Optical Scientific Inc.

(formerly known as Scientific Technology, Inc.)

WIVIS System Advantages

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WIVIS System Advantages Summery

- **Three different sensing technologies in WIVIS**

  1. In-beam optical scintillation for precipitation identification and discrimination
  2. Off-axis forward scattering for visibility measurement
  3. Acoustic detection for solid precipitation particles discrimination

  By combining all three OSi patented techniques, OSi has produced a sensor that provides the highest degree of accuracy and versatility possible.

- **200 million unit-hours of field experience**

  No other weather sensors have field experiences even close to that of WIVIS.

- **Ease of Installation**

  WIVIS could be mounted on the top of a pole or on the side of a tower.

- **Meets AWOS requirements for NWS / WMO codes**

  Simple polling character change gives either NWS or WMO weather codes.

- **Adaptive Algorithm**

  An Adaptive Algorithm enables the WIVIS sensor to perform optimally under all the diverse environmental conditions and the dust accumulation on optical components.

- **Precipitation correction for visibility**

  A correction based on different types of precipitation is used to obtain the true visibility.

- **Ambient Light Sensor (ALS)**

  With the actual ambient luminance measurements, WIVIS does not require further ambient light correction (such as day/night) for visibility measurements.

- **No field calibration / minimum field maintenance**

  WIVIS reliably provides accurate precipitation and visibility measurements without requiring periodic field calibration and requires only minimum field maintenance for extended unmanned field operations.

- **Self Diagnostics and Continuous Self-test**

  System error will be automatically detected to guarantee the data quality.

- **Easy Upload Capability**

  New firmware can easily be uploaded to a WIVIS in the field.

1. Introduction

OSi, formerly known as Scientific Technology, Inc. (ScTI), is the inventor and provider of the Automated Surface Observing System (ASOS) present weather sensor, the LEDWI (Light Emitting Diode Weather Identifier). By adding an off-axis receiver for visibility measurement, and combining both the optical signal and the acoustic signal, reliable detection and discrimination of ice particles can be achieved. The resultant instrument, WIVIS (weather identifier and visibility) sensor, has been providing reliable measurements of visibility and present weather for many years.

Designed for rugged, unattended operation, more than **2000** OSi LEDWI and WIVIS have been field proven in adverse environments around the world for highway, airport, commercial and international applications in locations such as North America, Europe, Asia, and even Antarctica. As of today, OSi has accumulated more than **200 million unit-hours** of field experience with LEDWI and WIVIS!

A major advantage of the WIVIS is that field calibration is not needed. After the system has been turned on and operating for about half an hour, the sensor's artificial intelligence (**AI**) and fuzzy logic algorithms automatically adjust all the parameters to optimum values. The WIVIS will then follow the change of the environment and automatically adjusts all key parameters. No human calibration is required for field operation.

A second advantage of the WIVIS is that measured weather parameters will not be affected by dust, dirt or ice on the lenses. WIVIS uses an adaptive baseline algorithm to negate the effects of the buildup of dust or dirt on the lenses. The weather processing algorithm includes an artificial intelligence and fuzzy logic based algorithm so that the baselines are self adaptive to correct in beam scintillation and off-axis forward scattering coefficients due to dirt on the lenses or the aging of the light source. The WIVIS can operate unattended for a long period of time without the need of frequently cleaning the optics.

The WIVIS is designed for long term unattended field operation. Installation and maintenance are straight forward. All maintenance procedures may be easily performed in the field by one technician. Routine preventative maintenance requires only lens cleaning and the removal of insect nests (spiders, etc). OSi recommends routine preventative maintenance is performed every six months.

The WIVIS uses DSP (Digital Signal Processor) techniques to process the weather induced optical and acoustic data. Flash memory stores the firmware to carry out the system algorithm. Therefore, any future upgrade of the system software can be done by using remote upload to refresh the memory. This feature will eliminate the effort typically required to change out program memory chips in the field for any future system software upgrades. Upgrades may now be preformed through the sensor's serial port.

