MODEL LPV-2

LONG PATH VISIBILITY TRANSMISSOMETER

TECHNICAL MANUAL FOR

THEORY OF OPERATION AND OPERATING PROCEDURES

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TRANSMITTER SYSTEM which includes: Light Projector and Control Unit mounted in Environmental Enclosure with Adjustable Base and All-Weather Aluminum Pier.

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SECTION 1.0

INTRODUCTION

The Model LPV-2 Long Path Visibility Transmissometer consists of a constant output light source transmitter and a computer controlled photometer receiver. The irradiance at 550nm wavelength from the transmitter can be measured to a high degree of accuracy both day and night, and over a path length of up to 15 km depending on expected extinction values. Both the receiver and transmitter operate from a 12 volt battery source and use 5 and 34 watts respectively. The signal is processed by an internal CMOS 8-bit computer and the output voltage can made proportional to extinction or visual range. The units can operate for long periods of time unattended in a continuous or timed cycle mode. The self resetting and battery backup systems ensure continued operation even after power blackouts and computer lockup due to local static electric discharges. Both units can be synchronized, programmed and calibrated at the home station and installed in the field ready for operation.

SECTION 2.0

TRANSMITTER - THEORY OF OPERATION

One of the major design requirements of the transmitter projector is that it operate with the low voltage (9 to 14 volts DC) and limited power available from batteries with integrated solar cell recharging panels. A modified low voltage tungsten lamp is used with a Koehler illumination projector system to give the equivalent light output of a bare unprojected 1500 watt lamp. Figure 2-1 shows a functional diagram of the transmitter projector system.

2.1 LAMP AND LAMP REGULATION

The tungsten lamp's nominal operating voltage is 5.8 and it uses 15 watts of power. It is critically prefocused and centered in a special mounting which allows easy replacement in the field without the need to align the lamp with the optics after lamp replacement. Expected life of the lamp at the normal operating voltage of 5.8 is approximately 500 hours of operation. Lamp output is adjustable by changing the applied voltage to it, which also affects lamp life greatly. For short working path lengths of 2 to 6 km, the lamp voltage could be set to 5 volts with the resulting decrease in light output of 50% but an increase in lamp life by a factor of 10. Conversely, setting the lamp voltage to 6.5 volts will increase lamp output by 40% and decrease life by 70%.

As the lamp ages, the applied voltage will increase to keep the output constant. At 6.8 volts, an LED on the side of the lamp controller will turn on indicating an abnormally high voltage and the need for lamp replacement. Typically, only a 0.2 to 0.3 volt increase in lamp voltage occurs after 500 hours of operation. This LED is also used to indicate the TEST (calibration mode) condition which is explained in Section 2.4.

To maintain the lamp output constant at better than 1%, an optical feedback method is used. Approximately 8% of the light in an area 0.17 degrees in diameter as referenced to the projected cone of light and centered around the optical axis is diverted 50 degrees to a silicon photodiode detector. A narrow band filter with a center wavelength of 550 nm and bandwidth of 10 nm is mounted in front of the detector so that only this wavelength is measured and regulated. A pre-amp configured as a current-to-voltage amplifier converts the photocurrent from the detector to a voltage which is fed to the inverting input of a high gain (gain = 200) difference amplifier. The non-inverting input is connected to an adjustable and highly stable reference voltage which is initially adjusted to achieve 5.80 volts output (higher or lower values depending on working path) going to the lamp. This circuit configuration will increase the voltage to the lamp, hence increase lamp output, until the voltage from the pre-amp is nearly equal to the reference voltage.

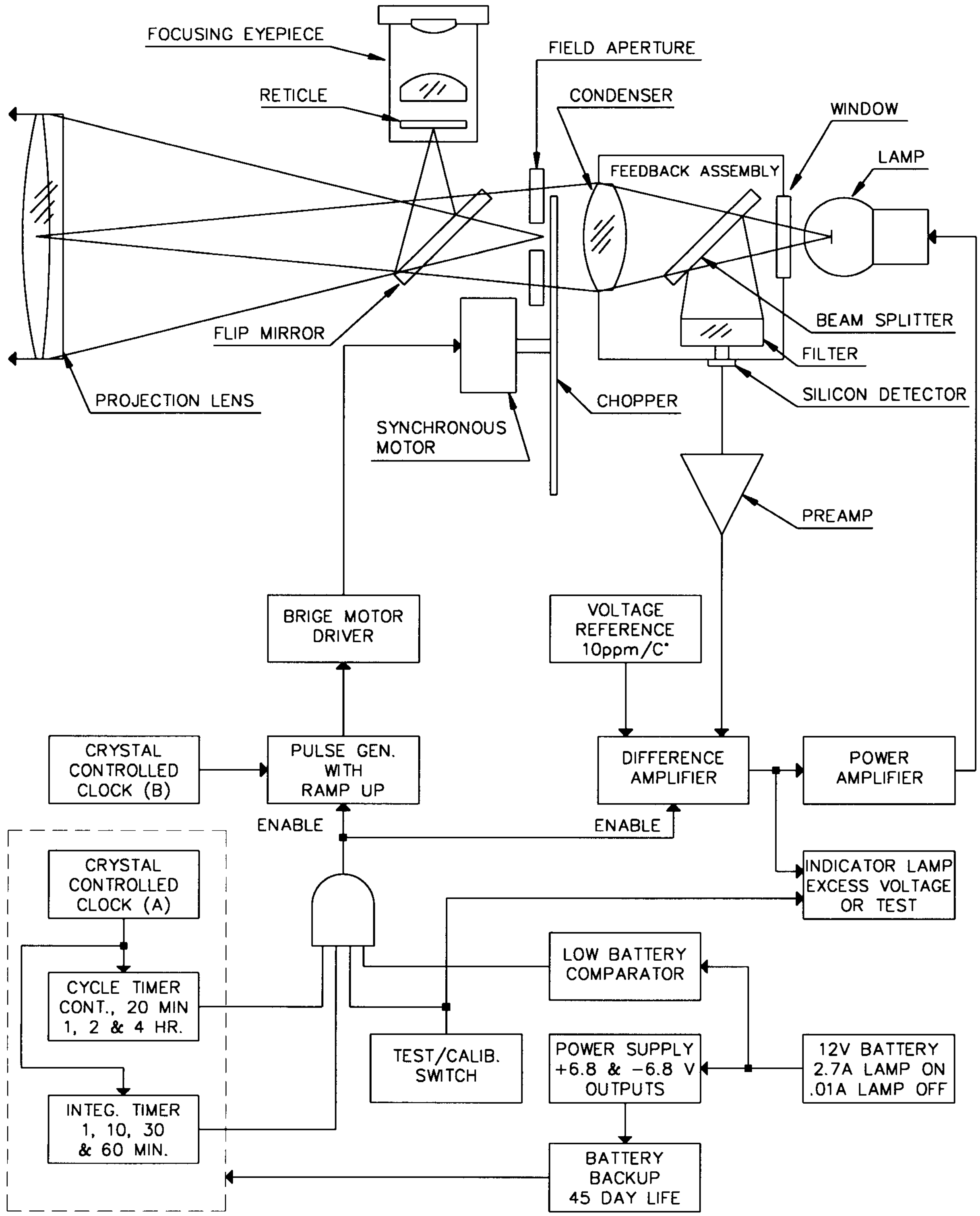


Figure 2-1. Transmitter Function Diagram.

Since dust and evaporated films could affect the transmission of the feedback optics causing the output of the lamp to increase by some unknown amount, the number of exposed optical surfaces are minimized by enclosing the feedback optics assembly and the projector condenser lens in a hermetically sealed block. The front surface of the condenser lens and both sides of the projector lens are the only surfaces which need to be cleaned on a routine basis.

2.2 PROJECTION OPTICS

To increase the output from the low power lamp to a level necessary to be measured accurately by the receiver, a Koehler projection system has been used in the transmitter. Use of this method increases the output of the lamp in a 1 degree diameter cone by a factor of approximately 100 without degrading the isotropy of the beam appreciably over an angular diameter sufficiently large to negate the effect of beam spread due to turbulence. Simply stated, the condenser collects the light contained in a solid angle of 11 degrees as seen from the filament and, with the projector lens, concentrates this light into a 1 degree cone. The 1 degree cone is set by a field aperture at the focus of the projector lens which is also mounted very close to the condenser lens. The condenser lens images the lamp filament on the plane of the projection lens. Proper operation requires that the filament image on the projection lens be entirely contained within its aperture.

The beam isotropy is dependent on the uniform illumination of the field aperture near the condenser lens. Because of shading within the coiled filament of the lamp (rear coils are shaded by the front coils), some non-uniformity is present. Experimental laboratory measurements made on a number of lamps has shown that the maximum non-uniformity to be expected is around 5% and varies smoothly across the 1 degree cone. Within the 0.17 degree cone observed by the feedback detector, less than 1% variation has been measured. Experiments to measure the effects of beam diameter and turbulence on receiver output were made at the Grand Canyon. The results show no measurable change even with beam diameters narrowed to 0.17 degrees in moderately high turbulence conditions. The working path length was approximately 16 km.

To properly point the transmitter projector at the receiver, an eyepiece with reticle can be inserted into the optical path at the focus of the projection lens with the use of hand operated first surface mirror. With the mirror in the down position, a 2.3 degree diameter image of the field is viewed at 14 power. The eyepiece and projection lens are preset for infinity focus but can be adjusted through a small range. NOTE: Any change in the focus position must occur before calibration and operation.

To aid in pointing, a reticle is mounted at the field aperture plane of the focusing eyepiece. Two rings which coincide with the 1 degree total cone diameter and 0.17 degree detector feedback diameter are etched on the reticle. For the most stable transmitter output (no more than 1% variation even with lamp changes), the receiver should always be sighted within the 0.17 degree ring.

2.3 LIGHT BEAM MODULATION

A four blade chopper mounted near the condenser lens modulates the beam at exactly 78.125 Hz. Modulation of the beam and synchronous detection by the receiver allows the transmitter signal to be separated from background noise. The chopper is rotated at the exact speed of 19.53125 revolutions per second by a low voltage synchronous timing motor. Pulses from a crystal oscillator are power amplified and shaped by a bridge driver to run the motor. To ensure reliable startup of the motor, the drive pulses are slowly ramped up to the proper frequency before locking onto the crystal oscillator frequency. The crystal oscillator chip used in the transmitter is the same as the receiver, hence the temperature coefficients are close. If the two units are operated close to ambient temperature, the chopper frequency should track the synchronous detection frequency minimizing any error due to temperature drift.

2.4 TIMED CYCLE MODE

To conserve power and lamp life, both the chopper and lamp can be powered up in a timed cycle mode. The possible cycle times (period between lamp/chopper turn on) are 20 minutes, and 1, 2, and 4 hours. The length of time the chopper/lamp will run (integration time) at the start of a each new cycle is selectable between 2, 16, 32 and 64 minutes. It is also possible to run the lamp and chopper continuously by setting the integration time to equal or exceed the cycle time.

When a new cycle starts, the lamp is turned on first and the motor second. The voltage to the lamp is increased gradually over a period of about 4 seconds to reduce the inrush current surge and thermal shock to the lamp filament. An inrush current surge from turning the lamp on abruptly could exceed 15 amps. Depending on the external battery and associated regulation, this current surge could cause the battery voltage to drop momentarily resulting in any of the following: loss of circuit voltage regulation causing unpredictable effects, activation of the low battery comparator causing the circuit to shut down (see low battery comparator) and possible detrimental voltage drops to other external instruments connected to the same battery supply. The slow turn-on also extends lamp life by minimizing the thermal shock to the filament.

The chopper motor is started approximately 3 seconds after the cycle starts. This eliminate the possibility of the remaining small lamp inrush current reducing the power delivered to the motor during the critical start-up period.

From the start of the cycle time, it takes approximately 10 seconds for both the lamp and chopper to reach stable operating levels.

To determine the proper operation of the unit, a toggle switch marked TEST on the side of the control unit is provided. When switched on, both the lamp and chopper will power up and stay on until the TEST switch is turned off. To indicate that this mode has been invoked, the LED on the side of the control unit, which normally indicates excessive lamp voltage, will turn on. The TEST mode is used to activate the transmitter without upsetting the synchronization of the cycle timer for the calibration procedure.

2.5 POWER SUPPLY

The input battery voltage can range from 10.2 to 15 volts DC. Internally, this voltage is converted and regulated to +6.8 and -6.8 volts for the digital and analog control portions of the circuit. In addition, a +18 volts is produced with a voltage doubler circuit to provide the proper gate turn-on voltage for the chopper bridge driver circuit which uses MOS switches. The power circuits, lamp and chopper motor use the power from the battery supply directly. In an idle state with both lamp and chopper motor off, the control circuit typically uses 10 ma and, when fully on, uses 2.7 amps with a 12.6 volt battery power supply.

In case of battery power interruption, the cycle and integration timer continue running by using an on-board battery backup consisting of 4 AA alkaline batteries. At an ambient temperature of around 25 degrees Celsius, these batteries will provide enough power for approximately 45 days of operation. When adequate 12 volt battery power is available, the battery backup switches out of the circuit and the cycle and integration timer continue running with the external power source.

An onboard low voltage battery comparator will cause the control circuit to switch off when the external battery voltage drops below 10.2 volts preventing complete draining of the external battery and improper lamp output. The built-in hysteresis of this circuit will prevent the transmitter from running again until the battery voltage reaches 12.3 volts allowing the battery adequate time to regain its full charge. The turn-off and turn-on points can be adjusted up or down to better match the characteristics of the battery used. However, the 2.1 volts hysteresis can only be changed by replacing board components. If the input voltage exceeds 17 volts, a 17 volt Zener placed between the power input and return lines will go into conduction causing the 5 amp AGC fuse to blow.

