RECOMMENDATION ITU-R SA.1744

Technical and operational characteristics of ground-based meteorological aids systems operating in the frequency range 272-750 THz

(Question ITU-R 235/7)

(2006)

Scope

This Recommendation provides the operational and technical characteristics of representative MetAids systems operating in the optical frequency range 272-750 THz.

The ITU Radiocommunication Assembly,

considering

a) that observations in the frequency range 272-750 THz (hereafter referred to as optical) provide data critical to operational meteorology and scientific research of the atmosphere and climate;

b) that the spectrum in the optical frequency range is used for active and passive meteorological sensor systems as well as many other applications;

c) that the technology for meteorological sensors using optical spectrum is continuously evolving to provide better accuracy and resolution of measurement data;

d) that frequencies in the optical frequency range are now being used for data links, range measuring devices, and other active systems on ground-based and space-based platforms, and as these systems are rapidly expanding and increasing in number, the interference between optical meteorological sensors and other optical systems is likely to increase;

e) that many applications of active and passive systems operating in the optical range are very similar to those being used at lower frequencies in the electromagnetic spectrum;

f) that it is timely to consider the nature of protective measures and sharing considerations to ensure that ground-based optical meteorological sensors can continue to operate without interference,

recommends

1 that operators of meteorological aids operating in the optical frequency range should take into account the possibility of interference from other optical transmitters in their choices of observatory sites and in the design of sensors;

2 that studies of interference to and from optical meteorological aids systems should take into account the technical and operational parameters provided in Annex 1.

Annex 1

1 Introduction

Ground-based meteorological sensor systems using spectrum in the optical frequency range are operated typically in the range 272-750 THz by a variety of meteorological services and other organizations interested in meteorological and climate research. This Annex provides the operational and technical characteristics of a representative set of meteorological sensors that transmit and receive signals at optical frequencies.

2 Laser ceilometers

2.1 Ceilometer technical characteristics

A ceilometer contains a laser as the transmitting source, and a photodetector for the receiver. A laser ceilometer senses and reports cloud levels in the atmosphere by using invisible laser radiation to detect cloud levels. They operate by transmitting a pulse of laser light into the atmosphere and sensing the light return as it is reflected back toward the ceilometer by objects in its path. By timing the interval between the transmission and reception, the height of particles (such as water droplets or ice crystals in clouds) above the ceilometer is calculated and reported to the data collection package.

Ceilometers are light detection and ranging (LIDAR) devices. Cloud height determination is based on electronic interpretation of backscattered returns, based on the LIDAR equation:

$$Pr(h) = E_0 \times \frac{c}{2} \times \frac{A}{h^2} \times \beta(h) \mathrm{e}^{-T} \qquad (1)$$

where:

$Pr(h)$: instantaneous power received from height h (W)

E_0: effective pulse energy, compensated for optics attenuation (J)

c: speed of light (m/s)

A: receiver aperture (m^2)

h: origination height of the backscattered return (m)

$\beta(h)$: volume backscatter coefficient at height h, the portion of light which is reflected back towards the ceilometer ($\mathrm{m}^{-1}\mathrm{sr}^{-1}$) (sr = steradian)

T: atmospheric transmittance which accounts for the transmitted and backscattered power by extinction at various heights between transceiver and height of backscatter; equal to 1 in a clear atmosphere (i.e. no attenuation); this term in the LIDAR equation allows for determining which backscattered returns are from cloud interaction and which are from other obstructions such as fog or precipitation.

2.2 Representative Ceilometer System A

System A is capable of measuring cloud heights to approximately 3 700 m. It is employed with other weather monitoring equipment such as visibility, precipitation, and temperature and dew point sensors for support of aviation operations and weather forecast activities.

System A determines cloud height by emitting a pulsed laser into the atmosphere and measuring the time required for backscattered returns from particles in the atmosphere, if present, to reach an adjacently mounted receiver. A laser pulse of nominal 904 nm wavelength (331.8 THz) and 150 ns duration is emitted once per measurement cycle. Receiver readings are then processed every 100 ns for 25.4 μs to provide 254 stored values for each measurement cycle, representing a 15 m height resolution over 3 850 m. For each cycle, a spatial density profile is obtained for the vertical atmosphere column directly above the ceilometer, from 0 to 3 850 m, which can be interpreted to yield cloud height and cloud layer data. The results of multiple cycles are averaged to minimize the effects of erroneous readings.

