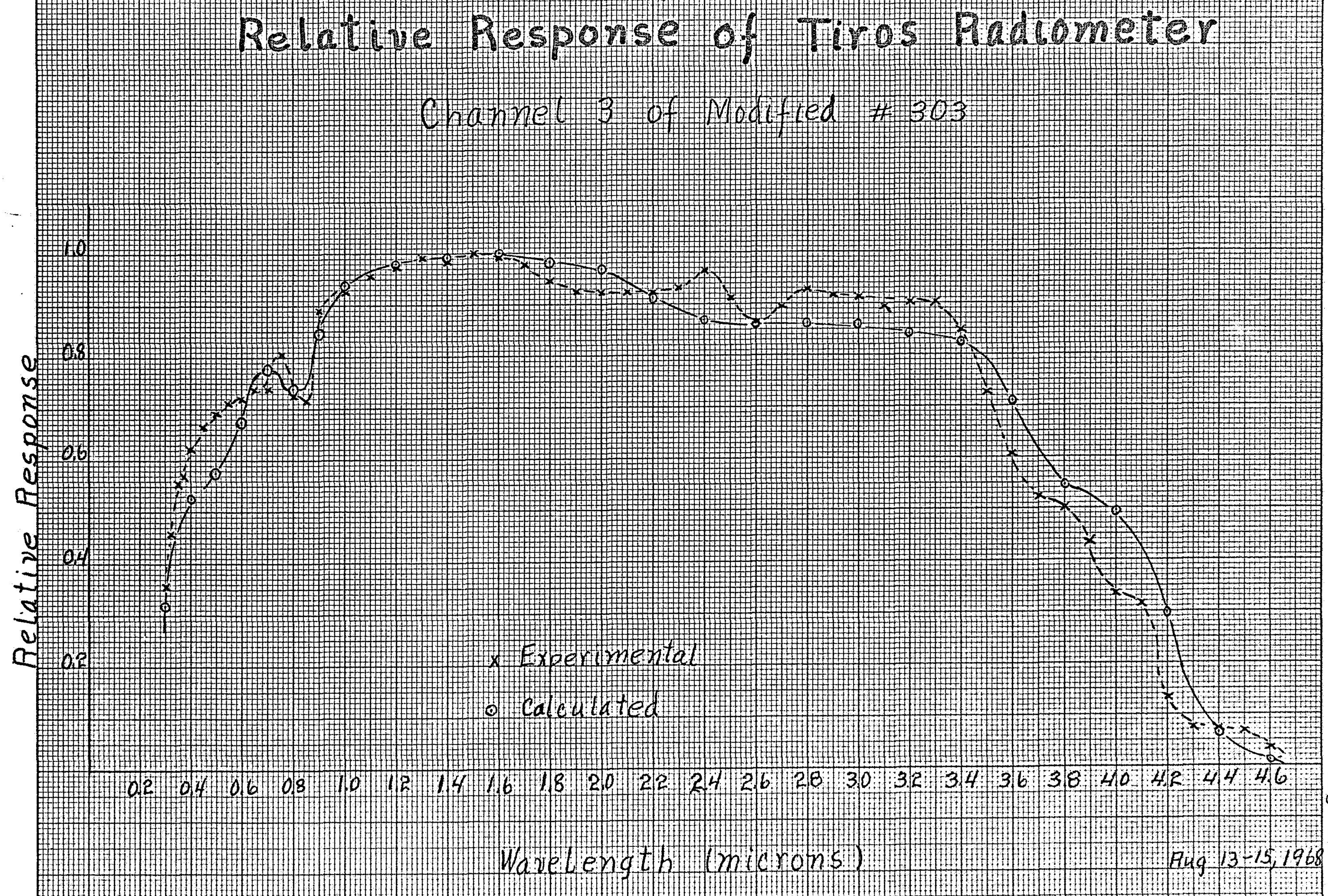
The relative spectral response obtained for the solar channel of the Tiros Five-Channel Radiometer #303 is presented in table 1 and plotted in figure 3. In addition to the experimental results for the solar channel, the theoretical or calculated values of the relative spectral response are also shown in table 1 and figure 3. The latter were obtained by normalizing to unity the product $R_pR_cT_fR_d$, where R_p is the spectral reflectivity of the radiometer prism, R_c the spectral reflectivity of the chopper, T_f the spectral transmittance of the filter-lens system, and R_d the spectral response of the thermistor bolometer of the solar channel. The data for these four factors were supplied by the Barnes Engineering Company, Stamford, Connecticut (Reference 4).

