HSS SENSORS

OPERATION AND MAINTENANCE MANUAL

FOR THE

VPF-730 COMBINED VISIBILITY & PRESENT WEATHER SENSOR

&

VPF-710 VISIBILITY SENSOR

Manual Part Number: 102186.05C
Document Number: 100183.04C

LIMITED WARRANTY

BIRAL warrants the VPF-730 Automated Present Weather Observing System against defective materials and workmanship for a period of one year. Any questions with respect to the warranty should be taken up directly with a factory representative. Shipping costs will be borne by buyer. All requests for repairs and replacement parts should be directed to:

BIRAL, PO Box 2, Portishead, Bristol, BS20 7JB, United Kingdom
Tel. +44 (0)1275 847787, Fax +44 (0)1275 847303, e-mail service@biral.com.

Please include the instrument serial number and part numbers with all requests for parts or service.

PROPRIETARY NOTICE

The information contained in this manual (including all illustrations, drawings, schematics and parts lists) is proprietary to BIRAL. It is provided for the sole purpose of aiding the buyer or user in operating and maintaining the instrument. This information is not to be used for the manufacture or sale of similar items without written permission.

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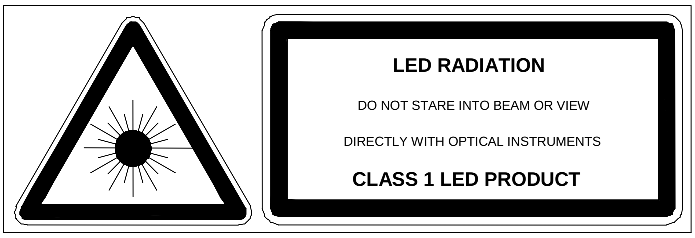
PATENT COVERAGE

The Present Weather Measurement Techniques are protected by the following Patents.

U.S. Patent No.	4,613,938
Canadian Patent No.	1,229,240
German Patent No.	3,590,723



IF YOUR EQUIPMENT IS FAULTY

When making any enquiries about this equipment please address them to:

BIRAL
P 0 Box 2
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E-mail: service@biral.com

In order to help us to expedite any repair/replacement please tell us as much of the following as possible:

Model number of equipment
Serial number of equipment
Number of assembly or part
Total number of hours in use
Nature of defect
Return address

Please ensure that your full name and address is included, particularly if using e-mail.

TECHNICAL MANUAL CONTENTS

1 INSTRUMENT OVERVIEW

1.1 SENSOR MODELS

The VPF-700 multipurpose meteorological sensor series has two basic models designated the 710 and 730. These two models utilise the same basic optomechanical and electronic components. All models have an optical transmitter and forward scatter receiver. Model VPF-730 is equipped with an additional (back scatter) receiver to aid in precipitation identification. All models have the same time-proven software for measuring visibility and performing self-test diagnostics. The VPF-730 has expanded, time-proven, software to perform precipitation detection identification and intensity measurements. The measurement capabilities of the models is as follows:

SENSOR MODEL	MEASUREMENT CAPABILITY
VPF-710	Visibility Fog Density
VPF-730	Visibility Fog Density Precipitation Identity Rain Rate Snowfall Rate

Photographs of the sensor models are shown in Figure 1-1.

Instrument Components

Each sensor has been engineered and manufactured with high-reliability components to provide accurate measurements under all weather conditions. Its rugged aluminium construction and durable hard-anodised coating are intended to serve you in the severest of environmental conditions throughout the long life of the instrument.
A basic Model VPF-700 sensor system consists of the major components listed below:

Item	QUANTITY
Forward scatter Sensor Assembly	1
Back scatter Receiver (VPF-730 only)	1
Self-Test Monitoring	1
Power Cable 6m	1
Signal Cable 6m	1

Accessories/Options

Sensor Pole Mounting Kit

Comprising U-bolt and fasteners for attachment of sensor to a mounting pole.

Calibration Kit

The calibration kit, containing a reference standard plaque and other accessories in a protective carrying case, is employed only at those times that the instrument calibration is being checked.

Advanced Self-Test and Monitoring

Detailed information of internal tests and monitors.

Heaters

8.4W per heater on 12VDC models, 15W per heater on all other versions.

External Temperature Sensor

Fitted as standard on VPF730 and on all heated sensors.

Power and Signal Cables

These may be ordered at various lengths but are usually supplied at 6m.

Communications Protocol

Configured for either RS232C or RS422.

Additional Inputs

Optional Ambient Light Sensor Input or Weather Station Module (0-10V analogue inputs).

Custom Configurations

Biral are pleased to offer any custom configuration or requirements that may be needed. Please contact Biral to discuss any special requirement you may have.

Model VPF-710 Sensor

Model VPF-730 sensor
Figure 1.1

1.2 ASSEMBLY INSTRUCTIONS

The Model VPF-710 sensor is a compact, one-piece unit that require no mechanical assembly instruction. Each sensor and its accessories are shipped in a double-walled cardboard shipping container. When unpacked, the sensor is ready for installation.

When in operation, the Model VPF-730 sensor is also a compact, one-piece package, but for shipment purposes the backscatter receiver is detached and stored separately inside the shipping container.

To assemble the Model VPF-730 sensor, its mounting port must first be uncovered. The port is sealed by a small metal disk bolted to the top of the conduit junction strut. Remove the disk to expose the 15-socket D-Subminiature connector and O-Ring environmental gasket.

<u>Note:</u> The metal disk should be retained for possible use in the remote possibility that the back scatter need be removed for servicing leaving the remainder of the sensor to function as a visibility sensor.

Unpack the backscatter receiver and note the orientation of the 15-pin D-Subminiature connector at the bottom of its pedestal. Before installing the backscatter receiver make sure the O-Ring is properly seated in its groove. The use of a small amount of vacuum grease smeared on the O-Ring helps in retaining the O-Ring in its groove and possibly improves the environmental seal.

Install the backscatter receiver while assuring the two connectors are mated properly in the process. After installing the backscatter receiver, tighten the three captive stainless steel socket-head cap-screws securely using a hex head ball driver.

1.3 MECHANICAL INSTALLATION

When selecting the manner of installation of the sensor, there are three primary factors to be considered: (1) height of the instrument above ground, (2) orientation of the instrument, and (3) electrical grounding. Each of these factors, along with several other considerations will be treated in the discussion that follows.

Height Above Ground:
For highway fog-warning systems, a recommended height for the sensor sample volume is the average distance of a vehicle driver's eyes above the roadway. Mounting heights for this application typically range between 1.5 to 2 meters (4.9 to 6.6 feet).

For airport applications, the standard height for visibility sensors in the U.S. is 4.3 meters (14 feet) above runway level. This height may differ in other countries.

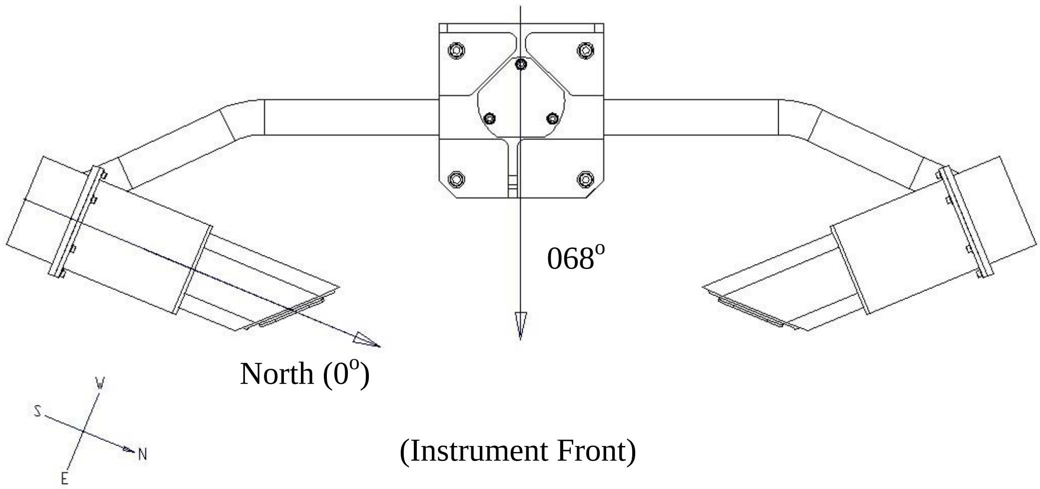
For general meteorological measurements, a sample volume height of 1.8 meters (6 feet) is a suitable height unless the particular application dictates otherwise.

Mounting the Sensor Head:
The sensor head should be attached at the very top of the mounting pedestal with a U-bolt as shown in Figure 1.2. The mast should be made from galvanised steel pipe or heavy walled aluminium tube whose outer diameter is in the range from 40 to 64 mm. Pipe or tubing with an outer diameter greater than 66 mm will not permit use of the U-bolt provided with the instrument. Pipe diameters less than 40 mm may not provide the U-bolt with adequate bearing surface. Note: Pipe sizes often refer to their inside diameter; some 60 mm (ID) pipe may be too large for the U-bolts to fit around.

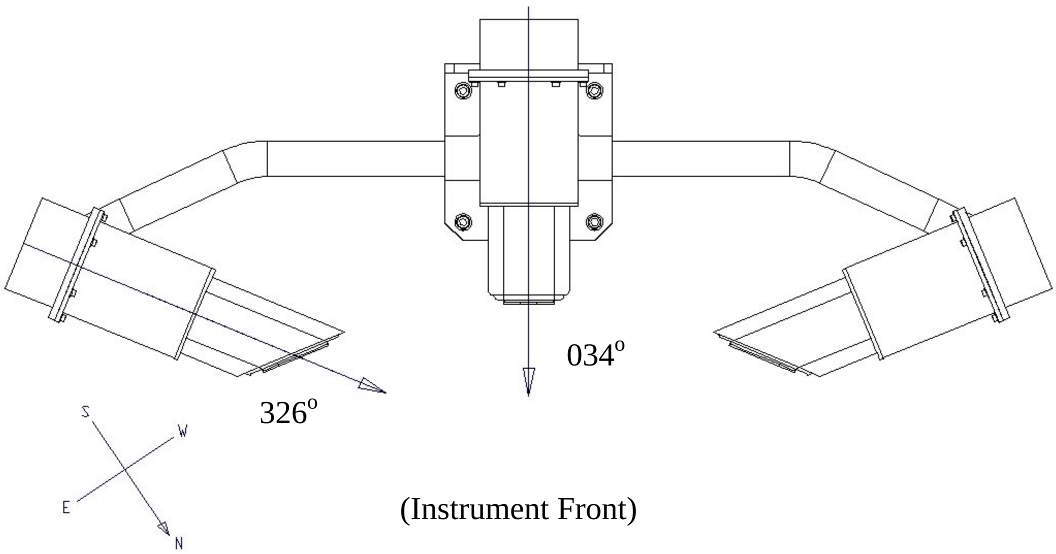
An optional stainless steel closed-circle U-bolt with hardware can be provided for securing the sensor to the top of the mast. A V-block saddle is attached to the sensor head mounting plate to oppose the U-bolt, thus providing a secure grip on the mast. The sensor head should be mounted near the very top so that the mast will not interfere with the free flow of fog or precipitation through the sample volume. The flat stainless steel washers should be placed next to the anodised surface of the mounting plate to prevent gouging by the lock washers as the nuts are tightened.

Orientation of Sensor Head
The sensor has lens systems in its transmitter and receiver assemblies. For fixed ground installations, one may take the precaution of orienting the sensor head so that the rising or setting sun does not appear in the field-of-view of the receiver lens(es). It is desirable to avoid sunlight from flooding the receiver optics and to avoid sunlight induced noise spikes from creating false precipitation counts, although false-alarm algorithms in those sensors invariably eliminate such false counts.

For the VPF710 the receiver optics should be aligned with true North (true South in the Southern Hemisphere) as shown below:



For the VPF730 the alignment should be such that neither the forward nor the back scatter receiver optics are aligned with the rising or setting sun. For the Northern Hemisphere the best mounting orientation is shown in the picture below (for the Southern Hemisphere the bearings should be increased by 180°)



For shipboard installations, the sensor head orientation is not critical from the standpoint of solar image effects. The constant motion of the ship, even when berthed will prevent any undesirable lenticular effects on transmitter or receiver components from occurring. However, for another reason it is preferable to orient the instrument so that the front of the instrument is pointed toward the stern of the ship. This orientation will offer the most protection for the windows against salt spray when the ship is underway.

Electrical Grounding

Possible instrument failure can result from the damaging effects of over-voltage transients induced on the AC-power line and the signal distribution lines. Destruction of sensitive operational amplifiers can result from unprotected lines, or instrument failure may occur over a long period of time due to slow device degradation. Destructive over volt transients can occur in many ways; e.g., lightning induced transients, AC power line transients and EMI/RFI electromagnetic noise. The power/control subsystem of the sensor contains transient surge-arrestors on all power and signal lines as a standard feature. EMI filters are present on the power and lines entering the power/control subsystem. It is essential to connect the sensor to earth ground for maximum protection of the instrument. The following notes are intended to provide some guidance in the design and construction of an electrical grounding system.

(1) Ground Rod: An eight foot ground rod should be used to make contact with moist soil during even the driest periods.

(2) Lead Lengths: No. 6 AWG solid copper wire should be used to connect the instrument (and thus the transient voltage suppressers) to the ground rod. Use the shortest and most direct paths to the ground. Simply connect the ground lead to the grounding screw provided on the back of the instrument.

(3) System Interconnections: Eliminate all isolated ground loops. The shield of the signal output cable, for example, should be attached only at one end of the cable and left floating at the other end. Preferably, it should be attached to ground at the sensor end of the signal cable.

(4) Connections: Use tight-corrosion-proof bare metal connections throughout the grounding system.

