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U.S. Geological Survey
Department of the Interior

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

Technical Letter
NASA-31
June 1966

Dr. Peter C. Badgley
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Washington, D.C. 20546

Dear Peter:

Transmitted herewith are 3 copies of:

TECHNICAL LETTER NASA-31

ULTRAVIOLET INSTRUMENTATION FOR

ORBITAL REMOTE SENSORS*

by

H. T. Betz**

Sincerely yours,

William A. Fischer
Research Coordinator for
USGS/NASA Natural Resources Program

*Work performed under NASA Contract No. R146-09-020-006
**IIT Research Institute, Chicago, Illinois

[redacted]

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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ULTRAVIOLET INSTRUMENTATION FOR ORBITAL REMOTE SENSORS*

by

H. T. Betz**

June 1966

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Prepared by the Geological Survey for the National Aeronautics and Space Administration (NASA)

*Work performed under NASA Contract No. R146-09-020-006
**IIT Research Institute, Chicago, Illinois

Technical Memorandum W6137-2

ULTRAVIOLET INSTRUMENTATION FOR ORBITAL REMOTE SENSORS

by

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for

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May, 1966

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Technical Memorandum W6137-2

ULTRAVIOLET INSTRUMENTATION FOR ORBITAL REMOTE SENSORS

1. INTRODUCTION

This report reviews some candidate systems for a remote sensing experiment in lunar or Earth orbit, operating in the ultraviolet region of the spectrum. Much emphasis has been placed recently on the use of remote sensing techniques, but UV fluorescence and reflectance measurements have not been treated in any detail, primarily because of suspected instrumental and interpretive difficulties. This is particularly true in the Earth orbital case, where atmospheric scattering and attenuation are severe. The calculations quoted in this report indicate that instruments can indeed be built which will provide spectral and imagery data from orbital altitudes.

The discussion of ultraviolet sensing of the Earth and moon from orbital satellites will be divided under the following headings:

1. Sensing reflected solar ultraviolet radiation

2. Sensing of surface luminescence

3. Imaging of the surface in the ultraviolet.

2. SENSING REFLECTED SOLAR ULTRAVIOLET RADIATION

Measurement of the reflectance of solar radiation in the 1500 Å to 3000 Å region affords a possible method of studying surface materials. The equipment needed to perform such a remote sensing experiment is simply a spectrometer capable of covering the desired spectral range with a resolution of about 10 Å.

A satisfactory instrument (described in reference 1), is an Ebert spectrometer using an electonic scan. The system was assembled by ITT, and uses the ITT image dissector ("ITT Videoscan") and a McPherson monochromator. As originally built, the instrument was scanned at a very high rate, but this can be easily changed to the desired rate for lunar or Earth use. The image dissector in the original instrument could not be used in the extreme ultraviolet because of its window material, however a lithium fluoride or sapphire window can easily be obtained, thereby extending the spectral range below 1500 Å. The calculations given here are for an instrument modified to permit extending into the UV with an S-20 photocathode, and LiF_2 or sapphire window. Specifications are shown in Table I.

The signal to noise ratio for the spectrometer may be calculated as follows. Due to the small cathode area of the image dissector, the dark current is small compared to the signal current. Hence, one may consider that the noise of the

Table I

SPECIFICATIONS FOR UV REFLECTANCE SPECTROMETER

Effective aperture	F/4.5
Focal length of collimator	5 inches (13 cm)
Reciprocal linear dispersion	131 Å/mm
Spectral range	3000 Å
Resolution ($\Delta\lambda$)	10 Å
Spectral responses of cathode (sapphire or LiF window)	S-20
Grating	600 lines/mm
Slit dimensions	0.002" x 0.2"
Scan rate	1 or 10 spectra/sec
Power required (estimated)	20 watts
Weight (estimated)	25 lb

image dissector is essentially the noise in signal and is expressed as

$$N = \sqrt{2\ e\ i\ \Delta f} \qquad (1)$$

where i is the cathode current, Δf the frequency bandwidth and e is the charge on the electron. Writing (1) in terms of the irradiance on the cathode of the image dissector gives

$$N = \sqrt{2\ e\ i\ H_d\ As\ \Delta f}$$

where

H_d = irradiance at the detector

A = area of the detector

s = sensitivity of the cathode in Amp $Watt^{-1}$

We may then say that the signal to noise, that is, the ratio of signal to noise in the signal is

$$\frac{S}{N} = \sqrt{\frac{H_d\ As}{2e\ \Delta f}} \qquad (2)$$

By incorporating the characteristics of the spectrometer, we can write this in terms of the ground (or lunar) irradiance. Thus:

$$\frac{S}{N} = \sqrt{\frac{N\,\Omega\,As\,\tau\ r}{\pi\ 2e\ \Delta f}} \qquad (3)$$

where $(\frac{Nr}{\pi})$ = radiance of the surface where the surface is considered to be a Lambertian scatter of reflectivity, r.

2.1 Lunar Orbital Use of the ITT Spectrometer

For the lunar surface study, signal to noise values at selected wavelengths from 1500 to 4000 Å are shown in Table II.

