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AIRBORNE LASER REMOTE SENSOR FOR OIL DETECTION AND CLASSIFICATION

Engineering Requirements and Technical Considerations Relevant to a Performance Specification

Hector C. Ingrao
Michael F. Cartwright
Melvin Yaffee

AUGUST 1975
INTERIM REPORT

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16. Abstract

This report outlines the engineering requirements for an Airborne Laser Remote Sensor for Oil Detection and Classification System. Detailed engineering requirements are given for the major units of the system. Technical considerations pertinent to a performance specification are included.

The stated requirements are derived from analysis and experiments conducted at the Transportation Systems Center under U.S. Coast Guard sponsorship and the conclusions of the U.S. Coast Guard - TSC Working Group on Fluorescence Oil Spill Surveillance between December 1973 and June 1974.

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PREFACE

This document has been prepared as an interim report in compliance with the Project Plan Agreement (PPA) CG-403 "Oil Spill Surveillance" and expanded in a mutual understanding as to its purpose and scope as developed on December 14, 1973 between H.C. Ingrao of the Optical Devices Group at the Department of Transportation Systems Center and Lt. Cmdr. G. Woolever in the Pollution Prevention Projects Branch of the Environmental Transportation Technology Division of the Office of Research and Development at the U.S. Coast Guard. Also, as a result of a change in the PPA, a "TSC Working Group on Fluorescence Oil Spill Surveilliance" was created with membership from TSC,U.S. Coast Guard and NASA.

This working group was charged with the responsibilty to review the physics of oil detection and classification in spills using remote sensing by induced fluorescence and to evolve a set of parameters to be used in the specification of an airborne laser remote sensor for oil detection and classification for the U.S. Coast Guard.

To stimulate synergism between different Government laboratories and agencies, the membership of the TSC working group on Fluorescence Oil Spill Surveillance was integrated by TSC, U.S. Coast Guard and NASA as follows:

H.C. Ingrao, TSC, chairman

Lt. A. Arecchi, U.S. Coast Guard R&D Center

M.F. Cartwright, TSC

Dr. R. Hiltabrand, U.S. Coast Guard R&D Center

H.H. Kim, NASA, Wallops Island

Lt. A. Maurer, U.S. Coast Guard Headquarters

B. Rubin, NASA OST Headquarters

LCDR G. Woolever, U.S. Coast Guard Headquarters

The material contained in this report is based on work carried out at TSC under U.S. Coast Guard sponsorship (DOT-TSC-USCG-503-74) and the recommendations developed by the aforementioned working group.

The objective of this report is to supply, on the basis of experimental results, a set of engineering requirements and technical considerations relevant to a performance specification for an Airborne Laser Remote Sensor for Oil Detection and Classification (RODAC). The purpose of this specification is to facilitate the procurement of a RODAC engineering prototype. The hardware specifications included in this report do not preclude other hardware and software approaches based on the same oil induced fluorescence principle, provided that there exists convincing experimental evidence on the proposed approaches.

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SYMBOL DEFINITIONS AND UNITS

SYMBOL	DESIGNATION	UNIT
A_r	Optical receiver area	$meter^2$
A_t	Target area illuminated by laser	$meter^2$
d_t	Diameter of illuminated target	meter
D	Diameter of receiver optics	meter
e	Base of natural logarithms	2.7182
E_c	Corneal irradiance	Watt cm^{-1}
f/	f - number	-
H_z	Frequency	Hertz
I_n	Current per transmitted pulse per channel	Ampere
J	Laser energy per pulse	Joule
K	Constant	-
n	Spectral channel number	-
P_n	Fluorescence power received by remote sensor per transmitted pulse and per receiver channel	Watt
P_o	Total fluorescence power received by remote sensor per transmitted pulse	Watt
P_L	Peak power laser transmitter	Watt
q	Distance swept by remote sensor optical axis due to roll	meter
R	Flight altitude	meter
S(λ)	Spectral radiant responsivity of the detector	Ampere $watt^{-1}$
t_s	Exposure time of the eye to laser radiation	msec
V	Voltage	Volt

SYMBOL DEFINITIONS AND UNITS (CONTINUED)

SYMBOL	DESIGNATION	UNIT
V_g	Ground speed vector	meter sec^{-1}
W	Power	Watt
X	Roll	Degree
Y	Pitch	Degree
Z	Yaw	Degree
α	Field of view, receiver (full angle)	rad
α_L	Atmospheric attenuation laser wavelength	$meter^{-1}$
α_o	Average atmospheric attenuation for the visible region	$meter^{-1}$
Δ	Separation between channel center wavelengths	nm
$\Delta\lambda$	Optical channel spectral width	nm
ε_c	Average efficiency of receiver optics	-
$\varepsilon_c(\lambda)$	Spectral efficiency of receiver optics	-
ε_L	Efficiency of transmitter optics	-
ε_o	Integrated oil fluorescence coefficient	-
$\varepsilon_o(\lambda)$	Spectral oil fluorescence coefficient	-
λ	Wavelength	nm
λ_f	Oil Fluorescence wavelength	nn
λ_n	Central wavelength, spectral channel	nm
λ_L	N_2 laser wavelength	nm
Ω_L	Solid angle illuminated by laser beam	str
Ω_o	Solid angle subtended by the telescope entrance pupil	str

1. ENGINEERING REQUIREMENTS

1.1 GENERAL DESCRIPTION

The Airborne Remote Sensor for Oil Detection and Classification (RODAC) shall be configured to satisfy two operational requirements: a) as a subsystem of the Airborne MRS Sensor System, the RODAC I; and b) as an independent system RODAC II. The block diagrams of both RODACs are given in Figure 1.

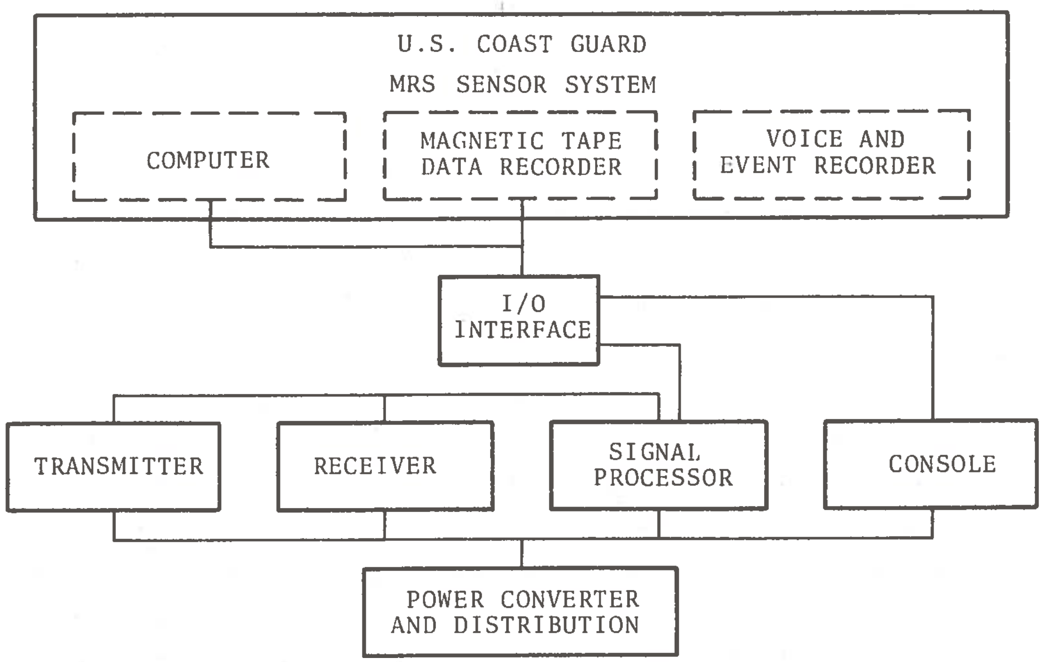
The RODAC will consist of two units properly interconnected. One unit will be the Optical Column which includes the optical and electro-optical components of the RODAC and the other unit includes the electronic subsystems and console. Figure 2 shows a schematic of the RODAC optical column and Figure 3, the artist's conception of the airborne RODAC II. Figure 4 gives the signal processor operational flow diagram and Figure 5, the RODAC console.

1.1.1 Transmitter

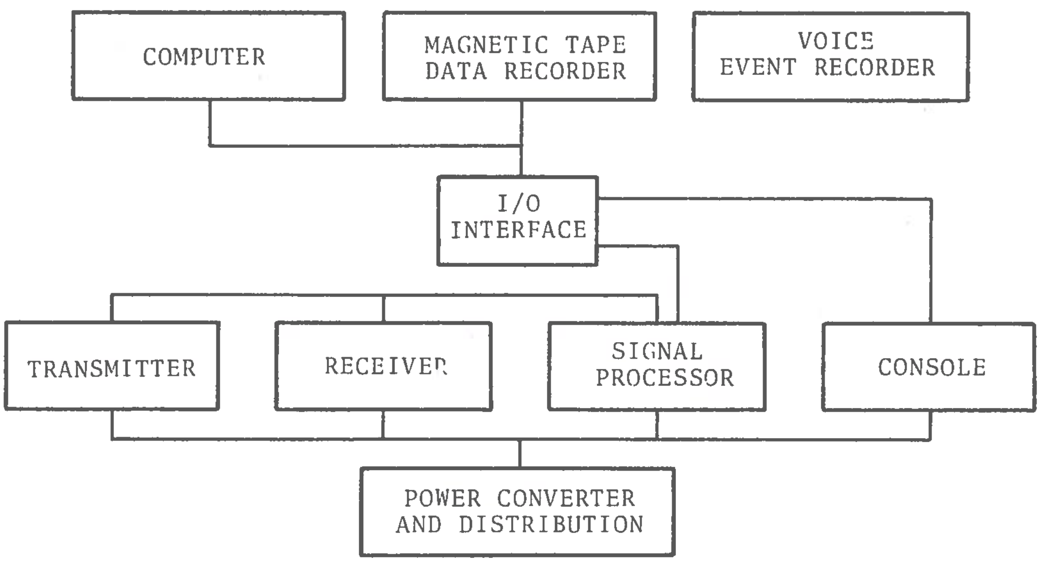
The transmitter consists of a Nitrogen laser, He-Ne laser and associated optics.

a. Nitrogen Laser. The power source for the transmitter will be a pulsed N_2 laser (337.1 nm). This laser shall employ a sealed plasma tube. Nitrogen lasers with gas flow are precluded from any consideration. The plasma tube shall have a rugged mount to allow the axis of the laser beam to maintain alignment in the aircraft environment within $\pm 2 \times 10^{-4}$ rad from the reference axis of the telescope optical axis. This tolerance shall be maintained after the laser has been mounted in the RODAC and subjected to the temperature cycles, vibration and impact tests established in the Environmental Test Section.

The MTBF of the laser, including the control module and the power supply shall be 2,000 hours or 70 million laser pulses at a rate of 100 pulses per second.



(a)



(b)

Figure 1. Block Diagram of the Remote Sensor for Oil Detection and Classification: a) For Configuration I (RODAC I) b) For Configuration II (RODAC II)

1.-Nitrogen Laser head
2.-He-Ne Laser head
3.-Optical switch
4.-Flat mirror
5.-Flat mirror
6.-Beam expander
7.-Main telescope mirror
8.-Optical shield
9.-Telescope secondary mirror
10.-Window for mirrors adjustments
11.-Optical column housing
12.-Window
13.-Spider
14.-Flat mirror
15.-Pedestal and safety door housing
16.-Safety door
17.-Viewer
18.-Airframe
19.-Flat mirror
20.-Optical shield
21.-Spider
22.-Laser shutter (deleted)
23.-Spectrometer
24.-Image Dissector
25.-Field Verification Telescope