The WIVIS built-in-test (BIT) function detects most failures. In the rare instance a WIVIS failure occurs, the failure is detected and identified in the sensor message. This information allows the maintenance technician to have the proper tools and spare parts with him when he responds to a service call for a WIVIS related issue.

2. Overview of Primary Present Weather and Visibility Sensing Techniques

It is extremely challenging to explain the very complex artificial intelligence based algorithm of WIVIS. However, a description is summarized as follows.

Several techniques have been developed to measure atmospheric precipitation parameters using optical, microwave, and acoustic technologies, i.e.,

1. Attenuation / Extinction
2. Scattering
3. Scintillation
4. Acoustic

But likewise, no single sensing technique meets every need of precipitation measurement and identification. To better understand the strengths and weaknesses of the primary technologies, an overview is given. The advantages and disadvantages of each technology are discussed below.

2.1 Attenuation / Extinction

Attenuation or extinction techniques are usually used with line-of-sight optical or microwave paths. The attenuation or extinction caused by atmospheric turbulence or turbidity is measured to obtain atmospheric parameters. The technology requires a relatively long path length from tens of meters to several kilometers such that the attenuation or extinction can be reliably measured. Because this technology will be affected by fog, haze, smoke, and dust, it is generally not suitable for measuring precipitation parameters. Therefore this technology is used mainly for visibility measurement. The transmissometers used in some airports to measure visibility are based on this principal. However, the measurement dynamic range of visibility is somewhat limited, usually from half of the pathlength to ten times of the pathlength (a factor of 20). In addition, extensive field maintenance is usually required to calibrate the source intensity and maintain beam pointing.

2.2 Scattering

Forward or backward scattering of optical or microwave signals can be used to measure atmospheric parameters. The scattering technique is the most sensitive for measuring fine particles such as fog, haze, drizzle, dust and smoke. Although this technique has been demonstrated as a stand-alone means of precipitation identification, there are several inherent problems that limit its performance. Similar to attenuation technology, the scattering technology will be contaminated by fog, haze, smoke, and dust for precipitation measurements. Furthermore, when there are multiple particles in the sampling volume, the detector is increasingly unable to separate them as the number of particle increases. This limits the high-end dynamic range and causes the sensor to be prone to false identifications, even at only moderately high precipitation intensities. Field tests showed that this technology used alone for precipitation identification is prone to false alarms and has severe limitations on separating drizzle and snow.

It is known that forward scattering coefficient induced by fog, haze, drizzle, and dust is direct related to the atmospheric visibility. A major advantage of using this technology to measure visibility is its dynamic range. With proper optical design, the forward scattering is able to measure atmospheric visibility from several feet to over ten miles (a factor of 10,000). Most of the presently commercially available visibility sensors are using this technology. One drawback of this technology is that the visibility measured by forward scattering is affected by the precipitation intensities. Usually a precipitation intensity correction is needed to obtain the true visibility when precipitation is falling

2.3 Scintillation

Optical scintillation technology has been developed (patented by OSi) for environmental remote sensing and is used exclusively by the OSi family of sensors for precipitation identification. Scintillations induced by weather particles falling through an optical beam are sensed and averaged to measure precipitation parameters. Contrary to scattering (forward or backward) and extinction technologies, scintillation technology only detects signals induced by moving particles -- which is a distinct characteristic of precipitation. This technology is completely immune to the contamination caused by fog, haze, dust, and smoke as demonstrated by extensive field tests.

The use of a narrow horizontal receiving aperture further enhances the differentiation between horizontal motion and the vertical motion that is the primary component of falling precipitation. Therefore even blowing sands do not contaminate the scintillation signals. This also allows the sensor to reliably differentiate rain and snow with the presence of strong horizontal wind. The WIVIS does not analyze or "count" each individual particle. Instead, it measures a statistical average of precipitation induced optical scintillation signals, and therefore gives reliable identifications, even at extremely high or low precipitation rates.

