MODEL NGN-2

OPEN-AIR INTEGRATING NEPHELOMETER

TECHNICAL MANUAL FOR

THEORY OF OPERATION AND OPERATING PROCEDURES

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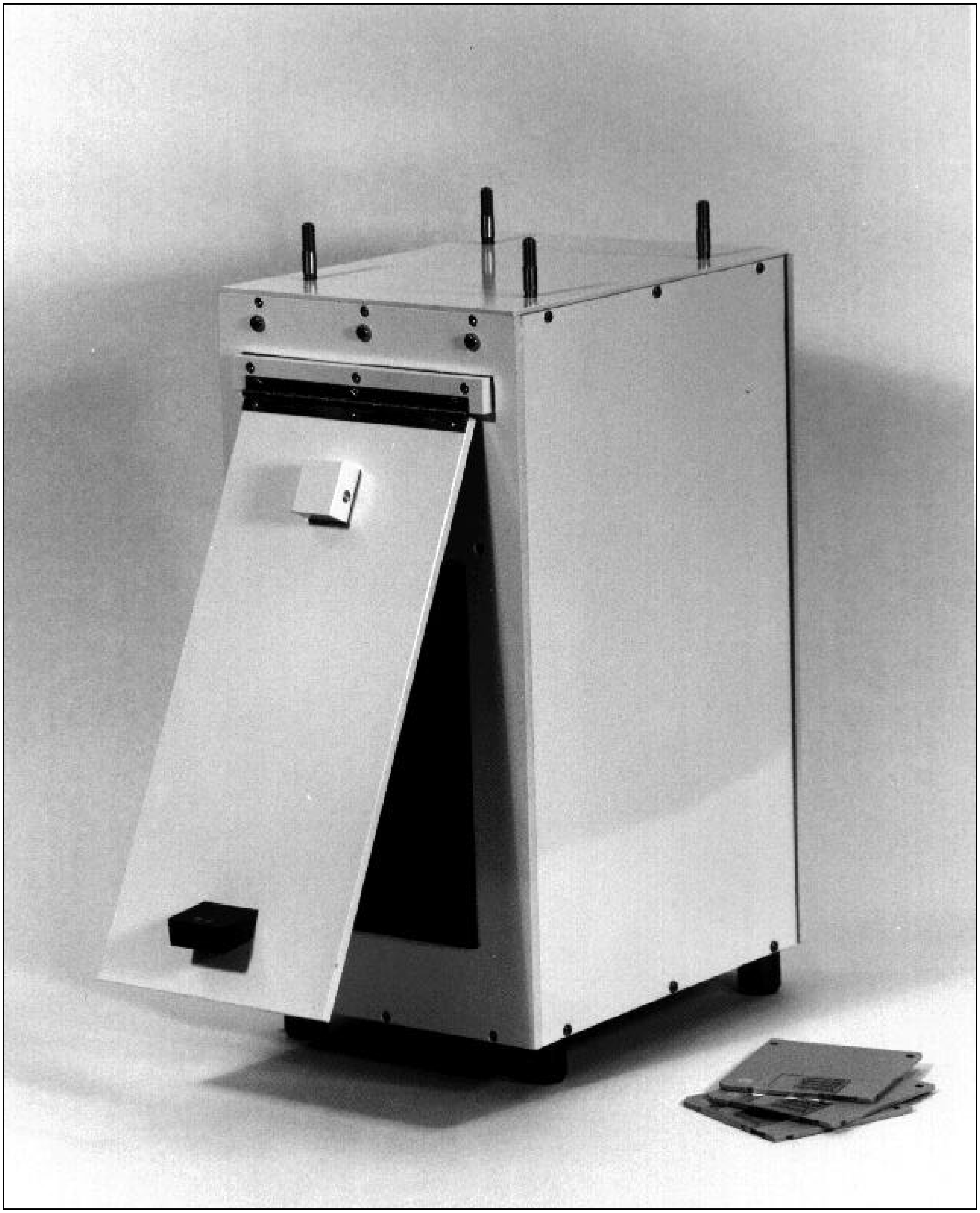

Figure 1-1. Model NGN-2 Open-Air Integrating Nephelometer.

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SECTION 1.0

INTRODUCTION

The Model NGN-2 (Next Generation Nephelometer) uses a unique integrating open-air design that allows accurate measurement of the scattering extinction coefficient of ambient air. Because of the open-air design, relative humidity and temperature of the air sample are essentially unchanged, thus the aerosol is negligibly modified when brought into the optical measuring chamber. With improvements made to the prototype NGN-1, the production Model NGN-2 nephelometer alters the temperature of the air sample by less than 0.5° C. Extinction due to scatter can accurately be measured from Rayleigh to 100% saturated fog conditions.

Using principals and techniques developed for the popular and successful Optec LPV transmissometer, the NGN-2 features low power consumption, solid compact design, and easy operation - all necessary parameters when installing and operating a measuring instrument in remote locations. Housed in a single environmentally sealed enclosure, the nephelometer contains all the necessary components for ambient stand-alone operation. The NGN-2 consists of a large inlet with motorized door, measuring chamber, clean air pump for calibration, blower, solenoid activated inlet for a span gas, temperature sensor, real time clock and rain detector for closing the inlet during wet conditions. See Figure 1-2 for a cross-sectional view of the NGN-2. A CMOS computer controls all operating functions and outputs data either in digital or analog format. External to the NGN-2 unit, a 13.8V DC, 5 amp power supply, compressed span gas and a data logger or printer are required.

