Design and development of infrared technique based snow surface temperature measurement probe

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This paper presents design and development of IR probe, developed first time in India, which is used to measure snow surface temperature without contact with snow. The design can operate round the clock in harsh weather conditions in snow bound areas (–40 °C to +50 °C) with high relative humidity and wind speed (200 km/h). This instrument has been installed in Siachen region, J & K region and interfaced with Data Collection Platform. The recorded temperature data is being transmitted hourly through satellite from Siachen and J & K region to central base station at SASE, Chandigarh. This instrument can measure temperature (– 40 °C to +100 °C) with the resolution of 0.1 °C and consumes low power. This paper mainly describes the characteristics of IR rays, basic principle involved in designing and principle of operation.

Keywords: IR probe, Snow surface temperature

Introduction

All objects emit infrared (IR) radiation, which is generated by the vibrations and rotations of atoms and molecules within the matter. As the temperature of the object increases the molecular activity in the object increases causing the object to generate more energy[1]. IR radiation (energy 10^{-3} eV to 10 eV, wavelength 10^{-5} to 10^{-1} cm and frequency 10^{11} - 10^{15} Hz), discovered in 1800 AD by Sir William Herschelle, is electromagnetic and travels through space at the speed of light. When IR energy strikes an object it may be reflected from that surface, transmitted through that surface or absorbed into that surface. The interplay of energy exchange in thermal radiation is characterized as

$$R + a + t = 1 \qquad \ldots (1)$$

where R, reflectivity; a, absorptivity and t, transmitivity.

When an object is at thermal equilibrium, the amount of emission is equal to the amount of absorption as per Kirchoff's Law

$$a = e \qquad \ldots (2)$$

where emissivity(e) is a measure of the ability or ease at which an object or surface emits IR radiation. Emissivity is defined as the ratio of the radiant energy emitted by an object at a temperature T and the radiant energy emitted by black body at T as

$$E = Wo / Wbb \qquad \ldots (3)$$

where Wo = energy emitted by an object at temperature T, and Wbb = energy emitted by the black body at the same temperature T. The emissivity value of snow is approx equal to 1.

As an object becomes hotter, it emits more IR energy as per Stefan-Boaltzmann law

$$W = e * sb * T^{-\overline{4}} \qquad \ldots (4)$$

where W = radiant energy, W/cm²; e = emissivity; sb = Stefan-Boltzmann constant; T = temp, K.

If two objects are placed near each other, then the amount of radiant energy from hotter object to the cooler object is proportional to the difference of the fourth power of their absolute temperatures. The wavelength at which the maximum amount of energy is emitted becomes shorter as the temperature is increased as per Wein's Displacement Law.

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Max. wavelength (λ_{max}) = 2.89 * 10³ K/T   ...(5)

where T = temperature, K; K, constant

      Main component in any IR system is the detector, which is used to convert radiant energy into an electrical energy that may be used to provide a variety of desired read-outs.

Types of Detectors

      There are two types of IR detectors (thermal & quantum). Thermal detector, which is based on the change of a physical property (resistance or thermo-electric force) of the detector as its own temperature is changed, includes thermocouples pneumatic detectors and bolometer[2,3]. A quantum detector is a semiconductor that produces a signal proportional to the photon flux that strikes its sensitive element. Quantum detectors include photoconductive, photovoltaic and photo-electromagnetic detectors. In general, thermal detectors have a uniform spectral response but exhibit a longer time constant.
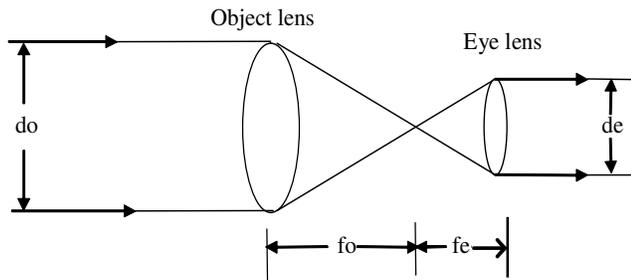

Fig. 1— Schematic view of telescopic system

Design of System

Optical System

      Main function of the optics in an IR system is that of collecting as much radiant energy while minimum noise. Thus the effective optical gain is the ratio of the optical receiving area to the detector area. IR optical systems can be categorized into telescopes (Fig. 1), where lens representations are only symbolic. An image of the source is viewed by some collecting element, which transfers radiant energy to IR detector. This collecting element is actually a collimating element, which has the objective focused source at its focal point[2,3]. Angular magnification M is defined as

$$M = fo/fe = do/de \qquad ...(6)$$

where *fo* and *fe* are the focal lengths of object and eye lens respectively.