Table II

SPECTRAL REFLECTIVITY OF LUNAR SURFACE

Wave-length in Å	N Irradiance* of Lunar surface Watts cm^{-2} A^{-1}	H Radiance of Lunar Surface Reflectivity = 0.1 Watts cm^{-2} A^{-1} $ster^{-1}$	S Sensitivity of Detector Amps/watt S-20 Cathode	S/N	S/N 1 scan/sec 250 elements/sec (Δf = 125)
1500	1×10^{-8}	3.2×10^{-10}	2.2×10^{-2}	$\frac{7.3 \times 10^{1}}{\sqrt{\Delta f}}$	6.5
2000	14×10^{-8}	4.5×10^{-9}	3×10^{-2}	$\frac{3.2 \times 10^{2}}{\sqrt{\Delta f}}$	2.85×10^{1}
3000	5×10^{-6}	1.6×10^{-7}	4×10^{-2}	$\frac{2.2 \times 10^{3}}{\sqrt{\Delta f}}$	2×10^{2}
3500	12×10^{-6}	3.8×10^{-7}	4.5×10^{-2}	$\frac{3.5 \times 10^{3}}{\sqrt{\Delta f}}$	3.1×10^{2}
4000	11×10^{-6}	3.5×10^{-7}	5×10^{-2}	$\frac{2.3 \times 10^{3}}{\sqrt{\Delta f}}$	2×10^{2}

Reflectivity of lunar surface assumed to be 10%.

Scan is 2500 Å or 250 spectral elements/scan

Transmission of entire optical system including grating is assumed to be 10%

S-20 cathode with lithium fluoride or sapphire window.

* Reference 2 and 3.

The advantage of the image dissector type of spectrometer over other spectrometers is primarily the electronic scan, since no moving parts are required to scan the spectrum. If it were desired, however, to rock the grating, an S-20 multiplier of the type FW130 or ruggedized version FW143 of ITT could be used to take advantage of the small dark current available with the small cathode area (see reference 4). This tube uses an imaging section preceding the electron multiplier and the effective cathode area may be chosen when the tube is constructed.

Table II is also valid for the type of system employing a rock grating and small cathode multiplier phototube.

2.2 Earth Orbital Use of the ITT Spectrometer

For Earth orbital use one must take account of the attenuation of the backscattering of the atmosphere. That is, in order to see the surface one must compare the radiation from the surface (which is attenuated by 2 passes through the atmosphere) to the radiation backscattered from the atmosphere. The signal to noise ratio then becomes

$$\frac{S}{N} = \frac{i_s}{\sqrt{2e\ i_t\ \Delta f}} \tag{4}$$

where I_s is the signal cathode current due to radiation from the surface, and i_t is the current due to total radiation (surface and atmosphere).

Writing (3) in terms of the spectrometer parameters and the radiance of the Earth's surface and the radiance of the atmosphere, we have

$$\frac{S}{N} = \frac{H_s}{\sqrt{H_t}} \sqrt{\frac{As\ \Delta\lambda}{2e\ \Delta f}} \qquad (5)$$

where

H_s = radiance of the Earth

H_t = total radiance (Earth plus atmosphere)

Other symbols are already defined in Eq. (1).

Reference 3 compiles data for solar irradiance outside the atmosphere from a number of different workers, and also gives values of measured attenuation coefficients for clear atmosphere at Mt. Lemon.

Table III shows the radiance of the Earth's surface for various reflectivities as calculated from Ref. 4 and is for vertical viewing and vertical solar irradiation. The values given are for sea level using the attenuation coefficient of the atmosphere as measured at Mt. Lemon.

Reference 5 gives data for the radiance of the atmosphere for various Sun positions, and various Earth reflectivities. These data are summarized in Table IV. It is to be noted that the values for Earth radiance differ by a factor of 2 in Tables III and IV. This is due to having used actual measured attenuation values in Table III while Table IV was based on Rayleigh scattering only.

The results of signal to noise calculations using Eq. 5 and Tables III and IV are summarized in Table V.

Table III

RADIANCE OF EARTH SURFACE

	H_s 10% Reflectivity Watt cm^{-2} $ster^{-1}$ A^{-1}	H_s 25% Reflectivity	H_s 5% Reflectivity
3000	9.6×10^{-11}	2.4×10^{-10}	4.8×10^{-11}
3200	2.23×10^{-8}	5.5×10^{-8}	1.11×10^{-8}
3500	9.6×10^{-8}	2.4×10^{-7}	4.8×10^{-8}
4000	2.25×10^{-7}	5.6×10^{-7}	1.12×10^{-7}

Table IV

APPARENT TOTAL RADIANCE DUE
TO ATOMS AND SURFACE OF EARTH

	H_t 0% Reflectivity	H_t 25% Reflectivity	H_o 25% Reflectivity
3000	5.5×10^{-7}	5.5×10^{-7}	- -
3200	6.3×10^{-7}	1.4×10^{-7}	1.1×10^{-7}
3500	6.7×10^{-7}	1.14×10^{-6}	4.7×10^{-7}
4000	6.4×10^{-7}	1.6×10^{-6}	9.6×10^{-7}