2.4 Acoustic

It is extremely difficult if not impossible to reliably discriminate a solid ice particle from a water droplet using optical techniques alone. If however, you have had the experience of hearing an ice particle hit a metal surface (as in hail on a car roof), you know the noise caused by the impact of solid ice particles is clearly distinguishable from the impact caused by water droplets or snow flakes. Based on this effect, OSi developed and patented an acoustic technology to detect ice pellets and hailstones. For the identification of hail and ice pellets the acoustic technique is far superior to other means. However, using an acoustic signal alone to quantify or discriminate the full range of precipitation types is virtually impossible. Blowing sand and other error mechanisms such as background noises can cause false identifications. However, by combining acoustic sensing technology with optical methods, reliable detection and discrimination can be achieved.

3. WIVIS Overview

Based on the above analysis, it is clear that no single sensing technique can be called on to meet every need of precipitation measurement and identification. Therefore, WIVIS incorporates three different sensing technologies:

2. In-beam optical scintillation detection,
3. Off-axis forward scattering optical detection, and
4. Acoustic detection.

Any one of these technologies by themselves can be used for precipitation / visibility identification and measurement. However, each one used individually has limitations. By combining all three patented techniques, and employing advanced detection algorithms, OSi has produced a sensor that provides the highest degree of accuracy and versatility possible, to date.

3.1 In-beam Optical Scintillation Detection

When a light emitted from an infrared emitting diode (IRED) meets a precipitation particle, a shadow is cast on the receiving plane. A horizontal slot aperture placed at the receiving plane along with the associated receiving optics and a sensitive photodiode allows the WIVIS to electrically "see" the scintillation signal induced by the falling particles. The signal that WIVIS sees at each moment in time will vary according to the size and velocity of the falling precipitant. The power spectra for different rain rates and different types of snow are shown in Figure 3.1-1. By measuring the energy in various frequency bands and comparing their ratios, the occurrence of precipitation (yes/no) and the type of precipitation (rain/snow) can be separated and identified. Rain-induced scintillation contains substantial frequency components above 1 KHz, while clear-sky / snow induced frequencies are usually below a few hundred hertz.

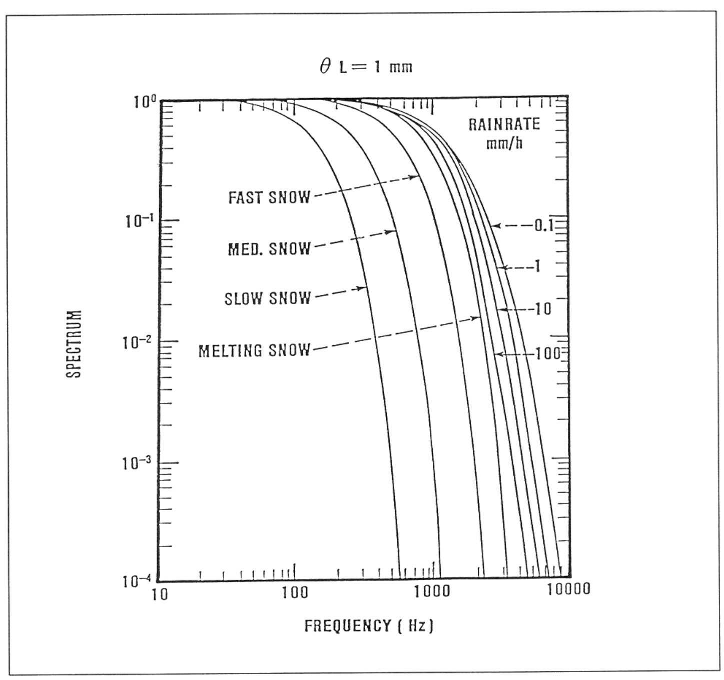

Figure 3.1-1: Temporal Power Spectrum of Rain- and Snow-induced Scintillation.

Based on the above analysis, the WIVIS implements a spectral analysis technique to measure and identify precipitation. One major concern of the in-beam system design was that the received signal must maintain a high enough signal-to-noise ratio (SNR) under various types of background light contamination (from sunshine, streetlights, etc.). The infrared emitting diode (IRED) is driven by a modulator to insure that the system is immune to background noise.