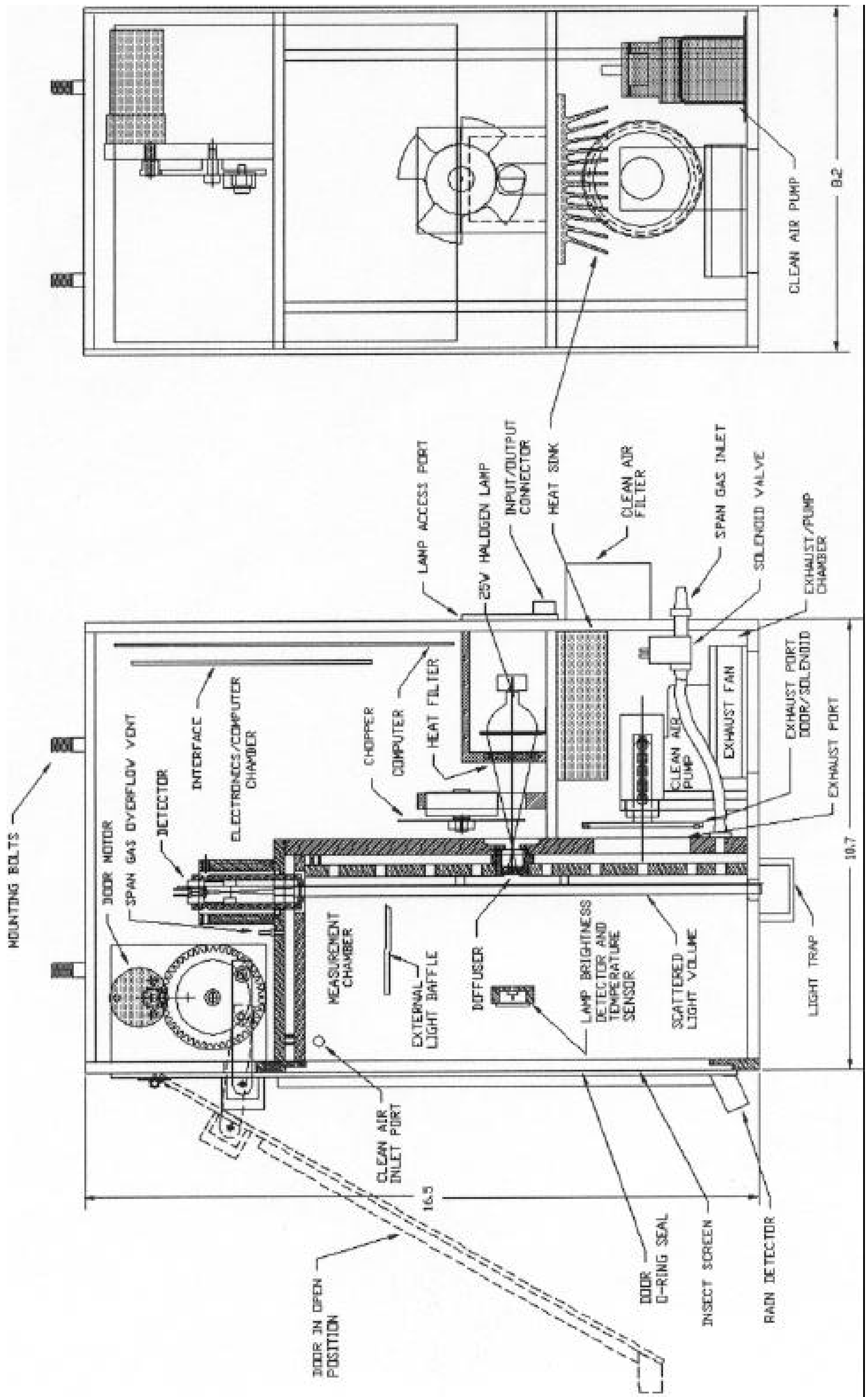

Figure 1-2. Cross-Sectional View of the NGN-2.

SECTION 2.0

THEORY OF OPERATION

2.1 OPTICAL DESIGN

The NGN-2 integrating nephelometer measures the scattering coefficient B_{scat} of a known volume of air. Refer to Figure 2-1. This air volume is illuminated by a near Lambertian diffuser made from flashed opal glass with a cos T fall off. More specifically, the diffuser radiates into a 2π steradian (180°) hemisphere using the following functional relationship

$$N_\theta = N_0 \cos\theta$$

where N_0 is the radiance normal to the diffuser's surface and T is the angle from a line normal to the plane of the diffuser to a point on the hemisphere. Because of optical and mechanical limitations in the design of this type of nephelometer, a small amount of truncation near 0° and 180° is necessary. The NGN-2 truncates at 5° and 175°.

A low voltage (13.8 volt DC) quartz halogen projector bulb with dichroic reflector illuminates the opal glass diffuser. In the light path between the diffuser and bulb, a heat absorbing glass filter blocks all radiation longer than 700 nm in wavelength and a mechanical chopper modulates the beam at a 10 Hz rate. The modulation principal allows a lock-in amplifier technique to be employed to separate the weak scattered light signal from ambient light and amplifier/detector noise.

Within the optical measuring chamber and directly in front of the diffuser, a photodiode detector with photopic spectral response measures N_0 and produces an output current directly proportional to the chopped light signal. This signal is used by the computer to lock-in to the scattered light signal and to normalize the scattered light signal with the N_0 value. Normalizing the scattered light signal compensates for lamp brightness changes due to power supply fluctuations, lamp aging and dust on the optical surfaces. All further discussion of this detector refers to it as the N_0 detector.

A telescope with a precisely defined field of view observes through a cylindrical pencil of air slightly above the diffuser. This pencil size volume of air is approximately 6 mm in diameter and 260 mm long and terminates in a light trap which reflects very little light back in the direction of the telescope. A small lens (Fabry lens) behind the field stop images the entrance pupil of the telescope (objective or front lens) onto the active area of a small silicon photodiode. This method of photometry is very common in stellar light photometers and is used to reduce the effect of response differences across the detector's surface and to allow all the light flux that passes through the field stop to be collected by the photodiode detector. Light flux

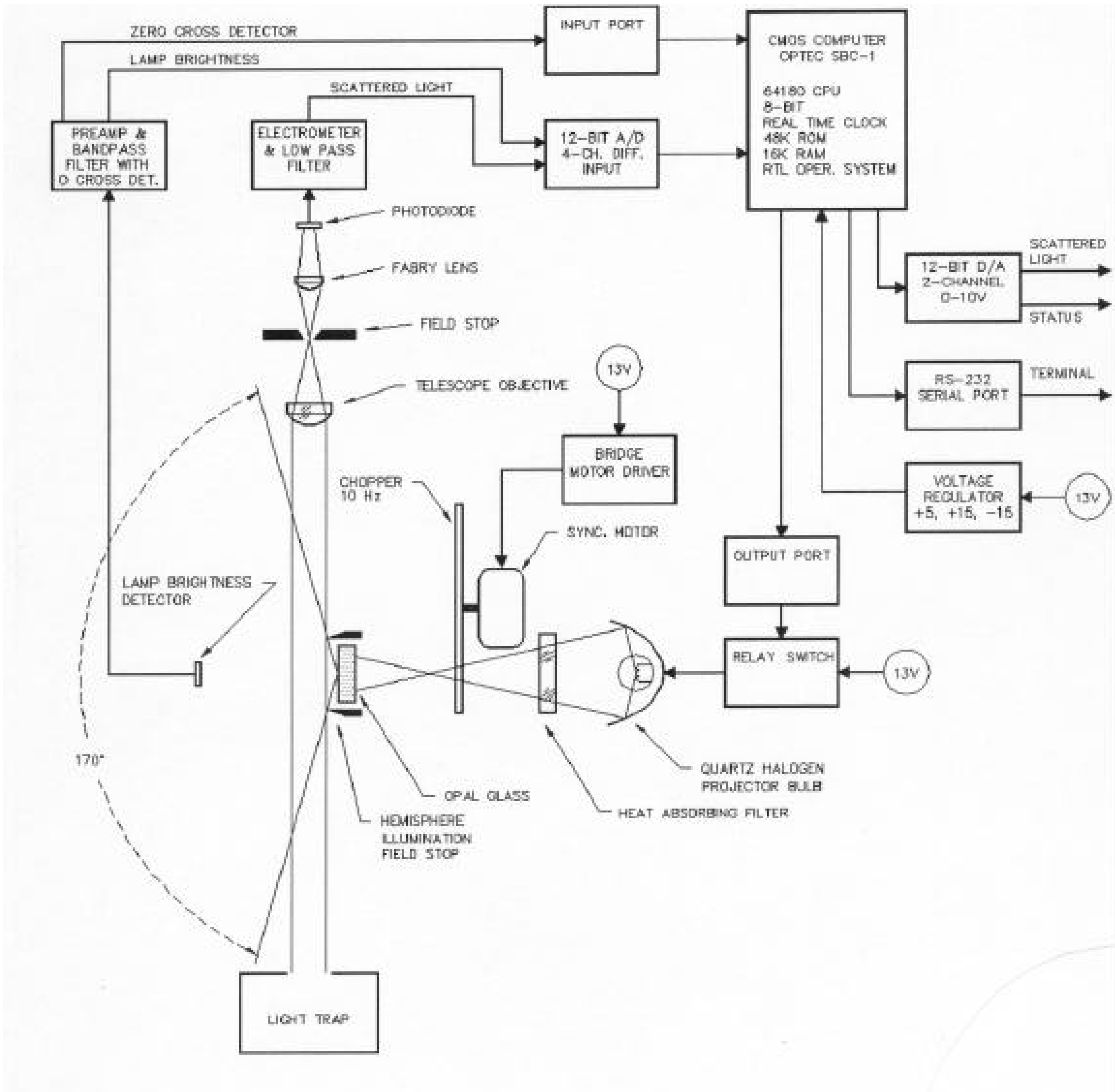

Figure 2-1. Electro/Optical Function Diagram.

measured by this photodiode is proportional to light scattered by the air sample plus light reflecting from the surfaces and stop edges in the optical chamber. This chamber wall component of the measured light is constant and small, usually only 3 to 4 Rayleighs. Similar to the photodiode measuring N_0, this photodiode has a photopic response filter. All further discussion of this detector refers to it as the scattered light detector.