Table V

SPECTRAL REFLECTIVITY OF EARTH SURFACE

λ Å	r Amps/watts	S/N	S/N $\Delta f = 125$
3000	2.6×10^{-2}	$2.3 \times 10^{-2}/\sqrt{\Delta f}$	-
3200	3.5×10^{-2}	$1.8 \times 10^{2}/\sqrt{\Delta f}$	16
3500	4×10^{-2}	$7.5 \times 10^{2}/\sqrt{\Delta f}$	67
4000	5×10^{-2}	$1.9 \times 10^{3}/\sqrt{\Delta f}$	168

Resolution ($\Delta\lambda$) = 10 Å

Scan spectral range = 2500 Å

Scan rate = spectral/second - f = 125

S-20 surface with sapphire window

Earth reflectivity = 10%

3. SENSING OF SURFACE LUMINESCENCE

A consequence of solar bombardment of the lunar surface with ultraviolet radiation, X-rays and high energy particles may be expected to be that of luminescence of the lunar surface rocks. Likewise the Earth's surface, while protected by the atmosphere from the short ultraviolet, X-rays and particles bombardment, may be expected to luminesce in selected areas as a result of the longer ultraviolet and near visible radiation which can reach the surface. Since the study of luminescent phenomena must take place during daylight illumination of the surface, a technique must be used which will permit one to see the low level luminescence in the presence of a high background of reflected light. To overcome this, Link devised the technique known as "The Method of Line Depths". This technique takes advantage of the fact that the central intensity of a Fraunhofer absorption line is about 0.1 of the continuum level. Hence, a small additional intensity due to luminescence will change the ratio of the continuum level to that of the central intensity of the line. (Since the luminescent spectrum of most materials consists of broad spectral regions devoid of fine structure the luminescent intensity will add nearly equally to both continuum and central intensity.) Hence, a measure of the ratio of the continuum level to the center for both the target area and the Sun directly, will give a measure of the luminescence. An even more sensitive approach is to actually measure the line contour from the target and compare it with that of the Sun. (This approach may be used to eliminate any effect due to the broad luminescent spectrum.) High resolution is required so as not to lessen the apparent depth of the line center. This technique, as applied to the lunar surface (from the Earth), is carefully explained in Kopal[6].

Figure 1 is a copy of the H_α line from the "Atlas of the Solar Spectrum"[7]. The width of the line at 1/2 minimum is approximately 1.2 Å. A resolution of 0.5 Å or better is required if the minimum value is to be reasonably well measured. The method of line depths may be equally well applied to a survey of Earth and the moon from satellite vehicles.

3.1 Spectrometer for Luminescence Study

A description of the equipment for the Earth orbital luminescence experiment follows:

The equipment is to consist of an electronically scanned grating spectrometer of 0.5 Å resolving power. The electronically scanned instrument utilizes an image dissector type of photomultiplier (typical type #F4011 by ITT) described previously which eliminates the need for mechanically scanning the spectrum by tilting the grating. A 25 micron (0.001 inch) slit is required by the image dissector. If one assumes such a slit width, then to resolve 0.5 Å with a 1200 line/mm grating in the first order, will require a focal length of 50 cm. The characteristics of the proposed instrument are shown in Table VI and Figure 2.