The infrared light emitted from the IRED is collected by the transmitter optics to form a partially coherent beam. The light beam is pointed to the receiver optics. Particles falling through the beam will modulate the beam to induce light scintillation of the received signal. The receiver optical assembly uses a horizontal line aperture to be sensitive to the small size and vertical motion of the precipitant.

The modulated light is detected by a PIN photodiode followed by a preamplifier. The output signal is sent to the signal processors. The signal processors filter the demodulated signal to determine its frequency component content. Within the signal processing section, two major frequency bands of the scintillation spectrum were selected: high band and low band.

There are actually four channels of signal processing: the low band channel, the high band channel, the particle channel, and the carrier channel. The use of these channels is summarized as follows:

a) The particle channel is used for precipitation state (yes/no) identification.
b) The high band and low band signals are used for precipitation type (snow/rain) identification.
c) The strength of the high band signal is used to determine intensity of rain.
d) The strength of the low band signal is used to determine intensity of snow.
e) The carrier channel monitors the received signal strength and detects accidental beam blocking or light source failure.

3.2 Off-axis Forward Scattering Detection

The in-beam scintillation channel was designed to be sensitive to drop sizes > 1 mm in diameter. In order to detect small particles more sensitively, an off-axis forward scattering channel has been implemented in WIVIS. It is known that the off-axis forward scattering detector is highly sensitive to small particles, including drizzle, fog and haze. The forward scattering is employed to measure visibility based on detecting the total amount of the forward scattered optical energy. In WIVIS, the particle forward scattered signals are detected by an off-axis photodiode. The resultant off-axis photodiode signal is demodulated and digitized. The advanced algorithms then operate on the digitized information to determine visibility values.

3.3 Acoustic Hail and Ice Pellet Detection

While the in-beam optical scintillation can sense hail, snow, or ice pellets as precipitation, it cannot accurately discriminate them. The primary difference in the particles is surface hardness. By using OSi patented HIPS (hail and ice pellet sensor) acoustic sensor as a standard part of the WIVIS, we can accurately detect and identify these types of frozen precipitation. The HIPS sensor head has a signal-processing card that amplifies, filters, and quantifies the acoustic signal, along with the necessary software to analyze the data. The HIPS sensor dome shaped head houses a sensitive acoustic microphone element. A heater is used to melt falling snow and ice accumulated on top of the acoustic dome. The heater is controlled by a firmware actuated relay and a high reliability sealed thermostat that is located inside the acoustic head. A dry dome surface will produce a distinct acoustic signature when ice particles hit the surface. The microphone located inside the dome detects the acoustic signal. The acoustic signal is then digitized. The algorithm operates on the digitized signal for hailstone, ice-pellet, and ice particle detection. The HIPS sensor head is completely sealed from water intrusion.

4. WIVIS CONFIGURATION

The WIVIS contains three major components, optical sensor, acoustic sensor (HIPS) and junction box.

4.1 Optical Sensor

The optical sensor uses a compact, triple aperture optical system to measure both precipitation and visibility.

As shown in Figure 4.1-1, the small box (TX) is the transmitter unit and contains an IRED and a lens with dual heaters. The large box (RX) contains two (2) independent receiver assemblies, each consisting of a photo diode, lens with dual heaters, and pre-amplifier electronics. One of the receivers detects present weather (in-beam) and the other detects visibility (off-axis). The two signals are processed by Digital Signal Processing (DSP) board located behind two receivers. A light block is attached to the sensor arm to reduce stray transmitter light from entering the off-axis receiver.

