Inter-Islands Optical Link Tests

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Abstract—**Free-space optical communication systems between satellites and also between a satellite and a ground station foreseen in Europe in the mid-1990's require far-field on ground experimentation prior to launch. To identify possible scenarios for a test site, an atmospheric near-infrared, semiconductor laser link between two mountain peaks 143.5 km apart located in two islands in the Canarian Archipelago was performed. The link confirmed the excellent atmospheric conditions of this scenario (low attenuation, turbulence induced effects below or close to saturation during nighttime) in addition to its high availability.**

As a SUPPORT activity to free-space optical communication systems to be flown in the mid-1990's, a preliminary experiment has been carried out between two 2400 m high, 143.5 km apart sites in the islands of Tenerife and La Palma in the Canarian Archipelago (Spain). The purpose was to test the expected good characteristics of this scenario as a long distance test range for optical communication payloads and for the installation of an optical ground station for in-orbit payload test and monitoring.

Specifically, the aim of the experiment was to validate the models developed for gases and aerosol attenuation, power scintillation, angle of arrival fluctuations, and associated spectral distribution. For computation of these latter (turbulence induced) effects, a simple path model formed by three homogeneous sections (two of 7 km close to the path ends, and one of 130 km with local ground below the inversion layer) was assumed. The structure constant C_n^2 is taken as $10^{-14}/10^{-17}/10^{-14}$ $m^{-2/3}$ during daytime and $10^{-15}/10^{-17}/10^{-15}$ $m^{-2/3}$ during nighttime.

A one-way link was established between a transmitter based on a 40 mW peak power, 830 nm GaAlAs laser diode modulated by a 10 kHz square wave and focused by a 10 cm aperture refracting telescope, and a receiver formed by a 7 in reflective telescope, a photodetector, and adequate filtering and amplification.

The transmitting telescope was provided with beamwidth control and both fine and coarse pointing capabilities by means of two precision adjustable mirrors. In the receiver two different large area (100 mm^2) photodetectors were alternatively used, one of them sensitive to spot position. In both cases, due to the large active area, receiving telescope pointing was not critical. Observation during daytime was possible by inclusion of appropriate optical filtering.

The experiment was performed during June 6, 7, and 9, 1989, under dry atmospheric conditions and good optical visibility. Total observation time was 15 h, 9 by day and 6 by night. Ninety minutes of data, distributed along the experiment, were recorded with help of an 8-channel instrumentation tape recorder.

Results obtained and their comparison to predicted values were as follows.

Attenuation

A fairly stable, minimum attenuation value of 3.5 (−1.9/+3.5) dB was measured during at least half the observation time. Maximum measured attenuation did not exceed 12 dB.

Although detailed attenuation curves have been calculated for this project [1], an accurate prediction of its value for the experiment could not be computed due to the fine structure of the absortion lines and the lack of accurate measurement of the laser spectral distribution and wavelength drifts. Anyhow, the 3.5 dB measured agree with the average attenuation computed for a laser spectral width of 0.7 nm or more in the range 832–836 nm.

Power Scintillation

An estimation of the turbulence-induced scintillation of the received power was done using the turbulence model described above and assuming spherical wave propagation, which is consistent with the total path length and the relatively large beam divergence.

Using the Rytov's approximation [2], the following values are found for log-amplitude variance in a point of the wavefront:

$$\sigma_\chi^2 = 1.1 \text{ in nighttime}$$

$$\sigma_\chi^2 = 7.4 \text{ in daytime}$$

In fact, as these figures exceed 0.3, saturation effects take place and they do not correspond to the values that can be expected in practice. These can be estimated using curves relating experimental data to the results predicted by the Rytov's approximation [3]. In this way a value $\sigma_\chi^2 \simeq 0.2$ is found for both cases.

Due to the partial incorrelation of intensity fluctuations over the wavefront, the fluctuations on the power collected by a finite aperture are lower than those calculated for a point receiver [4]. The aperture averaging effect has been computed in nighttime conditions by using the log-amplitude covariance

Manuscript received January 16, 1990. This work was supported by European Space Agency Contract No. 8131/88/NL/DG.

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IEEE Log Number 9035528.