SECTION 3.0

RECEIVER - THEORY OF OPERATION

The LPV receiver uses a very sophisticated and accurate method to retrieve the transmitter signal from amplifier and background noise and measure it. Simply stated, the modulated signal is locked onto and a small portion of the signal is sampled with the transmitter lamp off and is subtracted from the signal when the lamp is on for each cycle. This difference is integrated over many thousands of cycles, which reduces the combined noise sources to a value much less than the signal of interest. Having stated the method, the problem is then a matter of mere implementation.

3.1 SIGNAL ACQUISITION

A 63mm refractor lens (clear aperture of 58 mm) with a focal length of 350mm, is used to optically amplify the light from the transmitter and provide some smoothing of the signal noise caused by atmospheric turbulence. For calibration purposes, a neutral density filter with a transmission of approximately 1% can be inserted in the photometer body just in front of the detector. The refractor lens and photometer head are rigidly mounted in a heavy walled tube which maintains the precise alignment needed to keep the transmitter image centered on the detector. See Figure 3-1.

Light from the transmitter when entering the photometer head is directed either to the focusing eyepiece or the detector by means of a flip-mirror. The focusing eyepiece consists of a 25 mm focal length Ramsden eyepiece and a reticle with a precisely etched ring that determines the detector field of view. After the transmitter light is centered in the ring, the flip mirror is turned to expose the detector. Directly in front of the detector is a narrow band filter with a center wavelength of 550 nm, a bandwidth of 10 nm and a peak transmission of 60%, which is identical to the filter used in the lamp feedback system for the transmitter.

The detector is a sensitive silicon photodiode operating in the photovoltaic mode with a very low bias current (0.1 pa) electrometer amplifier operating in a current-to-voltage amplifier configuration as shown in Figure 3-2. Photocurrent from the detector (I_s) is balanced by an equal current in the feedback resistor (R_f), but flowing in the opposite direction so that the inverting input is kept near zero potential. The output voltage is thus:

$$E_{out} = R_f \times I_s$$

where R_f is equal to 4000M (4×10^{10}) ohms.

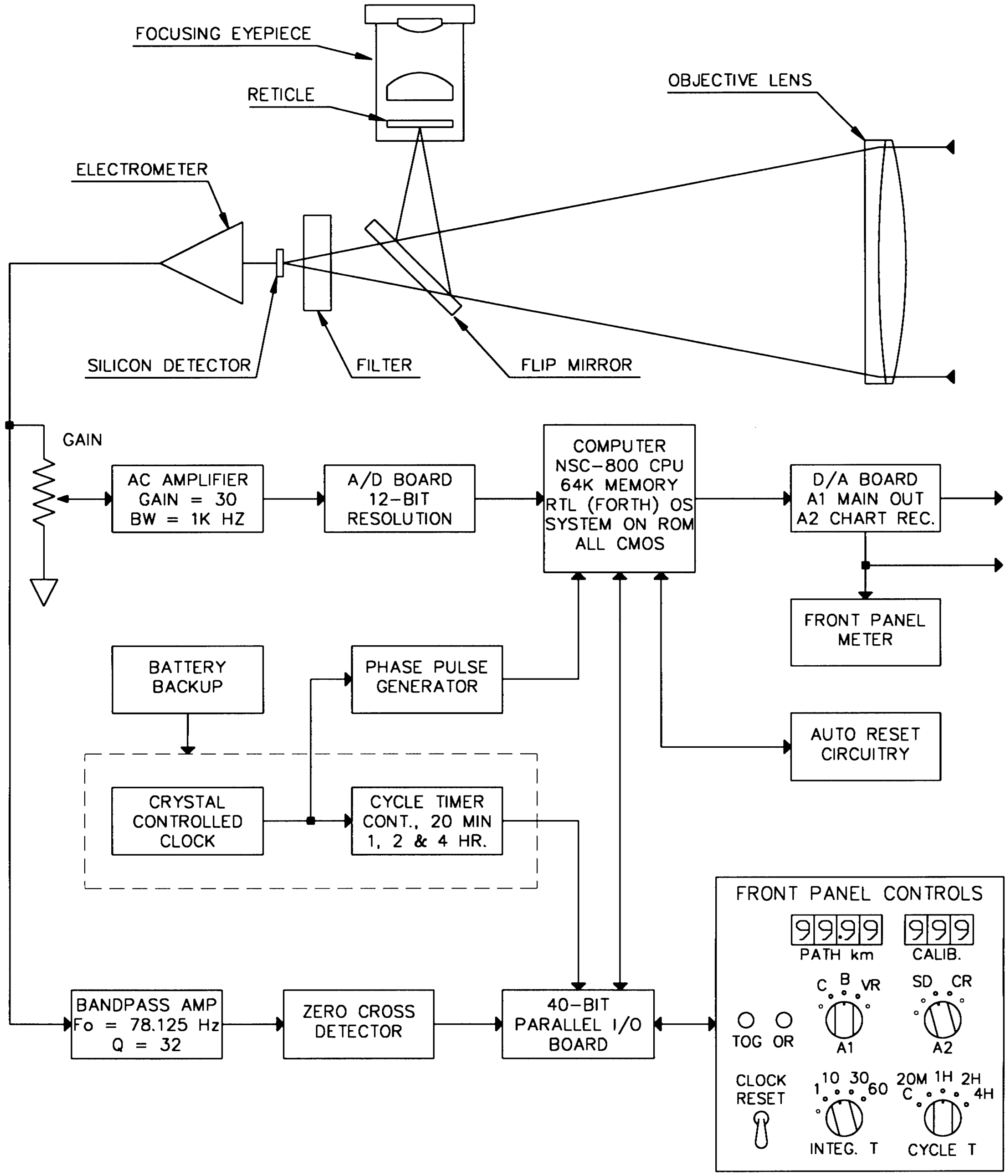


Figure 3-1. Receiver Function Diagram

Eout from the photometer head is dependent on detector response, filter/telescope transmission, electrometer gain, output from the transmitter, path length and, of course, atmospheric transmission. The approximate value of E_{out} for a path length of 5 km and extinction of 0.02 km^{-1} is around 25 mv p-p.

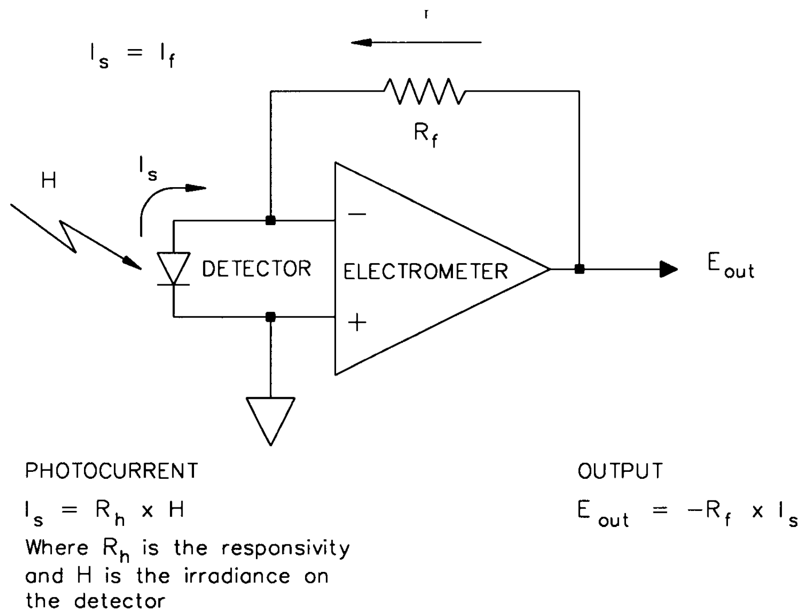


Figure 3-2. Current-to-Voltage Amplifier Configuration

The 1mm x 1mm square detector surface is masked with 0.75mm diameter circular aperture which coincides to the etched ring of the reticle. Since alignment of the detector aperture and reticle ring is extremely important, the electrometer- detector combination is rigidly mounted on a X-Y adjustable bracket centered in the photometer head housing by 4 setscrews located around the circumference of the bracket. Accurate adjustment of this bracket on an optical bench by loosening and tightening opposing setscrews ensures that the detector aperture aligns with the etched ring of the reticle to a centering error of less than 0.001 inch.

3.2 SIGNAL PREPROCESSING

Before processing by the computer, the signal from the photometer head, is scaled by a 10 turn potentiometer attenuator (gain control) with 3 digit dial readout located on the front panel and amplified by a low-noise amplifier with a fixed gain of either 30 (long path) or 2 (short path) and bandwidth of 1 to 1000 Hz. The gain of the low-noise amplifier is set by a jumper on the board. Default is jumper off for a gain of 30. The potentiometer has a rated linearity error of less than 0.25%.

The signal is scaled to achieve the maximum readings without over-voltaging (OV) the A/D converter input or over-ranging (OR) the D/A converter output. Since atmospheric turbulence can cause extreme momentary fluctuations of the signal strength, this scaling is usually done during times of peak turbulence. The OV LED next to the gain pot will light up if the peak signal voltage exceeds 2.500 volts which is the upper limit of the A/D converter. If the output of the D/A converter (this is the output going to the data logger and front panel meter) is over-ranged a maximum output voltage of 10.000 volts and a 1000 count on the front panel meter will be obtained. In addition, the OR LED on the front panel will turn on.

The DC saturation level for the detector pre-amplifier is approximately 13 volts. This voltage can be reached if the background illumination is sufficiently intense due to the Sun reflecting off snow or bright rocks. If this happens, the signal is lost (0 signal level) and a high extinction value is computed. The intense illumination will not harm either the detector or pre-amplifier unless the Sun itself is in the view.

A voltage comparator set for 11.0 volts is connected to pre-amplifier output. Once the voltage exceeds this level, the OV LED will turn on and stay on until the computer power is turned off & on. Normally, when the OR LED is activated by the peak signal exceeding 2.5 volts due to turbulence as discussed earlier, the display will flash momentarily and the problem may be remedied by reducing the gain. If at sometime during the monitoring period the DC saturation point had been exceeded, the OV display will stay on regardless of gain setting or even if the background illumination is totally blocked. A RC circuit with sufficiently large time constant at the input of the comparator prevents any intense but short lived illumination from activating the display. Again, if activated it can only be reset by turning the computer power off and then back on.

A part of this signal is used to find the time when the transmitter chopper is open (lamp on) or closed (lamp off). A bandpass amplifier with a Q of 32 and center frequency of 78.125 Hz allows the fundamental frequency of the chopped signal to pass to the zero cross detector. The positive half of the bandpass output (lamp on) results in the zero cross detector going positive and the negative half (lamp off) causes the bandpass to go negative with a very fast transition at the zero voltage points. See Figure 3-3. A small amount of voltage hysteresis built into the comparator prevents several pulses of very short duration from being generated during the crossing of the zero point due to signal noise which is not completely eliminated by the bandpass amplifier.

3.3 FRONT PANEL INPUT CONTROLS

Like the transmitter projector, the receiver computer has available a cycle and integration timer with its own battery backup. Both the transmitter and receiver timers are reset simultaneously, so that when the lamp turns on at the transmitter the computer starts a reading, with the integration time set by the front panel switch. The possible cycle times are the same as the transmitter's, which are 20 minutes, 1, 2 and 4 hours and continuous. Similar to but not equal to the transmitter, the receiver integration times are set shorter to prevent differential drifting of the separate crystal clocks from sliding the receiver integration time out of the transmitter integration time window. The receiver integration times are 1, 10, 30 and 60 minutes.

As will be discussed further on, the receiver computer is able to calculate directly the extinction and visual range values. In order to do so, the front panel has two BCD coded decimal thumb switch arrays to input the necessary constants for the calculation. The working path length switch array has a working range of 0 to 39.99 km with .01 km resolution. The second switch array is for the calibration constant. Its use and derivation will be discussed in Section 6.0.