2.2 PHOTODETECTORS

The detectors used for measuring both the scattered light and direct output from the diffuser N_θ, are P-N silicon photodiodes operating in the photovoltaic mode. Photons absorbed within the silicon layer of the photodiode excite electrons into the conduction band. Because of the instrinsic electric field generated across the P-N junction, these excited electrons cause a small current to flow when a connection is made between the P and N junctions.

The quantum efficiency, QE, is defined as the ratio of the number of incident photons to the resulting photoelectrons in the output current. The photodiodes used has a QE of approximately 75% in the photopic spectral band of interest. However, even with this high QE, photodiodes are unable to detect individual photons since amplifier plus detector noise is many times higher than the signal expected from an individual photoelectron.

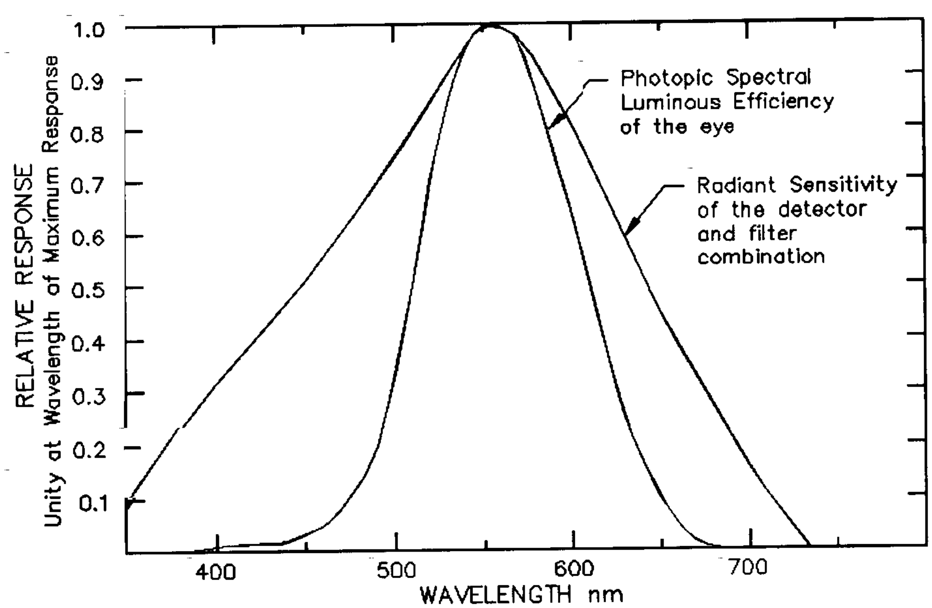

Figure 2-2. Photopic Spectral Response.

A photopic response filter is mounted on the photodiode with an optical adhesive. The spectral response of the detector/filter combination is shown in Figure 2-2. Important physical and electrical characteristics for this photodiode are shown in Table 2-1.

Size	1.3 x 1.3
Effective Area	1.6 sq. mm
Spectral Range	320 - 730 nm (5% cut-off)
Peak Response	550±20nm
Shunt Resistance	50 G Ω typical
Noise Equivalent Power	1×10^{-15} W/$\sqrt{Hz}$

Table 2-1. Photodiode Physical and Electrical Characteristics.

2.3 ELECTROMETER

Figure 2-3 shows the basic current-to-voltage amplifier used in the NGN-2 for both the scattered light and N_0 detectors. Photocurrent from the photodiode is balanced by an equal current in the feedback resistor but flowing in the opposite direction so that the inverting input is kept near zero potential. The output voltage is thus

$$E_{out} = R_f I_s$$

where R_f is the feedback resistance and I_s is the photocurrent.

Gain stability of this circuit in AC operation is a function of changes in the feedback resistance. With temperature, the prime forcing function on gain stability, the T-C coefficient of the scattered light electrometer amplifier is less than ±200 ppm/C°.

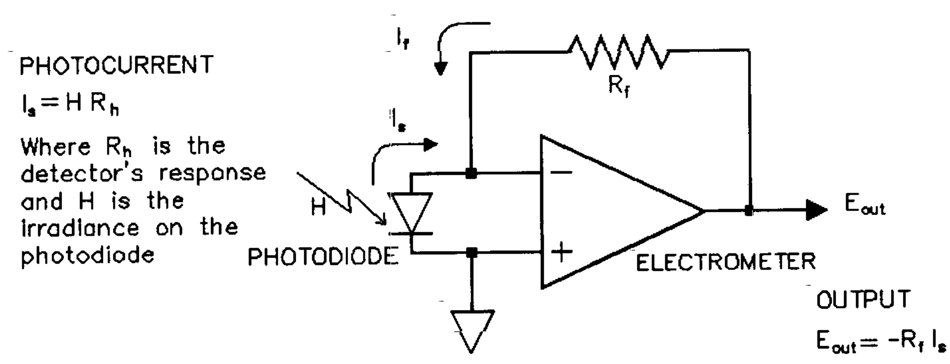

Figure 2-3. Current-to-Voltage Amplifier Configuration.

2.4 SIGNAL PRE-PROCESSING

Before processing by the computer, the signals from the scattered light and N_0 detectors are filtered and/or wave shaped to reduce noise and errors in the digitization process.

The current from the scattered light detector is converted to a voltage and amplified by a low-bias current electrometer op-amp as discussed in section 2.3. The high level signal from the electrometer is then passed through a DC blocking capacitor and a 3rd order low pass filter with a cut-off set for 35 Hz. This filter reduces noise pick-up and aliasing with higher frequency noise voltages. The resulting processed signal is ready for digitization by a 12-bit A/D converter.

Similarly, current from the N_0 detector is converted to a voltage and amplified by a low-bias current op-amp. The signal at that point is directed to two different functional routes - lamp brightness is measured to scale the scattered light output and the phase of the chopper is determined in order to phase-detect (lock-in) the weak scattered light signal.

The lamp brightness signal, N_0, is passed directly to a 12-bit A/D converter for digitization. The same signal is also processed by a 2nd order bandpass filter centered at 10 Hz (chopper frequency) and then wave shaped by a 0-cross comparator with TTL level output. When the bandpass amplifier is properly centered at 10 Hz, the resulting square wave signal from the comparator is exactly in phase with the chopped light. Lamp-on and lamp-off parts of the cycle can be accurately determined by observing the edge transitions of the comparator signal and determining if they are negative or positive going. This signal is routed to one of the available I/O ports of the computer.

2.5 COMPUTER PROCESSING

The OPTEC-1 Signal Board Computer has been designed by Optec to take advantage of low power CMOS ICs entirely. Based on the Hitachi 64180 microprocessor, the computer consists of a single 9" by 7.5" board with the important specifications listed in Table 2-2. The computer operating system and signal processing program are written in a unique language called RTL which stands for "Relocatable Threaded Language". RTL is a variant of the language Forth and as such it contains many of the features which have made Forth such a successful language. The nature of RTL lies somewhere between assembly language for speed and other higher level languages for easy and flexible programming.

When reset or powered on, the computer immediately computes a checksum number for the program on EPROM and checks it with a stored value also on the EPROM. If a mismatch occurs, the computer will stop and transmit an error message on the serial output line. This insures the integrity of the program before data is collected.

CPU	64180 from Hitachi 6.144 MHz clock rate Automatic reset via watchdog timer
Memory	48K EPROM 16K RAM 50 bytes non-volatile RAM
I/O	64 lines bidirectional
A/D	12-bit resolution +3.0 to -3.0 input voltage range 8 µsec conversion time 4 multiplexed differential inputs
D/A	12-bit resolution 2-outputs 0 to +10 or 0 to +5 output range
Real Time Clock	year:month:day:hour:minute:second 10 Year battery life
Serial Port	RS-232 port with the following functions available: RX, TX, CTS, RTS, DCD & GND up to 9600 baud

Table 2-2. Important Computer Specifications.