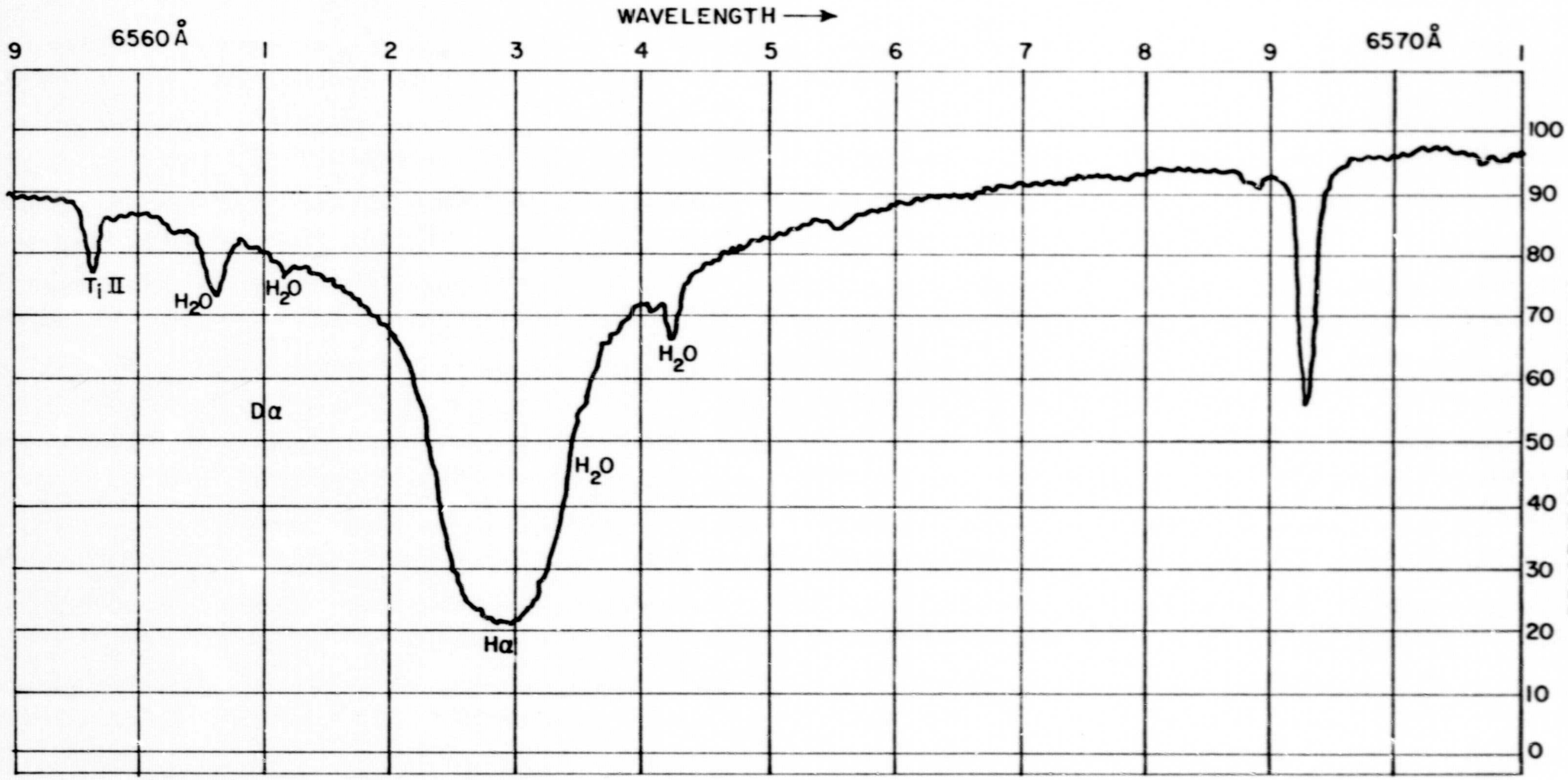

FIGURE I. PROFILE OF HYDROGEN α LINE
(Taken from the Utrecht Atlas)

IITRI/ASC

Table VI

SPECIFICATIONS OF CZERNY-TURNER SPECTROMETER

Grating size	100 x 100 mm
Grating spacing	1200 lines/mm
Focal length of collimator	50 cm
Effective aperture	F/4.5
Dispersion (1st order)	17 Å/mm
Slit size	0.51 cm by 2.5×10^{-3} cm
Slit area	1.3×10^{-3} cm^2
Resolution (with above slit)	0.4 Å at 5000 Å
Scan range	425 Å

