MODEL LPV-3 &
MODEL LPV-4

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 Optec LPV Long Path Visibility Transmissometer consists of a constant output light source transmitter and a computer controlled photometer receiver. The irradiance from the LPV-3 transmitter at a wavelength of 550nm or LPV-4 transmitter at a wavelength of 532 nm can be measured to a high degree of accuracy both day and night, and over a path length of up to 20 km. Path length is chosen based on the expected extinction values to be measured. A long path of greater than 3 km is used to measure extinction near Rayleigh and a short path of less than 3 km can be used to measure very hazy or near foggy conditions. Both the receiver and transmitter operate from a 13.8-volt battery source such as a 12-volt deep cycle or marine battery and use very little power. The receiver consumes only 4 watts of power. The LPV-3 transmitter uses approximately 20 watts of power when used in the middle power setting and the new LPV-4 transmitter consumes less then 1 watt when used at the same setting.

The output results can be read as a voltage proportional to extinction or visual range. In addition, a separate serial data interface (COM port) outputs a string of data items in ASCII format that includes all the calculated extinction values, visual range, raw instrument values along with a time stamp. The units can operate for long periods of time unattended in a continuous or timed cycle mode. The self-resetting and backup systems ensure continued operation even after power blackouts or computer lockup. Both units can be synchronized, programmed and calibrated at the home station and installed in the field ready for operation.

The Model LPV-3 Transmitter is an upgraded version of the Model LPV-2 Transmitter, which was discontinued October 2003. Instead of two units connected by a cable, the LPV-3 transmitter is contained in one unit with only a low voltage power cable needed. An improved user interface using two buttons with a 4-character display allows for easy control over the expanded LPV-3 features.

The Model LPV-4 Transmitter with green LED was introduced in 2011 and is an improved version of the LPV-3 Transmitter. Use of an LED in the transmitter allows an extended lamp life of approximately 50,000 hours of operation. Calibrations need only be done annually. Operating wavelength for this unit is set at 532nm compared to 550nm for the LPV-3 Transmitter.

As of September 2004, the LPV-2 Receiver has been upgraded to the Model LPV-3 Receiver. The large computer control box with thumb switches, rotary switch and analog display have all been replaced with a much smaller unit featuring a two-line forty character digital matrix display. All configuration settings are now selectable through a 4-button interface and simple menu system. The LPV-2 Receiver computer controller can be replaced directly with the LPV-3 Receiver controller with no change in cables or operational methods. An improved PC interface allows for complete configuration of the LPV-3 Receiver, testing certain important functions and data logging.

SECTION 2.0

LPV-3 TUNGSTEN LAMP TRANSMITTER THEORY OF OPERATION

One of the major design requirements of the transmitter projector is that it operates with the low voltage (10.6 to 15 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 1500-watt lamp. Figure 2-1 shows a functional diagram of the transmitter projector system. This LPV-3 model is an upgraded version of the LPV-2 transmitter that was designed in the 1980s. The LPV-3 model has the same functions as the LPV-2 but with improved accuracy, lower power and more flexible user interface.

2.1 LAMP AND LAMP REGULATION

A pulse width modulation method is used to power the lamp. Use of this method allows for very little power to be wasted in the lamp drive circuitry thereby extending battery life and reducing heat generated in the projector unit. The LPV-2 transmitter used a linear design which wasted as much power in the control circuit as in the lamp.

The tungsten lamp's nominal effective operating voltage is 6 in the MED setting and it uses 14 watts of power. It is critically pre-focused 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 MED setting is approximately 500 hours of operation. Lamp output is adjustable by changing the applied power to it, which also affects lamp life greatly. For short working path lengths of 1 to 3 km, the lamp power could be set to the LOW (12 watts of power) setting with the resulting decrease in light output of 50% but an increase in lamp life by a factor of 10. Conversely, setting the lamp power to the HI (16 watts of power) setting will increase lamp output by 40% and decrease life by 70%. Lamp power settings are selected via the 2-button interface. See Fig. 2-2 which shows effective lamp voltage vs. lamp power.

As the lamp ages, the applied power will increase to keep the output constant. When the system detects that the power has exceeded its upper limits, an ER=2 will be displayed on the DRO indicating the need for lamp replacement. In addition, the unit will shut down the lamp and chopper.

To maintain the lamp output constant at better than 1%, an optical feedback method is used. The feedback detector views an area of the chopper that interrupts the beam going to the projector optics. The chopper is coated with a flat white diffuse surface which scatters light very effectively. 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 10-bit A/D converter port of the PIC microcontroller. From there, the measured output from the lamp is compared in preset values for the LOW, MED and HI settings and the output to the lamp drive circuit is altered accordingly.

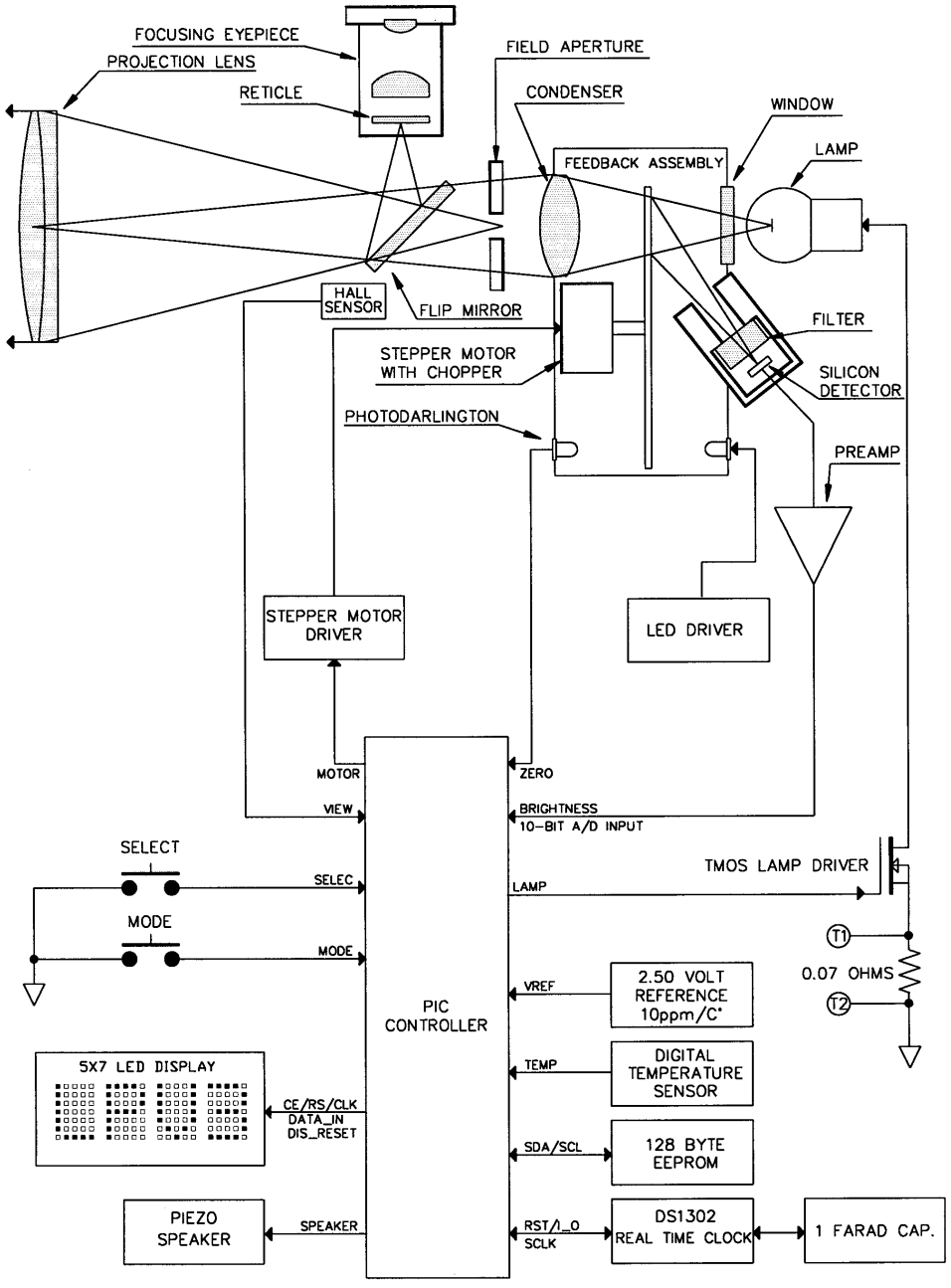


Figure 2-1. LPV-3 Transmitter Function Diagram.

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 optics and coated chopper blade

are enclosed in a 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 smaller 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 4-blade chopper is rotated at the exact speed of 19.53125 revolutions per second by a low voltage stepper motor. To ensure reliable startup of the motor, the drive pulses are slowly ramped up to the proper frequency before locking onto the set frequency of 78.125 Hz. It takes about 12 seconds for the motor to achieve its final frequency, at which time the lamp will turn on.

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 and chopper turn on) are 20 minutes, and 1, 2, and 4 hours. Cycle times are selected via the 2-button interface using the CYCL menu selection. The length of time the chopper and lamp will run (integration time) at the start of each new cycle is selectable between 2, 16, 32 and 64 minutes. These times are selected using the INTG menu selection. It is also possible to run the lamp and chopper continuously by setting the cycle time to CONT (continuous) in the CYCL menu selection.

When a new cycle starts the chopper motor is turned on first and the lamp second. The power to the lamp is increased gradually over a period of about 3 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 voltage comparator causing the circuit to shut down 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.

From the start of the cycle time, it takes approximately 15 seconds for both the lamp and chopper to reach stable operating levels.

2.5 POWER SUPPLY

The input battery voltage can range from 10.6 to 15 volts DC. If the voltage drops to 10.5, an ER=1 is displayed on the DRO and the unit will shut down. Internally, this input voltage is converted and regulated to +6.0 and -6.0 volts for the analog control portions of the circuit and +5.0 volts for the digital portion. 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 1.7 amps with a 13.8 volt battery power supply.

In case of battery power interruption, the DS1302 cycle and integration timer continues running by using an on-board power backup consisting of a 1 Farad capacitor. At an ambient temperature of around 25 degrees Celsius, this capacitor will provide enough power for approximately 45 days of operation. An ER=4 error code on the DRO indicates that the timer

needs to be reset as described in Section 5. This condition is usually due to the lack of charge on the capacitor. When adequate 12-volt battery power is available, the capacitor is charged back to full capacity in a few hours.

With the lamp on and the unit housed in an air tight environmental chamber in a warm climate, the critical electronic circuitry could possibly get hot enough to potentially cause circuit failure. To prevent this, an onboard temperature sensor monitors the operating temperature of the air around the main circuit board. At 60° C the microcomputer will suppress initiating a new cycle, display an ER=5, and will wait until the temperature cools. Of course, this protective feature is not available if the unit is working in the continuous mode.

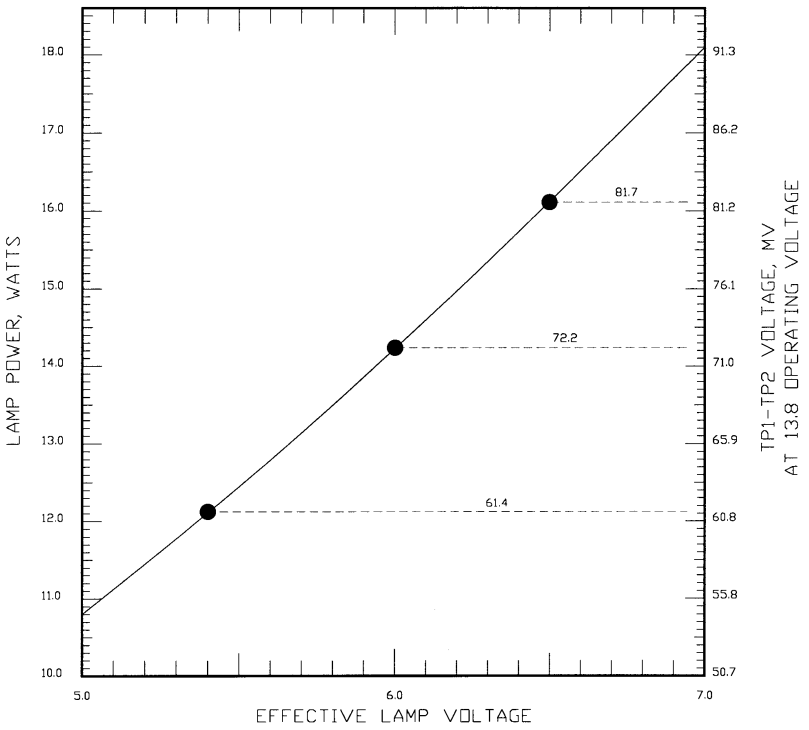


Figure 2-2. Test Point Voltages.

2.6 TEMPERATURE COMPENSATION (*FIRMWARE 1.10 AND ABOVE ONLY*)

Temperature always has some effect on the output brightness of a light emitter. The feedback electronics and optics are also affected by temperature. In order to obtain the highest possible accuracy, means for adjusting the output as a function of operating temperature is made. A digital temperature sensor is mounted on the main circuit board and produces an output voltage proportional to temperature. The voltage is processed by the PIC microcontroller and temperature in units of Kelvin is made available to the temperature compensation part of the operating program.

At 298° K no compensation is used. As the temperature deviates from this value, power to the lamp is lessened if it is warmer and the opposite if it is colder. The actual calibration is done in the lab with the transmitter in a insulated box with heating and cooling facilities. The T-C values can be seen and changed as described in Section 5.1.

SECTION 3.0

LPV-4 LED TRANSMITTER THEORY OF OPERATION

In keeping with the same design philosophy as the LPV-3 Transmitter, the LPV-4 Transmitter is an improved version having superior stability and lower operating power. The key element for this change is the replacement of the tungsten lamp with a high powered green (530 nm CW and 40 nm BW) LED. Stability and temperature drift is also improved with use of a hard coated long life dichroic filter centered at 532 nm and having a bandwidth of 10 nm within the feedback loop. Note that the operating wavelength is different compared to the LPV-3 Transmitter which is 550nm with a bandwidth of 10 nm. An LPV-3 receiver unit with a 532nm filter must be used with this transmitter.

3.1 LED AND LED REGULATION

An OPTEK Technology model OVSPGBCR4 green LED is used for the lamp. Key specifications for this LED are listed in Table 3-1 and Figure 3-1 below.

Material	InGaN
Color	Green, dominate wavelength 530 typical (nm) 520 Min (nm) to 535 Max (nm)
Color Bandwidth	40 nm
Luminous Flux	54 typical (lm) at 350 ma I_f current and 25° C 38 Min (lm) to 79 Max (lm)
Maximum Current	350 ma Max forward DC current 1000 ma Max pulsed current(10 μs, 0.1 duty cycle)
Operating Temperature	-40° C to +100° C
Maximum Power	1200 mW

Table 3-1. Specifications for OVSPGBCR4 LED from Optek Technology

To maintain the LED output constant at better than 1%, an optical feedback method is used. A thin square of clear glass is used in the main beam to reflect approximately 9% of the light to a silicon photodiode mounted on the side. A narrow band filter with a center wavelength of 532 nm and bandwidth of 10 nm is mounted in front of the detector so that only this wavelength is measured and regulated. See Figure 3-2.

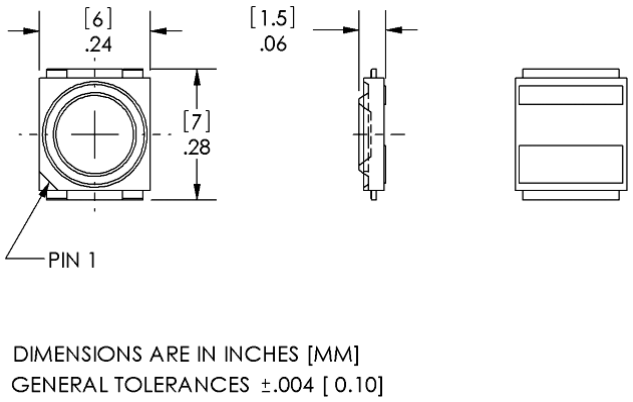


Figure 3-1. Mechanical Specifications for OVSPGBCR4 LED from Optek Technology

A pre-amp configured as a current-to-voltage amplifier converts the photocurrent from the detector to a voltage which is fed to the 10-bit A/D converter port of the PIC microcontroller. From there, the measured output from the LED, when it is on, is compared to preset values for the LOW, MED and HI settings and the output to the lamp drive circuit is altered accordingly. The ratio of brightness for the three settings is 1, 2 and 4 respectively.

3.2 LED DRIVER

The LED Driver is a voltage controlled device where the 13.8 main voltage is reduced to the operating voltage for the LED with an emitter-follower power transistor. The reference voltage applied to the base of the transistor is set by charging a capacitor with a variable duty-cycle 10 KHz signal from the PIC microcontroller. For the LOW, MED and HI LED settings a duty cycle of approximately 40%, 50% and 70% are used. See Table 3-2. This value is displayed in the TEST selection as described in Section 6.0 and made available in the DEBUG output. LED current is limited by a 12.5 ohm power resistor in series with the LED Driver and LED.