In the absence of noise, the difference between the signal level at the top of the cycle when the lamp is on and the bottom of the cycle when the lamp is off would give an accurate measurement of scattered light. Since noise due to the detector and amplifier electronics is usually several orders of magnitude greater than the signal, the average difference must be calculated over many hundreds of cycles.

The lock-in amplifier technique allows the computer to sample (take a voltage reading) at the same top and bottom points of the scattered light signal for many hundreds of cycles and then compute the average. The zero-cross detector signal from the N_0 detector allows the computer to determine the precise times when the chopper uncovers the lamp or covers it. Once those times are detected, a ¼ period delay is initiated before sampling is commenced to determine the top and bottom points of the wave form. The negative transition of the 0-cross detector signals a lamp-on condition and, conversely, a positive transition, signal a lamp-off condition. See figure 2-4. If a negative or posi-tive transition is not detected within a short time, an error condition code is transmitted on the serial port which would normally indicate a burned out bulb.

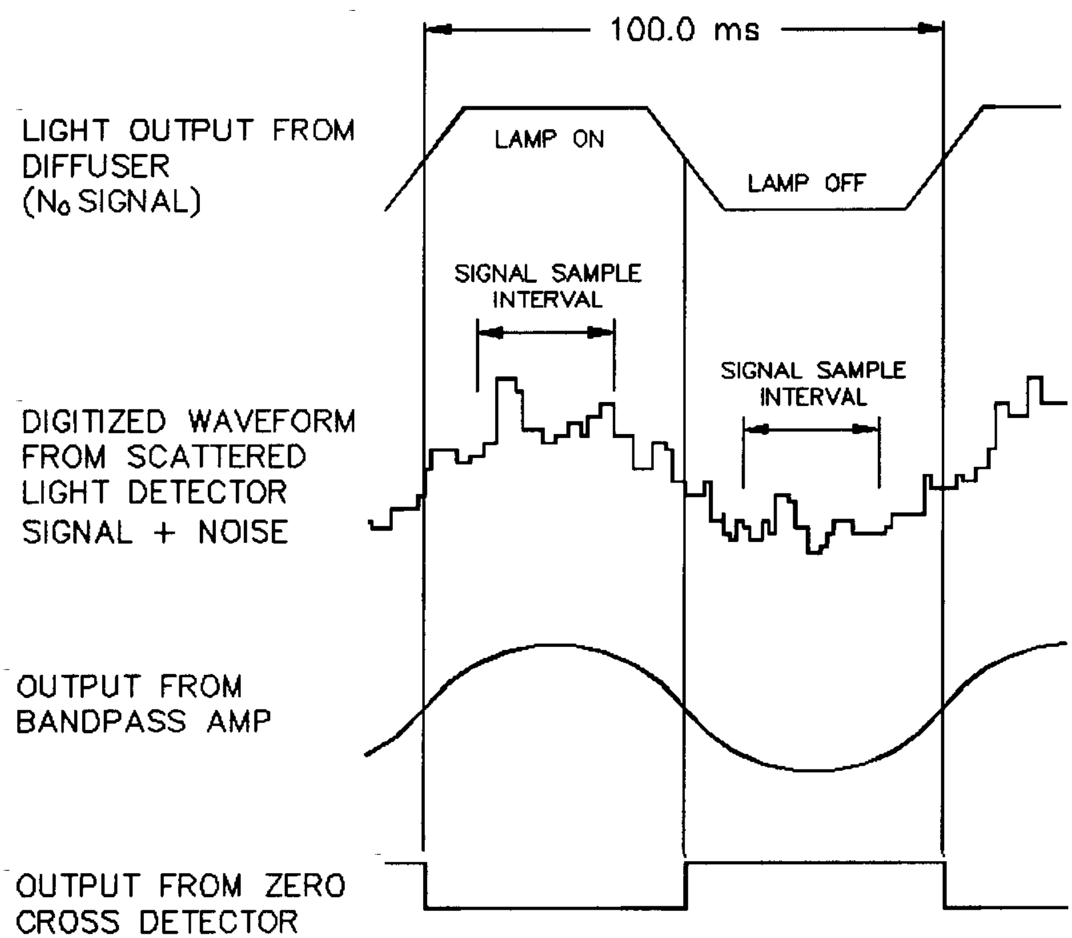

Figure 2-4. Signal and Control Processing Waveforms.

The computer integrates for 14 seconds the scattered light signal and then integrates for 1 second the signal from the N_0 detector, lamp brightness, for normalizing the scattered light result. This process is repeated 4 times to comprise the basic one-minute integration reading. Longer N-minute integration times are computed from the sum of N one-minute readings. Integration times less than one minute are not obtainable.

The NGN-2 begins operation using its default setting, MODE = 1, which sets the integration time to two minutes and then outputs the results on the serial and analog data lines. Clean air calibrations are performed approximately every 27 hours and span gas calibrations are performed only at power on or computer reset. Both clean air and span gas calibrations take approximately 20 minutes to perform. At the end of each integration, the results along with time, temperature and status are transmitted on the serial output line and the two D/A converters are updated in case of external analog data recording. Other operating sequences are easily selectable and are discussed in Section 3.0. Operating sequences unique to an individual user are possible but must be programmed at the factory.

2.6 CLEAN AIR & SPAN GAS CALIBRATION

Periodic clean air and span gas calibrations are performed in order to monitor and correct for instrument gain and zero intercept drift due to temperature changes and/or dirt accumulating on the measurement chamber optics. Clean air calibrations are usually performed more often since they are easy to do and use no source of expendable gas. Span gas calibrations with a dense gas such as Freon-22 ($CHClF_2$), Sulfur Hexafluoride (SF_6) or HFC-134a are usually done on power up or computer reset with an operator present. However, the operating program can be easily modified to accomplish this periodically and without an operator.

The scattering value for clean air reading is considered equal to one Rayleigh or 0.01 km^{-1} if temperature and pressure values are compensated for. A span gas such as Freon-22 would have a scattering coefficient equal to 7.69±0.08 times the clean air value. Knowing these two values allows a solution to be found for the following linear equation

$$y = ax + \mathrm{b}$$

where,

y = scattered light due to molecular and aerosol scatter in user selected units

a = scaling factor

x = normalized scattered light output for clean air or span gas

b = scattered light from the measurement chamber walls.

Clean Rayleigh quality air is obtained by recirculating the measuring chamber air through a 0.3 µm glass microfiber filter with the inlet door closed. This filter retains 99.97% of all particles larger then 0.3 µm. The clean air pumping requires approximately 5 minutes to completely filter all particles from the measuring chamber before a 10 integration is commenced. During the clean air cycle, a 7.0 volt Status signal is held on D/A channel-2 to indicate that a clean air calibration is in process. When the clean air calibration is completed, a 2.0 volt Status signal is sent to D/A channel-2 to indicate that the output on D/A channel-1 is a clean air reading. Simultaneously, the clean air value is sent to both the serial and D/A channel-1 lines.

A cylinder of compressed span gas pressure regulated to approximately 10 psi is connected to the solenoid activated gas inlet valve. When a span gas calibration is started, this inlet is opened for 10 minutes to allow the span gas to completely fill the measuring chamber before a 10 minute integration is commenced. During the span gas cycle, a 7.0 volt Status signal is held on D/A channel-2 to indicate that a span gas calibration is in process. The measured scattered light value is transmitted to the serial port along with a status code indicating a span gas calibration value. This value is also converted to an analog voltage and passed to the D/A channel-1 output. A 3.0 volt Status signal is held on D/A channel-2 to indicate a span gas reading.

2.7 MECHANICAL DESIGN

The NGN-2 contains nearly all of the equipment needed for an integrating nephelometer in one environmentally sealed enclosure which measures 10.7 x 8.2 x 16.5 inches and weighs 27 lbs. Only a source of low voltage DC power, span gas cylinder and data logging means are needed to complete a working instrument. Usually, the NGN-2 mounts from the top under some sort of protective roof such as a building overhang. The clean air filter module, access door for lamp changing, data/power cable connector and span gas inlet are mounted on one side of the unit for easy accessibility and maintenance.

