SECTION IV. THEORY OF OPERATION

6.4.1 INTRODUCTION

This section provides a detailed description of how the visibility sensor functions to calculate the visibility level and detect day/night conditions. The operating principles of the sensor are introduced, followed by simplified block diagram descriptions of the sensor and its components. The theory describes the individual functional areas to a level of detail necessary for the isolation of a faulty FRU.

6.4.2 SIMPLIFIED BLOCK DIAGRAM DESCRIPTION

The following paragraphs describe the basic operation of the visibility sensor. The physical principles upon which the sensor bases it operation are described, followed by a simplified block diagram of the sensor. The simplified block diagram description introduces the basic system components and their functional relationships.

6.4.2.1 **Principles of Operation**. The Belfort visibility sensor is a forward-scatter class sensor that projects a pulsed beam of xenon light into a sample volume of the atmosphere. Aerosols in the illuminated sample region scatter light into a receiver, which looks toward the sample volume at an angle of approximately 45 degrees. It has been empirically shown that the amount of light scattered forward at approximately 45 degrees is proportional to the extinction coefficient regardless of the type or size of scattering media. The spacing of the detector from the transmitter and the optical focusing afford a large unobstructed sample volume (0.75 cubic feet). The downward-looking hoods aid in preventing ice and snow buildup and create an unattractive environment for birds and insects that cause contamination of the optical path. The use of xenon as a light source has several significant advantages. The bulb has an extremely long life expectancy (intensity half-life of 10.5 years). Also, the use of visible light accurately simulates human perception of visibility. The xenon light source has a component of blue light (short wave lengths) that allows scatter to occur from hazes and other small particles that are prevalent under higher visibility conditions. This permits the visibility sensor to report accurately under these conditions as well as during fog, rain, and snow. The optical system includes filtering to reduce the overabundance of blue and ultraviolet light and hence permits proportional levels of radiation at all critical wave lengths to fill the scatter volume.

6.4.2.2 **Visibility Sensor Basic Block Diagram Description**. The basic visibility measuring system is depicted in figure 6.4.1. The six major functional blocks are the transmitter assembly, receiver assembly, day/night assembly, processor board, current sense board, and fiberoptic module. Each functional block is a field replaceable unit (FRU) that can be easily removed and replaced for sensor repairs. All operations of the visibility sensor are directed by the processor board. The processor board sends commands to the transmitter assembly to initiate a flash, and then receives data from the receiver assembly to measure the scattered light. After data are received from the receiver assembly, age detect (part of the transmitter assembly) data, day/night data, and voltage monitor data are collected. The processor board combines all of these data to compute the extinction coefficient to determine visibility and detects daytime or nighttime conditions. The processor board then communicates these results via the fiberoptic module to the DCP. The software that controls the operations of the sensor, runs diagnostics, monitors heater operations, and calculates the proper output values is located on the processor board.

6.4.3 DETAILED BLOCK DIAGRAM DESCRIPTION

The following paragraphs describe the operation of the visibility sensor components to a detailed block diagram level. The simplified version of the operating theory provides the level of detail required to understand the operation of each FRU and is intended to assist the maintenance technician in servicing the unit. The detailed block diagram is provided in figure 6.4.2. The functional operation of each component is depicted and point-to-point signal wiring is shown.

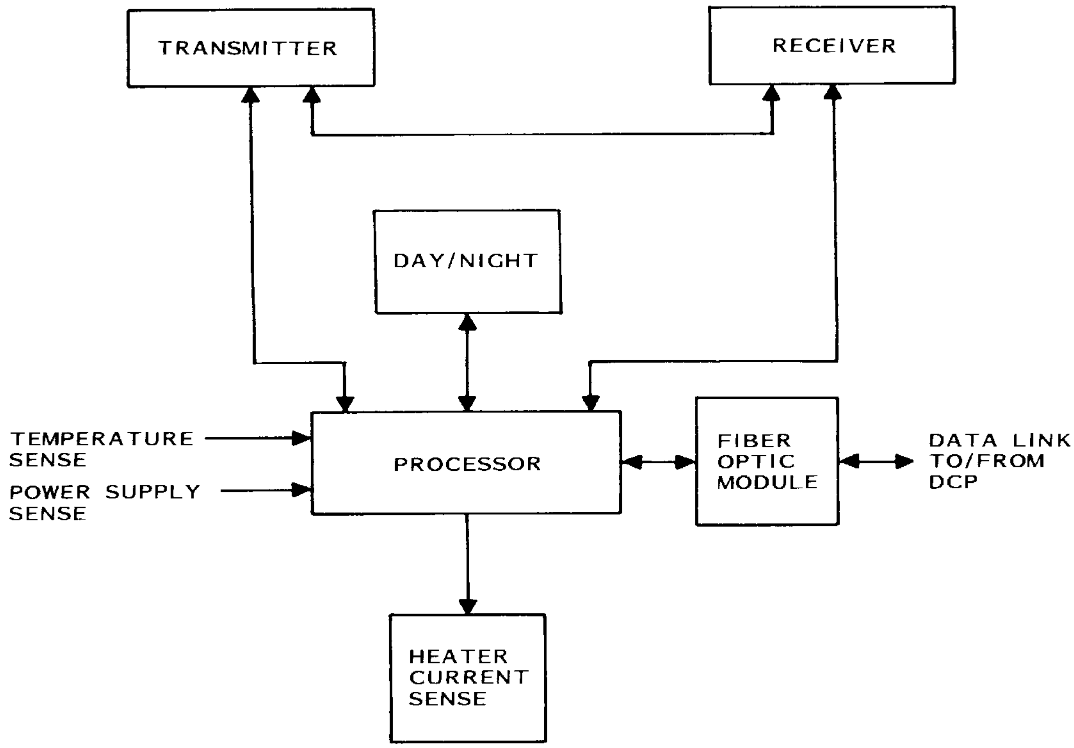

Figure 6.4.1. Visibility Sensor Basic Block Diagram

6.4.3.1 **Transmitter Assembly**. The transmitter assembly flashes a xenon flashlamp at a 2 Hz rate. The high voltage switching supply (located in the transmitter assembly) charges the energy storage (a storage capacitor) to full voltage. The trigger circuit sends a signal to the light pack to fire the xenon flashlamp. Light from the flashlamp is received by two detectors: the receiver assembly (paragraph 6.4.3.2) and the photodarlington transistor. The timing for the receiver sample is initiated by the photodarlington transistor, which outputs an electrical pulse when the xenon flash is generated. The photodarlington transistor output signal is used by the receiver assembly to detect the scattered light. Separate heater elements for the window and the hood are also provided in the transmitter assembly.