2.2.1 Transmitter assembly

A Gallium Arsenide (GaAs) laser diode emits 904 nm wavelength pulses at a repetition frequency of between 620 Hz and 1 120 Hz. The exact repetition frequency is processor controlled to yield a constant average power of 5 mW, with a nominal factory setting of 770 Hz.

Each laser pulse is emitted with a span of 30°. An 11.8 cm effective diameter lens with focal length of 36.7 cm is used to focus the incident beam. Maximum irradiance is 50 μW/cm^2, as measured with 7 mm diameter aperture.

The transmitter assembly contains a light monitor for determination of output laser power and incoming sky light power. A downward pointing photodiode is used to monitor output laser power. Interfering ambient light current, at peak magnitude, is much less than laser pulse current and thus does not affect the laser power derivation. Peak emitted laser power is 40 W. The laser power monitor output signal is input to the main processor board, and used to limit average emitted power to 5 mW. An upward pointing photodiode, with a maximum deflection from vertical of 5.7°, is used to monitor incoming light. Its signal is input to the optional solar shutter circuitry, discussed below, and the main processor for monitoring purposes. Sensitivity of the sky light monitor is approximately 0.4 A/W. Direct sunlight in a clear-atmosphere sky produces approximately 1 200 W/m^2, with a typical current of 1.1 mA. A clear blue sky typically yields a sky light monitor current of 10 μA; indoor conditions typically yield less then 1 μA.

Ceilometers of the design of System A that are installed in tropical regions from 30° N latitude to 30° S latitude are equipped with an optional solar shutter mounted on the transmitter assembly. The shutter protects the transmit laser from damage by direct sunlight. The shutter is set to close over the transmit lens during times when direct sunlight can enter the lens system. Ceilometers equipped with solar shutters are also equipped with tropical receiver assemblies, which have a different filter and mounting block than that installed on the standard receiver assembly.

2.2.2 Receiver assembly

An 11.8 cm effective diameter lens with 8.4 cm focal length is used to focus backscatter returns from particles in the atmosphere onto a silicon avalanche diode. Sensitivity of the photodiode is temperature-dependant. This is compensated for by temperature-dependant control of a biasing voltage in the receiver circuitry, which is factory-adjusted at room temperature to yield a nominal responsivity of 40 A/W.

A 50 nm bandwidth interference filter is mounted on the receiver lens to block out background radiation noise. A special filter is installed on units equipped with the optional solar shutter.

2.3 Representative Ceilometer System B

The System B ceilometer's principles of operation are identical to that of System A, with differences outlined in the following text. System B can be utilized to determine cloud heights and vertical visibilities to 7 300 m, and is capable of detecting three cloud layers simultaneously. In addition to cloud layer detection, it can determine the presence of precipitation or other obstructions to vision.

2.3.1 Transmitter assembly

An Indium Gallium Arsenide (InGaAs) laser diode emits 905 ± 5 nm (331.5 THz) wavelength pulses, with duration of 100 ns and at a repetition frequency of 5.57 kHz. Peak emitted power is 16 W, yielding 8.9 mW average power.

2.3.2 Receiver assembly

A 35 nm bandwidth interference filter, centred on 908 nm, is mounted on the System B receiver lens to block out background radiation noise. Responsivity is factory adjusted to 65 A/W at 905 nm.