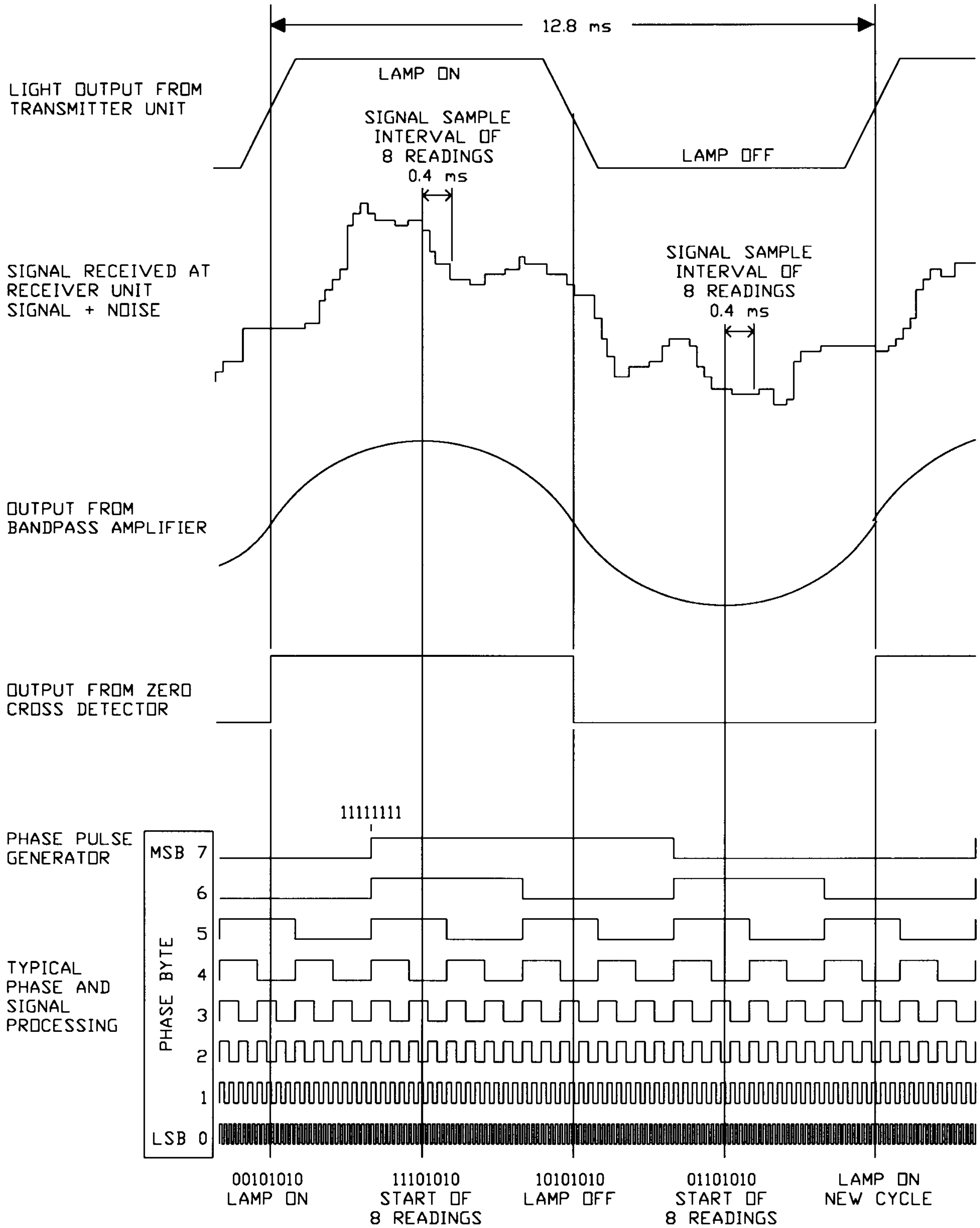


Figure 3-3. Receiver Signal Processing Waveforms

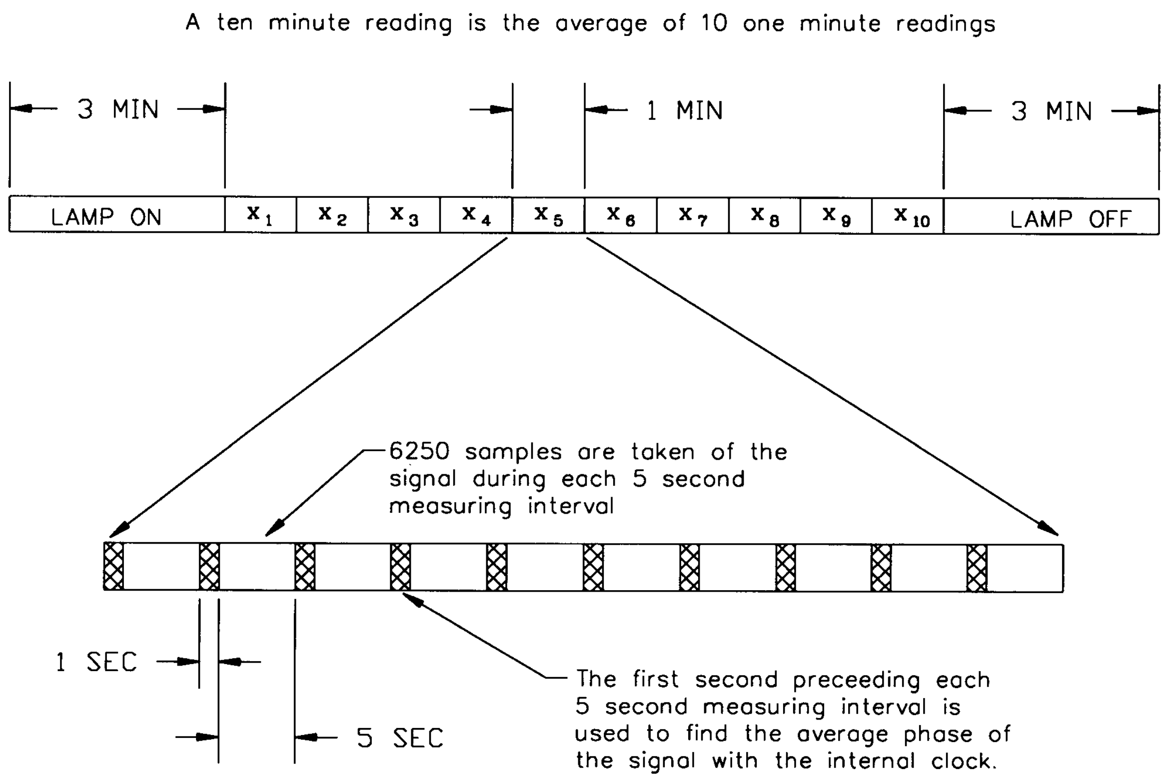


Figure 3-4. Example of a Ten Minute Integration

The computer can process and output the data as raw instrument values, extinction and visual range on the analog output channel, A1. In addition, the raw instrument value for each 1 minute integration and its population standard deviation based on 10, 30 or 60 one minute integrations (depends on the selection of integration time) are available on a separate analog output channel, A2. The selection of these outputs is determined by the A1 and A2 switches.

A 3« digit analog DC voltmeter is connected to the A1 analog output which will display the raw instrument values from 000 to 1000, extinction from .000 to 1.000 /km and visual range from 000 to 1000 km.

To indicate that a new reading has been made, a LED lamp on the front panel will toggle on (or off) until the next reading. This output is also made available to a rear connector for use by the external data logger.

3.4 COMPUTER PROCESSING

As inputs, the computer uses the raw input signal digitized by the A/D converter, the zero cross detector control output which indicates when the transmitter lamp is on or off, and the various inputs from the front panel which determine in what way and when to process the signal. The computer outputs either raw instrument readings (C), extinction (B) or visual range (VR) on one analog channel and the probable error of the raw readings (SD) or raw instrument readings (CR), based on 1 minute integration, on another analog channel. In addition, a digital output line toggles high and low when the reading is updated to indicated to the external data logger that a new reading is available.

The OPTEC-1 Single Board Computer has been designed 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 following specifications:

General	-20 to 60 degree C operating temp.
CPU	64180 from Hitachi 6.144 MHz clock rate Automatic reset via watchdog timer
Memory	32K EPROM, single IC 32K RAM 64K additional address space 50 bytes non-volatile RAM
I/O	64 lines bi-directional
A/D	12 bit resolution +3.0 to -3.0 V input voltage range 8 µsec conversion time 4 multiplexed differential inputs
D/A	12 bit resolution 2 outputs 0 to +10 and 0 to +5 V output range, jumper selectable
Serial Port	RS-232 port with DB25 connector as shown below:

<u>Signal</u> <u>DB25 Pin No</u>.

RX	3
TX	2
GND	7
Chassis	1

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 CRC 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 flash the TOG LED at approximately one Hertz indicating that the program has an error. Since this error checking part of the program consists of less than 4% of memory, chances are that if an error exists in the EPROM, it will not affect the error checking operation.

Before starting any signal processing, the program waits for the negative transition of the cycle timer. When this occurs, it polls the front panel controls to determine the proper operating parameters and output format and then proceeds to process the signal. The front panel is again polled after each 60 second interval during an integration, except for the A1 and A2 switches which are polled every 5 seconds during an integration and every few milliseconds when waiting. It is possible to flip through C (raw instrument values), B (extinction) and VR (visual range) with front panel switch A1 and see the new values displayed almost immediately. After an integration, the program holds the A1 and A2 outputs and waits for the next negative transition of the cycle timer before beginning another integration.

The serial output consists of the following information on one line ended by a carriage return and line feed:

DATE TIME C= *NNNNN.N* B= *N.NNN* VR= *NNN* N= *NN* SD= *NNNN*

where,

DATE	is the year, month and day
TIME	is the hour, minute and second
C	is the mean of the raw counts
B	is the extinction
VR	is the visual range
N	is the number of 1 min. integrations
SD	is the standard deviation of raw counts C.

When using the serial output to log data, it is recommended that the RX line be left open at the receiver computer. Any noise on this line could cause the receiver computer to go into the monitor mode which would stop the program.

In the absence of noise, the difference between the signal level at the top of the wave when the lamp is on and the bottom of the wave when the lamp is off would give an accurate measurement of the transmitter irradiance. Since noise due to the atmosphere and receiver electronics is always present and usually several orders of magnitude greater than the signal, the average difference must be calculated over many thousands of cycles.

In order to extract the signal from the background noise, the receiver must be able to determine precisely the phase of the incoming signal with respect to the receiver phase pulse generator running at the same frequency. At the start of a measurement period, the computer compares the zero cross detector's positive transitions with the output of the phase pulse generator for a period of 1 second and computes the average phase difference. See Figure 3-3. The phase pulse generator is an 8-bit binary down counter with the low order bit running at 256 times the base transmitter chopper frequency of 78.125 Hz or, in other words, 20,000 Hz. When triggered by the positive transition of the zero cross detector, the computer samples all 8 of the counter outputs which is then a binary representation of the phase difference with a resolution of 1 part in 256.

After the phase difference is measured, the center of the time intervals when the lamp is on and off can be determined by subtracting the binary equivalent of 1/4 wave (01000000) and 3/4 wave (11000000) respectively from the output of the phase pulse generator. Using the example in figure 4: If the average output of the phase pulse generator for the 1 second sampling period is computed to be 00101010, then the middle of the lamp on interval is

```
carry over>   1  00101010        lamp on
                -01000000        minus 1/4 wave
                 --------
                 11101010        middle of lamp on interval
```

and the middle of the lamp off interval is

```
carry over>   1  00101010        lamp on
                -11000000        minus 3/4 wave
                 --------
                 01101010        middle of lamp off interval.
```

There is always a carry over from the 9th bit since the counter resets to 11111111 after counting down to 00000000.

For each cycle during the next 5 seconds, 8 samples are taken of the signal starting at the middle of the lamp-on interval and, similarly, 8 samples are taken during the middle of the lamp-off interval. Since the A/D converter has a conversion time of 50 µS, the total sample time is only 0.4 ms long during each 1/2 cycle. A total of 6259 samples are taken during each 5 second measuring interval after which the computer again finds the phase difference between the zero cross detector and the phase pulse generator before beginning another 5 second measuring interval.

At the end of 60 seconds (ten measuring intervals of 5 seconds each), the average difference is computed, stored and/or sent to the desired analog channel (A1, A2) and in the desired format (C, B, VR) as set by the front panel controls.

Usually, an integration time much longer than 60 seconds is needed to smooth out the effects of turbulence. The computer will use these 60 second intervals to compute longer integration times. For example: If a 10 minute integration time was selected on the front panel, ten 60 second measuring intervals would be used to compute an average value. See figure 2-4. In addition, the standard deviation of the raw instrument readings for the 10 values are computed and, if selected, sent to the analog channel A2. The practical significance of the standard deviation output is for a check on the quality of data. A large value would indicate unstable seeing conditions such as those produced by rain squalls and smoke. A small value would mean "good data".

SECTION 4.0

TRANSMITTER - OPERATING PROCEDURES

Connect the input power cable to the input connector. If a cable is customer made, pin 2 is for the positive 12 volt terminal and pin 3 of the connector is for the negative (return) 12 volt terminal. Use 18 or 16 AWG stranded wire for making the input power cable to minimize power losses.

Reversing the voltage polarity to the input will result in blowing the fuse which is located on the inside circuit board near the input connector. If blown, replace with an AGC 5 amp or equivalent fuse. Exceeding 17 volts input voltage may also result in a blown fuse because of the input protection circuitry.

The control cable to the projector unit is symmetrical and either end can be connected to the control or projector unit. Frequent disconnects in dusty environments can result in worn connectors, which may make it difficult to reconnect properly. It is suggested that tuner cleaner or spray silicon lubricant be used occasionally on the connector parts to insure long life.

The flip mirror control is located on the left side of the projector unit. Turn this control clockwise until the stop is reached for siting the instrument on the receiver unit. While viewing through the focusing eyepiece, center the receiver telescope (or shelter if sufficiently far away) in the center of the circle. The center circle represents the area of the projected cone of light that is used in the lamp feedback control. The outer circle is the outside limit of the 1 degree cone of light which is projected.

The telescope is prefocused at the factory and further adjustment should be unnecessary. If the view through the projector is out of focus, loosen the front objective lens mount (slotted screw near the front of the telescope) and reposition the objective lens mount for best focus. IMPORTANT: This adjustment must be made before calibration. The unit will have to be recalibrated if the objective lens is repositioned. In any case, do not reposition the focusing eyepiece as this will cause a loss of alignment of the reticle to the light cone.

With the power off, remove top cover of the control unit to expose the integration time, cycle time and reset controls. Adjust integration and cycle time slide controls to the appropriate setting as required. The position of these controls are shown in Figure 4-1.

Permitted integration times are 64, 32, 16 or 2 minutes.Permitted cycle times are 4 hours, 2 hours, 1 hour or 20 minutes. As shown above, the unit is set for a cycle time of 1 hour and at the start of each hour (cycle) the lamp will turn on for a period (integration) of 16 minutes.

The reset pushbutton switch starts the cycle timer at the precise moment of release. It is suggested that the cycle time be reset at the exact start of the hour for local time or GMT.