The 78.125 Hz modulated signal is generated by switching a TMOS power switch connected to the cathode side of the LED to ground. The control signal for this comes from the free running 10 kHz oscillator programmed into the PIC microcontroller. An external binary ripple counter divides this signal by 128 to arrive at the correct 78.125 Hz operating frequency.

A measure of the LED current is made by measuring the voltage across a 1.00 ohm resistor which is connected between the TMOS switch and ground. This value is displayed in the TEST selection as described in Section 6.0 and made available in the DEBUG output.

LED Brightness Setting	Duty Cycle %	Current ma
LOW	40	45
MED	50	100
HI	70	230

Table 3-2. Duty cycle and current for LED brightness.

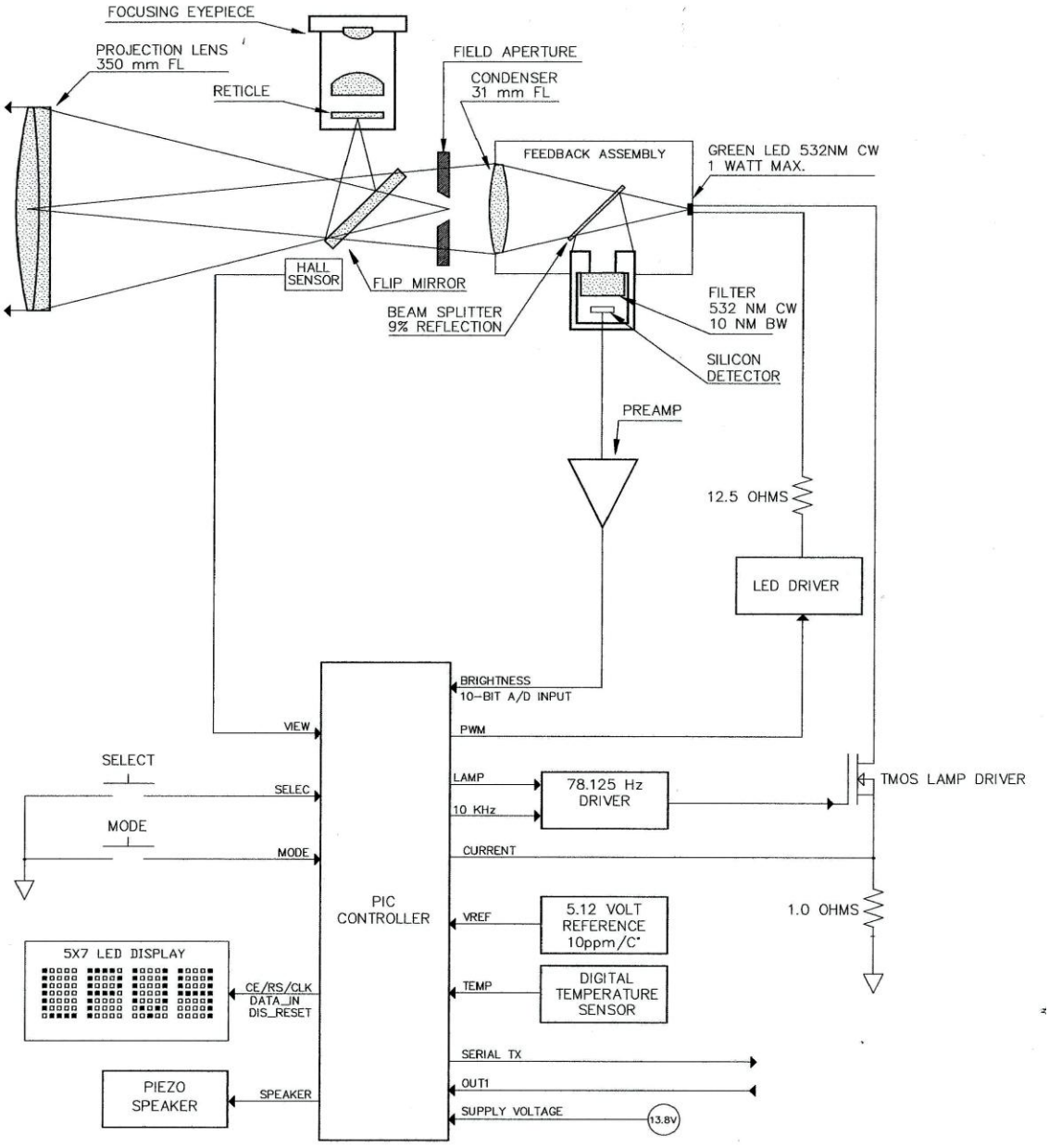


Figure 3-2. LPV-4 Transmitter Function Diagram.

3.3 PROJECTION OPTICS

To increase the effective light output from the LED 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 LED 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 LED emitter on the plane of the projection lens. Proper operation requires that the LED 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. Since the LED used does not have an integrated lens, the light fall-off follows the cosine θ law as a Lambertian emitter. The manufacturer's polar intensity diagram for the LED used is shown in Figure 3-3.

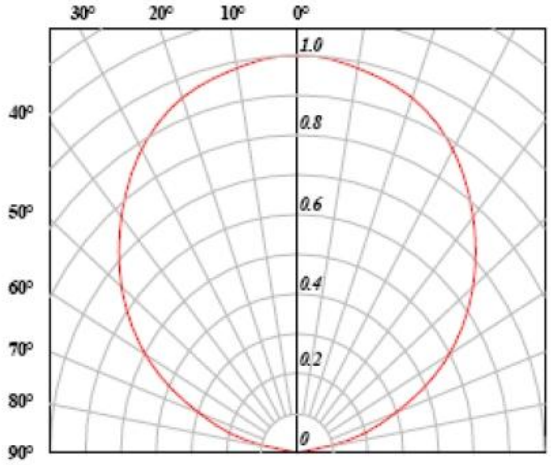


Figure 3-3. LED Polar Intensity Diagram.

From Figure 3-3, it is estimated that the fall-off of light within the 11 degree solid angle is less than 1% compared to on-axis.

To properly point the transmitter projector at the receiver, an eyepiece with reticle is 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, the receiver should always be sighted within the smaller 0.17-degree ring.

3.4 CONTINUOUS OPERATION

Unlike the LPV-3 transmitter which has a time-cycle mode, the LPV-4 transmitter operates continuously once power is applied. The LED uses such little power and has such an extraordinarily long life compared to the tungsten lamp of the LPV-3 transmitter, that the need to

operate at less then 100% duty cycle is negated. In case a time-cycle mode is needed an output pin is available to turn the LED off with logic 0 TTL level signal. A simple relay that shorts this pin to ground would turn the LED off. This signal line is labeled OUT1 in Figure 3-2.

3.5 TEMPERATURE COMPENSATION

Temperature always has some effect on the output brightness of a light emitter. The feedback electronics and optics are also affected by temperature. In order to obtain the highest possible accuracy, means for adjusting the output as a function of operating temperature is made. A digital temperature sensor is mounted on the main circuit board and produces an output voltage proportional to temperature. The voltage is processed by the PIC microcontroller and the temperature in units of Kelvin is made available to the temperature compensation part of the operating program. In addition, the temperature is also made an output for the DEBUG selection.

At 298° K (room temperature) no compensation is used. As the temperature deviates from this value, power to the LED is decreased if the temperature is warmer and the increased if it is colder. The actual calibration is done in the lab with the transmitter in a insulated box with heating and cooling facilities. The T-C values can be seen and changed in the TEST selection as described in Section 6.0.

3.6 DEBUG ROUTINE

For diagnostic and/or monitoring of the instrument, a serial TX line is made available that operates at 19.2 K baud if turned ON with the TEST selection. See Section 6.0 for more details in selecting this option.

The data can be captured with a laptop or similar computer with a RS-232 COM input and cable from Optec. In case the computer is not equipped with a RS-232 COM input, a USB-to-serial converter can be used which is also available from Optec. Table 3-3 shows the value and format for this output. Fields are separated by one space character.

TEMPERATURE in units of degrees Kelvin	VOLTAGE in tenths of a volt	CURRENT in milliamps	PWR Duty cycle from 1 to 254	BRIGHTNESS 0 LOW 1 MED 2 HIGH	VIEW 1 mirror up 0 mirror down	ERROR
NNN	NNN	NNN	NNN	N	N	N

Table 3-3. DEBUG Output and Format

Temperature in units of degrees Kelvin. Room temperature operation would display an approximate reading of 298. The temperature should not exceed 333° K (60° C).

Voltage is shown in units of tenths of a volt. Normal operating voltage of 13.8 volts would be shown as 138. The voltage should not be under 11.0 (display 110) or over 17.0 (display 170)

Current through the LED when on is displayed in units of milliamps. LO, MED and HIGH brightness settings would nominally display approximately 045, 100, and 230 respectively.

PWR or duty cycle is displayed as a 8 bit value where 100% duty cycle (ON all the time) is equal to 255. LO, MED and HIGH brightness settings would nominally display approximately 102 (40%), 125 (50%), and 180 (70%) respectively.

Brightness is the selected output power for the lamp with a 0 indicating the LOW state, 1 indicating the MED state and 2 indicating the HIGH selection.

View is the state of the mirror. A 0 output would indicate the mirror is up or out of the way for normal operation and a 1 would indicate the mirror is down for aiming purposes.

Error is a code indicating a state of failure. See Section 6.0 for a complete description of operating error codes.

Each value is separated by one space character and the data line is terminated by a line feed (LF Hex 10). A line of data is sent every 1 second.

Sample output:

```
310 138 100 125 1 1 0
310 138 101 126 1 1 0
```

The line of data would represent a normal reading with the following variable values for the first line:

Temperature:	310° K
Power Supply:	13.8 volts
LED Current:	100 ma
Duty Cycle:	125 (50%)
LED Setting:	1 (Medium)
Mirror Position:	1 (mirror up)
Error Code:	0 (no errors)
Line Feed:	HEX 10

SECTION 4.0

LPV-3 RECEIVER - THEORY OF OPERATION

The LPV receiver uses a very sophisticated and accurate method to retrieve the transmitter signal from amplifier, background and turbulence noise. Simply stated, the modulated signal from the transmitter 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.

4.1 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 very long paths greater than 7km, an optional 100mm f/6 telescope is available for increasing signal strength. 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.

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 (532 nm if the LPV-4 transmitter is used), 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. 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 detector is a sensitive silicon photodiode operating in the photovoltaic mode with a very low bias current (less than 0.1pa) electrometer amplifier operating in a current-to-voltage amplifier configuration as shown in Figure 4-2. 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:

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

where R_f is equal to 4000M ($4x10^{10}$) ohms.

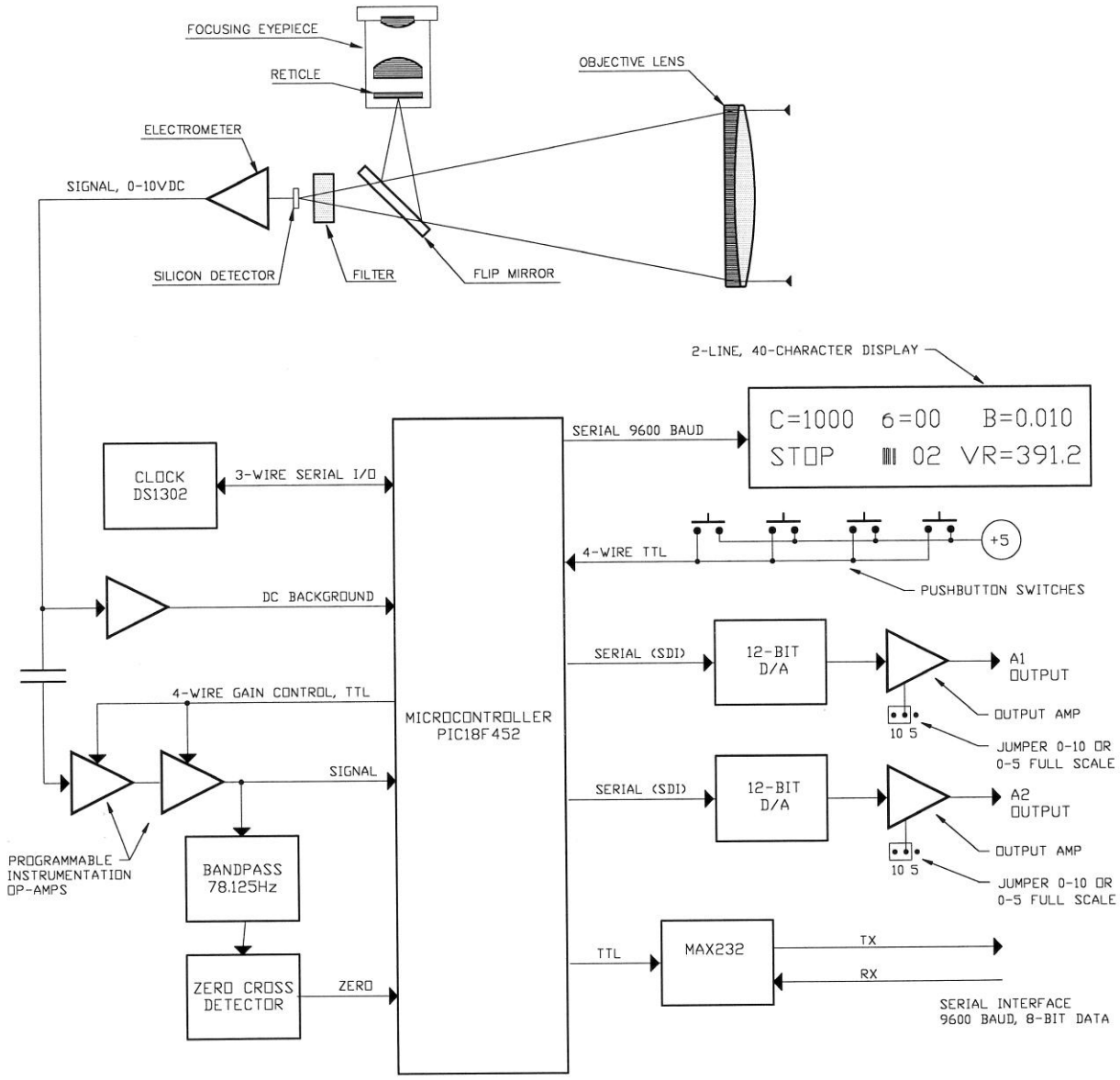


Figure 4-1. LPV-3 Receiver Function Diagram

E_{out} 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.

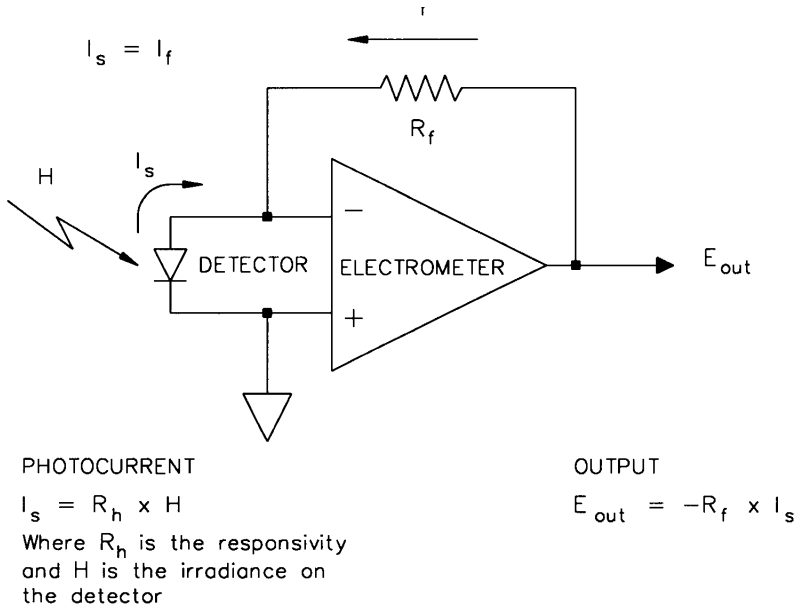


Figure 4-2. Current-to-Voltage Amplifier Configuration

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.

4.2 SIGNAL PREPROCESSING

Before digitizing and processing by the computer, the AC signal from the photometer head is scaled by a combination of two programmable gain instrumentation amplifiers (model PGA205) connected in series. The gain is software selectable by factors of two starting with a minimum gain of 1. The other selectable gain values are 2, 4, 8, 16, 32 and 64. The specified typical gain error for each amplifier is ±0.010% and the maximum gain error over the operating temperature is ±0.024%.

The signal is scaled to achieve the highest reading value without causing saturation of the A/D converter input. Since atmospheric turbulence can cause extreme momentary fluctuations of the signal strength, this scaling is usually done during times of peak turbulence. If the AC input peak-to-peak signal exceeds the 0 to 5.000 volt range of the A/D converter, a buzzer will sound for each instance. The rate of buzzing is an indication of the degree of saturation. Adjusting the gain to a lower value would prevent this error condition from occurring.

The DC saturation level for the detector pre-amplifier is approximately 10 volts. This voltage can be reached if the background illumination is sufficiently intense due to the Sun reflecting off snow, water or even bright rocks. If this happens, the signal is lost (zero signal level) and an

erroneous extinction value is computed. The intense illumination from the reflected sun will not harm either the detector or pre-amplifier unless the Sun itself is directly in the view. Try to avoid this condition since damage to the narrow band pass filter could occur.