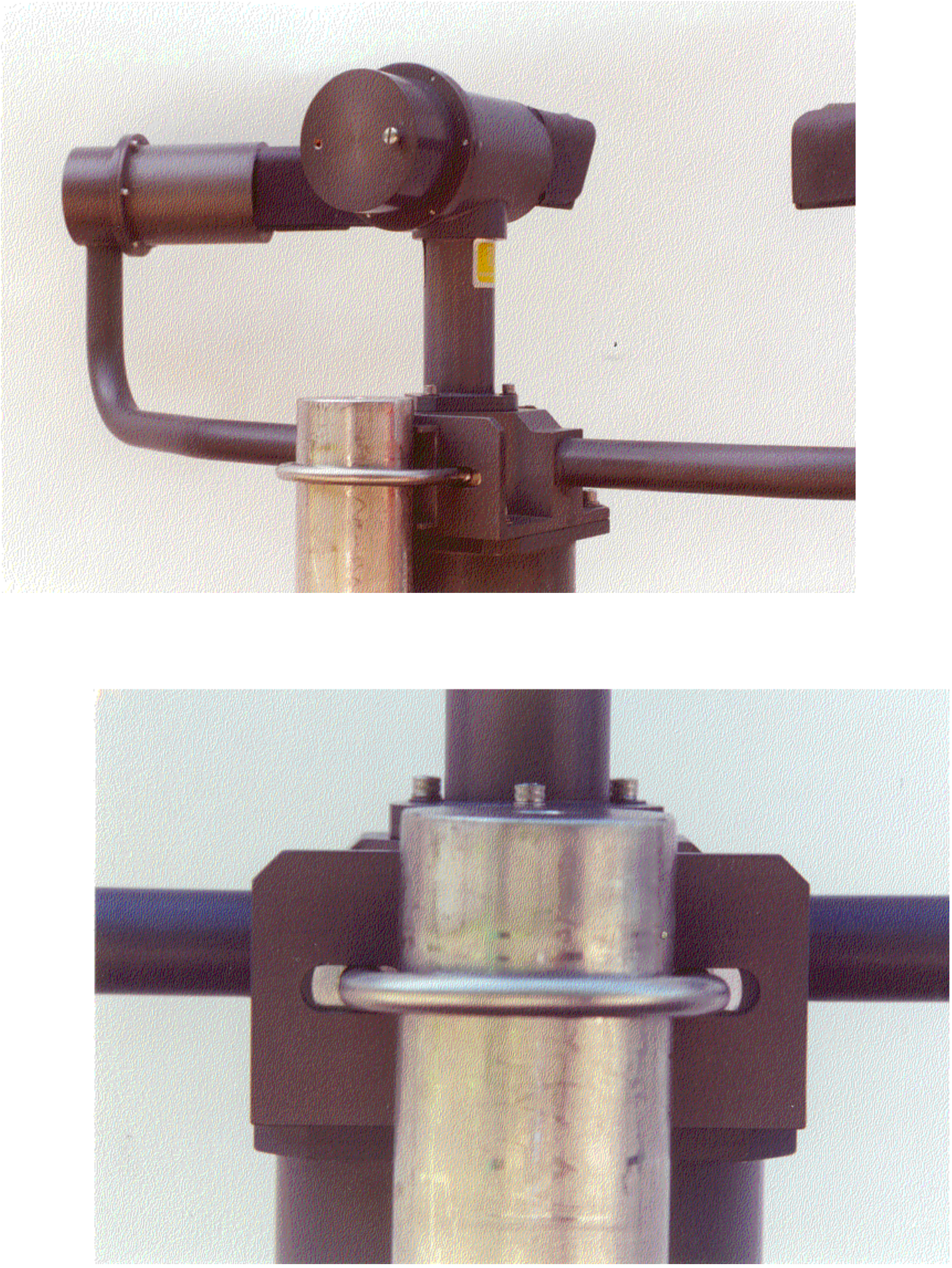


Figure 1.3 Two Views of the U-Bolt Mounting Method

1.4 ELECTRICAL INSTALLATION

For units with additional optional inputs see also sections 7 and 8

1.4.1 Cable Types

Power and signal connections to the sensor are made with separate cables furnished with the sensor. Connector plugs on each cable mate with receptacles on the bottom of the cylindrical electronics housing. The cables have connectors that are factory fitted to the cables and have metal coupling nuts. Contacts in the plugs and receptacles are gold over nickel-plated copper for maximum corrosion resistance. Internal gaskets assure watertight performance.

1.4.2 Connector Type

Chassis receptacles with o-ring environmental seals are provided for the power and signal cables and for the temperature sensor

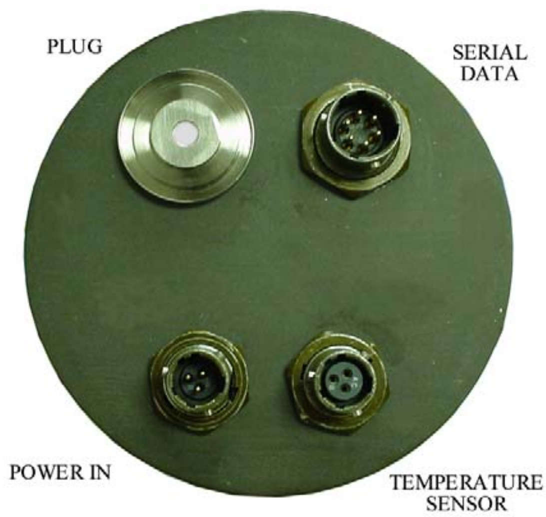


Figure 1.4.2 Connector Layout.

1.4.2.1 **INPUT POWER CONNECTIONS**

The power cable furnished with the sensor has the following pin and conductor assignments.

230Vac/110Vac

PIN NO	CONDUCTOR COLOUR	DESIGNATION
A	BROWN	AC Live
B	BLUE	AC Neutral
C	YELLOW/GREEN	Sensor Ground

24Vac/12 and 24Vdc

PIN NO	CONDUCTOR COLOUR	DESIGNATION
A	BROWN	12/24V AC or DC
B	BLUE	0V
C	YELLOW/GREEN	Sensor Ground.

1.4.2.2 **RS-232 SIGNAL INTERFACE CONNECTIONS**

When operating in the RS-232 interface mode, the output signal cable furnished with the sensor has the following pin and conductor assignments. The cable consists of 3 sets of twisted pairs

PIN NO	CONDUCTOR COLOUR	DESIGNATION
A	Red	TX Data
B	White	Not Used
C	Brown	RX Data
D	White	Not Used
E	Grey	Signal Ground
F	White	Equipment Ground

1.4.2.3 **RS-422 SIGNAL INTERFACE CONNECTIONS**

When operating in the RS-422 interface mode, the output signal cable furnished with the sensor has the following pin and conductor assignments. The cable consists of 3 sets of twisted pairs

PIN NO	CONDUCTOR COLOUR	DESIGNATION
A	Red	TX Data +
B	White	TX Data –
C	Brown	RX Data +
D	White	RX Data –
E	Grey	Signal Ground
F	White	Equipment Ground

Table 1.4. Electrical Power and Signal Connections

1.4.2.4 OPTION – SINGLE COMBINED POWER AND DATA CONNECTIONS

The VPF700 can be configured for use with a single cable for power and data. Please note that for safety reasons, this option is available only on DC powered versions with RS232 communications.

The output signal/power cable furnished with the sensor has the following pin and conductor assignments. The cable consists of 3 sets of twisted pairs

PIN NO	COLOUR	DESIGNATION
A	Red	+ve DC
B	White	-ve DC
D	Brown	Rx
E	White	Tx
F		NOT USED
C	Grey	Signal Gnd
G	White	Chassis Gnd

1.4.3 Electrical Installation Procedure

Power and signal cable connections to the power/control unit should be made as indicated in Table 1-1. After making those connections, the electrical installation procedure is as follows:

ELECTRICAL INSTALLATION PROCEDURE

STEP (1) Connect the power input cable to the local power source. Do not turn power source "ON".

STEP (2) Connect the signal cable to an asynchronous communications terminal with an RS-232 interface, or computer running a terminal program. Install external temperature sensor.

STEP (3) Set the connection interface parameters to the following factory settings:

FACTORY SET INTERFACE PARAMETERS

Baud Rate..1200
Bits/Byte 8
Stop Bits..1
Parity...None
Flow Control...None

STEP (4) Set up the sensor in the EXCO calibration check configuration (See Figure 1-4).

STEP (5) Turn the local power source "ON".

STEP (6) Send the following message from the terminal to the sensor:
P?<cr><lf>
<cr> is carriage return character (ENTER key on computer)
<lf> is line feed character sent by holding down the CTRL key and pressing the J key
The sensor will respond with its parameter message: TPW ... (See Parameter Message Format)

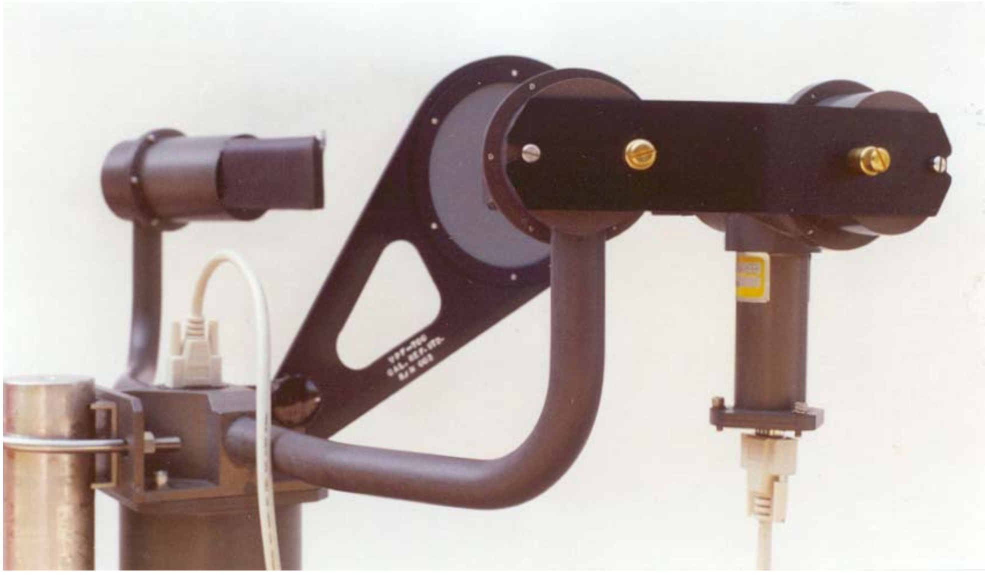
STEP (7) Send the following message from the terminal to the sensor-.
OS1 <cr><lf >
The sensor should respond. OK<cr><lf>

STEP (9) Perform the EXCO Calibration Check Procedure.
(See Section 4.1.1)

STEP (10) Remove the calibration reference standard. For VPF730 reinstall the back scatter receiver channel. Remove the back scatter receiver calibration mounting bracket.

STEP (11) Allow a couple of minutes for the instrument reading to stabilise. The instrument is now measuring the atmospheric extinction coefficient and monitoring present weather.

VPF710



VPF730

Figure 1.4.3 Sensors With Calibration Reference Standard Installed

2 SENSOR CAPABILITIES

2.1.1 Present Weather Definition

The term "Present Weather" is generally employed to define a large class of atmospheric phenomena that includes tornado activity, thunderstorm activity, precipitation, obstructions to vision, and "other atmospheric phenomena" such as aurora. For purposes of Automated Present Weather Sensors, the term "present weather" is restricted to those atmospheric phenomena that are local to the sensor. These phenomena include: (1) all forms of liquid and frozen precipitation; e.g., rain, drizzle, snow, snow pellets, snow grains, ice pellets (formerly sleet) and hail, and (2) those suspended particles that are classed as obstructions to vision; namely, mist, fog, haze, dust and smoke.

2.1.2 Automated Measurements

2.1.2.1 GENERAL

The present weather sensor utilises microprocessor technology to perform automatic visibility, precipitation and temperature measurements. The standard version is AC line-power operated, however, battery-powered versions are also available. Patented techniques are employed to identify precipitation and to determine the presence of fog during episodes of precipitation.

2.1.2.2 VISIBILITY RELATED MEASUREMENTS

The measurement capabilities of the sensor are summarised in Table 2-1. Determination of visual range is based on measurements of the atmospheric extinction coefficient (EXCO). Note that EXCO includes the attenuating effects of both suspended particles and precipitating particles. Meteorological optical range (MOR) is determined by application of the standard relation,

$$MOR = 3.00/EXCO \qquad (2\text{-}1)$$

Haze and fog are the two most common forms of obstructions to vision. In the absence of precipitation, the sensor determines the presence of haze or fog based on the MOR. If the MOR is less than 1 kilometre, then fog (F) is indicated in the output message. If the MOR is between 1 and 10 kilometres, then haze (H) is indicated in the Output message. If MOR is greater than 10 kilometres, no obstruction to vision is indicated.

VISIBILITY MEASUREMENTS	
Daytime visual range	10 meters to 75 kilometres (30 feet to 46 miles)
Error	≤ 10% 0 to 16 kilometres ≤ 20% 16 to 30 kilometres
Atmospheric extinction coefficient	300 km^{-1} to 0.04 km^{-1}
Obstruction to vision	(1) Identifies Fog or Haze (Precip. Absent) (2) Identifies Fog in Presence of Precipitation
PRECIPITATION MEASUREMENTS	
DETECTION	
(a) Liquid Precipitation:	0.00001 in/min. (0.00025 mm/min) 0.00060 in/hr (0.015 mm/hr)
(b) Snow (H_20 Equivalent):	0.000001 in/min. (0.000025 mm/min) 0.000060 in/hr (0.0015 mm/hr)
Identification/intensity	Drizzle: (Light, Moderate, Heavy) Rain: (Light, Moderate, Heavy) Snow: (Light, Moderate, Heavy)
Precipitation rate (error)	Rain-Up to 10 in/hr (±10%) (250 mm/hr ±10%) Snow-Rain Equivalent (±20%)

Table 2-1. Measurement Capabilities of the Model VPF-730 Automated Present Weather Sensor.

In the presence of precipitation, the sensor software measures the fraction of the atmospheric extinction coefficient due to precipitation and subtracts it from the total extinction coefficient to obtain a quantity we have named EXCO-EVENTS. If the value of EXCO-EVENTS is greater than 3.00, then fog is declared to be present in addition to the precipitation as an obstruction to vision.

If the sensor were equipped with a relative humidity indicator, or if ambient relative humidity measurements were transmitted to it, a third category of obstructions to vision could be added; namely, "smoke/dust". Assignment of "smoke/dust" to an obstruction to vision would be based on a visibility less than three kilometres and a temperature/- dew point spread greater than 4 degrees.

2.1.2.3 PRECIPITATION MEASUREMENTS

The sensor identifies three forms of precipitation, namely drizzle, rain and snow. All forms of frozen precipitation are classified as snow. Detection of the onset of precipitation is extremely sensitive, being 0.00025 mm per minute for rain and approximately 0.000025 water equivalent mm per minute for snow.

Intensity of precipitation may be defined differently from one country to another. In the United States, the intensity of precipitation is defined differently for drizzle and rain than for snow. For drizzle and rain, the intensity (light, moderate and heavy) is based on the rate of fall of precipitation. For snow the intensity is based on visual range unless fog is present. In classifying precipitation intensity, the sensor utilises the precise definitions given in the Federal Meteorological Handbook. These definitions are given in Table 2-2.

Note: If a sensor is intended for installation in a country where the definitions of precipitation intensity differ from the U.S. definitions, it is possible for the sensor to be produced with the appropriate definitions installed. BIRAL must be informed of this requirement at the time of order.

DRIZZLE	
Light	A trace to 0.01 inches (0.3 mm) per hour.
Moderate	More than 0.01 inches (0.3) to 0.02 inches (0.5 mm) per hours.
Heavy	More than 0.02 inches (0.5 mm) per hour.
RAIN	
Light	A trace of 0.10 inches (2.5 mm) per hour.
Moderate	0.10 to 0.30 inches (2.6 to 7.6 mm) per hour.
Heavy	More than 0.30 inches (7.6 mm) per hour.
SNOW (NO FOG)	
Light	Visibility equal to or greater than 5/8 statute miles, 0.55 nautical miles, or 1,000 meters.
Moderate	Visibility 5/16 to 1/2 statute miles, 0.25 to 0.5 nautical miles, or 500 to 900 meters.
Heavy	Visibility equal to or less than 1/4 statute miles, 0.2 nautical miles, or 400 meters.
SNOW (FOG PRESENT)	
Light	A trace to 0.10 inches (2.5 mm) water equivalent per hour
Moderate	0.10 to 0.30 inches (2.6 to 7.6 mm) water equivalent per hour.
Heavy	More than 0.30 inches (7.6 mm) water equivalent per hour.