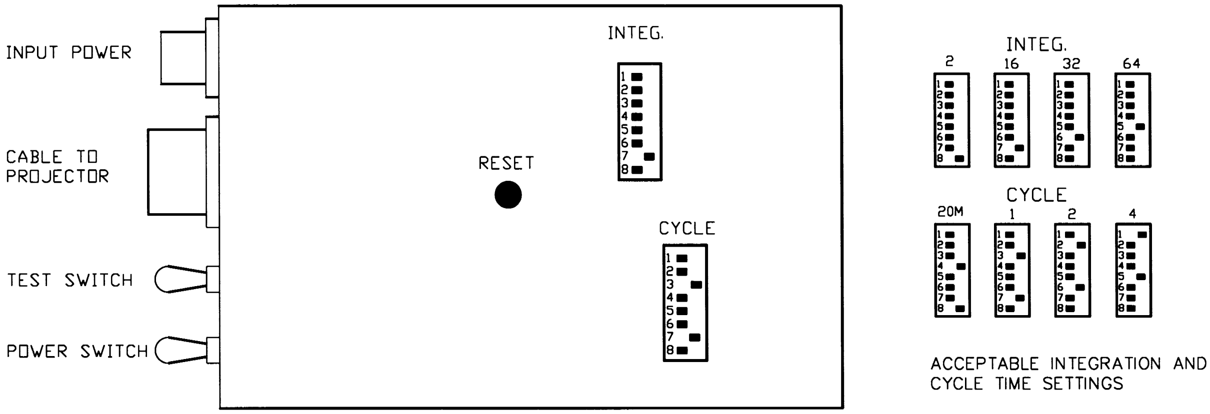


Figure 4-1. Inside View of Transmitter Control Unit

Because the battery backup keeps the cycle timer running at all times, the cycle reset can be performed without the 12 volt input power connected. It is suggested that all settings including reset be done in the shop before installation in the field.

Turning the power switch on will not necessarily start the lamp and chopper if the local time does not coincide with the cycle/integration time. Setting the reset will immediately start the lamp and chopper for the indicated integration time. The unit can be set for continuous operation by making the integration time greater than the cycle time. This would occur in the above example if the integration time switch had been set for 64 minutes.

For calibration, it is usually necessary to turn the transmitter on without the need to change the cycle time, integration time or resetting the timer clock. For this purpose, a test toggle switch has been mounted near the power switch. Placing this switch in the up position will turn on both the chopper and lamp so that calibration can be performed without upsetting the cycle timer. After calibration, the unit can be returned to its operational location and power connected. The transmitter should start up on its own at the next preset cycle. This switch setting should not be used for continuous operation in place of setting the integration time switch greater than the cycle time because the excess lamp voltage LED (see next paragraph) will not function properly. This LED will turn on during the test mode as a visual indication that this mode is activated. In addition, the low battery voltage circuitry described in Section 2.5 will be disabled.

The LED on the side of the control unit will turn on when the lamp voltage exceed 6.8 volts. At that point, a new lamp should be installed or the internal control for adjusting the lamp operating point (brightness) should be set lower. After proper centering, turn the flip mirror control completely counter clockwise which will allow the light to exit without obstruction.

SECTION 5.0

RECEIVER - OPERATING PROCEDURES

Insert the photometer head into the rear port of the telescope and secure by tightening the knurled plastic knob. Flip the mirror of the photometer head to the viewing position (fully clockwise until it stops) and then focus the telescope by rotating the objective lens cell. Make sure the pan head screw near the front is loose before attempting to focus. After proper focusing, secure the pan head screw but do not over tighten it. Unlike the transmitter projector telescope, refocusing the receiver telescope after calibration does not affect the calibration constant.

While viewing through the focusing eyepiece of the photometer head, maneuver the telelscope until the image of the transmitter is centered in the small ring of the reticle. If the transmitter's image drifts by more than 1/2 radius of the small ring from the center, errors in extinction could occur during periods of high turbulence because of light falling off the edge of the detector. Return the flip mirror to the measuring position by turning the knob counter clockwise until it stops.

Plug the cable from the photometer head into the port labeled "PHOTOMETER" on the rear panel of the computer enclosure. Connect the 12V power to the port labeled "12V DC" using the cable provided. If the cable is customer made, pin 2 is for the positive 12 volt terminal and pin 3 of the connector is for the negative (return) 12 volt terminal. Use 18 or 16 AWG stranded wire for making the input power cable.

Reversing the voltage polarity to the input will result in blowing the fuse which is located on the inside circuit board near the input connector. If blown, replace with an AGC 1 amp or equivalent fuse. Exceeding 17 volts input voltage may also result in a blown fuse because of the input protection circuitry.

The data acquisition and reduction computer is self starting and requires no user input except for the proper setting of the front panel controls discussed on the next couple of pages. To reset the computer, the power must be shut off for about 1 second. The computer can be operated in a monitor mode with an ASCII terminal or a PC computer with a terminal emulation program using Televideo cursor protocol. A version of PROCOMM, a shareware communication program, properly setup is supplied with the LPV at time of purchase.

Similar to the transmitter unit, the receiver has controls for cycle time, integration time and a timer reset using a momentary action toggle switch. These should be set to correspond to the transmitter settings as listed in Table 5-1.

TRANSMITTER		RECEIVER	
Transmitter	Receiver	Transmitter	Receiver
64	60	4	4H
32	30	2	2H
16	10	1	1H
2	1	20M	20M
continuous	(any pos.)		

Table 5-1. Transmitter and Corresponding Receiver Timer Control Settings

As stated in the previous section, if the transmitter time is selected to be greater than the cycle time, the lamp and chopper will run continuously and any receiver integration time can then be chosen.

The receiver integration times are approximately 2 to 3% greater than listed, for example a 10 minute integration is approximately 10 minutes plus 13 seconds. This is a result of the computation time and variable phase lock time of the computer which adds up to a small and variable error in the absolute integration time. Unlike the integration time, the cycle time is crystal controlled outside the computer and has a precision of 5ppm.

The receiver integration times are a little longer than the transmitter times to allow for drift errors in the synchronization of the two timers. Using the current example of a one hour cycle, starting at the hour mark for local time and a 16 minute integration time for the transmitter, the receiver reset toggle would be pressed at 3 minutes after the hour. This would give a three minute combined drift allowance for the cycle timers in each unit. At approximately 13 minutes after the hour (3 + 10 minutes) the receiver would output the results of a 10 minute integration.

A1

The A1 selector control is set for the desired output as follows:

C	Raw instrument reading used for calibration of the instrument (See Section 6.0 on calibration procedures)
B	Extinction value in units of /km
VR	Visual range value in units of km based on 5% contrast. (VR = 3.00/B) Visual range based on 2% contrast (VR = 3.92/B) can be implemented with an EPROM change. Contact Optec Inc.

These values are displayed on the front panel meter and sent to the output connector (pin 1 signal, pin 4 common) on the rear panel of the computer enclosure. The front panel meter displays the results to a precision of about 10 bits (0.1%) while the rear panel output, which is connected directly to the D/A converter, has 12 bits precision.

A2

The A2 selector control is set for the desired output as follows:

SD	Standard deviation of the raw instrument readings from A1. Small values represent a stable measurement period.
CR	Chart recorder type output of the raw instrument readings based on one minute integrations.

Either one of these values is sent to the output connector (pin 2 signal, pin 5 common) on the rear panel of the computer enclosure. Similar to A1, this output is connected directly to the D/A converter and has a precision of 12 bits.

PATH

The PATH thumbwheel switch is set for the transmitter to receiver path length to the nearest 0.01 km. For precise values of B (extinction) and VR (visual range) to be displayed, this value should be correctly entered. If this value is not known precisely at time of installation, it is suggested that the raw instrument readings be recorded for later reduction to B or VR.

CAL

The CAL. (calibration constant) thumbwheel switch is set according to the value calculated during calibration. See Section 7.0 on Calibration Procedures. Similar to the path thumbwheel switch, this value is needed to calculate precise values of B and VR.

There are three LED indicator lamps on the front panel which function as follows:

OV

This indicator has two functions which are: (1) to indicate that the signal is too great in amplitude for the A/D converter or (2) the DC background illumination is too great for the electrometer amplifier.

An Over-Voltage going to the A/D converter is indicated if this LED goes on or flashes. This will result in erroneous values of extinction. During periods of high turbulence, the gain control should be scaled downward until this indicator ceases to flash. A further scaling back of 10% is suggested.

If reducing the gain does not turn the indicator off or at least cause it to flash, then the DC level of the electrometer amplifier caused by excessive background illumination has exceeded 11 volts (near the saturation point of this amplifier stage) at some previous time. A smaller receiver telescope aperture or repositioning the transmitter to an area with a darker background is required to prevent this condition. To reset this indicator, the computer power must be turned off for at least 1 second.

TOG

Every time an integration period has ended this indicator will change state from OFF to ON or the reverse. This is a visual indication that an integration has been completed and the value outputted. This signal is connected to the rear output connector (pin 3 signal, pin 6 common).

OR

If the output to A1 exceeds the upper voltage limit of the D/A converter (10.000 volts), this indicator will turn on.

GAIN

The gain control potentiometer is set to the highest value possible without over-voltaging (OV indicator on) the A/D converter or over-ranging (OR indicator on) the D/A converter. Once set properly, the value shown on the counting dial is used in the calibration calculation (value of WG described in Section 6.0) to derive the calibration constant which is then dialed into the CAL. thumb switches. Typical values for the gain setting using the 58 mm telescope are listed in Table 5-2.

A gain potentiometer setting of less than 100 may cause appreciable errors in the final result because of the reduced precision of working with small numbers. Also, the linearity error of the gain potentiometer is more significant near the low end.

PATH LENGTH (km)	GAIN POT SETTING
2-3	200
3-5	300
5-8	500
8-12	700
12 up	999

Table 5-2. Typical Gain Pot Settings for Various Path Lengths using long path gain setting.

The OPTEC-1 SBC can be controlled by a remote terminal via a serial link. Pins 2 (TX), 3 (RX), and 7 (GND) of the DB25 serial connector could be used for such a link. Control of the RTL program may be interrupted with a carriage return or any keyboard character. The following is a list of the most important words for computer and instrument control.

BAUD	Sets serial port baud rate to 300, 1200, 9600.		
	Example:	9600 BAUD	\sets baud rate to 9600
			\default is 1200
YEAR	Sets real-time-clock chip to proper year.		
	Example:	91 YEAR	\sets year to 1991
MONTH	Sets real-time-clock chip to proper month		
	Example:	6 MONTH	\sets month to June
DAY	Sets real-time-clock chip to proper day.		
	Example:	15 DAY	\sets day to 15
HOUR	Sets real-time-clock chip to proper hour in military time.		
	Example:	16 HOUR	\sets hour to 4:00 PM
MINUTE	Sets real-time-clock chip to proper minute.		
	Example:	30 MINUTE	\sets minute to 30
TIME-PRINT	Prints time from real-time-clock in hh:mm:ss.dc format		
	Example:	TIME-PRINT	\computer will return 16:30:??.??
DATE-PRINT	Prints date from real-time-clock in yy:mm:dd format		
	Example:	DATE-PRINT	\computer will return 91:6:15
RUN	Starts the computer program. Same as a reset.		
TEST	This command tests the operation of the computer and various inputs and outputs.		

SECTION 6.0

CALIBRATION PROCEDURES

Calibration determines the raw reading of the transmitter that would be measured by the receiver if the optical sight path between the two units allowed 100% transmission, a vacuum like condition. The LPV-2 transmissometer must be calibrated as a unit. Each lamp will have its own calibration number for use with a specific transmissometer system. No component of the system, including lamps, may be interchanged with another transmissometer without re-calibration. The LPV-2 transmissometer may be calibrated using the two methods outlined below.

6.1 ND FILTER METHOD

The Model LPV-2 transmissometer is calibrated by a technique which negates the effect of the atmosphere. The calibration ND (neutral density) method is performed by moving the transmitter and receiver to a site which allows for a calibration path length between 0.25 and 0.50 km. This method assumes that the atmosphere is very clean with average extinctions of 0.01 to 0.06 km^{-1} and the air in the site path is well mixed. The transmission of the atmosphere at these distances is very close to 100% and can be ignored for the calculation of the calibration constant. See Table 5-1. A ND filter with transmission of approximately 1% is inserted into the photometer head of the receiver telescope. The exact transmission of this filter is measured at Optec and is indicated on the filter. The purpose of this filter is to attenuate the light amplitude by a know amount to keep the detector electrometer for saturating at these close distances.

The raw readings taken from the front panel display (the A1 switch on C) at this distance is then scaled to the working path length taking into account changes in receiver gain, shelter window transmissions and the ND filter transmission. The result is the calibration number which is dialed into the front panel thumb switches labeled CAL.

The calibration distance must be chosen as carefully as the working path length. Similar to the working path length, a site high off the ground to avoid thermal effects, away from smoke stacks, dirt roads or other sources of airborne particles and accessible by vehicle is definitely preferred. In picking the original working path site, the calibration path should be kept in mind. It is occasionally possible to select a site for the receiver that allows a clear view of a desirable calibration path as well. Moving the transmitter to a closer position is far easier and safer than moving the receiver unit.

Once the calibration site has been selected, the path length must be measured to an accuracy of 0.1%. This is usually only possible with a laser range finder which can determine distance to about 1 centimeter or better. A measuring tape is usable only on paths over a flat ground surface. It is possible to avoid the thermal effects of being so near the ground by doing the calibration an hour or two after sunrise or before sunset or on cloudy days. If the calibration path must be near the ground, a site off the road and over grass is preferred.

A 0.3 km calibration path length is recommended, however any path length from 0.25 to 0.50 km will work nearly as well. At 0.3 km the effect of atmospheric extinction is negligible usually being less than 0.05 km^{-1} (1.5% or less transmission drop) at most Western sites in the United States. In addition, this path length will give a high signal at a low gain setting with the supplied calibration ND filter.