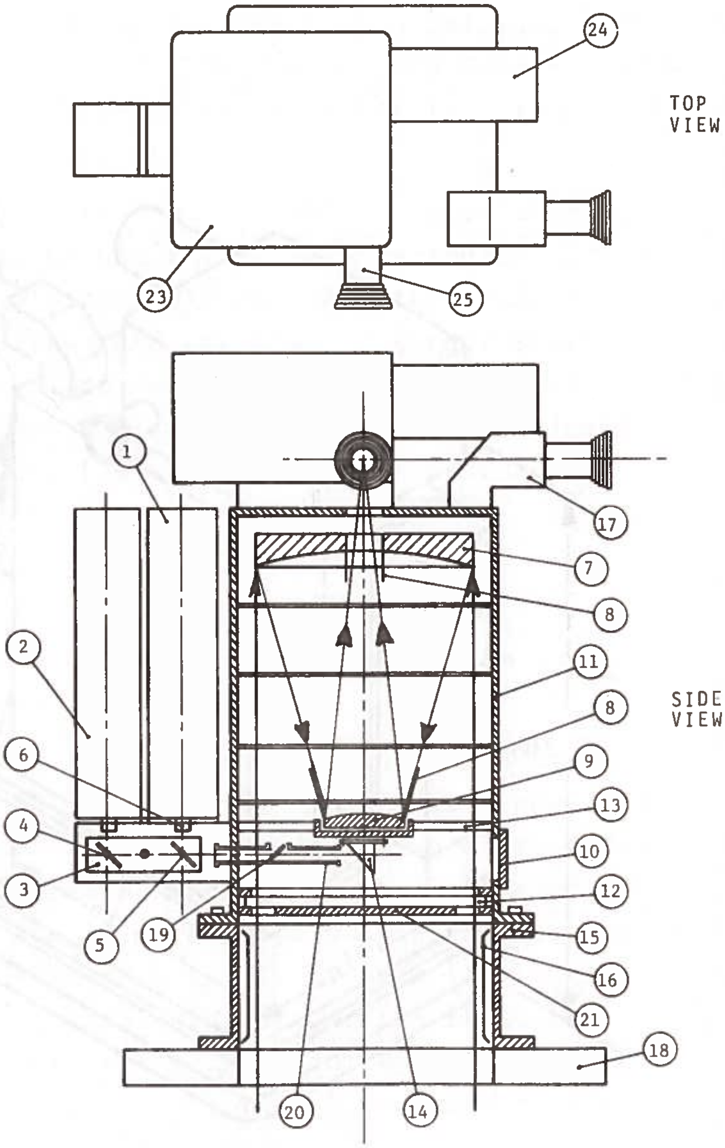


Figure 2. Schematic of the RODAC Optical Column

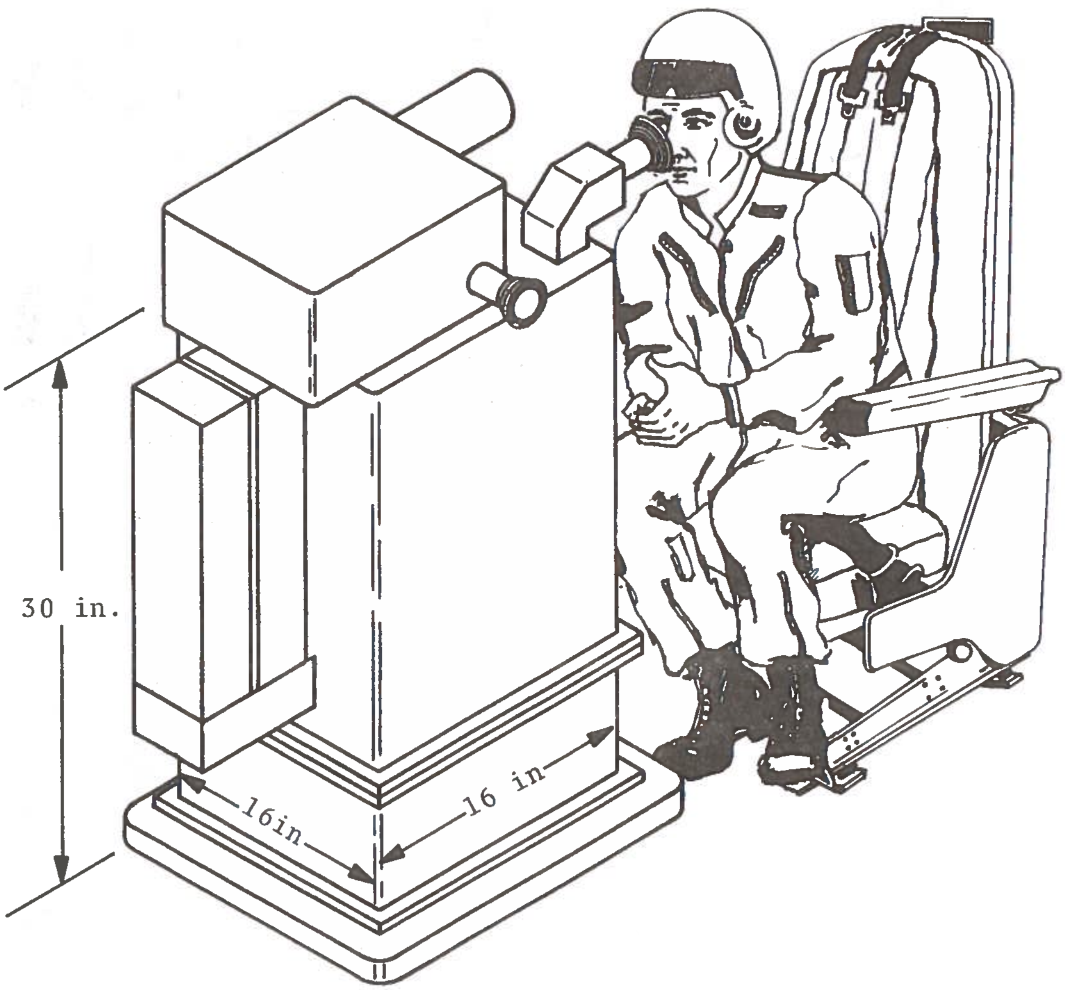


Figure 3. Artist's Conception of the RODAC II

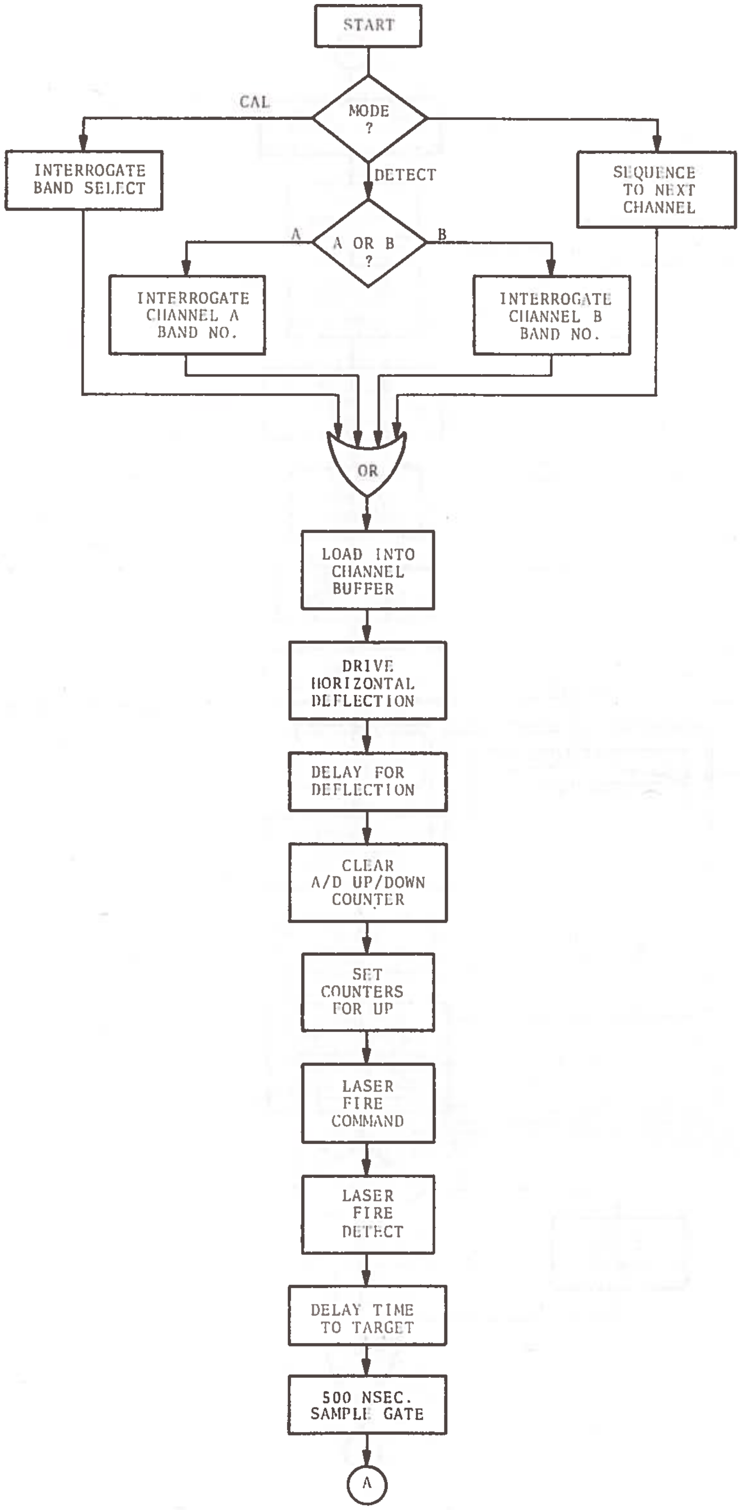


Figure 4a. Signal Processor Operational Flow Diagram

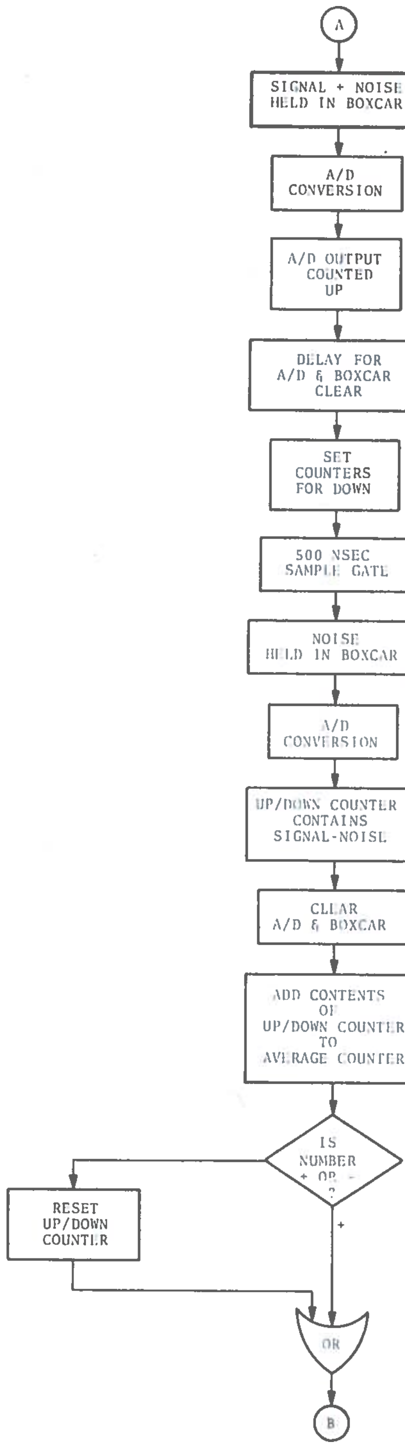


Figure 4b. Signal Processor Operational Flow Diagram (Continued)

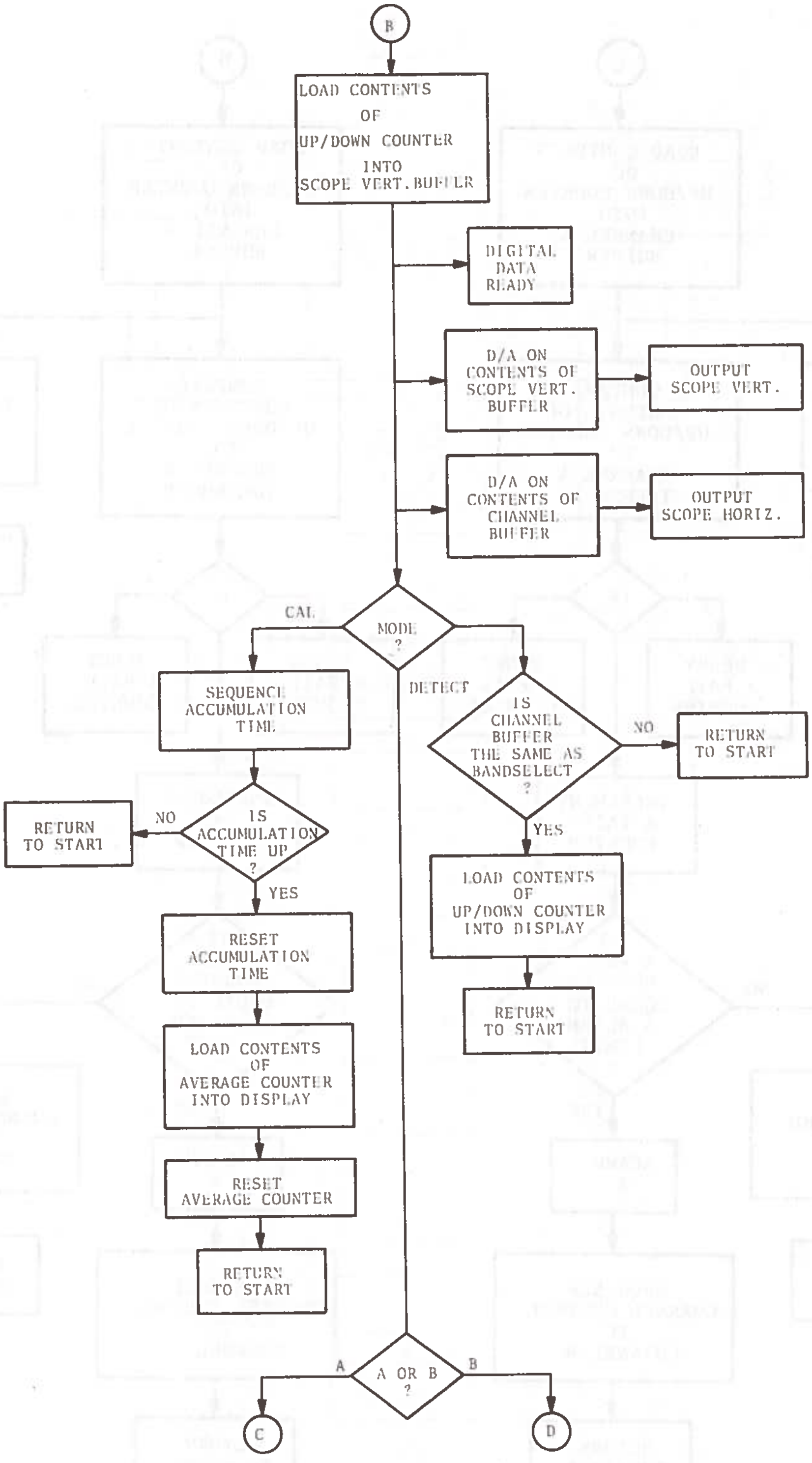


Figure 4c. Signal Processor Operational Flow Diagram (Continued)

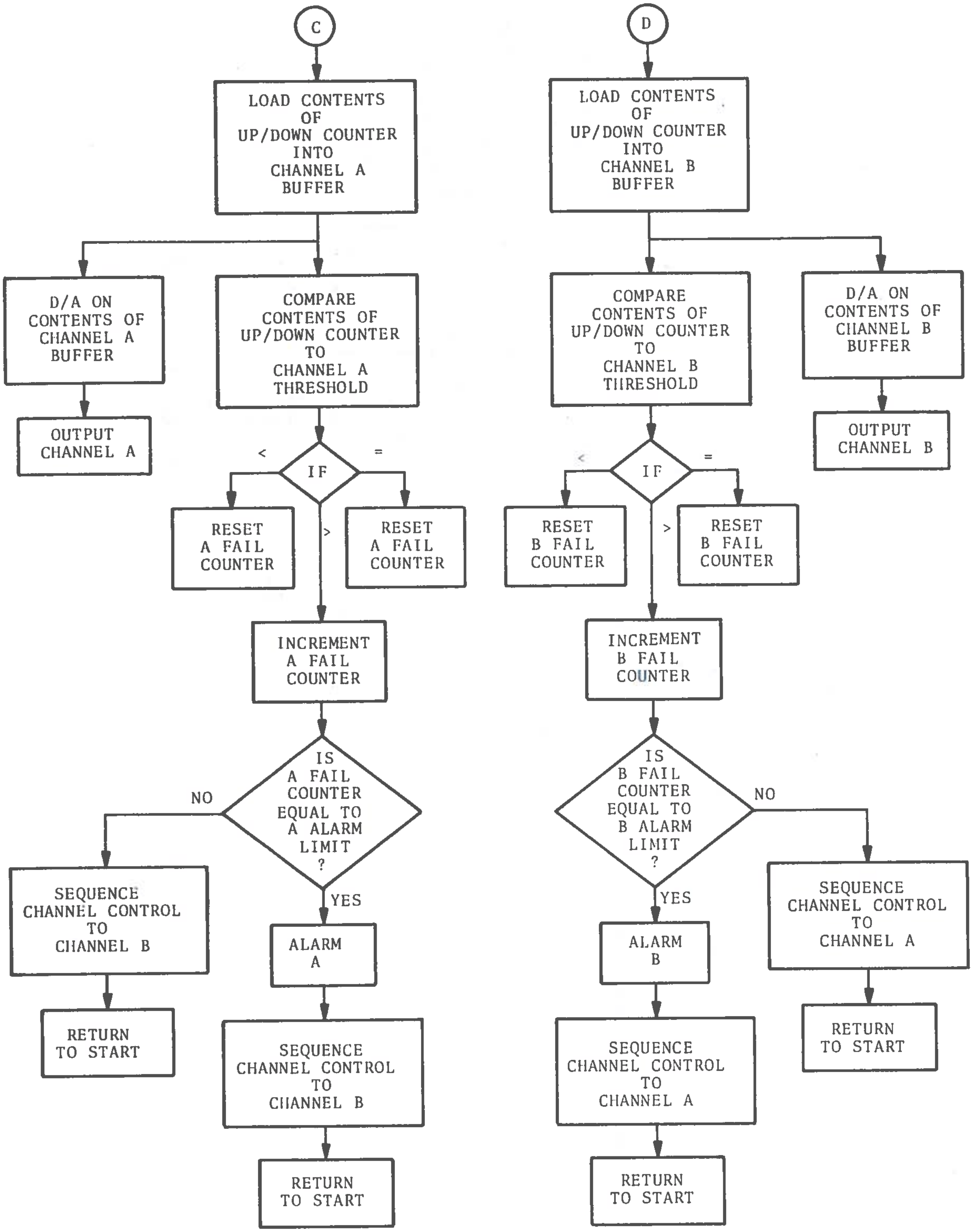


Figure 4d. Signal Processor Operational Flow Diagram (Concluded)

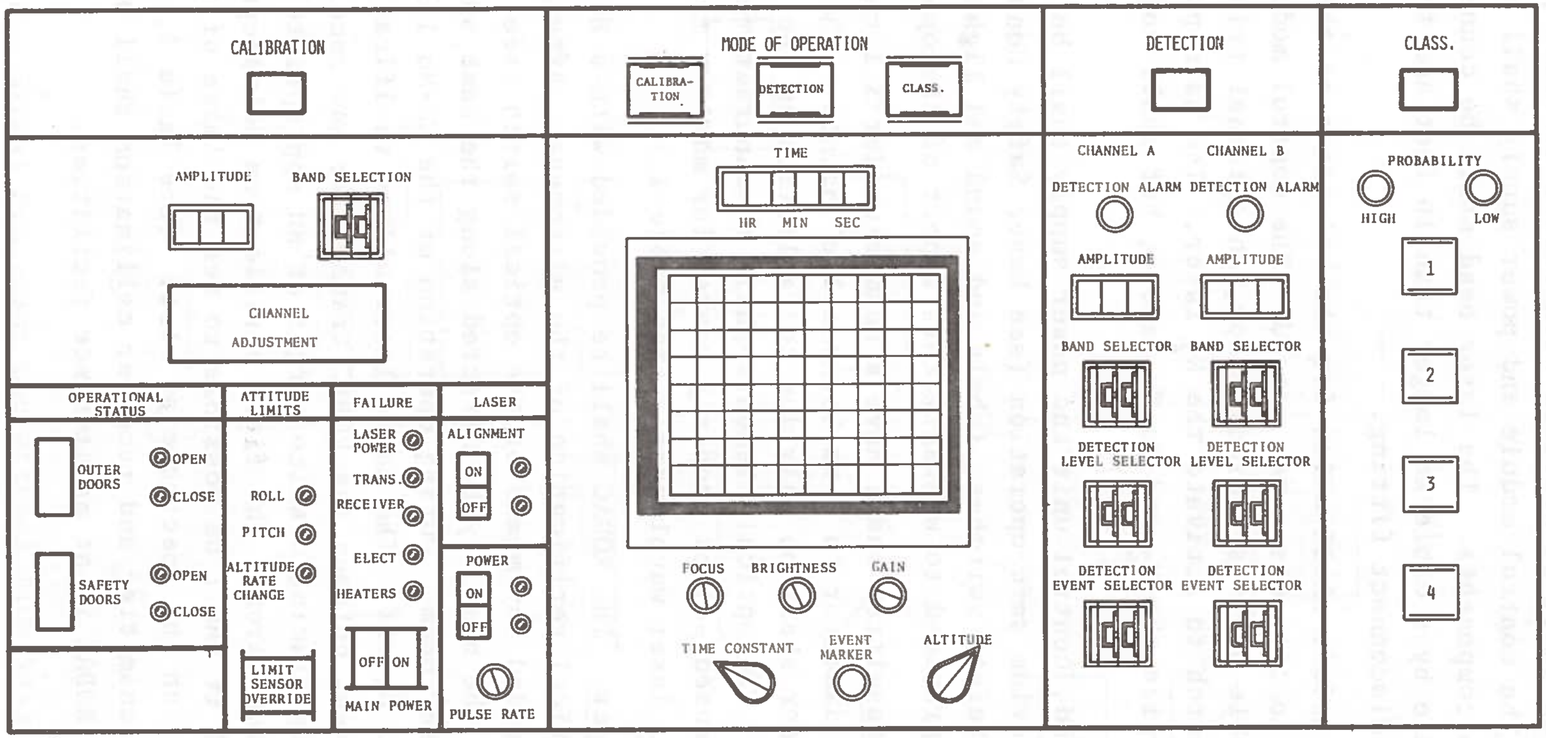


Figure 5. RODAC Console

The laser head shall be provided with screws to allow proper beam alignment. The control module and power supply shall be built using solid state components. The laser head shall be connected to the power module by a cable no longer than 10 feet and terminated by a quick disconnect fitting.

