MODEL NGN-3A

Integrating Polar Nephelometer with $PM_{2.5}$ size-cut inlet, internal temperature, internal humidity, internal barometric pressure and external temperature sensors

TECHNICAL MANUAL FOR

THEORY OF OPERATION AND OPERATING PROCEDURES

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Figure 1-1. Model NGN-3A Nephelometer.

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SECTION 1.0

INTRODUCTION

The Model NGN-3A is an advanced design integrating polar nephelometer used for the purpose of accurately measuring the scattering coefficient of dry air. The instrument uses a spiral sampler inlet to separate out particles larger than 2.5 microns to satisfy the current $PM_{2.5}$ standard. In addition, a heated optical measuring chamber dries the air sample to a preset relative humidity value. A RH (relative humidity) sensor is mounted in the sample air chamber to measure RH with a 1-minute rise time. By measuring the scattered light over a 170 degree angle, the scattering extinction coefficient, B_{scat}, is reduced and made available to the user in units of inverse megameters (Mm^{-1}). B_{mass} is computed by applying a conversion factor. B_{scat} or B_{mass} is made available for analog and digital data loggers, PC computers or can be read directly from the integrated LCD display. Besides B_{scat}, time, date, barometric pressure, temperature both inside and outside, RH and other important instrument settings are made available on the serial output.

A unique 4-button keypad allows complete control of the NGN-3A. The keypad allows the initiation of clean air (Rayleigh air for establishing the zero point) and span (gas of known scattering coefficient) calibrations to be made easily. Various conversion constants and operating conditions can also be programmed with the keypad.

The NGN-3A is entirely self-contained and, except for an external span gas supply, only a low voltage power source is required for operation.

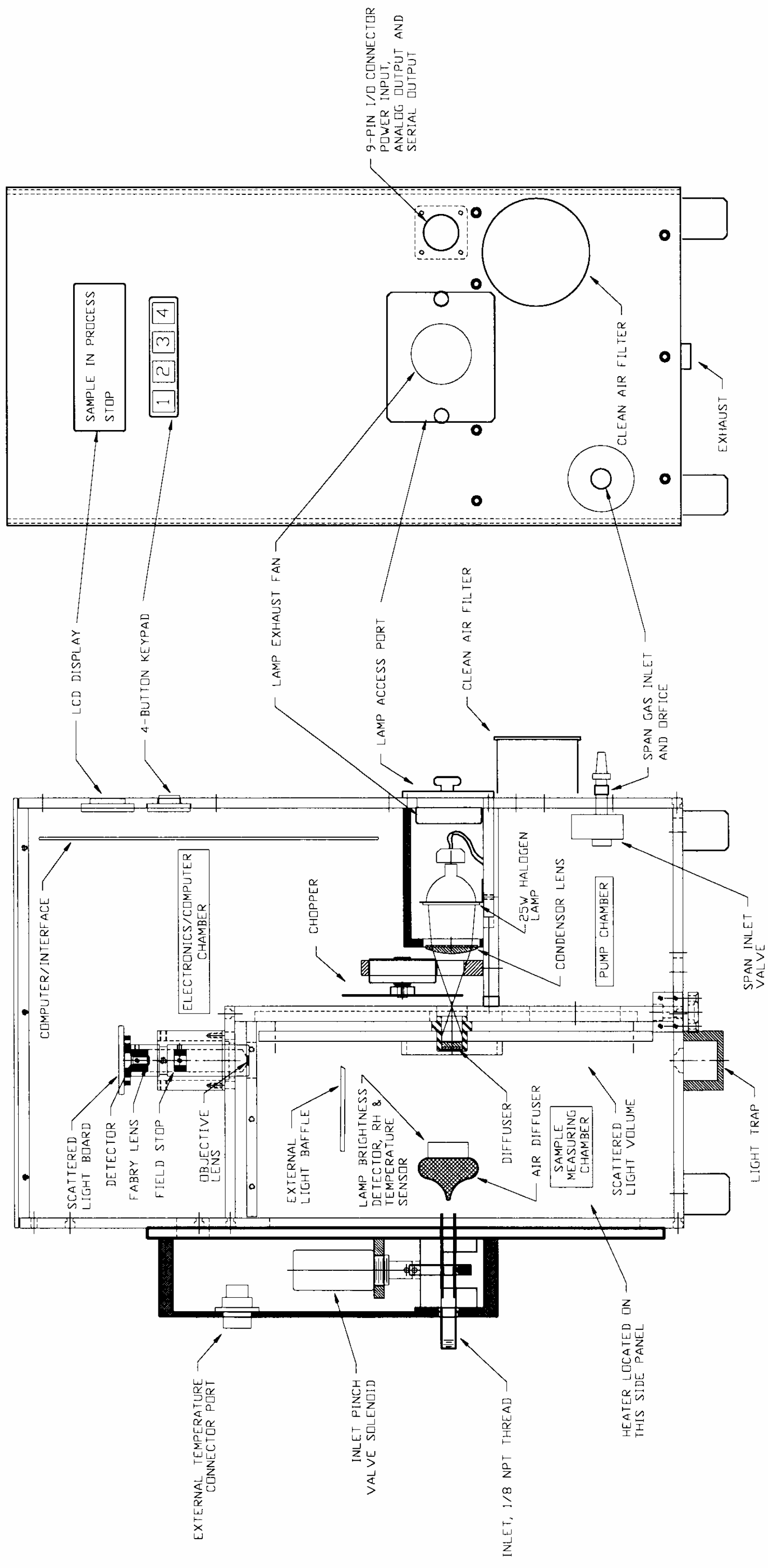


Figure 1-2. Cross-Sectional View of the NGN-3A.

SECTION 2.0

THEORY OF OPERATION

2.1 OPTICAL DESIGN

The NGN-3A integrating nephelometer measures the scattering coefficient B_{scat} of a know volume of air or SAMPLE. For the rest of this manual the measured volume of air will be referred to as the SAMPLE. Refer to Figure 2-1. This air volume or SAMPLE is illuminated by a near Lambertian diffuser made from an opal acrylic plastic with a $\cos\theta$ 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 θ is the angle from a line normal to the plane of the diffuser to a point on the hemisphere. Because of the 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-3A truncates at 5° and 175°.

A low voltage (13.8 volt DC) quartz halogen projector bulb with dichroic reflector illuminates the opal plastic diffuser. In the light path between the diffuser and bulb, a mechanical chopper modulates the beam at an exact 10 Hz frequency. The modulation principal allows a lock-in amplifier technique to be employed to separate the weak scattered light signal from the amplifier and 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. The normalized 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 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.

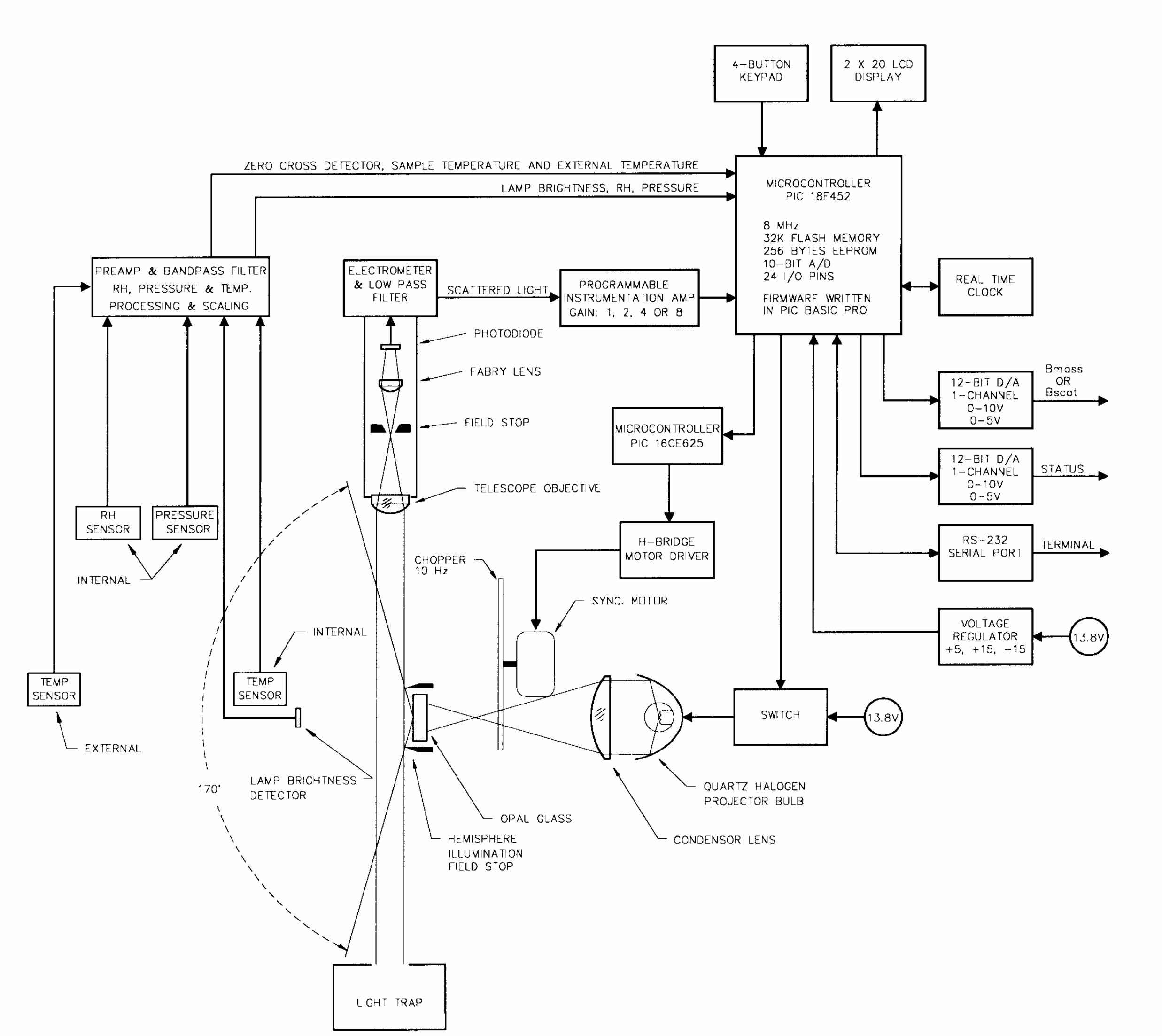


Figure 2-1. Electro / Optical Function Diagram.

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 intrinsic 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.

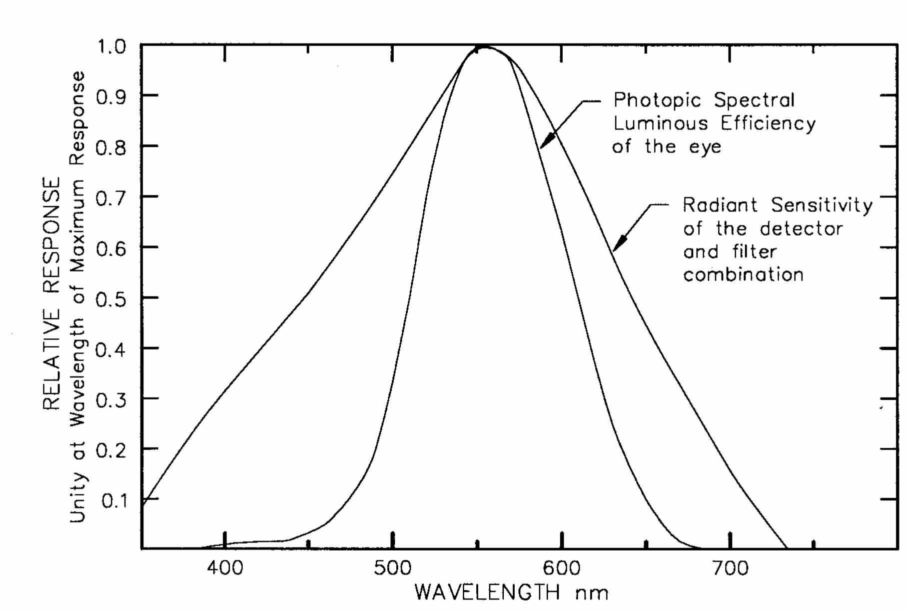


Figure 2-2. Photopic Spectral Response.