The interior of the instrument is separated into three areas - measuring chamber, exhaust/pump chamber and the electronics/computer chamber. See Figure 1-1.

Separated by a double wall, the optical measuring chamber is completely sealed from the rest of the enclosure to prevent either air or heat from the internal parts of the instrument from contaminating the measuring process. A large air inlet with motorized door allows ambient air to flow unmodified a short distance to the viewing volume. To prevent unwanted insects and large floating masses from entering the chamber, a 24 mesh (24 wires to the inch) stainless screen covers the inlet window. One side of the measuring chamber wall is easily removed to allow access to the chamber for cleaning and service. The exhaust fan mounted in the exhaust/pump chamber creates a strong negative pressure behind the rear wall of the measuring chamber which is perforated. This causes the ambient air to laminar flow through the measuring chamber without much turbulence.

To allow the span gas to fill the chamber and the overflow to vent outside, a small plastic tube is coupled from the top of the chamber to the exhaust/pump chamber. The heavier than air span gas will fill the bottom of the chamber first and force air out through the top vent tube.

Separate and sealed from the electronics/computer chamber, the exhaust/pump chamber houses the lamp cooling heat sink, clean air pump, exhaust port door, exhaust fan and span gas solenoid activated inlet valve. The exhaust air from the measuring chamber passes through the exhaust/pump chamber before being expelled. In the process, this air passes through a finned heat sink which helps to reduce the internal heat of the instrument which comes primarily from the 25 watt halogen lamp. A low voltage diaphragm pump is used to recirculate the measuring chamber air at a rate of approximately 2 liters/minute. On the positive pressure side of the pump, tubing

directs the air flow to the externally mounted clean air filter which mounts on the outside rear panel much like an automobile oil filter. A
solenoid activated door allows the measuring chamber exhaust port to be completely sealed during calibration measurements. The span gas inlet uses a 1/8" barbed tubing insert for coupling to the compressed gas cylinder which should be pressure regulated to 10 psi. A solenoid activated valve allows the span gas to fill the measuring chamber on computer command.

The electronics/computer chamber contains the projector lamp, chopper motor, scattered light detector/electrometer, computer, interface board and door open/close motor.

A 13.8 volt DC 25 watt projector bulb with dichroic reflector focuses most of its light energy onto the opal glass diffuser. Around the bulb a thick metal shield absorbs and conducts much of the heat energy from the bulb to the finned heat sink within the exhaust/pump chamber. Lamp life is estimated at around 700 hours of operation at the rated voltage. Connected directly to the 13.8 volt DC supply voltage through a relay switch, the lamp brightness is not well regulated and changes slightly when the various power functions of the instrument are activated. However, the N_0 detector continually monitors these brightness changes and scales the scattered light detector output accordingly.

Controlled by its own crystal oscillator, the low voltage synchronous chopper motor's rotational speed is precisely held to 2.5 rps. The four blade chopper thus interrupts the lamp beam at a 10 Hz rate. The chopper is activated when the lamp is turned on.

A geared 12 volt DC motor is used to open and shut the inlet port. The torque of this motor is governed to close the door securely without providing too much torque which could be dangerous to trapped fingers. About 4 seconds is required for the motor to close or open the door. The door is opened to an approximate 30° angle from the front panel of the NGN-2. To conserve power and prevent internal heat from building up, the voltage to the motor is turned off after 10 seconds of operation.

Connected to the computer board, the interface control circuit board provides the necessary interface between the computer and the various control/ measurement functions of the NGN-2.

The 13.8 volt DC input power is first routed to the interface board where current, voltage and transient protection devices provide safe power for the rest of the instrument. On board regulators provide +5, +15 and -15 volt power to the various digital and analog circuits. Maximum continuous current required during operation is approximately 4.5 amps.

Either solid state HEXFET devices, or mechanical relay switch is connected to the I/O ports of the computer control the electromechanical devices within the instrument. All devices are connected to the 13.8 volt DC input power and are turned on when the circuit is completed to the power return through the switch.

2.8 RAIN DETECTION & TEMPERATURE

Because the optical measuring chamber is open to the outside, wind driven moisture could be blown in the chamber causing erroneous readings and possibly disabling the measurement process for some period of time after the event. To prevent this, a moisture detector is mounted at the bottom of the door for the purpose of interrupting the measurement process in the event of rain or snow. The rain detector is essentially two stainless steel terminals mounted about 6 mm apart with a 12 volt potential difference between them. Any moisture between the two terminals will allow a small amount of current to flow which will be detected and the measurement process interrupted. At that point the computer closes the instrument and turns off all but essential systems. A small 2 watt heater below the terminals is turned on in order to speed the drying process. Once the surface between the two terminals is dry for one hour, the NGN-2 continues with the measurement cycle where it left off. Clean air and span gas calibrations are not affected by the detection of rain since they operate with the inlet door closed.

Temperature within the measuring chamber is also measured and transmitted to the serial output along with the scattered light values. Besides the importance of recording temperature along with the data for post processing, temperature information is needed for the proper detection of moisture when ambient condition are near and below the freezing point. At 2°C a small 2 watt heater mounted under the terminals is turned on to prevent water from freezing between the terminals. The volume resistance of ice is high enough so as not to be detected by this method if left on the terminals. The temperature sensor and amplifier are accurate to 0.8°C and has a range of -50 to +50°C.

SECTION 3.0

OPERATING PROCEDURES - STANDALONE MODE

3.1 BASIC OPERATION

Because of Optec's long association with the National Park Service in its field testing program of our visibility instruments, the design philosophy used for the NGN-2 was to keep it simple. For operation with a chart recorder or other analog recording device connected to the two D/A channels, the only operating procedure is to plug it in and walk away.

The standalone mode is initiated either at Optec or with the user's terminal as described in Section 4.0. Before installing and operating in a measuring mode, the terminal command PC-OFF is invoked to set the computer mode to standalone operation. The PC-ON command sets the NGN-2 for use with a XT/AT class computer running Optec's custom display and data reduction software. See separate manual for this product for a complete description and operating procedures.

Three possible operating sequences are available and are selected by using the terminal command *n* SELECT-MODE where *n* is the user's choice of 1, 2 or 3 which represent the three possible sequences. See Table 3-3 for a complete description of these operating sequences. Sequence number 3 can be user defined but must be programmed at Optec for inclusion within RTL and a custom EPROM generated.

The user has a choice whether to allow a span gas calibration to begin when the NGN-2 is powered-on or the RUN command is invoked. The terminal command SPAN-ON or SPAN-OFF will initiate or skip by a span calibration respectively when the operating program is started.

Selection results from these three operating commands are stored within the available 50 bytes of non-volatile RAM and are kept even if power is interrupted for extended periods of time. See Table 2-2. If defined by the user before delivery, these operating choices can be programmed at Optec. Changes afterwards would involve the user's use of a terminal or returning the NGN-2 to Optec for reprogramming.

At the beginning of a computer reset or power on and if the SPAN-ON command is invoked, the computer will initiate a span gas calibration cycle which lasts about 20 minutes. After the span gas cycle, the computer initiates one of the operating sequences defined previously.

The user is then expected to post process this data to extinction, visual range, mass concentration or other visibility related parameters. Optec has available at nominal cost Lotus 1-2-3 templates to aid in the data reduction. The advantage of this procedure is that the raw data set is retained and computer generated graphical output of data is superior to most instrument outputs of finished time-stamped data.

3.2 OUTPUTS & INPUTS

Both power and communication to and from the NGN-2 is through a single 9-pin circular connector on the rear panel. The pin number and function for each is described in Table 3-1.