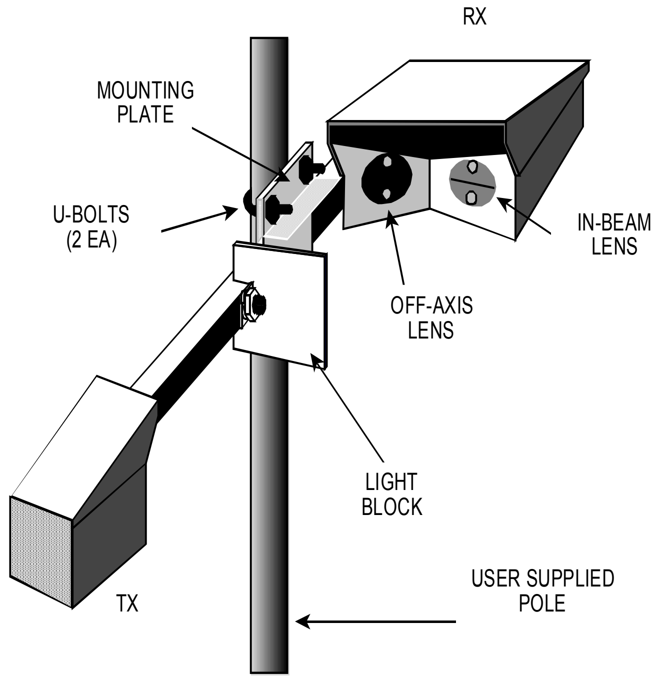

Figure 4.1-1 Major Components of the WIVIS Optical Sensor

The dual lens heaters which prevent dew, frost, and snow from building up on the lenses are self-regulating devices. They are "on" continuously but draw more current when the outside temperature is cold and less current when the temperature is warm. The WIVIS sensor is completely sealed from water intrusion.

4.2 WIVIS Ambient Light Sensor (ALS)

One of the major parameters in calculating visibility or visual range is the intensity of ambient light and distinguishing between daytime and nighttime. Most forward-scattering sensors measure the forward-scattering coefficient then convert the scattering coefficient to optical extinction coefficient σ. Then the visibility can be calculated proportional to the reciprocity of σ (Koschmieder’s Law). However this relationship is only valid for daytime visual range. For twilight and nighttime visual range, a correction is needed to obtain visual range from the extinction coefficient based on the background light (Allard’s law).

In WIVIS, with OSi's ingenious design, the visibility sensor and the ambient light sensor (ALS) are combined into one optical assembly. The receiver will detect both forward-scattering signal and the ambient light intensity simultaneously. The WIVIS ambient light sensor provides not only "day" or "night", it actually provides the real ambient light luminance from 0 to 10,000 candelas per square meter. With the actual ambient luminance measurements, WIVIS does not require further ambient light correction (such as day/night) for visibility measurements.

4.3 Acoustic HIPS Head

The HIPS sensor head uses a compact acoustic system to measure hard shell precipitation such as ice pellets and hail. It must be used with a WIVIS optical sensor host. As shown in figure 4.3-1, the HIPS sensor head assembly consists of a dome shaped acoustic sensor mounted to a cross arm. A thermostatically controlled heater is located in the acoustic head to melt falling snow and ice. The HIPS sensor head is completely sealed from water intrusion.