TABLE 1

Ceilometer characteristics

Parameter	System A	System B
Transmitter laser and optics		
Peak power	40 W	10-20 W
Duration (50% level)	135 ns (typical)	20-100 ns (typical)
Energy (diameter = 118 mm)	6.6 µWs	
Repetition rate	620-1 120 Hz	5-10 kHz
Source	Gallium Arsenide (GaAs) Diode	Indium Gallium Arsenide (InGaAs) Diode
Wavelength	904 nm	855/905/910 nm at 25°C
Operating mode	Pulsed	Pulsed
Transmitted pulse energy	6 µJ ± 10%	1-2 µJ ± 20%
Average power	5 mW	5-10 mW (full range measurement)
Maximum irradiance	50 µW/cm^2 meas. with ø 7 mm aperture	170 –760 µW/cm^2 meas. with 7 mm aperture
Optics system focal length	36.7 cm	35-40 cm
Effective lens diameter	11.8 cm	6-15 cm
Transmitter beam divergence	±2.5 mrad maximum	±0.4 - ±0.7 mrad
Lens transmittance	90% typical	96% typical
Window transmittance	97% typical, clean	98% typical, clean
Receiver optics		
Detector	Silicon avalanche photodiode	Silicon avalanche photodiode
Responsivity	40 A/W, at 904 nm	65 A/W, at 905 nm
Surface diameter	0.8 mm	0.5 mm
Interference filter	940 nm	908 nm typical centre wavelength
Filter 50% band pass	880-940 nm typical	35 nm at 880-925 nm typical
Filter transmissivity at 904 nm	85% typical, 60% minimum	80% typical, 70% minimum
Focal length	15.0 cm	
Reception lens effective diameter	11.8 cm	
Field of view divergence	±2.7 mrad	±0.66 mrad
Lens transmittance	90% typical	96% typical
Window transmittance	97% typical, clean	98% typical, clean

TABLE 1 (*end*)

Parameter	System A	System B
Optical system		
Lens distance, transmitter – receiver	30.1 cm	
Laser beam, entering Rx field of view	30 m	
Laser beam 90% within receiver field of view	300 m	
Performance		
measurement range	0 to 3 700 m	0 to 7 300-13 000 m
Resolution	15 m	3-15 m
Acquisition time	30 s, maximum (for 3 658 m range)	2-120 s
System bandwidth (3 dB)	10 MHz at low gain 3 MHz at high gain	3 MHz
Tolerance of precipitation	To 7.5 mm per hour, range-limited	

3 Visibility sensors

3.1 Visibility sensor technical characteristics

Visibility sensors are used to provide a means of automatically calculating the current visibility level, as well as an indication of current day/night conditions. The conventional meteorological method for measuring visibility is to determine the maximum distance a black target can be seen against the fog/cloud background. Visibility sensors provide automated measurement of visibility. With a visibility sensor, the ambient meteorological optical range (visibility) is measured using the forward scatter technique. This technique involves transmitting a flash of xenon light through a section of the atmosphere (which scatters the light) and measuring the scattered light level to determine the loss. An extinction coefficient is calculated from the amount of light received from the scattered xenon flash lamp light source. This coefficient is then translated into a value of visibility. The visibility sensor also computes and outputs a day or night indication as derived from an ambient light sensor.

3.2 Representative visibility sensor systems

The representative visibility sensor is capable of providing an extinction coefficient equivalent to visibilities up to and including 16 km. The day/night assembly indicates day or night condition according to the ambient light level and operates for ambient light levels up to 540 lux. The day/night sensor indicates day for illumination greater than 32 lux and indicates night for illumination less than 5 lux. The transition from indicating day to indicating night occurs once in the region from 32 to 5 lux (as illumination decreases), while the transition from indicating night to indicating day occurs once in the region from 5 to 32 lux (as illumination increases). The day/night sensor points in the same direction as the receiver.

The visibility sensor has either one or two EMI filters (based on model number of unit) that is/are located in the electronics enclosure.

3.2.1 Transmitter assembly

The transmitter assembly flashes a xenon bulb to produce visible light for scattering. Light is focused into the scatter volume by a fixed lens included with the transmitter assembly.

3.2.2 Receiver assembly

The receiver assembly detects the transmitted xenon light after it is scattered by the atmosphere. The detector is a positive-intrinsic-negative (PIN) photodiode mounted in the receiver canister. Light is focused onto the diode by a fixed lens included with the receiver assembly. The photodiode converts the light energy into an electrical current for signal processing.

The day/night assembly is a photometer that detects light via a photodiode mounted behind a clear window. The photodiode is positioned such that its field of view is 6° above the horizon.