The control module shall allow for the selection of the pulse rate from a few, to 100 pulses per second. The control module shall have available pulse synchronization, an external trigger, and also an on-off switch to activate the N_2 laser. The main power switch shall energize the N_2 and He-Ne lasers, but shall not trigger them.

The laser head, control unit and power supply shall be so designed as to provide safe operation (see Laser Safety Considerations Section). Safety switches, labels and sound and light signals shall be provided to warranty this aspect of the operation.

The laser transmitter shall have a beam expander 3:1 to increase the beam diameter to 9 mm between $1/e^2$ points. The losses in the beam expander shall be only due to reflection on the optical elements. The optical elements shall be manufactured of high grade clear fused silica properly coated for maximum transmittance at the N_2 laser wavelength. (See Table 1.)

b. He-Ne Laser. The RODAC shall be provided with a He-Ne Laser to allow optical verification of the alignment. After the laser beam is expanded, by means of the optical switch (see Figure 2, item 3) the beam may be directed along the same optical path as the N_2 laser beam. During operation of the He-Ne laser, the N_2 laser shall be off. The He-Ne laser allows verification of the optical alignment between the RODAC transmitter and receiver fields-of-view. By placing a white target at an appropriate distance and by viewing through the field verification telescope (see Figure 2, item 25) it shall be possible to see the image of the illuminated target on the spectrometer slit. (See Table 2.) Verification of the transmitter and receiver collimation shall be carried out when the RODAC is at maintenance facilities.

TABLE 1. N_2 LASER SPECIFICATIONS*

Wavelength	337.1 nm
Bandwidth	0.1 nm
Peak Power	7-180 KWatt Adjustable
Energy per Pulse	7×10^{-4} J typical
Average Power	75 mWatt at 75 KWatt peak and 100 ppsec
Repetition Rate	1-100 pps (adjustable)
Pulse Width	10 nsec
Beam Diameter at $1/e^2$ Points	3 mm
Beam Divergence	3 mrad (full angle)
Amplitude Stability	3 Percent
Jitter Stability	Within 2 nsec
Power Requirements	117 VAC 400 Hz, 400 Watts

Weight

Laser Head	22 lb
Power Supply	31 lb
Control Module	21 lb
	74 lb

	Linear Dimensions	Volume
Laser Head	17 x 5 x 4 in	.2 ft^3
Control	14 x 10 x 8 in	.65 ft^3
Power Supply	12 x 10 x 8 in	.55 ft^3
		1.40 ft^3

*The data given in Table 1 are based on a N_2 Laser specification as manufactured by Laser Energy Inc., 320 N. Washington St., Rochester NY 14625.

TABLE 2. HE-NE LASER SPECIFICATIONS*

Wavelength	632.8 nm
Power	5.0 mWatt cw
Beam diameter	0.8 mm at $1/e^2$ points
Beam divergence	1.1 mrad
Warm-up time	3 mWatt at turn on 5 mWatt, 3 minutes after turn on
Operating temperature	10 to 40°C
Altitude	Sea level to 10,000 ft
Humidity	relative humidity 100%
Power requirements	117 VAC, 400 Hz, 50 Watt

	Weight	Linear Dimensions	Volume
Laser head	7.5 lb	18.5 x 3.4 x 3.4 in	.12 ft^3
Exciter	7.5 lb	8.4 x 7.2 x 3.5 in	.12 ft^3
Totals	15.0 lb		.24 ft^3

*The data given in Table 2 are based on the He-Ne Laser Model 120 specifications as manufactured by Spectra Physics, 1250 W. Middlefield Rd., Mt. View CA 94040

c. Optics. The optical system of the transmitter shall consist of two flat mirrors (see Figure 2, items 5, 14) which shall direct the N_2 laser beam (1) in the direction of the vertical (Nadir). These mirrors shall be mounted rigidly to keep alignment. Both the transmitter and receiver optics shall be arranged in such a way to allow for angular adjustments with respect to the aircraft frame and shall have screws that allow locking in the adjusted position. The optical switch (see item 3) integrated with the mirrors (4), (5) and (20) allows the selection between the He-Ne laser beam for wavelength calibration and verification of the optical anlignment or the N_2 laser for regular remote sensing operation. In the wavelength calibration mode the mirror (4) and (19) shall be in the path of the He-Ne laser beam allowing the "feeding" of the spectrometer via telescope optics.

The flat mirrors which are part of the transmitting optics shall be super hard coated with a dielectric coating to have maximum reflectance at the laser wavelength (337.1 nm). These mirrors shall stand a peak power density* of 10 KWatt mm^{-2} during pulse duration of 20 nsec at a rate of 200 pulses per second. Particular attention shall be taken to minimize the scattering properties of the coating.

1.1.2 Receiver

The receiver consists of a telescope, a viewer, a window, a spectrometer, an image dissector, associated doors and fail safe mechanisms.

a. Telescope. The telescope shall be of the Cassegrain type, since this configuration renders a compact system when compared to any other two-mirror systems. Within the Cassegrain type a Dall-Kirkham system (ellipsoidal primary and spherical secondary) is recommended instead of the classical Cassegrain (paraboidal primary and hyperboidal secondary). The Dall-Kirkham system in this application gives equal optical performance at a lower manufacturing cost.

*These test conditions have been evolved for super hard coatings by Laser Energy, Inc., 320 North Washington St., New York NY 14626

The telescope primary mirror shall be 13 inches in diameter f/3 and the secondary will introduce an amplification ratio giving an overall f/4.7.

The material to be used for the optics, as well as for the telescope tube, shall be Tenzalloy or equivalent (Ref. 1). A telescope made from this material has several advantages for the application under consideration. One important advantage is the high thermal diffusivity of the Tenzalloy which minimizes the time required for temperature stabilization after a temperature change and therefore minimizes temperature gradients, maintains the telescope in focus regardless of temperature, provides easy mounting and adjustment of the primary mirror, etc.

The structure of the mirror shall be of a light weight type with reduction in thickness from the center to the edge (Ref. 1). The mounting of the mirror shall be in the form of a collar around the central hole. The mirror and mounting shall be manufactured from a single cast piece. The mirror blanks, primary and secondary, shall be properly stress relieved and annealed. The blanks shall be ground to the proper shape. This step shall be followed by a 75 microns electrolytic deposition of nickel-nickel-phosphate composition, Kanogen,* on which the final figuring and polishing process shall be carried out. After the surfaces are completed, aluminum shall be evaporated thereon, followed by the application of a protective coating.

The mounting of the secondary mirror shall be done in such a way that easy adjustments for proper alignment can be realized. The collimation between the transmitter and receiver optical axis shall be maintained within $\pm 4 \times 10^{-4}$ rad. Lock screws shall be provided to assure that once the alignment is carried out the mirror will be locked in position. The secondary mirror and its mounting shall be positioned in the telescope tube by means of a spider. The spider shall be apodized. The primary and secondary

*Trade name owned by the General Transportation Company of Chicago.

mirrors as well as the inside of the telescope tube shall be provided with sufficient optical shielding (Ref. 2) to eliminate direct viewing from the focal plane of the telescope as well as to minimize multiple reflections and scattering to acceptable levels compared with the fluorescence signals.

The telescope shall be of fixed focus (no focusing adjustment) and will be set for a target distance of 1000 feet.

The telescope optics shall be coated with aluminum and a protective overcoat (Spinel) against a salt air environment and shall be used to provide maximum efficiency over the spectral range from 350 nm to 700 nm. Particular attention shall be given to minimizing the scattering properties (Ref. 3) of the evaporated aluminum.

b. Window. A protective window will be provided at the entrance pupil of the telescope. This window will be fixed, and is intended to keep moisture, dirt and salt spray out of the optics. The installation of the window in the aircraft shall not compromise the pressurization requirements when the aircraft flies at ceiling altitude.

The window shall be made of clear fused silica Schlieren seed free quality such as Dynasil #4107 or equivalent. The finish thickness of the window shall be such that flexure when mounted in the cell will not impair the performance of the telescope. The window surface finish shall be such that the optical and photometric properties of the telescope are not impaired. In order to reduce weight the window should be mounted on a spider which will be oriented to coincide with the spider of the telescope secondary mirror and thereby not introduce extra obscuration.

The optical chamber confined by the telescope housing and the window shall utilize dessicants to eliminate moisture and provisions shall also be made to purge the chamber with dry nitrogen when necessary. The window shall have a heating element distributed (grid) on the clear aperture to keep the surface above the dew point. The overall obscuration of the window aperture by the grid shall not exceed 0.01 A_r, where A_r is the optical receiver area.

The heating element when operating at maximum temperature shall give undetectable irradiance on the spectrometer. The window shall withstand dynamic loads during the mission without degradation of performance. The window shall withstand thermal loads when flying at ceiling altitude.

c. Safety and Outer Doors. A safety door shall be provided in the lower part of the optical column and outside the window. This safety door shall be divided in two halves and shall be activated (open-close) manually by the RODAC operator. The safety door shall activate a switch to display its status in the console, i.e. (open-closed). This switch shall also interlock with both power supplies.

The outer door shall be part of the airframe and shall be designed and operated in accordance with aircraft engineering requirements and aircraft crew duties.

d. Light Funnel for Telescope-Spectrometer Coupling. A fiber optics light funnel shall be installed (Ref. 4) at the focal plane of the telescope to accommodate a circular field-of-view, (3 mrad, full aperture) into the spectrometer entrance slit of 0.6 mm width. The f-number of the telescope shall be maintained at the exit of the light funnel. The transmittance of this light funnel shall cover a range from 330 nm to 700 nm.

A removable beam splitter that can be introduced in the optical path in front of the light funnel shall be installed to allow the use of a small telescope for field verification of the alignment between the laser transmitter and the optical axis of the receiver.

e. Spectrometer. The spectrometer shall be an Ebert-Fastie type (Ref. 5) with a fiber optics light funnel in front of the entrance slit to increase the energy throughput.

The specifications for this spectrometer are presented as follows:

1) Grating: reflective replica, flat grating, 295 line mm^{-1}, blaze angle = 4.2°.

2) f/ ≅ 4.7

3) Spectral bandwidth: $\Delta\lambda$ avg. = 10.2 nm.

4) Linear dispersion:

   a. $\Delta\lambda/\Delta x$ = 18.0 nm mm^{-1}.

   b. from 435.8 nm (Hg V) to 546.1 nm (Hg), $\Delta\lambda/\Delta$ = 17.8 nm (avg.). The dispersion will vary somewhat across the image plane because of the dependence on the cosine of the diffracted angle.

5) Spectral range at focal plane to spectrometer (tilted 6.9° to align image plane with the tangential astigmatic focal plane): 345.0 nm to 703.0 nm.

6) Grating angle of incidence = 30.89°.

7) Diffraction angle for 450.0 nm = 22.37°.

8) Wavelength of peak spectral efficiency in the Ebert mode: 443.6 nm.

9) Wavelength of peak spectral efficiency in the Littrow mode: 550.0 nm.

Two spherical mirrors shall be used in this spectrometer instead of one, as is often used on conventional Ebert spectrometers, to minimize cost and to reduce the mass of the mirror and minimize vibratory induced forces. The mirrors have a curvature of 360 mm (180 mm focal length). The mirrors shall be secured in a rugged aluminum mount and retained with beryllium copper spring clips.

The diffraction grating shall be a 295 line mm^{-1} replicated type made of clear fused silica with a blaze angle of 4.2^{o}.

The width of the slit shall provide 10.0 nm resolution at a nominal dispersion of 17.8 nm mm^{-1} to accommodate 30 spectral channels, 10 nm wide and seperated by 12 nm between central channel wavelengths.

A two element cylindrical lens is positioned in front of the detector. The purpose of this lens is to demagnify the length of the slit to match the length of the aperture in the image dissector. This lens has anti-reflection coatings on all surfaces.

The dimensions for the image shall be selected to fit within the usable diameter of the photocathode.

f. Image Dissector. The photoelectric receiver shall be an image dissector tube (Ref. 6). This tube shall be mounted in a ruggedized housing along with its magnetic shield, focusing coil, and deflection yoke (Figure 6). Attached to the rear of this housing in its own shielded compartment shall be a module which contains the hardware, focus coil regulator, deflection yoke driver, and signal preamplifier. This complete receiver section is remote from the signal processor and is mounted with the receiving optics in such a fashion that the output image of the spectrometer can be focussed directly onto the 21 mm of the 26.2 mm image dissector photocathode diameter.

This image is magnetically focussed on the aperture plate in the rear of the drift section of the dissector tube. The electron image is magnetically deflected to a specific position with respect to the output aperture upon command of the signal processor. The energy passing through the aperture is amplified by a ten dynode electron multiplier in the image dissector tube. The amplified signal appears as a small current through the anode load resistor and the voltage thus produced is amplified in a wide band preamplifier.

1.1.3 Signal Processor

The RODAC shall operate in any of three selected modes during a surveillance flight: calibration, detection and classification. The principle of operation of these three modes (Ref. 6) may be followed by referring to Figures 4, 7, and 8. The operating modes discussed herein presume an overall preinstallation system alignment and calibration and describe the normal sequence of operations for each successive mission.

a. Calibration Mode. The calibration function is executed prior to detection and classification to identify any change in performance of the system since the previous surveillance mission.