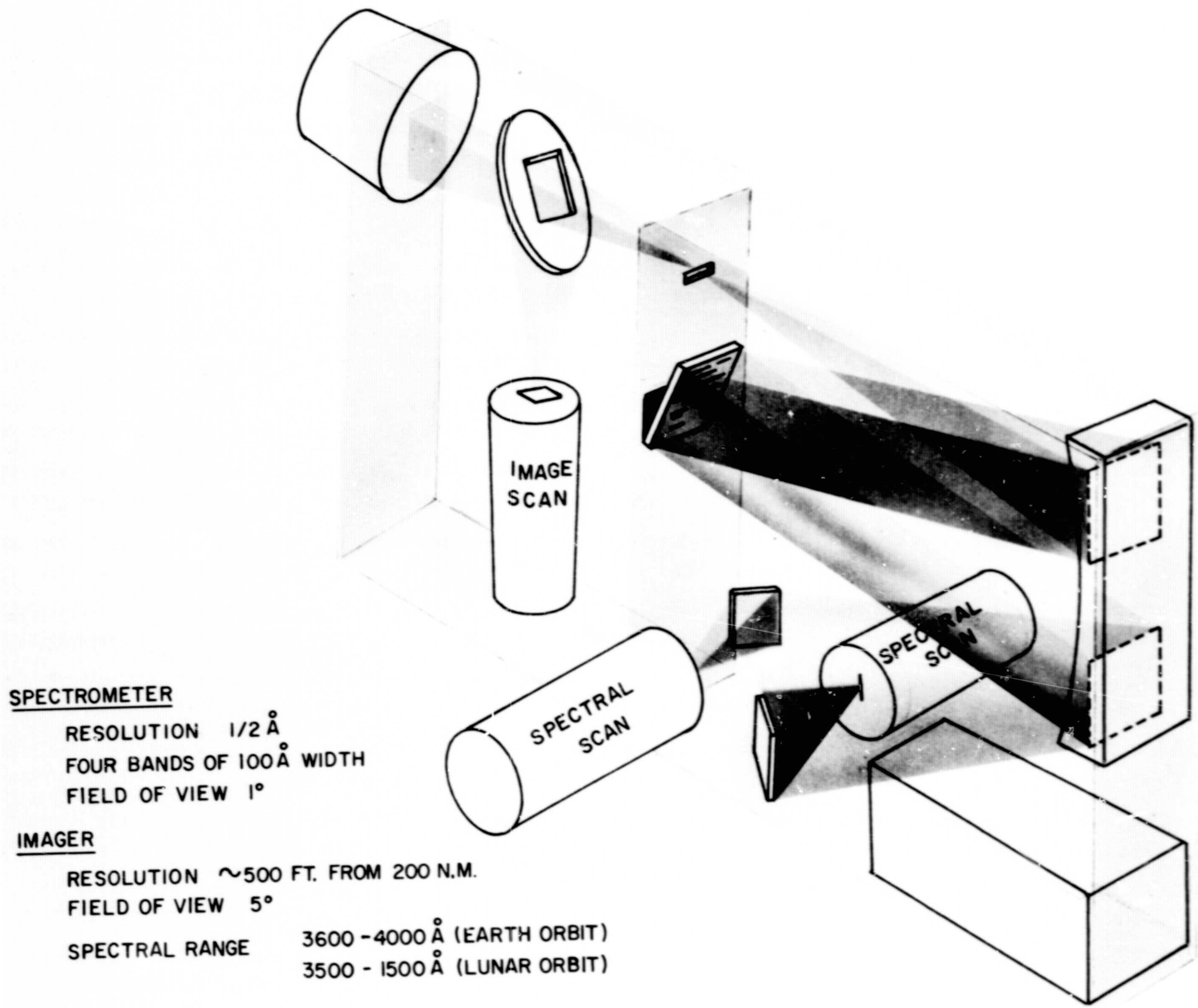

Figure 2 ULTRAVIOLET IMAGERY / LUMINESCENCE SPECTROMETRY EXPERIMENT

The slit length 0.2 inch must be imaged by fore-optics on the Earth's surface so as to scan a band 1° wide. This requires an objective of 30 cm focal length and of approximately F/3.5 to cover the square grating (see Figure 2).

The spectrometer may be of the Czerny-Turner or Ebert types. The grating 10.0 x 10.0 cm square, will be fixed in position and the entrance slit will be fixed at 25 microns. The spectrum is folded 90° as shown in Figure 2 by mirrors placed at each selected line. Image dissectors are arranged to accept each line and scan over the entire line and well into the wings. Several lines if close together may be covered by one image dissector.

The following is a selection of suitable Fraunhofer lines:

C - 6563 Å-H_α
D - 5890 Å and 5896 A-Na(d)
F - 4861 Å-H_β
G_1 - 4340 Å-H_γ
H & K - 3933 Å and 3968A-Ca

This would require 5 image dissectors arranged in two rows. More or fewer lines could be scanned. The 5 tubes should give data from which the spectral curve of the luminescence could be determined. The entrance slit is filled by a collector lens of 30 cm focal length which can conveniently be a photographic objective since extreme ultraviolet transmission is not required.

The contour of the Fraunhofer line from the Earth must be compared to that of the Sun in order to determine the luminescent level. This requires that the Sun be viewed periodically with the spectrometer. Since the instrument is looking vertically downward it is impossible to view the Sun directly and equally difficult to extend a scattering plate into the Sun's rays and view it with the spectrometer. This can, however, easily be accomplished with a fiber optics bundle which can be extended to any convenient position either inside or outside of the spacecraft so as to be in the Sun's rays. (It could be cemented to the surface of the siacecraft if desired.) A scattering plate (ground glass) would be affixed to the end in the Sun. The inner end of the bundle would be near the entrance slit and be periodically reflected into the slit by an electrically operated mirror. The bundle would be 1/4 to 3/8 inch diameter by 10-12 ft in length. Estimated weight

6 image dissectors @ 15 lb with deflection coils	30 lb
Optical system	40 lb
Electronics	10 lb
Total weight	80 lb

Signal to noise calculations were made for the spectrometer for two Fraunhofer lines. Results for Earth orbit are shown in Table VII. The values for solar irradiance at sea level are taken from Smithsonian tables, reference 8. Since the values from reference 8 consider a path of 2 atmospheres,

Table VII

LUMINESCENCE SPECTROMETER IN EARTH ORBIT

Position	A	N* Irradiance of Earth-Sea Level W cm^{-2} A^{-1}	Radiance of Earth 50% Reflectivity W cm^{-2} A^{-1} $Ster^{-1}$	Sensitivity S-20 Amp. $Watt^{-1}$	S/N	S/N $\Delta f = 400$
Wing	6562	11.6×10^{-6}	1.9×10^{-6}	0.012	$\frac{9.2 \times 10^2}{\sqrt{\Delta f}}$	46
Center	6562	1.8×10^{-6}	2.9×10^{-7}	0.012	$\frac{2.3 \times 10^2}{\sqrt{\Delta f}}$	18
Wing	4861	12.0×10^{-6}	1.9×10^{-6}	0.07	$\frac{2.3 \times 10^3}{\sqrt{\Delta f}}$	112
Center	4861	1.8×10^{-6}	2.9×10^{-7}	0.07	$\frac{9 \times 10^2}{\sqrt{\Delta f}}$	45

Reflectivity of Earth assumed to be 50%

Spectral bandwidth assumed to be 0.5 Å

Total transmission of all optics assumed at 40%

S-20 photocathode

* See Smithsonian table, reference 8 .

they represent reasonable values for vertical illumination and vertical viewing.

Table VIII summarizes the signal to noise calculations for the lunar orbital case. The values for irradiance of the lunar surface are from reference 2 and 3.

A reasonable scan time for both Earth orbit and lunar orbit would be 2 spectral lines/second. If 200 Å are allowed for each line then there are 400 spectral elements for scan, that is 1/800 sec per spectral element. Minimum allowable bandwidth is therefore $\frac{1}{2\Delta t}$ or $\Delta f = 400$.