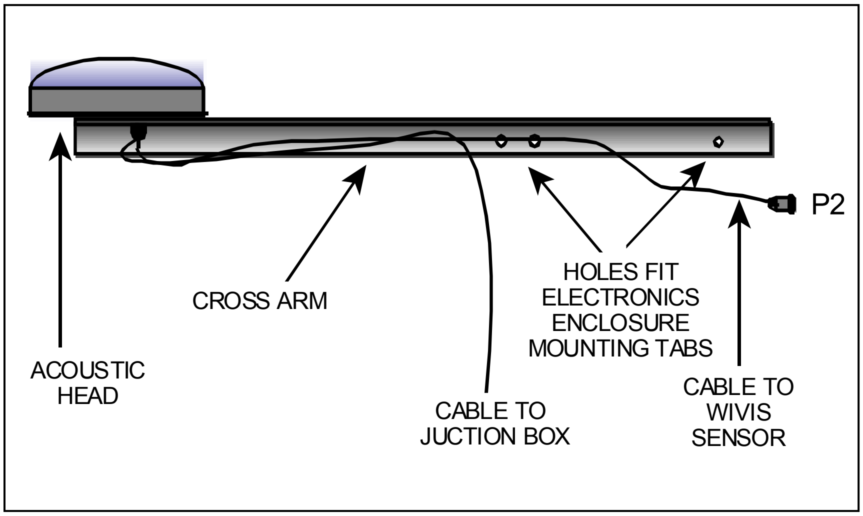

Figure 4.3-1 Major Components of the HIPS Sensor Head

4.4 Temperature Probe

A metal encased thermistor probe has been added to the bottom of the WIVIS head. The all-metal probe is fabricated of stainless steel to ensure electrical contact with the enclosure while minimizing thermal contact with it. This preserves the EMI shielding of the enclosure and provides reliable measurements of the ambient temperature.

4.5 Junction Box

The WIVIS junction box contains the power supply and surge protection modules. The junction box is a NEMA-4 type box with hinged access door. Mounted inside the box are a power supply, an AC surge suppressor and an RS-232 surge protection module.

5. Present Weather Requirement

The WIVIS sensor fully meets the FAA AWOS present weather requirement with capability to detect and identify the NWS and WMO weather codes as follows.

NWS Code Format

WX Code	NWS WX Code Description	WX Code	NWS WX Code Description
L-	Light Drizzle	I-	Light Ice Pellet
L_	Moderate Drizzle	I	Moderate Ice Pellet
L+	Heavy Drizzle	I+	Heavy Ice Pellet
R-	Light Rain	A-	Light Hail
R_	Moderate Rain	A	Moderate Hail
R+	Heavy Rain	A+	Heavy Hail
P-	Light Precipitation	__	No Precipitation
P_	Moderate Precipitation	--	Start-up code
P+	Heavy Precipitation	ER	Error Condition
S-	Light Snow	CL	Lenses need to be cleaned
S_	Moderate Snow		
S+	Heavy Snow		

The "_" (underline) character above represents an ASCII space character and is shown above only for readability. The "--" code will be output in this and other data fields during the first 60 seconds or so after reset or power-up of the sensor.

WMO Code Format

WX Code	WMO WX Code Description	WX Code	WMO WX Code Description
00	No Significant Weather	61	Rain, not freezing, slight
04	Haze	62	Rain, not freezing, moderate
10	Mist	63	Rain, not freezing, heavy
20	Fog detected in last hour	64	Rain, freezing, slight
21	Precip detected in last hour	65	Rain, freezing, moderate
22	Drizzle detected in last hour	66	Rain, freezing, heavy
23	Rain detected in last hour	67	Rain/snow, slight
24	Snow detected in last hour	68	Rain/snow, moderate or heavy
30	Fog	71	Snow, slight
41	Precipitation, slight or moderate	72	Snow, moderate
47	Freezing precip, slight or moderate	73	Snow, heavy
51	Drizzle, not freezing, slight	74	Ice Pellet, slight
52	Drizzle, not freezing, moderate	75	Ice Pellet, moderate
53	Drizzle, not freezing, heavy	76	Ice Pellet, heavy
54	Drizzle, freezing, slight	93	Hail, Light
55	Drizzle, freezing, moderate	93	Hail, Moderate
56	Drizzle, freezing, heavy	96	Hail, Heavy
57	Drizzle and rain, slight	--	Start-up code
58	Drizzle & rain, moderate or heavy	ER	Error Condition
		CL	Lenses need to be cleaned

The "--" code will be output in this and other data fields during the first 60 seconds or so after reset or power-up of the sensor.

6. WIVIS Algorithm and Software

The outputs of the signal processing channels are converted to digital form and processed. As part of the algorithm, the electronic processor maintains a 1-minute average of all the data channels (low band, high band, particle count, off-axis scattering, and acoustic signal). When polled by the user's data collection system, WIVIS outputs its present weather, visibility, and ambient light data in RS-232 format.