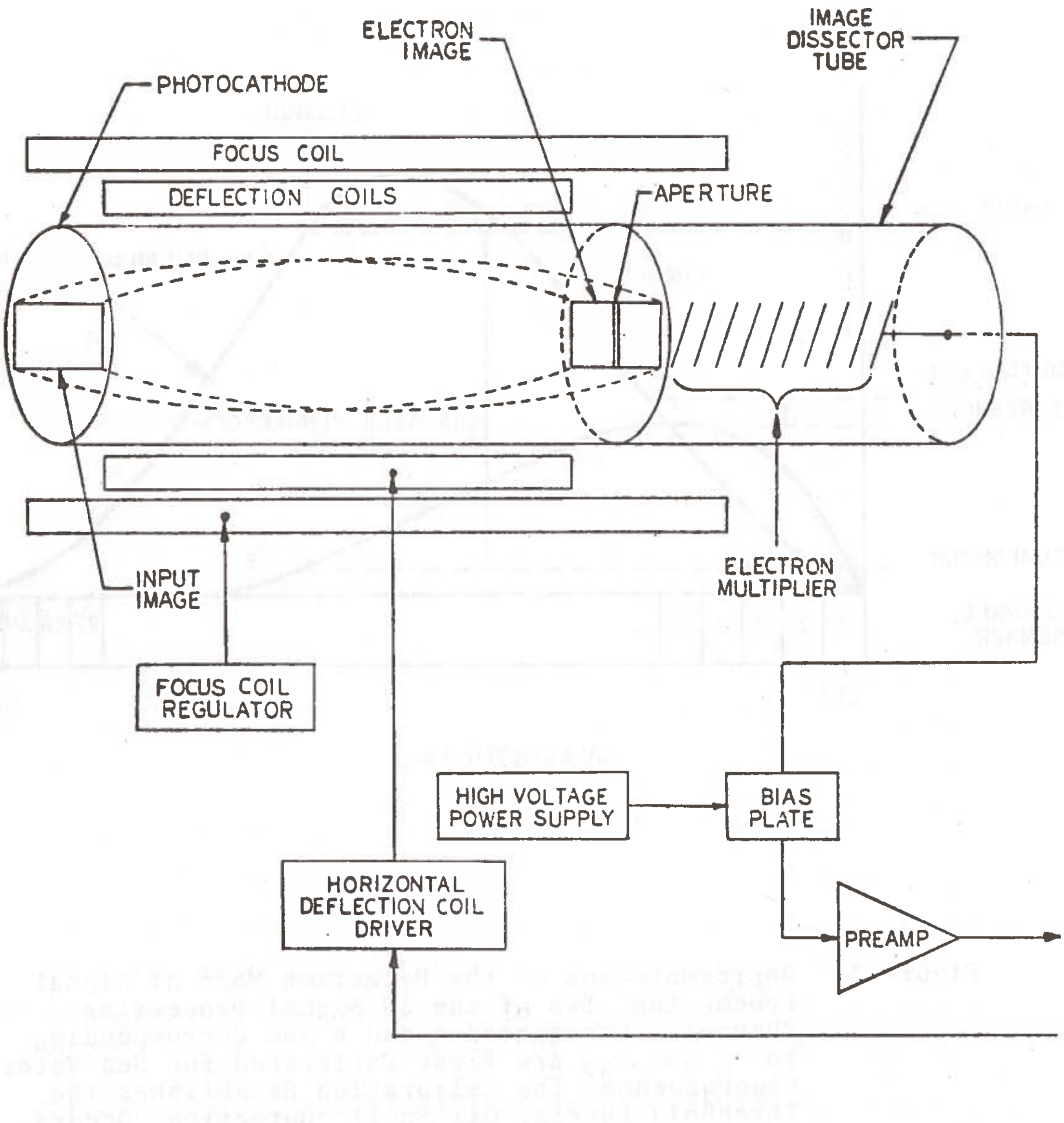


Figure 6. Image Dissector and Block Diagram of Associated Circuitry

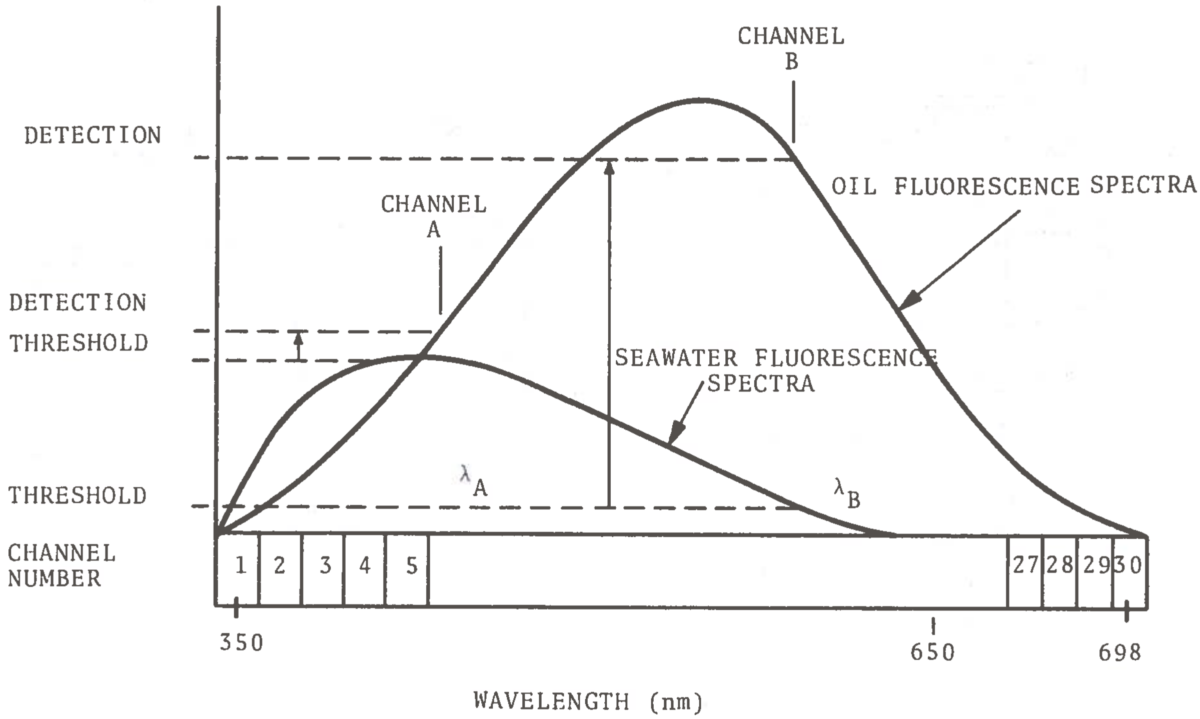


Figure 7. Representation of the Detection Mode of Signal Processing. Two of the 30 Signal Processing Channels, Designated A and B and Corresponding to λ_A and λ_B, Are First Calibrated for Sea Water Fluorescence. The Calibration Establishes the Threshold Levels. Oil Spill "Detection" Occurs When the Signal Level in both Channel A and B Exceeds the Thresholds a Predetermined Number of Times

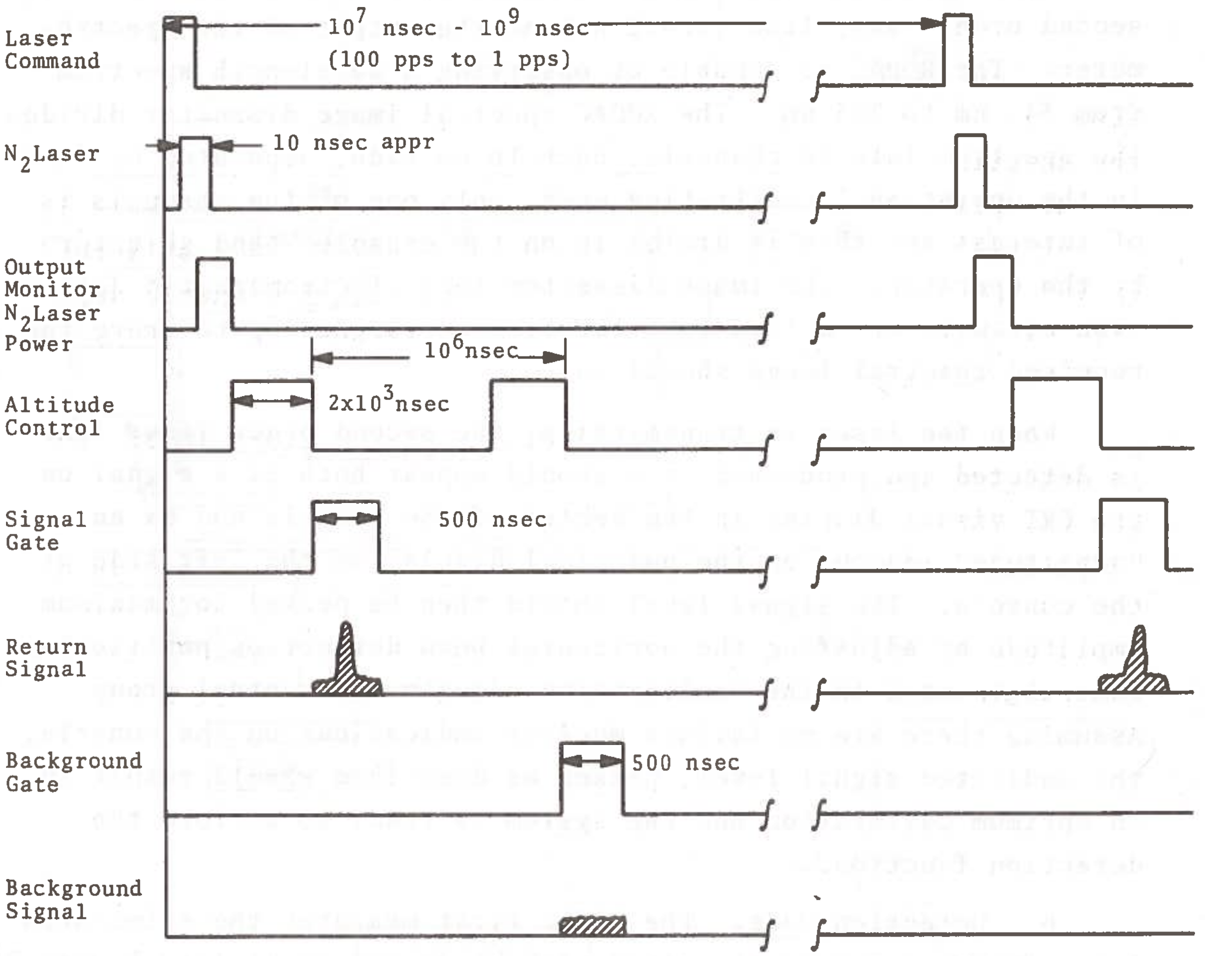


Figure 8. RODAC Time Sequence

The calibration function makes it possible to determine that reasonable levels of transmitted and received signals are available and that the spectrometer-image dissector interface has not been physically or electronically deregistered.

Wavelength calibration is effected by the observation of the second order laser line (674.2 nm) at the output of the spectrometer. The RODAC is capable of observing a wavelength spectrum from 345 nm to 703 nm. The RODAC spectral image dissector divides the spectrum into 30 channels, each 10 nm wide, separated by 2 nm. In the operational calibration mode, only one of the channels is of interest and this is dialed in on the console "band selector" by the operator. The image dissector tube electromagnetic deflection circuits are driven to a location corresponding to where the received spectral image should be.

When the laser is transmitting, the second order laser line is detected and processed, and should appear both as a signal on the CRT visual display in the center of the console and as an "amplitude" readout on the numerical display on the left side of the console. The signal level should then be peaked for maximum amplitude by adjusting the horizontal beam deflection positioning control located in the "calibration adjustment" control group. Assuming there are no failure monitor indications on the console, the indicated signal level, peaked as described should result in an optimum calibration and the system is ready to perform the detection function.

b. Detection Mode. The RODAC first measures the stimulated laser fluorescence of the water without an oil spill (see Figure 7). Two of the thirty channels are selected and identified as Channel A and Channel B (a channel is a spectral resolution element). Threshold level is then obtained as follows: the RODAC selects Channel A. When the channel is selected, the laser is commanded to fire and the RODAC follows a time sequence (see Figure 8). At a time determined by the distance to the target a range gate is opened for 500 nsec. The output of the range gate contains background noise plus any fluorescence stimulated by the laser striking the target. The peak amplitude of this signal plus noise is detected and held in a peak detector and hold circuit, where an analog-to-digital conversion is done on the contents and the result is stored. Again the range gate is opened for 500 nsec and a sample of the background noise is taken. This noise is detected and also held in the peak detector and hold circuit for the analog-to-digital conversion. The noise is now subtracted from the signal plus noise, detected on the first opening of the range gate, and the difference stored as Channel A signal. Now the RODAC selects Channel B and the laser is again fired with the above sequence repeated. The resulting information is stored as Channel B signal. This procedure is repeated and the digital representation of Channel A and B are accumulated in storage registers for a period of time and an average of each register is determined and displayed to the operator. When the operator determines he has a representation of a clean water amplitude level he will set these values plus some safety margin above the average threshold level into the Detection Level Selector as the thresholds for Channels A and B respectively. Subsequent laser pulses and signal processing follow the same sequence as above except that the digital representations of the signals are not stored but compared to their respective thresholds. If the difference exceeds the threshold, a register is incremented by one. If a pre-programmed number of consecutive registrations is exceeded from either Channel A or Channel B, it is possible that an oil spill has been detected and an alarm is generated. The number of consecutive registrations required to cause an alarm is manually set using the Detection Event Selector. The purpose of this arrangement is to reduce the false alarm rate due to random noise or spurious signals above threshold.

c. Classification Mode. When detection is obtained the RODAC mode of operation automatically switches to a classification mode of operation. In this mode the thirty channels are stepped sequentially and the entire cycle repeated continuously. For each channel the laser is commanded to fire. The range gate is opened twice as described previously, so that the noise can be subtracted from the signal, but at this time no storage takes place. Instead, the information is sequentially outputed for further processing evaluation and display.

The Signal Processor of the RODAC shall be based on the logic utilized in the OMSA (Ref. 6).

The sequence of events for one cycle of the Signal Processor can be followed by referring to the flow diagram, Figure 4.

The cycle starts with the selection of the Channel (1-30). Depending on the mode of operation, the timing logic will interrogate one of the following channel registers and load and contents of that register into the CHANNEL buffer.

CAL mode	contents of BAND SELECT
DETECT mode	contents of CHANNEL A BAND or CHANNEL B BAND alternately
CLAS mode	state of automatic channel sequencer.

The contents of the CHANNEL buffer are converted into analog form and used to drive the magnetic deflection coil of the image dissector such that the position of the photocathode image corresponding to the 10.0 nm wide channel required for this cycle is positioned on the aperture at the rear of drift tube. A delay of approximately 1.5 milliseconds is provided to allow the magnetic deflection to settle to the proper position.

Next the up-down counter, which is used to store the output of the analog-to-digital converter, is cleared and set to count "up". The first conversion will be done on a sample of the background plus any fluorescence stimulated by the laser.

Now the laser is commanded to fire and a time sequence starts (see Figure 8). All ranging logic waits for the actual firing of the laser indicated by a synchronization signal received from the laser modulator. When the actual time of the laser firing is detected, a delay begins which corresponds to the time for the laser energy to reach the target plus the time of the fluorescent energy to propagate from the target area to the optical receiver.

This time delay should be adjustable by the operator from the console or preferably the adjustment shall be automatic with manual override.* When this time has elapsed a sample gate is opened for 500 nanoseconds (5×10^{-7} sec). This sample contains background noise plus any fluorescence stimulated by the laser. The sampled signal is held in the peak sample and hold circuit while an analog-to-digital conversion is done and the data stored in the "up" direction of the up-down counter. A delay is now provided to clear the peak sample and hold circuit and set the up-down counter to "down."

Without changing the position of the photochathode image with respect to the aperture, another 500 nsec sample is taken. This time, the sample will contain only the background. Again the sample is held in the peak sample and hold circuit and an analog-to-digital conversion is made. Thus, by counting this new data "down" a simple subtraction is performed, and the up-down counter contains just the digital equivalent of the amplitude of any fluorescence generated by the laser. Again the peak sample and hold circuit is cleared.

The data contained in the up-down counter is added into the average counter which is used in the CAL mode and explained later. This does not clear the up-down counter.

A test is now performed to determine whether the data stored in the up-down counter is positive or negative. If it is negative the counter is reset.

Now the content of the up-down counter is loaded into the SCOPE VERT buffer. At this time, data is ready for external use. Both the SCOPE VERT buffer and the CHANNEL buffer are connected in parallel to digital-to-analog converters which track the contents of these two buffers.

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*The MRS System has available continuous altitude information in digital form.

The processing of the data in the up-down counter from this point in the sequence depends upon the mode of operation. For the CAL mode, an accumulation time counter is incremented by one. If the accumulated time is not complete the sequence will return to START. When the time is complete, the contents of the average counter is divided by 1024 and loaded into the LED display buffer. The average counter and accumulation time counter are reset and the sequence returns to START.

For the CLAS mode the required data is already available in both analog and digital form. If the content of the Channel buffer is the same as the BAND SELECT register the content of the up-down counter is loaded into the LED display buffer and the sequence returns to START.

For the DETECT mode the operational sequencer first looks to determine whether it is in a Channel A cycle or a Channel B cycle. For this example a Channel A cycle is chosen. The content of the up-down counter is loaded into the Channel A buffer. A digital-to-analog converter produces a voltage at the Output of Channel A on the front panel of the Signal Processor according to the contents of the Channel A buffer.

The content of the up-down counter is at this time compared to the Channel A Threshold (determined in the CAL mode). If the content of the counter is greater than the threshold, the A channel fail counter is incremented by one. If the data is either equal to or less than the threshold the A channel fail register is reset. Next the state of the fail register is compared to the A Alarm Limit. If it is equal to or greater than the Alarm Limit, an A alarm is triggered.

If it is less than the A Alarm Limit no alarm is indicated. Regardless of whether an alarm condition exists or not, the sequence switches to a Channel B cycle and returns to START. The Channel B cycle is exactly the same as the Channel A cycle using its respective buffer, digital-to-analog converter, threshold, and alarm limit.

1.1.4 Computer

The RODAC shall make use of a minicomputer to carry out the oil fluorescence spectra pattern recognition function in real or quasi real-time when the system is performing in the classification mode. It may also be used to carry out other computational and housekeeping functions.