Chopping System

      A large number of IR systems incorporate a chopper that periodically interrupts flow of IR radiation from the target to detector. In this way, detector's output is an AC signal, easier to handle than a DC signal. In the better designed systems, during the shutter is closed, detector is made to see the radiation of a reference body, that is kept at known temperature to establish a base for the measurement of radiation from the target (Fig. 2). Maximum chopping frequency is determined by the time constant of the detector as

$$f_{max} = \frac{1}{2\pi t} \qquad ...(7)$$

where f_{max} is a maximum operating frequency, Hz; and t is time, sec.
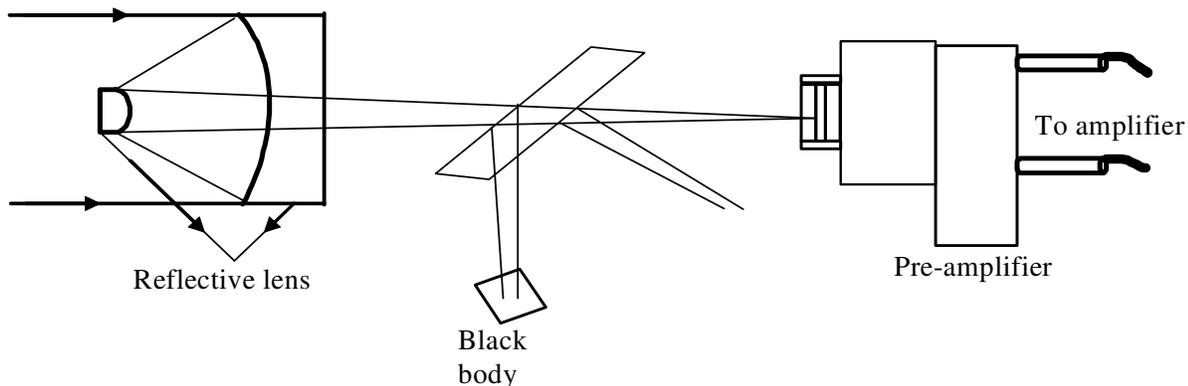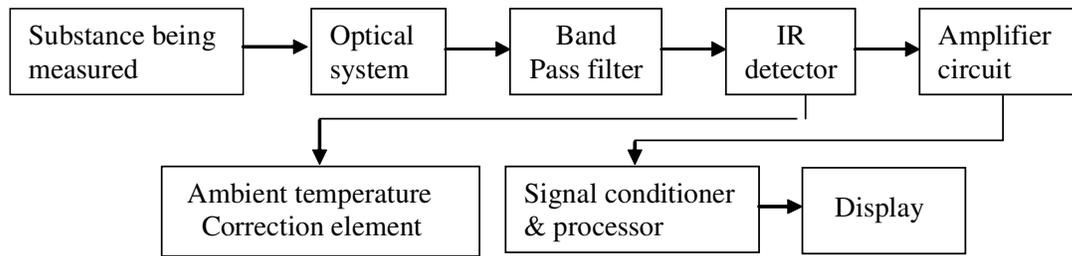

Fig. 2—Internal configuration of sensor

Fig. 3— Block diagram of the system

Chopper disc is kept at a minimum size by placing it as close to the detector as possible. A synchronous motor is used to rotate the chopper blades. Number of blades (or openings) on the disc and speed of motor determines chopping (or modulation) frequency as

$$f_{ch} = rpm * No/ 60 \qquad ...(8)$$

where f_{ch} = modulation frequency, Hz; No = number of openings in the chopper; and *rpm* = rotations per min of the motor.

Chopping of incoming radiation is not necessary (and may be undesirable) in IR systems that are used to observe rapid changing thermal transients. For example, a 10-sec thermal transient may occur at the instant the chopper blade (rather than the chopper opening) is blocking the detector field of view[3,4].

Electronic Design

The raw signal obtained by the detector must be amplified and appropriately processed for the desired information in terms of voltage and frequency. During design, the following four points has been considered: 1) Detector electrical configuration; 2) Noise characteristics & filter; 3) Signal bandwidth; and 4) Amplifier characteristics.

To minimize stray pick up and cable loss, amplifier has been located very close to the detector. For proper impedance matching between detector and signal conditioning unit, an emitter follower is used. Designed preamplifier circuit is coupled with the thermopile detector for amplification of signal. In signal conditioning and processing circuitary, five LM108 op-amps, voltage to frequency converter, external resistors, capacitors, potentiometers and a thermistor are used. Thermistor controls temperature of the case of detector and makes changes in output voltage. When detector is used to measure very low temperatures, surrounding

temperature of detector will cause an error in the output voltage, which will ultimately lead to wrong temperature reading. Since voltage across thermistor changes as the temperature of thermistor changes, it can be used as the temperature-controlling device.