6.4.3.2 **Receiver Assembly**. The receiver assembly is used to detect the forward scattered light level from transmitted flashes and report the data to the controller board. The receiver diode receives scattered light from the sample volume through a lens. The light pulse strikes the receiver diode, causing the diode to create an electrical pulse proportional to the amplitude and duration of the scattered light pulse. The electrical signal from the diode is bandpass filtered and amplified and then input to a sample and hold circuit. The logic input to the sample and hold circuit is timed to catch the received signal at its peak. The sample and hold circuit is normally in the sample mode. The trigger signal from the transmitter assembly, created from the xenon light pulse, places the sample and hold circuit in the hold mode where it can take the light measurement. Once the received pulse is sampled at the peak of the signal and held there by the sample and hold circuit, an analog-to-digital converter transforms the voltage level into a digital value. The measured data is loaded into a first-in first-out (FIFO) memory, which, when full, is read by the processor board through a serial data interface for further processing. The processor board then places the sample and hold circuit back into the sample mode. After 33.3 milliseconds, the sample and hold circuit returns to the hold mode to measure the background (dark) light. The new data are then read in the same manner. Both light and dark measurements are required to calculate the extinction coefficient. This procedure is repeated for every flash. Separate heater elements for the window and the hood are also provided in the receiver assembly.

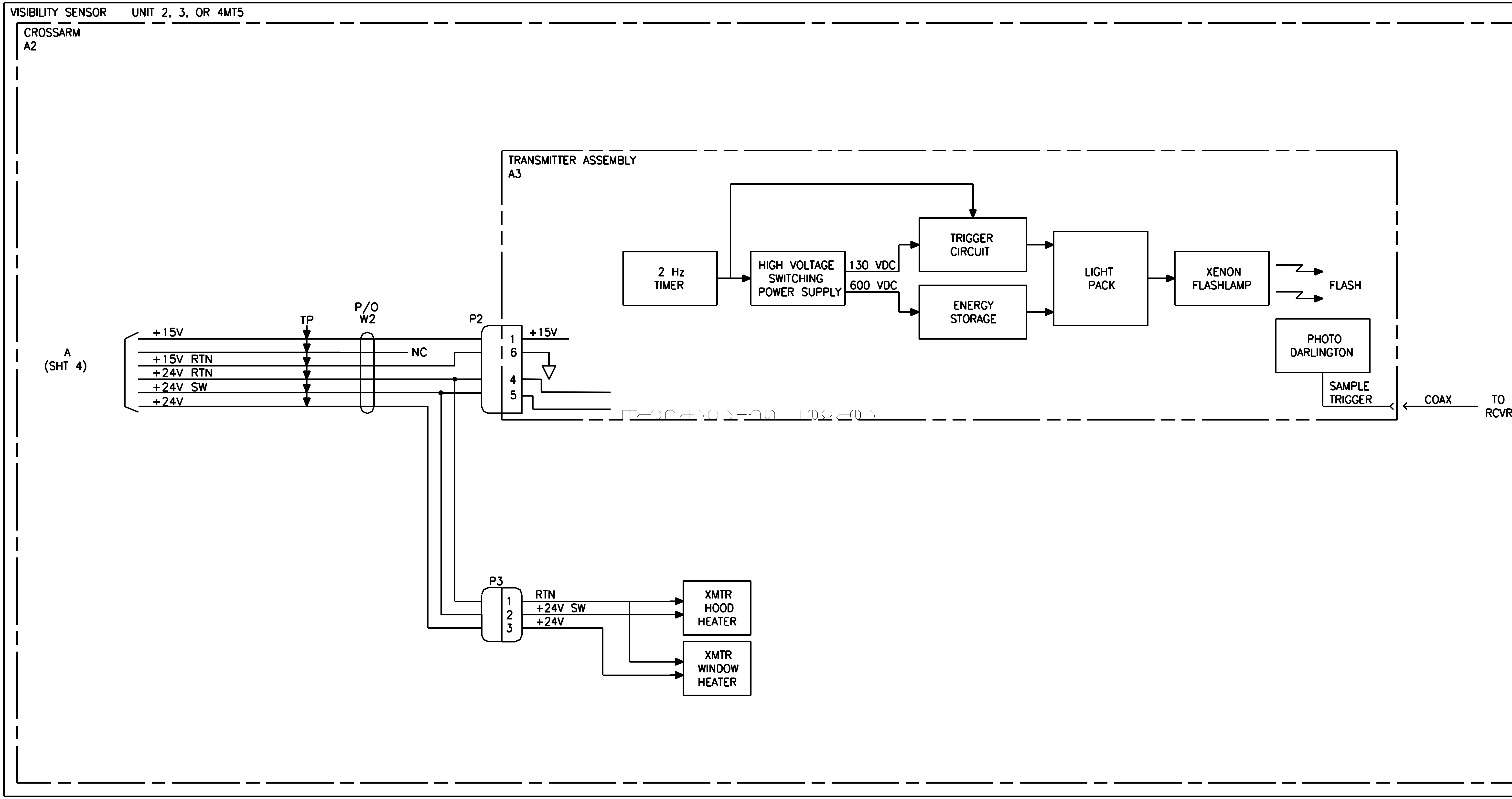

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Figure 6.4.2. Visibility Sensor Detailed Block Diagram (Sheet 1 of 4)