The computer to be used shall be a ROLM RUGGEDNOVA 1602 or equivalent. The RODAC in the system I configuration shall share this computer.

The 1602 includes a 1 microsecond core memory cycle time, interrupt processing capability, and memory expansion to 65K. It contains a microprocessor which executes 32-bit microinstructions at a 5 MHz rate. One-eighth of the microprogram capacity is utilized in implementing the 1602 instruction set.

The 1602 computer shall interface with the signal processor via I/O interface. The computer shall store enough oil signature information carry out the pattern recognition (see Sections 2.1.2 and 2.3).

1.1.5 I/O Interface

The I/O interface shall be used to couple all the RODAC subassemblies which require the usage of the RUGGEDNOVA 1602 computer and the magnetic tape data recorder of the MRS System. The requirements are discussed in Section 1.1.6 and 2.1.2.

1.1.6 Data Recorder

The RODAC shall satisfy two main functions: detection and/or classification in real-time, and data gathering for further processing at the U.S. Coast Guard facilities.

To satisfy the second requirement, data have to be recorded on magnetic tape for further processing.

The first block of data that has to be recorded is the one relative to the operational status of the remote sensor plus time:

Time: hour, minute, second

Position: latitude, longitude

Operational Status: outer door (open-close)
safety door (open-close)

Altitude: roll (acceptable-unacceptable)
pitch (acceptable-unacceptable)
yaw (acceptable-unacceptable)
altitude rate change (acceptable-unacceptable)
altitude

When the instrument operates in the calibration mode:

Calibration:	yes
Detection:	no
Classification:	no
Band selector:	0-30
Amplitude:	0-99

When the instrument operates in the detection mode:

Calibration:	no
Detection:	yes
Classification:	no
Channel A:	0-30
Amplitude:	0-99
Detection Level Selector:	0-99
Detection Event Selector:	1-99
Alarm:	yes-no*
Channel B:	0-30
Amplitude:	0-999
Detection Level Selector:	0-99
Detection Event Selector:	1-99

*When the detection by any of the channels or the classification takes place, the time has to be recorded with the precision of a second.

Alarm: yes-no*

When the instrument operates in the classification mode:

Calibration: no

Detection: no

Classification: yes

Oil Types: 0-4*

Probability: high - low

Integration time: 1-9 steps

Spectral Data: maximum rate of 20 spectral channels per second at a resolution of 8 bits (1 part in 256) at all sampling rates.

An incremental magnetic tape recorder for the data recording shall be used. Voice and event marks shall be recorded on a separate reel magnetic tape recorder. In order to be able to cross-correlate the recorded data with the voice-event recording both shall have the proper base (seconds). A separate recorder for voice and events allows independence between the data processing and the reconstruction of remote sensing events and descriptions after the mission.

1.1.7 Console

The display and controls shall be all integrated in one console with the exception of the optical controls and adjustments that will be in the main body of the RODAC.

The console shall be designed in such a way that the man-machine interface is properly considered for the type of mission that the RODAC is intended. For better definition of the man-machine interface the operators of the system will be U.S. Coast Guard Technicians (AT, AE and MST ratings).

The proposed console (Figure 5) reflects the different RODAC modes of operation as described in Section 1.1.3.

The console shall have clearly identified the functions of the system and display all the housekeeping elements (operational status, attitude limits and failure), the operational status as described in Section 1.1.2c and the attitude limits as described in Section 1.2. Reduction in laser power output, laser transmitter power supply failure, receiver power supply failure, electronics power supply failure, and failure of the heaters will be displayed on the console as well as the normal operation. All indicating lights, red (warning) and green (operational) shall be LEDs.

1.2 AIRCRAFT FLIGHT REQUIREMENTS DURING REMOTE SENSOR OPERATION

In order to avoid fluctuations in the fluorescence signals received by the remote sensor and therefore degradation in the detection and classification capabilities of the system, due to changes in aircraft attitude during the measurements, these changes will be constrained, during remote sensing, to the following limits (see Figure 9):

1) Roll shall not exceed $\pm 10°$.
2) Pitch shall not exceed $\pm 5°$.
3) Yaw shall not exceed $\pm$ 10°.
4) Altitude rate changes during remote sensing shall not exceed ± 30 ft sec^{-1} or a total 100 ft change at 1000 ft altitude durin the RODAC integration time to complete one spectral measurement

A unit, Aircraft Attitude Limit Sensor (ALS), shall send an inhibit signal to the N_2 Laser trigger circuit when any of the above limits are exceeded. When the aircraft regains acceptable flight attitude the inhibit signal will cease and the remote sensor shall again operate normally.

An override control shall be available to disable the ALS at the discretion of the operator.

1.3 PHYSICAL DESCRIPTION

The RODAC system shall consist of a transmitter, a receiver, a signal processor, an I/O interface, a computer, a console, a data

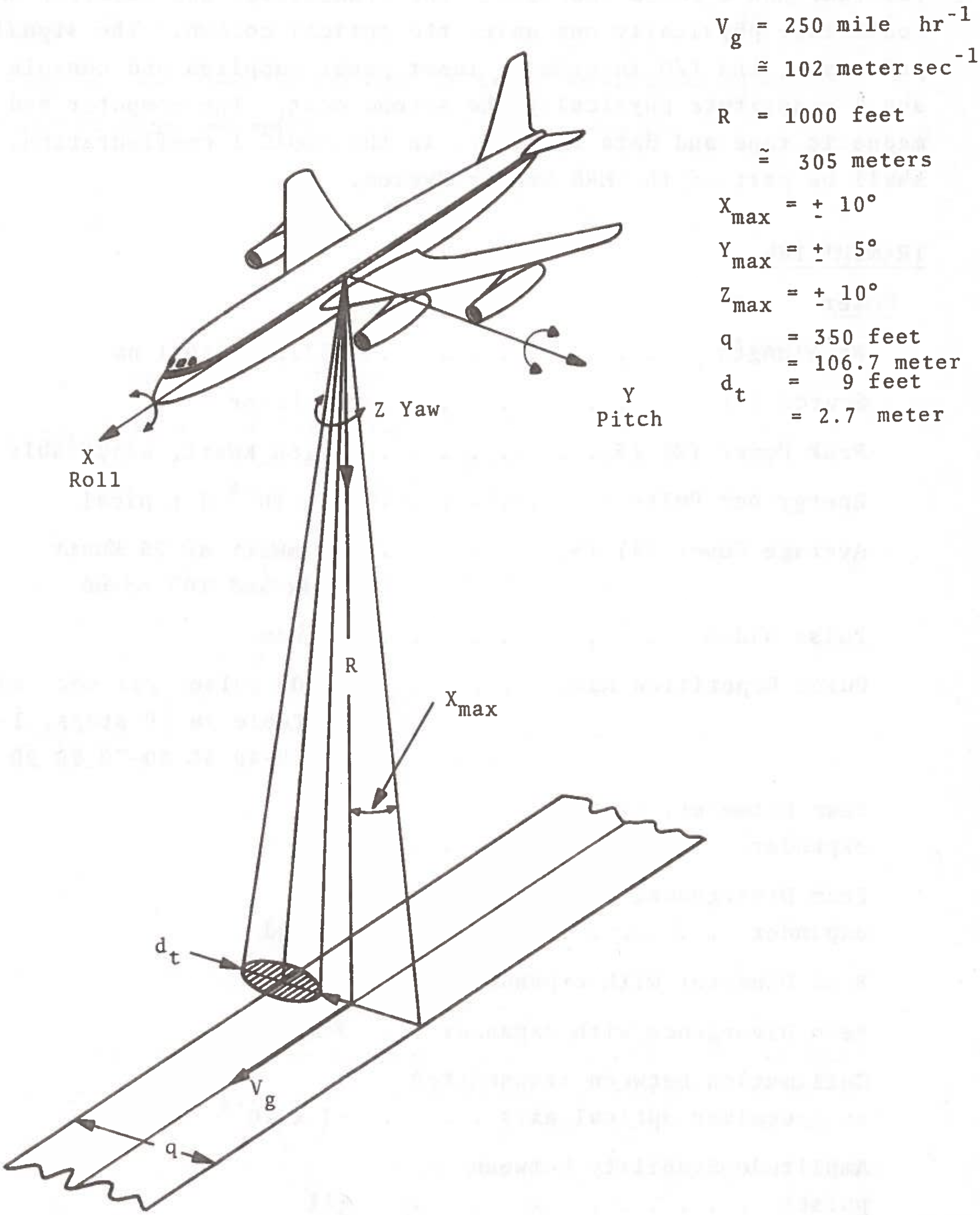

Figure 9. Schematic Showing the Relationship Between RODAC Resolution Element and Aircraft Attitude

recorder and a voice recorder. The transmitter and receiver shall constitute physically one unit, the optical column. The signal processor, the I/O interface, laser power supplies and console shall constitute physically the second unit. The computer and the magnetic tape and data recorder, in the RODAC I configuration, shall be part of the MRS Sensor System.

TRANSMITTER

Power

Wavelength.	337.1 nm ±0.1 nm
Source (1).	N_2 Laser
Peak Power (2) (3).	7-180 KWatt, adjustable
Energy per Pulse.	7×10^{-4} J typical
Average Power (4) (5)	75 mWatt at 75 Kwatt peak and 100 ppsec
Pulse Width	10 nsec
Pulse Repetition Rate	1-100 pulses per sec adjustable in 10 steps, 1-10-20-30-40-50-60-70-80-90-100
Beam Diameter, without expander.	3 mm
Beam Divergence, without expander	3 mrad
Beam Diameter with expander . . .	9 mm
Beam Divergence with expander . .	9 mrad
Collimation between transmitter and receiver optical axis	$\pm 4 \times 10^{-4}$ rad
Amplitude Stability between pulses	±3%
Amplitude Stability (3)	±3%

Flat Mirrors

flatness and surface finish . .	compatible with the resolution of the optical system
optical coating (8)	maximum reflectance at the specific laser wavelength and compatible with power densities
Power consumption (6)	117 VAC, 400 Hz, 400 Watt, max.
Size, N_2 Laser Head	17 x 5 x 4 in max.
Weight, N_2 Laser Head	22 lb, max.

ALIGNMENT

Wavelength	632.8 nm
Source	He-Ne
Power	5 mWatt, cw
Beam diameter, without beam expander	3 mm
Beam divergence, without beam expander	1 mrad
Beam diameter, with expander . .	9 mm
Beam divergence, with expander	3 mrad
Power consumption (6)	117 VAC, 400 Hz, 50 Watt, max.
Size, He-Ne laser head	18.5 x 3.4 x 3.4 in, max.
Weight, He-Ne laser head.	8 lb, max.

RECEIVER

Wavelength	345-703 nm
Number of Channels	30
Channel width	10 nm (between 10% points)
Separation between Channels . . .	12 nm (between central channel wavelength)

Blocking Filter 337.1 nm line . .	
Rejection	10^3: 1
Transmittance in 400-700 nm region	90%
Telescope Aperture	13 in
Telescope Optical Configuration	Cassegrain Type
f-number, overall	4.7 approx.
Telescope Optical Material . . .	Tenzalloy + Kanogen or equivalent
Optical Coating (7)	Aluminum
Protective Optical Coating . . .	Compatible with maximum reflectance and environmental requirements

Window

Material (10)..............	Clear fused silica Dynasil #4107 type or equivalent
Size......................	13-1/2 in clear aperture
Flatness and surface finish.	Compatible with the resolution of the optical system
Heater	
Type....................	Conductive grid on window, 1% total window area, max.
Power Consumption.......	15 Watt, max.

Optical Column

Material..................	Same as telescope optical material
Size......................	30 x 15 x 15 in., max
Weight (9)................	100 lb, max.
Optical Shielding..........	Baffles to minimize stray light at focal image plane (See Section 1.1.2)

Spectrometer

Type........................	Ebert-Fastie or similar
Grating.....................	Reflective replica, flat, 295 lin. mm^{-1}
f-number....................	To match telescope
Linear dispersion...........	18 nm mm^{-1}
Resolution	10 nm
Demagnification lens at exit.	As required
Spectral format.............	21 mm x 6.3 mm (358 nm range)

Image Dissector

Type........................	magnetically focused
Spectral response...........	S-20 extended red
Maximum response............	420 nm $\pm$ 10 nm
Minimum photocathode radiant responsivity...............	60 mAmpere $Watt^{-1}$ @ 420 nm
Gain	5×10^5 @ 1400 $\pm$100 volts
Dark current	1×10^{-10} Ampere @ 5×10^5 gain
Aperture size.	6.3mm x .55 mm
Photocathode Uniformity. . .	95 $\pm$5% of photocathode diameter shall be $\pm$2% of max. responsivity
Photocathode diameter. . . .	26.2 mm $\pm$0.7 mm
Voltage Divider.	Compatible with linearity over fluoresence signal dynamic range
Tube diameter.	38 mm
Power requirements	
High voltage.	2000 VDC, 6 mAmpere, max. (input 15 Watt max.)
Low voltage, (coils). . .	28 VDC, 6 Watt, max.

Finish — Iridite per MIL-C-5541 for all parts that require electrical conductivity.
Primer: one coat zinc chromate per MIL-8585.
Exterior: two coats baked-on vinyl, medium texture finish, Fed. Color #26373.

	Interior: Parts enclosing optical path, one coat air dried 3M velvet black #101. Contracting surfaces shall not be painted to preserve electrical conductivity.
Hardware	All stainless steel.
Finish	Chromic acid anodize, type 1 MIL-8625 for all parts that do not require electrical conductivity. Painting same as for all other parts.

SIGNAL PROCESSOR

Logic. . . . . As described in Section 1.1.3
Circuitry . . . . Solid state components, state-of-the-art

Power consumption. . . . . . . 117 VAC, 400 Hz, 200 Watt, max.

Weight . . . . 38 lb, max.
Size . . . . 19 x 7.6 x 19 in, max.

COMPUTER

Type. . . . . Ruggednova 1602 (AN/UYK-19V)

Memory

Capacity . . . . Up to 65K

Cycle. . . . . 1 Microsec

Microprocessor . . . . 35 bit, 5 MHz rate

Power consumption . . . . 117 VAC, 400 Hz, 275 Watt, max.

Size. . . . . 7.6 x 10.1 x 12.6 in, max.

Weight. . . . . 38 lb, max.

I/O INTERFACE

It shall be compatible with the Ruggednova 1602 and the appropriate subassemblies in the RODAC.

CONSOLE

Numerical readout. . . . . . . .Seven-segments LEDs.

Visual display . . . . .5 in square CRT

Indicator lights	LEDs red, high illuminance LEDs green, high illuminance
Time readout	Seven-segment LEDs hours, minutes and seconds
Selector switches.	Thumbwheel type, decimal presentation
Mode of operation selectors. .	Pushbutton switches illuminated
Circuitry.	Solid State, state-of-the-art.
Input/output	Via cables to other RODAC subassemblies
Power consumption.	70 Watt, max.
Size	10 x 22 x 10 in, max.
Weight	15 lb, max.

DATA RECORDER

Type.	Incremental digital, magnetic tape
Tracks.	Two
Recording format.	NRZI* standard
Data.	See Section 1.1.6
Storage capacity.	Compatible with Ruggednova 1602 and RODAC data gathering
Write speed	(Compatible with Ruggednova 1602 and RODAC data gathering)
Power consumption	2 Watt, max.
Size.	4 x 5 x 4 in, max.
Weight.	5 lb, max.

VOICE-EVENT RECORDER

Type.	Magnetic tape, reel
Reel.	7 in diameter, 3600 ft capacity
Tracks.	Two
Speed	1-7/8 in sec^{-1}
Frequency response.	40 to 6,000 Hz

*Non-Returning to Zero Inverter

Recording . . . . Track one; time base (tone second signals)

Track two; voice and event marks (400 HZ tone)

Counter . . . . 999 capacity, resetable

Power consumption . . . . . . 117 VAC, 400 Hz, 15 Watt max.

Size. . . . . 12 x 7 x 10 in, max.

Weight. . . . . 15 lb, max.

FAILURE AND STATUS INDICATORS

Failure monitor . . . . 100% of the time; laser transmitter output, laser transmitter power supply receiver power supply, electronics power supply heater for electronics.

Operational status . . . . . . 100% of the time; outer door (open or closed), safety door (open or closed)

Aircraft attitude. . . . . . . Acceptable or unacceptable, roll, pitch, yaw, altitude rate change. Altitude.

TOTAL POWER CONSUMPTION ALLOCATION

N_2 Laser. . . . . .400 Watt, max.

He-Ne Laser. . . . . 50 Watt, max.

Window heater. . . . . 15 Watt, max.

Image Dissector (without coils) . . . . 15 Watt, max.

Signal processor (with Image Dissector coils). . . . . . . 200 Watt, max.

Computer. . . . . 275 Watt, max.