Table 2-2. US Precipitation Intensity Definitions
(Based on Federal Meteorological Handbook No. 1 Part B.1.)

2.1.3 Sensor Features

2.1.3.1 GENERAL

The VPF-730 is both a visibility sensor and a present weather sensor. It has the necessary optimum configuration for accurate measurement of visibility in the densest of fogs to very clear air conditions. It can detect the onset of precipitation as readily as a human observer and can measure the size and velocity of precipitation particles. Unique patented techniques utilising precipitation size/velocity distributions and back scatter/forward scatter ratios provide essentially error-free identification of the type of precipitation. False alarms and false identifications are kept to a minimum by the application of empirically derived algorithms sensitive to the characteristic of electronic noise and insects. Also unique is the sensor capability for separating the contribution of extinction due to precipitation from the total atmospheric extinction coefficient, thus giving the sensor the capability to identify fog whenever it is simultaneously present during a precipitation episode.

In addition to its optimal and unique measurement capabilities, the VPF-730 has a number of distinctive physical features:

Compactness:
The sensor is a single package, small in size and weight. It can be readily installed by one person and can be used in portable or fixed installations.

Proven Software:
The basic software incorporated into the sensor has evolved over a long period of time and has been tested and proven in hundreds of sensors.

Ease of Maintenance and Calibration:
Routine maintenance, including a check on calibrations, is performed in a matter of a few minutes. A re-calibration if required, takes only slightly longer and is easily performed by one person.

2.1.4 Real Time Data Displays

The output of the sensor is a serial-digital message that is provided at the signal interface at a sample time interval selected by the operator (a typical sample time interval is one minute). The message is provided automatically, or if the sensor is in the polled mode the data message is transmitted after the polling command is sent to the sensor.

A printer can be used to record the data message. However, a PC terminal offers much more flexibility:

(1) each message can be time-tagged with the date and time,
(2) the message content can be condensed for a particular application,
(3) data processing can occur, such as the application of Allard's Law for visibility of point light sources,
(4) precipitation accumulation for selected intervals of time (e.g., every hour, every six hours, every 24 hours, etc.) can be obtained,
(5) all or selected parts of data message can be archived.

2.1.5 Sensor Specifications

The specifications for all versions of the VPF-700 sensor series are summarised in Table 2-3. To adapt the table to a particular sensor model, disregard non-pertinent information. For example, in the case of the Model VPF-710 visibility sensor, disregard those portions of the specification pertaining to precipitation measurements.

SPECIFICATIONS
MODEL VPF-700 MULTIPURPOSE SENSOR SERIES

Visibility Measurements	
Visual Range Coverage	10 m to 75 km
Measurement Error at 16 km	<= 10%
Measurement Error at 2 km	<= 2%
Measurement Time Constant	30 seconds
Atmospheric Extinction Coefficient (EXCO) Measurements	
Range of Coverage	300 km^{-1} to 0.04 km^{-1}
Linear Dynamic Range	7500:1
RMS Noise (Night-time)	<= 0.02 km^{-1}
RMS Noise (Daytime)	<= 0.03 km^{-1}
Stability of EXCO Zero Setting	
Ambient Temperature Effects	<= 0.02/km
Long Term Drift	<= 0.02/km
Precipitation Measurements	
Detection Threshold: Rain	0.015mm/hr (0.0006 in/hr.)
Detection Threshold: Snow (H20 Equiv.)	0.0015mm/hr (0.00006 in/hr.)
Rain Rate (Maximum)	~ 250mm/hr (10 in/hr.)
Rain Rate Accuracy	<= 10%
Identifications:	DZ, RA, SN, UP, GR, NP
Intensities:	DZ-, DZ, DZ+, RA-, RA, RA+, SN-, SN, SN+,
Maintenance	
MTBF (Calculated)	18,000 hrs.
Calibration Check	6 months
Clean Windows	3 months
Self Test Monitoring	Included

Table 2-3(a). Sensor Specifications.

SPECIFICATIONS
MODEL VPF-700 MULTI-PURPOSE SENSOR SERIES
INSTRUMENT CHARACTERISTICS

Physical	
Scattering Angle Coverage	39° to 51°
Sample Volume	400 cm^3
Weight (Battery Powered) (AC-Line Powered Sensor)	10 lbs. (4.5 Kg) 15 lbs. (6.8 Kg)
Length	29 in. (0.74 m)
Light Source	
Type	IRED
Central Wavelength	0.88µm
Bandwidth	0.08µm
Lifetime	>10 years
Modulation Frequency	2000 Hz
Detector	
Type (Photovoltaic)	UV-215BG
Response	Silicon
Filter Bandwidth	0.08µm at 0.88µm
Temperature Sensor	
Type	LM135A
Range	-60°C to 100°C
Power Requirements	
Basic Sensor	2.5 W
De-Icing Heaters (Optional)	45 W (VPF730) 25W for 12VDC models 30 W (VPF710) 17W for 12VDC models
No-Dew Windows (Sense-Controlled)	2.5 W (VPF730) 1.7 W (VPF710)
Environmental	
Temperature Range	-50°C to +60°C
Altitude	0 to 20,000 ft
Precipitation	All weather
Humidity	0 to 100%

Table 2-3(b). Sensor Specifications (Continued).

SPECIFICATIONS
MODEL VPF-700 MULTI-PURPOSE SENSOR SERIES
DIGITAL COMMUNICATION INTERFACE

Communication Parameters:	
Interface Type	RS-232C, (Full Duplex)
Optional	RS-422
Baud Rates (selectable)	1,200; 2,400; 4,800; 9,600; 19,200; 38,400; 57,600
Data Bits	8
Parity	None
Stop Bits	1
Flow Control	None
Message Termination	CR-LF
Message Check Sum:	Selectable
Reporting Interval	Programmable (Response to poll, or Automatic at programmable intervals: e.g., 30 seconds to several minutes; 1 minute typical)
Message Content:	• Instrument Identification Number (Programmable) • Reporting Interval (seconds) • Daytime Visual Range (Kilometres) • Atmospheric Extinction Coefficient (1/km) • Precipitation Type • Obstruction to Vision (Fog, Haze, None) • Precipitation Amount (One Minute Interval) • Temperature • Self-Test & Monitoring Flags

Table 2-3(c). Sensor Specifications (Continued).

SPECIFICATIONS
MODEL VPF-700 MULTI-PURPOSE SENSOR SERIES
SENSOR SELF-CHECK CAPABILITIES

Advanced Self-Test and Monitoring

- Optical Source Power
- Forward-Scatter Receiver Sensitivity
- Back-Scatter Receiver Sensitivity
- Transmitter Window Contamination
- Forward-Scatter Receiver Window Contamination
- Back-Scatter Receiver Window Contamination
- Power Supply Voltages
- Non-Volatile Memory Check Sum Test
- EPROM Check-Sum Test
- Restart Occurrence
- Sensor Sample Interrupt Verification
- RAM Read/Write Verification
- Register Read/Write Verification
- A/D Control Signal Test
- A/D Conversion Accuracy Check
- Input Voltage Check (Battery Check on DC Powered Sensors Only)
- Forward-Scatter Background Illumination Level
- Back-Scatter Background Illumination Level

Standard Self-Test and Monitoring

- Optical Source Power
- Transmitter Window Contamination
- Non-Volatile Memory Check Sum Test
- EPROM Check-Sum Test
- Restart Occurrence
- Sensor Sample Interrupt Verification
- RAM Read/Write Verification
- Register Read/Write Verification
- A/D Control Signal Test
- A/D Conversion Accuracy Check
- Forward-Scatter Background Illumination Level

AVAILABILITY
Advanced Self-Test and Monitoring is an Optional Accessory on the VPF-700 Series
Standard Self-Test and Monitoring is a Standard Feature on the VPF-700 Series

Table 2-3(d). Sensor Specifications (Continued).

2.2 VISIBILITY MEASUREMENT PRINCIPLES

2.2.1 Visibility Measurement Terminology

The VPF-700 Sensor Series has all the capabilities of a forward scatter meter (FSM); i.e. it belongs to the class of nephelometers which measure the amount of light scattered at angles less than 90 degrees by small particulates suspended in, or large particles passing through its sample volume. In the case of the VPF-700 Sensors, the sample volume is defined by the intersection of the transmitted beam of light and the ray-cone which defines the field of view of the forward scatter receiver as shown in Figure 2-1.

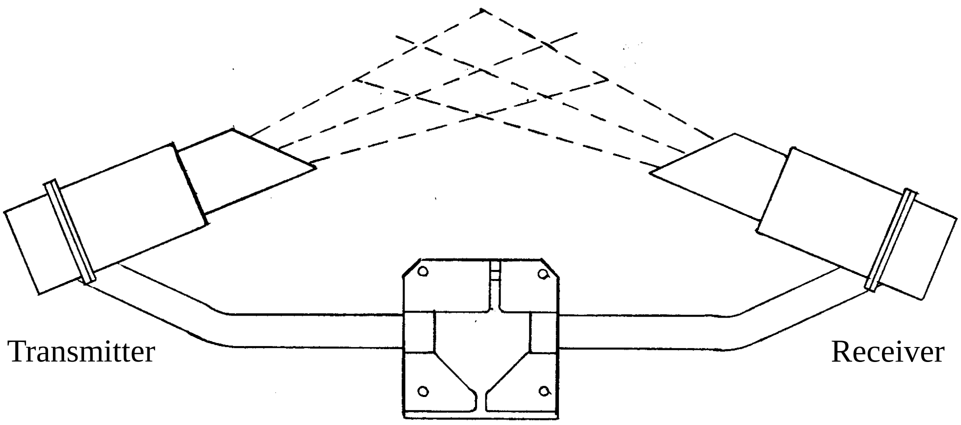


Figure 2-1. Top view of the Sensor Head.

Suspended particles such as fog, haze and smoke aerosols and precipitating particles such as rain, snow, ice pellets, drizzle and mist account for essentially all of the atmospheric extinction of visible and near-visible optical radiation for horizontal visual ranges up to approximately 100 kilometres. Beyond that range scattering by the molecular constituents of the atmosphere begin to play a role. In the visible and near visible spectral regions the dominant aerosol attenuation process is Mie-scattering. Aerosol absorption plays a negligible role in most natural environments, thus the atmosphere scattering coefficient and extinction coefficient are synonymous.

Visual Range Determination

Nearly all instrumental methods of determining visual range start with a quantitative measurement of the atmospheric extinction coefficient β. Because β is measured in the vicinity of the instrument an assumption must be made that the prevailing environmental conditions are uniform over the scale of visual ranges of interest. The extinction coefficient is converted to visual range by application of:

(1) Koschmieder's Law (for daytime visual range),
(2) Allard's Law (for night-time visual range), or
(3) Variations on Koschmieder and Allard's Laws.

When an observer looks at a distant target the light from the target that reaches the observer is diminished by absorption and scattering (the two components of extinction). In addition to the light that originates at the target and ultimately reaches the observer, extraneous light scattered into the line-of-sight by the intervening atmosphere is also seen by the observer. It is this air light which we recognise as haze or fog.

The effect of extinction and added air light on the perceived brightness of visual targets is shown graphically in Figure 2-2. From this illustration we note that the apparent contrast between object and horizon sky decreases with increasing distance from the target. This is true for both bright and dark objects.

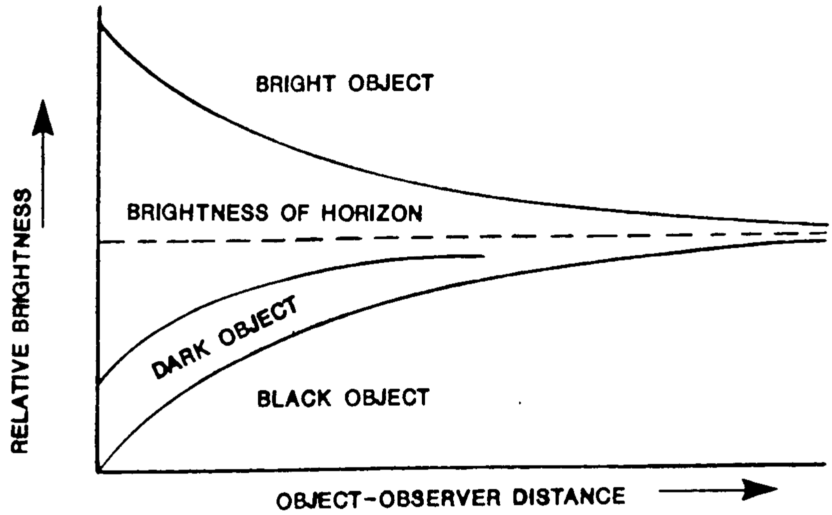


Figure 2-2. Effects of Atmosphere on the Apparent Brightness of Target Objects.

Daytime Visual Range

The original formula for calculating daytime visual range VR that was formulated by Koschmieder in 1924 is:

$$V_R = \frac{3.912}{\beta} \qquad (2\text{-}2)$$

Where β is the atmospheric extinction coefficient.

Subsequent investigations concluded that Koschmieder used too optimistic a value (0.02) for the liminal contrast threshold value of the human eye. A liminal value of 0.05 is believed to be more realistic. For the latter contrast threshold Koschmieder's Law is modified to become

$$V_R = \frac{3.00}{\beta} \qquad (2\text{-}3)$$

This simple law accounts for both the extinction of light by the atmosphere and the addition of air light by the same atmosphere - for a black target viewed against the horizon sky. Thus, the strict definition of daytime visual range implies the limiting distance at which a black target can be discerned against the horizon sky.

Night-time Visual Range

Night-time visual range refers to the distance at which an observer can see lights through the atmosphere at night. Allard gave the formula for the distance at which lights of intensity **I** can be seen at night in 1876.

Allard's Law is expressed as:

$$E_t = \frac{Ie^{-\beta V}}{V^2} \qquad (2\text{-}4)$$

Where Et is the observer's illuminance threshold and β is the atmospheric extinction coefficient.

In addition to the extinction of light by the atmosphere, this formula accounts for the decrease of light from the point sources of light as the inverse square of the distance.

This formula for calculating night-time visual range has a significant mathematical difference from the formula derived from Koschmieder's law. Where the latter has a single algebraic relation between visibility and extinction coefficient, the former has a transcendental relation between the two quantities. Thus, the solution can only be found by an iterative numerical procedure or from a prepared table of values.

Meteorological Optical Range

Meteorological Optical Range (MOR) is the length of the path in the atmosphere required to reduce the luminous flux in a collimated beam from an incandescent lamp at a colour temperature of 2700°K to 0.05 of its original value. That is, the length of the path in the atmosphere for which the regular transmittance is 0.05.

For practical purposes one may calculate MOR in the same manner as Daytime Visual Range; i.e. MOR is given by relation (2-3)

$$MOR = \frac{3.00}{\beta} \qquad (2\text{-}5)$$

The use of MOR satisfies the requirements of a meteorologist since it yields a one-to-one correlation with atmospheric transmittance and a change from day to night does not produce, by itself, a change in the visibility.