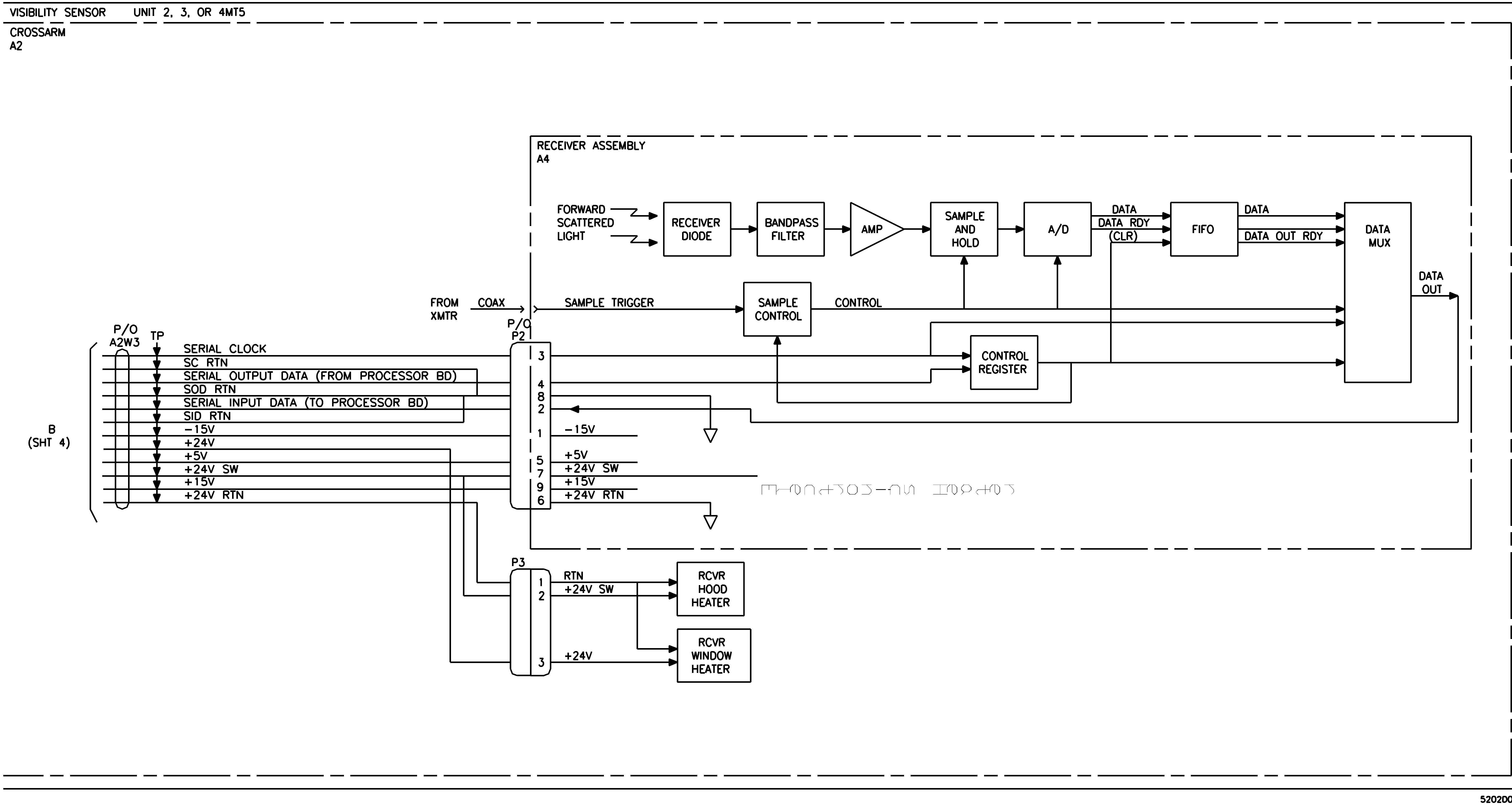


Figure 6.4.2. Visibility Sensor Detailed Block Diagram (Sheet 2)