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 W typical
Noise Equivalent Power	$1\text{x}10^{-15}$ 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-3A 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°.

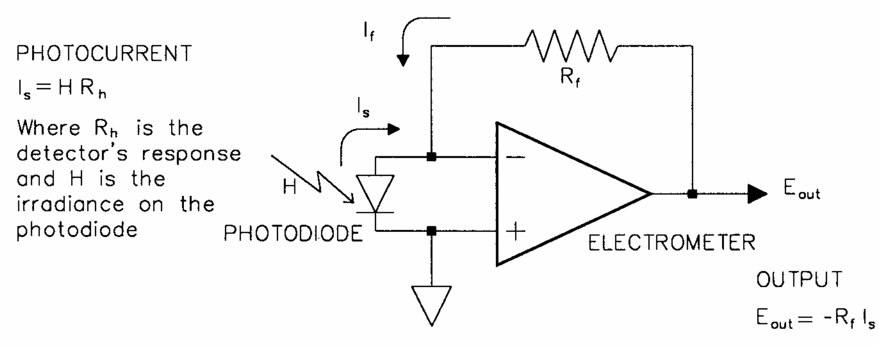


Figure 2-3. Current-to-Voltage Amplifier Configuration.

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. A programmable gain instrumentation amplifier is the last stage of amplification before the A/D converter. This amplifier stage applies a preset gain of 1, 2, 4 or 8 depending on jumper settings. The default gain setting is 4 which is found to be appropriate for most applications. The resulting processed signal is ready for digitization by a 10-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 10-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 zero-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

A PIC microcontroller model 18F452 is used to operate the various instrument functions and process the data. The firmware is written in PIC Basic Pro from Microtechnology Labs. The important characteristics of this microcontroller as used in the NGN-3A are listed in Table 2-2.

Model	PIC18F452-20I/P from Microchip
	8.00 MHz clock rate
	Power on reset
Memory	32K Flash, 16K single word instructions
	1536 bytes RAM
	256 bytes EEPROM
I/O	25 lines bi-directional
A/D	5 lines at 10-bit resolution
	0 to 5.0 input voltage range
	8 µsec conversion time
Serial Port	USART with 2 byte buffer, RS-232 protocol
	RX, TX & GND
	9600 baud, 8 bit, no parity
Package	40-pin DIP

Table 2-2. Important Microcontroller 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 greater than the signal, the average difference must be calculated over many hundreds of cycles.

The lock-in amplifier technique allows the A/D section of the microcontroller 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 microcontroller 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 waveform. The negative transition of the zero-cross detector signals a lamp-on condition and, conversely, a positive transition, signals a lamp-off condition. See Figure 2-4. If a negative or positive 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.

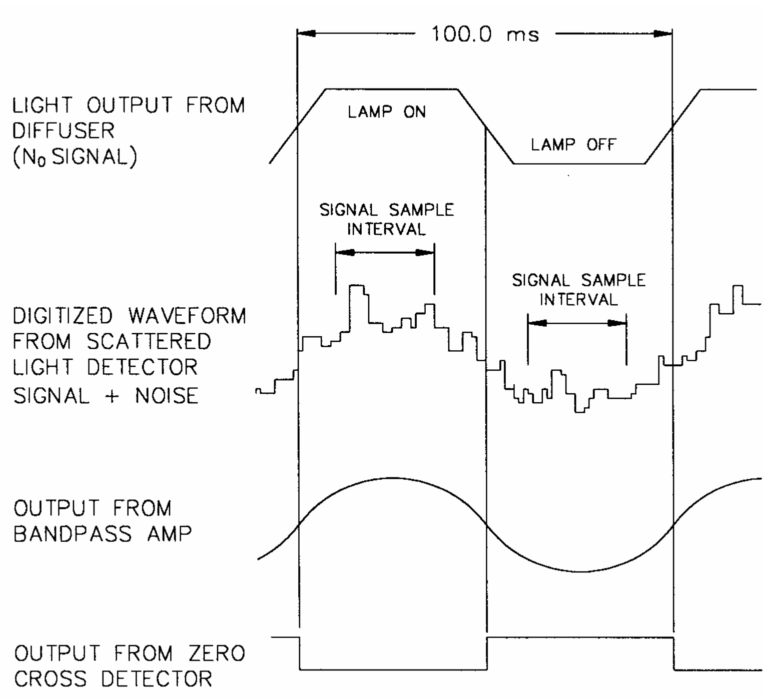


Figure 2-4. Signal and Control Processing Waveforms.

The microcontroller integrates for 1 second the signal from the N_0 detector, lamp brightness. The next 57 seconds is used to integrated the scattered light signal. Finally, the next 1 second is used to integrate again the N_0 signal. The remainder of this one minute integration is used to process the data and acquire the temperature, barometric pressure and RH readings. 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 scattered light reading is normalized with respect to the lamp brightness. This value is used for the calculations of B_{scat} and B_{mass}.

The NGN-3A begins operation using its default setting, MODE = 1. See Table 3-1 for detailed description of MODE 1 operation. At the end of each integration, the results along with time, date, temperature both internal and external, relative humidity, barometric pressure and status are transmitted on the serial output line. The two D/A converters are updated in case of external analog data recording and the LCD display shows B_{scat} in units of inverse megameters or B_{mass} in units of micrograms per cubic meter. Other operating sequences are easily selected and are discussed in Section 3.0. Operating sequences unique to an individual user are possible and are reserved for MODE 3 but must be programmed at Optec.

2.6 ZERO AIR & SPAN GAS CALIBRATION

Periodic ZERO (Rayleigh clean air) 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. ZERO air calibrations are usually performed more often since they are easy to do and use no source of expendable gas. SPAN gas calibrations are done with a dense gas such as HFC-134a (Suva 134a) and are usually initiated from the 4-button keypad with an operator present. However, the operating program can be modified to accomplish this periodically and without an operator.

The scattering value for ZERO air reading is considered equal to one Rayleigh or 10.0 Mm^{-1} if temperature and pressure values are compensated for. The SPAN gas HFC-134a has a scattering coefficient equal to 7.1 times the ZERO air value. Knowing these two values, ZERO air and SPAN gas, allows a solution to be found for the following linear equation

$$y = ax + b$$

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 circulating the measuring chamber air through a 0.45 µm glass microfiber filter with the inlet pinch valve closed. This filter retains 99% of all particles larger then 0.3µm. The clean air pumping requires approximately 5 minutes to completely filter all particles from the measuring chamber before a 10-minute integration is commenced. During the ZERO air cycle, a 7.0-volt (STATUS = 7) status signal is held on D/A channel-2 to indicate that a ZERO air calibration is in process. When the ZERO air calibration is completed, a 2.0-volt (Status = 2) 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 ZERO air value is sent to both the RS-232 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 5 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 = 7) 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 = 3) status signal is held on D/A channel-2 to indicate a SPAN gas reading.

When a ZERO calibration is initiated from the 4-button keypad, the resulting ZERO air value can be saved to battery backed memory. This value is renamed CALIB-ZERO and is used with the SPAN gas value to compute the '*a*' constant (scaling factor) in the preceding equation. Depending on the value stored in INTERVALS (810 default), a ZERO is run after every INTERVALS x INTEG minutes. With the default values of 810 and 2, a ZERO would be run every 27 hours. This ZERO air is renamed CURRENT-ZERO and is subtracted from the SAMPLE air value. Thus, if a SAMPLE air value equals the current zero, B_{scat} will equal 0.

2.7 B_{SCAT} AND B_{MASS} COMPUTATION

The following equation computes B_{scat} in units of inverse megameters given the values of SAMPLE, CURRENT-ZERO, SPAN and CALIB-ZERO:

$$B_{scat} = \frac{(\text{SpanGasCoefficient}) * (\text{SAMPLE} - \text{CURRENT-ZERO}) * 10}{(\text{SPAN} - \text{CALIB-ZERO})}$$

where (SpanGasCoefficient) equals the number of Rayleighs the span gas scatters above clean air minus one Rayleigh. For Suva 134a, scattering coefficient equals 7.10 Rayleighs, this number is equal to 7.10 – 1.00 which is 6.10.

Once B_{scat} is computed, B_{mass} in units of $\mu g/m^3$ is found with the following equation

$$B_{mass} = B_{scat}/C_{st}$$

Where C_{st} is a user input value with 3.00 the default value.

2.8 MECHANICAL DESIGN

The NGN-3A contains nearly all of the equipment needed for an integrating nephelometer in one environmentally sealed enclosure that 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-3A would mount on a counter or table with the inlet side facing the wall and the side with the LCD display facing the user. The clean air filter module, access door for lamp changing, data/power cable connector and span gas inlet are mounted on one side with the LCD display 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 1-2. Figure 2-5 shows schematically the pathways for sample air, zero air and span gas.

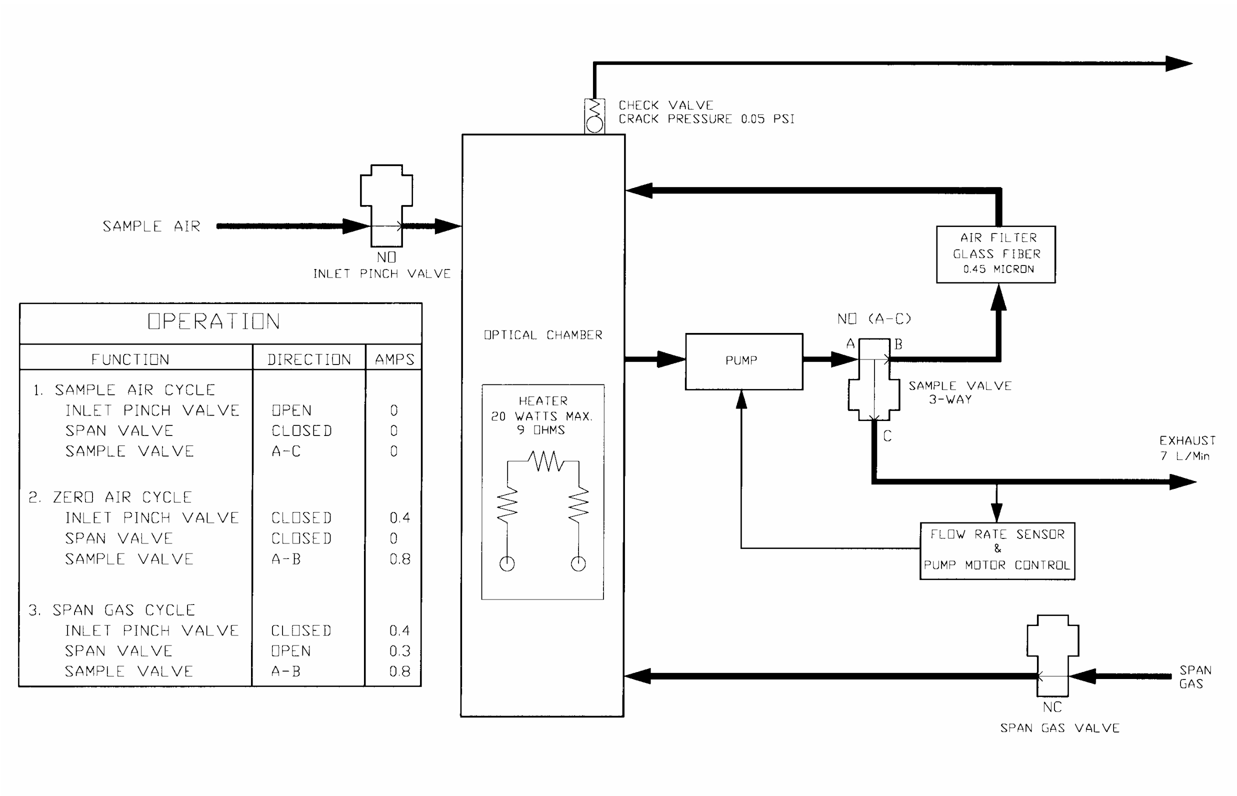


Figure 2-5. Sample Air / Gas Pathways.