Extinction Coefficient Calibration

The calibration of the prototype sensor was carried out at the Weather Test Facility (WTF) of the Air Force Geophysical Laboratory which is located at the Otis Air National Guard Base (ANGB) on Cape Cod, Massachusetts. The calibration was made by comparison of atmospheric extinction coefficient measurements with those of standard FAA approved transmissometers. Comparisons were made over an extremely wide range of fog and haze situations.

The calibration of each duplicate Present Weather Sensor is traceable back to the measurements made with the prototype instrument at the AFGL Weather Facility. This "primary" calibration is transferred to other instruments of the same type using a "primary reference standard" whose "equivalent extinction coefficient" was established at the time of the primary calibration. A secondary reference standard similar in construction to the primary standard is furnished with each instrument so that the sensor calibration can be periodically checked. The secondary reference standard has received its value of equivalent extinction coefficient by a comparison with the primary reference standard - the calibration constant for the secondary reference standard.

Measurement Range
The visibility measurement range as given in Table 2-3 is a fixed range that is set at the factory. The operator in the field cannot change it. If a change of coverage is required, the sensor must be returned to the manufacturer.

2.2.2 Theory of Forward Scatter Meters

2.2.2.1 OPTICAL SENSOR CONFIGURATION

The VPF-730 visibility measurement capability derives from its forward scatter meter (FSM) configuration. Unlike a transmissometer, which measures the total atmospheric extinction coefficient, a FSM measures only an angular portion of the atmospheric scattering coefficient, that is, the scattering in a narrow range of angles around a central forward scatter angle.

The application of the standard universally accepted formulae for the calculation of daytime and night-time visibility requires that the total atmospheric extinction coefficient be measured, not the angular scattering coefficient. Thus, it is necessary to show that a measurement of the angular scattering coefficient, under certain strict conditions, can be related to the total atmospheric extinction coefficient (EXCO). Where EXCO includes both scattering and absorption of radiation at all angles from 0 to 180 degrees, and by all atmospheric constituents be they suspended aerosols, precipitation or molecules of air.

The first step in that conversion process is to demonstrate that the total atmospheric scattering coefficient and total atmospheric extinction coefficient are synonymous for all practical purposes.
Assumption (1):'The visibility measurements are restricted to less than 100 kilo-meters. (Rayleigh scattering by air molecules does not contribute significantly to atmospheric attenuation of visible light for visibility less than 100 kilometres.)

Assumption (2): Absorption by fog, natural aerosols and precipitation contributes a negligible amount of attenuation compared to their scattering for visible and near visible radiation.

Given the above reasonable assumptions, the total scattering coefficient can be equated to the total extinction coefficient.

The next step in the process requires equating the angular scattering coefficient as measured by a FSM with the total scattering coefficient. That transition requires restrictions to be placed on the physical configuration of a FSM and on the wavelengths of radiation employed.

Visibility in Fog & Haze
The angular scattering coefficient can be separated into two components, a phase function Φ (θ) and the total scattering coefficient σ as follows:

$$\sigma(\theta) = \Phi(\theta)\sigma \qquad (2\text{-}6)$$

To replace the total scattering coefficient by the angular scattering coefficient, as required for valid measurements with a FSM, it is obvious that the phase function must be a constant for all environmental conditions in which visibility measurements are of interest (usually all weather conditions).

During WWII, British scientists discovered a natural phenomenon that allowed substitution of the angular scattering coefficient for the total scattering coefficient. In the scattering angle region between 35 to 55 degrees, they found very little change in the phase function for all classes of fogs and hazes. It was given the code name "Loofah". (See: W.E.K. Middleton, Vision through Atmosphere, University of Toronto Press). Much post-WWII work has substantiated the existence of this phenomenon.

Many FSM's employ a 35-degree scattering angle configuration since this angle provides more scattered light, hence more signal, than do greater "Loofah" angles. (The phase function has an inverse dependence with increasing scattering angle, its value being largest at smaller angles).

Whatever central angle is chosen for the FSM configuration, there is no simple way of providing an absolute calibration for the FSM. Calibration of a FSM must be accomplished by a comparison of measurements with an instrument that measures the atmospheric extinction coefficient directly. A transmissometer is such an instrument. Only one FSM of a given type, usually the prototype, need be calibrated against a well-maintained visible light transmissometer. The calibration of the prototype sensor is transferred to a calibration reference standard, which then serves as the primary reference standard for calibration of all other FSM's of an identical configuration. The primary standard for a given FSM is not a reliable reference standard for FSM'S with any other size, central angle, types of optics or light source.

Well-maintained transmissometers that are available for calibration purposes are airport type transmissometers, dedicated to the measurement of visual range in heavy haze and fog. Such transmissometers prove to be accurate calibration references only over a limited range of visibilities, namely 1/2B to 20B, where B is the baseline of the transmissometer. A typical airport transmissometer has a baseline in the neighbourhood of 100 meters. Thus, its range of valid measurements extends from 50 meters to 2000 meters. This range encompasses only two environmental conditions, fog and very heavy haze.

To assure that the fog calibration of HSS sensors remains valid for lighter haze conditions and clear air, extensive use has been made of visual observations and televisiometer measurements. Proper targets for such observations must satisfy the conditions required by daytime visual range formulae; i.e., large, dark objects silhouetted against the horizon sky with no cloud cover present. A minor wavelength dependence effect is present for haze measurements, which is discussed later.

Visibility During Precipitation

It is highly desirous that the fog/haze calibration of a FSM carries over to various forms of precipitation. For this condition to be satisfied requires that the measurements of a fog/haze calibrated FSM give identical results to a transmissometer in snow and rain.

Forward scatter meters configured for a central scattering angle of 35 degrees and calibrated against transmissometers in fog/haze environments will overestimate the visibility in snow and underestimate the visibility in rain. To find out if there is a common "Loofah" angle for fog, haze, snow and rain HSS FSM's with central scattering angles other than 35 degrees have been operated for several years comparing their measurements with those of transmissometers in all types of weather. The results indicate that with a scattering angle near 45 degrees, a fog/haze calibration will remain valid for snow.

There is no common "Loofah" angle that allows transmissometer measurements in rain to agree with those of a FSM. The best result that can be achieved is a minimisation of the difference between the readings of a FSM in rain verses those of transmissometer. Since FSM's give higher EXCOs in rain than transmissometers (i.e. the corresponding visibilities are lower) the difference is a fail-safe error if one accepts the transmissometer readings as the "true" value.

Disagreement between FSM's and transmissometers in rain has two root causes:

(1) The phase function for scattering by rain is dramatically different from that of fog, haze and snow: (the phase function has a highly forward-directed diffraction component that accounts for one-half of the light energy scattered by a raindrop) and,

(2) The receiver of a transmissometer is unable to distinguish between unscattered light and diffracted light and treats both as unscattered radiation. As a result, transmissometer measurements underestimate the total extinction coefficient.

There are two schools of thought regarding which sensor type gives the more valid visibility measurement in rain, FSM's or transmissometers. One school believes the eye performs the same function as the transmissometer receiver, hence the transmissometer readings give the correct extinction coefficient. The second school counters with the opinion that while the first argument may be valid for point light sources, it is certainly not valid for non-self-luminous objects, especially for the theoretical black target used in the definition of daytime visual range. In the second case, the target contrast is reduced by the background light that results from scattering by the raindrop at all angles. There is no light emanating from a black target to be diffracted toward the eye.

Transmissometer Equivalent EXCO

A BIRAL present weather sensor can satisfy either school of opinion using its unique measurement techniques. For those that believe that the FSM measurements characterise the true extinction coefficient in rain, the total EXCO value normally provided by the sensors is always available. For the other school who believe that the true extinction coefficient in rain is that measured by transmissometers, the BIRAL present weather sensors can provide the Transmissometer Equivalent EXCO. (TEXCO)

The Transmissometer Equivalent EXCO is arrived at by the following steps:

(1) The sensor must first determine that the precipitation is rain not snow or other form of frozen precipitation.

(2) Separate the total EXCO into its components: EVENTS EXCO and EXCO MINUS EVENTS. (This step is essential to remove the fog or haze component from EXCO).

(3) Using an empirically determined relationship, convert the FSM EVENTS EXCO) to TRANSMISSOMETER EVENTS EXCO.

(4) Restore the EXCO-EVENTS component (i.e. non-rain component of EXCO) to arrive at TEXCO.

(5) Output EXCO, EXCO-EVENTS and TEXCO.

2.2.2.2 WAVELENGTH DEPENDENCE OF FSM MEASUREMENTS

Measurements by forward scatter meters and transmissometers in fog have no wavelength dependence on the radiation employed by their light sources. This fact is easily confirmed by the observation that fog is white in appearance.

Such is not the case with haze that has a decidedly blue cast in appearance. The transition to fog from haze is not a gradual affair. Middleton points to an abrupt transition in wavelength dependence at an extinction coefficient of 4 km^{-1}. This he takes to be the transition point from haze to fog. Above 4 km^{-1}, there is no variation of the extinction coefficient with wavelength. Below 4 km^{-1}, there is a distinct variation. Angstrom demonstrated that this wavelength variation of extinction in haze is due to aerosol scattering and has a wavelength dependence of

$$\sigma(\lambda) = const \frac{1}{\lambda^{1.3}} \qquad (2\text{-}7)$$

Others have shown this variation to be generally applicable for the spectral range from visible to near-infrared wavelengths of 1.0 micron and for visibilities extending to 100 kilometres.

BIRAL FSM's operate at a wavelength of 0.88 microns because of the high powered IREDs available at that wavelength compared with LED's operating in the visible spectral region at the peak of the eye response (0.55 microns).

The variation with wavelength in haze implies that if two FSM'S, one operating at 0.88 micron and one at 0.55 micron are calibrated against a visible light transmissometer in fog then their measurement in haze will differ by the amount

$$\sigma(0.88) = \left(\frac{0.55}{0.88}\right)^{1.3} \sigma(0.55)$$

$$= 0.54\sigma(0.55) \qquad (2\text{-}8)$$

In fog and haze, the visible light transmissometer will measure the total scattering coefficient σ (.55). A visible light FSM might also give σ (.55) in haze, but it does not because it measures the angular scattering coefficient not the total scattering coefficient.

Atmospheric aerosol models show, in addition to the wavelength dependence, a slight wavelength dependence of the phase functions as well. For the two wavelengths of interest in the above example, the phase functions in fog and haze are as follows.

$$\Phi_{FOG}(0.55) = \Phi_{FOG}(0.88) = 0.13 \qquad (2\text{-}9)$$

$$\Phi_{HAZE}(0.55) = \Phi_{HAZE}(0.88) = 0.22 \qquad (2\text{-}10)$$

Thus, a FSM operating at 0.88 micron and calibrated in fog will show a phase function difference in haze by the amount

$$\Phi_{HAZE}(0.88) = \frac{0.22}{0.13}\Phi_{FOG}(0.88)$$

$$= 1.7\Phi_{FOG}(0.88) \qquad (2\text{-}11)$$

For a FSM operating at 0.88 microns, the two wavelength dependent components of the angular scattering coefficient are in the opposite direction and nearly offset one another. The net result is that a calibration made in fog will be applicable to haze situations.

Such is not the case for a FSM operating at 0.55 microns. At that wavelength there is no spectral difference between FSM and a visible light transmissometer. The total scattering coefficient portion of the angular scattering function will remain unchanged, but the phase function will jump in the transition from fog to haze. Larger than "true" extinction coefficients will result with the subsequent underestimation of the true visual range in haze.

2.3 PRECIPITATION MEASUREMENTS

An automated present weather sensor must be capable of determining the type, intensity and quantity of precipitation in addition to the visibility. In the case of the VPF-730 sensor these precipitation parameters are established by a combination of several methods.

Identification:

The type of precipitation is established by one of two independent techniques. In one of the techniques, the ratio of the backscatter atmospheric extinction coefficient (BACKSCATTER EXCO) to the forward scatter atmospheric extinction coefficient (FORWARD SCATTER EXCO) is determined. A ratio greater than a specific value indicates snow while a ratio lower than a specific value indicates rain. In the second the size and velocity distributions of the precipitation particle are used to determine the type of precipitation. These two techniques are intended to compliment one another. However, under some circumstances one of the techniques is programmed to override the other. The particular circumstances under which the one is programmed to veto the other has been established by several years of empirical observations.

Precipitation Recognition Matrix

The VPF-730 measures the amplitude and duration of the light pulse created by each precipitation particle as its falls through the sample volume. From the amplitude and duration it then determines the particle size and velocity. The size and velocity information is collected in a data matrix by the microcomputer and is stored for a time interval (the measurement time period, usually one minute) adequate to provide a statistically significant and representative sample of particle sizes and velocities. The size and velocity distributions of particles in the matrix are available to determine the type of precipitation. Small numbers of particles with distributions not indicative of rain or snow are considered not to be precipitation and are rejected by false alarm algorithms.

Once precipitation occurrence has been determined, the particle size distribution is used to measure the intensity. To measure the intensity, the number of particles in each size bin of the matrix are summed, then multiplied by the equivalent volume of water and a calibration constant. If the precipitation is identified as snow, a density factor is applied to determine the equivalent water content.

Because the size/velocity matrix is a convenient presentation for identifying various forms of precipitation we have termed it the "Precipitation Recognition Matrix". Types of precipitation are identified from their "Signature" in the Precipitation Recognition Matrix. The "Signature" is the particle size/velocity distribution that is characteristic of each type of precipitation phenomena.

An example of a precipitation recognition matrix is shown in Figure 2-3. This figure portrays a 16 x 21-matrix array of particle sizes and velocities. Sizes are arranged in columns and velocities in rows.

The Marshall-Palmer model for raindrop size-distribution and the Gunn-Kinzer measured velocities for raindrops in stagnant air were used to construct the matrix scales. If rainfall behaved in the exact manner of the Marshall-Palmer and Gunn-

Kinzer models all raindrop measurements would fall in the data bins along the diagonal of the Precipitation Recognition Matrix. In practice, several factors tend to disperse the size/velocity relationship from the idealised characterisations.

(1) The Marshall-Palmer size distribution for raindrops is only a best-fit approximation,

(2) Winds and wind gusts can perturb the velocity/size relationship,

(3) The shape of the sample volume can significantly influence the velocity/size characteristics of particles. (i.e. Particles falling through a portion of the sample volume other than the centre, or falling in other than a vertical direction because of wind, will exhibit slightly different velocity/size characteristics depending upon the shape of the sample volume and the direction of the wind).

For the foregoing reasons, one expects raindrop counts to show up in some off-diagonal bins of the Precipitation Recognition Matrix as shown in the schematic illustration given in Figure 2-3. Indeed, this conjecture is substantiated in practice. Figure 2-3 is a schematic portrayal of the use of the Precipitation Matrix to identify different kinds of precipitation. The locations of various forms of precipitation, which are schematically illustrated in the matrix, are also borne out in practice.

Signal Processing

A functional block diagram of the VPF-730 is shown in Figure 2-4. Those components of the sensor housed in the transmitter and receivers are shown enclosed in one dashed line. Those components housed in the power/control system are shown enclosed in the other dashed line.

When a particle of precipitation passes through the sample volume, light from the LED source, which is housed in the transmitter section of the sensor head, is scattered into the receiver section where it is sensed by the photo detector. Because the LED source is modulated at a 2 kHz frequency, the detector and amplifier chain generates an AC signal whose amplitude is proportionally to the size of the particle and whose duration is inversely proportional to its velocity.