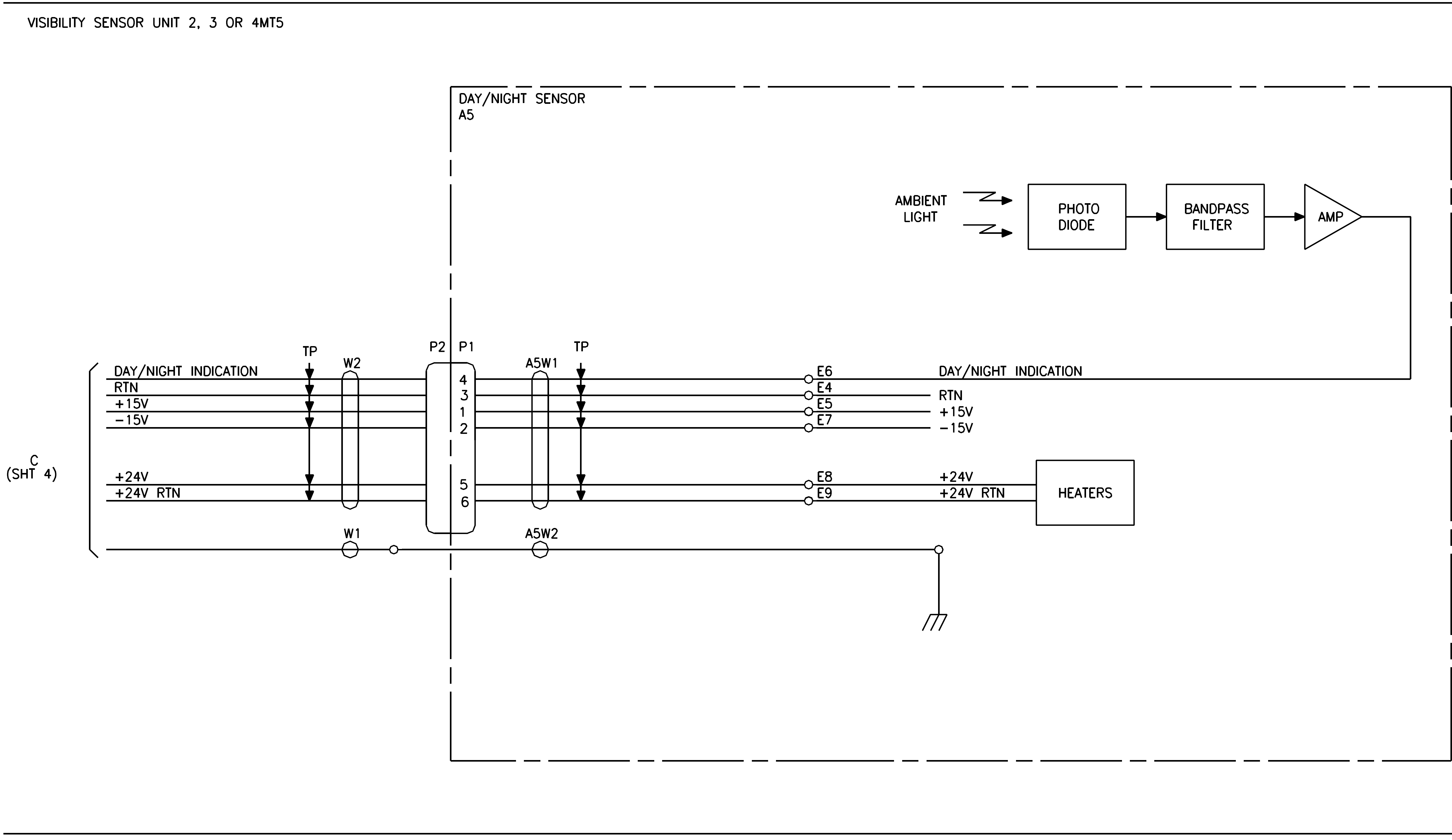
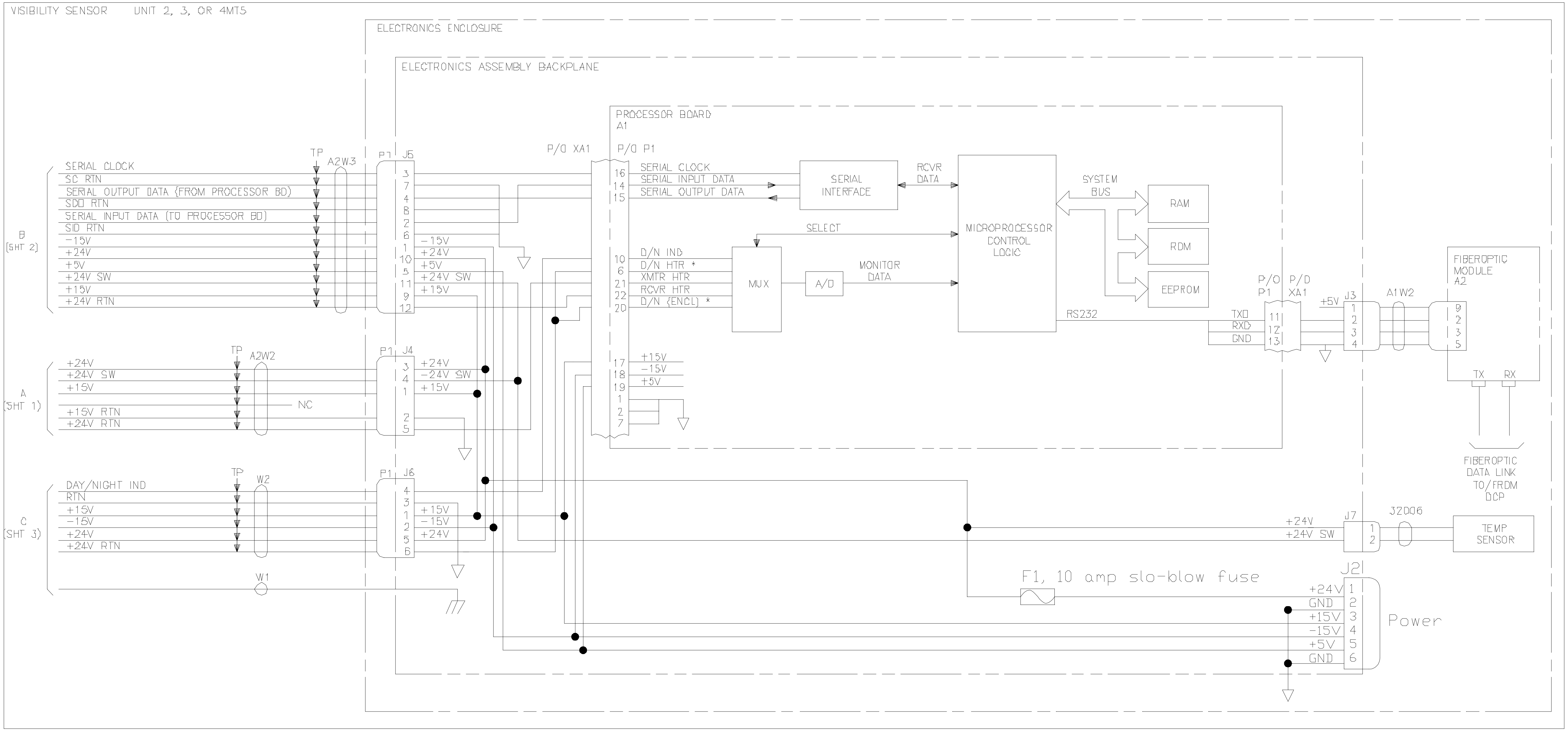


Figure 6.4.2. Visibility Sensor Detailed Block Diagram (Sheet 3)



5202011

* P1-6 IS UNUSED FOR 32194-1, -2 AND DAY/NIGHT HEATER
RETURN FOR 32194-3 AND -4
P1-20 IS DAY/NIGHT HEATER RETURN FOR 32194-1, -2
AND ENCLOSURE HEATER RETURN FOR 32194-3 AND -4

Figure 6.4.2. Visibility Sensor Detailed Block Diagram (Sheet 4)

6.4.3.3 **Day/Night Assembly**. The day/night assembly is essentially an ambient light photometer. It detects light using a PIN receiver diode in the assembly such that light is received from the sky with a 6-degree viewing angle. The day/night receiver diode receives light through a window (not a lens) mounted in the day/night assembly. The light strikes the day/night receiver diode, causing the diode to create an electrical signal proportional to the amplitude of the ambient light. The electrical signal is then bandpass filtered and amplified. The voltage signal is then sent to the processor board for further processing. Separate heater elements for the window and the hood are also provided in the day/night assembly.