Path Length (km)	Extinction km^{-1}						
	.01	.02	.03	.04	0.5	.06	.10
0.10	.999	.998	.997	.996	.995	.994	.990
0.20	.998	.996	.994	.992	.990	.988	.980
0.30*	.997	.994	.991	.988	.985	.982	.970
0.40	.996	.992	.988	.984	.980	.976	.961
0.50	.995	.990	.985	.980	.975	.970	.951
0.60	.994	.988	.982	.976	.970	.965	.942

* ideal calibration path length for instruments used at Western sites.

Table 5-1. Atmospheric Transmittances for Various Calibration Path Lengths and Extinction Values.

In order to prevent the transmitter from saturating the photometer electronics at the short calibration distance, a precision ND filter is placed in the photometer head of receiver telescope. This filter precisely reduces the incoming light from the transmitter by a factor of approximately 100 (exact transmission is indicated on the filter and is within the range of 1 to 2%. At a gain setting of 200, the expected raw readings with 1 minute integration is around 700. The A1 output will over range at 1000 requiring an adjustment of gain or path length to keep the reading around 700 for maximum accuracy. It is recommended that a gain setting less than 125 not be used for calibration.

Placing the TEST switch on the transmitter to the ON position will run the transmitter in a continuous mode until switched off. The internal clock with battery backup will not be effected by the TEST mode but should cycle the unit properly after calibration without resetting the clock. Since the low battery circuitry will be disabled, it is up to the user to make sure that an adequate supply voltage is available during the calibration procedure.

At least 10 consecutive 1 minute integrations should be recorded. Typically, the scatter of the readings should not exceed ±3 from the average value which, as mentioned previously, should be around 700 for a 0.3 km path. Reading sequences which show scatter greater than 3 are indicative of ground thermal problems or gross changes of transparency due to rain, snow or windblown dust and a successful calibration is in doubt.

After computing the mean value, the following formula is used to calculate the calibration number:

$$\text{CAL.} = (CP/WP)^2 \times (WG/CG) \times (1/FT) \times WT \times (1/T) \times CR$$

where,

CP	= calibration path length, 0.1000 to 0.5000km
WP	= working path length, 2.00 to 29.99 km
CG	= calibration gain, 100.0 to 999.9
WG	= working gain, 100.0 to 999.9
FT	= calibration filter transmission
WT	= total shelter(s) window transmittance. If windows are used on both ends, multiply their transmittances together. Typical value for two windows is 0.846
T	= estimated or measured atmospheric transmittance for calibration path, 0.950 to 0.996 typical
CR	= average of 10 readings at the calibration path

In Appendix A, a sample calibration report form is shown. This report form may be copied and used as is or modified for the user's specific needs. Considering the complexity of the calibration, a programmed approach to calibration with trained technicians is recommended.

6.3 DIFFERENTIAL PATH METHOD

For sites where the extinction exceeds 0.10 km-1, the calibration technique and calculation must take into account the atmospheric transmission over the short calibration path length. This is done by using a differential method which in effect measures the atmospheric extinction between the calibration point and the base point. The base point or base length does not have to be the operational working path length but the process is easier if it is. Assuming that conditions are homogeneous throughout the site during calibration, a calibration number is calculated and entered into the thumb wheel switch marked CALIB. Usually all eastern United States installations must use this method of calibration. Since these sites have path lengths of less than 3 km, the receiver low gain setting (gain = 2) is normally used. The ND filter is not used for this method.

The calibration site/length must be chosen as carefully as the working path length. Similar to the working path length, a site high off the ground to avoid thermal effects, away from smoke stacks, dirt roads or other sources of airborne particles and accessible by vehicle is definitely preferred. In picking the original working path site, the calibration path should be kept in mind. It is occasionally possible to select a site for the receiver that allows a clear view of a desirable calibration path as well. Moving the transmitter to a closer position is far easier and safer than moving the receiver unit.

Once the calibration site has been selected, the path must be measured to an accuracy of 0.1%. This is usually only possible with a laser range finder which can determine distance to about 1 centimeter or better. A measuring tape is usable only on paths over a flat ground surface. It is possible to avoid the thermal effects of being so near the ground by doing the calibration an hour or two after sunrise or before sunset or on cloudy days. If the calibration path must be near the ground, a site off the road and over grass is preferred.

A calibration path length of 1/3 the base or working path length is recommended. For example: If the working path length is 2 km, a 0.7 km calibration path would work well. This calibration-base length ratio will result in a signal ratio of about 10/1 given a constant gain setting. Considering the lower gain setting when the instrument is moved to the calibration point and the limited dynamic range of the instrument output, a suitable signal-to-noise ratio is obtainable for the calibration calculation if this 1/3 calibration-base ratio is maintained. Of course, the actual calibration path length may have to deviate from this value depending on site constraints. A calibration path length shorter than 0.12 km (400 ft.) should be avoided due to possible saturation of the receiver photometer detector.

Do not use a calibration gain setting less than 125. A value of 150 to 250 would give best results if the receiver output is not over ranged, that is, the A1 output does not exceed 10.000 volts. Adjust the calibration path length or the output of the transmitter (lamp voltage) to obtain a proper receiver output reading.

Placing the TEST switch on the transmitter to the ON position will run the transmitter in a continuous mode until switched off. The internal clock with battery backup will not be effected by the TEST mode but should cycle the unit properly after calibration without resetting the clock. Since the low battery circuitry will be disabled, it is up to the user to make sure that an adequate supply voltage is available during the calibration procedure.

At least 10 consecutive 1 minute integrations should be recorded at each point. Start with the base or working path point, move to the calibration point and then finish by moving back to the base or working path point to complete the data taking. Typically, the scatter or standard deviation of the readings should not exceed 1% from the average value. Scatter greater than this might be indicative of ground thermal problems or gross changes of transparency due to rain, snow or windblown dust and a successful calibration is in doubt.

After computing the mean values for each point, the following formula is used to calculate the site extinction.

$$B = - \frac{\ln\left(\frac{WR \times WP^2 \times CG}{CR \times CP^2 \times WG}\right)}{WP - CP}$$

where,

CP	= calibration path distance
WP	= base/working path
CR	= calibration path reading
WR	= base/working path reading
CG	= calibration gain
WG	= base/working gain

once B is known, the transmission for the base or working path may be calculated using,

$$T = e^{-B \times WP}$$

and the calibration number is

$$CAL = \frac{WR}{T}$$

where WR is the raw reading at the working path distance.

A complete derivation of the equations used for the differential path method is provided in Appendix B.

SECTION 7.0

SPECIFICATIONS

7.1 GENERAL OPERATING PERFORMANCE

EXTINCTION RANGE		0.010 to 1.000 km^{-1}
RESOLUTION		
	Extinction (B)	0.001 km^{-1}
	Visual Range (VR)	1 km
ACCURACY		
	Transmission	±3%
	Extinction	±0.003 km^{-1} for 10 km working path and 0.010 nominal extinction value
MEASURED WAVELENGTH		
	Filter	550 ±2 nm, 10 ±1 nm bandwidth at ½ power points
OUTPUT, PANEL		
	A1	Extinction (km^{-1}) to .001 Visual Range (km) to 1 km Instrument values to 0.01 V
OUTPUT, ANALOG		
	A1 (Extinction)	0 to 10 V, 0.01 V = 0.001 km^{-1}
	A1 (Visual Range)	0 to 10 V, 0.01 V = 1 km
	A1 (Calibration)	0 to 10 V raw instrument value
	A2 (Chart Rec.)	0 to 10 V raw instrument value
	A2 (Std. Dev)	standard deviation (N-1 samples) of the raw 1 minute instrument values
OUTPUT, SERIAL		
	RS-232	8 data bits, 1 stop bit, no parity 300, 1200, 9600 (default) baud
POWER SUPPLY		
	Auto battery	12-14 volt
OPERATING TEMPERATURE		-20° TO +45° C

7.2 TRANSMITTER SPECIFICATIONS

TELESCOPE		
	Clear aperture	58.0 mm
	Focal length	350 mm
	Lens type	coated and cemented achromat
BEAM		
	Diameter	1 degree, projected cone of light
	Feedback Dia.	0.17 degree as referenced to the projected cone and centered within 1 degree cone
	Uniformity	5% over 1 deg. cone 1% over 0.17 deg. center cone
FEEDBACK FILTER		
	Center Wavelength	550 ±2 nm
	Bandwidth	10 ±1 nm
LAMP		
	Type	6 volt, 15 watt special prefocused tungsten filament lamp mounted in machined base
	Regulation	constant to ±1.5%
	Life	500 hrs. continuous at 6.0 volts
CHOPPER FREQUENCY		78.1250 ±.0001 Hz
CLOCK		
	Cycle times	20 minutes, 1, 2, and 4 hrs.
	Lamp-on times	2, 16, 32, 64 minutes and continuous
	Freq. Tolerance	±5ppm
POWER SUPPLY		
	Voltage, input	10.2 to 15 volts DC
	Power (lamp off)	0.12 watt at 12.5 volt input
	Power (lamp on)	34 watts at 12.5 volt input
SIZE		
	Projector	18 x 4 x 6 inches (LxWxH)
	Controller	9.5 x 5.4 x 1.9 inches
WEIGHT		
	Projector	4 lbs
	Controller	2 lbs

7.3 RECEIVER SPECIFICATIONS

TELESCOPE	
Clear aperture	58.0 mm
Focal length	350 mm
Lens type	coated and cemented achromat
PHOTOMETER HEAD	
Detector	silicon PIN photodiode
Detector NEP	8 x 10^{-16} W/û$_{\mathrm{Hz}}$
Active Aperture	0.75 mm
Filter	550 nm with 10 nm bandwidth
DETECTOR/ELECTROMETER	
Type	current-to-voltage
Gain	4×10^{9}
Bandwidth	DC to 500 Hz
Noise	5 mv p-p DC to 500 Hz
Gain T-C	-200 ppm/°C
BANDPASS AMPLIFIER	
Center frequency	78.125 ± 0.100 Hz
Q	32
A/D INPUT AMPLIFIER	
Gain	30 (long path) 2 (short path jumper selected)
Bandwidth	1 to 1000 Hz
Gain T-C	± 50 ppm/C
SIGNAL GAIN CONTROL	
Turns	10
Linearity	0.25%
Accuracy	0.5%
COMPUTER	
Processor	64180 from Hitachi
Memory	32K RAM, 32K ROM, all CMOS
I/O	64 lines bi-directional
Real-time Clock	6.144 Mhz clock rate
A/D	12 bit, 15µS conversion, all CMOS
D/A	12 bit, 0-10 V output, 2-channel, CMOS

OPERATING PROGRAM	Custom version of RTL (relocatable threaded language) a variation of Forth resident on ROM

INPUT CONTROLS

power	On-off toggle switch
gain	10-turn pot with digital readout
A1	3-pos. switch (C,B,VR)
A2	2-pos. switch (SD,CR)
cycle time	5-pos. switch (C,20M,1H,2H,4H)
integration time	4-pos. switch (1,10,30,60 M)
path length	4-digit BCD switch
calibration	3-digit BCD switch

DISPLAY

AI	3 1/2 digit panel meter
OV	A/D over voltage, LED lamp
OR	D/A over range, LED lamp
TOG	Changes state after integ., LED lamp

POWER SUPPLY

Input voltage	9 - 15 V DC, reverse voltage protected
Input current	400 ma at 12.5 V DC input voltage
Output voltages	+5, +15, -15

SIZE

Telescope	12.8 x 2.9 inches (L x Dia.)
Computer	14 x 12 x 9.5 inches (L x W x H)
Photometer Head	5 X 2.5 x 3.5 inches (L x W x H)

WEIGHT

Telescope	6 lbs
Computer	7 lbs
Photometer Head	2 lbs

APPENDIX A

LPV CALIBRATION DATA SHEET

Location:____ Date: _______________

Instrument ID:_________________________ Technician:__________________________

Weather/Comments:____

==
WORKING SETTINGS

Working Path (WP) _______________km Integration Time: 1 10 30 60

Working Gain (WG) _______________ Cycle Time: C 20M 1H 2H 4H

A1 Setting: C B VR

A2 Setting: SD CR

Shelter Windows Transmittances (WT)
Receiver . Transmitter _______._______ Previous Calib. Number _________

==
CALIBRATION SETTINGS

Calib. Path (CP) _______________km Receiver Through Glass: Y N

Calib. Gain (CG) _______________ Transmitter Through Glass: Y N

ND Filter Transmission: ___.__%

==
EXTINCTION CONDITION BEFORE AND AFTER CALIBRATION

	TIME	B_{ext}			TIME	B_{ext}	
Before:	_______	_____	M E	After:	_______	_____	M E

(M measured or E estimated)

Atmospheric transmittance at time of calibration (T):___________

(calculate T using $e^{-(B_{ext} \times CP)}$ or use Table 6-1)

CALIBRATION READINGS

Start time: ___________ (spare data area)

	Reading	Toggle	Reading	Toggle
1	_________	_______	_________	_______
2	_________	_______	_________	_______
3	_________	_______	_________	_______
4	_________	_______	_________	_______
5	_________	_______	_________	_______
6	_________	_______	_________	_______
7	_________	_______	_________	_______
8	_________	_______	_________	_______
9	_________	_______	_________	_______
10	_________	_______	_________	_______
Total	___________		___________	

Average (CR) ___________

==

CALIBRATION NUMBER CALCULATION

Calib.#____________ = $(CP/WP)^2 \times (WG/CG) \times (1/FT) \times WT \times (1/T) \times CR$

Note: modify WT if calibration is done through a shelter window

==

ADDITIONAL COMMENTS

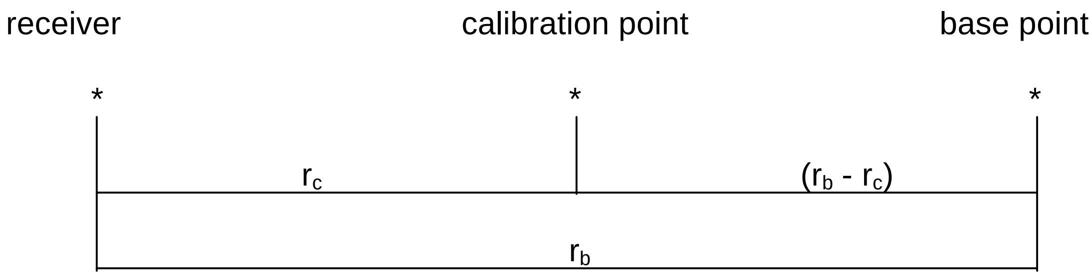
____

____

APPENDIX B

DIFFERENTIAL PATH CALIBRATION METHOD DERIVATION

The following is a complete derivation of the equations used in computing the calibration constant using the differential path method.



where,

r_c = calibration path distance
r_b = working path
E_c = calibration path reading
E_b = working path reading

basic principals

1) $T_c = e^{-Br_c}$ calibration path transmission

2) $T_b = e^{-Br_b}$ working path transmission

3) $T_{bc} = e^{-B(r_b - r_c)}$ diff. path transmission

where B is the extinction coefficient and is assumed to be constant through the entire path r_b.