Quantity and Intensity

Typically a sampling time interval of one minute is employed in automated present weather sensors. When rain is identified the quantity of water falling in the one-minute sampling time interval is determined from the number and size of the raindrops passing through the sample volume. The intensity is established by a comparison of the quantity of rainfall in one minute with the rate of fall intensity scale published in the Federal Meteorological Handbook (see Table 2-2). Other reporting codes and intensities may also be provided to conform to local standards, to determine the system in use please consult the calibration data supplied with the sensor. When snow is identified the intensity is established on the basis of the visual range provided there is no fog present. If fog is present the snowfall intensity is established on the basis of the equivalent water content rate of fall as indicated in Table 2-2. The equivalent water content of snowfall is determined from the measured snowflake size distribution and an empirical calibration constant.

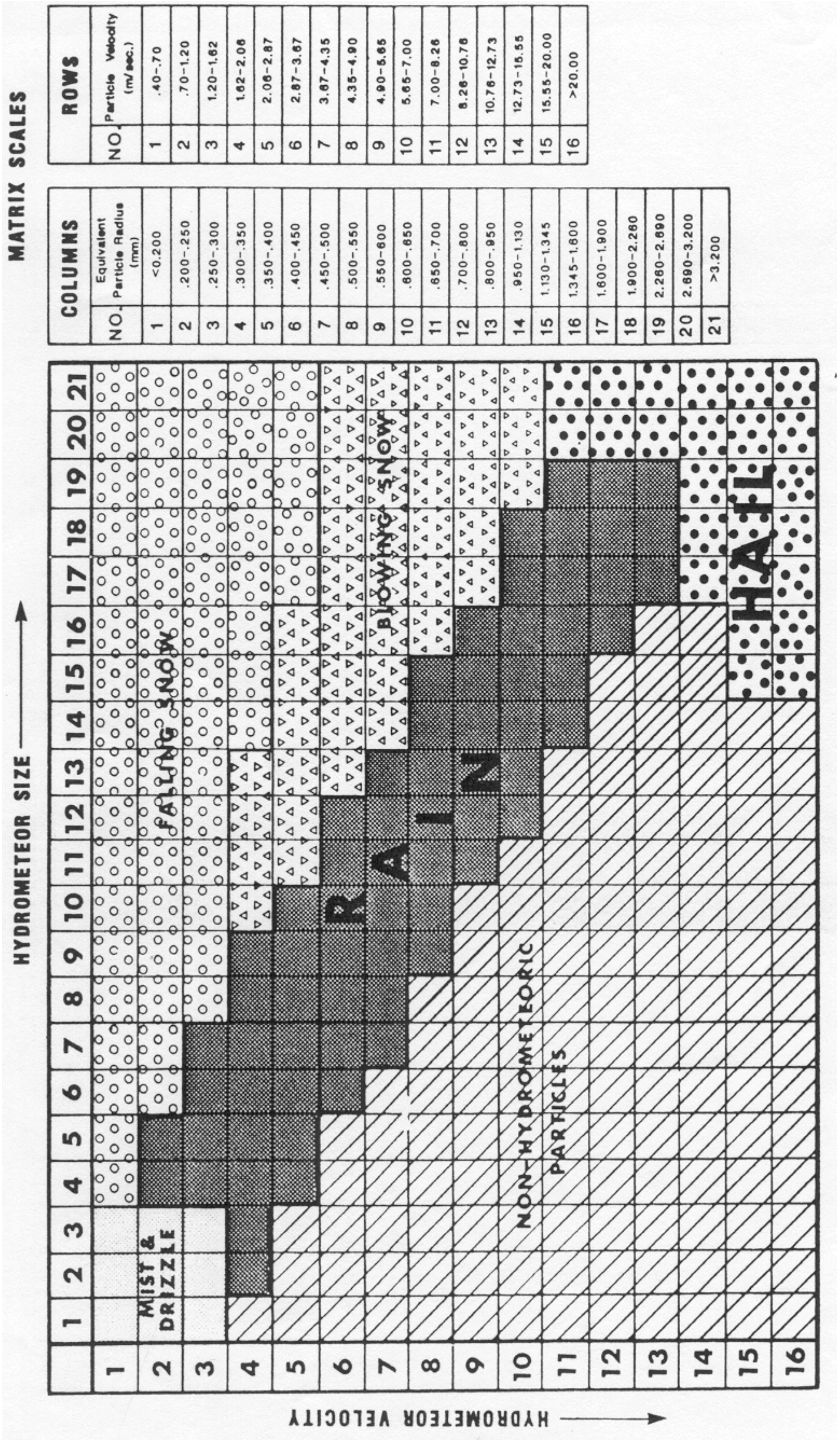


Figure 2.3 General size/velocity characteristics of various types of precipitation displayed on the precipitation recognition matrix.

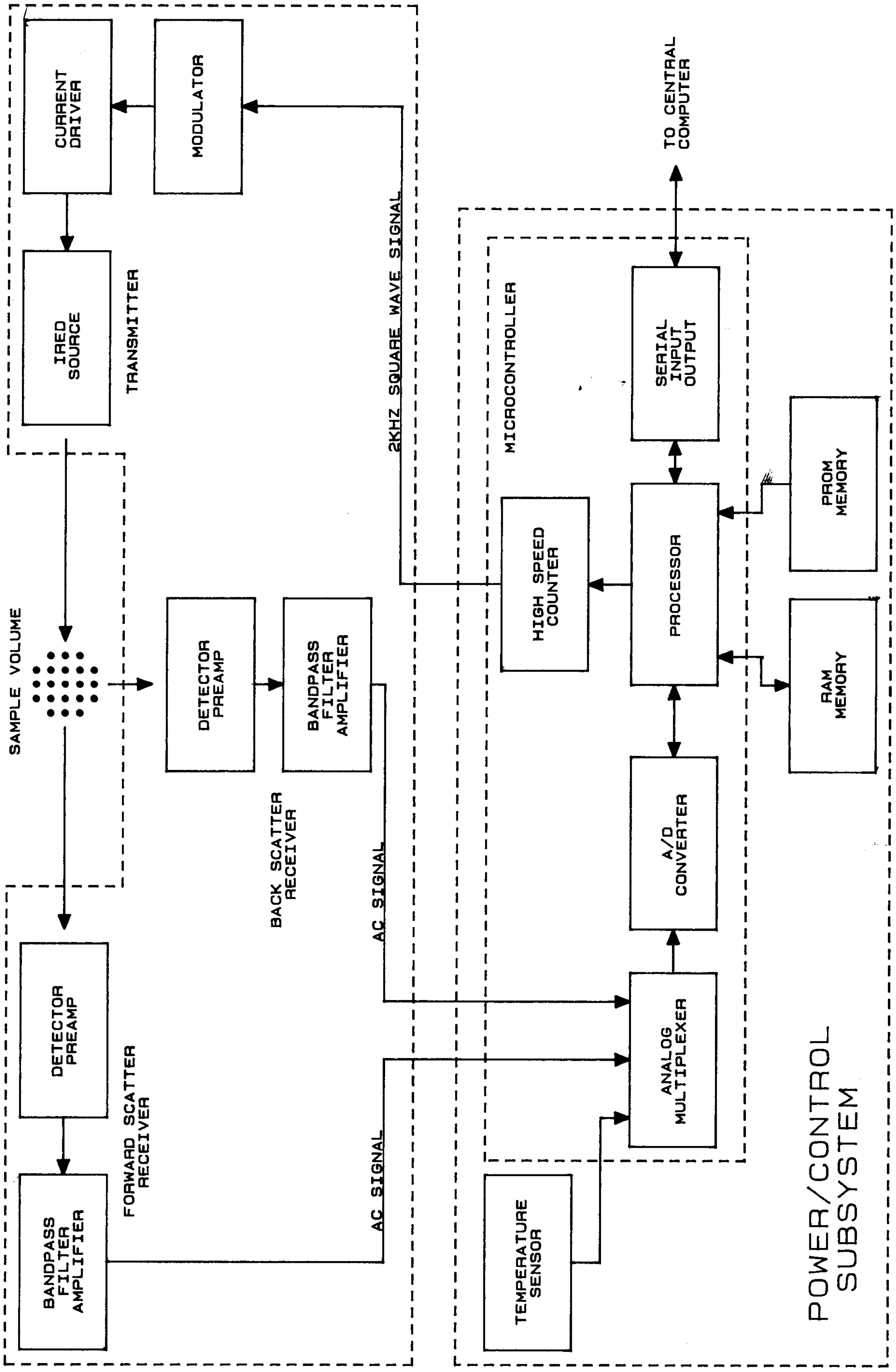


Figure 2.4 VPF-730 Sensor functional block diagram.

3 COMMUNICATIONS CONFIGURATIONS

3.1 COMMUNICATIONS PARAMETERS

3.1.1 Processor Board Communications Signal Levels

The sensor can be configured to use either RS232C signal voltage levels or RS422 differential signal voltage levels. If communications with most personal computers and terminals is desired, the RS232C configuration should be selected. If there is a long distance between the sensor and its control computer (more than 300 meters), then the RS422 configuration should be selected and a RS422 communications port installed in the control computer.

The configuration of the sensor is set during manufacture. If such a change is required contact BIRAL or the sensor supplier for help.

3.1.2 Communication Protocol

The communications specification is set by default to 1200 Baud Rate, 8 Data Bits, 1 Stop Bit, No Parity and no Flow Control (1200, 8, 1, N, N). The baud rate is user configurable to any of the standard values between 1,200 and 57,600 baud.

See section on Set Instrument Parameters for baud rate set procedure.

3.2 OPERATING STATE CONFIGURATION

The operating state of the sensor is determined by the current binary value of the operating state word (changed by the "OS" command, see 6-4 Operating State Word Binary Bit Meanings). The operating state word is stored in non-volatile memory and the sensor will power up in its last set state.

Example Configurations:

1. Send command: OS00000001

- The sensor operated continuously, present weather calculated every minute with messages sent automatically
- Heaters enabled
- Expanded data message mode
- Window de-misters always on (Window de-misters controlled only on DC powered sensors)

2. Send command: OS00100001

- The sensor operated continuously, present weather calculated every minute with messages sent automatically
- Heaters enabled
- Compressed data message mode
- Window de-misters always on (Window de-misters controlled only on DC powered sensors)

3. Send command: OS11101001

- The sensor operated continuously, present weather calculated every minute with messages sent automatically
- Heaters disabled
- Compressed data message mode
- Window de-misters always off

4. Send command: OS01000000

- The sensor operated continuously, present weather calculated every minute with messages sent only when polled
- Heaters disabled
- Expanded data message mode
- Window de-misters controlled by built-in-test window contamination monitors (DC powered sensor)

3.3 CHECK SUM USAGE

A check sum byte which can be included with messages sent by the sensor to its control computer provide a means of verifying message validity, that noise in the communications link has not changed the message. Generally, noise is not a problem, and check sum verification is not required. Therefore, the sensor communications protocol can be set for the following check sum configurations:

(1) No check sums in transmitted messages, and
(2) Check sums inserted into transmitted messages.

The sensor is configured at the factory for no check sums in transmitted messages (configuration 1).

The sensor can be configured to generate messages with a check sum byte by setting the sixth bit in the options word (See Table 6-14 of the manual). The check sum is positioned after the message and before the end characters. The check sum value is between 0 and 127, and is the sum modulo 128 (the remainder after the sum is divided by 128) of all the ASCII values of the characters in the message except the end characters. The check sum value is replaced by its bit wise complement if it happens to be either ASCII 8 (backspace), ASCII 10 (linefeed), ASCII 13 (carriage return), ASCII 17 through ASCII 20 (DC1 through DC4), or ASCII 33 (exclamation point ‘!’).

The calculation is as follows:

$C_1 \ldots C_m$ <CK sum><end chars>

Message

$$< CK >= \left(\sum_{n-1}^{m} c_n \right) MOD128$$

IF <ck sum> = 8 THEN <ck sum> = 119
IF <ck sum> = 10 THEN <ck sum> = 117
IF <ck sum> = 13 THEN <ck sum> = 114
IF <ck sum> = 17 THEN <ck sum> = 110
IF <ck sum> = 18 THEN <ck sum> = 109
IF <ck sum> = 19 THEN <ck sum> = 108
IF <ck sum> = 20 THEN <ck sum> = 107
IF <ck sum> = 33 THEN <ck sum> = 94

4 OPERATIONAL PROCEDURES

4.1 CHECK SENSOR PERFORMANCE

4.1.1 Check EXCO Calibrations

The Atmospheric Extinction Coefficient (EXCO) calibration of the forward scatter channel and the back scatter channel are checked by the procedure outlined below. The Reference Standard used for the calibration check has been assigned two values: a forward scatter value and a back scatter value. The forward scatter value is a simulation of a true atmospheric extinction coefficient expressed in inverse kilometres. The backscatter value, although it also is expressed in inverse kilometres, is an artificial value assigned only for the purpose of checking that the sensitivity of the backscatter channel is within its proper limits.

EXCO CALIBRATION CHECK PROCEDURE

STEP 1: Clean all windows on the sensor head using a glass cleaning fluid and soft cloth or tissue, preferably lens tissue. Check the cleanliness using a flashlight if possible.

STEP 2. For VPF730 only, install the backscatter receiver calibration bracket on the forward scatter receiver. See figure 5.3

STEP 3. For VPF730 only, remove the backscatter receiver from its mount and install it on the backscatter receiver calibration bracket. (Connect the backscatter receiver connector using the backscatter receiver extension cable.) See figure 5.3.

STEP 4. Attach the calibration reference standard to the sensor head. See figure 5.2 or 5.3

STEP 5. Send the command “RST<end chars>”. Verify the response “OK”.

STEP 6. If the sensor is operating in the polled mode, send the “D?” command at 60 second intervals.

STEP 7. Wait for the fifth (5^{th}) data message from the sensor. Verify that the forward- scatter is within ±3% of the value assigned to the reference standard.

STEP 8. Verify that the back scatter EXCO value in the fifth (5^{th}) data message is within ±10% of the back scatter value assigned to the reference standard.

STEP 9. Insert A ZERO PLUG in both the forward scatter head and the back scatter receiver head blocking all light from reaching the respective windows.

STEP 10. If the sensor is operating in the polled mode, send the “D?” command at 60 second intervals.

STEP 11. Send the command “RST<end chars>”. Verify the response “OK”

STEP 12. Wait for the fifth (5th) data message from the sensor. Send the command “BT”? <end chars>”. Verify that the response value is between 0.01 and 0.05 km^{-1}.

STEP 13 For VPF730 only, send the command “BB? <end chars>”. Verify that the response value is between –0.10 and +0.10 km^{-1}.

STEP 14. Remove the zero plugs and the calibration reference standard from the sensor head.

STEP 15. For VPF730 only, return the backscatter receiver to its original position and remove the backscatter receiver calibration bracket.

4.1.2 Check Temperature Sensor Calibration

The temperature sensor has a long thermal lag. The temperature read will be incorrect for at least 30 minutes if the sensor is moved from one location to another of different temperature just prior to testing. In operation, at a fixed site, this is not a problem because ambient temperature changes are slow. If a very accurate check of the temperature reading is required, the sensor should be operated for about 60 minutes at a fairly constant temperature before making the check. A verification of correct operation of the temperature sensor can be made without this “warm up” period. The check is made as follows:

TEMPERATURE SENSOR CHECK PROCEDURE

STEP 1. Use as a reference standard a thermometer accurate to ± 1 degree C. Insure the standard thermometer has had time to stabilise to the ambient temperature environment.