It will be observed that the experimental values of the relative spectral response of the solar channel has a maximum value of unity at 1.5 microns. Moreover, the relative response is 90% or greater in the range 0.9 micron to 3.3 microns, and drops fairly rapidly below 0.9 micron and above 3.3 microns. In the range 0.9 micron to 1.6 microns the experimental values agree reasonably well with the theoretical calculations, with a difference of one percent or less. In the range 1.6 microns to 3.3 microns the differences are approximately five percent. From 3.3 microns to 4.7 microns the experimental values decrease more rapidly than do the theoretical values.

Table 1
RELATIVE SPECTRAL RESPONSE
OF TIROS RADIOMETER 303

Wavelength λ	Relative Spectral Response		Wavelength λ	Relative Spectral Response	
Microns	Exper.	Calc.	Microns	Exper.	Calc.
.30	.357	.317	2.0	.922	.968
.32	.458		2.1	.922	
.35	.552		2.2	.922	.912
.37	.570		2.3	.933	
.40	.623	.525	2.4	.966	.870
.45	.664		2.5	.911	
.50	.692	.574	2.6	.863	.861
.55	.712		2.7	.896	
.60	.720	.672	2.8	.929	.861
.65	.737		2.9	.918	
.70	.737	.779	3.0	.915	.859
.75	.804		3.1	.896	
.80	.725	.740	3.2	.900	.840
.85	.712		3.3	.900	
.90	.890	.844	3.4	.849	.824
1.0	.927	.939	3.5	.728	
1.1	.957		3.6	.607	.710
1.2	.974	.981	3.7	.523	
1.3	.991		3.8	.501	.546
1.4	.983	.992	3.9	.435	
1.5	1.00		4.0	.339	.494
1.6	.991	1.00	4.1	.317	
1.7	.978		4.2	.134	.298
1.8	.944	.981	4.3	.075	
1.9	.922		4.4	.073	.066
			4.5	.069	
			4.6	.035	.011

Figure 3


Relative Response of Tiros Radiometer
Channel 3 of Modified # 303
Relative Response
1.0
0.8
0.6
0.4
0.2
x Experimental
o Calculated
0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8 4.0 4.2 4.4 4.6
Wavelength (microns)
Aug 13-15, 1968

CONCLUSIONS

From an examination of the results, it would seem that the instrumentation used in this study is appropriate for determining the relative spectral response of a detector.

A permanent set-up is being constructed at the present time. In addition, the alignment of the optics in the monochromator is being rechecked with care. When this improvement has been completed, it is expected that the experimental results will show a corresponding improvement.

ACKNOWLEDGMENTS

The principal investigator wishes to acknowledge the cooperation of Andrew W. McCulloch and James T. McLean, Code 622, Goddard Space Flight Center in connection with the investigations.

REFERENCES

1. R. C. Jones, D. Goodwin and G. Pullan, "Standard Procedures for Testing Infrared Detectors and for Describing their Performance", Office of the Director of Defense Research and Engineering, 1960.

2. W. L. Eisenman, "Procedures Used in the Study of Properties of Photodetectors", Report 541, Naval Ordnance Laboratory Corona, 1961.

3. Earle B. Brown, Modern Optics, New York, Reinhold, 1965, p. 373-376.

4. Barnes Engineering Co., "Calibration and Test Data for Five-Channel Satellite Radiometer, Serial Number 303, 1963.

ADDENDUM

In addition to setting up the instrumentation and determining the relative spectral response of the solar channel of the Tiros radiometer #303 reported above under the research grant NGR 21-023-001, the following measurements were made, as well as preliminary procedures tried, for the following investigations:

1. The Electro-Optical Industries 3000°C Blackbody
   a. Measurement of the transmittance of the CaF_2 window
   b. Checked the temperature calibration from 1020°C to 2293°C

2. The Perkin-Elmer Monochromator, Model 99
   a. Checked the wavelength calibration of the quartz prism
   b. Checked the wavelength calibration of the rock salt prism

3. Measurement of the transmittance of the new quartz window of thermopile 4928A

4. Checked the calibration of the HRIR with Tom Cherrix

5. Compared the spectral distribution of the Santa Barbara Research Corporation albedo source with that of a standard 1000W quartz-iodine lamp by means of
   a. The Perkin-Elmer Monochromator in conjunction with an integrating sphere (16") and thermocouple and photomultiplier detectors
   b. As in a, but using an 8" sphere and a Golay detector
   c. A water-cooled thermopile and monopass filters.