The inverse of equations 1), 2), and 3) are:

4) $\ln T_c = -Br_c$

5) $\ln T_b = -Br_b$

6) $\ln T_{bc} = -B(r_b - r_c) = -Br_b + Br_c$

note that

7) $\ln T_{bc} = \ln T_b - \ln T_c$

or,

8) $\ln T_{bc} = \ln \left(\frac{T_b}{T_c}\right)$

In a vacuum, the output of the transmitter unit as a function of distance is equal to:

9) $E = \frac{I_0}{r^2}$

where E can be considered the raw reading of the receiver unit and I_0 the transmitter output at r = 0.

In an atmosphere, the above equation can be written as:

10) $E = \frac{I_0}{r^2} \cdot T$

For the calibration and working path distances, equation (10) can be written as :

11) $E_b = \frac{I_0}{r_b^2} \cdot T_b$

12) $E_c = \frac{I_0}{r_c^2} \cdot T_c$

where E_b and E_c are the raw readings at the working and calibration path distances.

Solve for T,

$E_b r_b^2$

13) $$T_b = \frac{\ }{I_0}$$

14) $$T_c = \frac{E_c r_c^2}{I_0}$$

substitute (13) and (14) into equation (8),

15) $$\ln T_{bc} = \ln\left(\frac{\left(\frac{E_b r_b^2}{I_0}\right)}{\left(\frac{E_c r_c^2}{I_0}\right)}\right)$$

16) $$\ln T_{bc} = \ln\left(\frac{E_b r_b^2}{E_c r_c^2}\right)$$

Substitute (16) into equation (6) and solve for B.

17) $$B = -\frac{\ln\left(\frac{E_b r_b^2}{E_c r_c^2}\right)}{r_b - r_c}$$

once B is known, the transmission for any path can be calculated using,

18) $$T = e^{-Br}$$

and the calibration number is

19) $$C = \frac{E}{T}$$

where E is the raw reading at the working path distance.

If gain adjustments are made at the calibration and working path distances, equation (17) is modified as :

20) $$B = -\frac{\ln\left(\frac{E_b r_b^2 G_c}{E_c r_c^2 G_b}\right)}{r_b - r_c}$$

where G_c = calibration gain and G_b = working gain.

APPENDIX C

ENVIRONMENTAL ENCLOSURE

Either the transmitter projector with control unit or the photometer head with the telescope can be installed in the environmental enclosure. The enclosure top plate is removable by loosening the four hand knobs visible on top of the enclosure, rotate the two knobs which go through slots to one side free of the top plate and then swinging the top plate open. A long handle screwdriver is needed to secure either the transmitter projector or receiver telescope to the bottom of the enclosure.

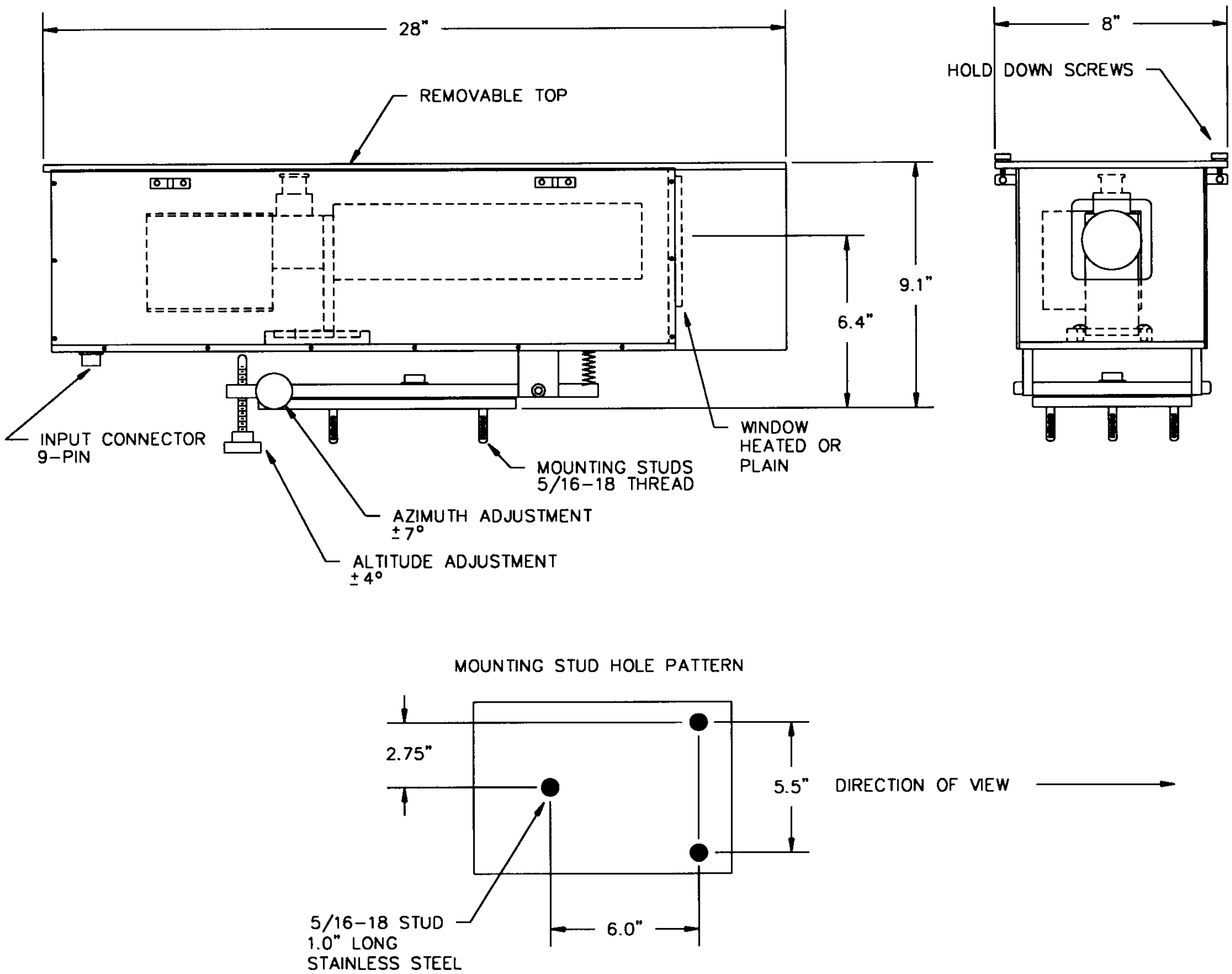
A short 9-pin control cable is used to connect the transmitter projector to the control unit. The control unit is near the front of the enclosure on its side with the TEST LED visible and the connectors facing the rear of the enclosure. Small rubber bumpers are mounted on the enclosure to support the control unit in this resting position. Two cable connectors are available for power - one for the control unit and the other for the heated window option. Secure the L bracket securely to the foot mount in the center of the enclosure by means of the two pan head screws. Make sure the telescope view is not blocked by the window or stray cable.

The receiver photometer head with small telescope is mounted in the enclosure by means of placing the L bracket within the foot mount located near the center of the enclosure and securing the two pan head machine screws. Make sure the telescope view is not blocked by the window or stray cables. Connect the available 9-pin connector to the photometer cable.

Successful operation of the transmissometer requires precise alignment of both the receiver and transmitter telescopes. Because of the critical alignment of these instruments, great care should be exercised in construction of the mount for the environment enclosures to insure that this alignment can be obtained and held even during diurnal temperature changes and wind loading. It is recommended that our permanent mounting pier (stock no. 86676) be used to hold the enclosure. Since the enclosure with instrument weighs approximately 33 lbs, the mounting plate and/or structure should be made from thick stock - 3/8 to 1/2" aluminum or steel plate.

The base of the enclosure allows for a small amount of azimuth and altitude adjustment. The maximum adjustment range for azimuth is 14° (±7° from center) and 8° (±4° from horizontal) for altitude. This small adjustment range requires some care in placing the pier or mounting plate in order that, once the enclosure is roughly mounted on the pier or plate, alignment can be accomplished by turning the fine adjustment screws within this limited range. See Figure C-1 for mounting and connecting details.

Clean the enclosure windows with alcohol only. Commercial window cleans usually have some kind of chemical polish which will change the transmission of the glass by an unknow amount.



CONNECTOR WIRING		
PIN	FUNCTION	INSTRUMENT
1	−15 V	RECEIVER
2	+15 V	RECEIVER
3	SIGNAL	RECEIVER
4	NC	
5	NC	
6	SIGNAL GND.	RECEIVER
7	13.8 V RETURN	TRANSMITTER OR RECEIVER
8	13.8 V DC	TRANSMITTER OR RECEIVER
9	SHIELD	RECEIVER

Figure C-1. Environmental Enclosure Details

APPENDIX D

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 12 all weather steel enclosure which measures 10 x 8 x 6 inches. Mounting and connecting details are shown in Figure E-1. The unit will supply regulated 13.8 ±0.3 V DC at up to7.5 amps to the LPV receiver, transmitter and heated window units.

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, 16 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 12 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 16 or 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. Depending on current requirements, cord lengths up to 100 feet are usually accomplished without problems. Distance 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.

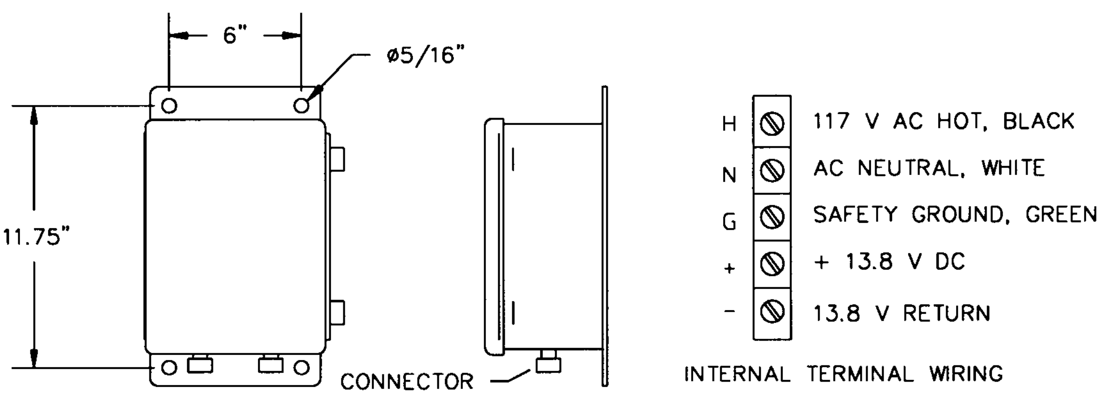


Figure D-1. 13.8 V DC Power Supply Mounting and Connecting Details

APPENDIX E

CONNECTOR PIN DEFINITIONS

TRANSMITTER

PIN #	DESCRIPTION
1	NC
2	+10.2 to 15 V DC
3	Power Return
4	NC

4-Pin Power Input Connector

PIN #	DESCRIPTION
1	-6.8 V
2	+6.8 V
3	Lamp Feedback Signal
4	Positive Lamp Voltage
5	Lamp Return
6	Signal Common
7	Motor
8	Motor
9	Shield, Case Ground

9-pin Control Connector

RECEIVER

PIN #	DESCRIPTION
1	NC
2	+10.2 to15 V DC
3	Power Return
4	NC

4-pin Power Input Connector

PIN #	DESCRIPTION
1	Analog 1 Signal
2	Analog 2 Signal
3	Toggle Signal
4	Analog 1 Common
5	Analog 2 Common
6	Digital Common
7	NC
8	NC
9	Shield, Case Ground

9-pin Output Connector

PIN #	DESCRIPTION
1	-15.0 V
2	+15.0 V
3	Photometer Signal
4	NC
5	NC
6	Signal Common
7	13.8 V (Enclosure Option)
8	13.8 V Return
9	Shield, Case Ground

9-pin Photometer Connector

PIN #	DESCRIPTION
1	Shield, Case Ground
2	TX
3	RX
4	NC
5	NC
6	NC
7	Ground
8 - 25	NC

25-pin RS-232 Interface Connector

APPENDIX F

WIRING AND CIRCUIT DIAGRAMS

(See Attached Sheets)