2.8.1 MEASURING CHAMBER

Separated by a double wall, the optical measuring chamber is completely sealed from the rest of the enclosure to prevent either air or heat/cold from contaminating the SAMPLE. The SAMPLE enters the chamber from a small tube located near the center of the chamber. The inlet is opened or closed by a solenoid operated pinch valve. When the SAMPLE air stream enters the chamber it immediately comes in contact with a unique air foil which disperses the SAMPLE quickly and completely into the entire volume of the chamber. The SAMPLE air is pulled into the chamber by a small pump that is regulated to draw 7.0 liters/minute through the chamber.

One wall of the chamber is resistively heated to raise the SAMPLE air in the chamber to a preset temperature (temperature difference) above the ambient air temperature. The default value is 10 °C. In the case where a preset relative humidity is selected, the sample air temperature is raised until the RH (relative humidity) is equal to or less than the preset value. The default value is 60%. A remote temperature sensor is located externally to be near the inlet to monitor the ambient temperature.

To allow the span gas to fill the chamber, a small plastic tube is coupled from the top of the chamber to the exhaust outlet. The heavier than air span gas will fill the bottom of the chamber first and force air out through the top vent tube. The overflow vent uses a check valve that will allow the span gas to escape but would prevent air from contaminating the SAMPLE air during normal operation or ZERO calibration.

2.8.2 EXHAUST/PUMP CHAMBER

Separate and sealed from the electronics/computer chamber, the exhaust/pump chamber houses the pump, span gas solenoid activated inlet valve and sample valve. See Figure 2-5.

A low voltage diaphragm pump is used to pull the SAMPLE air through the measuring chamber and recirculate the measuring chamber air during a ZERO calibration at a rate of approximately 7 to 9 liters/minute. A pot (P1, AIR FLOW) on the side of the interface board allows adjustment of the flow rate over a small range for the sample airflow only.

During a ZERO or SPAN calibration, the sample valve directs the air/gas through the 0.45-micron air filter before it is returned to the sample air chamber. The pump works at its maximum flow rate during these calibrations which is approximately 9 l/m. A solenoid activated pinch valve on the inlet tubing allows the measuring chamber to be completely sealed during calibration measurements. The span gas inlet uses a 1/4" ID barbed tube fitting 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. An orifice on the span gas inlet restricts the flow to approximately 2 l/m when the input pressure is regulated to 10 psi. Do not connect a source of span gas to the inlet unless an orifice is in line during operation unless provision are made to restrict the flow rate in other ways.

2.8.3 ELECTRONICS/COMPUTER CHAMBER

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

A 13.8 volt DC 25 watt projector bulb with dichroic reflector focuses most of its light energy onto the opal plastic diffuser. Around the bulb a thick metal shield which absorbs and conducts much of the heat energy from the bulb to the outside wall. In addition, a small fan vents air around the lamp to the outside. 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 if the voltage fluctuations are reasonably small and slow.

Controlled by its own PIC microcontroller, 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 10.00 Hz rate. The chopper is activated when the lamp is turned on.

The 13.8 volt DC input power is routed to the computer 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 5 amps. A fast acting 5 x20 mm fuse with a rating of 7 amps is used to protect the circuit.

Solid state power MOSFET devices buffer the I/O ports of the microcontroller to the various 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.

SECTION 3.0

OPERATING PROCEDURES

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-3A 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.

Two possible operating sequences are available, MODE 1 and MODE 2. MODE 3 is not defined but could be programmed for a specific user application. The default selection is MODE 1 with integration time set for 2 minutes and the number of cycles before the next clean air calibration set to 810. See Table 3-3 for a complete description of the operating sequences.

OPERATING	DESCRIPTION
1 (OPERATE-1)	Continuous 2 minute integrations (default integration time is 2 minutes but can be changed) with a clean air calibration approximately every 27.0 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. Both the intervals and integration time can be changed to suit user's application.
2 (OPERATE-2)	2 minute integrations (default integration time is 2 minutes but can be changed) every 10 minutes. The lamp goes off during the remainder of the cycle in order to extend lamp life. With a 2 minute integration time, effective lamp life would be extended to 3500 hours of operation. A clean air calibration is done after a preset number of intervals. This mode is not synchronized with the real time clock but begins whenever the program is initiated.
3 (OPERATE-3)	Undefined.

Table 3-1. Operating Sequences for Standalone Operation.

At the beginning of a computer reset or at power up, the instrument will do a ZERO air calibration. This process will take approximately 15 minutes during which time the LCD will display "ZERO IN PROCESS". The resulting value is used as the CURRENT-ZERO in the calculations until the next ZERO air calibration is done. Next, the NGN-3A will pull in ambient air SAMPLES and do SAMPLE air readings with time integration time selected by the user. Default is 2 minutes. The readings are cycled a preset number of times, INTERVAL, until the next ZERO air calibration. The default value of INTERVAL is 810. During the period of SAMPLE air readings, the LCD displays "SAMPLE IN PROCESS".

3.2 OUTPUTS & INPUTS

Both power and signal to and from the NGN-3A 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. The serial output is set at 9600-baud, no parity and 8 data bits. A short cable with both power and serial data connectors is supplied for operating the NGN-3A in the lab.

PIN NUMBER	FUNCTION
1	+13.8±0.3 volt DC, 5.0 amps required
2	Power Return
3	RX, RS-232 serial data in, 9600 baud
4	Common for RS-232
5	TX, RS-232 serial data out, 9600 baud
6	Analog Channel-1, (scattered light)
7	Analog Channel-1, Common
8	Analog Channel-2, (status)
9	Analog Channel-2, Common

Table 3-2. 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 5 amps continuously and be set for 13.8±0.3 volts. The NGN-3A requires the power supply voltage to be within 11.5 to 14.5 volts at all times. Power on surges can sometimes cause the power supply to shut down if its output is specified too low. 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-3A unit to the power supply is great. Normally, a 16 AWG cable is adequate for distances up to 20 feet. Distances of around 50 ft. will require 12 AWG cable. Consult Optec about your installation requirements. Optec offers a universal 10 amp power supply (Stk. No. 86905). Consult the current 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. For connection to a printer, only RX and GND needs to be connected. A sample of output data is shown in Appendix F. The first field in the data line, column 1, is called STATUS. This item indicates what was measured and if there were any error codes generated. Table 3-3 defines the possible values for STATUS.

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-3A. Further discussion of this topic is beyond the scope of this manual but Optec will help plan a safe wiring strategy when requested.

STATUS	DESCRIPTION
1	Sample Air Reading. The analog output could be for B_{scat} or B_{mass}. Check the BMODE value to confirm selection of units
2	Zero Air Reading. The analog output could be for B_{scat} or B_{mass}. Check the BMODE value to confirm selection of units
3	Span Gas Reading. The analog output could be for B_{scat} or B_{mass}. Check the BMODE value to confirm selection of units
4	Lamp Low or Burned Out. If the lamp output drops below a preset value or no zero cross signal is detected during a reading, the NGN will shut down and indicate this Status value.
5	Not Used
6	Chopper Motor Failure. During the lamp turn on procedure, the frequency stability of the chopped signal is measured. If it is not within certain limits, the NGN will shut down and indicate this Status value.
7	Zero or Span Gas Calibration in Process. During the calibration process, a Status value of 7 is indicated.
8	Not Used
9	Supply Voltage Error, If the supply voltage is less than 11.5 or greater than 14.5 volts, the unit will shut down and show this Status value.

Table 3-3. Description of Status Column Values.

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 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.

3.5 ANALOG OUTPUT

The analog output channels 1 and 2 provide a 0 to 10.000 volt full-scale output 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. A jumper pair on the compute/interface 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 serial output values.

The D/A converter has 12-bit resolution which allows for 4095 voltage states between 0 and 10.000 volts. Thus, each bit represents a voltage change of 0.002442 volts. A scattered light digital reading of 10.0 Mm^{-1} would produce an output on analog channel 1 of 0.100 volts and 1000.0 Mm^{-1} an output of 10.000 volts. The serial digital output has both greater resolution and dynamic range. The maximum value of B_{scat} read from the serial output or the LCD display is 9999.9 Mm^{-1}. Typically, Rayleigh air can be resolved to about 7% precision and the high end (10.00 volts) limits extinction readings to 1000.0 Mm^{-1}.

Examples:

10.0 Mm^{-1} or 10.0 μg/m3 = 0.100 volts
100.0 Mm^{-1} or 100.0 μg/m^3 = 1.000 volts
1000.0 Mm^{-1} or 1000.0 μg/m^3 = 10.000 volts

Divide the voltage by two if the 0 to 5.00 volt jumper setting is used.

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-3A. Further discussion of this topic is beyond the scope of this manual but Optec engineers will help plan a safe wiring strategy when requested.

SECTION 4.0

NGN-3aControl.exe - A PC CONTROL & MONITOR PROGRAM

4.1 SET-UP

Controlling and modifying the NGN-3A operating program begins with the proper interfacing with a PC computer running Windows 95 through XP. Read Section 3.4 first to insure proper connection to the NGN-3A computer. The TX line should also be connected. Download the latest version of of the control program from the Optec website at: www.optecinc.com. Look for the software download link on the NGN-3A page. Install it and follow the instructions. The help file included with the program will give complete documentation on how to use the program. Check the ReadMe file for version changes and other important new information.

A COM port needs to be available on the PC. If one is not installed, a USB to serial converter would work. Optec can supply this item if requested.

4.2 IMPORTANT PROGRAM CONSIDERATIONS

Run the NGN-3a Control program in the usual way and select COM port in the setup up pull down menu. Click on the appropriate COM port that is connected to the NGN-3A. The COM port information is not saved with this program and will have to be selected each time the program is started. After this, select Connect from the same pull down menu. If the unit is already running in a normal mode, click on the large STOP button to interrupt the operating program and start the serial loop mode. This mode allows for changing the setup variables, testing the instrument and running calibrations.

All of the setup values for the NGN-3A are available for modification with the NGN-3aControl program with the exception of serial number and run time counter. Changing these values require the input of a password that is not available to the user. Click on the large NGN-3a SETUP button to review and change the setup variables. There are two windows to view. The first window to open shows the POST information from the instruments and various controls for changing the most common setup values. The second window may be opened by clicking on the 'Advanced' button. These setup values need to be changed with some caution since they control the sensor calibration set points and could give erroneous results if the wrong values are inserted.

The START ZERO button will initiate a clean air calibration consisting of a five minute pump time before a 10 minute integration is initiated. The results would show in the data display window. If the CALIB-ZERO value needs to be changed, open the NGN-3a SETUP window and enter a new value

In a similar fashion, the START SPAN button will initiate a span gas calibration. After the end of the calibration procedure, the new value can be entered in the NGN-3a SETUP window.

Clicking on the TEST ROUTINES button will bring up a window that allows the user to test various functions of the instrument. Many of these test functions are designed for the technician and are not suggested for common use. Consult the help file for particular information about each function.