This background DC level is sampled before the reading is started. If the DC level exceeds 8.00 volts, the reading is paused until the DC level falls below 8.00 volts. An error code of ER=2 is displayed and transmitted on the serial output indicating that the DC background threshold has been exceeded. Once the DC level is below 8.00 volts, the operating program will be restarted.

A part of this signal is used to find the time when the transmitter chopper is open (lamp-on) or closed (lamp-off). A digital band pass amplifier (LMF100) with a Q of 100 and center frequency of 78.1250 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 4-3 below. 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.

4.3 SIGNAL PROCESSING

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. This is done by locking onto the fundamental chopping frequency of 78.1250 Hz by use of a digital band pass filter with a high Q of 100 followed by a zero cross detector circuit. There is still considerable amount of phase jitter after this stage which is smoothed out by using a phase lock loop circuit. The final square wave output of the phase locked loop with exact 50% duty cycle is now precisely in phase with the chopped signal. This signal is then used by the computer to determine the time to sample the signal.

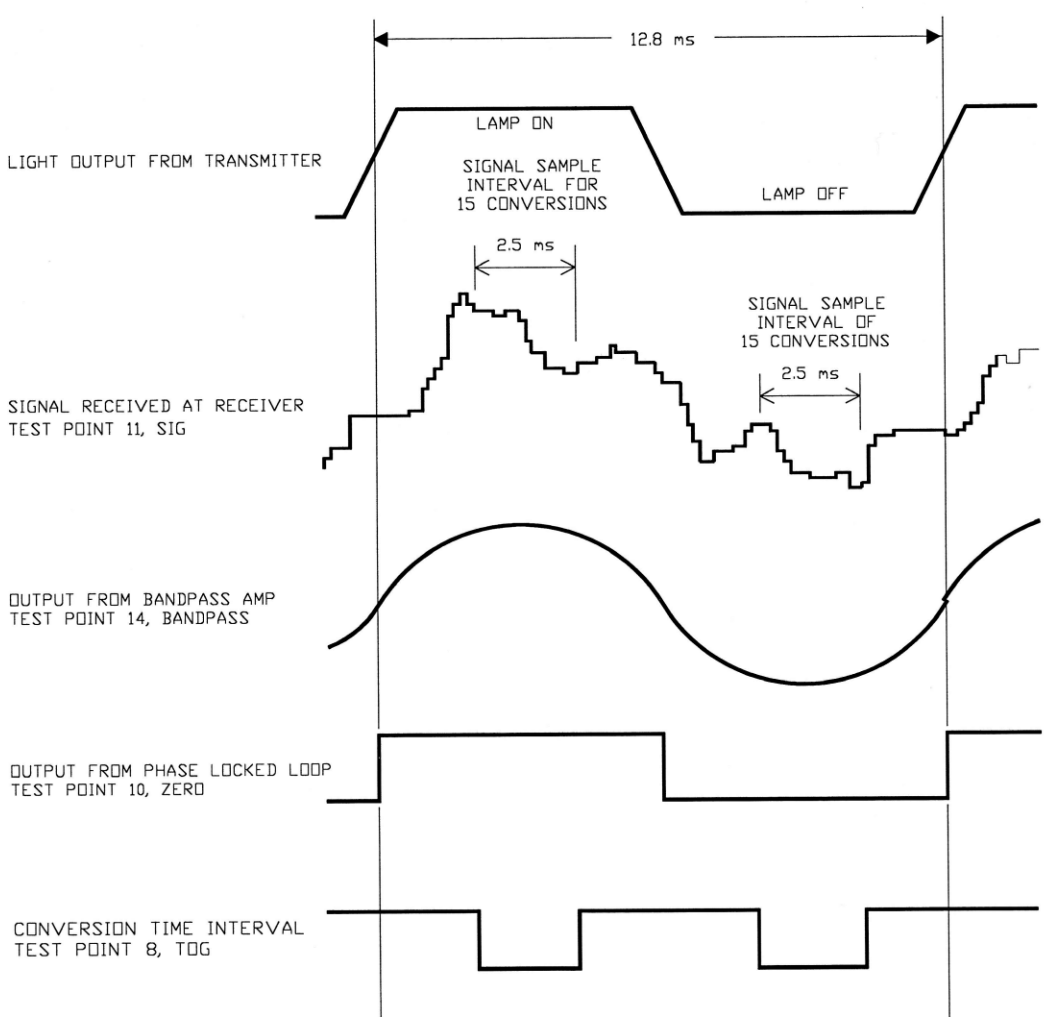


Figure 4-3. Receiver Signal Processing Waveforms

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, then ten 60-second measuring intervals would be used to compute an average value for the reading. See Figure 4-4. In addition, the standard deviation of the raw instrument counts for the ten 1-minute integrations is 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".

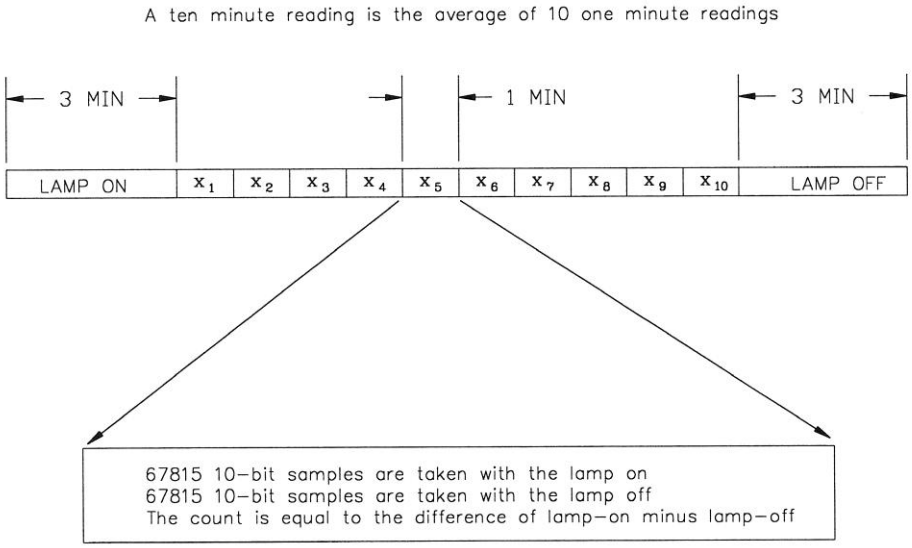


Figure 4-4. Example of a Ten-Minute Integration

4.4 COMPUTER PROCESSING

The computer can process and output the data as count, extinction and visual range. The count is the raw instrument values as internally derived from the A/D conversions and has no units. The count divided by the lamp calibration number is the transmittance of the air path. All three values are sent to the serial output data line and any one of them can be sent to the analog output channel, A1. In addition, the raw instrument value for each 1 minute integration or population standard deviation based on readings that are comprised of two or more one-minute integrations are available on a separate analog output channel, A2. The outputs of A1 and A2 have a full scale range of 10 or 5 volts which are selectable by jumpers on the main circuit board. The outputs have 12-bit resolution and are protected from shorts or incoming static voltages.

The maximum value of count (C) is limited by the single precision integer math of the computer and is 65535 in decimal. In keeping with the conventions used in the older LPV-2 receiver, the count number is formatted before it is sent to the serial output as N_1 N_2 N_3 N_4 . N_5 . Thus, an internal count value of 10,000 is transmitted to the serial output as 1000.0. In similar fashion, the count is formatted before displayed on the front panel of the receiver as N_1 N_2 N_3 N_4 . This value is rounded up one if the N_5 digit is equal to 5 or greater. Thus, an internal count value of 10,000 is displayed as 1000 and sent to the serial output as 1000.0.

With the jumper on the 0 to 10 volt setting on the main board for analog output A1, each integer count value is equal to 0.1mv output. Thus, an internal count of 10,000 is read as 1.000 volts on the A1 output. The A1 output has a 10X multiplier that can be turned on using either the 4-button interface or the PC control program. This would increase the 1.000 volt output given in the previous example to 10.000 volts. Using this setting would make the A1 output operate in similar fashion to the LPV-2. Since the analog output is controlled by a 12-bit D/A converter,

only 4095 voltage levels are possible. Each ADU of the converter is equal to 2.44mv if the 0 to 10 volt jumper is set and equal to 1.22mv if the 0 to 5 volt jumper is set. In the conversion from count to ADU to set the D/A converter, the value of ADU is rounded up or down to more accurately represent the true value of count.

The calculated range of extinction B in units of inverse kilometers (km^{-1}) is 0.0000 to 6.5535. The numbers are formatted this way and transmitted on the serial output. For the front panel display, the value of extinction is rounded to the nearest 0.001 km^{-1} and *B* is displayed to only three decimal places.

With the jumper on the 0 to 10 volt setting on the main board for analog output A1, an extinction value of 1.0000 km^{-1} is equal to 1.000 volts. An extinction value of 0.0100 km^{-1} (Rayleigh) is equal to 0.0100 volts which may be difficult to measure accurately considering the 2.44 mv ADU step resolution and limitation in the users analog data logger. It may be necessary to use the 10X multiplier feature to raise this level to 0.100 volts.

The calculated limits for visual range (Vr) in units of km is 0.6 to 391.2 assuming that the visual range constant is set to the default value of 3.912. The numbers are formatted this way and transmitted on the serial output. This formatting is also used on the front panel display.

With the jumper on the 0 to 10 volt setting on the main board for analog output A1, a visual range value of 391.2 km is equal to 3.912 volts. This assumes that the multiplier for the A1 output is set for 1X which is the default value.

Like the LPV-3 transmitter circuit, the receiver computer has available a cycle and integration timer with time set by its own real time clock with 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 selected integration time. The possible cycle times are the same as the LPV-3 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 selectable from 1 to 60 minutes in integer steps of 1 minute.

The LPV-4 transmitter operates in a continuous mode and does not require the transmitter and receiver computer to be synchronized or reset simultaneously as described above. The receiver cycle time can be set for 20 minutes, 1, 2, 4 hours, or continuous. Receiver integration times of 1 to 60 minutes can be selected with any of the timed cycle modes.

4.5 Calculations for Extinction, Visual Range and Std. Deviation

The receiver computer is able to calculate directly the extinction (*B)* and visual range (*Vr*) values. In order to do so, certain constants needed for the calculation can to be entered using either the PC control program or the 4-button interface menu. These constants include: the working path length (*Wp*) in meters, the lamp calibration number (*CAL*) calculated during the calibration procedure and the visual range constant (*Vrc*).

Calculation for extinction, *B*:

$$B = \frac{-\ln \frac{Wr}{CAL}}{Wp}$$

where

Wr	=	internal raw instrument count value, working reading
CAL	=	lamp calibration number
Wp	=	working path length from receiver to transmitter (meters)

Calculation for visual range, *Vr*:

$$Vr = \frac{Vrc}{B}$$

where

Vrc	=	visual range constant (equal to 3.912 for 2% contrast or 3.000 for 5% contrast)

Calculation for standard deviation, σ :

$$\sigma = \sqrt{\frac{\sum (C - Cavg)^2}{N}}$$

where,

C	the count for each 1-minute integration,
C_{avg}	the average of all count values in the data set,
N	the number of 1-minute integrations making up the total reading.

4.6 Serial Output Data

The serial interface consists of RX, TX and ground using a standard 9-pin sub-D male connector on the rear panel of the receiver computer. Serial interface protocol is 9600 baud, 8 data bits, no parity and 1 stop bit. A serial data logger can be used to capture data or the free PC control program available from Optec can be used for simple data logging.

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

C	B	VR	N	SD	DATE	TIME
*NNNN.N_*	*_N.NNNN_*	*_NNN.N_*	*_NN_*	*_NNN.N_*	*_YYMMDD_*	*_HHMM_CR/LF*

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

where,

C	the mean of the raw counts and has no units
B	the extinction in units of km^{-1}
VR	the visual range in units of km
N	the number of 1 min. integrations
SD	the standard deviation of raw counts C.
DATE	the year, month and day
TIME	the hour and minute.

SECTION 5.0

LPV-3 TUNGSTEN LAMP 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 damage to the unit. Exceeding 17 volts input voltage may also result in damage to the unit.

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. While in the viewing mode, a few bars of "On a Clear Day" will play and repeat. With the lamp on and the unit in operation, a chirping sound is played when the unit is in the viewing mode. Both of these tones are audio reminders to return the flip mirror to the open position when viewing is finished.

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.

5.1 The 2-Button Interface

The transmitter is programmed with the use of two momentary pushbuttons labeled MODE and SELECT with the settings and prompts viewable on a 4-character display. See Figure 5-1 for a view of these controls.

When the unit is in a cycle mode and running with the lamp not on, the settings menu can be brought up by holding down the MODE key until a prompt is received. If the unit is in running continuously or anytime when the lamp is on, it can be interrupted by holding both the SELECT and MODE key down together until the ready prompt is displayed. See Figure 5-2 for a flow diagram of the configuration menu.

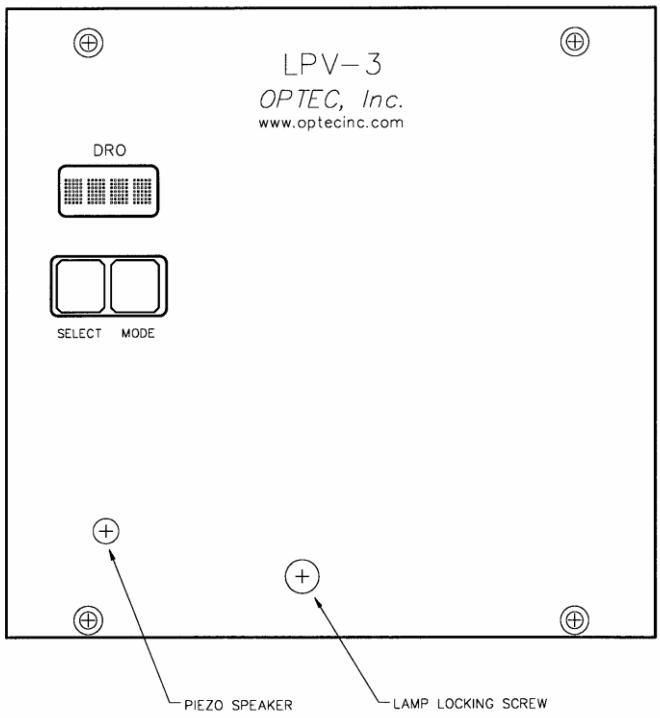


Figure 5-1. View of LPV -3 Transmitter Control Unit

INTG

This selection allows for changing the integration time which is the time that the lamp is on. Possible selections are: 2, 16, 32 and 64 minutes. These integration times are identical to the integration times available with the LPV-2 transmitter.

CYCL

The available cycle times are: 20 minutes, 1 hour, 2 hours, 4 hours and CONTinuous. This is the time the unit is waiting until the beginning of a new integration. In the case of CONT, the unit will always be running with the lamp and chopper powered as long as suitable power is available. Most error checking is disabled in the CONT mode except when the lamp burns out or the chopper motor fails. An error code of ER=5 will be displayed in such a circumstance.

TEST

Pressing the SELECT button with TEST displayed will turn on the chopper motor and lamp for testing purposes. The unit will remain running until the MODE or SELECT button is pressed again. The integration times and cycle times are not interfered with.

