Fog detection and visibility measurements using forward scattered radiation

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An optoelectronic system for fog detection and visibility measurement is presented. The visibility measurements are based on the forward scattering of light emitted by the LED transmitter. The paper contains the description of the system, principles of its operation and some results of field tests.

1. Theory

The clear visibility of the environment is very important in all kinds of mobility. When dense fog develops along roadways, the safety of motorists is imperilled. Thus, automated visibility monitoring of fog, snow, dust and smoke is of utmost importance.

The principles of fog detection and visibility measurements are based on light propagation properties in the atmosphere, where absorption and scattering influence the transmitted beam.

According to the Bouguer's law the power loss in the absorbing and scattering environment is proportional to the input power of the beam P_i and the path lenght of the transmission dR. It leads to the well know formula for the output power P_0 of the beam:

$$P_0 = P_i e^{-bR} \tag{1}$$

where b is the extinction coefficient which stands for absorption and scattering.

The visibility measurements are based on formula (1). So called standard visibility V_n is understood as a daylight visual range of a large dark object seen against the horizon sky as a background, computed on the assumption that the contrast threshold of the observers eye has a value of k = 0,02. According to Koschmider (1925) the kontrast k changes in the same manner as formula (1). In practice however, the treshold kontrast is estimated sometimes as k = 0,05. So, for $P_0/P_i = 0.05$ one obtains

$$R = V_n = 3.0/b \quad \text{and} \quad P_0/P_i = e^{-3.0R/V_n} \tag{2}$$

Formula (2) gives two possible methods of the standard visibility V_n measurements:

Transmission method

According to this method the light attenuation along a known distance R is measured, where the standard visibility is

$$V_n = \frac{3.0R}{\ln\frac{P_i}{P_0}} \tag{3}$$

From (3) it follows that for a given accuracy of attenuation measurement the shorter is the standard distance R, the lower accuracy of V_n is obtained. Short distances R demand high accuracy of low attenuation measurements. For sufficiently long distances R transmission meters are the most accurate instruments for visibility measurements.

Forward and back scattering methods

In the above methods the loss of the transmitted power ΔP is measured, which for short standard ranges $R << V_n$ leads to:

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$$\Delta P = P_i - P_0 = P_i \, 3.0R/V_n \qquad (4)$$

So, the denser the fog, the lower the visibility and the more light is scattered and measured by the receiver.

However, it is difficult to measure the whole power loss ΔP, since the light is scattered in all directions and partialy absorbed in the given volume of space.

Thus, optical measuring receivers with limited field of view can measure the scattered light in a rather narrow range of angles only. Therefore, instead of measuring the total scattered power ΔP from a given volume of space d which is illuminated by the power density E, only a part of it ΔP_m is measured. The measured power ΔP_m can be calculated by integrating the scattered light intensity $I(\Theta)$:

$$\Delta P_m = 2\pi \int_0^u I(\Theta)\sin(\Theta)d(\Theta) \qquad (5)$$

where u is the half of receivers field of view

Light intensity $I(\Theta)$ is produced by many elementary space volumes dv which are iluminated by the power density E. Each of them scatters light according to the scattering function $\beta(\Theta)$:

$$I(\Theta) = E\beta(\Theta)dv \qquad (6)$$

According to (5) the scattered power can be calculated, if the scattering function $\beta(\Theta)$ and the scattering volume v are known. The latter is the volume of intersection of the transmitting beam and the receivers field of view.

In practical instruments two possible solutions are employed. One possible approach is to measure backscattered light in the direction Θ opposite to the illuminating light $\Theta \approx 180^\circ$.According to the second solution the forward scattering in the directions close to $\Theta \approx 0$ is measured. The light scattered in forward directions is nearly two orders higher, than the backscattered.

It results from (4), that the relative accuracy of standard visibility measurement is equal to the accuracy of scattered power measurement. However due to irregularities of the scattering function and limited fields of view of the optics, the accuracy of visibility measurement in monochromatic light would result in errors [5, 7] :

For the back scattering method: between + 100% and – 50%

For the forward scattering method: ± 11%.