PIN NUMBER	FUNCTION
1	+13.8±0.3 volt DC, 4.5 amps required
2	Power Return
3	Serial I/O, RS-232, RX (receive)
4	Serial I/O, RS-232, GND (common)
5	Serial I/O, RS-232, TX (transmit)
6	Analog Channel-1, (scattered light)
7	Analog Channel-1, Common
8	Analog Channel-2, (status)
9	Analog Channel-2, Common

Table 3-1. Pin-out and Function for the Power and Communication Connector.

3.3 POWER SUPPLY

Any high quality low voltage source can be used to supply DC power if it can supply a minimum of 4.5 amps continuously and be set for 13.8±0.3 volts. The user should take into account voltage loses on the power cable due to the finite resistance of copper when planning cable lengths. A heavy gage cable may have to be used if the distance from the NGN-2 unit to the power supply is great. Normally, a 16 AWG cable is adequate for distances up to 20 feet. Optec can supply a power supply mounted in a NEMA 12 enclosure. See price list.

3.4 SERIAL I/O

At present, the serial output supports RX, TX and GND for the RS-232 interface. Default values for this interface are: 8 data bits, 1 stop bit, no parity and 9600 baud. Televideo 920 terminal emulation is supported in Full-Duplex mode. For connection to a printer, only RX and GND needs to be connected. A sample of output data is shown in Figure 3-1 where the columns labeled A through H represent data as described in Table 3-2. Low capacitance cables would allow lengths up to 150 feet to be used without problem. For greater lengths, high current drivers or fiber optic cables would be required. Since this is a direct electrical connection to the computer circuitry, not electrically isolated, great care should be used in planning to protect against lightning and power surges in the AC line or building structures from damaging the NGN-2.

Further discussion of this topic is beyond the scope of this manual but Optec will help plan a safe wiring strategy when requested.

Serial digital data may be recorded with a variety of means. The simplest would be a dot matrix printer connected to RX and GND. Of course, this method makes it difficult to transport the data to a computer for post processing. A more desirable method would be to use a PC-XT or similar computer with a data capture program. Again, only RX and GND in a two wire cable need to be connected to the computer. At Optec we use a shareware telecommunication program called PROCOMM for both data capture and control (described in section 4.0). Configured versions of this product are available from Optec at a nominal charge to cover cost of the media and preparation only.

A	B	C	D	E	F	G	H	Comments
3	383	3841	199	10	23.43	910425	1500	*Span Calibration*
2	98	3839	51	10	23.49	910425	1516	*Clean Air Calibration*
1	290	3752	154	2	23.03	910425	1520	*Beginning of Ambient Air Readings*
1	287	3723	154	2	22.89	910425	1522	
1	282	3714	152	2	22.87	910425	1524	
1	276	3708	149	2	22.80	910425	1526	
5								*Measurements Interrupted by Rain*
1	265	3682	144	2	21.34	910425	1636	*Rain Stops,*
1	267	3685	145	2	21.37	910425	1638	
.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	*Data Deleted*
1	225	3671	122	2	20.75	910425	1759	
2	95	3813	50	10	21.32	910425	1820	*Clean Air Calibration after 3 Hours*
1	223	3736	119	2	20.52	910425	1824	

Figure 3-1. Sample Output from Serial I/O Port.

COLUMN	DESCRIPTION	
A	Status	1 = Ambient Air Measurement 2 = Clean Air Calibration 3 = Span Gas Calibration 4 = Lamp Low or Burned Out 5 = Rain 6 = Chopper Motor Failure 7 = Span/Clean Air Calib. in Process (D/A Channel-2 output only) 8 = Fog Level Reached
B	Raw Scattered Light Value	
C	Raw Lamp Brightness Value	
D	Normalized Scattered Light Value	
E	Integration Time in Minutes	
F	Temperature in °C	
G	DATE: Year - Month - Day	
H	TIME: Hour (24 hr. clock) - Minute	

Table 3-2. Description of Columnar Data in Sample Output (Figure 3-1).

3.5 ANALOG OUTPUT

The analog output channels 1 and 2 provide a 0 to 10.00 volt full scale signal which is directly proportional to the normalized scattered light and status values respectively. For the status values described in Table 3-2, that is the 1, 2, 3 etc. digital codes, the analog channel 2 represents these as 1.00, 2.00, 3.00 etc. volts with an accuracy of ±0.02 volts. An internal jumper on the computer board can be set to allow for a 0 to 5.00 volt full scale signal if required. Of course, the scatted light and status values will be one half their digital values.

The D/A converter has 12-bit resolution which allows for 4096 voltage states between 0 and 10 volts. Thus, each bit represents a voltage change of 0.00244 volts. A scattered light digital reading of 100 would produce an output on analog channel 1 of 0.100 volts and 10,000 an output of 10.000 volts. Since the digital output is a signed single precision number having 32768 states, both greater resolution and dynamic range are available with the digital output. Through simple programming changes at the factory, the analog output can be tailored to have greater dynamic range at the expense of resolution. The reverse is also possible. Typically, Rayleigh air can be resolved to about 15% precision (± least significant bit) and the high end (10.00 volts) limits extinction readings to about 7.0 km^{-1}.

Care should be exercised when connecting a data logger to these analog voltage outputs. It is recommended that only high impedance, preferably differential amplifiers, be used to buffer these outputs. Most high quality data loggers and strip chart recorders have suitable input amplifiers. Low capacitance shielded cable is recommended and the distance to the data logger should not exceed 20 feet. Since this is a direct electrical connection to the computer circuitry, not electrically isolated, great care should be used in planning to protect against lightning and power surges in the AC line or building structures from damaging the NGN-2. Further discussion of this topic is beyond the scope of this manual but Optec engineers will help plan a safe wiring strategy when requested.

OPERATING SEQUENCE	DESCRIPTION
1 (OPERATE-1)	Continuous 2 minute integrations with a clean air calibration approximately every 27 hours. A total of 810 integrations (1620 minutes total) with 15 minutes allotted to perform a clean air calibration. This mode is not synchronized with the real time clock but begins whenever the program is initiated.
2 (OPERATE-2)	A single 10 minute integration is initiated at the beginning of each hour. At 6, 12, and 18 hours a clean air calibration is performed. At 0 hours a span gas calibration is performed. This mode is synchronized with the real time clock.
3 (OPERATE-3)	Begins with a clean air calibration and then performs a 2 minute integration followed by a 3 minute low power vent mode. This maintains the optical chamber at near ambient temperatures. A clean air calibration is performed approximately every 6 hours. This mode is synchronized with the real time clock to begin a reading a time divisible by 5. The start time is reported on the serial data line.

Table 3-3. Operating Sequences for Standalone operation.

SECTION 4.0

OPTEC-1 SBC PROGRAM MONITOR

4.1 SET-UP

Controlling and modifying the operating program begins with the proper interfacing with a terminal or telecommunication program running on a PC computer. Read Section 3.4 first to insure proper connection to the NGN-2 computer. The TX line should also be connected.

4.2 IMPORTANT PROGRAM COMMANDS

A number of functions can be controlled directly from the terminal keyboard including setting the real time clock, operating various mechanical functions to determine proper operation and starting a span gas or clean air calibration under user command. To operate the computer in the monitor mode, enter a key stroke within 2 seconds of power up or a Ctrl-C anytime during operation. The computer may take up to 60 seconds before it interprets the entry from the keyboard. The common ">" prompt will appear when the computer is ready for user commands. The monitor only accepts capital letters and numbers. Table 4-1 lists the important commands that can be used easily. For those commands written as "*n* COMMAND", the "*n*" represents some numerical input such as 10 MINUTE for setting the real time clock to 10 minutes pass the hour.

Any ASCII terminal should work with the NGN-2 computer. In order to use some complex functions such as the EDIT command for modifying the operating program, the terminal or telecommunications program must have Televideo 920 or similar emulation. Screen cursor commands will not operate properly with other terminal emulations.

After changes have been made, the command RUN will restart the program with the span gas calibration. The command ABORT will reset the computer in monitor mode and is useful if attempted changes to the program were unsuccessful and some stack and loop counters have been corrupted.