To return the NGN-3A program to its normal running mode, click on the large START button. A clean air calibration will begin immediately and this will set the CURRENT-ZERO value. The control program can be terminated in the usual way. Terminating the control program without clicking on the START button will leave the NGN-3A in the serial mode. The user can restart the control program and then click on the START button or the user could shut down the power to the NGN-3A momentarily. Either method will restart the NGN-3A in its normal operating mode.

With the NGN-3A running in its normal mode, the output serial data is displayed in the data display window. Up to 2000 lines of data can be recorded in the data display window. This method of storing and displaying data is intended for short observing runs or for testing the instrument. When long periods of data logging is required, open a new or old data file and then select Log Data in the Files pull down menu. Only one line of data is displayed in the data display window but an unlimited amount of data will be saved to the data file.

SECTION 5.0

OPERATION OF 4-BUTTON KEYPAD

The NGN-3A nephelometer features menu-driven software which can be accessed through the liquid crystal display (LCD) and associated buttons on the instrument's front panel. A flow chart of the menu structure is presented in Figure 5-1. The first line of the display is informational. The second line of the display has up to 4 positions, each associated with the button below it. References to the LCD text and software commands in this section are printed in **BOLD CAPS**.

When the NGN-3A is powered up, the system briefly displays the software version number and then initiates a zero calibration, as indicated by the LCD message **ZERO IN PROCESS**. If left alone, the instrument will perform a 10-minute calibration and begin monitoring. When monitoring in the normal mode, the LCD will display the current scattering and mass readings such as **B=0015.3 M=0005.1**, where B is the particle scattering in units of Mm^{-1} and M is the mass reading in units of $\mu g/m^3$.

The instrument program may be interrupted at any time during the startup, initial zero calibration, or normal monitoring by pressing the button associated with **STOP**. Hold button #1 down until the **SELECT FUNCTIONS** menu appears. This may take a few seconds. When the program is interrupted in this way the instrument is no longer monitoring but the user can select among several functions under the **SELECT FUNCTIONS** menu. As indicated in the flow diagram, pressing **RUN** will re-boot the program and return to the normal power up sequence. A manual zero or span calibration may be initiated from this menu with the **ZERO** or **SPAN** command, or internal variables can be checked or modified with the **VARS** command.

When either a manual zero or span calibration is initiated the LCD will display **ZERO IN PROCESS** or **SPAN IN PROCESS** for the duration of the calibration and venting. Once completed after approximately 15 minutes the LCD will display the zero or span value as **CALIB-ZERO= 032**, where the value is in normalized raw counts. The operator may document this value and press **DONE** to return to the **SELECT FUNCTION** menu. The operator may instead choose to save this value as the instrument's calibration zero or span, which is used to calculate scattering and mass. To do this press **SAVE**, then **DONE**. Generally the calibration zero and span values are set once for a given study and changed only if the instrument undergoes servicing or is suspected of malfunctioning.

The **VARS** command opens a menu tree designed to set internal or output variables. The CALIB command allows the operator to check and set the instrument's calibration zero (**ZERO**) and span (**SPAN**) values (as normalized raw counts). Each of these variables can be increased or decreased with the +1 and –1 commands. In addition, when accessing the calibration zero value the instrument's current zero is first displayed on the screen for approximately 5 seconds. Once any of these variables have been checked or set, pressing **DONE** will return to the previous menu level. To resume normal monitoring the NGN-3A must be re-booted either by turning power off then on again, or by returning to the top of the menu structure and selecting the **RUN** command. It is important to note that the NGN-3A will always perform a zero calibration on start-up.

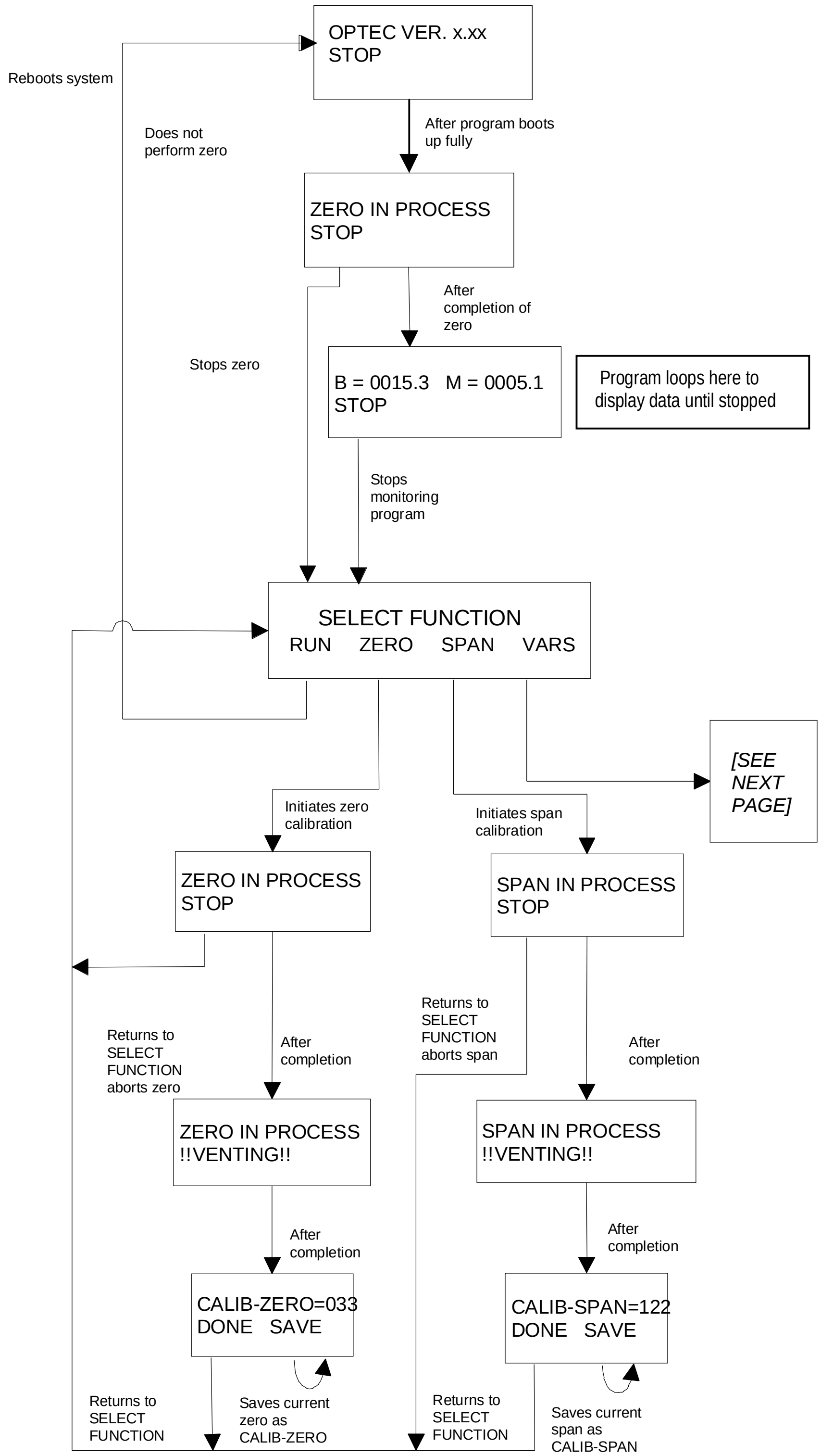


Figure 5-1. Flow Diagram of NGN-3A Front Panel Software.

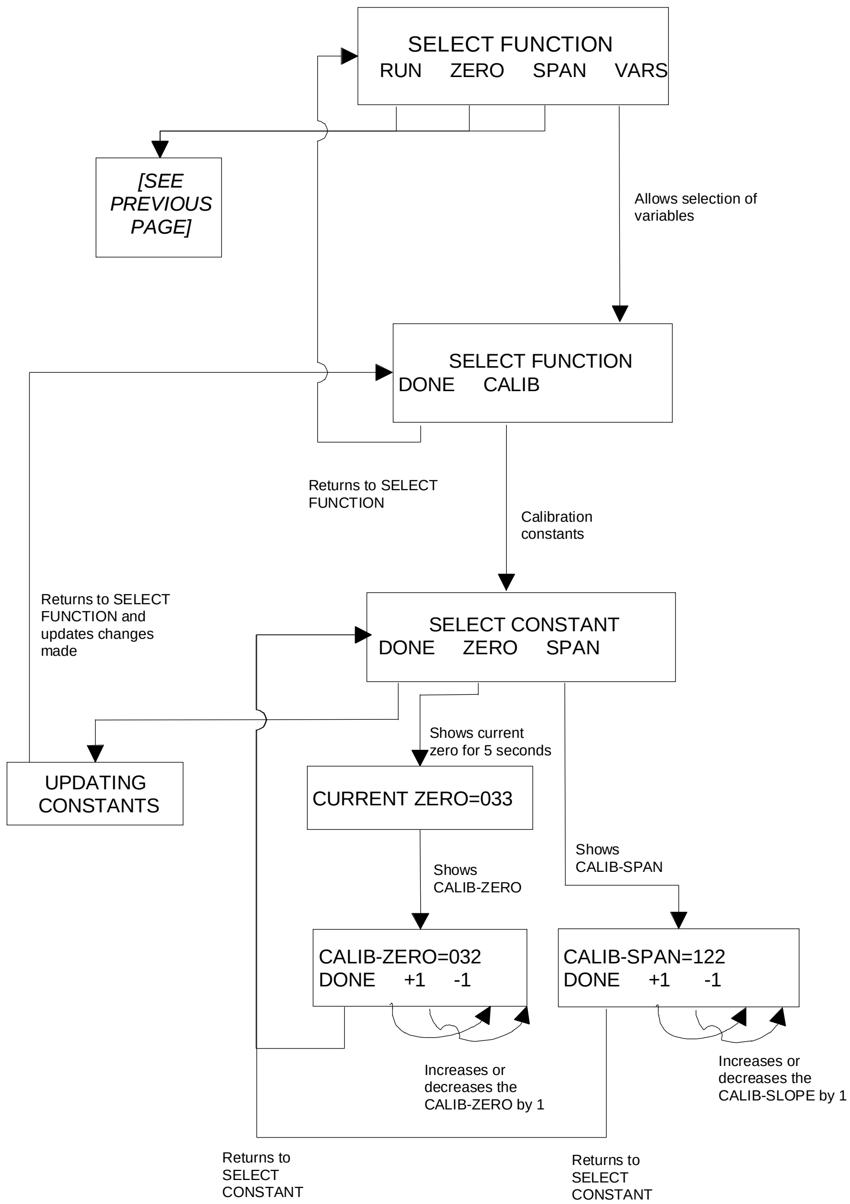


Figure 5-1 (Continued). Flow Diagram of NGN-3A Front Panel Software.