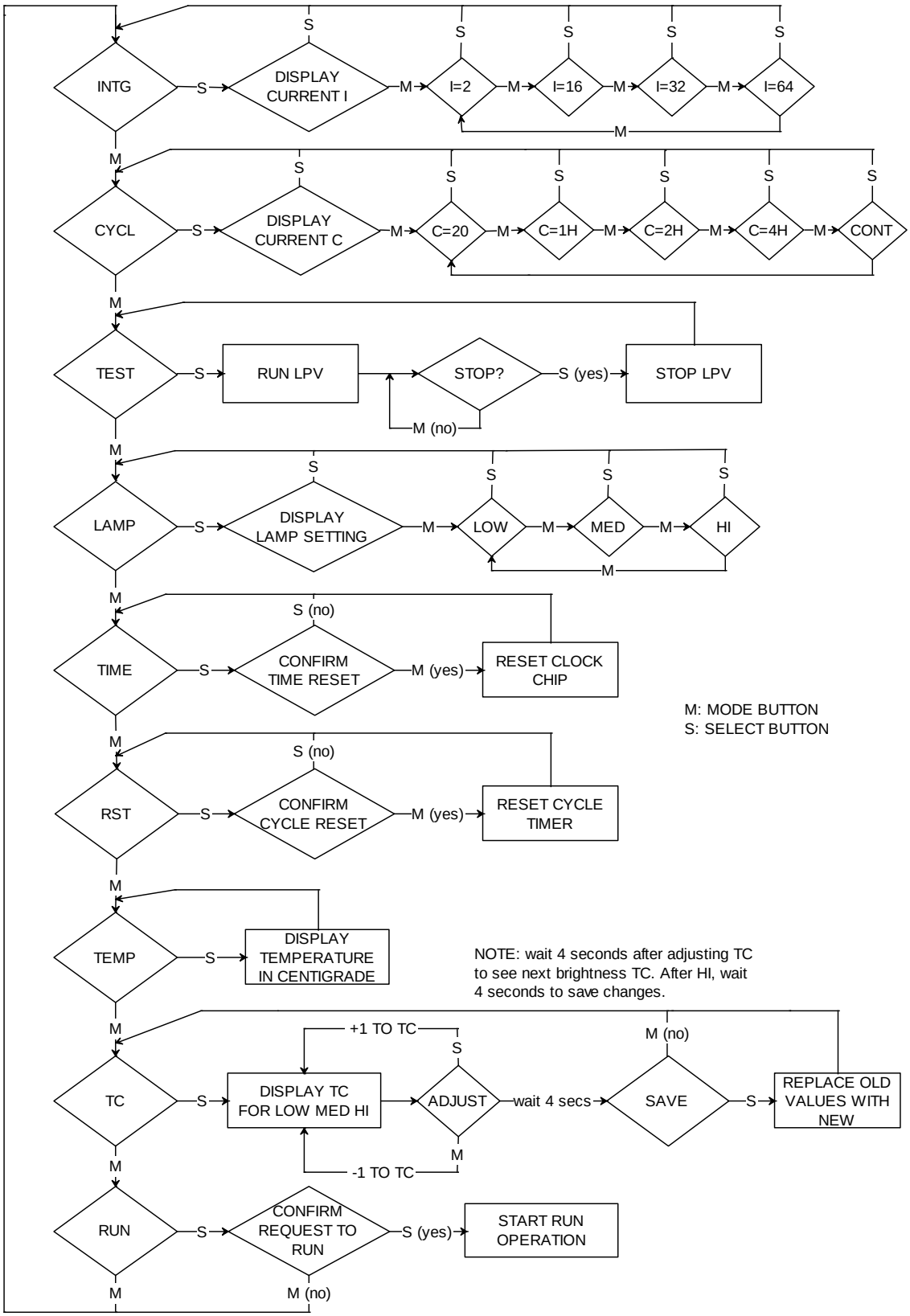


Figure 5-2.Configuration of LPV-3 Menu Flow Diagram

LAMP

This selection allows for a choice of lamp power. The possible selections are LOW, MED and HI. For most situations, the MED selection is recommended which relates to an effective operating voltage of 6.0 going to the lamp.

TIME

If the DS1302 real time clock chip ever runs the 1 Farad capacitor down, it will lose the initialization settings. This selection only needs to be done if an error code of ER=4 is observed on the display. The unit should be left plugged into a power source for a couple of hours to recharge the capacitor. Use the RST menu selection to start the clock at the proper time

RST

With this displayed, pressing the SELECT button twice will start the cycle clock and an integration at this point in time. Normally, the RST is selected to start the instrument running approximately one minute before the receiver will begin an integration.

TEMP (firmware 1.10 and above)

Selecting this option displays the internal temperature in Centigrade

TC (firmware 1.10 and above)

The temperature coefficients for the LO, MED and HI lamp brightness settings are available to be seen and changed with this option. When selected, the values for LO, MED and HI are displayed in order every 4 seconds. If changes are needed, enter new values by using the SELECT and MODE keys to increment up or down the values. After 4 seconds, the next brightness level is available for change or view. After the HI setting is viewed and a period of 4 seconds is passed, an option to save the new values is offered. If a zero value is entered, an ER=6 error code is displayed for a few seconds but operation of the LPV-3 will continue normally.

5.2 Troubleshooting and Error Codes

ER = 1	Supply voltage is less than 10.6 volts
ER = 2	Maximum safe power to the lamp has been exceeded.
ER = 3	No zero cross signal detected. Chopper failure.
ER = 4	Real Time Chip has lost power and needs to be initialized
ER = 5	Temperature of circuit board has exceeded 60° C
ER = 6	Displayed if the TC coefficient are zero (firmware 1.10+).

Table 5-1 . Summary of LPV-3 Transmitter Error Codes

ER=1
This usually indicates that the supply voltage from a battery is failing and the battery needs to be recharged.

ER=2
Error 2 indicates the lamp needs replacing. Even if not yet burned out, as the lamp ages the glass envelope usually darkens and the filament looses material. With less efficiency and to keep the output constant, more power must be delivered to the lamp. With the error code, the maximum safe power has been exceeded and the lamp needs to be replaced.

ER=3
If the chopper motor fails, no signal will be detected by the photodarlington. Without this signal, the unit cannot operate properly and will display this error code. Check the chopper for proper operation.

ER=4
If the unit has been sitting for a long period of time without power, the real time clock chip will run down the 1 Farad capacitor. With the power restored and turned on, use the 2-button interface to invoke the TIME command. This will reinitialize the timer chip. Leave the unit on for a couple of hours to fully charge the capacitor. A fully charged capacitor should operate the timer in excess of 45 days. A RST command will also have to be done to synchronize the transmitter with the receiver.

ER=5
In case the internal temperature of the unit exceeds 60° C, the unit will not turn the lamp or chopper motor on. This feature is disabled if the unit is powered in continuous mode. Excessive heat may cause damage to the optical and electronic components. This feature insures that the 14 watts of the lamp and 4 watt of the stepper more do not add to the heat budget.

ER=6
If the internal temperature coefficients are set for zero, this error is displayed for a few seconds after power up. Operation of the unit is not effected. This just indicates that temperature coefficients have not been entered. This would be the result if a new PIC has been installed with a firmware revision upgrade.

SECTION 6.0

LPV-4 LED LAMP TRANSMITTER OPERATING PROCEDURES

Connect the input power cable to the input connector. If a cable is made by the cusotmer, 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. Refer to Appendix D for more detailed wiring instructions. The transmitter turns on immediately after power is supplied and stabilizes after about 2 seconds.

Reversing the voltage polarity to the input will NOT result in damage to the unit as in the case of the LPV-3 transmitter. Exceeding 17 volts input voltage may result in damage to the unit if applied for a long time.

The flip mirror control is located on the left side of the projector unit. Turn this control clockwise until the stop is reached for sitting 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 LED feedback control. The outer circle is the outside limit of the 1-degree cone of light, which is projected. While in the viewing mode, a few musical bars of "On a Clear Day" will play and repeat. This is an audio reminder to return the flip mirror to the open position when viewing is finished.

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 lamp 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.

6.1 The 2-Button Interface

The transmitter is programmed with the use of two momentary pushbutton keys labeled MODE and SELECT with the settings and prompts viewable on a 4-character display. The LPV-4 transmitter push-button interface is identical to the LPV-3 transmitter push-button interface shown in Figure 5-1.

The unit begins to operate at the selected operating variables as soon as power is supplied. To enter the configuration menu, press and hold the MODE button. If there are any errors displayed prior, these are reset and an ER=0 is shown for about 600 ms. After that, STOP is displayed and the user has the option to continue running the operating program normally by pressing the MODE key or to enter the configuration menu by pressing the SELECT key. See Figure 6-1 below for a flow diagram of the configuration menu options.

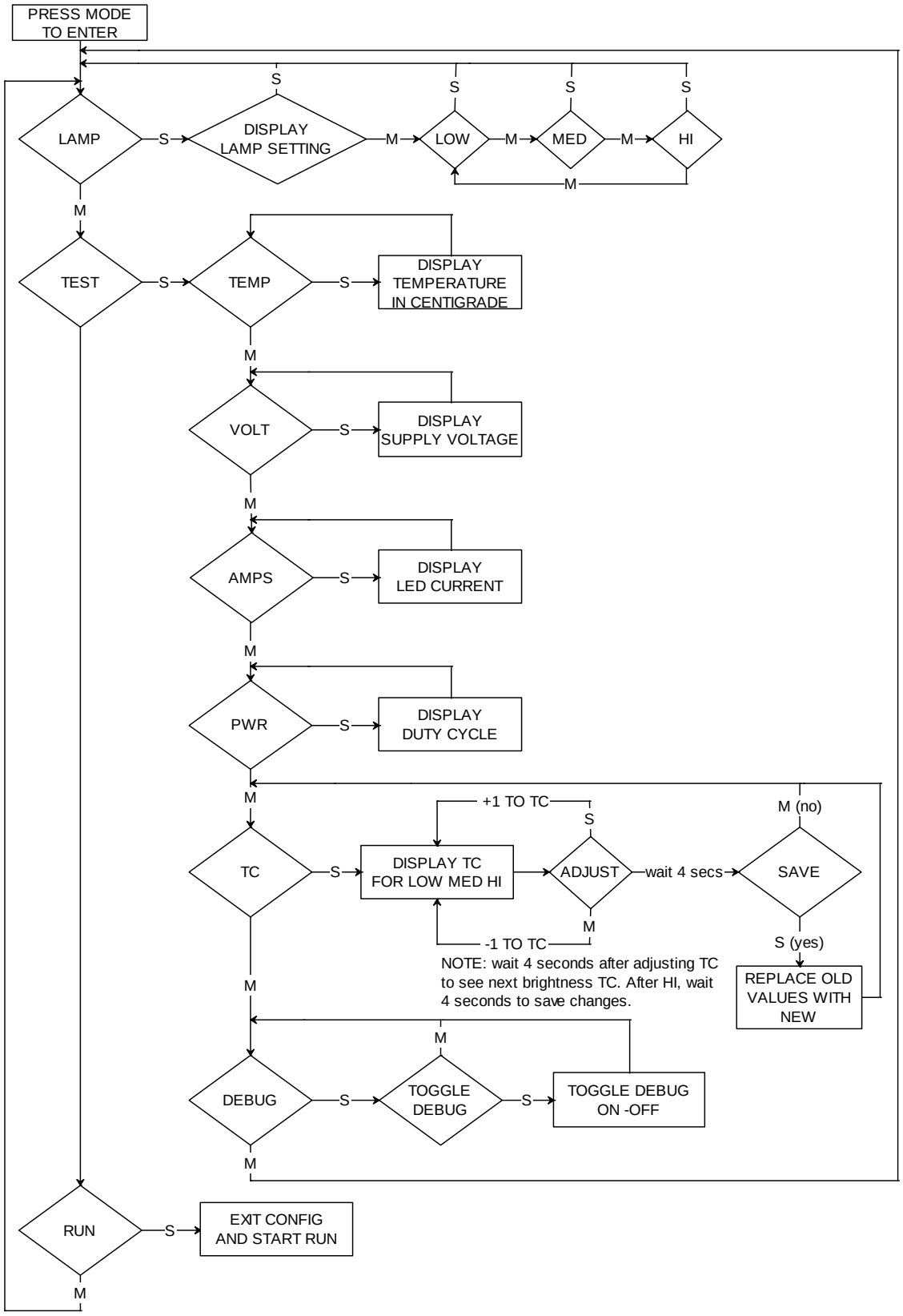


Figure 6-2. LPV-4 Configuration Menu Flow Diagram

LAMP

This selection allows for a choice of LED power. The possible selections are LOW, MED and HI. For most situations, the MED selection is recommended. The ratio of light output for each setting is approximately 1 : 2 : 4. Calibration as described in Section 8.0 would have to be performed for the power setting selected.

TEST

This is an entry point to the more advanced setting and options described in section 6.2 below. Use the SELECT key to enter the advanced options.

RUN

Pressing the MODE key will return the user back to the LAMP option. Pressing the SELECT key will exit the configuration menu and start the operating program.

6.2 TEST (Advanced Options)

TEMP

Pressing the SELECT key will display internal temperature in degrees C. The temperature should be under 60° C for safe operation.

VOLT

Pressing the SELECT key will display the power supply voltage. 13.8 volts is the nominal voltage. The voltage should not be under 11.0 or over 17.0.

AMPS

Pressing the SELECT key will display the peak current in units of milliamps through the LED. For LED Brightness LO, MED and HI the display values are approximately 45, 100 and 230 respectively. A value 130% higher then these values would indicate a problem,

PWR

Pressing the SELECT key will display the duty cycle in percent for the power going to the LED. For LED brightness LO, MED and HI the display values are approximately 40, 50 and 70%. Any value near 100% would indicate that there is little room for brightness regulation.

TC

Pressing the SELECT key will allow for observing and/or changing the temperature coefficients. These values have been entered at Optec and should not be changed unless advised by

technicians at Optec such as the case of a firmware upgrade. Once the SELECT key is pressed the three coefficients for the LO, MED and HI brightness settings are displayed with a pause of approximately 4 seconds between them. If no entry is done during this time then SAVE would be displayed after HI is shown and the user can press either SELECT or MODE to return to the menu and keep the current values. If the values are changed by pressing the SELECT or MODE key within the 4 second window, then the new values can be saved or discarded when the SAVE word is displayed.

Each integer value represents 0.01% of temperature compensation. Nominal values for the LPV-4 are approximately 4 to 6.

DEBUG

Pressing the SELECT key will toggle the DEBUG option on or off. When on, operating parameters are sent on a serial line for data capture or observation with a terminal program. See Section 3.6 for details.

6.3 Troubleshooting and Error Codes

ER = 0	Transmitter is working normally
ER = 1	Power Supply under 11.0 volts
ER = 2	LED output weak
ER = 3	LED current exceed 400ma but less than 450 ma maximum
ER = 4	Internal temperature over 60° C
ER = 5	No LED current, open circuit
ER = 6	Duty cycle is 100%, FATAL ERROR
ER = 7	LED current exceeds 450ma, FATAL ERROR

Table 6-1 . Summary of LPV-4 Transmitter Error Codes

ER=0
Indicates that the transmitter is working within normal limits.

ER=1
If the power supply/battery voltage drops below 11.0, this error code would be displayed. Normal operating voltage is 13.8 ±1.0. The lamp would turn off and stay off until the supply voltage is raised to at least 11.5 volts. At this voltage the unit will run normally.

ER=2
If the duty cycle exceeds 97% (DEBUG output of +245), this would indicate that the LED cannot output the required light or there is a failure in the feedback electronics or optics. Normally, if there is a failure an ER=7 error would be generated and the unit would shut down.

ER=3
In the HI LED brightness, the LED current would normally be less than 200ma. If this LED current exceeds 400ma, then this error code would be generated. A structural failure of the LED would be suspect.

ER=4
When the internal temperature exceeds 60° C, the transmitter will shut the LED off and display the error. Once the temperature drops below 57° C, the lamp will turn on and run normally.

ER=5
If there is no current through the LED, this error code would be displayed. Besides the obvious LED failure a check of the cable from the LED to the circuit should be checked. This is a fatal error and the unit will power down the LED electronics. Contact Optec for repair of transmitter.

ER=6
If the duty cycle reaches 100% (DEBUG output of 254), this would indicate that there is no ability to regulate the LED output and the unit would shut down. This is a fatal error. Contact Optec for repair of transmitter.

ER=7
As with the case of ER=3, the normal operating current is 200 ma or less. If the LED current exceeds 450ma the LED structure would be damaged. This is a fatal error and the unit would shut down. Contact Optec for repair of transmitter.

SECTION 7.0

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 if necessary. Make sure the pan head screw near the front of the telescope is loose before attempting to focus by slightly adjusting the objective lens forward or backward. 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 telescope 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 13.8V power to the port labeled "13.8V DC" using the cable provided. If the cable is customer made, pin 2 is for the positive 13.8-volt terminal and pin 3 of the connector is for the negative (return) 13.8-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 tripping the internal resetable fuse which is located on the inside circuit board. If activated by the reversed power connection or the unlikely event of an internal short, the device will go into a high impedance state and stay there until the fault condition is corrected.

The data acquisition and reduction computer is self-starting and requires no user input except for the proper settings and input of the operating constants. To reset the computer, the power must be shut off for about 1 second.

7.1 Front Panel Display

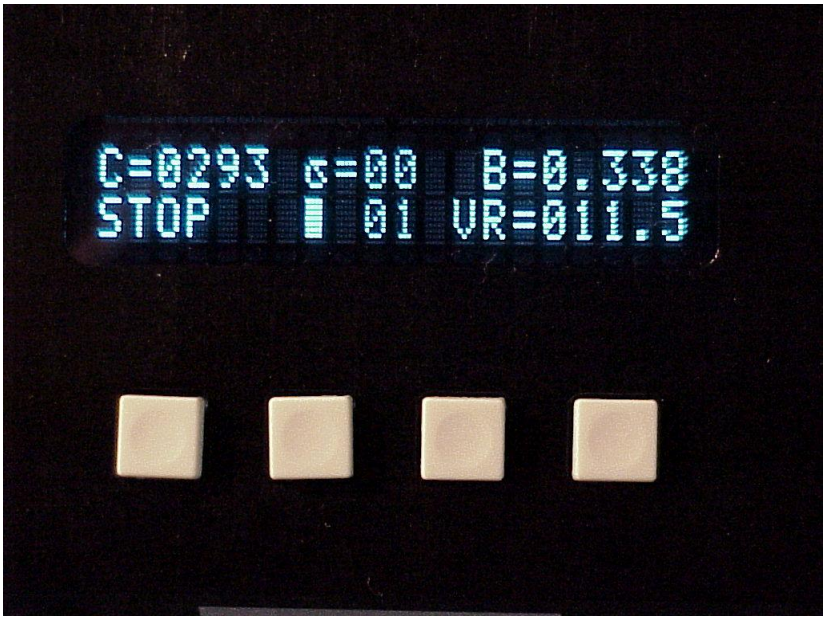


Figure 7-1. Receiver Front Panel Vacuum Fluorescent Display

C=0293

Raw instrument reading normally referred to as count. If several 1-minute integrations were specified, this number would be the average of all the values. This number is the same as the serial output value rounded to the nearest unit value. Range of values are 0000 to 6553.