STEP 2. Verify that the value in the temperature field in the sensor data message matches the reference thermometer reading to within ±3 degrees C.

4.1.3 Check Receiver Background Brightness Measurement

The receiver background brightness value measures the optical signal detected by the receiver caused by the ambient background. This value is used to set the threshold values for precipitation particle detection. The following procedure will check this function (this procedure is used for both the forward scatter and backscatter receivers):

BACKGROUND BRIGHTNESS MEASUREMENT CHECK PROCEDURE

STEP 1. Insert a zero plug in the receiver hood, blocking all light from the window.

STEP 2. Send the command “R?” <end chars>”.

STEP 3. Verify that the value in the receiver background field is less than 00.06.

STEP 4. Remove the zero plugs from the Sensor Head receiver hood.

STEP 5. Send the command “R?” <end chars>” while shining a flashlight directly into the receiver window.

STEP 6. Verify that the value in the receiver background field is much greater than 00.06.

4.1.4 Check Window Demister Function

The windows of the transmitter forward scatter receiver and backscatter receiver are heated continuously to prevent any moisture condensation from occurring. To check that the window heaters are operating proceed as follows:

WINDOW HEATER CHECK PROCEDURE

STEP 1. Allow power to be applied to the instrument for at least 10 minutes before the check is made.

STEP 2. Using a thin tissue paper to cover the tip of the middle finger of your hand, place your finger against a window for a few seconds. The higher temperature of the window as compared to the ambient temperature should be readily apparent. If the heater is not functioning properly, then refer to the Troubleshooting Section of the manual.

STEP 3. Repeat this procedure for the other window(s). (NOTE: The tip of the middle finger is usually more sensitive to temperature differences than that of the index finger. However, the index finger may be used if it is more convenient to sense the temperature differential.)

4.1.5 Check Window Monitor Check

The transmitter window and the forward scatter receiver window are monitored for contamination. The values measured are used to adjust the EXCO value, and are also used to determine when the windows should be cleaned. The performance of the monitoring circuits can be checked by the following procedures:

TRANSMITTER WINDOW MONITOR CHECK PROCEDURE

STEP 1. Clean the transmitter window.

STEP 2. Send the command “R? <end chars>”.

STEP 3. Verify that the ‘transmitter window contamination’ field value is 00 to 02.

STEP 4. Insert a white card in the transmitter hood that blocks the window, and almost touches it.

STEP 5. Send the command “R? <end chars>.

STEP 6. Verify that the Transmitter window contamination field value is greater than 10.

STEP 7. Remove the white card.

RECEIVER WINDOW MONITOR CHECK PROCEDURE

This section for advanced self-test configured sensors only

This procedure is used for both forward and (for VPF730) back scatter receivers.

STEP 1. Clean the forward scatter receiver window.

STEP 2. Wait for operational data in message from the sensor.

STEP 3. Send the command “R? <end chars>”.

STEP 4. Verify that the ‘forward scatter receiver window contamination’ field value is 00 to 02.

STEP 5. Insert a white card in the forward scatter receiver hood that blocks the window, and almost touches it.

STEP 6. Wait for operational data message from the sensor.

STEP 7. Send the command “R? <end chars>”.

STEP 8. Verify that the forward scatter receiver window contamination field value is greater than 10.

STEP 9. Remove the white card.

4.2 SET INSTRUMENT PARAMETERS

4.2.1 Set Communications Parameters

The sensor communications parameters are specified in Section 3-1 of the manual. The user can only change the baud rate using the following procedure:

BAUD RATE CHANGE PROCEDURE

Send the command “%B <end chars>”.

The following message will be returned

SELECT REQUIRED BAUDRATE BY TYPING %B(NUMBER)
1….1200 BAUD
2….2400 BAUD
3….4800 BAUD
4….9600 BAUD
5….19K2 BAUD
6….38K4 BAUD
7….57K6 BAUD

The user can select the baud rate to use, for example to select 9600 baud the user would type

“%B4 <end chars>”

The user then receives the prompt:

CHANGING SETTINGS. NEW BAUDRATE IS: 9600 baud
SEND ‘OK’ USING NEW SETTINGS WITHIN 1 MINUTE TO CONFIRM CHANGE

The user must send the response “OK <end chars>” at the new baud rate within 60 seconds. Otherwise the sensor will reset and continue operation with the original baudrate settings. If an “OK <end chars>” response is received at the new baudrate the sensor will update its settings and restart.

4.2.2 Set Operating State

The operating state of the sensor can be set as described in Part 3-2. Send the command “OS <binary value> <end chars>” and verify the instrument response of “OK”.

4.3 SYSTEM IDIOSYNCRASIES

The present weather sensor is designed to be configured for any possible operating scenario. The system should allow complete operator control over instrument performance. These design goals are sometimes in conflict and result in system characteristics that can cause user confusion.

4.3.1 System Reset

There are two levels of system reset, complete and functional. Complete reset includes initialisation of all instrument programmable hardware functions including the communications protocol followed by a functional reset. Functional reset includes the following:

1. Non-volatile memory is read and parameter values are set except for the communications protocol in use. A change in communications protocol is made with a complete reset.

2. All timing is initialised, there is a 10-second stabilisation period followed by a measurement period.

3. All data is initialised.

Complete reset is caused by the removing and reapplying sensor power. The following causes Functional reset:

1. Receipt of a reset command, syntax "RST".

2. Receipt of a set operating "OS" command, syntax "OS….

3. Completion of any calibration sequence in response to a calibration command, syntaxes "CE", "CA", "CT" or "CS" command.

4.3.2 Programmable Parameters

Many parameter values can be changed by commands and are stored in the non-volatile memory. Examples of these parameters are.

Measurement period set by the "TM" command.
Instrument identification number set by the "ID" command.

When a parameter value is changed by command, the new value will not be incorporated in instrument operation until a functional reset occurs.

4.3.3 Non-volatile Memory Check Sum Usage

The Present Weather Sensor self-Test and Monitor function includes a check sum of the non-volatile memory that stores sensor parameters. Whenever a parameter is changed, the check sum should be updated. If calibration of a sensor function is performed (commands "CE", "CA", "CT", and "CP"), the check sum is automatically updated. Whenever a parameter such as the operating state or measure time is changed the self-test field in data messages and the self-test message may indicate a non-volatile memory check sum error. This error is corrected by sending the command “CS <end chars>”.

4.3.4 Maintenance Operating Modes

The sensor can be commanded into modes in which normal operation is suspended in order to make diagnostic measurements required for fault isolation. The visual range and EXCO values reported in data messages provide maintenance information and do not represent the atmospheric conditions when the sensor is in a maintenance mode. The first character in the self-test field of the data message will be “X” when the sensor is in a maintenance mode. The modes can be initiated only if the calibration bit in the Operational State word is set. The sensor is returned to its normal operating state by any reset (“RST” and “OS…” commands or power removal and reapplication) or by sending the “OS” command. The maintenance modes are described below:

Receiver Gain Test Mode
The receiver gain test mode is initiated by sending the “SG” command to the sensor. In this mode, the transmitter IRED optical source is turned off continuously, and the forward scatter receiver and backscatter receiver gain test sources are turned on continuously. The response to the “BT?” and “BB?” command will be large negative values representing the signals from the test sources detected by the receiver photodiodes. In the data message, total EXCO field value will be 0.02 (the minimum value) and the backscatter EXCO value will be a large negative value.

Receiver Window Contamination Test Mode
The receiver window contamination test mode is initiated by sending the “SW” command to the sensor. In this mode, the transmitter IRED optical source is turned off continuously, and the forward scatter receiver and backscatter receiver window contamination test sources are turned on continuously. The response to the “BT?” and “BB?” command will be negative values representing the signals from the test sources scattered by the receiver windows that is detected by the receiver photodiodes. In the data message, total EXCO field value will be 0.02 (the minimum value) and the backscatter EXCO value will be a negative value.

Source Off Test Mode
The source off test mode is initiated by sending the “SX” command to the sensor. In this mode, the transmitter IRED optical source and the receiver test sources are turned off continuously. The data message EXCO fields’ values represent the weak signals electronically coupled between the transmitter and the receivers.

5 CALIBRATION PROCEDURES

5.1 CALIBRATION CHECK DEVICES

Routine maintenance of the VPF-700 sensors is recommended at a periodic three-month interval. Calibration checks on the sensors need only be performed during every second such routine maintenance. In some locales, routine maintenance may have to be performed at shorter intervals because of excessive window contamination. For such locales, calibration checks should have their own six-month schedule.

Routine maintenance consists of:

(1) Cleaning the windows with a mild window cleaner or soap and water.

(2) Assuring that the window demisters are functioning.

(3) In cold weather checking to be sure the heated hoods (if installed) are also functioning.

The types of calibration cheeks to be performed depend upon the particular sensor model involved. For Model VPF-710, only the forward scatter EXCO and temperature (if applicable) checks are required. For Model VPF-730 sensors, a check of the backscatter EXCO and temperature is also required.

In the case of VPF-730 sensors, if the EXCO checks indicate that the sensor is functioning properly, then the calibration parameters for precipitation rate, intensity and accumulation will automatically be assured their factory set values.

Procedures for performing the calibration checks are provided in the following sections of the manual.

EXCO calibration checks are relatively straightforward and require a VPF-700 calibration kit. A typical calibration kit for the Model VPF-730 sensor, as shown in figure 5.1, consists of a foam-lined carrying case, the calibration reference standard, a bracket for mounting the back scatter receiver during the calibration check and an interconnect cable for powering the backscatter receiver during the calibration cheek process. The model VPF-710 sensor does not, of course, require the backscatter calibration accessories.

The calibration check configuration for Model VPF-710 sensors requires the reference standard to be installed in its mounting position on the sensor and then the calibration check can begin. See figure 5.2.

The calibration check configuration for the Model VPF-730 requires back scatter receiver to be removed from its normal position and suspended alongside the forward scatter receiver using the mounting bracket contained in the calibration kit. The interconnect power cable is then attached to the bottom of the back scatter receiver and the receptacle in the post exposed by removal of the back scatter receiver. The calibration check can then begin. See figure 5.3. It is not necessary to power-down the sensor while configuring the sensor for the calibration check, or reconfiguring it to its normal operating state.

5.2 EXCO CALIBRATION PROCESS

EXCO calibration of the sensor is a semi-automatic process that requires a terminal or computer with a communications port (RS232 or RS422 depending on sensor configuration) capable of sending messages entered by an operator to the sensor, and receiving and displaying messages from the sensor. Additional items needed include (1) a back scatter receiver calibration mounting bracket, (2) a back scatter receiver extension cable, (3) an EXCO calibration reference standard, and (4 and 5) two foam plugs to block the optical paths of the sensor's forward scatter and back scatter receivers.

The operator initiates the EXCO calibration procedure by sending the calibration enable and EXCO calibration commands to the sensor. The sensor's microcontroller then executes the EXCO calibration procedure that is stored in the EPROM as part of the computer program. The sensor sends messages directing the operator to perform tasks and to send a message indicating the tasks are complete. If a response to any message is not received within four minutes, the sensor's microcontroller aborts the calibration procedure, sends the "CAL ABORTED" message, and returns to executing its main computer program, measuring and reporting EXCO using the unchanged calibration constants. During the EXCO calibration, the sensor measures its forward scatter EXCO signal and back scatter EXCO signal values for two conditions: (1) with the optical paths blocked and (2) with the calibration reference standard in place and the optical paths unblocked. At the end of the calibration, the sensor's microcontroller calculates new gain and zero offset values that it stores in the non-volatile memory. It then sends a calibration complete message and returns to executing its main computer program, measuring and reporting EXCO using the new calibration constants.

The suggested procedure to be used for EXCO calibration is as follows:
Note that the calibration should be performed outside and on a day with no precipitation and a visibility of greater than 10km.

<u>EXCO CALIBRATION</u>

NOTE: For VPF710 sensors ignore references to backscatter
NOTE: <end chars> are the termination characters for messages between the sensor and the terminal, being <cr> (the "ENTER" key) followed by <lf> (pressing the "J" key while the "CTRL" key is held down).

STEP 1. Send the parameter command: "CO<end chars> "

STEP 2. The sensor's response will be: "OK "

STEP 3. Send the forward scatter EXCO calibration command: "E<end chars>"

STEP 4. The sensor’s response will be:
CLEAN WINDOWS,
BLOCK FWD SCAT RCVR OPTICS,
BLOCK BK SCAT RCVR OPTICS,
INSTALL BK SCAT CAL BRACKET, THEN
REMOVE BK SCAT RCVR FROM MOUNT,
INSTALL BK SCAT RCVR ON BRACKET,
INSTALL REF STD,
ENTER FWD SCAT EXCO (/KM)
FORM: XXX.XX

STEP 5. Clean the sensor’s transmitter, forward scatter receiver, and back scatter receiver optical windows, and insert foam plugs into the forward scatter and backscatter receiver hoods blocking the optical paths. Install the backscatter receiver calibration bracket on the forward scatter receiver. Remove the backscatter receiver from its mount and install it on the calibration bracket. Connect the backscatter receiver to the sensor electrically using the extension cable. Then, install the calibration reference standard on the sensor. After completing these tasks, enter the reference standard equivalent forward scatter EXCO value (/KM) followed by the end characters.
EXAMPLE: “034.30<end chars>”

STEP 6. The sensor’s response will be:
ENTER BACK SCAT EXCO (/KM) FORM: XXX.XX

STEP 7. Enter the reference standard equivalent backscatter EXCO value (/KM) followed by the end characters.
EXAMPLE: 068.70<end chars>

STEP 8. Wait two minutes. Then, the sensor will send the message:
REMOVE BOTH RCVR OPTICS BLOCKS, ENTER “OK”

STEP 9. Remove the foam plugs from the receivers’ optical paths. Then send the message:
“OK<end chars>”

STEP 10. The sensor’s response will be:
EXCO CAL CONTINUES

STEP 11. Wait two minutes. Then, the sensor will send the message:
EXCO CAL COMPLETE REMOVE REF STD
REINSTALL BK SCAT RCVR

STEP 12. Remove the calibration reference standard from the sensor, disconnect the extension cable, and reinstall the backscatter sensor on its mount.

STEP 13. The EXCO calibration process is complete.

5.3 TEMPERATURE SENSOR CALIBRATION PROCESS

Calibration of the sensor's temperature sensor is a semi-automatic process that requires a terminal or computer with a communications port (RS232 or RS422 depending on sensor configuration) capable of sending messages entered by the operator to the sensor, and receiving and displaying messages from the sensor. Additionally, an accurate thermometer must be used to determine the ambient temperature. The sensor must be powered and operating in a stable temperature environment for at least one hour before the temperature calibration is performed. To achieve an accurate calibration, the sensor should not be in direct sunlight for an hour prior to the calibration process.