6.4.3.4 **Processor Board**. The processor board directs all of the actions of the visibility sensor. Its primary task is to take measurements of the sample volume and calculate the visibility extinction coefficient and day/night condition.

The extinction coefficient for the sample volume of atmosphere is proportional to the ratio of light energy received by the receiver diode to the light energy input to the sample volume by the xenon flash transmitter. Two measurements are performed during each sample cycle (½ second). During the first measurement (the light measurement), the transmitter sends a trigger signal to the receiver assembly as the flashlamp fires. The sample and hold circuit in the receiver assembly responds to the trigger signal to latch the receiver signal at its peak. This peak level is converted into a digital value that is read by the processor. The data collected during this first measurement period are directly proportional to the amount of light that was scattered into the receiver.

During the second measurement (the dark measurement), the sample and hold is returned to the sample mode by the processor. In the absence of the flash (no scattered signal reaching the receiver), the receiver level is sampled and held. This measurement is then converted to a digital form and read by the processor. The receiver data collected during this second measurement period are directly proportional to the amount of ambient background light (background noise) that was observed by the receiver. The difference between the two measurements is used to determine extinction coefficient. The subtraction cancels the effects of any possible offsets in the receiver assembly. The day/night signal is converted to digital form on the processor board. The processor uses the day/night data to determine if the ambient light indicates day. The day/night sensor always indicates day for illumination greater than 3 fc, and always indicates night for illumination less than 0.5 fc. The transition from indicating day to indicating night occurs once in the region from 3 to 0.5 fc (as illumination decreases). The transition from indicating night to indicating day occurs once in the region from 0.5 to 3 fc (as illumination increases). The day/night assembly is calibrated before installation. Two calibration factors are supplied with the calibrated day/night assembly: edge of day, which indicates the transition point for daytime, and edge of night, which indicates the transition point for nighttime.

The processor board also monitors the operation of the heaters. The board monitors the electrical current levels used by the heaters. The signals sensed indicate whether the associated heater element is on or off. When it is cold enough for the heaters to turn on (temperatures less than 40 degrees Fahrenheit), the heaters cycle on and off. The processor periodically verifies the operation of the heaters as a part of its normal processing.

6.4.3.5 **Fiberoptic Module**. A fiberoptic link provides for two-way serial communication between the visibility sensor and the DCP. The fiberoptic module performs the electrical-to-optical and optical-to-electrical conversions required. The electrical interface between the controller board and the fiberoptic module is an RS-232C serial interface. The fiberoptic link with the DCP consists of separate transmit and receive optic fibers.

6.4.3.6 **Power Distribution**. Both ac and dc power are present in the visibility sensor electronics enclosure (Figure 6.4.3). If one filter protrudes from the top of the power input box, the sensor is a one-filter configuration as illustrated on figure 6.4.3, sheet 2. If two filters protrude from the top of the power input box as illustrated on figure 6.4.3, sheet 1, the sensor is a two-filter configuration. DCP cables are connected to the sensor in an identical manner for either configuration. Two types of ac power are applied from the

DCP: electronics ac and heater ac. The electronics ac power is passed through surge suppression and EMI filter circuits and is applied to electronics power supply PS1. The ±15 vdc and +5 vdc output by the electronics power supply are applied to the sensor electronics via the electronics assembly. The heater ac power is passed through surge suppression and EMI filter circuits and applied to the heater power supply. The +24 vdc output of the heater power supply is applied to the electronics assembly where it is distributed to all of the heaters.

Take note that the F2 fuse in figure 6.4.3 is a ¼ amp fast blow fuse. Furthermore, the S1 temperature sensor in figure 6.4.3 is a cut-off switch that will open at 30°F and closes at 50°F. Should the electronics enclosure drop below 30°F, all power to the sensor will be terminated.

6.4.4 **COMMAND DESCRIPTION**

The visibility sensor responds to V commands issued by the DCP during normal operation and by the technician during calibration. The following paragraphs describe visibility sensor commands.

6.4.4.1 **Quick Reference**.

6.4.4.1.1 **Polled Mode**.

a. The V1 command reports sensor status, extinction coefficient, and day/night status.

b. The VL command reports sensor serial number; sensor status; day/night status; enclosure temperature; flash, dark, and day/night measurements; visibility in miles; and extinction coefficient in inverse kilometers.

6.4.4.1.2 **Continuous Output Mode**. The VP command sets the delay between output messages (delay of zero = >off) that report the measurement values of the most recent sample, visibility in miles, and extinction coefficient in inverse kilometers.

6.4.4.1.3 **Other**.

a. V0 displays sensor status and current firmware revision.

b. V2 is used as a communications check, causing known and unchanging values for extinction coefficient to be reported.

c. V3 is used to enter heater calibration mode. (Refer to table 6.5.3, step 9.)

d. V4 enables/disables the data quality algorithm.

e. VD calculates the standard deviation of the sensor's "zero drift".

f. VF allows the entry/modification of calibration coefficients and configuration information.

g. VH allows the entry/modification of initialization coefficients.

h. VG invokes extended diagnostics.

I. VE clears and initializes the EEPROM (nonvolatile RAM).

NOTE

If VE is performed, the sensor must be recalibrated unless calibration constants have been recorded otherwise (i.e., written down) and known to have not changed. The calibration constants must be reentered after VE or the sensor will not operate properly.