σ=00

This is the standard deviation of the count values. If readings consisting of only one 1-minute integration are specified, this value defaults to 00. This number is the same as the serial output value rounded to the nearest unit value. Range of values are 00 to 25.

B=0.338

The value of extinction B in units of inverse kilometers (km^{-1}) is shown here. This number is the same as the serial output value rounded to the nearest one-thousandth. Range of values are 0.000 to 6.553.

STOP

Pressing the button under this word will stop the data acquisition program and start the menu configuration program. Follow the displayed dialogs to enter changes in constants or other operating parameters.

||| 01

During integration, the time bar will slowly lengthen until the 1-minute integration is complete. The number on the right shows which integration is in process and will reset to 1 once the total reading is complete. Range of values for the integration counter is 01 to 60.

VR=011.5

This is the visual range Vr in units of km. The number displayed is the same number sent to the serial output. Range of values possible are 000.0 to 999.9. A legitimate range of values would be 000.6 to 391.2 if the readings and constants were correct.

7.2 4-Button Interface

The user has the ability to change all of the constants and most of the operating parameters except setting the clock with the 4-button interface. The top line usually displays the value to be modified and the second line displays the functions of the button directly underneath the command word. To return to the data acquisition program after modifications are complete, press the button under the RUN word. The user will then have the option to start the data acquisition program with out resetting the cycle timer by pressing the button under YES or initialize the cycle timer by pressing the button under RESET.

GAIN

Gain is adjustable from 1 to 64 by multiples of 2. Adjust GAIN to the highest value without saturating the A/D converter. When the A/D converter samples a signal outside its input voltage limits, a beep will sound. The rate of beeping is an indication of the level of saturation of the A/D converter. Decrease the GAIN until the beeping stops. This adjustment should be made with the transmitter during a time of high turbulence and low extinction.

The value displayed in the upper right corner of the front panel display during the GAIN adjustment is the DC background value in ADU units. The range of values is 0 to 1023 and can be considered close to the voltage in units of millivolts. Thus, a value of 800 would be close to the threshold value of 8.00 volts, which would be close to the saturation point for the electrometer amplifier. If the DC value is too high, then steps need to be taken to reduce the background brightness or some data will be lost.

CAL

The lamp calibration number is entered here for when a new lamp is installed. To rapidly change the current value to the new value, press the button under the 20X and then press the button under the + or – symbol. The lamp calibration value will then increment in units of 20.

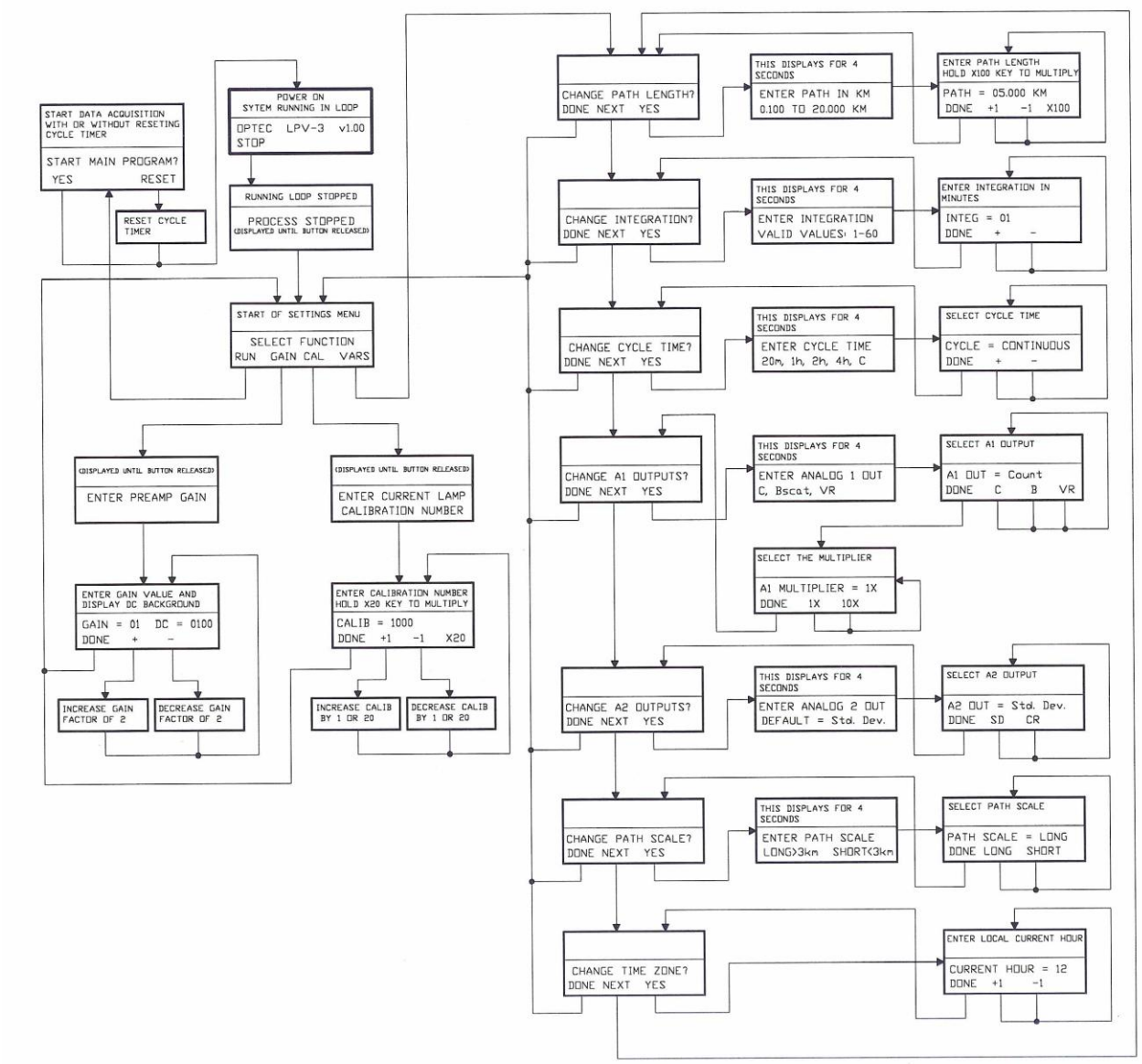


Figure 7-2. Receiver Menu Flow Diagram

VARS

Pressing the button under VARS brings up a larger sub-menu for changing more of the constants and operating parameters not commonly accessed. The user can move forward in this circular menu by pressing NEXT, or exit the menu by pressing DONE, or change the selected parameter by pressing YES.

CHANGE PATH LENGTH

Change working path length as measured from front of receiver telescope to front of transmitter telescope in units of meters. Round off measured distance to the nearest meter. This distance is important and should be measured with a laser range finder for greatest accuracy. To move quickly to the desired path, press the button under the 100X while pressing the button under the + or –

button. This will change the current path by units of 100 meters. Press the button under DONE to return to VARS menu.

CHANGE INTEGRATION

Enter the desired integration time in units of minutes. Press the button under the + or – symbols to increment the integration counter up or down. Permitted values are from 1 to 60. Press the button under DONE to return to the VARS menu.

CHANGE CYCLE TIME

The valid cycle times are 20 minutes, 1 hour, 2 hour, 4 hours and continuous running. Press the button under the + or – symbols to change to the desired cycle time. This cycle time should match the selected cycle time for the transmitter. When exiting the menu program, the user will have the choice to RESET the cycle timer. Pressing this key will start cycle timer and a reading will begin immediately. Normally, the RESET button is pressed a couple of minutes after the transmitter lamp has turned on in order for both the transmitter and lock in amp of the receiver to stabilize before a reading is started. Press the button under DONE to return to the VARS menu.

CHANGE A1 OUTPUTS

For users wishing to use the analog outputs for data collection, select the desired output for A1 using this option. The Count (C), Extinction B or Visual Range Vr can be selected by pressing the button under the desired output. Once the output is selected, the user has the option to multiply the analog voltage by a factor of 10. This would be necessary if Bscat was selected and expected the extinction values would be near Rayleigh. See Section 3-4 for conversion from voltage to selected output value.

CHANGE A2 OUTPUTS

Either the standard deviation (SD) of the count values or the count (CR) for each 1-minute integration can be selected for analog output to A2. Press the button under the desired output value. The CR output is normally for a chart recorder, which is considered largely obsolete, but it still provided for backward compatible with the LPV-2 receiver model. Press the button under DONE to return to the VARS menu.

CHANGE PATH SCALE

This allows for an internal change in the computation of the count value and is not a change in the gain setting. For working path lengths longer than 3 km, press the button under the LONG word. For working path lengths shorter than 3 km, press the button under the SHORT word. The count value is divided by a factor of 4 when the SHORT path scale is selected. Press the button under DONE to return to the VARS menu.

CHANGE TIME ZONE

Normally, the receiver clock is set by the PC control program to whatever local time the PC is set to. This may not correspond to the correct time at the instrument location and the field installer may not have a computer to correct the time. This option allows the user to change the hour value to match the local time. Press the button under the +1 or –1 symbols to change the receiver time hour up or down. Press the button under DONE to return to the VARS menu.

At this point, the VARS menu returns to CHANGE PATH LENGTH if the NEXT key is pressed.

SECTION 8.0

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 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 transmissometer may be calibrated using either of the two methods outlined below. The use of either method depends upon the site transmission. The user can compute the CAL calibration constant using the equations below or by using the utility program **LPV-3 Calibration Calculator** available for download from the Optec website: www.optecinc.com /visibility/downloads.htm.

8.1 ND FILTER METHOD

The Model LPV transmissometer is calibrated by a technique that 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 8-1. A neutral density (ND) filter with transmission of approximately 1% to 2% 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 known amount to keep the detector electrometer from saturating at these close distances.

The raw instruments readings (Count) taken from the front panel display 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, CAL, which is entered into the receiver computer menu program by selecting CAL as described in Section 5.2.

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. If neither a laser range finder or tape measure can be used to measure the path accurately, it is suggested that a land surveyor be employed to measure the distances.

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 8-1. 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%. Set the GAIN value of the receiver until a reading around 700 for count is obtained.

Placing the LPV-3 transmitter in the TEST mode will run the transmitter continuously until switched off. The internal clock with backup will not be affected 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. For the LPV-4 Transmitter, just attach power and the unit will run continuously.

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:

$$CAL = (\frac{Cp}{Wp})^2 \cdot \frac{Wg}{Cg} \cdot \frac{1}{Ft} \cdot Wt \cdot \frac{1}{T} \cdot Cr$$

where,

C_p	calibration path length, 0.1000 to 0.5000 km
W_p	working path length, 0.100 to 20.00 km
C_g	calibration gain, 1, 2, 4, 8, 16, 32 or 64
W_g	working gain, 1, 2, 4, 8, 16, 32 or 64
F_t	calibration filter transmission with typical value around 0.01
W_t	total shelter(s) window transmittance. If windows are used on both ends, multiply their transmittances together. Typical value for two windows is 0.902
T	estimated or measured atmospheric transmittance for calibration path, 0.950 to 0.996 typical
C_r	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.

8.2 DIFFERENTIAL PATH METHOD

For sites where the extinction B 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 LPV-3 Receiver computer as described in Section 7.2 . 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 PATH SCALE setting of SHORT is normally used.

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 and would not be suitable for measuring distances of a kilometer or more. 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 were 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.

For the LPV-3 Transmitter, selecting the TEST mode on the transmitter will run the transmitter continuously until switched off. The internal clock will not be affected 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. For the LPV-4 Transmitter, just attach power and the unit will run continuously.

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.

The differential method can be used for short paths such as with the ND filter method described in Section 8.1. In this case the ND filter is left in for both path readings and the ND transmission is factored into the equation for CAL.

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

$$B = -\frac{\ln \frac{Wr \cdot Wp^2 \cdot Cg}{Cr \cdot Cp^2 \cdot Wg}}{Wp \cdot Cp}$$

where,

Cp	calibration path distance (shorter distance)
Wp	base or working path (longer distance)
Cr	calibration path reading
Wr	base or working path reading
Cg	calibration path gain
Wg	base or working path gain

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

$$T = e^{-B \cdot Wp}$$

and the calibration number is

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

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

Once the site extinction B is measured differentially and converted to transmission T, then the equation for CAL in Section 8.1 can be used to compute the CAL values for the other lamps to be calibrated. It is not necessary to use the differential method for each lamp if it can be assumed that the site transmission has not changed or it is monitored by doing a differentially calibration in the middle and end of the calibration process.

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

SECTION 9.0

SPECIFICATIONS

9.1 GENERAL OPERATING PERFORMANCE

EXTINCTION RANGE		0.0100 to 6.5535 km^{-1}
RESOLUTION		
	Extinction (B)	0.0001 km^{-1}
	Visual Range (VR)	0.1 km
ACCURACY		
	Transmission	±3%
	Extinction	±0.003 km^{-1} for 10 km working path and 0.010 nominal extinction value
MEASURED WAVELENGTH		
	Filter (LPV-3)	550 ±2 nm, 10 ±1 nm bandwidth at ½ power points
	Filter (LPV-4)	532 ±2 nm, 10 ±1 nm bandwidth at ½ power points
OUTPUT, FRONT PANEL DISPLAY		
	B	Extinction (km^{-1}) to 0.001
	Vr	Visual Range (km) to 0.1 km
	C	Instrument values from 0 to 6553
	σ	Standard Deviation from 0 to 25
OUTPUT, ANALOG		
	A1 (Extinction)	0 to 10 V, 0.010 V = 0.001 km^{-1} 0 to 5 V, 0.005 V = 0.001 km^{-1} 10X multiplier option can be applied to A1
	A1 (Visual Range)	0 to 10 V, 0.010 V = 1 km 0 to 5 V, 0.005 V = 1 km 10X multiplier option can be applied to A1
	A1 (Calibration)	0 to 10 V, 0.010 V = 10.0 count 0 to 5 V, 0.050 V = 10.0 count 10X multiplier option can be applied to A1
	A2 (Chart Rec.)	0 to 10 V, 0.010V = 10.0 count
	A2 (Std. Dev)	standard deviation of count samples
OUTPUT, SERIAL		
	RS-232	9600 baud, 8 data bits, 1 stop bit, no parity
	Outputs	Count, Bscat, Visual Range, Standard Dev., Integrating, Time and Date
POWER SUPPLY		
	12 volt auto battery	12-14 volts Receiver, 10.6–15 LPV-3 Transmitter 11.0 – 17.0 LPV-4 Transmitter
OPERATING TEMPERATURE		-20° TO +45° C

9.2 LPV-3 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, 14 watt special prefocused tungsten filament lamp mounted in machined base
	Regulation	constant to ±1.5%
	Life	500 hrs. continuous at MED setting
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	10.6 to 15 volts DC NOT reverse voltage protected
	Power (lamp off)	0.12 watt at 13.8 volt input
	Power (lamp on)	24 watts at 13.8 volt input
SIZE		
	Projector	18 x 5 x 6 inches (LxWxH)
WEIGHT		
	Projector	5 lbs

9.3 LPV-4 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	532 ±2 nm
	Bandwidth	10 ±1 nm
LAMP		
	Type	OVSPGBCR4 green LED from Optek Technology
	Regulation	constant to ±1.5%
	Life	50,000 hrs. continuous at MED setting
CHOPPER FREQUENCY		78.1250 ±.0001 Hz
POWER SUPPLY		
	Voltage, input	11.0 to 17 volts DC reverse voltage protected
	Power (lamp off)	0.09 watt at 13.8 volt input
	Power (lamp on)	0.80 watts at 13.8 volt input
SIZE		
	Projector	18 x 5 x 6 inches (LxWxH)
WEIGHT		
	Projector	5 lbs

9.4 LPV-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	8×10^{-16} W/$\sqrt{}_{Hz}$
	Active Aperture	0.75 mm
	Filter	550 nm with 10 nm bandwidth
DETECTOR/ELECTROMETER		
	Type	current-to-voltage
	Gain	$4x10^9$
	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 ± 0.001 Hz
	Q	100
	Type	Built on LMF100 Mode 3 design with 4064 phase locked loop added for increased phase stability
A/D INPUT AMPLIFIER		
	Gain	Software selectable: 1, 2, 4, 8, 16, 32, 64
	Bandwidth	1 to 1000 Hz
	Gain error	± 0.024% maximum
COMPUTER		
	Processor	PIC18F452 from Microchip
	Memory, bytes	1536 RAM, 32K ROM, 256 EEPROM
	I/O	22 lines used
	Real-time Clock	DS1302 with 1F capacitor backup power
	A/D	10 bit, 4µs conversion, 0 to 5.000 volts
	D/A	12 bit, 0-10 V output or 0-5 V output
OPERATING PROGRAM		Programmed in PIC BASIC PRO version 4.5
INPUT CONTROLS		
	power	On-off slide switch
	Interface	4 pushbuttons control all functions

DISPLAY

Type	vacuum-fluorescent
Input	Serial ASCII data at 9600 baud
Operating Temperature	-20° to 70° C
Humidity	0 to 80% RH non-condensing

POWER SUPPLY

Input voltage	12- 14 V DC, reverse voltage protected
Input current	400 ma at 13.8V DC input voltage
Output voltages	+5, +15, -15

SIZE

Telescope	12.8 x 2.9 inches (L x Dia.)
Computer	9 x 8 x 2.4 inches (L x W x H)
Photometer Head	6 X 2.5 x 3.5 inches (L x W x H)

WEIGHT

Telescope	6 lbs
Computer	3 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 $e^{-(Bext \times CP)}$ 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.#_____ = $(CP/WP)^2$ x (WG/CG) x (1/FT) x WT x (1/T) x CR

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

==========

ADDITIONAL COMMENTS

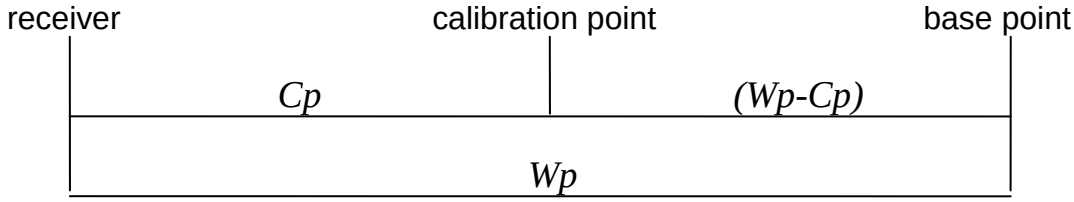
_____

_____

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,

Cp	calibration path distance
Wp	working path
Cr	calibration path reading
Wr	working path reading

basic principals

1) $Tc = e^{-B \cdot Cp}$ calibration path transmission for *Cp*

2) $Tw = e^{-B \cdot Wp}$ working path transmission for *Wp*

3) $Twc = e^{-B(Wp-Cp)}$ differential path transmission for *Wp-Cp*

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

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

4) $\ln Tc = -B \cdot Cp$

5) $\ln Tw = -B \cdot Wp$

6) $\ln Twc = -B(Wp - Cp) = -B \cdot Wp + B \cdot Cp$

note that

7)

$$\ln Twc = \ln Tw - \ln Tc \quad \text{or,}$$

8)

$$\ln Twc = \ln \frac{Tw}{Tc}$$

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

9)

$$E = \frac{Io}{r^2}$$

where E can be considered the raw reading of the receiver unit and Io the transmitter output at a distance of zero, $r = 0$.