The operator initiates the calibration procedure by sending calibration enable and temperature calibration commands to the sensor. The sensor's microcontroller then executes the temperature calibration procedure, which is stored in the EPROM as part of the computer program. The sensor sends a message asking the operator for the ambient temperature. If a response to the message is not received within four minutes, the sensor's microcontroller aborts the calibration procedure, sends the "CAL ABORTED" message, and returns to executing its main computer program, measuring and reporting EXCO with no changes to the values of the calibration constants. During the calibration process, the sensor measures its temperature signal value, calculates a new value for the temperature calibration constant that sets the temperature to that entered by the operator, and stores the constant in non-volatile memory. It then sends a calibration complete message and returns to executing its main computer program, measuring and reporting EXCO.

The suggested procedure to be used for calibration is as follows:

TEMPERATURE CALIBRATION

NOTE: <end chars> are the termination characters for messages between the sensor and the terminal, being <cr> (the "ENTER" key) followed by <lf> (pressing the "J" key while the "CTRL" key is held down).

STEP 1. Send the parameter command: CO<end chars>

STEP 2. The sensor's response will be: OK

STEP 3. Send the EXCO calibration command: CT<end chars>

STEP 4. The sensor's response will be:
ENTER TEMP DEG C
FORM: (-)XX.X

STEP 5. Send the message:
<thermometer temperature (degrees C)><end chars>
EXAMPLE: 19.3<end chars>

STEP 6. The sensor's response will be:
CAL IN PROGRESS

STEP 7. Almost immediately, the sensor will send the message:
CAL COMPLETE

STEP 8. The calibration process is complete.

5.4 PRECIPITATION AMOUNT CALIBRATION PROCESS

Precipitation amount calibration of the sensor is a process which requires a terminal or computer with a communications port (RS232 or RS422 depending on sensor configuration) capable of sending messages entered by an operator to the sensor, and receiving and displaying messages from the sensor. This process provides for adjusting the calibration factor of the sensor precipitation measurement.

The amount of adjustment to this factor is determined by making an independent measurement of the liquid accumulation over several rain episodes and comparing the accumulation reported by the sensor to this independent measured accumulation. The operator initiates the precipitation amount calibration procedure by sending the calibration enable and precipitation amount calibration commands to the sensor. The sensor's microcontroller then executes the precipitation amount calibration procedure, which is stored in the EPROM as part of the computer program. The sensor sends a message asking the operator to enter the precipitation amount adjustment factor. If a response to the message is not received within ten minutes, the sensor's microcontroller aborts the calibration procedure, sends the "CAL ABORTED" message, and returns to executing its main computer program, measuring and reporting precipitation amount using the unchanged calibration constants.

The value to be entered to adjust the precipitation amount factor is calculated as follows:

$$\text{Value entered} = \frac{\text{Desired precip accumulation}}{\text{Sensor's reported precip accumulation}} * 100$$

EXAMPLE: Over several rainstorms, a reference sensor measures an accumulation of 225 millimetres. The sensor reported an accumulation of 244 millimetres. To adjust the sensor's precipitation accumulation factor, the value to be entered is:

$$\frac{225}{244} \times 100 = 92.2$$

The suggested procedure to be used for precipitation amount calibration is as follows:

PRECIPITATION AMOUNT CALIBRATION

NOTE: <end chars> are the termination characters for messages between the sensor and the terminal, being <cr> (the “ENTER” key) followed by <lf> (pressing the “J” key while the “CTRL” key is held down).

STEP 1. Send the parameter command: CO<end chars>

STEP 2. The sensor’s response will be: OK

STEP 3. Send the precipitation amount calibration command: CA<end chars>

STEP 4. The sensor’s response will be:
ENTER PRECIP AMT ADJ FACTOR
IN PERCENT (30.0 TO 300.0)
FORM: XXX.X

STEP 5. Send the message:
<desired adjustment in percent><end chars>
EXAMPLE: 92.2<end chars>

STEP 6. The sensor’s response will be:
CAL COMPLETE

STEP 7. The precipitation amount calibration process is complete.

Figure 5.1. 730 Reference Standard Calibration Kit

Figure 5.2. 710 Reference Standard Calibration Configuration

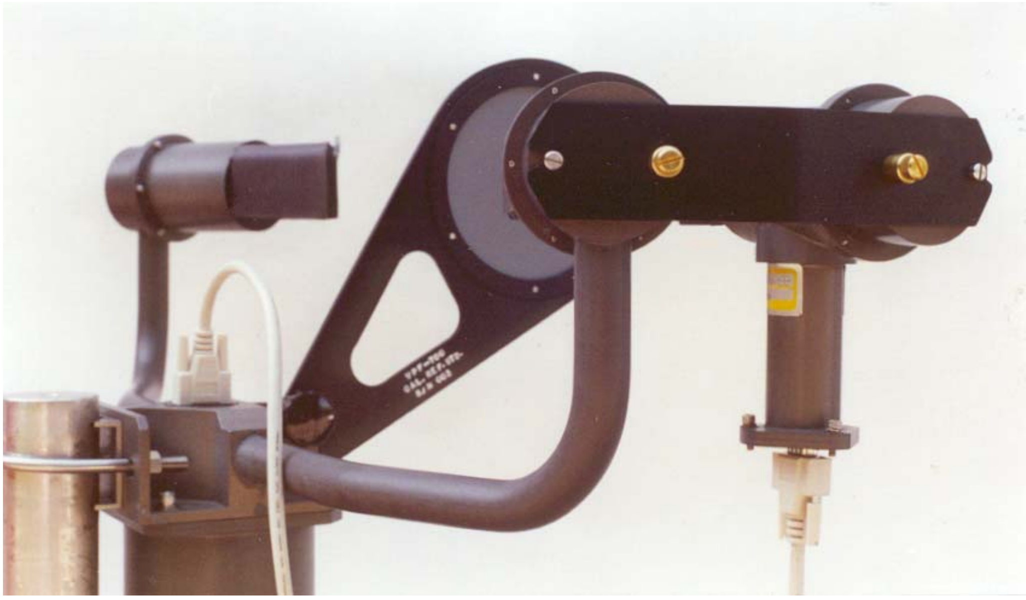


Figure 5.3. 730 Reference Standard Calibration Configuration

6 COMMANDS AND RESPONSES

6.1 COMMAND AND RESPONSE MESSAGES

Command Messages

Command	Quantitative Response	Meaning
A?< end chars>*	See Precipitation	Send accumulated Accumulation precipitation and Message time of accumulation
AC <end chars>*	None	Clear accumulated precipitation and time
BB?<end chars >*	±XXX.XX	Send present value of Back Scatter EXCO (Beta)
BL? < end chars>*	±XXX.XX	Send present value of EXCO (β) less precipitation particle component
BT? <end chars>	±XXX.XX	Send present value of Total EXCO (β)
C? < end chars >	See Calibration	Send calibration parameters message
CA< end chars>*	See Precipitation	Perform Precipitation Amount Calibration (Cal must be enabled)
CE <end chars>	See EXCO	Perform both Forward Calibration and Back Scatter EXCO calibration (Cal must be enabled)
CO < end chars >	None	Enable a calibration
CS< end chars>	None	Set Non-volatile Memory Checksum
CT< end chars>	See Temperature Calibration	Perform temperature calibration (Cal must be enabled)
CX < end chars >	None	Disable calibrations

NOTE: <end chars> are ASCII characters CR (13) and LF (10)
*THESE COMMANDS NOT VALID FOR 710

Command Messages (Continued)

Command	Quantitative Response	Meaning
D?< end chars>	See Operational Message	Send latest operational message
Dn? <end chars>	Operational messages with "O" prefix	Send accumulated operational messages, starting with the latest for n messages (1 to 10)
DHO <end chars>	None	Turn on heaters. If they would not be on normally, the heaters will turn off within 2 minutes. (For maintenance only)
DHX <end chars>	None	Turn off heaters
IDxx <end chars>	None	Set instrument identification number (0 to 99)
M?< end chars>*	See Matrix response	Send Precipitation Matrix accumulated over last 5 measurement periods
osb(b ...) <end chars>	None	Set Operational State (See Operational State Bits p.61)
P?< end chars>	See Parameter Message	Send parameter values
PV? <end chars>	See Program Version	Send program version Message
R? < end chars >	See Remote Maintenance Message	Send self-test and monitoring message
RST < end chars >	None	Restart instrument
SG < end chars >	None	Set gain maintenance mode (Cal must be enabled)

NOTE: <end chars> are ASCII characters CR (13) and LF (10)
*THESE COMMANDS NOT VALID FOR 710

Command Messages (continued)

Command	Quantitative Response	Meaning
SO < end chars >	None	Source on, normal mode (Cal must be enabled)
SW< end chars>	None	Set window maintenance mode (Cal must be enabled)
SX< end chars>	None	Source off maintenance mode (Cal must be enabled)
T? <end chars>	See Instrument Times Message	Send instrument times message
TDxxxx <end chars> Default = 300	None	Set delay before sending each line of a message (milliseconds)
TMxxxx <end chars> Default = 60	None	Set measurement period (seconds)
WT? < end chars > Default = 10	XX	Send window contamination threshold for fault indication (percent transmission)
WTn < end chars >	None	Set window contamination threshold for fault indication, per cent transmission. Range: 0 to 40% (Cal must be enabled)
%B < end chars >	See Set Instrument Parameters	Perform communications baud rate change

NOTE: <end chars> are ASCII characters CR (13) and LF (10)

Command Messages (continued)

Response	Meaning
BAD CMD<end chars>	Command was not among those understood by Instrument
COMM ERR<end chars>	An error was detected in a character in the command; start over
OK < end chars >	Command with no quantitative response was understood and Executed
TIMEOUT <end chars>	Command was sent with more than 10 seconds between characters; start over
TOO LONG< end chars>	Command message was longer than 24 characters including end characters; start over

NOTE: <end chars> are ASCII characters CR (13) and LF (10)

6.2 CALIBRATION PARAMETER MESSAGE FORMAT

Sent in response to command "C?"

XXXX,±XXX,XXXX,±XXX,XXXX,XXXXX

Precipitation amount adjust constant
(Typically 1000 to 1600)

Temperature sensor calibration constant
(Typically 18000 to 21000)

Backscatter EXCO calibration offset constant
(Typically -300 to +300)

Back scatter EXCO calibration gain constant
(Typically 1800 to 4000)

Forward scatter EXCO calibration offset constant
(Typically –00 to +300)

Forward scatter EXCO calibration gain constant
(Typically 3000 to 5500)

6.3 MATRIX RESPONSE FORMAT

Sixteen lines are sent in response to the command M?. Each line has at least one numeric value, but all zero value elements to the right of the last nonzero value element are removed. The maximum number of elements in a row is twenty-one (21).

Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>
Mnnn[,nnn….]<end chars>

6.4 OPERATING STATE WORD BINARY BIT MEANINGS

The numeric value included with the operating state command determines the operating configuration of the instrument. This value is entered as a binary number (1’s and 0’s). Leading 0’s in the value need not be entered. The value is stored in non-volatile memory and the operating configuration when power is applied is that set by the last entered operating state (OS.….) command. The value can be determined by sending the "P?" command and observing the “operating state” field in the instrument's response. The binary bits have the following meaning:

bbbbbbbb

Bit 1: 1 = Data message sent automatically after calculation
0 = Data message sent only in response to "D?"' command

Bit 2: 1 = Calculate values and determine data message in response to "D?" command, ignoring measurement interval timing
(Bits 1 and 3 must be 000)
0 = Values calculated and data message determined after each measurement interval

Bit 3: Reserved

Bit 4: 0 = Heaters enabled (heaters will turn on if temperature is less than 2°C)
1 = Heaters always off

Bit 5: Reserved

Bit 6: 1= Compressed data message mode
0= Expanded data message mode

Bits 7 and 8: DC Powered sensors only (power saving)
(AC Powered sensors should have window heaters always on)
00 = Window demisters always on
01 = Window demisters controlled by window contamination. If any window's attenuation increases, caused by contamination or condensation, to more than the percentage specified by WT command, the heaters will turn on for 300 seconds or until the attenuation in reduced to 4/5 the turn on threshold.
11 = Window demisters always off

<u>EXAMPLE (default setting)</u>
OS00000001<end chars>
Window demisters always on
Expanded data message mode
Heaters enabled
Values calculated and data message sent automatically after each measurement interval

6.5 OPERATIONAL DATA MESSAGE VPF730 (Compressed Format)

Compressed format sent when Operating state word Bit 6 is “1”. Sent automatically after calculation when Operating State Word bit 1 is “1”. Also sent in response to command “D?”

CPxx,cc,xxx.xx,xx.xxxx,ttt.t,ccc<end chars>

- ccc — Self-Test & Monitoring
- ttt.t — Temperature (degrees C)
- xx.xxxx — Amount of water in precipitation in last measurement period (mm)
- xxx.xx — Transmissometer Equivalent EXCO (/KM)
- cc — Present Weather Code
- xx — Instrument Identification number

<u>Precipitation Type Codes</u>

00	No significant weather observed, or sensor starting
04	Haze or Smoke
30	Fog
40	Indeterminate Precipitation Type
51	Light Drizzle
52	Moderate Drizzle
53	Heavy Drizzle
61	Light Rain
62	Moderate Rain
63	Heavy Rain
71	Light Snow
72	Moderate Snow
73	Heavy Snow
89	Hail

<u>Self-Test & MonitoringValues</u>

c c c

Third c:
O - Other self-test values OK
X - Other self-test fault exists

Second c:
O - Windows not contaminated
X - Window contamination Warning
F - Window contamination Fault

First c:
O Sensor not reset since last R? command
X - Sensor reset since last R? command

6.6 OPERATIONAL DATA MESSAGE VPF730 (Expanded Format)

Extended format sent when Operating State Word Bit is "0".
Sent automatically after calculation, when Operating State Word Bit is "1". Also sent in response to command "D?"

PWxx,xxxx,xxxx,xxx.xx KM,ccc,cc,xx.xx,xx.xxxx,xxxx.x C,xxxx,xxx.xx,xxx.xx,±xxx.xx,xxxx,xxx,ccc,xxx.xx, <end chars>

- Instrument ID Number
- Last measurement period (seconds)
- Time since this report was generated (seconds)
- Meteorological optical range (km)
- Precipitation type message
- Obstruction to vision message
- Detector Background Illumination
- Amount of water in precipitation in last measurement period (millimetres)
- Temperature (°C)
- Number of precipitation particles detected in last measurement period
- Transmissometer Equivalent EXCO
- EXCO less precipitation particle component (/km)
- Back scatter Channel EXCO
- Precipitation Message Index
- Precipitation Indicator 2
- Self-Test & Monitoring
- Total EXCO (/km)

Note: See next page for definition of codes

OPERATIONAL DATA MESSAGE VPF730 (Expanded Format)(Continued)

Explanation of message sub-strings:

Self-Test & Monitoring Values

```
c c c
| | |
| |  O = Other self-test values OK
| |  X = Other self-test fault exists
| |
|  O = Windows not contaminated
|  X = Window contamination Warning
|  F = Window contamination Fault
|
O = Sensor not reset since last "R?"
X = Sensor reset since last "R?"
```

Precipitation Type Codes

“NP “	No precipitation
“DZ- “	Light drizzle
“DZ “	Moderate drizzle
“DZ+“	Heavy drizzle
“RA-“	Light rain
“RA “	Moderate rain
“RA+“	Heavy rain
“SN-“	Light snow
“SN “	Moderate snow
“SN+“	Heavy snow
“UP “	Indeterminate precipitation type
“GR “	Hail
“X “	Initial value or Error.