1041-1135/90/0500-0380$01.00

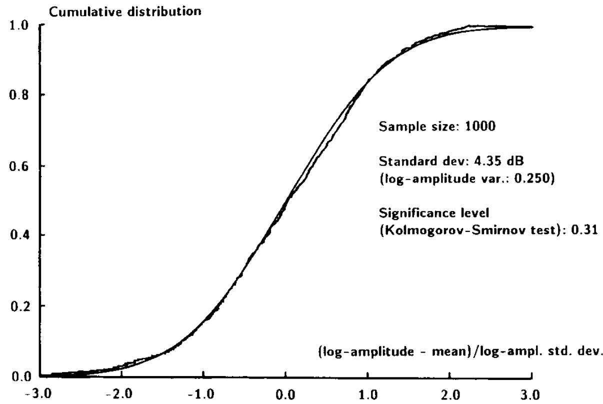

Fig. 1. Normalized cumulative distribution for a 1000 point sample of the detected received signal (150 Hz video filtering). The normal distribution function is also shown for comparison.

function derived in [5] for weak turbulence with the modification proposed in [6]. The experimental result for a night experiment compared with the calculated value is given below.

Measured log-amplitude variance (nightime, minimum attenuation): 0.25, corresponding to a 4.35 dB amplitude standard deviation.

Computed log-amplitude variance: 0.18 (3.71 dB standard deviation).

The measured figures suggest a situation near the saturation limit, with long correlation radius that make aperture averaging of little importance.

Fig. 1 shows the cumulative distribution (1000 points sample) of the received amplitude. Agreement with a Gaussian (predicted) distribution can be taken as a validation of the measurement.

Spectrum Analysis

Fig. 2 shows a typical result of the spectrum corresponding to the detected signal after rectification. It can be seen that the spectral width of the scintillation at -20 dB is somewhat more than 50 Hz.

Angle of Arrival Fluctuations

Turbulence-induced wavefront distorsions at the receiver cause apparent fluctuations of the wave angle of arrival. They were measured with a SiTek 2L10 position sensitive photodiode whose *x-y* position accuracy was greatly degraded when the optical power levels received (ranging between -54 and -48 dBm) were in the lower end of the quoted range. Anyway, a selection of the values recorded during the (short) periods of time of strong received signal, due to scintillation, produced the following values:

Measured standard deviation: (daytime), 19.8 μr
(nighttime), 7.0 μr
Computed standard deviation: (daytime), 19 μr
(nighttime), 6 μr

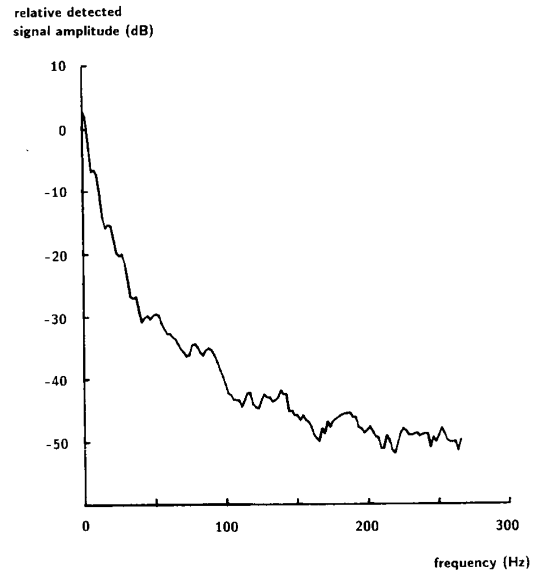

Fig. 2. Typical spectrum of the detected received signal after rectification. Note that significant components are contained within a 50 Hz band.

Computed values were obtained using the expressions in [2] with the model for turbulence along the path described above and for the 7 in diameter aperture used.

Conclusion

The experiments performed show that the atmospheric attenuation around 830 nm is not an obstacle to use the described Canary Islands scenario as a terrestrial test range for free-space optical communications systems.

Some brief measurements of turbulence-induced effects have been carried out as well, showing good agreement with both theory and model. The impact of the turbulence-induced effects on a communications link has to be further assessed. To this end, it is felt that additional and more complete experimental characterization of the effects of turbulence is needed.

The reasonably low attenuation values over the 143.5 km horizontal path indirectly points also towards the feasibility of satellite-to-ground links at those wavelengths.

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