Console . . . . 70 Watt, max.

Data Recorder	2 Watt, max.
Voice-Event Recorder.	15 Watt, max.
	1042 Watt, max.

TOTAL WEIGHT ALLOCATION

N_2 laser (11)	74 lb, max.
He-Ne laser (12).	15 lb, max.
Optical column.	100 lb, max.
Spectrometer.	10 lb, max.
Image Dissector package . . .	5 lb, max.
Signal Processor.	38 lb, max.
Computer.	38 lb, max.
Console (without operator's seat)	15 lb, max.
Data Recorder	5 lb, max.
Voice-Event Recorder.	15 lb, max.
	315 lb, max.

TOTAL VOLUME ALLOCATION

N_2 laser.	1.40 ft^3, max.
He-Ne laser	.24 ft^3, max.
Optical column (9).	3.90 ft^3, max.
Spectrometer.	.48 ft^3, max.
Image Dissector Package	.20 ft^3, max.
Signal Processor.	1.60 ft^3, max.
Computer.	.56 ft^3, max.
Console	1.27 ft^3, max.
Data Recorder	.05 ft^3, max.
Voice-Event Recorder.	.48 ft^3, max.
	10.18 ft^3, max.

NOTES:

(1) The source shall be a pulsed N_2 laser closed system opposed to a continuous flow system.

(2) The power measured at the exit of the laser (without beam expander) shall be measured by a device such as a dsic calorimeter traceable to an NBS calibration.

(3) The peak power of the N_2 laser shall not decrease more than 30% after 10 minutes of operation, and no more than $\pm 3\%$ thereafter.

(4) Apply item (2) but for average power.

(5) The far field intensity of the N_2 laser with beam expander shall be uniform to $\pm 15\%$ over an area centered on the beam axis and encompassing at least 80% of the beam energy. This uniformity shall be measured by a photodetector scanning the far field.

(6) An elapsed time meter shall be included in the power supply or in any similarly suitable system to monitor the laser operating time.

(7) The coating shall exceed Mil-M-13508, shall pass the tape test, shall be resistant to humidity and salt spray, shall allow for cleaning using standard optical procedures and shall stand a temperature range -80°F to +160°F.

(8) The coating shall conform to MIL-13508A and MIL-C-675A, shall pass the tape test, shall be resistant to salt spray, shall withstand 24 hours exposure to 100% humidity at 50°C, shall withstand eraser test per MIL-C-675A, and shall stand a temperature range -196°C to +250°C.

(9) The weight of the optical column comprises the weight of its mounting, its housing, the telescope optics, its mounting, the window, outer doors, safety doors, viewer, field verification telescope and optical switch.

(10) Equivalent material shall be selected mainly in terms of comparable coefficient of thermal expansion, low fluorescence and decay time.

(11) Comprised of Laser head (12 lb), power supply (31 lb) and control module (21 lb).

(12) Comprised of Laser head (7.5 lb) and exciter (7.5 lb).

2. TECHNICAL CONSIDERATIONS RELEVANT TO A PERFORMANCE SPECIFICATION

Additional technical considerations are given below as a baseline to help frame performance specifications which can be used for the procurement of an Airborne Laser Remote Sensor Oil Detection and Classification System (RODAC)(Ref. 8) by the U.S. Coast Guard.

They are supported by specific design criteria, graphs and discussions to facilitate substantiating the selection of performance specifications and by the U.S. Coast Guard operational requirements. The final performance specifications for the system will be prepared by the U.S. Coast Guard.

2.1 U.S. COAST GUARD AIRBORNE LASER REMOTE SENSOR OIL DETECTION AND CLASSIFICATION SYSTEM

The Transportation Systems Center, at the request of the U.S. Coast Guard Office of Reserch and Development (ORD), conducted a study and a program to determine the feasibility of using laser excited oil fluorescence as a means of detecting and classifying oil spills in the marine environment. The study consisted of a review of the literature on oil fluorescence, an analysis of the properties of oil and oil slicks on the sea surface, and the theoretical analysis of the remote fluorometry of oil spills. As a result of this study, an experimental measurements program was undertaken including laboratory and field tests. Laboratory measurements were made of 29 crude and refined oils commonly transported in the marine environment. These measurements included API gravity, fluorescence and reflectance spectra, fluorescence coefficients and fluorescence lifetimes. Similar measurements were made with a laboratory model of the laser oil spill remote sensor that was designed, built at TSC and installed at the U.S. Coast Guard Station at Point Allerton, Hull, Massachusetts. Results of these measurements (Ref. 9, 10) clearly showed that under certain conditions oil spill identification and classification can be made in the ocean environment, and furthermore, that remote sensing of oil spills using laser excited oil fluorescence is technically feasible. A two phase program was undertaken for the further development of this technique. Phase I - Development of an experimental airborne laser oil spill remote sensing system and Phase II - Field Airborne Tests of the experimental system.

In-house tests of the experimental system were conducted on twenty-five different oil samples. Measurements consisted of detecting and recording the fluorescence emission spectrum of each sample at each altitude.

The system was later installed in a Type CH53 helicopter. Following the installation, several flight tests were performed.

2.1.1 Oil Detection

Detection is defined as the capability of the RODAC to detect the presence of oil in a marine environment, distinguishing the oil from the water in the marine environment and also from other contaminants on the surface of the water. Once the system has been initially calibrated, it normally functions by producing an observed signal output only when the return signal indicating the presence of oil exceeds a precalibrated threshold level, for a minimum signal integration period. The observed signal is then a) processed in real-time, i.e., classified and b) also stored on magnetic tape as a distinct record of the specific return signal for future analysis and/or documentation.

2.1.2 Oil Classification

Oil classification is defined as the ability of the remote sensing system to discriminate between groups of the oils on the basis of the induced fluorescence spectra as measured by the airborne laser remote sensor (Refs. 11, 12, 13). On the basis of the 30 channel spectral data, the onboard computer will carry out the pattern recognition of the spectral signature (Refs. 7, 14). This computation requires previous storage in the computer memory of the spectral signatures of the most common oils used and/or transported in the marine environment, as well as other signature and classification data on the basis of which the pattern recognition is carried out in real or quasi- real-time. The computer system to perform the pattern recognition will be software oriented to allow the introduction, without hardware modifications, of new spectral signature catalog data or other classification information. Three classes of oil shall be discriminated when using the 30 spectral channels. This discrimination shall consist of three API gravity ranges, less than 20° (heavy), 20°-30° (medium) and greater 30° (light), and preferably four ranges (see Figure 5). Only a single class is addressed during one pass by the computer.

The decision as to which class of oil it is shall be made on probabilistic terms. The criterion for this decision shall be the likelihood function.

2.1.3 Operational

2.1.3.1 Mission Description - The U.S. Coast Guard is responsible for pollution surveillance, enforcement of both domestic and international antipollution regulations, and initiation of various antipollution countermeasures to minimize possible pollution hazards to the navigable waters of the United States.

In response to this requirement, the U.S. Coast Guard has under development with the Aerojet Electrosystems Company a prototype multi-sensor Airborne Oil Spill Surveillance System (AOSS) which will be used to provide the experimental basis for selection of the MRS sensors suitable for day/night all weather airborne detection mapping and documentation of oil spills at sea. The prototype AOSS multi-sensor system utilizes a side looking X-band radar mapping system, a passive forward looking microwave imaging system, a multi-channel IR line scanner and an LLLTV system for multispectral operation in the UV and visible bands. The foregoing interface with a common signal processor/display/recorder to facilitate real and/or near real-time observation by the system operator and data storage for playback and/or documentation.

In addition, the U.S. Coast Guard had under development with the Transportation Systems Center an experimental model Airborne

Laser Remote Sensor for Oil Detection and Classification (RODAC) utilizing laser excited fluorescence as a means of detecting and classifying oil spills in the marine environment. The U.S. Coast Guard will be procuring engineering prototype model laser excited oil fluorescence systems, initially in a stand alone configuration (System I) and eventually as a subsystem (System II) integrated with some or all of the MRS subsystems.

2.1.3.2 System I - The initial engineering prototype model (stand alone) configuration is depicted in Figure 1b, RODAC I, and it is this configuration whose requirements are defined in Section 1.

2.1.3.3 System II - The requirements for the design of System I were established against U.S. Coast Guard criteria which project the eventual integration of RODAC I with other MRS sensor sub-systems, sharing in common as much as possible the processing, display and storage (recording) of acquired data. To this end and recognizing the use by Aerojet of the ROLM 1602 (militarized) computer in their AOSS, the requirements in Section I were developed. The major difference between the System I and System II configuration are depicted in Figure 1.

2.1.3.4 Aircraft Characteristics -

	Requirement	To be Determined
Designation		X
Manufacturer		X
Type		X
Speed during remote sensing	200 knots	
Cruising Range	1500 nautical miles	
Altitude Ceiling	40,000 feet	
Remote Sensing Altitude	1000 feet	
Flight Duration	5 hours	
Fuel Consumption at 250 knots		X

	Requirement	To be Determined
Fuel Weight		X
Equipment, MRS Sensor System	1200 lb	
RODAC I	200 lb	
Crew and Operators	1200 lb	

The cabin shall be pressurized. From 0 to 8,000 feet the cabin shall be at sea level pressure.

2.2 LASER SAFETY CONSIDERATIONS

Intense highly collimated beams of optical radiation, characteristic of laser sources, can be hazardous to the eye and must be used with care. Any source which is to become the basis for an operational RODAC system must be designed to ensure eye safety for all reasonable situations.

The effect of optical radiation on eye tissues has been the subject of many studies; an excellent review of present understanding in the field is given by Sliney and Freasier (Ref. 15). There are several physical mechanisms by which radiation can damage ocular components. For visible wavelengths, thermal damage to the chorioretinal tissue is of most concern. On the other hand, ultraviolet radiation, strongly absorbed by the cornea and lens, can cause cataracts and corneal burns.

For a given corneal irradiance E_c (Watt cm^{-2}), the amount of radiant energy absorbed in the chorioretinal tissue depends on several things: the size of pupil opening, the entrance angles of the incident light, and the ocular transmission and retinal absorption characteristics for the spectrum of the incident radiation. The temperature rise of the absorbing tissue depends on its specific heat, the retinal image size, and the relative rates at which energy is deposited in and conducted away from the image region.

There are several sets of exposure criteria which have been published. In 1972, both the American National Standards Institute

(ANSI) Committee Z-136 and the American Conference of Governmental Industrial Hygienists (ACGIH) proposed essentially the same standards for laser exposure limits. A comprehensive discussion of the experiments and analyses underlying these standards is presented by Sliney and Freasier (Ref. 15), who also summarize the values established for maximum ocular exposure limits.

Because of the differences between the N_2 and the He-Ne radiation, they will be treated separately below.

2.2.1 N_2 Laser Safety Criteria

The ACGIH threshold limit value (TLV) for intrabeam viewing at 337.1 nm is 1 J cm^{-2}. However, this value is given for exposure times only as short as 10^{-3} sec, whereas the N_2 pulse width is around 10 nsec. Assuming that the maximum allowable corneal irradiance is constant from 10^{-3} down to 10^{-8} sec, this rate would be 1 J cm^{-2} x$(10^{-3}$ sec$)^{-1}$ = 1 KWatt cm^{-2}. (It is in fact probable that the allowable irradiance is considerably larger for 10^{-8} sec than for 10^{-3} sec; thus the result of 1 KWatt cm^{-2} is conservative.)

At the exit aperture of the N_2- laser transmitter, the irradiance is 20 KWatt over an area of 7 x 10^{-2} cm^2, or 300 KWatt cm^{-2}. This exceeds the TLV by a factor of 300. By virtue, however, of the beam divergence (θ = 3 mrad), the irradiance at a distance of 25 meters is reduced to a tolerable value of approximately 500 Watt cm^{-2}.

It is unlikely that an observer on the water, should he be exposed accidently to the N_2 radiation, will encounter more than a single pulse, since the narrow pencil of light will move across his view in a very short time. For an aircraft ground speed V_g, altitude R and divergence angle θ, the time t_s of exposure to the beam is approximately $t_s = \frac{R\theta}{V_g}$. For V_g= 44 meter sec^{-1} (100 miles hr^{-1}), R = 100 meter and $\theta = 3 \times 10^{-3}$ rad., one finds $t_s < 10$ msec. Thus the beam scans across the eye in a time shorter than the minimum separation between pulses (at 100 pps) demonstrating that cumulative effects of repetitive pulsing can be ignored. By introduction of the proposed beam expander the divergence shall increase to 9 m rad and therefore the cumulative effects shall be even smaller.

2.2.2 He-Ne Laser Safety Criteria

The Ne-Ne laser emits continuous radiation in the visible (λ = 632.8 nm). The exposure time associated with accidental intrabeam viewing will be short for two reasons: First, the blink reflex ordinarily elicited by exposure to bright visible light will limit the duration of viewing to approximately 0.1 sec. Second, as was the case for the N_2 laser above, because of the motion of the aircraft, it is unlikely that the well-collimated beam can be viewed by any one observer for a significant time. A calculation similar to the one above (but with $\theta = 10^{-3}$ rad) shows that the beam will scan a fixed point in around 2 msec.

With such short exposure times, the ocular exposure limit (that is, the maximum recommended corneal irradiance for a 7 mm pupil) for 632.8 nm is 1×10^{-3} Watt cm^{-2}. The irradiance of the He-Ne laser at the transmitter output is 0.6 Watt cm^{-2}. At a distance of 25 meters, the irradiance is reduced by the beam divergence to the tolerable value of 1×10^{-3} Watt cm^{-2}.

Hence for altitudes greater than 25 meters, no hazard exists for ordinary operation of either the specified N_2 of He-Ne lasers.

The preceding discussion pertains to the situation in which the RODAC system is operational aboard a flying fixed wing aircraft. A helicopter operation, in which the transmitting sources could conceivably hover over an unwitting observer, would require reconsideration of the potential eye hazards.

Precaution should be taken to ensure that on-the-ground operation of the transmitters, for maintenance or alignment purposes, is carried out only under supervision by trained personnel. In particular, staring into the transmitters, or at specular reflections of the emitted beams, must be avoided.

2.3 OIL FLUORESCENCE SPECTRAL CATALOG

For the purpose of onboard pattern recognition the U.S. Coast Guard shall supply approximately 100 oil fluorescence spectra representative of the wide range of oils used or transported in the marine environment. These spectra shall be supplied in a tabular format with the same spectral resolution as the data gathered by the remote sensor. The oil fluorescence spectra shall be corrected for the instrumental profile and/or spectral radiant responsivity $S(\lambda)$ of the detector (see Figure 10). The dynamic range in amplitude (oil peak fluorescence coefficient) of these spectra is 10^3. Since there are several definitions of oil fluorescence coefficient which result in different values of that parameter for the same oil, we establish the following special purpose definition as the one to be used for the spectral catalog and the remote sensor:

> The fluorescence coefficient at a wavelength λ is defined as the ratio of the radiant intensity (Watt ster.$^{-1}$) of the fluorescence emitted normal to the oil surface, in a 10 nm bandwidth centered at λ, to the normally incident excitation power at 337 nm (assumed to be confined to 10 nm or less). The bandwidth is taken to be the width between 10% points. (See Figure 10.) The fluorescence coefficient shall be reduced to one sterradian solid angle. The thickness of the oil sample shall be such that changes in thickness shall not introduce any changes in the fluorescence emission power.

It should also be pointed out that the spectra for the catalog shall be obtained from oil films, not from oils in solution, and with an excitation centered on 337 nm and no more than 10 nm wide. Furthermore the level of irradiance shall be that usually used in laboratory type spectrophotofluorometers.

The catalog data requires 40 channels instead of the 30 to be used in the RODAC to allow for future improvement in the RODAC and refinement in the pattern recognition computations.