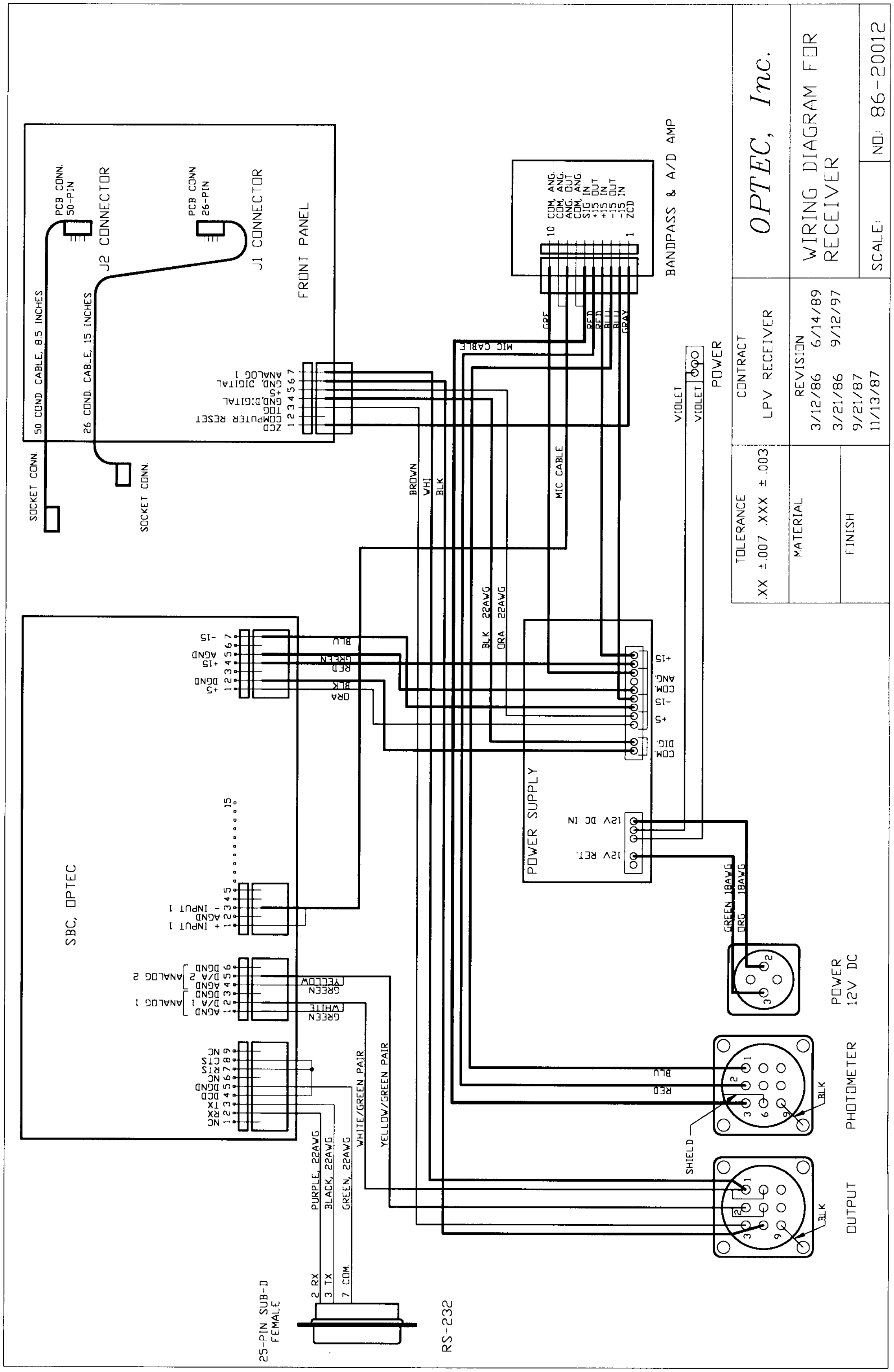


Figure F-1. Wiring Diagram for Receiver.

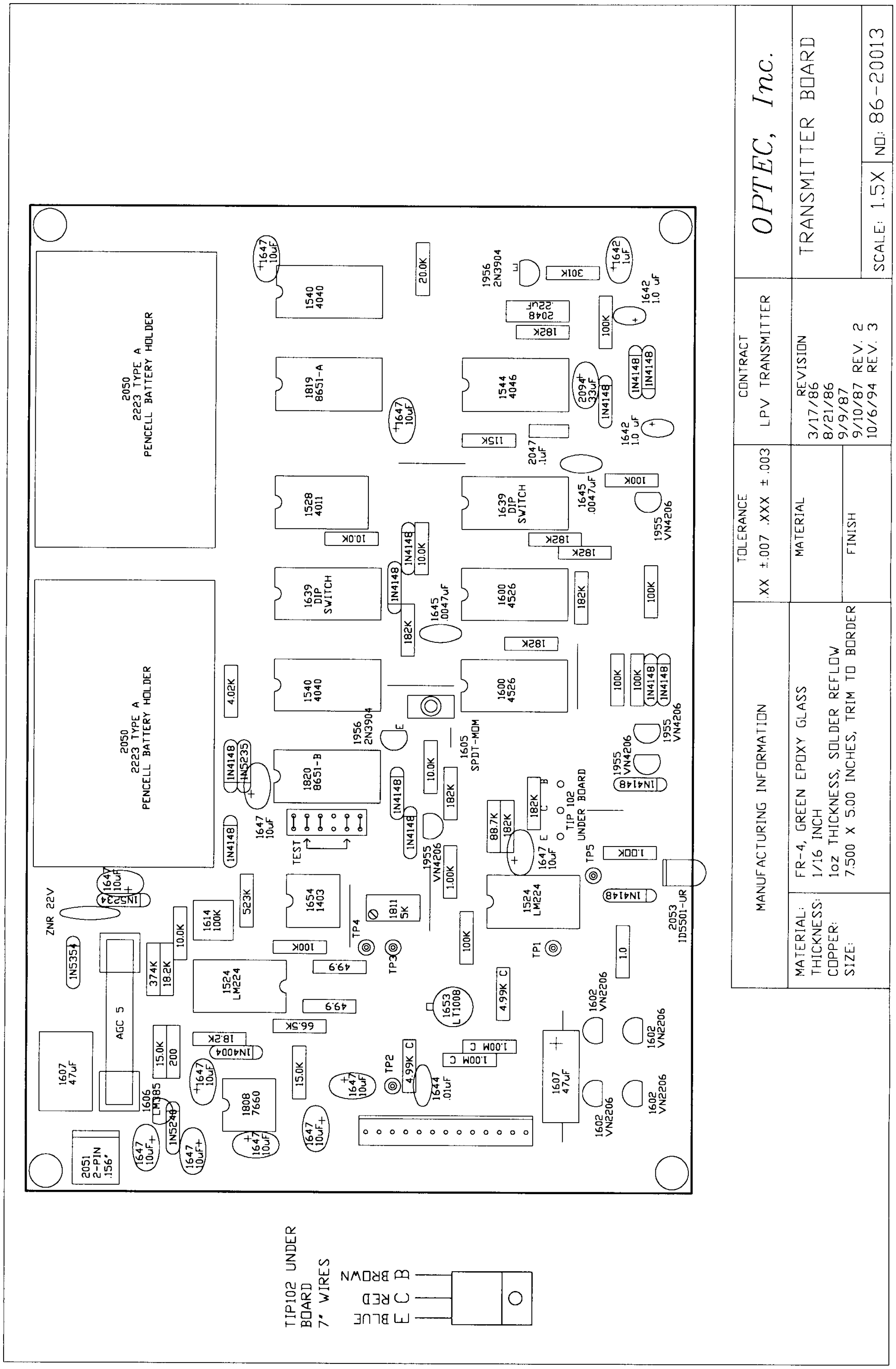


Figure F-2. Transmitter Board Layout.

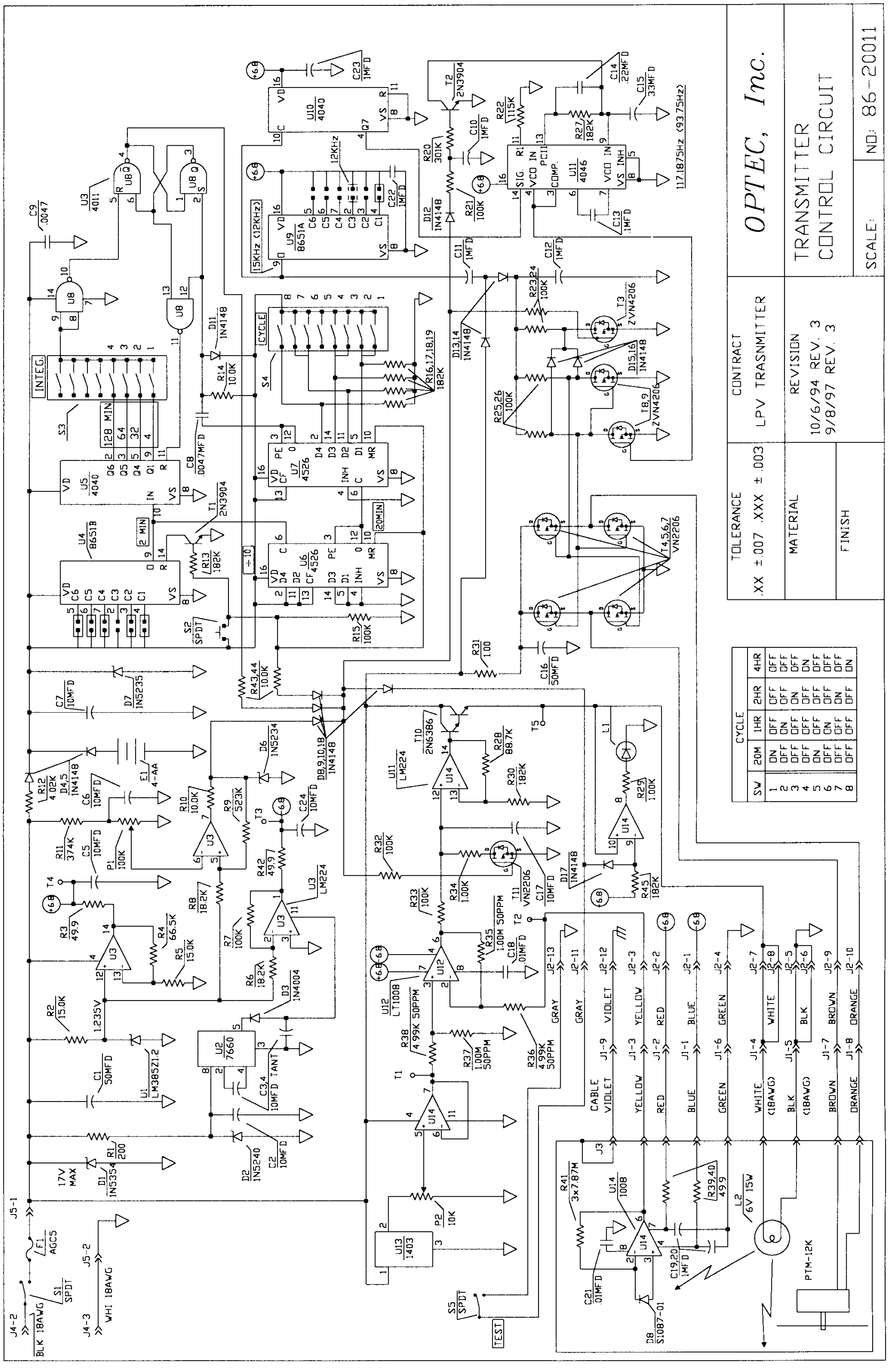


Figure F-3. Transmitter Control Circuit Diagram.

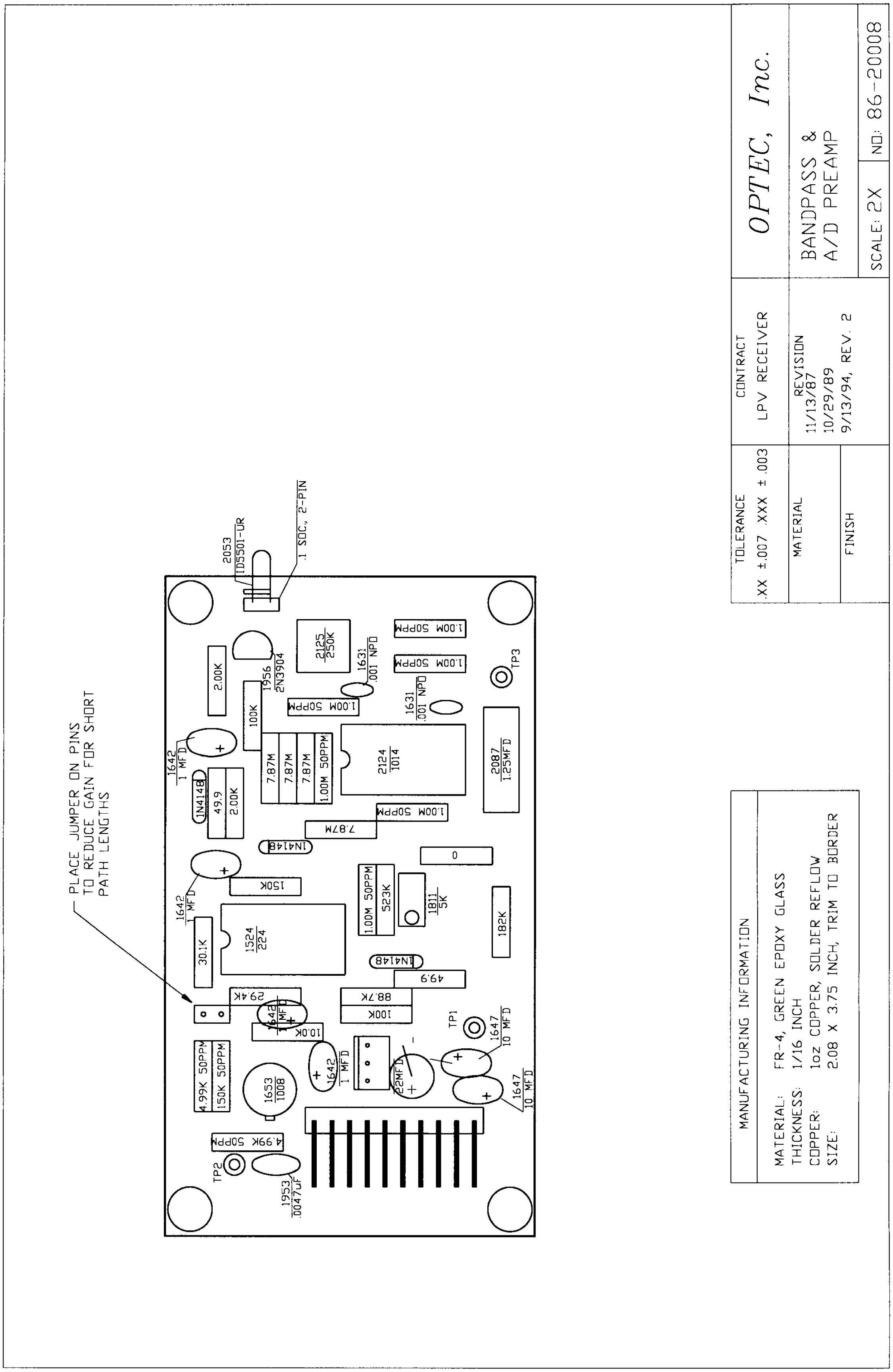


Figure F-4. Bandpass & A/D Preamp Board Layout.