3.2 Interferometer for Luminescence Studies

A scanning interferometer of the Fabry Perot type may be used as a spectrometer, instead of the grating instrument previously described, and would result in a much greater efficiency.

The central order of the interferometer is imaged by a collimator on an exit aperture after which it is relayed to the cathode of a multiplier phototube. The size of the central aperture is chosen to give the desired spectral resolution and the spacing of the interferometer plate is chosen to give the desired free spectral range. An interference filter is used to limit the spectral range to one order. The spectrum is scanned by changing the optical path length between the parallel plates. The entire system is described by Jacquinot (reference 9).

Table VIII

LUMINESCENCE SPECTROMETER IN LUNAR ORBIT

Position	A	N Irradiance of Moon W cm^{-2} A^{-1}	H Radiance of Moon 50% reflectivity W cm^{-1} A^{-1} $Ster^{-1}$	S Sensitivity Amp/watt	S/N	S/N $\Delta f=400$
Wing	6562	1.7×10^{-5}	1.4×10^{-6}	.012	$\frac{7.9 \times 10^2}{\sqrt{\Delta f}}$	40
Center	6562	2.5×10^{-6}	2.1×10^{-7}	.012	$\frac{2.0 \times 10^2}{\sqrt{\Delta f}}$	16
Wing	4861	2.0×10^{-5}	1.6×10^{-6}	0.07	$\frac{2.1 \times 10^3}{\sqrt{\Delta f}}$	102
Center	4861	3.0×10^{-6}	2.4×10^{-7}	0.07	$\frac{8.2 \times 10^2}{\sqrt{\Delta f}}$	41

Reflectivity of lunar surface assumed to be 25%

Spectral bandwidth assumed to be 0.5 A.

Total transmission of all optics assumed to be 40%

S-20 photocathode - lithium fluoride or sapphire window.

The scanning may be accomplished by changing the pressure of the gas between the plates, or by mechanically changing the separation of the plates. Changing the gas pressure would be very inconvenient in a spacecraft in addition to being too slow for this application. The mechanical scan can, however, be accomplished by driving the plates either by piezoelectric elements or by magnetostrictive elements (see reference 10).

Specifications for such an instrument are outlined in Table IX.

The results of signal to noise calculations for Earth orbit are summarized in Table X. A bandwidth of 400 cycles is assumed in column 6 in order to compare results directly with those of the spectrometer.

A more realistic value would be to scan approximately 10 Å for each line at the rate 2 scans/sec. If collecting optics are not used, the total angular field of view would be 2.5×10^{-2} radians or 1°25'. This could be adjusted to any desirable angular size with the proper collecting system.

Perhaps the most convenient way to build an interferometer system is to provide an interferometer, fore-filter and multiplier assembly for each line to be studied. This permits coating the interferometer plates for the maximum efficiency for each line. The entire system of 6 interferometers is still a small package compared to the spectrometer.

Table XI gives a similar calculation for lunar orbital use.

Table IX

SPECIFICATIONS FOR FABRY-PEROT INTERFEROMETER

Diameter of plates	25 cm
Area of plates	5 cm^2
Plate separation	0.02 cm
Free spectral range	10 Å at 6500 Å
Finesse	20
Spectral bandwidth	0.5 Å at 6500 Å
Resolving power	13,000 at 6500 Å
Solid angle of acceptance	$\Omega = 5 \times 10^{-4}$ ster

Table X

INTERFEROMETER IN EARTH ORBIT
FOR LUMINESCENCE MEASUREMENT

Position	A	N* Irradiance	H* 50% Reflectivity	S Sensitivity S-20 Amp watt^{-1}	S/N	S/N $\Delta f = 400$
Wing	6562	11.6×10^{-6}	1.9×10^{-6}	0.012	$\frac{4.5 \times 10^3}{\sqrt{\Delta f}}$	2.25×10^2
Center	6562	1.8×10^{-6}	2.9×10^{-7}	0.012	$\frac{1.8 \times 10^3}{\sqrt{\Delta f}}$	9.0×10^1
Wing	4861	12.2×10^{6}	1.9×10^{-6}	0.07	$\frac{1.1 \times 10^4}{\sqrt{\Delta f}}$	5.5×10^2
Center	4861	1.8×10^{-6}	2.9×10^{-7}	0.07	$\frac{4.3 \times 10^3}{\sqrt{\Delta f}}$	2.15×10^2

Overall transmission estimated as follows:

Interferometer - 60%
Fore-filter - 40%
Aperture - 75%
Optical collector-60%

Total transmission - 11%

* See Table VI.

Table XI

INTERFEROMETER IN LUNAR ORBIT
FOR LUMINESCENCE STUDY OF SURFACE

Position	A	$\bar{N}$* Irradiance W cm-2 A-1	H Radiance 25% Reflectivity W cm-2 ster-1 A-1	S Sensitivity S-20	S/N	S/N Δf = 400
Wing	6562	1.7×10^{-5}	1.4×10^{-6}	0.012	$\frac{3.9 \times 10^{3}}{\Delta f}$	195
Center	6562	2.5×10^{-6}	2.1×10^{-7}	0.012	$\frac{1.6 \times 10^{3}}{\Delta f}$	80
Wing	4861	2.0×10^{-5}	1.6×10^{-6}	0.07	$\frac{1.0 \times 10^{4}}{\Delta f}$	500
Center	4861	3.0×10^{-6}	2.4×10^{-7}	0.07	$\frac{3.95 \times 10^{3}}{\Delta f}$	196

Total transmission of interferomer estimated at 11%

Reflectance of moon estimated at 25%

* See reference 5.