In an atmosphere with transmission T at distance r, the above equation can be written as:

10)

$$E = \frac{Io \cdot T}{r^2}$$

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

11)

$$Wr = \frac{Io \cdot Tw}{Wp^2}$$

12)

$$Cr = \frac{Io \cdot Tc}{Cp^2}$$

where Wr and Cr are the raw readings at the working and calibration path distances. Solve for transmission,

13)

$$Tw = \frac{Wr \cdot Wp^2}{Io}$$

14)

$$Tc = \frac{Cr \cdot Cp^2}{Io}$$

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

15)

$$\ln Twc = \ln \left(\frac{\frac{Wr \cdot Wp^2}{Io}}{\frac{Cr \cdot Cp^2}{Io}} \right)$$

16)

$$\ln Twc = \ln \frac{Wr \cdot Wp^2}{Cr \cdot Cp^2}$$

Substitute (16) into equation (6) and solve for B the extinction coefficient for the differential distance $Wp - Cp$ is.

17)

$$B = -\frac{ln \frac{Wr \cdot Wp^2}{Cr \cdot Cp^2}}{Wp - Cp}$$

once B is known and assume to be constant for any path, the transmission for any path can be calculated using the classic equation,

18) $$Tw = e^{-B \cdot Wp}$$

and the calibration number is

19)

$$CAL = \frac{Wr}{Tw}$$

where Wr 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)

$$B = -\frac{ln \frac{Wr \cdot Wp^2 \cdot Cg}{Cr \cdot Cp^2 \cdot Wg}}{Wp - Cp}$$

where Cg is the calibration gain and Wg is the working gain.

Appendix C

ENVIRONMENTAL ENCLOSURE

Either the transmitter projector or the receiver 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.

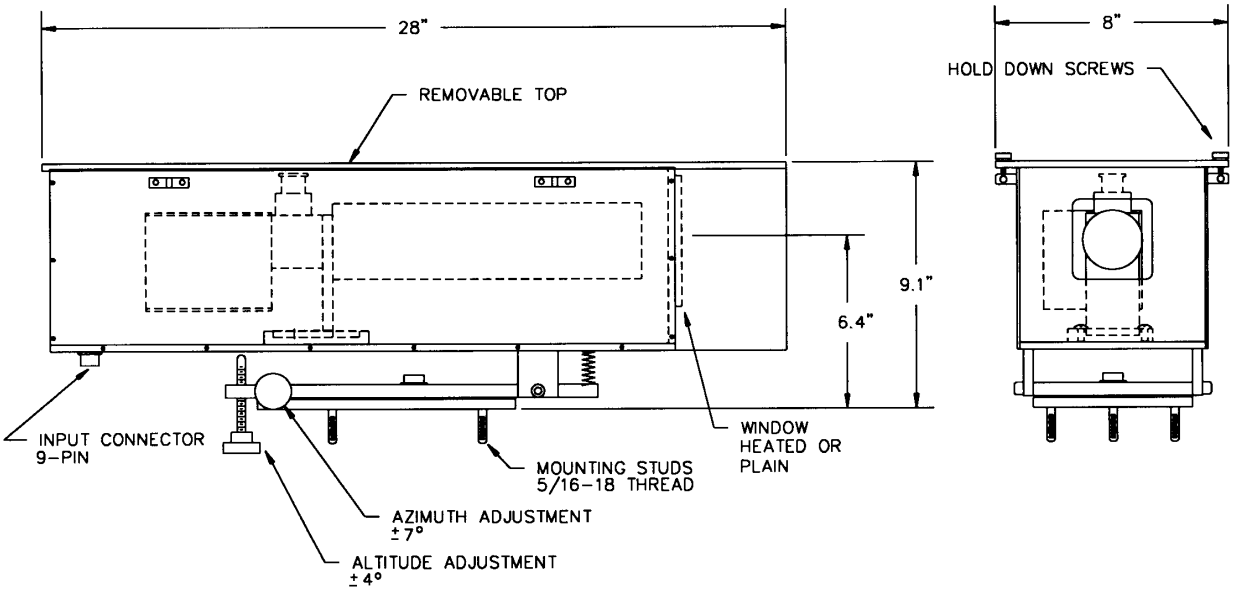
The transmitter projector with integrated control is mounted in the enclosure by means of placing the L bracket within the foot mount located near the center of the enclosure and securing the two pan head machine screws. Two cable connectors are available for power - one for the projector unit and the other for the heated window option. Make sure the telescope view is not blocked by the window or stray cable.

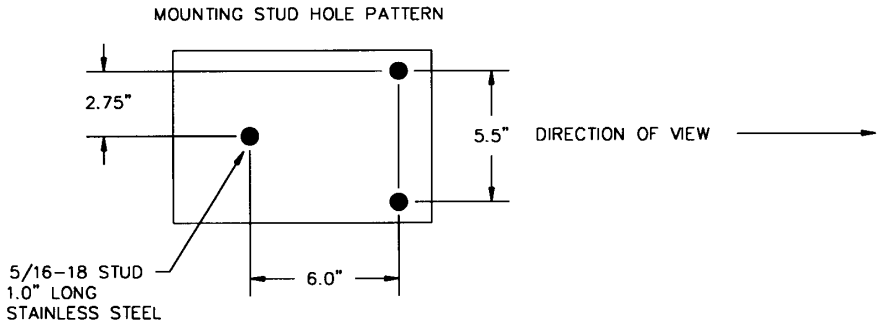
The receiver photometer head with small telescope is mounted in the enclosure by means of placing the L bracket within the foot mount located near the center of the enclosure and securing the two pan head machine screws. Make sure the window or stray cables do not block the telescope view. Connect the available 9-pin connector to the photometer cable and the heated window, if supplied, to the 4-pin connector.

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 a polish which will change the transmission of the glass by an unknown 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

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 60 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 200 feet from the transmitter or receiver units. Of course, the wire size would have to be reduced to 18 or 16 AWG near the units to accommodate the terminals to the circular connector going into the instrument or environmental enclosure. Connect as follows:

Red terminal	+13.8 VDC
Black terminal	13.8 V return

Appendix D

CONNECTOR PIN DEFINITIONS

TRANSMITTER

PIN #	DESCRIPTION
1	NC
2	+10.6 to 15 VDC for LPV-3 +11.0 to 17 VDC for LPV-4
3	Power Return
4	NC

4-Pin Power Input Connector

RECEIVER

PIN #	DESCRIPTION
1	NC
2	+12 to 14 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 Return (Enclosure Option)
8	13.8 V (Enclosure Option)
9	Shield, Case Ground

9-pin Photometer Connector

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

DB-9 RS-232 Interface Connector

Appendix E

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 180-264VAC 50/60 Hz. The unit will supply 13.8±0.3 VDC at up to 10 amps to either the receiver or transmitter unit

Two different output connectors are available depending on distance to the receiver or transmitter. For distances up to 60 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 60 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 200 feet from the transmitter or receiver units. Of course, the wire size would have to be reduced to 18 or 16 AWG near the units to accommodate the terminals to the circular connector going into the instrument or environmental enclosure. Connect as follows:

Red terminal	+13.8 VDC
Black terminal	13.8 V return

Appendix F

WIRING AND CIRCUIT DIAGRAM

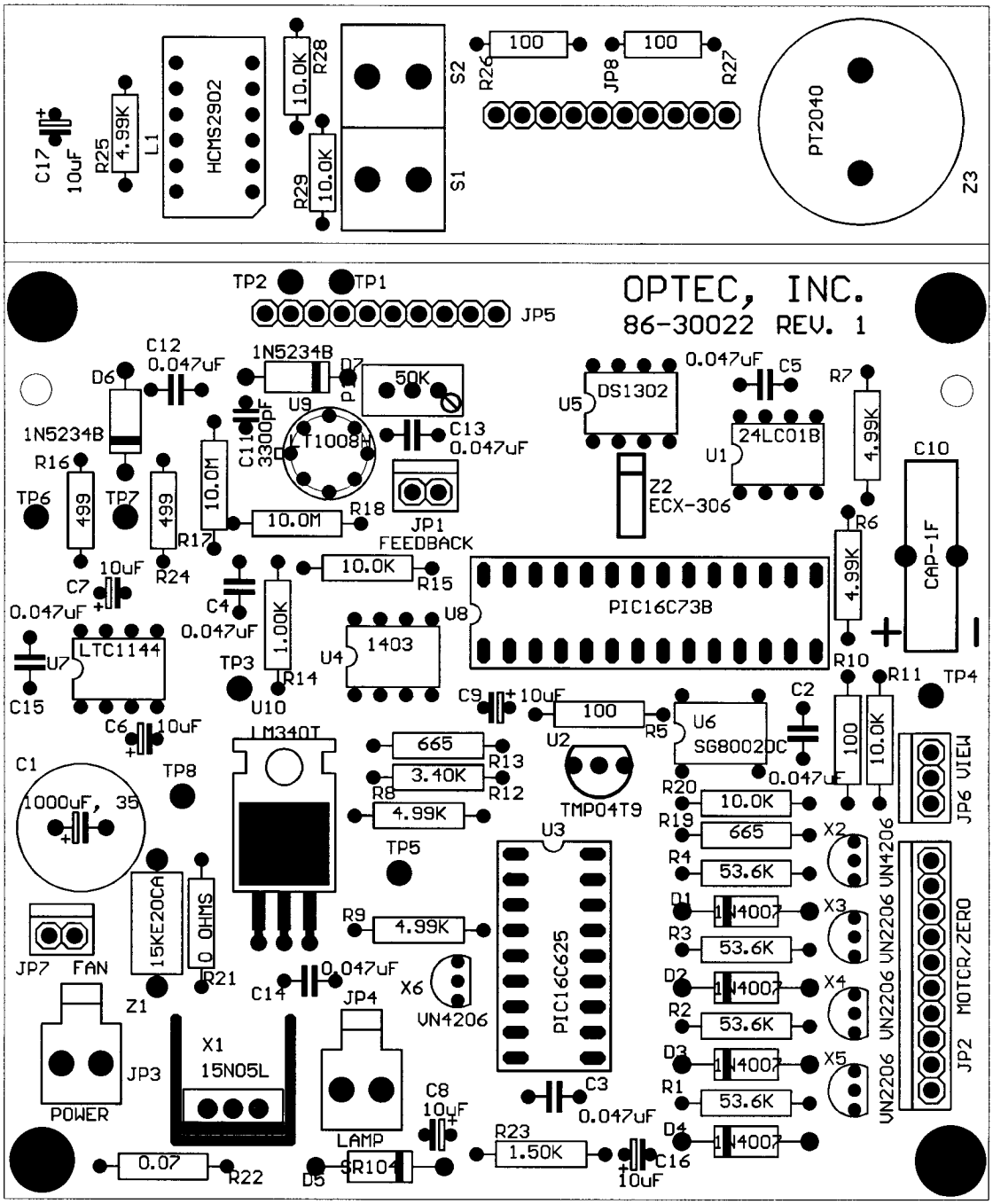


Figure F-1. LPV-3 Transmitter Board Layout.

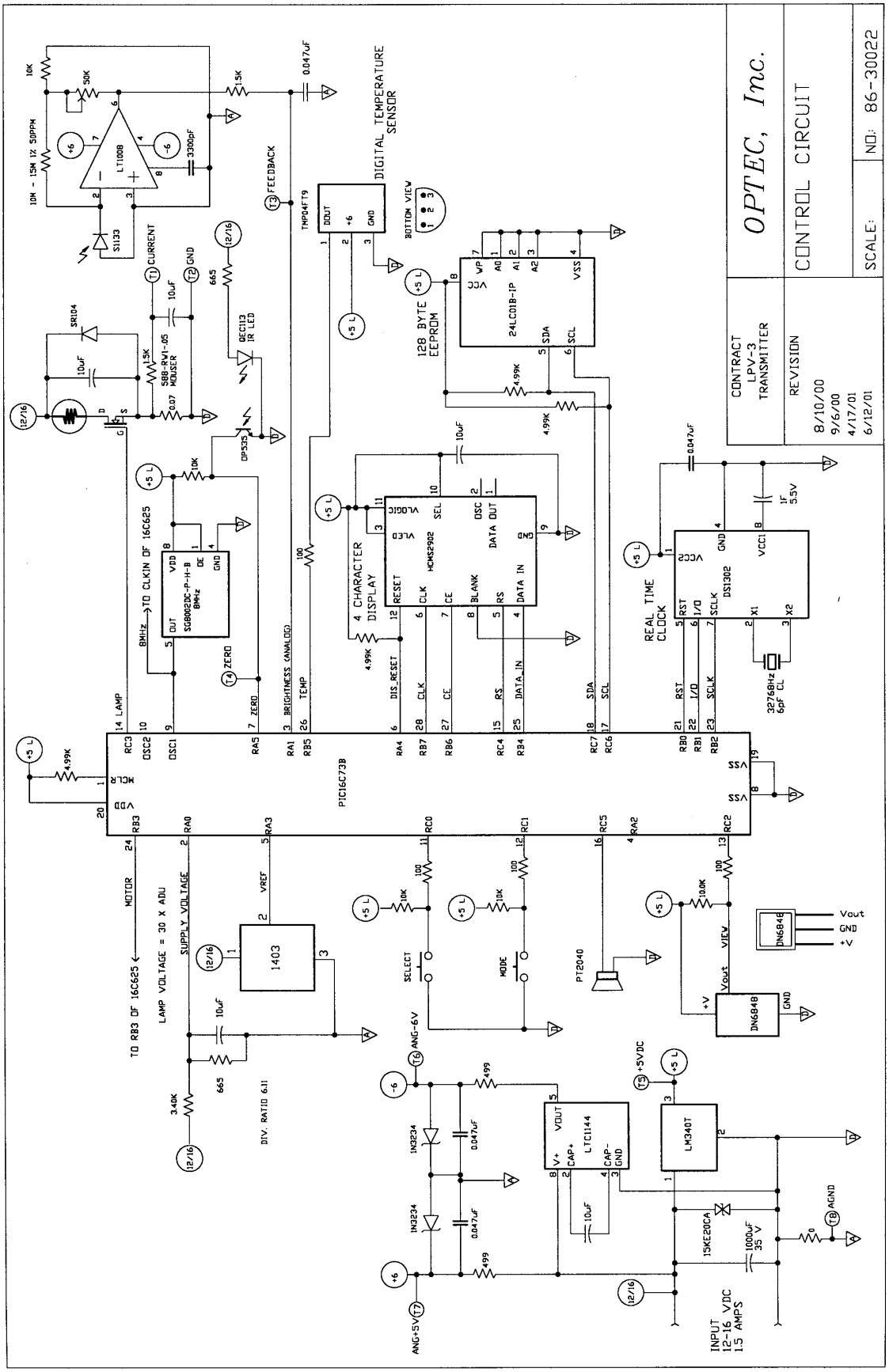


Figure F-2. LPV-3 Transmitter Control Circuit Diagram.