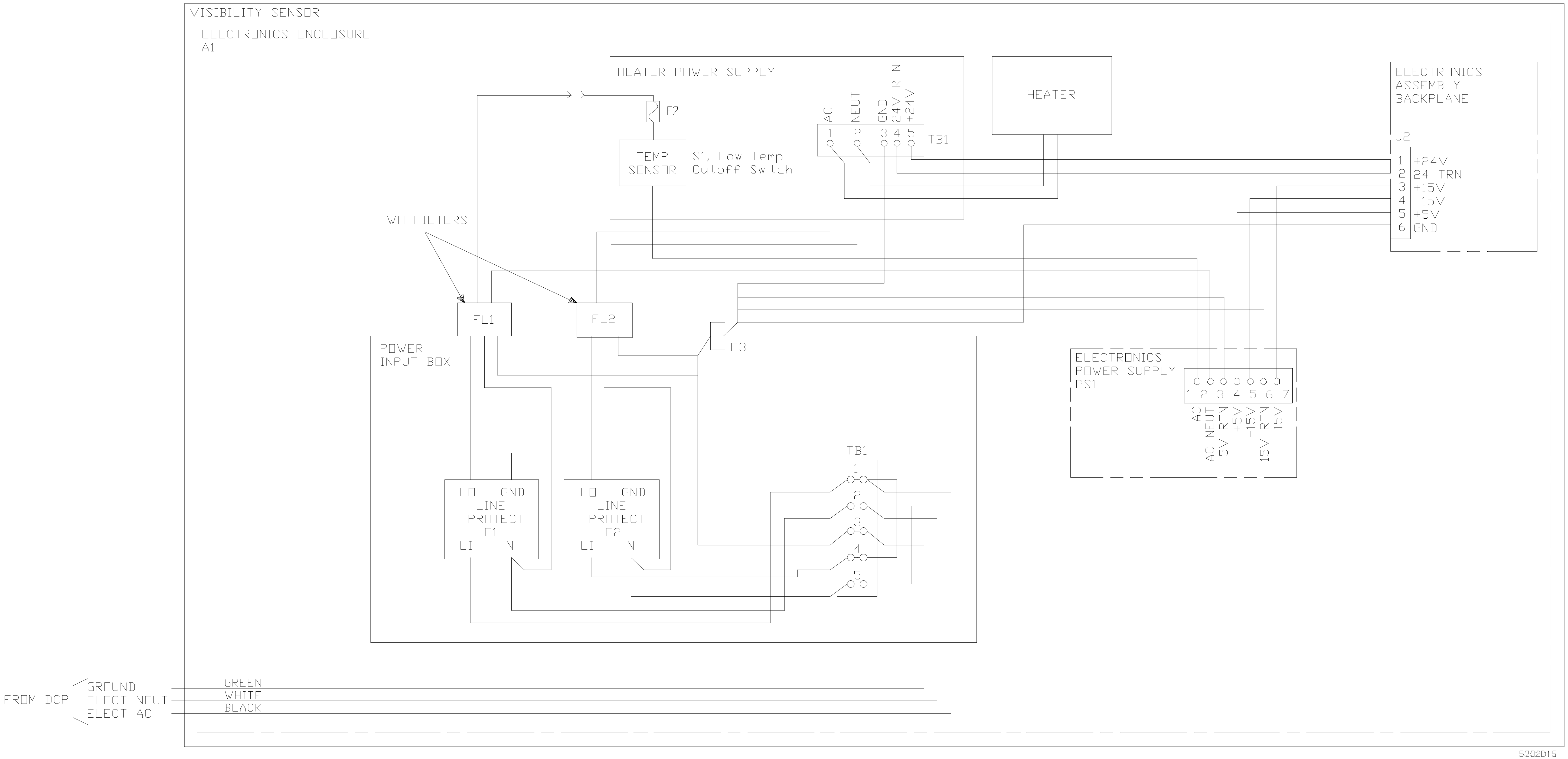


Figure 6.4.3. Visibility Sensor Electronics Enclosure Power Distribution Diagram (Sheet 1 of 2)