TABLE 2

Visibility sensor characteristics

Parameter	System A	System B
Source	Xenon flash lamp	Infrared LED
Wavelength	400-1 100 nm	400-1 100 nm
Pulse repetition rate	0.1-1 Hz	1 Hz
Receiver sensor	PIN photodiode	Silicon photodiode
Principal viewing direction	Horizontal	20° below horizon
Field of view	6° above the horizon	9 mrad
Receiver bandwidth	400-700 nm	400-700 nm
Optical sensor damage level	Greater than direct sunlight	Greater than direct sunlight
Sensor visibility measurement range	Up to 16 km	Up to 75 km

4 Precipitation sensors

4.1 Technical characteristics

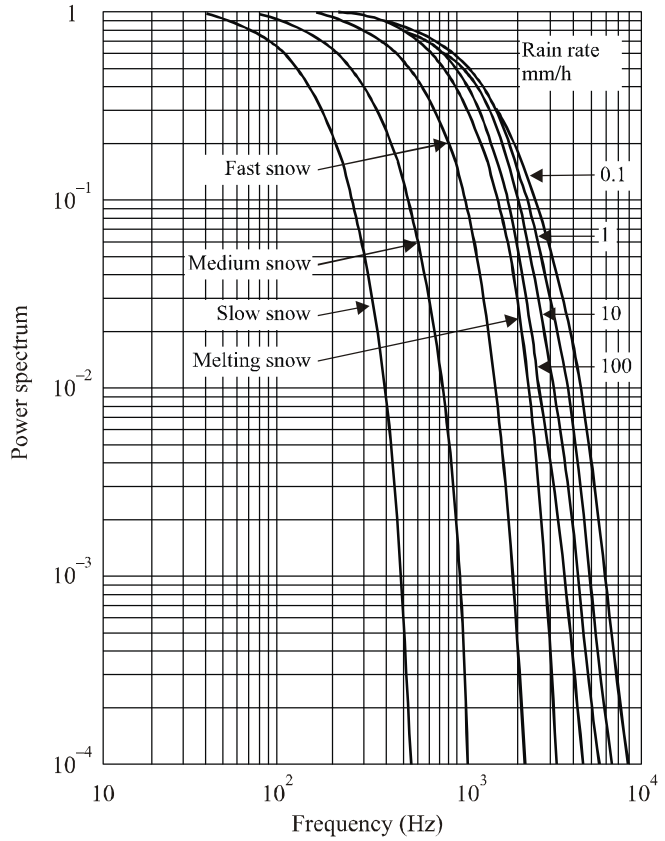
Precipitation sensors, also known as forward scatter sensors, are employed to provide assessment of both precipitation occurrence (true or false) and, if present, the characteristics of that precipitation (rain, snow, etc.). They can also be used for measurement of visibility. Methods to measure precipitation parameters have focused on using optical and microwave technologies. Categorically, the measured parameters can be scaled based on the attenuation (or extinction), scattering, Doppler, or scintillation of energy sources from transmitter to receiver.

The precipitation sensors outlined here take advantage of the scattering effect that occurs when an interfering particle (precipitation) interacts with a partially coherent light source. These particle-induced scatterings of the incident light source produce scintillations at the receiver. Scintillations induced by weather particles falling through an optical beam are sensed and averaged to measure precipitation parameters. The temporal frequency spectrum of the induced scintillation varies according to the size and velocity of the falling precipitation. The power spectra for different rain rates and different types of snow are shown in Fig. 1.

FIGURE 1

Temporal power spectrum of snow-induced scintillation – Power spectra for different rain-rates shown for comparison

θL = 1 mm



Scintillation technology only detects signals induced by moving particles, and is thus immune to contaminations caused by fog, haze, dust, and smoke. The use of a horizontal receiving aperture further enhances the differentiation between horizontal motion and the vertical motion, which is the primary component of falling precipitation. The in-beam carrier signal strength is used to normalize the scintillations to eliminate errors caused by source intensity changes, dirt on the optics, etc.

4.2 Representative precipitation sensor system

Precipitation sensors use weather-particle-induced scintillation of a light source, such as an infrared emitter diode (IRED) system, to identify precipitation state and type (rain, snow, drizzle, etc.) and measure precipitation intensity. The sensor typically contains two major assemblies: a U-shaped frame assembly and a main electrical enclosure assembly. The transmitter and receiver sensor heads are mounted at opposite ends of the frame assembly. Separation between the transmitter and sensor heads is typically on the order of 1 m apart.

The temporal power spectrum of the detected scintillation is calculated by an internal processor and is compared to normalized reference values to determine current precipitation parameters. Precipitation-induced power spectra for this system yields minimal energy typically greater than 5 kHz, therefore the transmitted emission is modulated with a carrier signal to ensure adequate signal to noise ratio under various types of background light contamination. This carrier wave modulated signal is the amplitude modulated by particles falling through the beam. The receiver optical assembly uses a horizontal line aperture to be sensitive to the vertical motion of the precipitant.