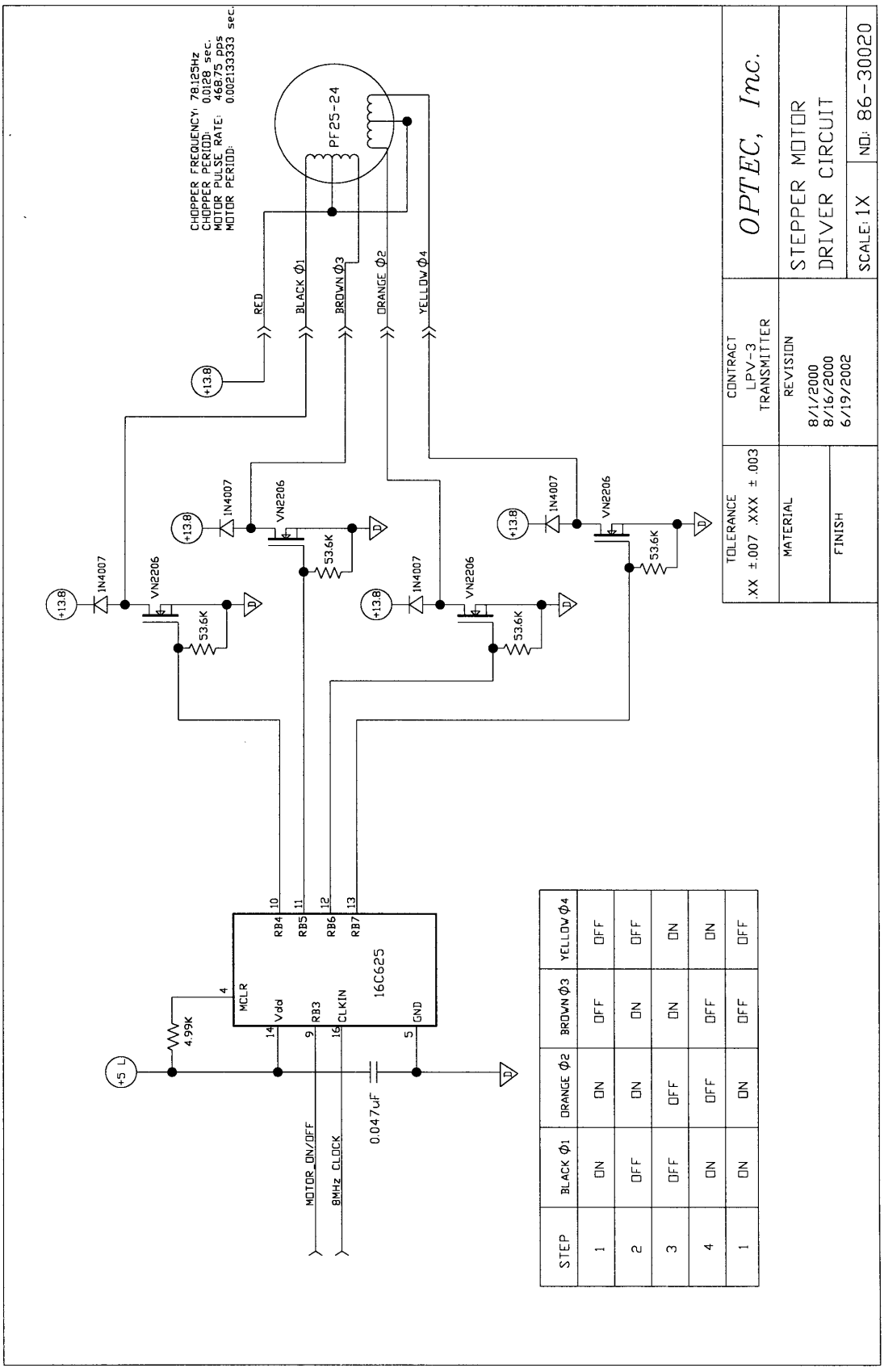


Figure F-3. LPV-3 Transmitter Stepper Motor Control Circuit Diagram.

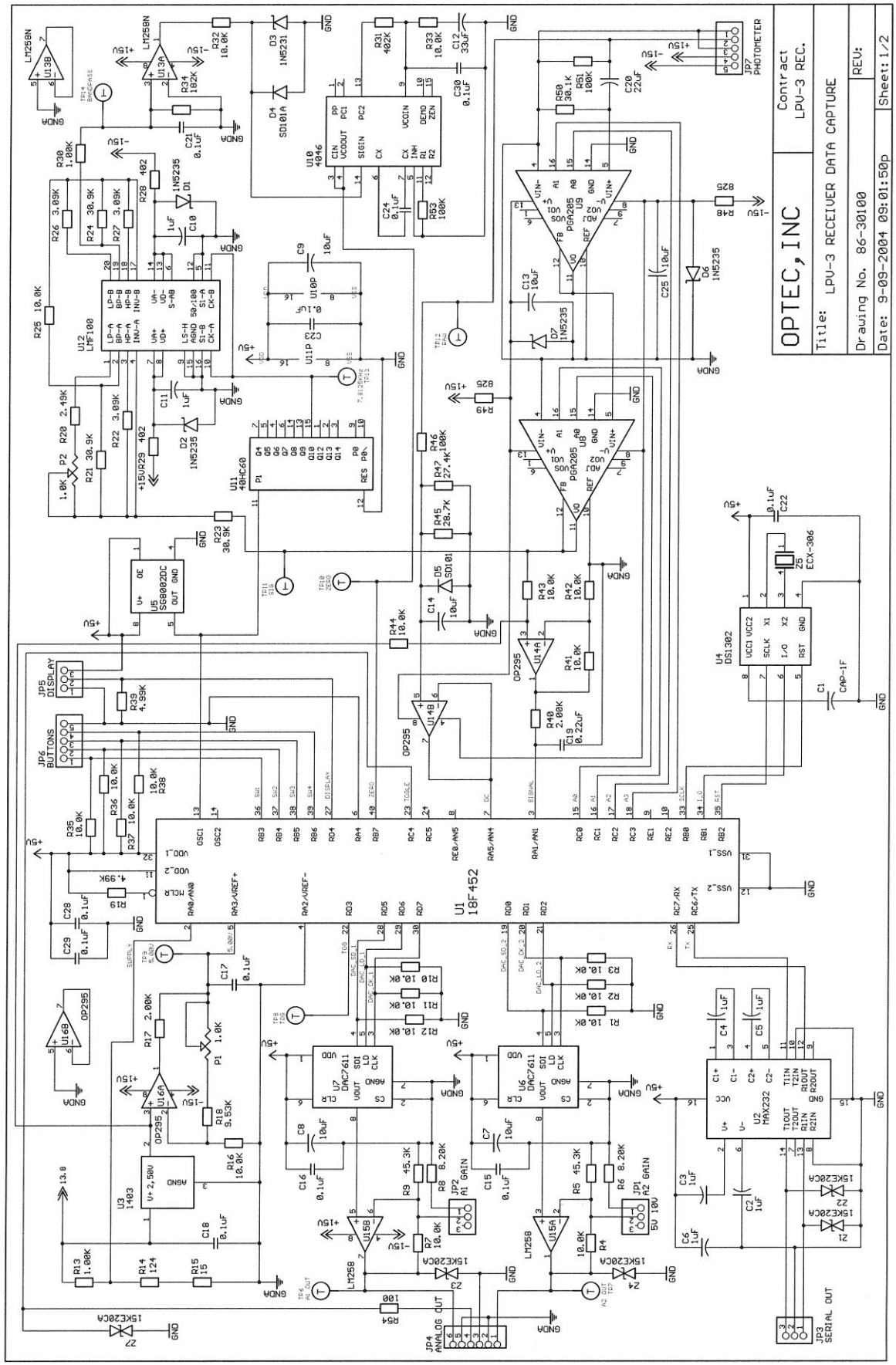


Figure F-4. LPV-3 Receiver Circuit Diagram.

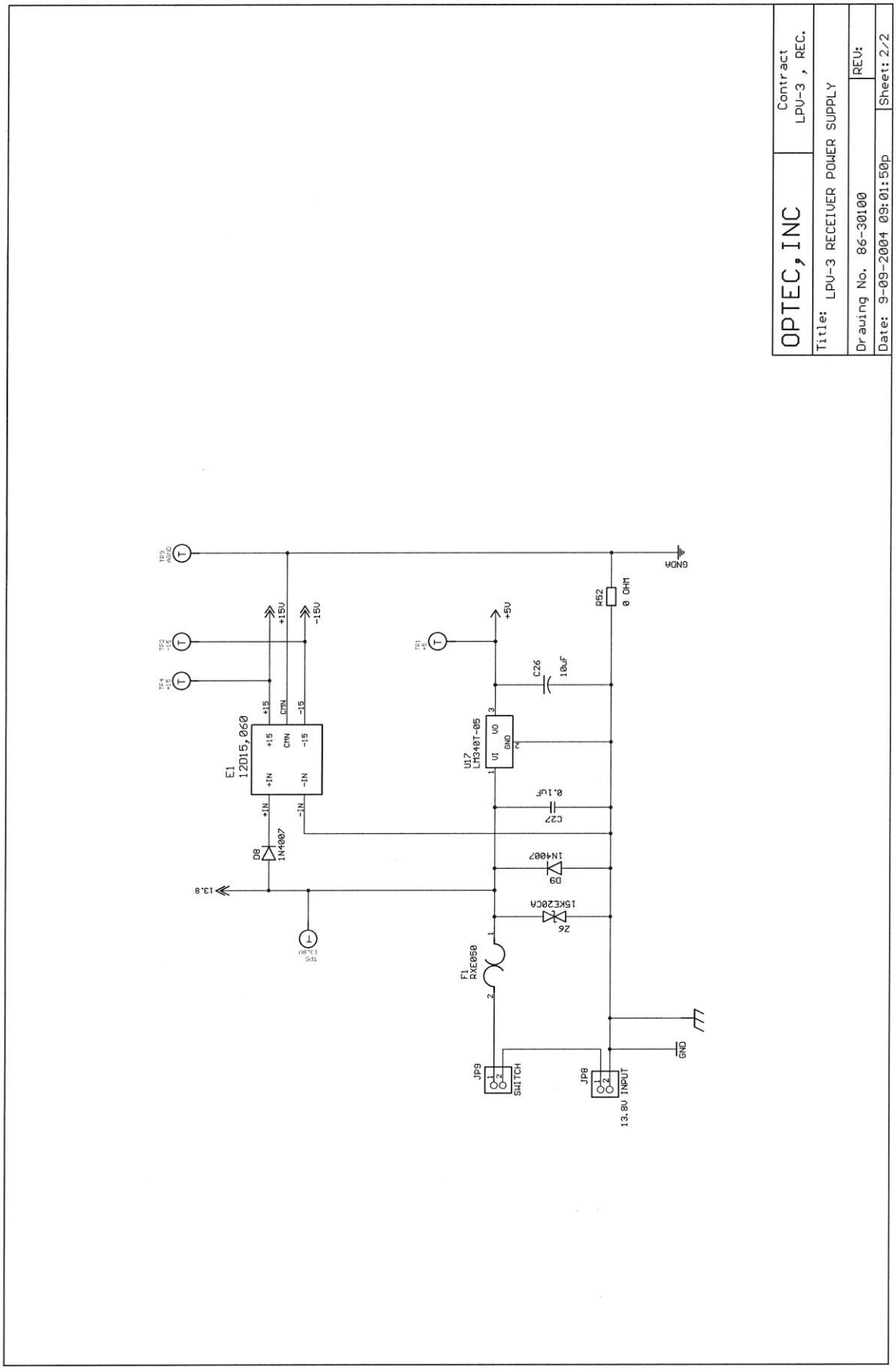


Figure F-5. LPV-3 Receiver Power Supply Circuit Diagram.

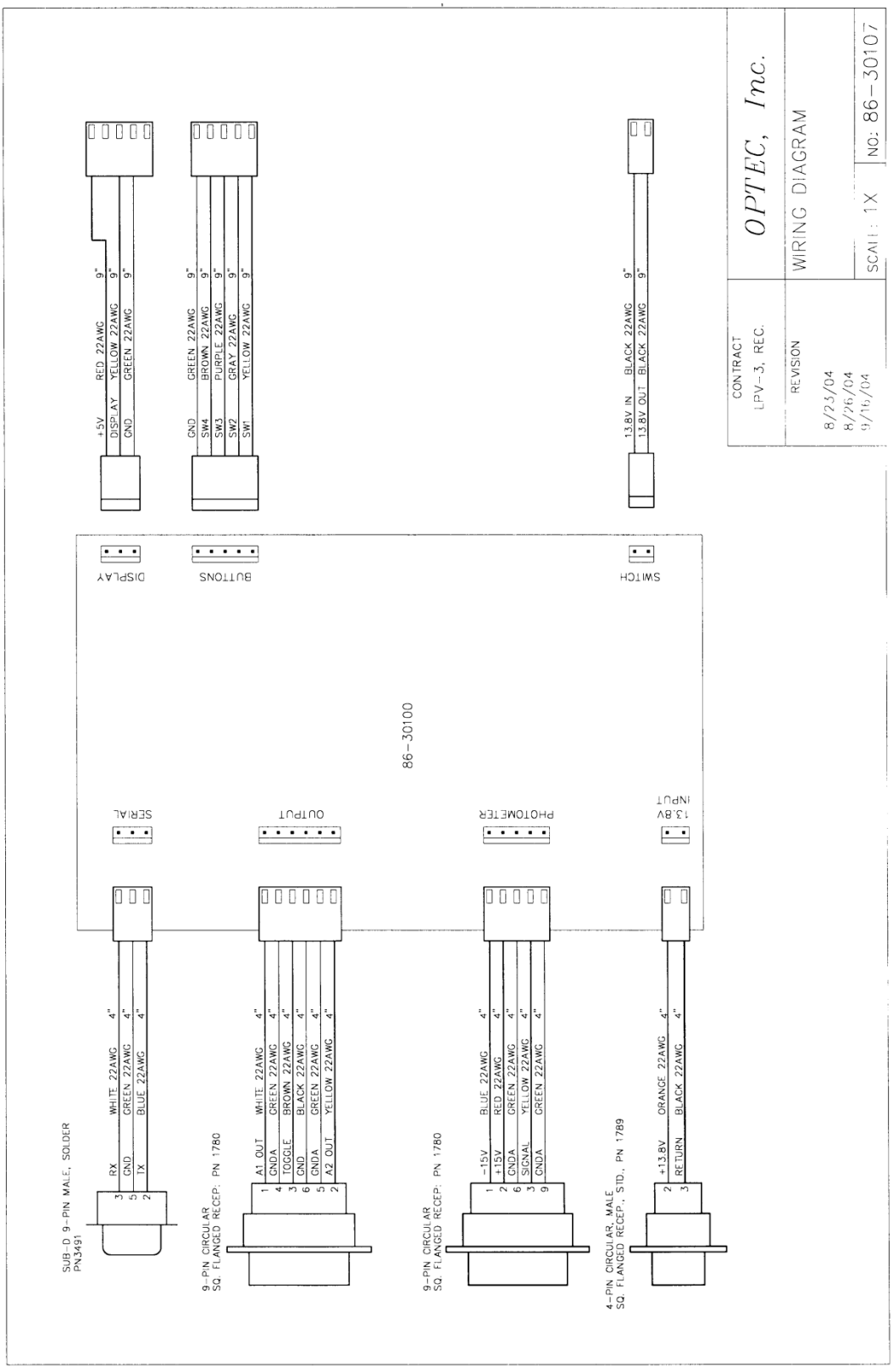


Figure F-6. Wiring Diagram for LPV-3 Receiver.