4. IMAGING OF THE SURFACE IN THE ULTRAVIOLET

4.1 Imaging System in Earth Orbit

Associated with the grating spectrometer is an imaging system which covers a larger field of view than the spectrometer, the latter being centered in the former. The imaging system will use the same objective as the spectrometer (30 cm focal length) and, with the use of a beam divider, will collect light from portions of the lens not used by the spectrometer. This lens could therefore conveniently be an F/2.5 lens of 30 cm focal length. (This is a standard photographic objective.) The imaging system will use an additional image dissector tube with a scan length of 25 cm thus giving a field of view of 5°.

No auxiliary optics are required and the imaging system and spectrometer are ont unit and require only the one objective opening in the vehicle.

Figure 3 shows the area covered by the spectrometer and imaging system with the system fixed in the spacecraft so as to look vertically downward from an estimated altitude of 2000 km. A complete schematic diagram of the entire optical system is shown in Figure 2.

The useful area of the image converter is approximately 1" x 1". If we assume a resolution element of .005", we have 200 elements per vertical scan line. If the horizontal scan is the same resolution, we must scan at the rate of 80 lines/sec. (Orbital velocity is approximately 2°/sec,

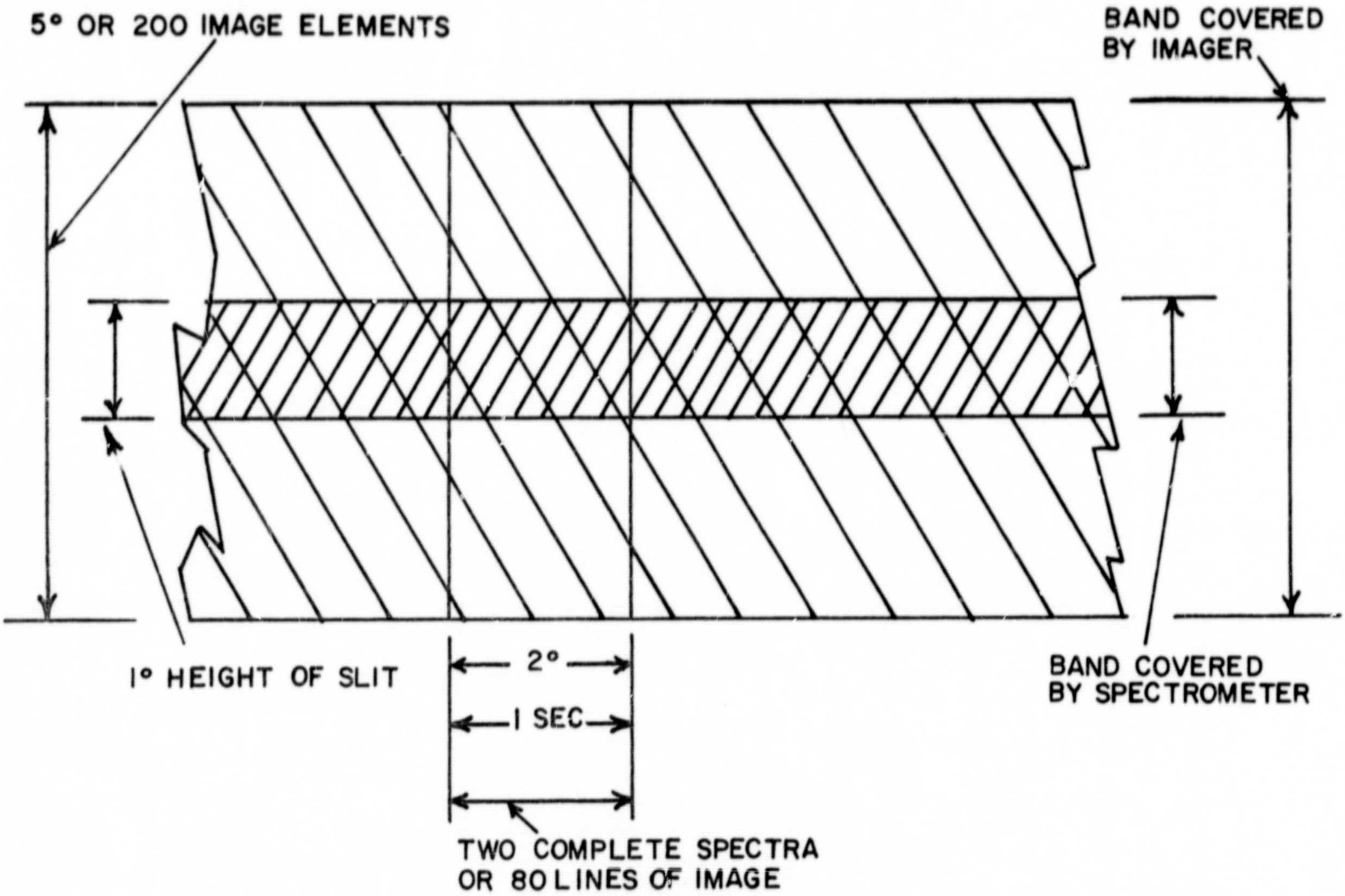

FIGURE 3. AREA VIEWED BY SPECTROMETER AND IMAGING SYSTEM

therefore 200 elements are equal to 5°.) This uses the spacecraft velocity for horizontal scan and the image tube for vertical scan only. The minimum electronic bandwidth is $\Delta f = \frac{80 \times 200}{2} = 8 \times 10^3$ cycles/sec. A filter may be used to limit the spectral response of the image converter.