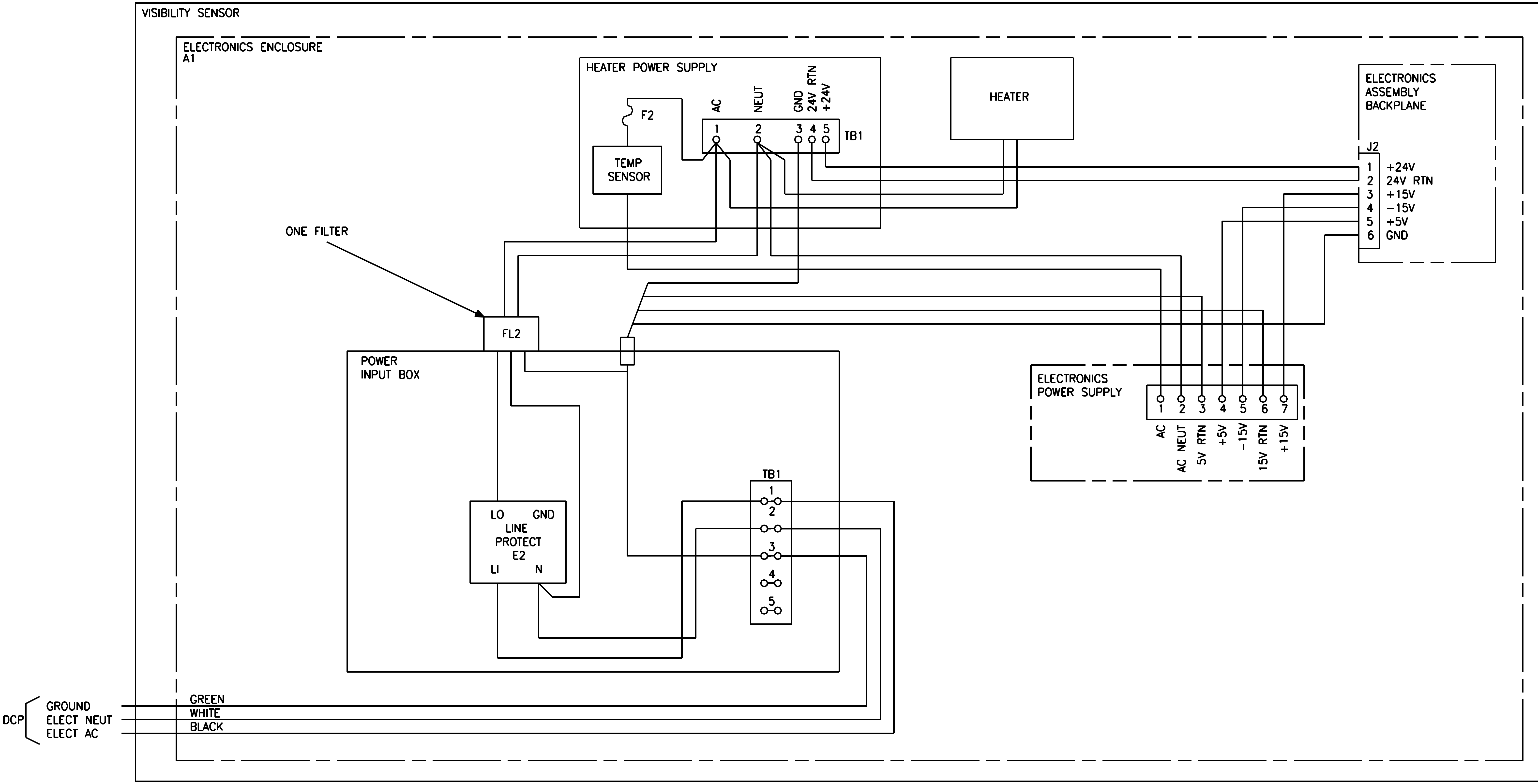


Figure 6.4.3. Visibility Sensor Electronics Enclosure Power Distribution Diagram (Sheet 2)

6.4.4.2 **Power Up/Reset Message**.

VIS VER 021

Total message length is 21 characters. The time for total message transmission at 2400 bps is 0.07 second.

6.4.4.3 **V0 Command (Roll Call)**.

Byte	Description	Value
1	Start of transmission	STX
2	Carriage return	CR
3	Line feed	LF
4	Sensor identification	V
5	Sensor status	P/F
6-8	ROM version	XXX
9-10	Checksum (in ASCII)	CHECKSUM
11	End of transmission	ETX
12	Carriage return	CR
13	Line feed	LF

Total message length is 13 characters. A sensor status of P indicates that the sensor has passed all diagnostic tests. A sensor status of F indicates that the sensor has failed one or more diagnostic tests. More information as to the nature of the failure is available by sending a VG command to the sensor.

6.4.4.4 **V1 Command (Extinction Coefficient)**.

Byte	Description	Value
1	Start of transmission	STX
2	Carriage return	CR
3	Line feed	LF
4	Sensor ID	V
5	Sensor status	P/F
6-10	Extinction coefficient	XXX.X
11	Day/night status	D/N
12-13	Checksum (in ASCII)	CHECKSUM
14	End of transmission	ETX
15	Carriage return	CR
16	Line feed	LF

The total message length is 16 characters. The extinction coefficient consists of five characters including the number and the decimal point. The position of the decimal point shifts, depending on the value of extinction coefficient to yield the most accurate reading in the available space. The extinction coefficient range is 186.4/km (52.8 feet) to 0.018/km (100 miles).

6.4.4.5 **V2 Command (Simulated Data)**.

Byte	Description	Value
1	Start of transmission	STX
2	Carriage return	CR
3	Line feed	LF
4	Sensor ID	V
5	Sensor status	P/F
6-10	Extinction coefficient	12.34

Byte	Description	Value
11	Simulated day/night status D	
12-13	Checksum (in ASCII)	CHECKSUM
14	End of transmission	ETX
15	Carriage return	CR
16	Line feed	LF

The total message length is 16 characters. This message is constant except that the sensor status reports the actual pass/fail status of the instrument to avoid confusion.

6.4.4.6 **V4 Command (Data Quality)**.

Data quality? (Y or N)[Y]>Y
New Cksum=9f
Old Cksum=9f
---> End of v4 >---
****

This command is used to enable or disable the use of the data quality algorithm during visibility measurements. This data quality algorithm is designed to ignore errant readings that are caused by debris passing through the scatter volume temporarily (e.g., windblown leaves, windblown snow, birds, etc). The data quality algorithm causes the sensor to appear stuck temporarily if there is a sudden and significant change in ambient visibility but the sensor output data conform to the actual conditions within a 3-minute period.

6.4.4.7 **VD Command (Standard Deviation of Zero Drift)**. The firmware includes a function that calculates the standard deviation of the sensor indication about zero when in the zero state. This is the best possible means of determining zero drift and, thus, the overall accuracy of the individual instrument. The VD command calculates the standard deviation of a number of zero state samples. The number of samples is selecTable in the range of 2 to 65,535 with 120 samples as the default. To invoke VD, the opaque filter is placed on the receiver and the instrument is allowed to settle for at least 3 minutes. After settling time, the technician types VD. When prompted for the number of samples, the desired number is entered or ENTER is pressed to accept the default. The function then displays a countdown of the samples being used for the calculation. The results of the VD command are std_dev and VIS. std_dev is the calculated standard deviation of zero drift, which is consistent with the classical mathematical definition. VIS is the maximum visibility (in miles) at which there is a 90-percent statistical probability of being 10 percent accurate. The VIS output of the VD command should be no less than 100 miles. The value of FI calculated by the VZ command should be in the range of +1.0 to -1.0.

NOTE

It is normal for the extinction coefficient and visibility readings to go negative when in the zero state. This does not happen in actual ambient visibility and should not be construed as a malfunction of the device.