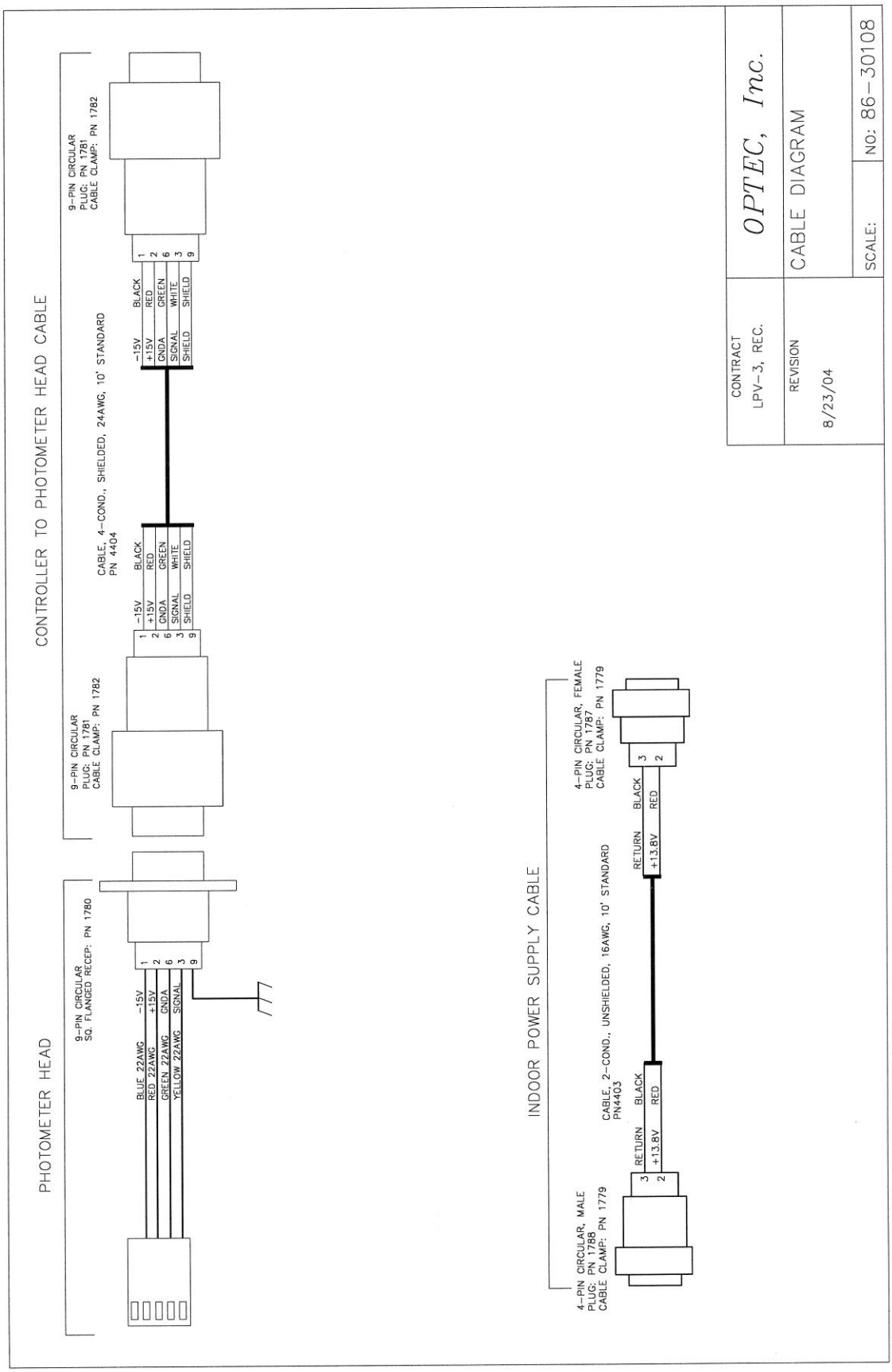


Figure F-7. LPV-3 Receiver Cable Wiring Diagram.

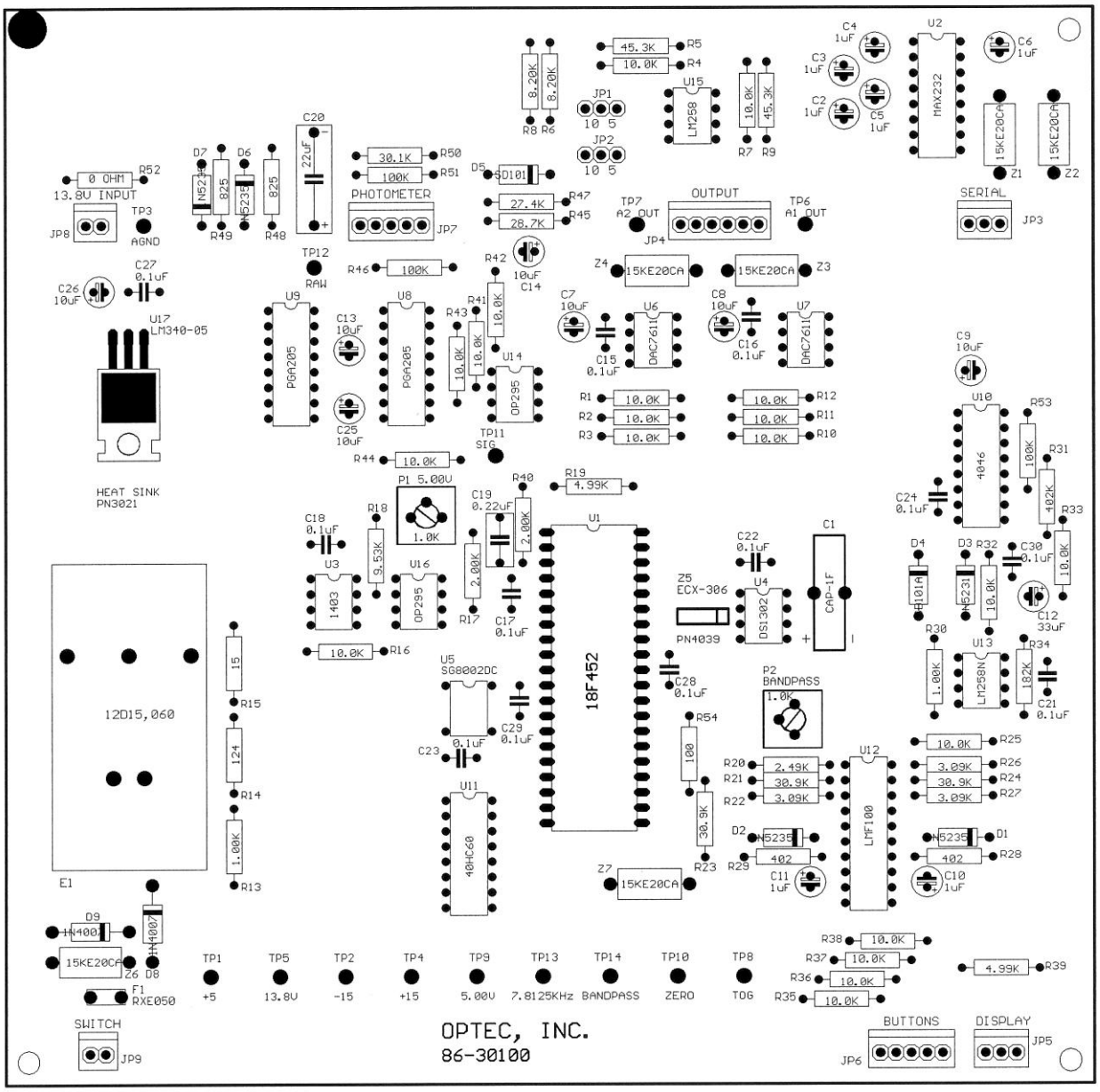


Figure F-8. LPV-3 Receiver Circuit Board Layout.

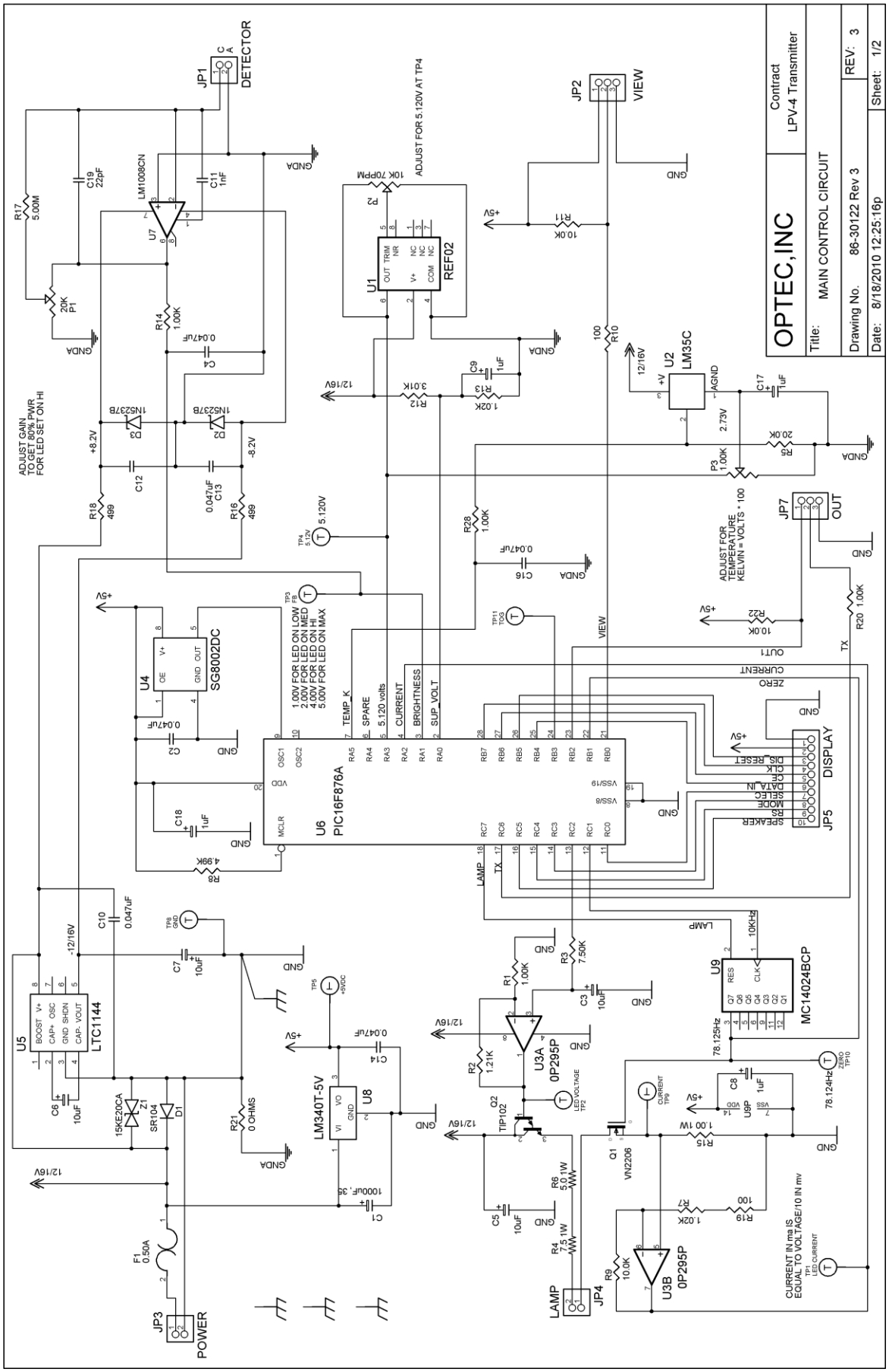


Figure F-9. LPV-4 Transmitter Circuit Diagram – page 1.

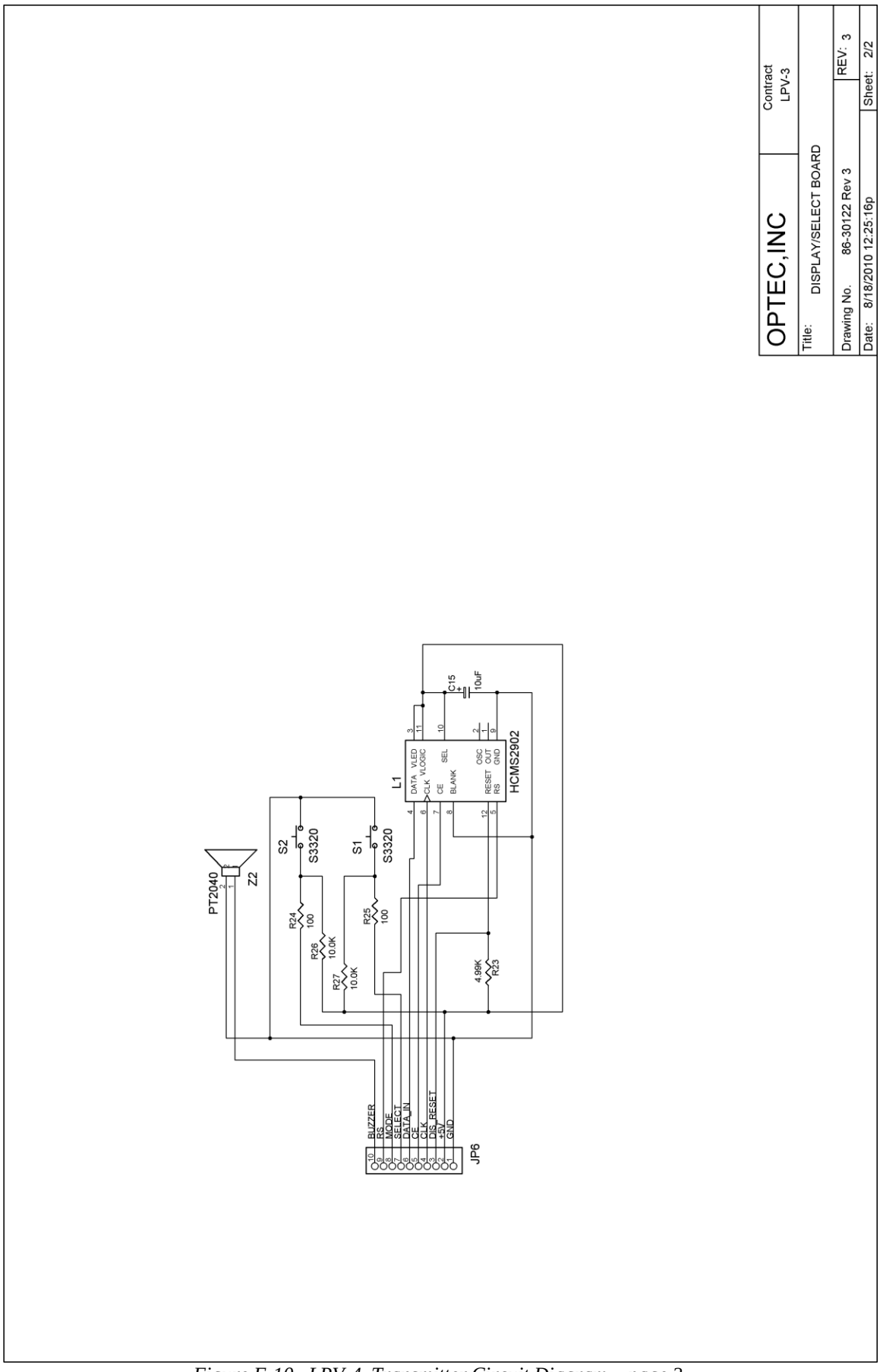


Figure F-10. LPV-4 Transmitter Circuit Diagram – page 2.

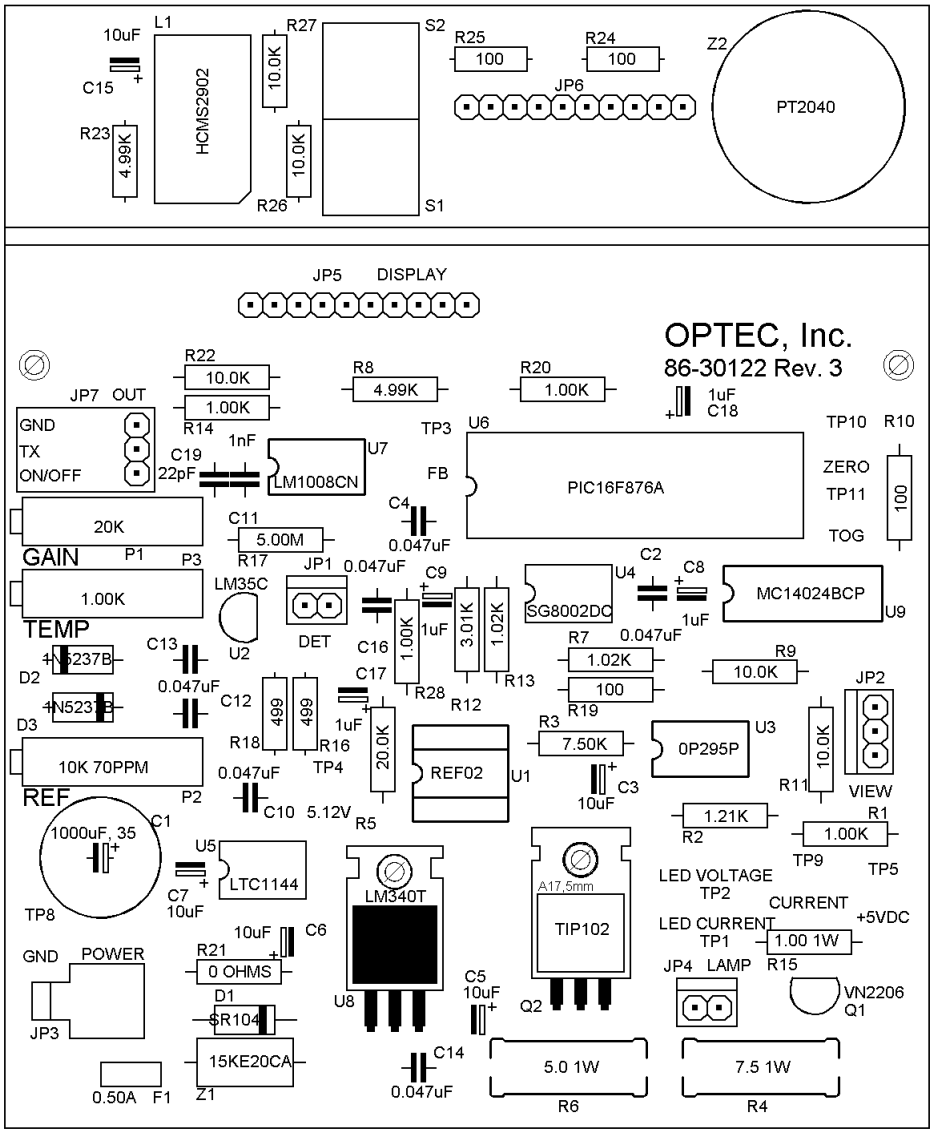


Figure F-11. LPV-4 Transmitter Board Layout.