6.1 Adaptive Baseline Algorithm

The present weather sensor is deployed in various weather zones from arctic to tropical, from below sea level to high altitude, from marine to desert environment. The weather environment varies dramatically from summer to winter and from day to night. The sensor algorithm has to be able to adapt to all the environmental conditions of extreme cold to very hot weather, strong sunlight, super-saturated humidity, low pressure and strong wind. OSi has developed an Adaptive Baseline Algorithm to enable the WIVIS sensor to perform optimally under all the diverse environmental conditions.

The basic philosophy of the adaptive baseline is that during periods of no precipitation, the noise level of a specific channel will adapt to the environment. A major advantage of the adaptive algorithm is that the sensor will always perform at its optimum condition on all the environmental conditions. As an example, when sun is shinning, the ground turbulence is strong. It will generate a strong optical scintillation signal and a high baseline. However, before precipitation begins, clouds will normally block the sun. This results in reduced turbulence and hence reduced unwanted scintillation. With the adaptive algorithm, the baseline will decrease as the unwanted scintillation decreases. This baseline under the cloud cover will be much less than the clear sky baseline. Therefore, the sensor can take the full advantage of the reduced background noise level to be more sensitive to light precipitation. The adaptive baseline algorithm increases the detection sensitivity of extremely light precipitation by more than a factor of ten.

6.2 Precipitation Detection and Discrimination

For in-beam scintillation detection, it is clear from Figure 3.1-1 that the rain-induced scintillation spectrum has more high frequency component than that of the snow-induced spectrum. Therefore, by taking the ratio of the high band to the low band signals, it is a reliable method to discriminate rain from snow.

The above algorithm was successfully implemented in LEDWI and WIVIS. For more than two thousand units deployed in the airports and along the highways, this algorithm gave excellent identification of rain and snow for more than fifteen years of continuous operation.

6.3 Visibility Algorithm

The forward scattering is the most sensitive technique for measuring fine particles such as fog, haze, drizzle, dust and smoke. It is known that forward scattering coefficient is direct related to the atmospheric visibility. A major advantage of using this technology to measure visibility is its dynamic range. With proper optical design, forward scatter sensors are able to measure atmospheric visibility from several feet to over ten miles.

One drawback of this technology is that the visibility measured by forward scattering is affected by the precipitation intensities. Usually a precipitation intensity correction is needed to obtain the true visibility during heavy precipitation especially for snow. Because WIVIS in-beam scintillation channels provide reliable precipitation type identification and accurate intensity measurement, a correction based on different types of precipitation intensity (such as rain rates or snow intensities) is used to obtain the true visibility when precipitation is falling.

A major operational concern of forward scatter visibility measurements is the dust accumulation on optical components. It is known that forward scatter sensors are sensitive to lens contamination such as dust. Any dust particle deposited on the lenses will reduce the light intensity and increase forward scattering. This is the reason why industrial visibility sensors require frequent field calibration and optical components cleaning for unattended field operation.

The WIVIS advanced artificial intelligence algorithms result in a sensor that is very tolerant of optical surface contamination. The WIVIS **AI** (artificial intelligence) based algorithm are able to decide that the detected signal is not all induced by the visibility obscuration particles, part of it is contributed by non-visibility induced particles such as the dust on the lenses. The non-visibility induced signals can always be removed from the calculation of true visibility. In addition, field calibration is not required on this **AI** based algorithm. This algorithm has been implemented in the WIVIS for more than fifteen years of field operations and reliably provides accurate visibility measurements without requiring periodic field calibration and requires only minimum field maintenance.

A simple demonstration that may be preformed to illustrate the WIVIS visibility algorithms ability to correct for environment induced measurement errors. For example, spraying a salt solution on the lens will contaminate the exterior optical surfaces. The salt will remain on the lens causing contamination. The expected salt spray response for existing visibility sensors without smart algorithm will report visibilities substantially in error because of this level of contamination. In Figure 6.3-1, a spray is introduced sometime around 9:26. The reported visibility drops to a low value. The exact value is dependent on the amount of the salt spray. The existing commercially available visibility sensors will continue to report the salt induced low visibility values (dashed line) until the salt is cleaned. However, after spraying a salt solution onto the exterior optical surfaces of the WIVIS, the reported visibility will momentarily be disturbed due to sudden introduction of a contamination, but the WIVIS will correct the visibility readings and report reasonable visibility values (solid curve) after a recovering period. The time of recovery may vary dependent on the background atmospheric condition at that time.