The specifications of the imaging system are shown in Table XII.

Signal to noise calculations for various spectral bandwidths are shown in Table XIII for Earth orbit.

4.2 Imaging System in Lunar Orbit

This equipment can be identical to that used in Earth orbit. However, due to the absence of an atmosphere, it may be desirable to extend the response of the system farther into the ultraviolet. A separate objective designed for the wavelength desired would be required instead of the camera objective, and an additional port must be provided in the spacecraft. Table XIV gives typical values for lunar use and is extended to shorter wavelengths than Table XIII.

Table XII

IMAGING SYSTEM SPECIFICATIONS

Cathode	S-20
Scan area	2.5 cm x 2.4 cm 1 inch x 1 inch
Scan element	.0126 cm x .0126 cm (.001 in x .001 in)
Area of scan element	1.6×10^{-4} cm^2
Optical collector	F/2.5 photographic objective
Solid angle of collector (This is the peripheral area when square area for spectrometer is removed.)	8.6×10^{-2} ster
Transmission of objective	Estimated at -0.60

Table XIII

IMAGING SYSTEM SIGNAL TO NOISE IN EARTH ORBIT

Spectral Band	N* Irradiance of Earth at Sea Level Watt cm^{-2}	H Radiance of Earth 25% reflectivity Watt cm^{-2} $ster^{-1}$	S Averaged Over the Wavelength Interval Amp $watt^{-1}$	S/N ($\Delta f = 8 \times 10^3$)
3600-4200 Å	26×10^{-4}	2.1×10^{-4}	5×10^{-2}	1.84×10^2
3600-5000 Å	109×10^{-4}	8.7×10^{-4}	5×10^{-2}	3.7×10^2
3600-4000 Å	14×10^{-4}	1.1×10^{-4}	5×10^{-2}	1.3×10^2
3600-7000 Å	349×10^{-4}	27.5×10^{-4}	4×10^{-2}	5.8×10^2

= 0.6 - the transmission of the optical system

= 25% - the reflectivity of the Earth's surface

$\Delta f = 8 \times 10^3$

* See reference 8 for radiance values.

Table XIV

IMAGING SYSTEM IN LUNAR ORBIT

Spectral Band	N* Irradiance of moon in Watt cm^{-2}	H Radiance of Moon 10% Reflectance Watt cm^{-2} $Ster^{-1}$	S Averaged over the Spectral Band Ampers/watt	S/N $\Delta f = 8 \times 10^3$
1500-2000	1.8×10^{-5}	5.7×10^{-7}	.02	6.0
2000-2500	2.8×10^{-4}	8.9×10^{-6}	.025	27.0
2500-3000	1.5×10^{-3}	4.8×10^{-5}	.03	67.0
3000-3500	4.8×10^{-3}	1.5×10^{-4}	.036	131.0
2500-3500	6.3×10^{-3}	2.0×10^{-4}	.033	144.0

Reflectivity of moon estimated at 10%

Solid angle of collector lens - 8.6×10^{-2} steradians F/3

S-20 - photocathode lithium fluoride cr sapphire window

Transmission of optics estimated at 60%

*See reference 2 and Space Science Review, Towsey, page 22.

REFERENCES

1. Harber, R. A., ITT Industrial Laboratories Memorandum dated February 12, 1965. "Technical Description and Specifications for an Electronic-Scanning Spectrometer".

2. The Upper Atmosphere, Meteorology and Physics, Richard A. Craig, Editor, Academic Press, 1965.

3. Dunkelman, L. and R. Scolnik, J. Opt. Soc. Am., 49, 356 (April 1959).

4. ITT Industrial Laboratories, Memorandum dated April 1, 1963. "Special Purpose Multiplier Phototubes Types FW118, FW129, FW130, FW142, FW136, FW143, FW178.

5. Coulson, K. L., Planet. and Space Sci., 1, 277 (1959).

6. Physics and Astronomy of the Moon, Ed. by Z. Kopal, Academic Press, Inc. p. 385 (1962).

7. Photoelectric Atlas of the Solar Spectrum, by M. Minnaert, G. F. W. Mulders and J. Houtgast, Utrecht, 1940.

8. Smithsonian Physical Tables, 1954 edition.

9. Jacquinot, P., Reports on Progress in Physics, p. 268, 1960.

10. Slater, P. N., H. T. Beta, and G. Henderson, Japan. J. Appl. Phys., Vol. 4, Supplement I, p. 440, 1965.

11. Tousey, R., Space Sci. Rev., Vol. II, No. 1, p. 3 (July 1963).