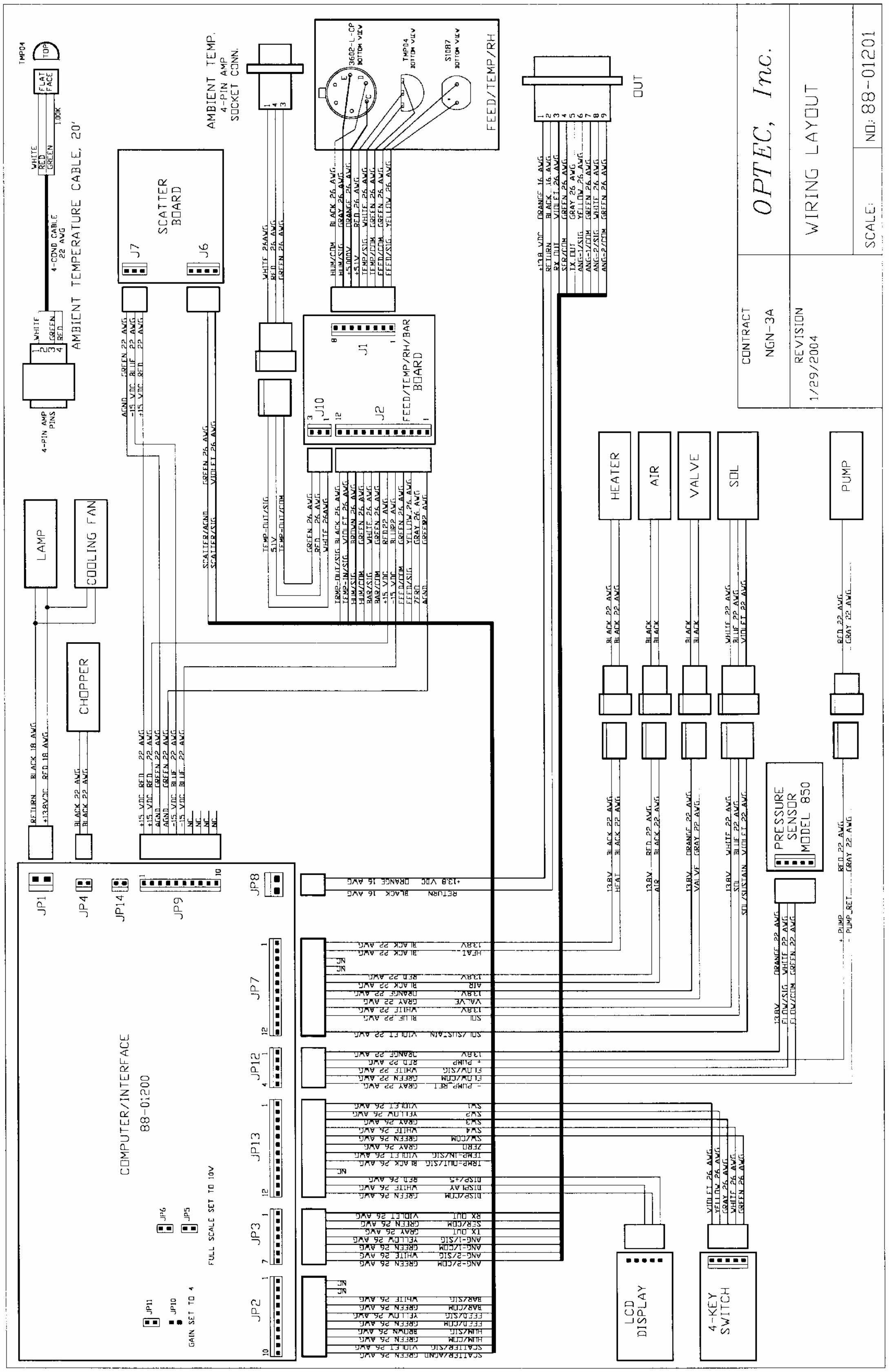
SECTION 6.0

SPECIFICATIONS

EXTINCTION RANGE	serial output: from 0.1 to 9999.9 Mm^{-1} analog output : from 0.2 to 1000.0 Mm^{-1}
RESOLUTION	serial output: 0.1 Mm^{-1} analog output: 1 ADU = 2.44 mv = 0.244 Mm^{-1} (12 bit resolution)
ACCURACY	±7% of true value for air near Rayleigh and using two minutes of integration
MEASURED WAVELENGTH	550 nm Center Wavelength, 200 nm Bandwidth
OUTPUT, SERIAL	RS-232, RX, TX, GND 9600 baud , 8 data bits, 1 stop bit, no parity
OUTPUT DATA, SERIAL	STATUS, SCATTERED LIGHT, LAMP BRIGHTNESS, NORMALIZED SCATTERED LIGHT, INTEGRATION TIME, INTERNAL TEMPERATURE, DATE , TIME, B_{scat}, B_{mass}, CALIB-SPAN, CALIB-ZERO, CURRENT-ZERO, EXTERNAL TEMPERATURE, INTERNAL RH, INTERNAL BAROMETRIC PRESSURE
OUTPUTS, ANALOG	2 analog channels 0 to 10.000 volt, 1 ADU = 0.00244 volt, jumpers JP5 & JP6 on or 0 to 5.000 volt, 1 ADU = 0.00122 volt, jumper JP5 & JP6 off 2 Ω output impedance, current limited
OUTPUT DATA, ANALOG	Channel 1: B_{scat} or B_{mass} Channel 2: STATUS value (see Table 3-3.)
TEMPERATURE SENSORS	Analog Devices type TMP-03, accuracy of ±0.2 °C
RELATIVE HUMIDITY SENSOR	Honeywell Type HIH-3602, ±2% 0-100% RH, non-condensing at 25 °C, temperature compensating algorithm.
BAROMETRIC SENSOR	Motorola type MPX4100A, accuracy of ±0.5 kPa at 0 to 50 °C range of 20 to 105 kPa
POWER SUPPLY	13.8±0.3 volt DC, 7 amps, regulated required
OPERATING TEMPERATURE	-10 to +45°C
SIZE	10.7 x 8.2 x 16.5 inches
WEIGHT	27 lbs.
FINISH	high gloss white powered metal paint