2. System design

The block diagram of the visibility meter is shown in Fig 1. The main block of the system consists of the transceiver head located outside, where the visibility is

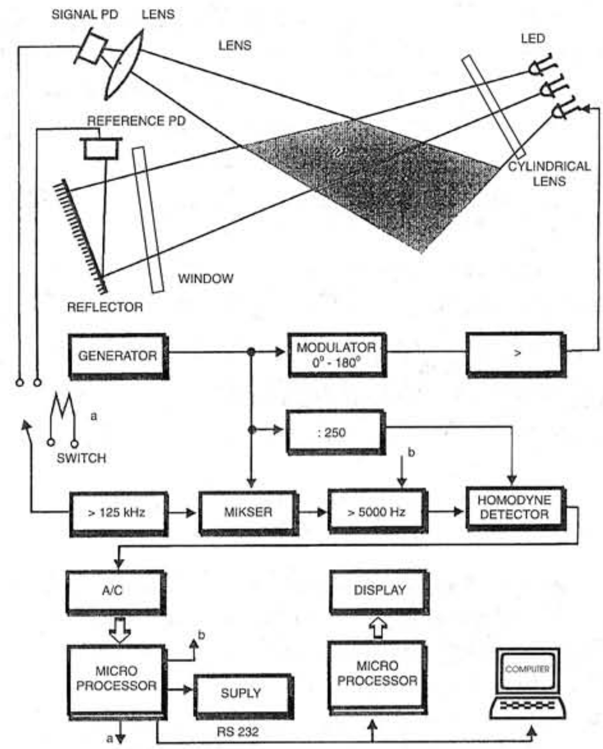

Fig. 1. Block diagram of the visibility meter.

to be measured. The display block together with the supply unit are located inside the building, where the visibility data are displayed and recorded. Both blocks are connected by a 40 m long cable. Data from the transceiver head to the display unit and to the computer are transmitted by means of the RS 232 link.

Optoelectronic transmitter includes 3 IR LED diodes $\lambda = 0{,}85$ m connected in series and producing a beam of 13° width. The beam is inclined by 13° with respect to the horizontal line. The diodes are modulated by the square wave of 125 kHz which is additionaly PSK modulated by another square wave of 500 Hz. Both waves are obtained from the same standard generator. The radiating power density in the scattering volume covers the range of $E = 0{,}12 - 1{,}38$ mW/cm^2. The relative high frequency modulation of LED diodes is beneficial so that the low frequency interferences like filament and fluorescent lamps can be filtered out by a high pass filter.

The optoelectronic receiver containes two photodiodes. One for the scattered signal detection, and the second, as a reference for radiated power and receiver gain control. During the visibility measurement the diodes are switched alternatively and the final result of the scattered power measurement is taken as a product as the signal P_0 and reference P_i measurements. The silicon p-i-n photodiodes were chosen because of their good stability and responsivity for the LED radiation. The avalanche photodiodes have highly unlinear gain and are very sensitive to the reverse bias voltage and temperature. Thus, their current gain is strongly influenced by the interference background light and the temperature. The receivers optical field of view is equal to 12° and is also inclined to the horizontal line by 13°. The receiver contains a low noise amplifier, a homodyne mixer for obtaining PSK 500 Hz signal, a narrow-band 500 Hz amplifier and a homodyne detector. The gain of the narrow-band amplifier can be automaticaly 10 times decreased, when the scattered power exceeds the adequate level. The DC signal proportional to the scattered power is analog-to-digital converted and read by the microprocessor.

The PSK modulation with the 0° – 180° phase shifts makes it possible to double the received signal. Rejection of the backgroud radiation is obtained by means of IR filter and a high pass filter at the input of the receiver. Numerical calculations based on formula (5) and (6) for a given configuration of the system design show that the received power reaches the value of (7,5 – 0,3) nW for the standard visibilities changing from (0,1 to 10)km.

The visibility meter is controlled by a microprocessor which performs the following functions:

- Reads the digital data of measured signals.
- Switches the measuring sequences like measurement and calibration, gain of the amplifier, time of measurement.
- After each measurement switches some supplying voltages in order to economize supplying source.
- Calculates the product P_0/P_i and the standard visibility.
- Averages the measured data.
- Sends via the RS232 link the calculated data and the information about the state of transceiver to the display unit and to the computer.

The second microprocessor in the display unit performs the following functions.

- Reads the visibility data and the state of measurement.
- Controls the function of LCD display.
- Sends data to the digital-to-analog converter to obtain DC voltage proportional to the standard visibility. Such a voltage is demanded by the road service systems.

3. Experimental results

The visibility measurements were carried out from November 1996 up to April 1997. During tests some changes of electronics and software have been introduced which improved the resistance to temperature changes and stability of the system. The measuring system was preliminary calibrated by means of visual observations. The results are shown in Fig 2 which presents the scattered power measurements as a function of estimated visibility. The measurements were performed each minute, then averaged over 4 and then 8 measurements. Due to unhomogeneities of the fog carried by the wind the deviation of the measured visibility in 1 minute steps reached the value of ± 50%. The mean of 4 measurements is shown in the Fig. 2.