The following is an example of a catalog spectrum:

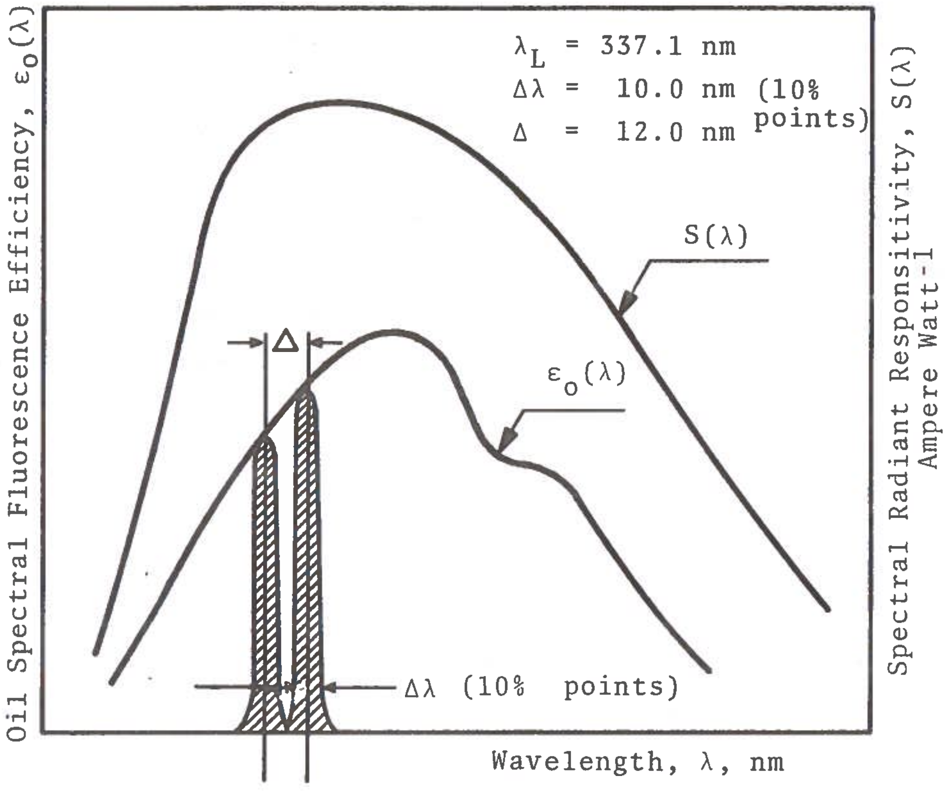

Figure 10. Diagram Showing the Image Dissector Spectral Response, Oil Fluorescence Spectra and RODAC Optical Channels

Oil Catalog Number: 98

API Gravity: 46.5

Channel	Central Wavelength λ_n nm	Fluorescence Coefficient, $\varepsilon_o(\lambda_n)$	Channel#	Central Wavelength λ_n, nm	Fluorescence Coefficient, $\varepsilon_o(\lambda_n)$
1	(350)	999×10^{-8} str^{-1}	21	(590)	
2	(362)		22	(602)	
3	(374)		23	(610)	
4	(386)		24	(626)	
5	(398)		25	(638)	
6	(410)		26	(650)	
7	(422)		27	(662)	
8	(434)		28	(674)	
9	(446)		29	(686)	
10	(458)		30	(698)	
11	(470)		31	(710)	
12	(482)		32	(722)	
13	(494)		33	(734)	
14	(506)	500×10^{-6} str^{-1}	34	(746)	
15	(518)		35	(758)	
16	(530)		36	(770)	
17	(542)		37	(782)	
18	(554)		38	(794)	
19	(566)		39	(806)	
20	(578)		40	(818)	999×10^{-8} str^{-1}

2.4 REMOTE FLUOROMETRY OF OIL SPILLS

2.4.1 Basic Radiometric Equations

To assess the signal levels we shall consider a geometry as indicated in Figure 11 where the transmitter sends a laser beam whose peak power P_L attenuated by the transmitter optics with an efficiency ε_L at a wavelength λ_L, is distributed in a solid angle Ω_L.

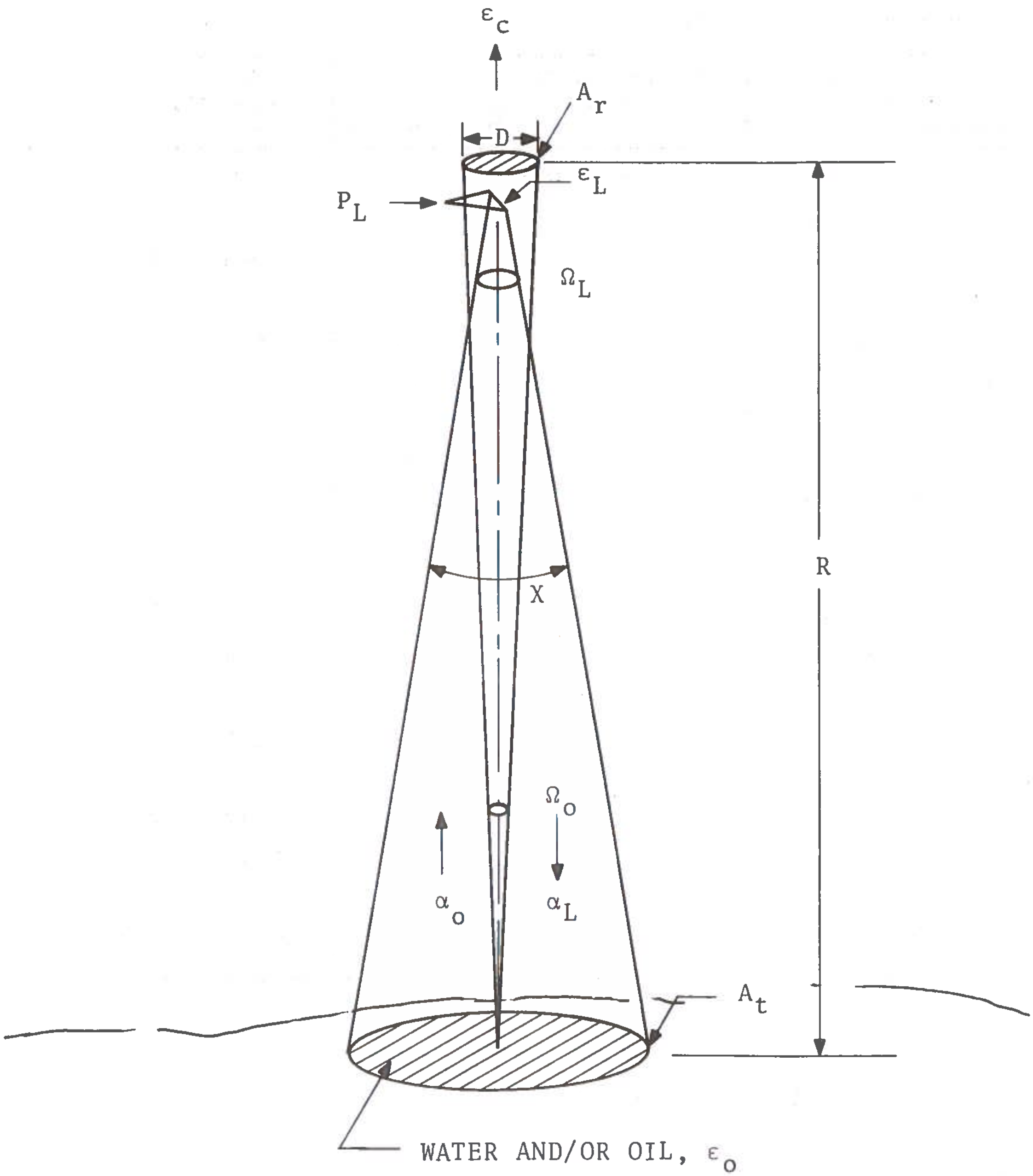

Figure 11. Schematic Showing the Relationship of Transmitting and Receiving Optics and Target

This beam propagates in the atmosphere characterized by an attenuation α_L for the laser wavelength and α_o for the visible region. Upon reaching the water and/or oil and due to the fluorescence mechanism defined by the integrated oil fluorescence coefficient ε_o, the excited surface radiates through a solid angle Ω_o defined by the remote sensor and flying altitude R.

A portion of the energy is collected by the remote sensor receiver, with an optics with diameter D, an average efficiency ε_c (the transmitted and received beams are attenuated passing through the atmosphere, with exponential attenuation coefficients which depend on the medium and the wavelength).

To assess the remote sensor optical receiver we will consider the following radiative equation which gives the total fluorescence power P_o received per transmitted laser excitation pulse:

$$P_o = \frac{P_L \, \varepsilon_L \, \varepsilon_c \, \varepsilon_o \, D_n^2 \, e^{-(\alpha_L + \alpha_o)R}}{4R^2} \text{ Watt per pulse,} \qquad (1)$$

which assumes that the field-of-view of the transmitter is matched to the receiver field-of-view (i.e., the area illuminated by the transmitter is the same area "seen" by the receiver).

Also the P_o could be expressed as:

$$P_o = K \, P_L \sum_{n=1}^{n=30} \varepsilon_o(\lambda) \text{ Watt per pulse} \qquad (2)$$

where K is a constant for certain optical configurations of the RODAC, and a given flying altitude, $\varepsilon_o(\lambda)$ is the spectral oil fluorescence coefficient, and n the number of the RODAC spectral channels. The integrated oil fluorescence coefficient is defined in this report as:

$$\varepsilon_o = \sum_{n=1}^{n=30} \varepsilon_o\left(\lambda_n\right). \qquad (3)$$

The power P_n received per optical channel at the telescope entrance pupil:

$$P_n = \frac{P_L \ \varepsilon_L \ \varepsilon_o \left(\lambda_n\right) \ D^2 n e^{-\left(\alpha_L + \alpha_c\right) R}}{4R^2}, \qquad (4)$$

where λ_n is the central wavelength of the spectral channel n.

If $\varepsilon_c(\lambda_n)$ is the overall spectral efficiency of the receiver optics and $S(\lambda_n)$ is the spectral responsivity of the photo-detector which in this case is an S_{20}, then equation 4 becomes:

$$I_n = \frac{P_L \ \varepsilon_L \ \varepsilon_c(\lambda_n) \ S(\lambda_n) \ \varepsilon_o \ (\lambda_n) \ D^2 \ n \ e^{-\left(\alpha_L + \alpha_o\right) R}}{4R^2} \quad \text{Ampere per pulse per channel} \qquad (5)$$

where I_n is the image dissector output current per channel and per transmitted pulse.

To evaluate equation 5 we shall assume that the RODAC operates in very good visibility conditions, therefore

$$e^{-\left(\alpha_L + \alpha_o\right) R} = 1 \qquad (6)$$

Thus equation 5 becomes:

$$I_n = \left[\frac{D^2 \ n \ \varepsilon_L \ \varepsilon_C\left(\lambda_n\right) \ S\left(\lambda_n\right)}{4}\right] \frac{P_L}{R^2} \ \varepsilon_o \ \left(\lambda_n\right) \quad \text{Ampere per pulse per channel} \qquad (7)$$

Since the power of the laser could change from pulse to pulse and the altitude of the aircraft could change within certain operational limits, P_n shall be normalized for P_L and R^2, therefore:

$$\frac{P_n \ R^2}{P_L} = \left[\frac{D^2 \ n \ \varepsilon_L \ \varepsilon_c\left(\lambda_n\right) \ S\left(\lambda_n\right)}{4}\right] \varepsilon_o \ \left(\lambda_n\right), \qquad (8)$$

or

$$\varepsilon_o\left(\lambda_n\right) = \frac{P_n R^2}{P_L}\left[\frac{D^2 n\ \varepsilon_L\ \varepsilon_c}{4}\left(\lambda_n\right)\ S\left(\lambda_n\right)\right]^{-1} \quad (9)$$

This in fact is the parameter that we want to measure to detect and classify oils.

2.4.2 Evaluation of the Spectroradiometric Equation

To evaluate the signal level to be obtained with a RODAC of the characteristics proposed in this report, we will evaluate Equation 7 with the following set of parameters:

P_L = 2×10^5 Watt

ε_L = 0.8

ε_c = 0.2

S(458 nm) = 3×10^3 Ampere Watt^{-1}
@ an image disector gain of 5×10^4

D = 0.30 meter

R = 305 meter (1000 ft)

$\varepsilon_o\left(\lambda_{10}\right)$ = 1×10^{-6}*

n = 10 (central wavelength 458 nm).

Introducing the above values to Equation 7, we obtain:

$$I_{10} = \frac{2 \times 10^5 \times n \times 0.8 \times 0.2 \times 3 \times 10^3 \times (0.3)^2 \times 10^{-6}}{4 \times 305^2}$$

per pulse (channel 10)

$$I_{10} = 7.2 \times 10^{-5} \text{ ampere per pulse (channel 10)}$$

*To validate the assumed ε_o (λ_{10}) consider that using N_2 laser excitation and 7 nm bandpass it was measured for a heavy crude °API 25.0), ε_o (459 nm) ≃ 1×10^{-3} and for an asphalt (°API 7.2), ε_o (495 nm) ≃ 7×10^{-6}.

If the current signal I_{10} is fed to a voltage amplifier with an input impedance of 500 ohms the voltage signal will be 3.6 x 10^{-2} volt. The dark current of the image dissector under the same conditions will be in the order of 1 x 10^{-10} ampere and therefore develops a 5 x 10^{-8} volts in a 500 ohms resistor. We assume that the amplifier following the image dissector is Johnson noise limited — that is, the rms noise is governed by the following equation:

$$e_{rms} = \sqrt{4KTRB} \text{ Volt,} \qquad (10)$$

which at room temperature becomes,

$$e_{rms} = 126 \sqrt{RB}\ 10^{-12} \text{ Volt,} \qquad (11)$$

and where the R is the input resistance and B the bandpass of the amplifier. For R=500 ohm and B = 50 MHz, e_{rms} = 2 x 10^{-5} Volt, which means that based on the operating assumptions the RODAC will not be limited by the irreducible noise of the system, since for the example given above the fluorescence signal is 3.6 x 10^{-2} volts, the Johnson noise is 2 x 10^{-5} volts, and the image dissector dark signal is 5 x 10^{-8} volts. If we allow for the misalignment of the optical system and added losses in the system we still have a substantial signal-to-noise ratio at 1000 feet altitude and for 10^{-6} oil fluorescence efficiency.

2.5 SPECTRAL CALIBRATION

The RODAC shall be periodically calibrated. This calibration shall give the relative spectral efficiency $\varepsilon_c(\lambda)$ $S(\lambda)$ of the receiver optics within 5% (±2.5%). This spectral calibration shall be carried out at the facilities on the ground and by means of a source. The values $\varepsilon_c(\lambda)S(\lambda)$ shall be given for the same wavelength intervals (30 channels) as the ones used for the oil fluorescence spectra catalog (Section 2.3).

2.6 CORRELATION OF RODAC AND MRS SYSTEM FIELD-OF-VIEW

The MRS System will have several sensors with different resolutions and fields-of-views. In order to evaluate more meaningful the RODAC data it shall be required to locate the RODAC field-of-view temporarily and spatially within the field-of-view of one or more MRS sensors.

3. GENERAL REQUIREMENTS

3.1 GENERAL DESCRIPTION

This specification sets forth the general requirements for an engineering model prototype Airborne Laser Remote Sensor for Oil Detection and Classification (RODAC).

3.2 APPLICABLE DOCUMENTS

The following documents apply only to the extent indicated in this specification. A file of all documents will be available for viewing at Coast Guard Headquarters through the Contracting Officer.

3.2.1 Department of Defense Documents

Not Applicable.

3.2.2 Department of Transportation Documents

13080.1A USCG Aircraft Repair & Supply Center Engineering Specification

ATN No. 2-68A Aircraft Painting and Marking Details

CG-311 Coast Guard Personnel Manual

FAA-D-1272C Instruction Booklets, Electronic Equipment.

3.2.3 Military Specifications

MIL-E-5400M Electronic Equipment, Airborne, General, Specification for

MIL-A-8865 (ASG) Airplane Strength & Rigidity Misc. Loads

MIL-I-45208A Inspection System Requirements.

MIL-C-675A Coating of Glass Elements (Anti-Reflection)

MIL-M-13508 B Mirror Coating Process: Front Surface Aluminized, For Optical Elements

MIL-P-8585 Primer Coating, Zinc Chromate, Low Moisture Sensitivity

MIL-A-8625 Anodic Coatings, For Aluminum and Aluminum Alloys

MIL-C-5541B Chemical Conversion Coating on Aluminum and Aluminum Alloys

3.2.4 Military Standards

MIL-STD-415D Test Provisions for Electronic Systems and Associated Equipment, Design Criteria

MIL-STD-461A Electromagnetic Interference Characteristics, Requirements for Equipment

MIL-STD-462 Electromagnetic Interference Characteristics, Measurement of

MIL-STD-454B Standard General Requirements for Electronic Equipment

MIL-STD-704A Electric Power, Aircraft Characteristics and Utilization of

MIL-STD-810B Environmental Test Methods

3.3 MAINTENANCE REQUIREMENTS

The RODAC system shall have a documented Mean Time Between Failure (MTBF) of not less than 600 operating hours with preventive maintenance specified below. Preventive maintenance shall be performed by the contractor at the aircraft base of operation on an interval of not less than 200 operating hours or 180 days service time whichever occurs first. Preventive maintenance measures shall be determined by the contractor and may include such items as:

a. The regular maintenance, recheck and service to be provided by the U.S. Coast Guard shall be carried out by Marine Service Technicians (MST rating) supported by Aviation Electronic Technicians (AT rating).