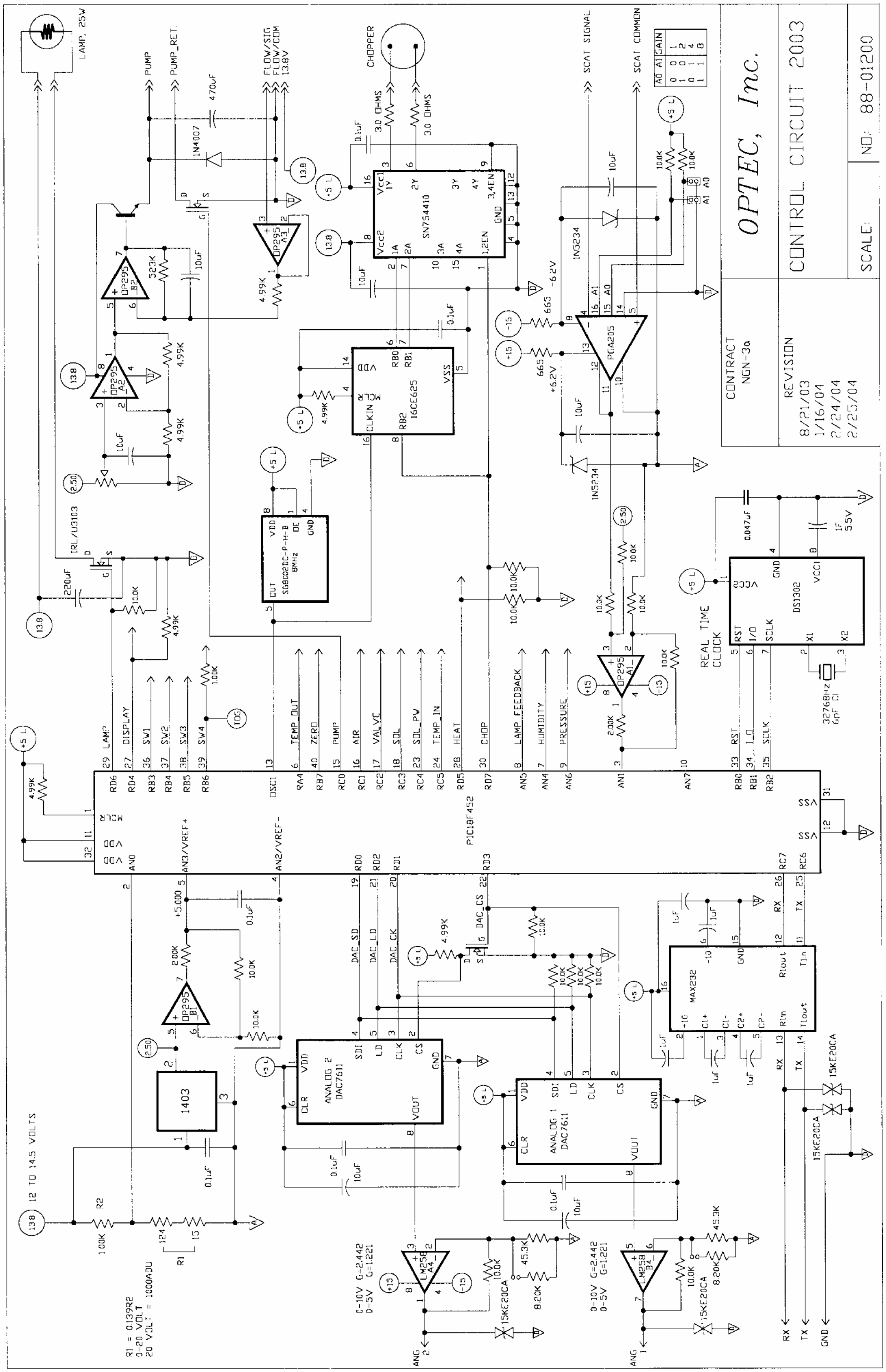
Appendix A

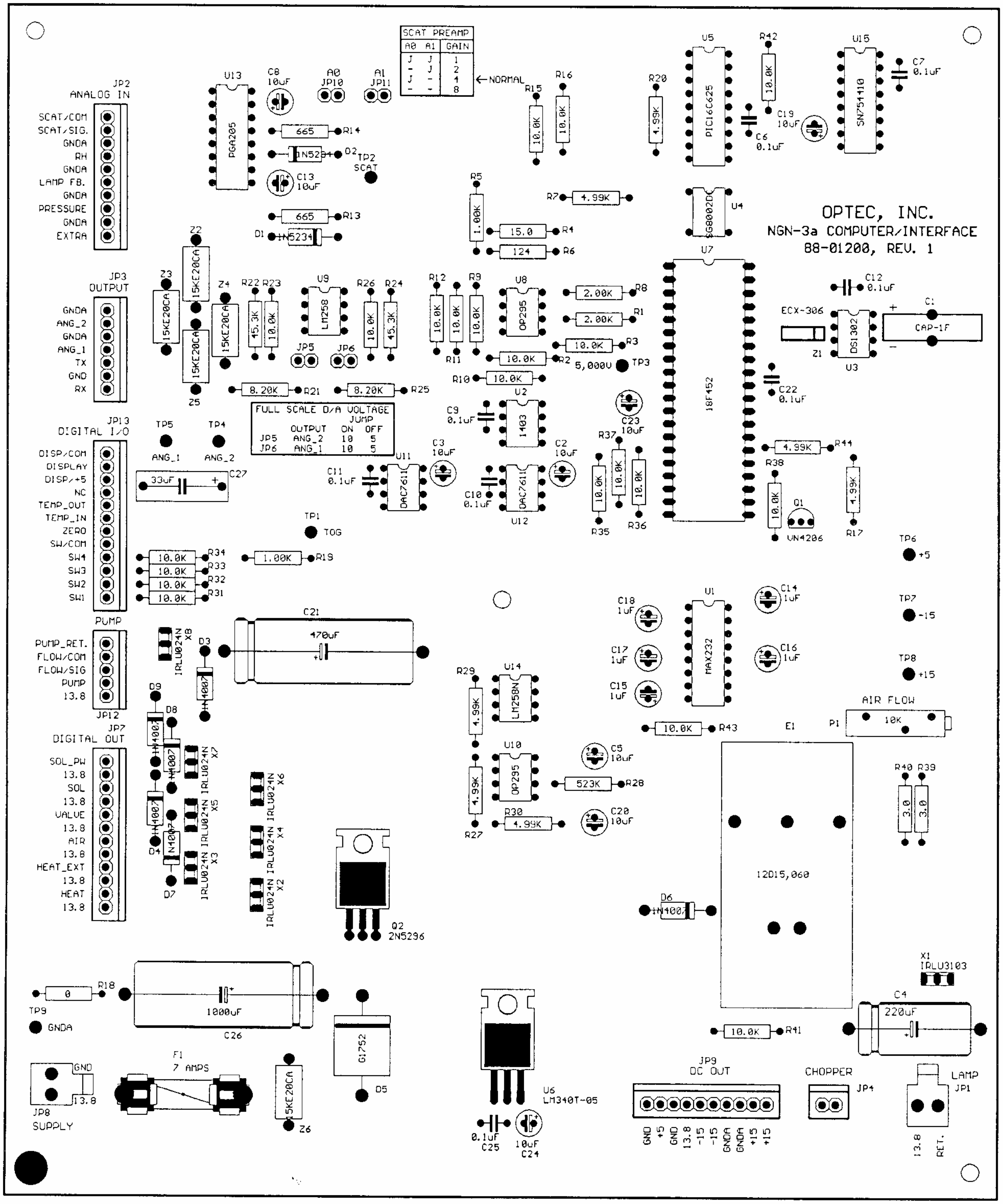
WIRING DIAGRAM


OPTEC, Inc.
WIRING LAYOUT
NO: 88-01201
SCALE:
CONTRACT
NGN-3A
REVISION
1/29/2004
COMPUTER/INTERFACE
88-01200
AMBIENT TEMPERATURE CABLE, 20'
AMBIENT TEMP.
4-PIN AMP
SOCKET CONN.
SCATTER
BOARD
FEED/TEMP/RH/BAR
BOARD
FEED/TEMP/RH
LAMP
COOLING FAN
CHOPPER
HEATER
AIR
VALVE
SOL
PUMP
PRESSURE
SENSOR
MODEL 850
LCD
DISPLAY
4-KEY
SWITCH
OUT
GAIN SET TO 4
FULL SCALE SET TO 10V

Appendix B

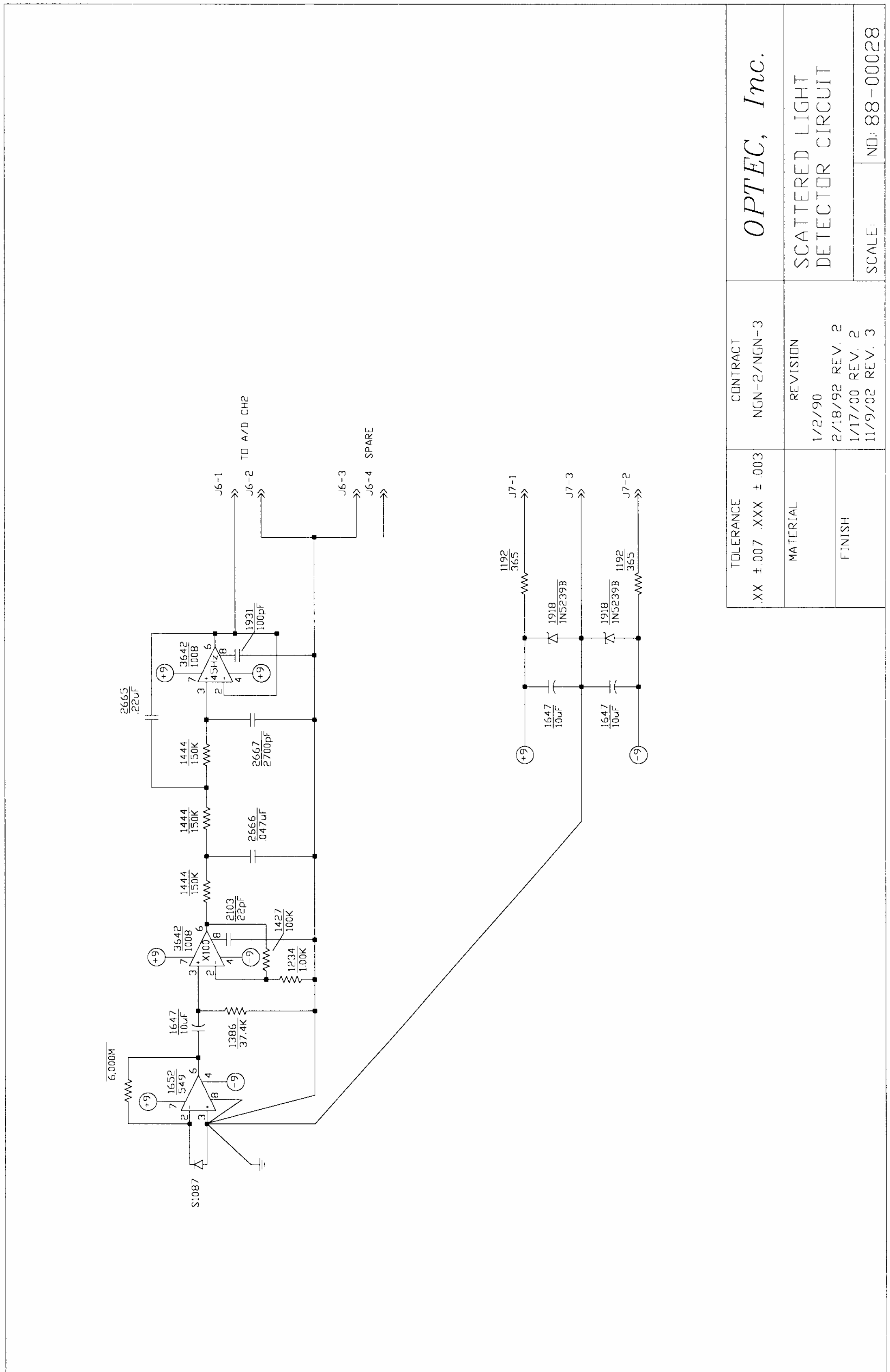
COMPUTER/INTERFACE BOARD

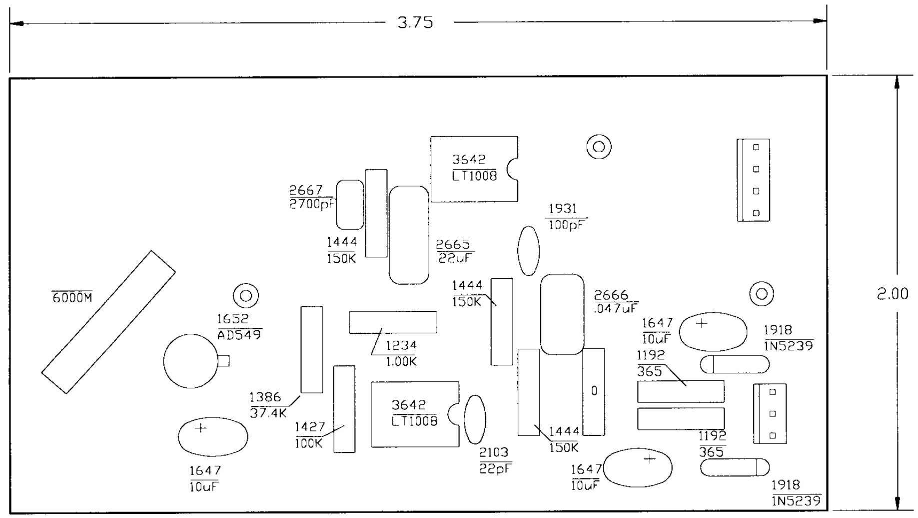

OPTEC, Inc.
CONTROL CIRCUIT 2003
NO: 88-01200
SCALE:
CONTRACT
NGN-3a
REVISION
8/21/03
1/16/04
2/24/04
2/25/04


OPTEC, INC.
NGN-3a COMPUTER/INTERFACE
88-01200, REV. 1
SCAT PREAMP
FULL SCALE D/A VOLTAGE
ANALOG IN
OUTPUT
DIGITAL I/O
DIGITAL OUT
PUMP
AIR FLOW
DC OUT
CHOPPER
LAMP
SUPPLY

Appendix C

SCATTER LIGHT BOARD


OPTEC, Inc.
SCATTERED LIGHT
DETECTOR CIRCUIT
SCALE:
NO: 88-00028
CONTRACT
NGN-2/NGN-3
REVISION
1/2/90
2/18/92 REV. 2
1/17/00 REV. 2
11/9/02 REV. 3
TOLERANCE
.XX ±.007 .XXX ±.003
MATERIAL
FINISH
J6-1
J6-2 TO A/D CH2
J6-3
J6-4 SPARE
J7-1
J7-3
J7-2
S1087
6,000M
1652
549
1647
10uF
1386
37.4K
3642
1008
X100
2103
22pF
1427
100K
1234
1.00K
1444
150K
2666
.047uF
2667
2700pF
2665
.22uF
45Hz
1931
100pF
1192
365
1918
1N5239B