COMMAND	DESCRIPTION AND USE
PC-ON	Sets NGN-2 to PC computer mode
PC-OFF	Sets NGN-2 to standalone mode
SPAN-ON	Span calibration done when powered on
SPAN-OFF	Skips span calibration when powered on
n SELECT-MODE	Sets operating sequence to 1, 2 or 3 Example: 1 SELECT-MODE \set OPERATE-1
n BAUD	Sets serial port to 300, 600, 1200, 2400, 4800 or 9600 baud Example: 1200 BAUD \sets baud to 1200
n YEAR	Sets real time clock to proper year Example: 91 YEAR \sets year to 1991
n MONTH	Sets real time clock to proper month Example: 6 MONTH \sets month to June
n DAY	Sets real time clock to proper day Example: 15 DAY \sets day to 15
n HOUR	Sets real time clock to proper hour Example: 16 HOUR \sets hour to 4:00PM
n MINUTE	Sets real time clock to proper minute and seconds to 0 Example: 30 MINUTE \sets minute to 30
TIME-PRINT	Prints time in hh:mm format
DATE-PRINT	Prints date in yy:mm:dd format
RUN	Starts the program
DOOR CLOSE	Closes inlet door
DOOR OPEN	Opens inlet door
FAN ON	Turns on exhaust fan
FAN OFF	Turns off exhaust fan
PUMP ON	Turns on clean air pump
PUMP OFF	Turns off clean air pump
SOL ON	Opens exhaust port door
SOL OFF	Closes exhaust port door
VALVE ON	Opens span gas inlet valve
VALVE OFF	Close span gas inlet valve
LAMP ON	Turns on halogen lamp
LAMP OFF	Turns off halogen lamp
CALIB	Begins calibration cycle
SPAN	Begins span gas calibration cycle

Table 4-1. Important Computer Commands and Their Use.
(Continued next page)

COMMAND	DESCRIPTION AND USE
n TO INTEG	Set integration time for ambient air readings Example: 10 TO INTEG \sets 10 minute\integration time
n BAUD-STORE	Set computer to *n* baud rate after RUN is initiated. Computer boots up at 9600 baud and then switchs to new rate after 3 seconds. Only 300, 1200 and 9600 rates accepted. Example: 300 BAUD-STORE \sets baud to 300.
SN	Shows serial number
SHOW-RUN-TIME	Shows total accumilated integration time in hours
FREQ-TEST	Checks chopper frequency. Prints 000 +/-001 if frequency is within specification. Stop with ^C.
OUTPUT-TEST	Checks analog channels 1 and 2. Sets outputs to 0.00, 5.00 and 10.00 volts.
A/D-TEST	Checks operation of A/D converter. Prints scattered light and lamp instantaneous values when envoked.
TEMP-TEST	Checks temperature calibration. Prints temperature until stopped with ^C
ABORT	Resets various stacks and loops without changing variable values. Use to reset computer. Stays in monitor mode.
n FOG-LIMIT-STORE	Sets normalized scattered light value where condensing fog conditions exist. Unit will shut down for a period of 1 hour. (10000 default value)
n LAMP-LIMIT-STORE	Sets lower value of acceptable lamp value as shown in Fig. 3-1 column C. Unit will shut down. (2000 default value)
n MULTIPLIER-STORE	Sets multiplying factor for D/A channel-1. Allows for greater resolution for scattered light reading at the expense of dynamic range. (1 default value)
POST-ON	Serial sign-on message enabled (default)
POST-OFF	Serial sign-on message disabled
*n*INTERVALS-STORE	Sets number of integrations to perform before a clean air calibration is done.
TEST-ON	Power on self-test enabled
TEST-OFF	Power on self-test disabled (default)

Table 4-1. Important Computer Commands and Their Use.

SECTION 5.0

SPECIFICATIONS

EXTINCTION RANGE	0 to 32,768 count (Serial Output) (typically equal to 0.01 to 24.00 km^{-1} after post processing) 0 to 10.00 volts (Analog Channel 1 or 2) (typically equal to 0.01 to 7.00 km^{-1} after post processing)
RESOLUTION	±1 count, (Serial Output) (one Rayleigh is approximately 12 counts) ±2.44 mv (Analog Channel 1 or 2) (one Rayleigh is ˜12.0 mv with multiplier = 1)
ACCURACY	±10% of true value for air near Rayleigh and using two minutes of integration (longer integrations will increase the S/N by $INTEGRATION^{-½}$ ie. 10 minutes of integration will increase accuracy to ±4.5%)
MEASURED WAVELENGTH	550 nm Center Wavelength, 100 nm Bandwidth Photopic Response
OUTPUT, SERIAL	RS-232, RX, TX, GND 8 data bits, 1 stop bit, no parity Televideo 920 emulation, FULL-DUPLEX mode 9600 baud default, others selectable
OUTPUT DATA, SERIAL	STATUS, Raw SCATTERED LIGHT Count, Raw LAMP BRIGHTNESS Count, NORMALIZED SCATTERED LIGHT Count, INTEGRATION TIME in Minutes, TEMPERATURE, DATE in year:month:day, TIME in hour:minutes
OUTPUTS, ANALOG	2 analog channels 0 to 10.000 volt, 0.00244 volt steps or 0 to 5.000 volt, 0.00122 volt steps, jumper selected 2 Ω output impedance, current limited
OUTPUT DATA, ANALOG	Channel 1: NORMALIZED SCATTERED LIGHT Channel 2: STATUS value (see Table 3-2.)
POWER SUPPLY	13.8±0.3 volt DC, 4.5 amps, regulated required
OPERATING TEMPERATURE	-20 to +45°C
SIZE	10.7 x 8.2 x 16.5 inches
WEIGHT	27 lbs.
FINISH	high gloss white powered metal paint

Appendix A

NGN-1 & BELFORT 1590 COMPARISON

A comparison between the prototype Optec NGN-1 and Belfort 1590 was performed at Optec in Lowell, Michigan, between December 1990 and April 1991. The following diagram shows both instruments tracking scattering from ambient air during an approximate 14 hour period from midnight of March 20th to around 2:00 pm. The NGN-1 is set for continuous operation with 1 minute integrations and a 10 minute clean air calibration cycle every 60 minutes. The Belfort 1590 performs a heated inlet and unheated measurement with a one hour cycle time between each - the unheated inlet measurements are always higher. Every 6 hours the Belfort 1590 performs a clean air calibration. The vertical scale of both instruments was set to read the same using Freon-22 as the calibration span gas.

Around 6:00 AM, a morning fog condition occurred, confirmed by visual inspection, which was tracked by the NGN-1 but not by the Belfort 1590. The approximate 3° C temperature rise of air passing through the Belfort instrument even in the unheated inlet mode causes a sudden drop of the relative humidity and dissipation of the fog before it is measured in the optical chamber.

For low relative humidity conditions, both instruments tracked well together during the comparison study at Optec. A more intensive comparison study is planned for the period of May to September 1991 at Shenandoah National Park by the National Park Service.