3.4 ENVIRONMENT

The operational and non-operational environments shall be as specified in MIL-E-5400M, Section 3.2.24 for Class IA equipment. The following modifications shall apply.

3.2.24.1 Change Table I to following temperatures:

Non Operating (storage) -55°C to +125°C

Operating 0°C to + 55°C.

In addition, attitude will vary ±45° from the vertical in any azimuthal direction.

3.5 PHYSICAL DESIGN

The RODAC I shall be an assembly consisting of an optical column and a console, suitably shock and vibration isolated. A separate operator's station chair shall be provided. Conceptual drawings are given in Figures 2 and 3. The assembly excluding the chair and computer shall not exceed 250 lb in weight and 10 ft^3 in volume.

The RODAC shall be designed in such a way as to require one operator only to perform all system functions.

3.5.1 Console

All the RODAC displays and controls shall be located in a single console. This console will provide the system operator with all controls, indicators, and displays necessary for proper operation of the RODAC system. The system operator will be seated in a Contractor-furnished aircraft type chair preferably facing forward or aft. The crewman's seat shall be equipped with a seat belt and shoulder harness. The seat must meet minimum load factors in accordance with MIL-A-8865 (ASG) for non-takeoff and landing usage. The console shall be provided with a working surface in the form of a sliding table which locks into either the extended or storage position. The table shall extend 16 inches from the panel and support a minimum of 75 pounds on its outer edge.

The console must meet minimum load factors as follows:

a. Longitudinal 8.0G forward, 1.5G aft

b. Lateral 1.5G to right and left

c. Vertical 4.5G down and 2.0G up.

No operator discomfort shall result from heat radiated from the console during four hour missions. The console shall be finished in accordance with AR&SC LESPEC 13080.1A. The console shall be shock-mounted to the aircraft.

3.5.2 Interconnection

All interconnections between major subsystems of the system shall be strain-relieved plug-type connectors. The contractor shall furnish all plugs, connectors, and interconnecting cables. All plugs/connectors shall securely lock into place.

3.5.3 Electronics

All electronics less CRTs shall be solid-state components mounted on plug-in circuit cards which shall be provided with a positive means of securing the card within the card rack. Except for CRTs and photosensitive tubes, all use of non-solid-state components must be approved by the Contracting Officer.

3.5.4 Test Points

Test points shall be provided in accordance with MIL-STD-415D, Section 5.2.4 for Class C and D equipment. At least one conveniently located ground test point shall be available on each assembly. A circuit card extender providing access to the pins on the circuit card will satisfy the test point requirement for printed circuit cards.

3.5.5 Internal Controls

All internal controls and tuning adjustments shall be located so as to be readily accessible. In no case shall the setting of the final adjustment or control be dependent on, or varied by, the placement or presence of any cores or shielding, which must be moved to gain access thereto. Locking devices shall be provided to secure adjustments under the specified vibration conditions.

3.5.6 <u>Wire Coding</u>

All wiring shall be color-coded and a code listing provided to aid in line differentiation for equipment maintenance. Digital signal lines may be of one solid color.

3.5.7 <u>Electromagnetic Interference (EMI) Protection</u>

The Coast Guard realizes that EMI isolation of each device may not be cost effective. The system shall be designed to enhance the electromagnetic compatibility of the system and other avionics systems on board the aircraft. Equipments shall be considered incompatible when magnetic or electric field radiations by the systems cause one another to function or operate outside their design limits. When such incompatibility is found to exist, the contractor shall recommend to the USCG equipment modification or replacement as necessary to correct the condition.

3.5.7.1 <u>EMI Shielding</u> - The RODAC within the aircraft may be enclosed in an EMI shielded equipment enclosure to reduce interference.

3.5.7.2 <u>Tests</u> - The contractor shall perform those tests listed in Section 3.10.2. Successful completion of these tests shall be considered evidence of EMI compatibility.

3.5.8 <u>Power Requirements</u>

The following allotments of aircraft power have been made for the RODAC II System.

DC 27.5 ±2.0 Volts, 4 Ampere

AC 115.0 ±5.0 Volts, 400 ±5.0 Hz, 1.0 KWatt, 1 phase.

These values are to be considered as maximum. Normal operation shall not require more than 85% the maximum power allotment from any source. The system, if it requires AC power, shall have a power factor of no less than 0.85.

3.5.8.1 Power - The equipment shall be designed to operate properly from the aircraft power generating system.

The equipment shall be Class B utilization equipment in accordance with MIL-STD-704A.

The equipment is not required to operate within specification under abnormal electrical system operation (as defined in MIL-STD-704A) but shall not be damaged in any manner.

The equipment will not be operated under emergency electric system operation (as defined in MIL-STD-704A).

3.5.8.2 AC Susceptibility - The equipment shall withstand the transient of curves 5 and 6 for Figure 3 of MIL-STD-704A during normal operation (and operate within specification) and curves 2 and 3 (dashed line) under abnormal system operation without damage.

3.5.8.3 DC Susceptibility - The equipment shall withstand transients of ± 10% under normal operation (and operate within specification) and ±20% under abnormal system operation without damage.

3.5.9 Electrical Bonding

All cabinets, panels, and chassis shall be electrically bonded for grounding purposes. Protective finishes shall be omitted at those points where their presence would prevent proper electrical bonding as required for shielding or connection. Provision shall be made to assure permanence of electrical contact between the surfaces of all parts in contact over long periods of time or in the presence of humid, saline atmosphere. Metal to metal connections shall be, or shall be made to be, galvanically compatible to prevent electrolytic action.

3.5.10 Component Selection

Component selection shall be such that under no conditions of operation or adjustment procedures will the current, voltage, or wattage rating exceed 80% of rated value. Electrolytic capacitors shall be operated at no more than 80% of rated working voltage.

3.5.11 Material

All chassis shall be fabricated from aluminum alloy of sufficient strength to be physically rigid when removed from their enclosures. There shall be no visible indication of chassis bending when the chassis is supported at the center of either side of the diagonally opposite corners.

3.6 SPARE PARTS

For each system the contractor shall provide one spare of each electronics circuit card required by the RODAC system. This shall not include lasers, detectors, photomultiplier tubes, or CRTs. He shall also provide a listing of those additional items in electronics and hardware he may feel are required as spare parts for proper support of the airborne remote sensing system. These spare parts will be the subject of future negotiations.

3.7 DOCUMENTATION

3.7.1 Technical Manuals

A complete, integrated manual composed of existing equipment manuals and system manuals is required. It shall cover all aspects of installation, operation, maintenance and safety precautions. Installation sections shall include drawings and procedures for all installation requirements. Operation sections shall include in addition to flight operation procedures, a complete preflight preparation and test procedure. The manual shall include examples of display presentations. Maintenance sections shall include inflight operator maintenance as well as ground maintenance and equipment preparation as may be required for contractor repair.

Manuals shall be written and produced in accordance with FAA-D-1272C. Final requirements are for three copies per system and an additional twelve copies to the Contracting Officer.

3.7.2 Training Documentation

Within 45 days after award of contract, the contractor shall submit for approval, preliminary training documentation which shall include a proposed manual for use in his training program and a detailed outline of his proposed course of instruction.

3.7.3 Engineering Plans and Drawings

Within a specific number of days from the award of the contract, the contractor shall present a complete set of drawings and detailed instructions for approval by the Contracting Officer specifying those modifications to the aircraft as may be required for installation of the RODAC system. All modifications to the aircraft excluding physical installation of equipment will be performed by the Coast Guard or under Coast Guard authorization. The contractor shall perform all final installation, interconnection, test and check-out of the RODAC system.

3.8 INSTALLATION

Based on specifications supplied by the Contractor, the Coast Guard will perform or contract for modifications to the aircraft.

3.9 QUALITY ASSURANCE

The Contractor shall maintain a quality assurance program consistent with the intent and scope of MIL-I-45208A.

3.9.1 Test Procedure

All quality assurance tests specified herein will be performed on the first operational system. Each subsequent system will be tested in accordance with Section 3.10.2 through Section 3.10.4

except as specified herein. The Contractor shall supply all equipment and personnel necessary to perform these tests. The following procedural provisions shall be adhered to for all tests:

Sixty days prior to the performance of a test, the contractor shall submit a detailed step-by-step description of the test he will perform to satisfy the specification. The description shall include detailed operational directions for setting controls on the hardware, directions for obtaining and recording measurements, and methods of performing any mathematical calculations. The contractor shall indicate specific test criteria to be used for acceptance and rejection. Approximately thirty days before the test period, the Coast Guard will return the accepted or modified test plan to the contractor. Tests shall be carried out entirely by contractor personnel in accordance with the test plan and in the presence of the Government Inspector.

3.9.2 Coast Guard Inspection and Testing Rights

It is not the intention of the Coast Guard to test each and every part of the system to the full extent of this specification. The Contracting Officer will designate in writing to the contractor a Government Inspector(s) who shall have the right to inspect the contractor's facilities and procedures at any time during the contract period. Circuit cards and associated power supplies, wiring harnesses, controls and indicators will be inspected in regards to quality of workmanship. Workmanship will be judged against Requirement 9 of MIL-STD-454B. Cards will be checked for component selection, circuit layout, proper construction and soldering as well as agreement with contractor supplied drawings.

3.9.3 Production Period Testing

The contractor is not required to submit test plans for any test performed on subassemblies prior to their integration into the system. However, he shall notify the Contracting Officer ten days prior to any and all major subsystem tests so that the Government Inspector may attend.

3.9.4 Environmental Testing

Conformance to Section 3.4 shall be proven by completion of the following tests in accordance with MIL-STD-810B. Complete records of the raw and processed data from these tests shall be maintained and furnished to the Contracting Officer 30 days after completion of the test.

Parameter	MIL-E-5400M Paragraph	MIL-STD-810B Method
Temperature	3.2.24.1	504
Altitude	3.2.24.2	504
Temperature-Altitude	3.2.24.3	504
Humidity	3.2.24.4	507
Vibration	3.2.24.5	514
Shock, Equipment	3.2.24.6.1	516 - Procedure I
Shock, Crash Safety	3.2.24.6.2	516 - Procedure II
Salt Atmosphere	3.2.24.9	509
Dust	3.2.24.7	510
Fungus	3.2.24.8	508
Attitude	See below	

Attitude: Attitude tests shall be made on any testing device capable of performing the following tests.

a. The equipment shall be inclined at the rate of 5 to 7 cycles per minute in one plane to angles of 45° on either side of the vertical for a minimum of 30 minutes.

b. Test (a) shall be repeated with the equipment reoriented 90° to the plane in which is was originally tested.

c. At the conclusion of the tests above, the cyclic motion shall be stopped and the attitude adjusted to an angle of 15°. The equipment shall then be operated for a minimum of one hour. The equipment shall then be rotated through the vertical to 15° in the opposite direction and the test for continuous operation shall be repeated.

A failure of any feature of the system during the testing period will be considered a failure in meeting specifications.

The equipment shall not be required to operate within specifications for roll greater than ±10°; however, normal operation shall resume upon return to within ±10° roll of the vertical.

3.10 ACCEPTANCE TESTS

3.10.1 Operational Tests

Not later than 60 days prior to installation of the first system, the contractor shall forward to the Contracting Officer a detailed step-by-step test procedure by which the contractor will prove system conformance to this specification. This test procedure shall follow the general outline and intent of the tests specified below. The procedure shall include detailed operational directions for setting controls on the hardware, directions for obtaining and recording measurements, methods of performing any mathematical calculations, and guidelines for acceptance or rejection. The Government will modify (as required) and approve the test procedures before actual testing is performed.

The operational tests are divided into two general categories, those tests performed in the laboratory or on the ground and those tests performed in-flight.

3.10.2 Laboratory and Ground Tests

The following tests will be performed either in a laboratory supplied by the contractor or in the aircraft on the ground at a Coast Guard facility. Any test equipment necessary for these tests shall be supplied by the contractor unless specifically defined otherwise herein.

EMI. The system shall be tested for interference and susceptibility in accordance with the following test methods from MIL-STD-462 to the limits specified in Section 6 of MIL-STD-461A, Class 1C, except as noted.

CE 03
RE 02
RS 01

RS 03 1 GHz max. freq.
CS 01
CS 02
CS 03

3.10.3 System Power Controls - Failure Alert

All system power controls shall be checked for proper operation. The contractor shall suggest a means of simulating a failure of each of the major subsystems and the failure alert will be checked for proper detection of the failure.

3.10.4 Bank Test

During the test flights of the RODAC system, the aircraft will be put through a series of banking maneuvers to bank angles of up to 45°. At the pilots discretion, the aircraft will be flown in a series of up to six successive banks. At the completion of the test run, the system shall return to the normal operating condition and continue to operate within the limits of the specification.

3.10.5 Physical Inspection

A government Inspctor will be present during the installation period to observe installation procedures and Contractor instruction of Coast Guard trainees in addition to inspecting the equipment being installed. His function will be as follows:

a. He will monitor installation to assure that the contractor's manuals are acceptable in all aspects for installation and training purposes.

b. He will assure that the contractor meets training requirements as specified herein. Assurance will be based upon thoroughness of instruction and a liberal use of the installation process as an integral part of the training program.

3.11 DELIVERY

All portions of the system shall be shipped by the contractor to the Coast Guard facilities specified for installation by the contractor.

3.11.1 Packing for Shipment

Since final acceptance of each system by the Coast Guard is dependent upon operational flight tests, all packing, handling, and shipping during the initial delivery phase is to be performed at the risk of the contractor.

3.11.2 Packing Materials

Each subassembly shall be delivered in a packing container of sufficient strength and durability to be used in repeated shipment for maintenance purposes. Any and all packing containers and materials shall become property of the Coast Guard.

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APPENDIX A

CONSIDERATIONS ON THE RODAC FIXED FOCUS TELESCOPE

The operational altitude of the surveillance aircraft, when operating in the short range inspection mode is 1000 feet. Departures from this altitude have to be contemplated when deemed necessary by operational requirements. The minimum altitude under exceptional conditions shall be no less than 500 feet and maximum of 2000 feet.

The distance δ from the telescope focal plane to the image plane is expressed by:

$$\delta = \frac{f^2}{R-f} ,$$

where f is the focal length of the telescope and R is the distance from the telescope to the target. Substituting in the above equation the values of f = 155 cm and different values of altitude, R_1 = 500 feet (152 m), R_2 = 1000 feet (305 m) and R_3 = 2000 feet (610 m), we obtain:

$$\delta_1 = 1.6 \text{ cm}$$

$$\delta_2 = 0.8 \text{ cm}$$

$$\delta_3 = 0.4 \text{ cm}$$

This means that for the telescope focused at 1000 feet, the out-of focus at 2000 feet will be $\delta_2 - \delta_3$ = 4 mm and at 500 feet, $\delta_1 - \delta_2$ = 8mm. The difference in image diameter for a point source on axis and at 2000 feet when the telescope is focused at 1000 feet is 0.7mm. For the same focusing distance and conditions, but observing at 500 feet distance, the image size increases by 1.5mm. These increases are small compared with the area illuminated at the image plane. It should be emphasized that the telescope does not function as an "image forming system" but as "light collector." Thus this basic difference relaxes even more the focusing needs, and therefore it is not required to provide for refocusing when the aircraft changes altitude.

APPENDIX B

CONSIDERATIONS ON OPTICAL SCANNING FOR THE RODAC

The considerations on the optical scanning feature for the RODAC could be done on the basis of: technical feasibility, operational requirements, and/or cost.

Let us assume that the instantaneous field of view is as in the proposed RODAC 9 mrad x 9 mrad. At 1000 ft altitude the area illuminated by the RODAC is 9 ft x 9 ft or 81 ft^2. If we consider that the ground velocity of the aircraft is 250 miles hr^{-1} and that the assumed optical scanning scans perpendicular to the ground velocity vector a half field of 0.2 rad ($11^{\circ}5$) the area to be surveyed is 1240 x 10^3 ft sec^{-1}. The laser in the proposed RODAC will radiate at 100 pps rate, and since each pulse will illuminate an area 81 ft^2, the total area illuminated by the laser per second will be 8100 ft^2. Therefore, only 0.65% of the area scanned will be sensed by the RODAC. On this basis the scanning is not feasible.

Quite often the concept "scanning" is equated to the concept of "beam directing." The main difference lies in the rate of change in position of the instantaneous field of view. In the scanning concept the field of view is swept by the instantaneous field to generate a raster. In this case the rate of change is much faster than the time available to survey a given area. In the concept of "beam directing" the instantaneous field of view of the optical system is position to aim to a preselected target or position in space. This last concept is applicable to the RODAC and it should be explored in accordance with possible operational needs.

Based on the above, any further consideration of the optical scanning feature for the RODAC is not warranted.