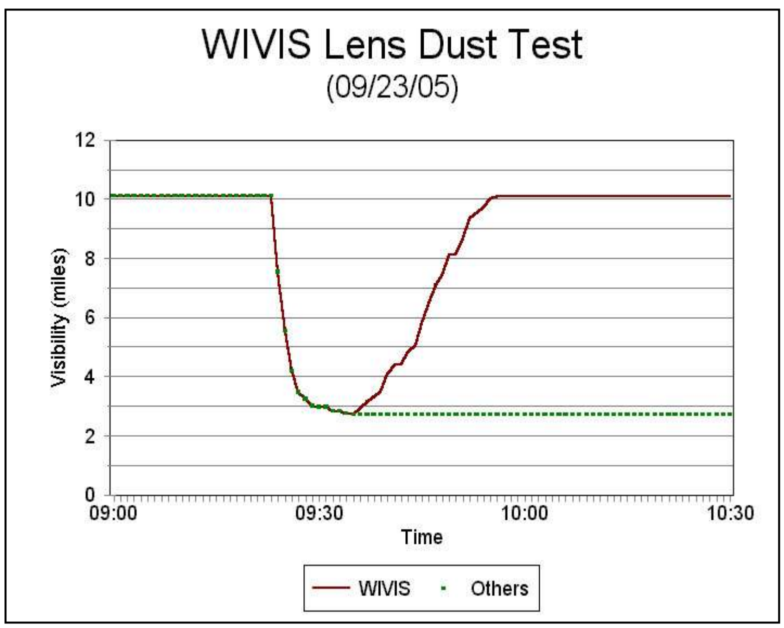

Figure 6.3-1 Salt spray test for WIVIS and other Visibility Sensors.

6.4 Sensor Self Diagnostics and Continuous Self-test

The WIVIS includes both power-on and advanced continuous self-testing. The WIVIS built in test code operates continuously in a background mode and does not interfere with the rest of the firmware controlled operations.

6.5 Temperature Probe Data Quality Algorithm

A precision thermistor-type temperature probe is attached to the bottom of the WIVIS head. The thermistor probe is connected to one of the A/D channels on the DSP board. The firmware collects the temperature data from the probe. It is used for automatic temperature compensation for any temperature-related drift. Therefore, all the channels will be more stable throughout the wide range of temperature that WIVIS has to experience. A major reduction in false alarms was also made with the temperature data. The measured temperature is applied to data quality check. For example, when "S" is detected and the temperature is higher than 45 F, the WIVIS software set the weather code to "NP". Insects nearly always cause this situation. The raw temperature data is included in the data reporting string.

6.6 Lens Heater Trend Analysis

An algorithm has been employed to monitor the condition of the lens heaters. The algorithm monitors the change in carrier strength as an indication of whether the heaters are working or not. The algorithm differentiates changes in carrier strength from a variety of sources:

1) heavy precipitation/fog,
2) IRED aging,
3) dust on the lens, and
4) dew or frost on the lens.

IRED aging and/or dust on the lens is characterized by a continual decrease in the carrier or “X” value. Dew or frost on the lens is characterized by a decrease in carrier strength during formation followed by an increase in carrier during evaporation.

6.7 Upload Capability

The WIVIS uses a DSP (Digital Signal Processor) based hardware engine to process the weather induced optical and acoustic data. Flash memory is used to store the firmware that carries out the system algorithm. Therefore any future upgrade of the system software can be done by using remote upload through the sensor’s serial port to update the program memory. This feature will eliminate the effort typically required to physically change programmable memory chips on the field.