Obstruction to Vision Codes

“ “	No Obstruction
“HZ“	Haze
“FG“	Fog

6.7 OPERATIONAL DATA MESSAGE VPF710 (Compressed Format)

Compressed format sent when Operating State Word Bit 6 is “1”. Sent automatically after calculation when Operating State Word Bit is “1”. Also sent in response to command “D?”.

CPxx,xxx.xx,ccc<end chars>

Self-Test & Monitoring

Total EXCO (/KM)

Instrument Identification Number

Self-Test & Monitoring Values

C C C

O - Other self-test values OK
X - Other self-test fault exists

O - Windows not contaminated
X - Window contamination Warning
F - Window contamination Fault

O - Sensor not reset since last ‘R?’ command
X - Sensor reset since last ‘R?’ command

6.8 OPERATIONAL DATA MESSAGE VPF710 (Expanded Format)

Extended format sent when Operating State Word Bit 6 is “0”.
Sent Automatically after calculation when Operating State Word Bit 1 is “1”.
Also sent in response to command “D?”.

VSxx,xxx.xx,ccc,bbbbbb,x.xxx,xx.xx,xxx,xx,xxx,xx,xxxx,±xxx.xx,xxxx < end chars >

Not used
Not used
AC interrupts per second
Receiver (forward scatter) window contamination (clean 00 to 02, 10% Attn 10)
Forward scatter receiver gain (80 to 120)
Transmitter window contamination (clean 00 to 02, 10% Attn 10)
Infrared optical power (95 to 105)
Forward scatter receiver background illumination (Dark 00.00 to 00.10, bright day 06.00 10.00)
A/D reference channel measured value (2.450 to 2.550)
1=Transmitter sync signal missing
1= A/D control signal error
1= RAM error detected
1= EPROM check sum error
1= Non-volatile memory check sum error
1= Sensor reset has occurred
Self-Test & Monitoring
Total EXCO (/Km)
Instrument ID number

Self-Test & Monitoring Values

CCC

O - Other self-test values OK
X - Other self-test fault exists
O - Windows not contaminated
X - Window contamination Warning
F - Window contamination Fault
O - Sensor not reset since last R? command
X - Sensor reset since last R?- command

6.9 PARAMETER MESSAGE FORMAT

Sent in response to command "P?"

```
TPWxx,cccccccc,bbbbbbbb,xx,xxx,xxxxx,xxxx,xxx,xxx,xxxx,xxxx,xxx,xx,xxxxx<end chars>
```

- Instrument Identification number
- Program revision date
- Operational state setting (binary)
- Offset value for EXCO (/Km)
- Maximum particle count in 5 measurement periods (for intermittent mode, the present period) to never be considered precipitation.
- Minimum particle count in 5 measurement periods (for intermittent mode, the present period) to always be considered precipitation.
- Adjustment factor, Precipitation particle size for its peak signal relative to the fog EXCO average signal.
- 160 Hz filter particle size radius threshold (microns).
- 40 Hz filter particle size radius threshold (microns).
- Precipitation amount adjust.
- Reserved.
- Sample volume height adjust.
- Particle minimum velocity to be precipitation.
- Minimum particle count to use matrix more recent than minutes for analysis

6.10 PRECIPITATION ACCUMULATION MESSAGE FORMAT

Sent in response to command "A?"

```
xxx.xx
    or     ,xxxx <end chars>
xxxx.x       |
    |
    |         Total time of accumulation in minutes
    Accumulated precipitation in millimetres
```

6.11 PROGRAM VERSION MESSAGE FORMAT

Sent in response to command "PV?"

The sensor will respond with a string that defines the software used within the sensor.
The string will be dependent on the sensor build.
The general format of the message will be:

SI XXXXXX.YY

Revision number

Software number

6.12 SELF TEST & MONITORING MESSAGE FORMAT

Sent in response to command “R?”.

hhh,x.xxx,xx.x,xx.x,x.xx,xx.x,xx.x,xx.x,xxx,xxx,xxx,xx,xx,xx,±xx.x,xxxx<end chars>

- Hexadecimal Representation of Self-Test Discrete Flags
- A D Reference Channel Measured Value (2.450 to 2.550)
- Power Input Voltage (Input Voltage ±2V) – **DC Sensors Only** (Ignore this reading for AC sensors)
- +12 VDC Power Supply Value (11.25 to16.0) - **Advanced Only**
- +5 VDC Power Supply Value (4.50 to 5.50) - **Advanced Only**
- -12 VDC Power Supply Value (11.25 to 16.0) - **Advanced Only**
- Forward Scatter Receiver Background Illumination (Dark 00.00 to 00.10, Bright Day 06.00 to 10.00)
- Back Scatter Receiver Back round Illumination (Dark 00.00 to 00.10, Bright Day 06.00 to 10.00)
- IRED optical Power (85 to 110)
- Forward scatter Receiver Gain (80 to 120) - **Advanced Only**
- Back Scatter Receiver Gain (Option: 80 to 120) - **Advanced Only**
- Transmitter Window Contamination (Clean - 00 to 02, 10% Attn 10)
- Forward scatter Receiver window contamination - **Advanced Only** (Option: Clean - 00 to 02, 10% Attn 10).
- Back scatter Receiver window contamination - **Advanced Only** (Option: Clean - 00 to 02, 10% Attn 10).
- Temperature (°C)
- AC Interrupts per second (3300 to 4200)

Hexadecimal Bit Codes

hhh

First digit:
- 8 Sensor reset since last R? command
- 4 Receiver test in progress (IRED Optical power value invalid)
- 2 IRED Commanded off (IRED Optical power value invalid)

Second digit:
- 8 Register error detected
- 4 Ram Error detected
- 2 Non-Volatile memory check sum error
- 1 EPROM Check sum error

Third digit:
- 4 A/D Control signal error
- 2 Deicing heaters on
- 1 Window heaters on

6.13 TIMING PARAMETERS MESSAGE FORMAT

Sent in response to command "T?".

xxxx,xxxx,xxxxx,xxxx

Min Window Heat Time
(when Operating State bits 7 and 8 = 01)
(0-9999 seconds) (default = 300)

Delay before each communications response line
(0 to 10000 milliseconds) (default = 0)

Time between measurement of peripheral signals
during measurement interval (5 to 999 seconds) (default = 5)

Measurement interval for each operational data message
(10 to 300 seconds) (default = 60)

6.14 OPTIONS WORD BINARY BIT MEANINGS

The numeric value set at the factory for the options word determine the configuration options of the sensor. The value can be determined by sending the ‘OP?’ command and comparing the instrument's response to the following table. The binary bits have the following meaning:

bbbbbbbb,bbbbbbbb

Bit 1: Reserved

Bit 2: Not used

Bit 3: 0 - Use temperature sensor value in PW determination
This bit should not be changed.

Bit 4: Not used

Bit 5: Not used

Bit 6: 1 - Add a check sum character to all sensor output messages
0 - Don't add a check sum character to all sensor output messages

Bit 7: 1 - Don't adjust EXCO and MOR values in data messages
for measured window contamination
0 -Adjust EXCO and MOR values in data messages
for measured window contamination

Bits 8 to 16: Not used

Default setting = 00000000,00000000

7 AMBIENT LIGHT SENSOR (OPTIONAL)

For detailed specification of Ambient Light Sensor (ALS) see appropriate manual

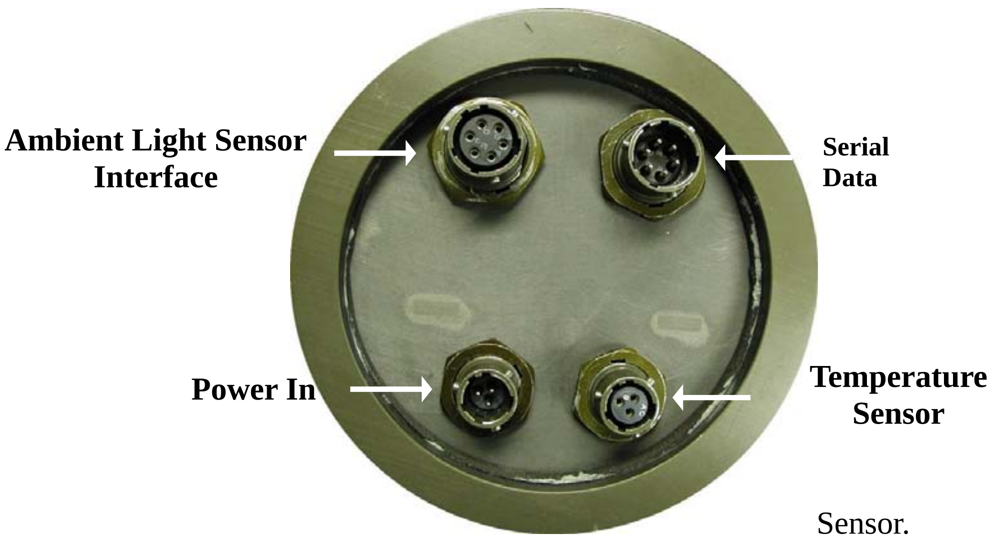
7.1 ELECTRICAL CONNECTIONS for AMBIENT LIGHT SENSOR

(For Standard Connections see Section 1.4)

THIS CONNECTION SHOULD BE MADE BEFORE APPLYING POWER TO THE SENSOR

7.1.1 Connector Type

A chassis receptacle with an o-ring environmental seal is provided for the Ambient Light Sensor



Sensor.

Figure 7.1

7.1.2 Pin Functions 235/115AC Interface

The functions for the chassis mounted 6-Way socket is as follows:

Pin Number	Function (235/115AC Interface)
A	28VAC – AC Supply
B	28VAC – AC Supply
C	Signal Return
D	Light Sensor Signal High Range(0-10VDC)
E	Light Sensor Signal Low Range(0-10VDC)
F	Not used

7.1.3 Pin Functions 24V DC Interface

The functions for the chassis mounted 6-Way socket is as follows:

Pin Number	Function (24V DC Interface)
A	+12V DC Power input
B	-12V DC Power input
C	Signal/heater power Return
D	Light Sensor Signal High Range(0-10VDC)
E	Light Sensor Signal Low Range(0-10VDC)
F	+5V DC Window Heater Power

7.2 COMMAND RESPONSE VARIATIONS for AMBIENT LIGHT SENSOR

(For Ambient Light Sensor equipped sensors) Any responses not listed here are as standard.

7.2.1 Calibration Parameter Message Format (ALS versions)

Sent in response to command "C?"

For units equipped with an analogue input port, the following fields are appended to standard message:

,±XXXXX,±XXXXX,±XXXXX,±XXXXX,±XXXXX,±XXXXX,±XXXXX,±XXXXX

- ALS Low Range channel 1 offset
- ALS Low Range channel 1 gain setting
- ALS High Range channel 2 offset
- ALS High Range channel 2 gain setting
- Not Used
- Not Used
- Not Used
- Not Used

7.2.2 Operational Data Message (ALS versions)
(Both Expanded and Compressed formats)

Sent in response to ‘D?’ and also after calculation when operating state word bit 1 is set to ‘1’.

For units equipped with an Ambient Light Sensor, the following fields are appended to standard message:

, EXT:XXXX,XXXX,XXXX,XXXX

Not Used

Not Used

ALS High Range channel 2 (0000=0.00V, 1000=10.00V)

ALS Low Range channel 1 (0000=0.00V, 1000=10.00V)

8 WEATHER STATION MODULE (OPTIONAL)

8.1 ELECTRICAL CONNECTIONS FOR WEATHER STATION MODULE

(For standard connections see Section 1.4)

THIS CONNECTION SHOULD BE MADE BEFORE APPLYING POWER TO THE SENSOR

8.1.1 Connector Type

A chassis receptacle with an o-ring environmental seal is provided for Weather Station Module cable. A dust-cap is provided to cover and protect the sensor when this input is not being used

8.1.2 Pin Functions

The functions for the chassis mounted socket are as follows: (} Denotes a twisted pair)

Pin Number	Wire Colour (for supplied cable)	Function
A	Red }	Signal Channel 1 (0-10VDC)
B	White }	Return Channel 1
C	Brown }	Signal Channel 2 (0-10VDC)
D	White }	Return Channel 2
E	Black }	Signal Channel 3 (0-10VDC)
F	White }	Return Channel 3

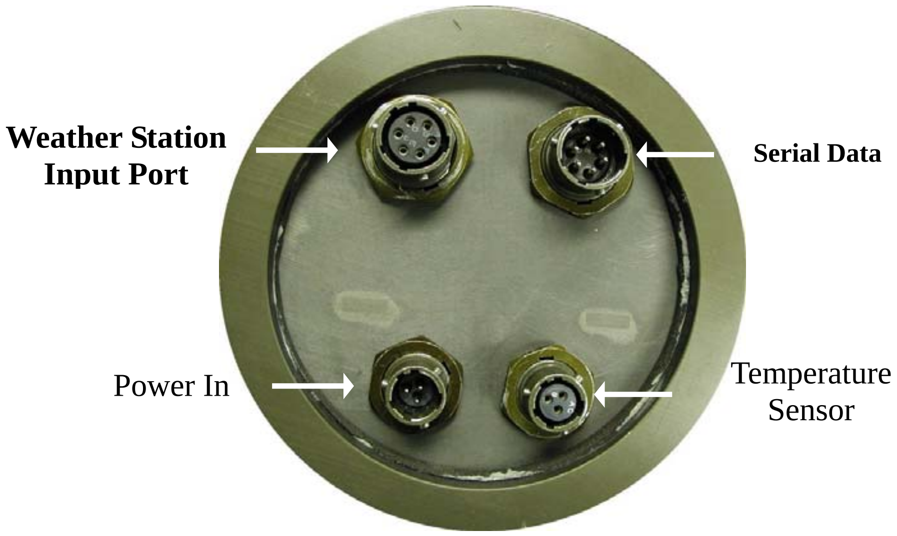


Figure 8.1

8.2 COMMAND RESPONSE VARIATIONS for WEATHER STATION MODULE

(For Weather Station Module equipped sensors) Any responses not listed here are as standard.

8.2.1 Calibration Parameter Message Format (WSM versions)

Sent in response to command "C?"

For units equipped with an analogue input port, the following fields are appended to standard message:

,±XXXXX,±XXXXX,±XXXXX,±XXXXX,±XXXXX,±XXXXX,±XXXXX,±XXXXX

- WSM channel 1 offset
- WSM channel 1 gain setting
- WSM channel 2 offset
- WSM channel 2 gain setting
- WSM channel 3 offset
- WSM channel 3 gain setting
- Not Used
- Not Used

8.2.2 Operational Data Message (WSM versions)
(Both Expanded and Compressed formats)

Sent in response to ‘D?’ and also after calculation when operating state word bit 1 is set to ‘1’.

For units equipped with a Weather Station Module, the following fields are appended to standard message:

, EXT:XXXX,XXXX,XXXX,XXXX

Not Used

WSM level channel 3 (0000=0.00V, 1000=10.00V)

WSM level channel 2 (0000=0.00V, 1000=10.00V)

WSM level channel 1 (0000=0.00V, 1000=10.00V)

9 Notes