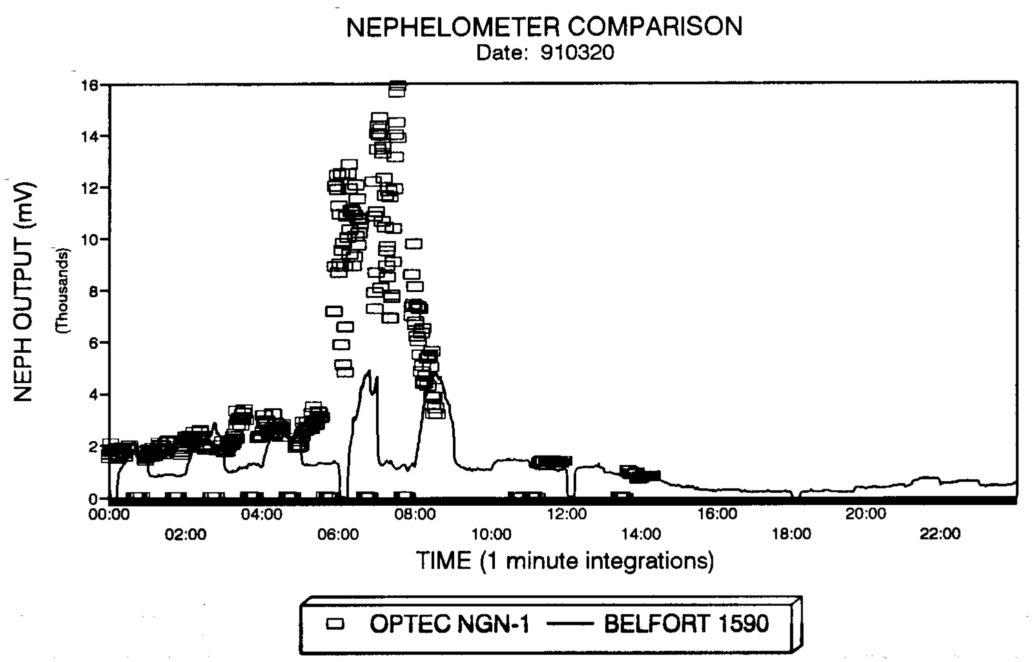

Figure A-1. Optec/Belfort Nephelometer Output Comparison.

APPENDIX B

SPAN GAS CALIBRATION

Span gas calibrations have been performed with Helium, Argon, Clean Air, Carbon Dioxide, Freon-22 and Freon-12. The prototype NGN-1 output, like the production Model NGN-2 output, is shown to be extremely linear when plotted with the known scattering coefficients of these gases.

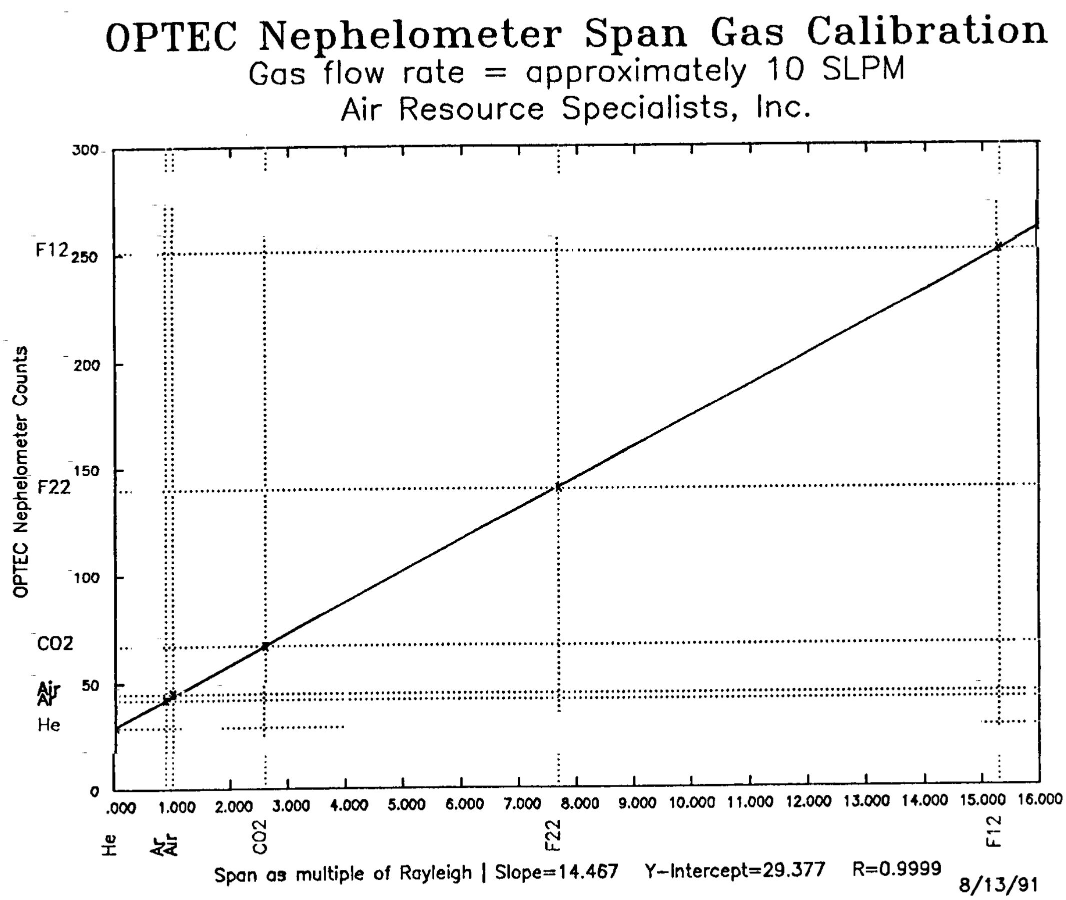

Figure B-1. NGN-1 Output with Various Span Gases.

APPENDIX C

13.8 V DC POWER SUPPLY

For AC installations, the 13.8 V DC power supply, stock No.86910, is required. This power supply is mounted in a NEMA all weather steel enclosure which measures 10 x 8 x 6 inches. Mounting and connecting details are shown in Figure C-1. The unit will supply regulated 13.8 ±0.3 V DC at up to 7.5 amps to the NGN-2 nephelometer.

Two water tight cord connectors for cord diameters of 0.250 to 0.375" are mounted on the bottom panel for SJO or SJEO electrical cords. It is recommended that 3 conductor, 18 AWG, SJEO cord be used to connect 117±7 V AC, (Hot, Neutral and Safety Ground) to the power supply. If conduit is desired for the AC hook-up, one of the water tight cord connector can be removed thus allowing 1/2 NPT pipe to be installed directly to the NEMA enclosure. There is no fuse protection or power-on switch on this power supply. The user must install proper current protection, lightning surge protection and power interrupt features before the 13.8 V DC power supply unit. It is recommended that a 10 amp fast acting fuse be used on the AC line. Screw terminals inside the unit allow connection of the 3 conductor cable to the transformer using insulated ring or spade terminals for #6 screw and 18 AWG wire.

Output DC is routed through the remaining water tight connector using 2 conductor, 16 AWG, stranded cord - type SJEO cord is recommended. With the size wire, distances up to 20 feet can be accommodated with negligible voltage loss. Distances longer that this may require the user to analyze ohmic losses in cable and adjust wire size accordingly. Longer distances may also expose the cable to lightning strikes.

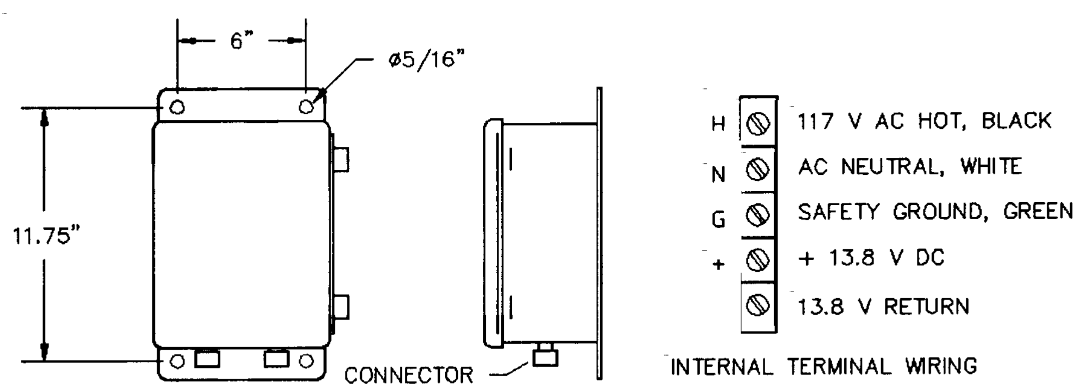

Figure C-1. 13.8 V DC Power Supply Mounting and Connecting Details.