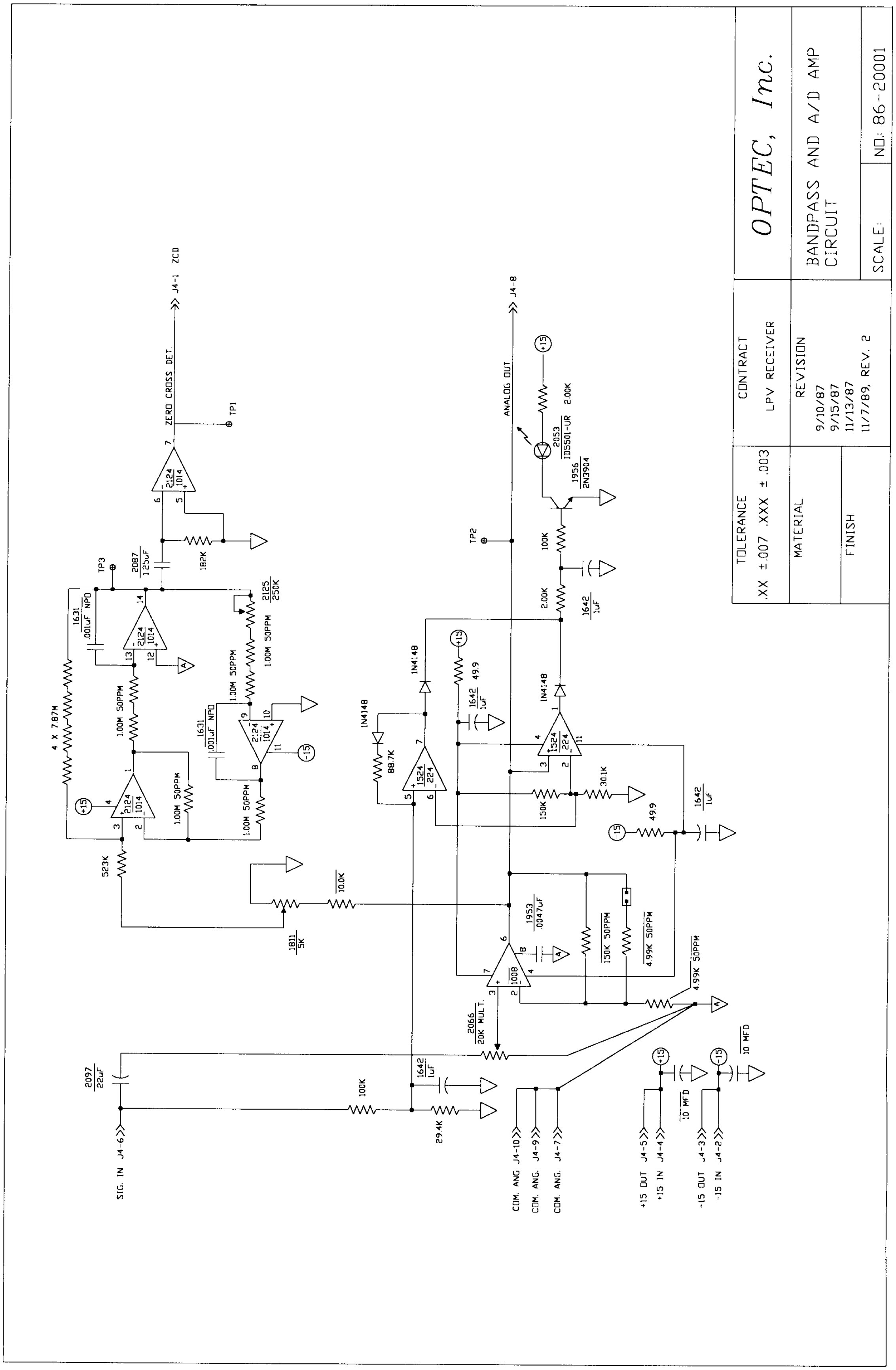


Figure F-5. Bandpass & A/D Preamp Circuit Diagram.

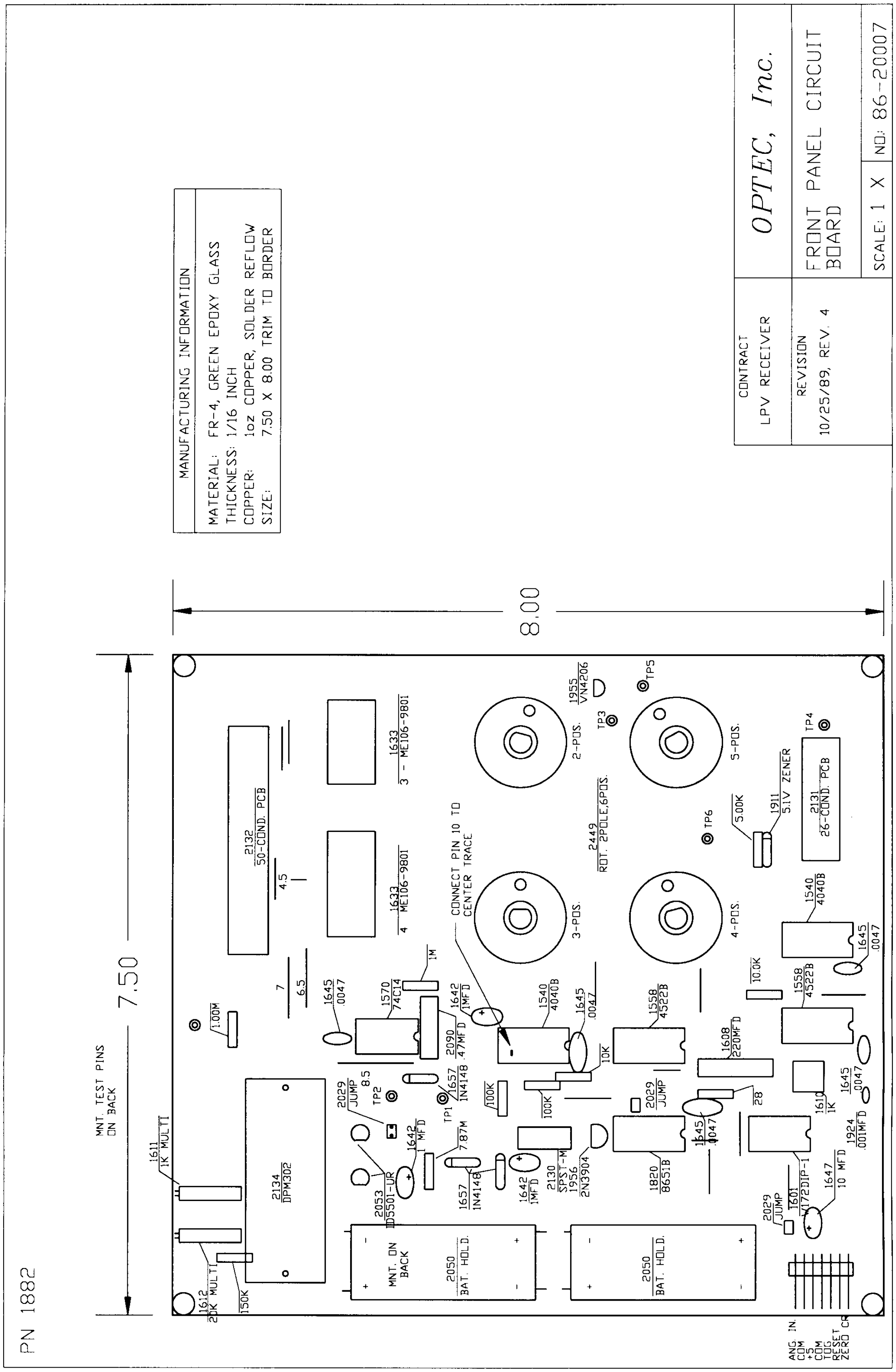


Figure F-6. Front Panel Circuit Board Layout.

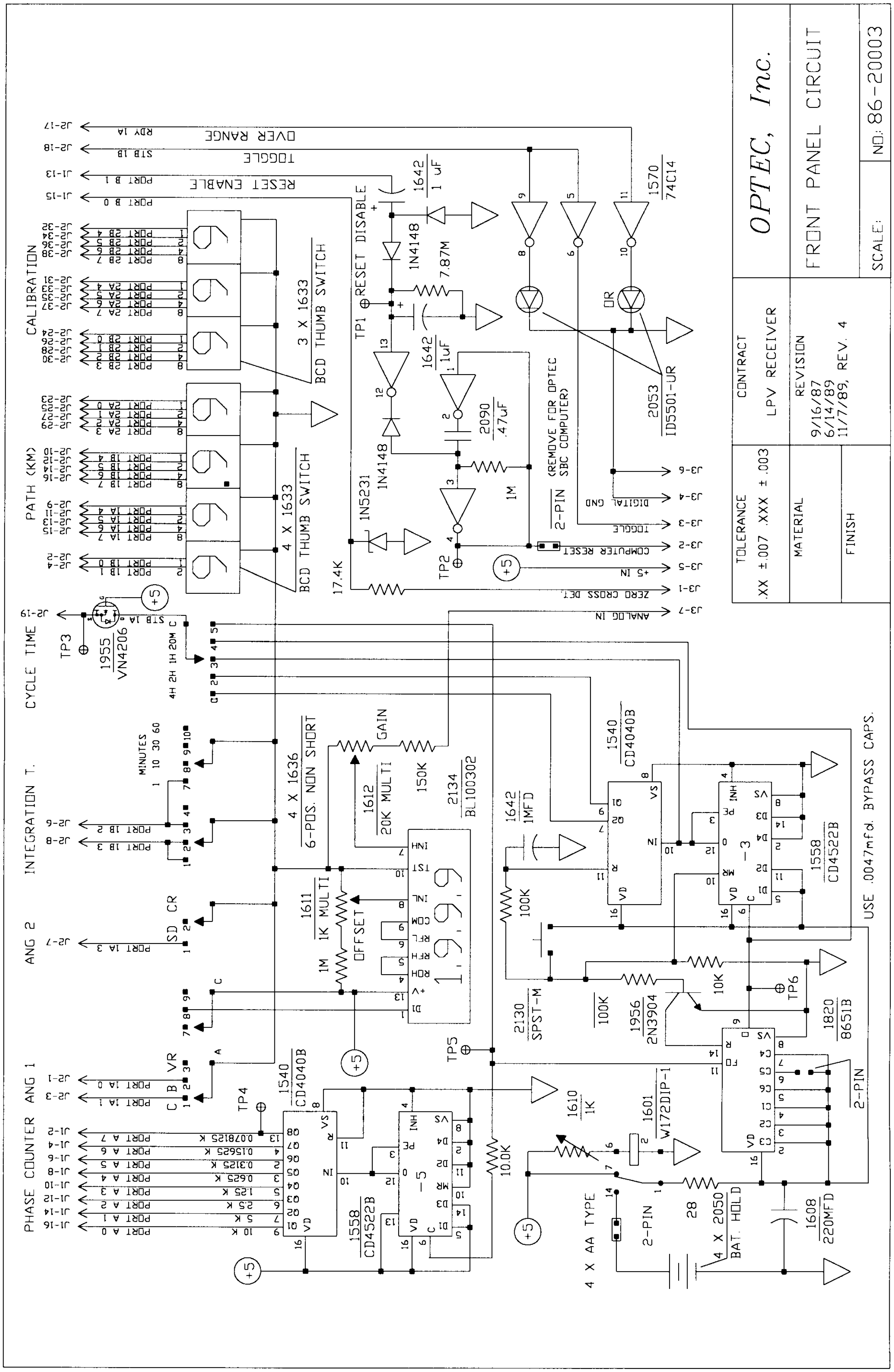


Figure F-7. Front Panel Circuit Diagram.