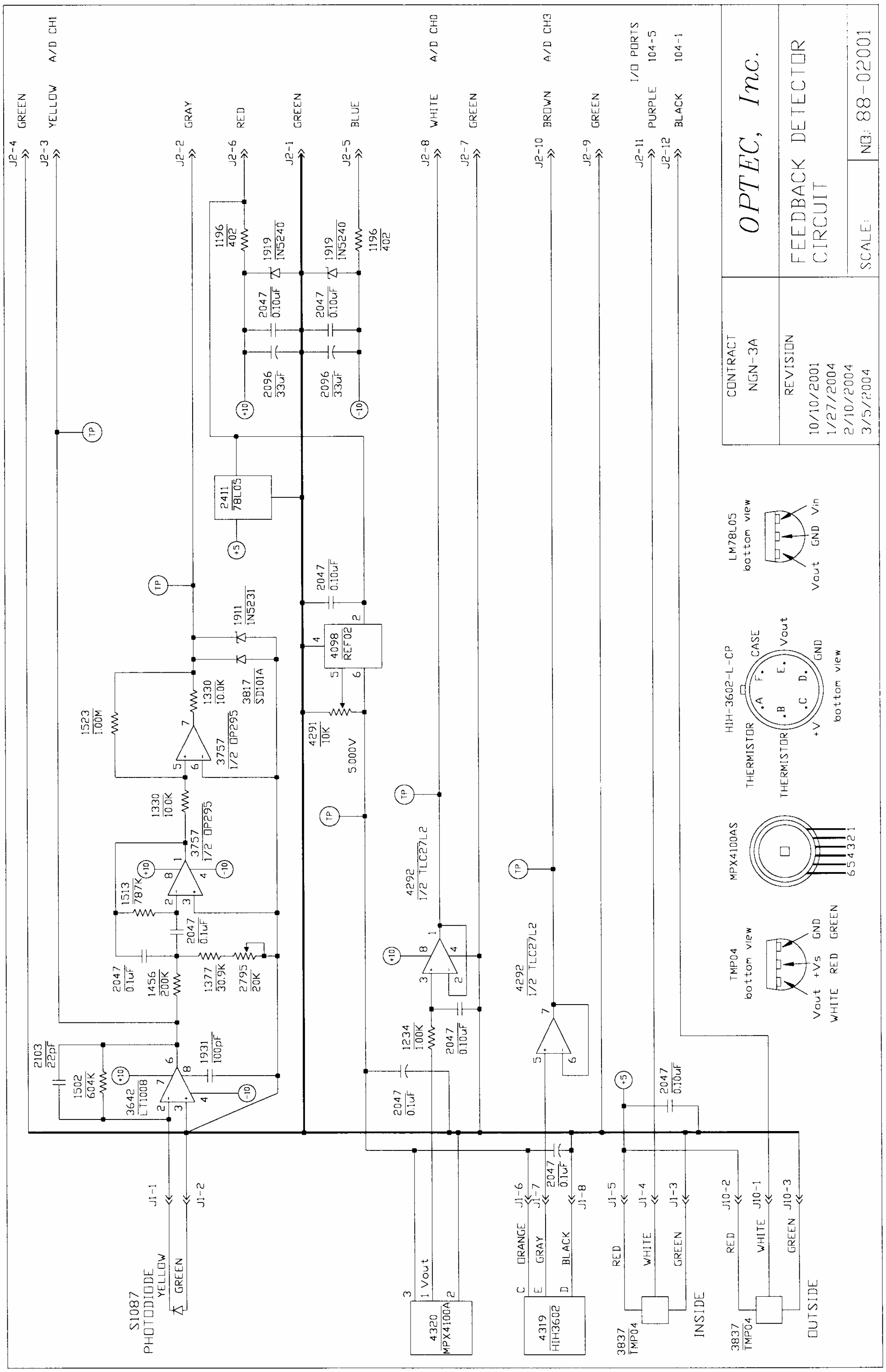


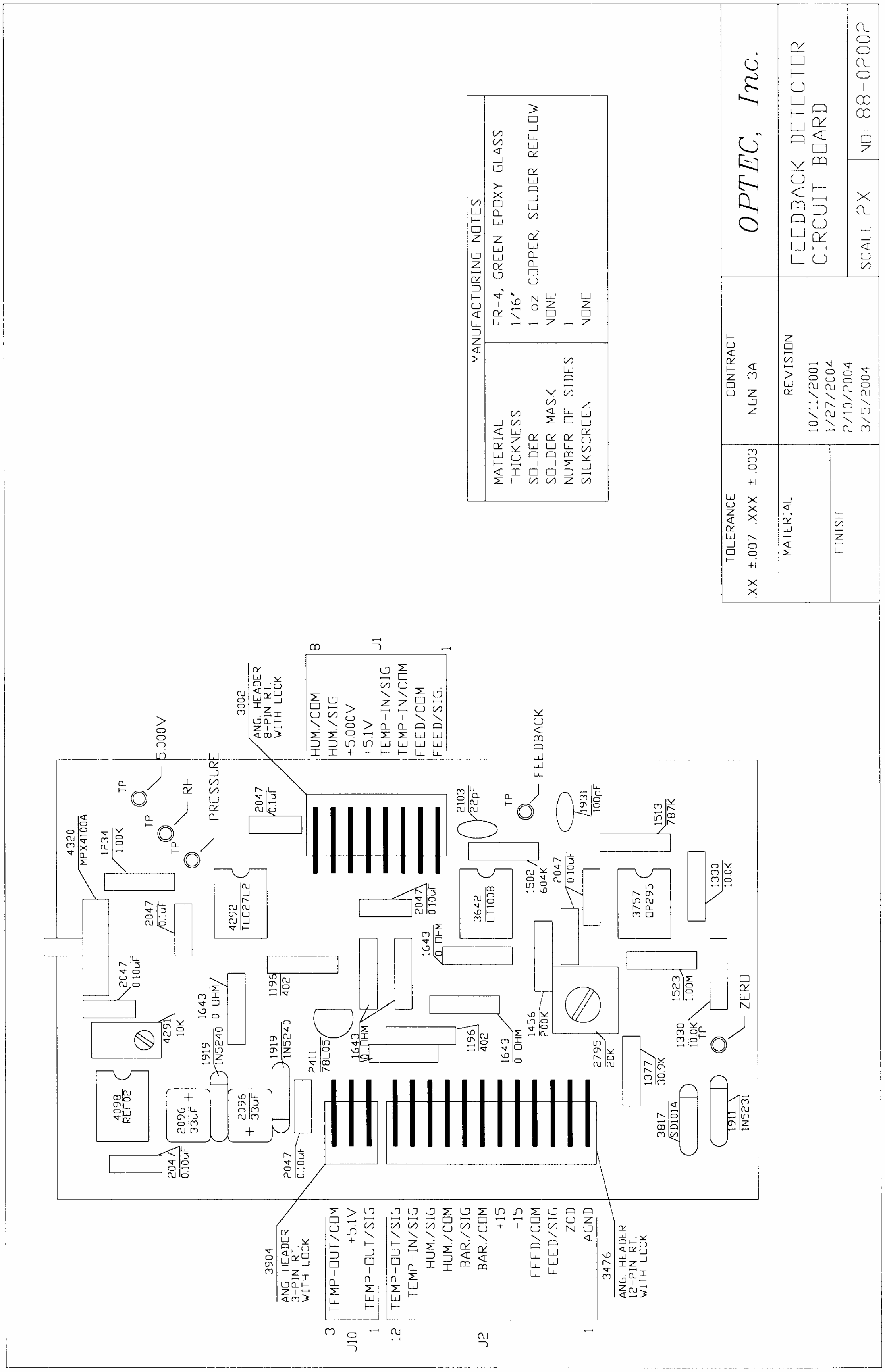
MANUFACTURING NOTES	
MATERIAL:	FR4 GREEN EPOXY GLASS
THICKNESS:	0.062"
COPPER:	1 OZ THICKNESS, TIN PLATE
SIDES:	ONE SIDE, COMPONENT SIDE SHOWN
SILK SCREEN:	NO
SOLDER MASK:	NO

TOLERANCE	CONTRACT	*OPTEC, Inc.*	
.XX ±.007 .XXX ± .003			
MATERIAL	REVISION 1/3/91 2/18/92 REV. 2 11/9/02 REV. 3	SCATTERED LIGHT DETECTOR CIRCUIT BOARD	
FINISH		SCALE: 2X	NO: 88-00029

Appendix D

FEEDBACK LIGHT BOARD


OPTEC, Inc.
FEEDBACK DETECTOR CIRCUIT
SCALE:
NO: 88-02001
CONTRACT
NGN-3A
REVISION
10/10/2001
1/27/2004
2/10/2004
3/5/2004
LM78L05 bottom view
Vout GND Vin
HIH-3602-L-CP
THERMISTOR
CASE
Vout
GND
+V
bottom view
MPX4100AS
6 5 4 3 2 1
TMP04 bottom view
Vout +Vs GND
WHITE RED GREEN
S1087 PHOTODIODE
YELLOW
GREEN
4320 MPX4100A
4319 HIH3602
3837 TMP04
INSIDE
OUTSIDE
A/D CH1
A/D CH0
A/D CH3
I/O PORTS
104-5
104-1
5.000V


OPTEC, Inc.
FEEDBACK DETECTOR
CIRCUIT BOARD
SCALE: 2X
NO: 88-02002
TOLERANCE
.XX ±.007 .XXX ±.003
CONTRACT
NGN-3A
MATERIAL
FINISH
REVISION
10/11/2001
1/27/2004
2/10/2004
3/5/2004
MANUFACTURING NOTES
MATERIAL FR-4, GREEN EPOXY GLASS
THICKNESS 1/16"
SOLDER 1 oz COPPER, SOLDER REFLOW
SOLDER MASK NONE
NUMBER OF SIDES 1
SILKSCREEN NONE
3002
ANG. HEADER
8-PIN RT.
WITH LOCK
J1
HUM./COM
HUM./SIG
+5.000V
+5.1V
TEMP-IN/SIG
TEMP-IN/COM
FEED/COM
FEED/SIG.
3904
ANG. HEADER
3-PIN RT.
WITH LOCK
J10
TEMP-OUT/COM
+5.1V
TEMP-OUT/SIG
3476
ANG. HEADER
12-PIN RT.
WITH LOCK
J2
TEMP-OUT/SIG
TEMP-IN/SIG
HUM./SIG
HUM./COM
BAR./SIG
BAR./COM
+15
-15
FEED/COM
FEED/SIG
ZCD
AGND
5.000V
RH
PRESSURE
FEEDBACK
ZERO
TP
4320 MPX4100A
1234 100K
4292 TLC27L2
3642 LT1008
3757 OP295
4098 REF02
2411 78L05
4291 10K
1919 1N5240
2096 33uF
3817 SD101A
1911 1N5231
1513 787K
1502 604K
1330 10.0K
1523 100M
1456 200K
2795 20K
1377 30.9K
1196 402
1643 0 OHM
2047 0.1uF
2047 0.10uF
2103 22pF
1931 100pF

Appendix E

13.8 VDC POWER SUPPLY

For AC installations, the 13.8 V DC power supply (Optec stock #86905) is required. This power supply measures 8 x 6 x 2 inches and will accept any of two switched inputs of 90-132 VAC 50/60Hz or 180-264 VAC 50/60 Hz. The unit will supply 13.8±0.3 VDC at up to 10 amps to the NGN-2/3 nephelometer.

Two different output connectors are available depending on distance to the nephelometer. For distances up to 20 feet, connection to the 4-pin Amp circular connector is recommended. Parts for the plug with crimp terminals compatible with 16 or 18 AWG wire are included with the power supply. Connect as follows:

Pin 1	(not connected)
Pin 2	+13.8 VDC
Pin 3	13.8 V return
Pin 4	(not connected)

For distances greater than 20 feet, connection to the banana jacks are recommended to limit voltage loss due to the resistance of the power cable. Use of 12 AWG wire would allow the power supply to be mounted 50 feet from the nephelometer. Of course, the wire size would have to be reduced to 18 or 16 AWG near the nephelometer to accommodate the terminals to the circular connector going into the instrument. Connect as follows:

Red terminal	+13.8 VDC
Black terminal	13.8 V return

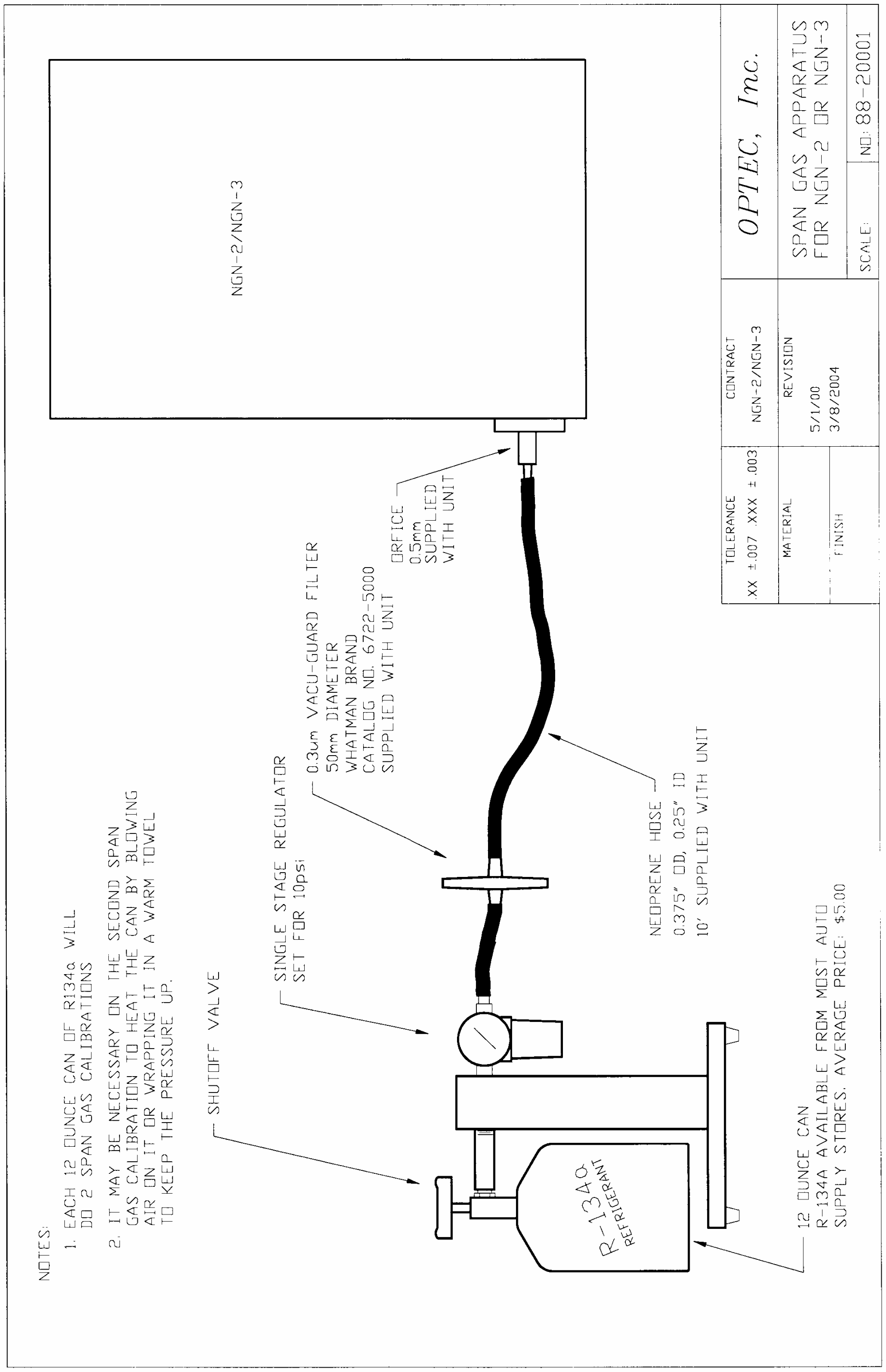
Appendix F

SAMPLE LINE FOR SERIAL DATA

	STATUS	RAW SCATTER COUNT	RAW LAMP COUNT	NORMALIZED SCATTER VALUE	INTEGRATION TIME IN MINUTES	MEASURING CHAMBER TEMPERATURE IN KELVIN	DATE IN YEAR-MONTH-DATE	TIME IN HOUR-MINUTE	Bscat IN INVERSE MEGAMETERS	Bmass IN MICROGRAMS PER CUBIC METER	CALIB-SPAN	CALIB-ZERO	CURRENT-ZERO	EXTERNAL TEMPERATURE IN KELVIN	RELATIVE HUMIDITY IN %	BAROMETRIC PRESSURE IN kPA
SAMPLE SERIAL DATA LINE	1	00161	3561	00090	02	306.6	011102	1244	0041.8	0013.9	107	024	033	296.2	30	101.3

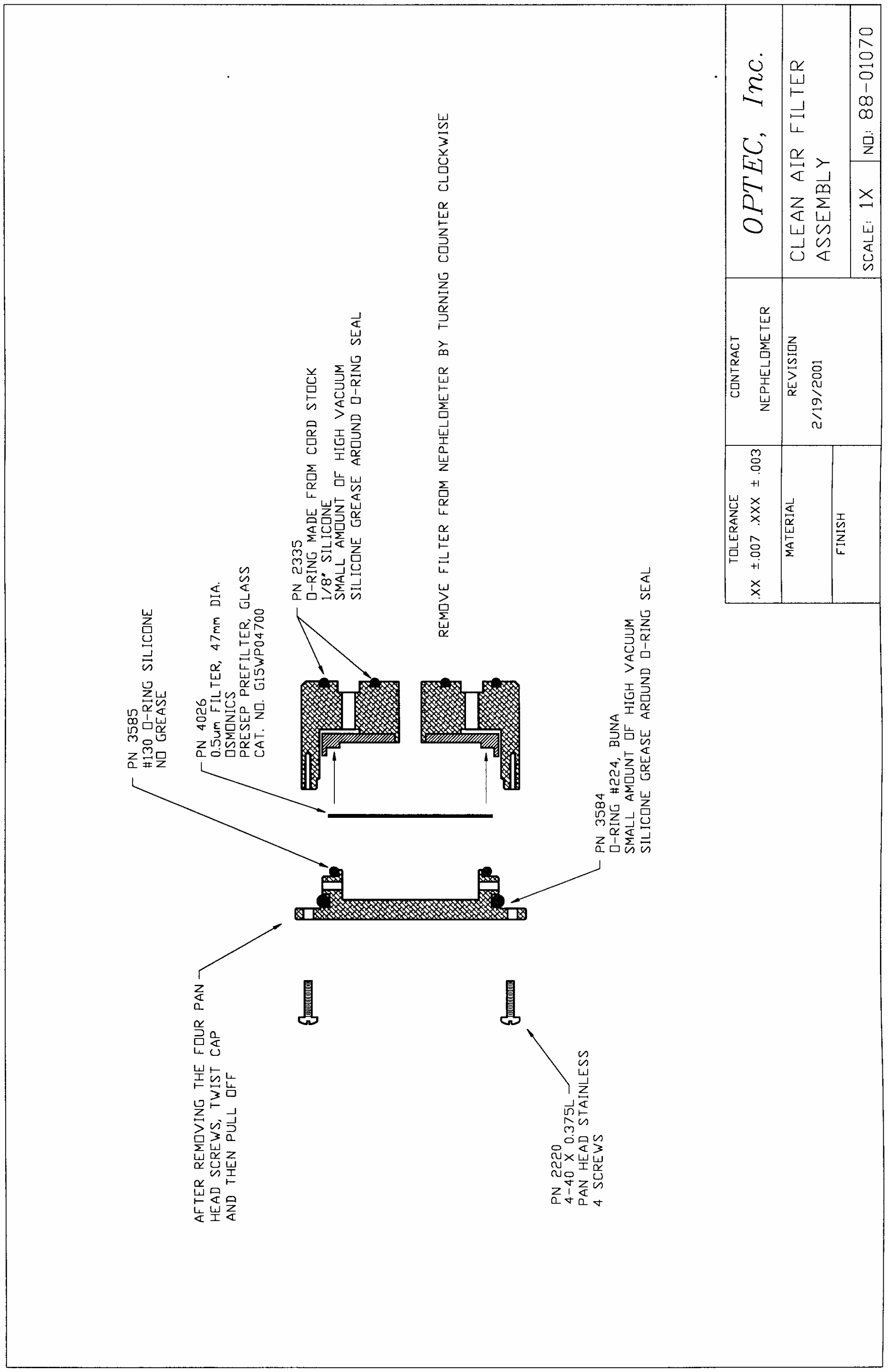
Appendix G

SPAN GAS APPARATUS



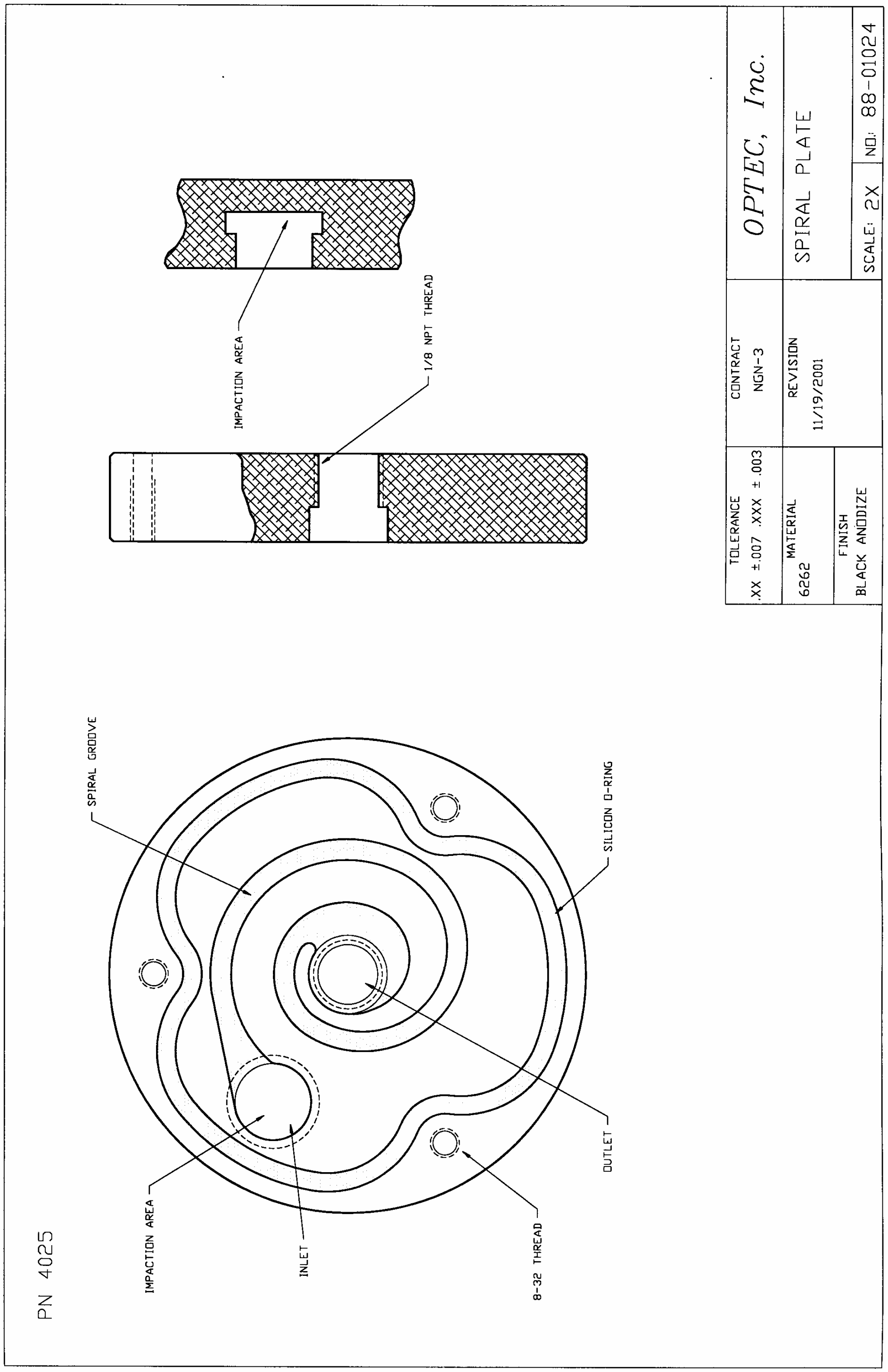
Appendix H

CLEAN AIR FILTER



Appendix I

SPIRAL SAMPLER



CLEANING PROCEDURE

Separate the two halves of the unit by removing the three socket cap screws.

The cleaning procedure depends somewhat on the usage and sampling conditions. In cases where the sampled air is mostly clean, wiping with a dampened Kimwipe may be sufficient. For a through cleaning, use warm water and detergent, followed by a rinse with water and isopropyl alcohol.

GREASING

The design of the Spiral Sampler suppresses particle bounce because of relatively gentle particle deposition in the spiral grove. For many type of aerosols, the sampler has been found to perform well. However, for some situations, as in desert locations, excessive penetration of large bouncy particles has been observed. Therefore, when dry dusty aerosol is present, it is recommended that the spiral groove be coated with grease. When the spiral groove is greased following the procedure presented below, the sampler has been found to show no significant penetration of large bouncy particles. Tests have been conducted with particle loadings corresponding to 8 hours of sampling with particle concentrations up to 4000 $\mu g/m^3$.

GREASING PROCEDURE

Although other greases may be used depending on the application, Apiezon M vacuum grease is recommended because of its extremely low vapor pressure, which ensures that the sample chamber and plumbing will not be contaminated as a result of outgassing. The Apiezon M grease should be dissolved in toluene at a concentration of 0.1 g/cc. The usual precautions for handling hazardous solvent should be observed. The grease solution can be conveniently stored in a small capped bottle.

Starting with the spiral groove plate that is clean, use a Q-tip to apply the Apiezon solution to the inside surface of the groove. The impaction area at the start of the groove should have a good coating of grease. After allowing the spiral plate to dry completely, attach the cover plate and tighten the three socket caps screws until no gap is seen between the two plates.