6.4.4.8 **VD Command (Calibration Coefficients/Configuration Information)**. The VF command, invoked by typing VF, allows the technician to enter the calibration coefficients and configuration information required for proper operation. The VF command responds as follows:

****
E2PROM chk_sum = 0

E0 = 19.399999...==>
F0 = 1.000000...==>

```
WINDOW = 113.999999...==>
VIS_SER_NO?    1...==>
Day/Night installed? (Y or N)[Y]>
Heaters installed? (Y or N)[Y]>
-------------------------------------
E0 = 19.399999
F0 = 1.000000
WINDOW = 113.999999
VIS_SER_NO = 1
D/N installed = Y
Htrs installed = Y
New Cksum=9f
Old Cksum=9f
---> End of vF <---
*************************************
```

a. E0 is the factory-initialized value for the standard extinction coefficient obtained from the calibration filter/scatter plate set. E0 is changed only when a new scatter plate/filter combination is used.

b. F0 is the factory-initialized value for the extinction coefficient adjustment factor. F0 is changed only when an FRU replacement calibration is performed. F0 is not used for measurement calculations; it is for reference only.

c. WINDOW is the time constant (in seconds) of the window averaging filter for extinction coefficient data. This should be set to 114. (The processor stores 114 as 113.999999 in floating point format.)

d. VIS_SER_NO? is the serial number of the visibility meter, which is shown on the Belfort ID marker.

e. Day/Night installed? allows the sensor to be configured with or without the day/night option. If day/night is not configured in, all day/night diagnostics pass and day/night status reads X instead of D or N.

f. Heaters installed? allows the sensor to be configured with or without the cold weather option. If heaters are not configured in, all heater diagnostics (except transmitter and receiver window heaters) pass.

g. Values are changed by entering a new value at the ...==> prompt.

h. The information below the dashed line is a verification of the data entered. The information also contains EEPROM checksum information.

i. If no data are to be changed in a particular field, <ENTER> is pressed. <ESC> is pressed to abort the remainder of the data entry.

6.4.4.9 **VL Command (Polled Mode, Extended Output Message)**.

SER001 AOK Night 26.1 001031 001024 000024 Vis: 23.40 Ext: 0.079646

The total message length is 72 characters (including CR/LF at the end). This message reports the serial number of the sensor, sensor status, day/night status, enclosure internal temperature, value of the latest flash and dark measurements, value of the latest day/night measurement, visibility in miles, and extinction coefficient in inverse kilometers.

6.4.4.10 **VG Command (Extended Diagnostics)**.

VPN 0.06553PPPP PPP PP PPP PPPP 26.4 9f

Byte	Description	Value
1	Start of transmission	STX
2	Carriage return	CR
3	Line feed	LF
4	Sensor ID	V
5	Sensor status	P/F
6	Day/night status	D/N
7-13	Latest extinction coefficient	XXX.XXX
14	ADD check	P/F
15	RAM check	P/F
16	ROM check	P/F
17	EEPROM check	P/F
18	Space	
19	Receiver operational status	P/F
20	Transmitter operational status	P/F
21	Day/night operational status	P/F
22	Space	
23	Receiver hood heater	P/F
24	Transmitter hood heater	P/F
25	Space	
26	Receiver window heater	P/F
27	Transmitter window heater	P/F
28	Day/night window heater	P/F
29	Space	
30	Receiver electronics heater	P/F
31	Transmitter electronics heater	P/F
32	Day/night electronics heater	P/F
33	Enclosure electronics heater	P/F
34	Space	
35-39	Inside ambient temperature	XXX.X
40	Space	
41-42	Checksum	XX
43	End of transmission	ETX
44	Carriage return	CR
45	Line feed	LF

The total message length is 45 characters. The processor is dedicated full-time to the test during the check period and is not available to output visibility data.

6.4.4.11 **VH Command (Calibration Factors)**.

```
FE = 0.873497...==>
FI = 0.408333...==>
EDGE_OF_DAY = 90.000000...==>
EDGE_OF_NIGHT = 30.000000...==>
DAY_NIGHT_ZERO = 10...==>
-------------------------------------
FE = 0.873497
FI = 0.408333
EDGE_OF_DAY = 90
EDGE_OF_NIGHT = 30
DAY_NIGHT_ZERO = 10
New Cksum=9f
Old Cksum=9f
---> End of vH <---
*************************************
```

a. FE is a calibration constant and is a multiplier in the equation that calculates the extinction coefficient. FE is directly proportional to the extinction coefficient.

b. FI is the zero offset. FI is subtracted out of the measurement data as a part of the extinction coefficient calculation.

c. EDGE_OF_DAY is the digital measurement that corresponds to an ambient light level of 3 foot-candles.

d. EDGE_OF_NIGHT is the digital measurement that corresponds to an ambient light level of 0.5 foot-candle.

e. DAY_NIGHT_ZERO is the minimum reading that the processor should obtain from the day/night sensor. DAY_NIGHT_ZERO is used for diagnostics.

6.4.4.12 **VP Command (Automatic Report)**. The VP command is used to provide a periodic output message that reports several operating values including the extinction coefficient in inverse kilometers and visibility in miles. This command also provides the capability to alter the delay between messages in increments of 1 second. The delay should be set to zero to turn off the output message. The following is an example of the response to the VP command:

```
Delay?   0...==>60
New Cksum=7c
Old Cksum=2e
---> End of vP <---
*************************************
001031 001024 000107 000024 N 004095   23.4    0.079646
001031 001024 000107 000024 N 004095   23.4    0.079646
```

The columns of data in the VP output message are as follows:

(1) The latest flash measurement
(2) The latest dark measurement
(3) Flash - dark + K (K is an arbitrary constant)
(4) The latest day/night measurement
(5) The latest day/night status
(6) Reserved
(7) The latest visibility in miles
(8) The latest extinction coefficient in inverse kilometers

6.4.4.13 **VR Command (Reset Sensor)**. The VR command invokes a reset of the processor, which initializes the visibility meter.