Final output of temperature measuring probe is available in volts and in frequency, so that it can be used with most of the snow data recording systems. The developed probe has been interfaced with the Data collection platform available with Snow & Avalanche Study Establishment (SASE), Manali, which has installed these systems at various field stations at snow bound areas in Himachal Pradesh and Jammu & Kashmir of India.

Principle of Operation

IR radiation is converted into equivalent electrical signal of certain amplitude and frequency. Once electrical signal is made available by using IR detectors, the signal can be processed in different stages and finally temperature of the object is displayed at LCD[1,2]. An IR thermometer measures radiant energy beyond the sensitive range of human eye. When an object becomes sufficiently heated, IR energy will become visible as the object become red hot. As the temperature increases, it emits wavelengths further across the visible range. Ultimately, the object glows white hot. In this design (Fig. 3), optical system collects IR radiation from the object being measured and focus it on the tiny IR detector, which in turn converts it to a proportional electrical signal, which is the exact electrical analog of the incoming IR radiation and hence the object's temperature. This minute electrical signal is then amplified in the preamplifier and converted into the desired form as per requirement[4,5].

Measuring Principle of Thermometer

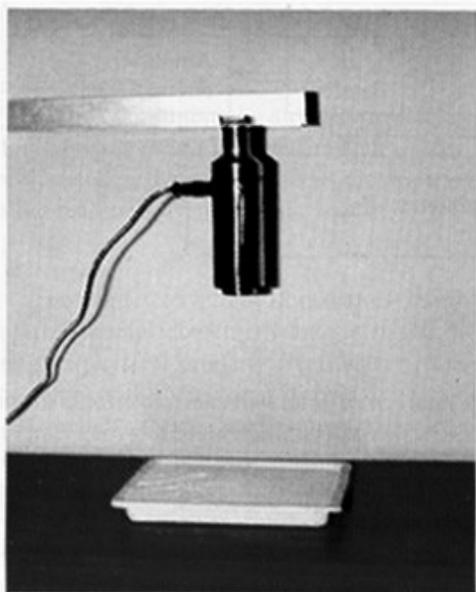IR energy emitted from object being measured is collected via high performance IR detector through

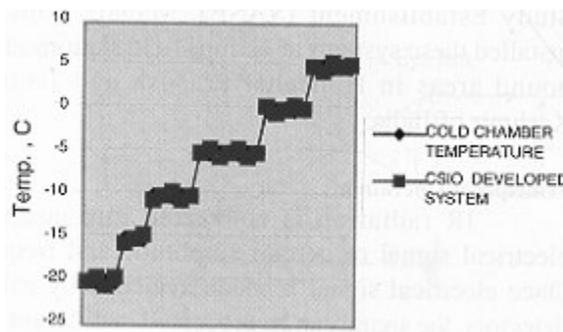Fig. 4—CSIO developed IR based temperature measuring probe

Fig. 5—Comparison of the temperatures of reference unit and developed system

the Germanium optical lens, and the band pass filter to eliminate unwanted wavelengths. The collected energy is then converted into voltage form for amplification and further processing as per requirement. In addition, operations on inputs from the ambient temperature correction sensor and those for emissivity corrections are also performed[5].

Results and Testing

CSIO developed sensor (Fig. 4) was tested in the cold chamber at SASE, Manali. A number of temperature settings (–25 °C to +05 °C) have been made of cold chamber and the developed snow surface temperature-measuring probe has been kept inside the cold chamber. The reading of developed probe noted with each settings. The results of developed system were found same for each setting (Fig. 5).

Specifications of the system are as follows: range, -40-100 °C; resolution, 0.1 °C; accuracy, ± 0.5 °C; repeatability, ± 0.1 °C; and spectral pass band, 8<wavelength<14 ¼.

The 8 to 14 micrometer range is called the window to the atmosphere and has been selected as the wave band to be measured. Wavelengths in this band are less subject to absorption by CO_2 and water vapor in atmosphere as follows: sighting, line of sight; response time, 0.25 sec; turn-on-time, 0.25 sec; emissivity, 0.2-0.98 settable; power requirement, 12 V, 30 ma; output signal, a) voltage 0 ± 5 V and b) frequency 0-10 KHz; and weight, < 2 kg.

Conclusions

IR based snow surface temperature measurement probe has been successfully designed and developed by CSIO, Chandigarh and also being used by SASE, Manali at J&K and Siachen region. Data is being received at Chandigarh through satellite link on hourly basis. All the supplied system are working round the clock in deep Himalayan region and results were compared with similar type of imported temperature sensing probe, the results were found comparable. The probe was found most suitable for snow bound region.

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