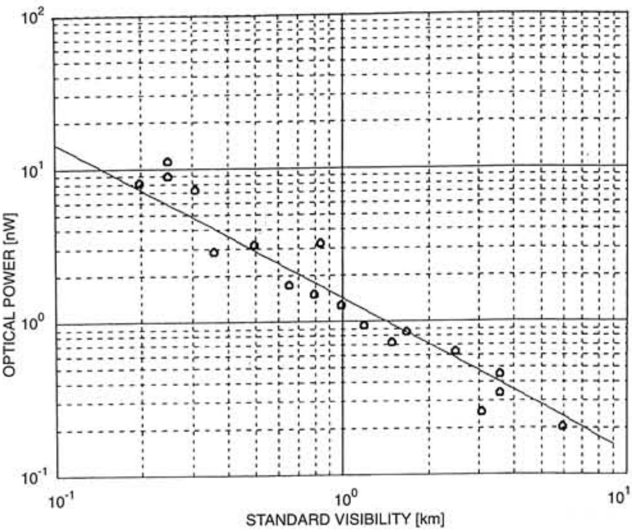

Fig. 2. Scattered power measured by the receiver as a function of the standard visibility.

Using these preliminary measurements rough calibration of the meter was obtained by means of a simple formula:

$$V_n = 42P_i/P_0 \text{ [km]} \tag{7}$$

where P_0 and P_i are the results of measurement of scattered power and measurement during the calibration, respectively.

The visibility measurements were compared with two other visibility meters of VAISALA production during two foggy days in January 1997 (Fig 3). These instruments were installed close to the ground south and north of Warsaw in places named Okęcie and Bielany respectively, our meter named PW was in-

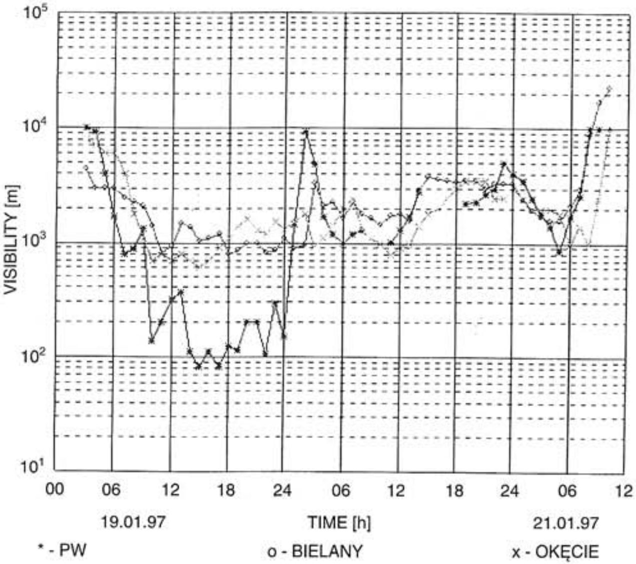

Fig. 3. Visibility measurements with 3 different visibility meters.

stalled just in the center of the town on the level of the VI floor. During one day a good convergence of all results was observed while in the other day different results were obtained.

The above measurements can be treated as preliminary since during the field test of the instrument only few foggy days happened. The autors hope to continue the tests during autumn 1997 when fog occurs more often.

References

1. AEG. *Telefunken Visual Range Meter AEG/DFVLR Scattered Light Recorder Type MS 05*
2. K.Holejko: *Ocena wielkości sygnału w optoelektronicznych miernikach zamglenia o fali ciągłej. Rozprawy Elektroniczne* **32** Z.4 (1986) s. 1207.
3. Pekka Utela, Taisto Haavasoja. *A New Visibility and Present Weather Sensor.* VAISALA News No. 142. (1997).
4. *Photonics Spectra. IR Fog Detection to Improuve Highway Safty*. Photonics Spectra. January (1995).
5. G.H. Ruppersberg: *Principles et Procedes de Mesure Automatique de la Visibilite*, Biulletin de IAJSM 31. Janv. (1967).
6. Shulmberger Enertec. *Ev 1000 Visibility Meter.* Prospect.
7. H. Vogt: *Visibility Measurements Using Backscattered Light*, J.Atm Sc. Berlin (1968).