To reduce the potential for EMI/RFI related problems, the main electronics assembly enclosure is precision fitted with an EMI gasket of silicon rubber imbedded with oriented Monel wires.

4.2.1 Transmitter assembly

A precipitation sensor typically uses an infrared emitting diode as its transmission source. The transmit source is focused through a lens in the transmit assembly.

4.2.2 Receiver assembly

Modulated light is typically detected by a PIN photodiode. A larger receiving angle is used for the receiver device to minimize signal fluctuations caused by vibration of the mount. The receiver uses the same lens type as the transmitter.

TABLE 3

Precipitation sensor characteristics

Parameter	System A	System B
Transmitter source	Infrared LED	Diode
Source wavelength	880 nm	870-920 nm
Transmitted power	10 mW	2-20 mW
Lens characteristics	175 mm/f3.5	Not specified
Modulation frequency	Not specified	2.0-4.0 kHz
Receiver sensor	PIN photodiode	Silicon photodiode
Receiver bandwidth	780-1 100 nm	780-1 100 nm
Die size	2.75 mm^2	Not specified
Lens characteristics	175 mm/f3.5	Not specified
Filter mount	1 mm horizontally-oriented slot with infrared filter No. 87C	IF filter
Receive sensor damage level	Greater than direct sunlight	Greater than direct sunlight
Principal viewing direction	Horizontal	20° below horizon
Receiver field of view	100 mrad	100 mrad
Optical path length	0.5 m	0.3-1.0 m

5 Sunshine sensors

Sunshine sensors are passive sensor devices used to automatically measure global and diffuse radiation from the sun as well as the duration of bright sunshine during a day. Sunshine sensors are used for a broad variety of applications that all rely on detecting the state of bright sunlight and/or the level of solar radiation. The World Meteorological Organization (WMO) definition for bright sunlight is a light level greater than 120 W/m^2 in the direct solar beam. Sunshine sensors are obviously used for operational and research meteorology, but are also used for applications such as building heating/cooling and solar shade management, agronomy and agriculture, and climatology.

Several different types of sensors are in use but they all work on the same basic principle. The sensor unit contains one or more photo diodes, with some units having many photodiodes. The difference in design between systems lies in how the measurement of diffuse and direct sunlight is detected. For detection of the two parameters, the sensor must be capable of having a sensor placed in direct sunlight at any time during the day, and must also be capable of shading at least one sensor from direct sunlight. The manner in which photo detectors are shaded from sunlight differs. Some devices use a shade ring that falls between the sensor and the arc in which the sun travels during the day. Other devices rotate the sensor so that it alternately has view of direct and diffuse sunlight, and a third type contains an array of sensors with a shading pattern paced above them so at least one is shaded and one has direct view of the sun at any time during the day.

TABLE 4

Sunshine sensor characteristics

Parameter	System A
Detector type	Photodiode
Sunshield type	Pattern over multiple photodiodes
PAR sensitivity range	0-2 500 μmol/m^{2}s
PAR measurement resolution	0.6 μmol/m^{2}s
Energy sensitivity range	0-1 250 W/m^2
Energy measurement resolution	0.3 W/m^2
Luminance sensitivity range	0-200 klux
Luminance measurement resolution	0.06 klux
Spectral response bandwidth	400-700 nm
Response time	<200 ms

6 Luminance sensors

Luminance sensors are meter systems that measure the background luminance of the atmosphere. Background luminance affects the assessment of the visibility measured by visibility sensors (transmissometers). They are passive devices, much like sunshine sensors.

TABLE 5

Luminance sensor characteristics

Parameter	System A	System B
Detector type	Silicon photodiode	Silicon photodiode
Luminance sensitivity range	Not specified	2-40 000 cd/m^2
Luminance measurement resolution	Not specified	1 cd/m^2
Spectral response bandwidth	400-700 nm	400-700 nm
Principal viewing direction	30° above horizon	30° above horizon
Receiver field of view	87 mrad	105 mrad
Sensor burnout level	Greater than direct sunlight	Greater than direct sunlight

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