Lab Implementation of 10Gbps/channel Optical Transmitter Diversity Scheme for Geostationary Satellite Feeder Links

Ahmad Mustafa, Dr. Dirk Giggenbach, Dr. Juraj Poliak, Amita Shrestha, Dr. Ramon Mata-Calvo, Christian Fuchs
German Aerospace Center (DLR), Institute of Communications and Navigation, Oberpfaffenhofen, Germany
Contact: ahmad.mustafa@dlr.de

Abstract

Free-space optical (FSO) communications is an attractive alternative to microwave technology in geostationary (GEO) communication satellite feeder link applications, due to the possibility of transmitting information with high data rate, small antenna size, secure communication, and no spectrum licensing requirements. However, optical links through the atmosphere suffer from scintillation effects caused by index of refraction turbulence of the air. It aggravates stable signal detection in the uplink scenario. The benefits of transmitter diversity to mitigate the fading effects in the uplink GEO feeder link are verified by the recently conducted ArtemEx measurement campaign using unmodulated optical beams. In this paper, the lab implementation of the transmitter diversity technique using a 10Gbps data signal and using measured fading vectors from the ArtemEx campaign is presented.

1 Introduction

Many space applications such as Geostationary Communication Satellite Systems will require more than 1Tbps throughput in future. This is difficult to achieve with traditional RF technology as it is approaching the capacity limits and more than 40 ground stations would be required. High-speed optical feeder links can solve this data link bottleneck as optical carrier frequencies, with their higher bandwidths, offer throughput higher than Tbps using Dense Wavelength Division Multiplexing (DWDM) technology [1]. Moreover, because of high directivity, beam tapping is almost impossible and no governmental licensing fee is required to use the optical spectrum. It makes FSO communications an ideal candidate to overcome the limitations of RF transmission systems.

However, the performance of optical communication links is highly dependent on the weather conditions. Severe weather conditions like clouds can have a detrimental impact on the performance of the transmission systems which has to be recovered by large scale Ground Station Diversity. One of the main challenges in the long-haul optical links through the atmosphere is turbulence, which is a random process. The laser beam propagating through the atmosphere suffers from scintillation effects caused by the index of refraction turbulence of the air. In ground to satellite links these effects are more dominant in the uplink signal than in the downlink.

Spatial diversity is a beneficial method to mitigate the fading on the optical signal. **Figure 1** shows a realization of the spatial diversity scheme. By placing two or more transmitter telescopes at moderate spatial separation on ground, the turbulent paths are de-correlated and the fading effects on the uplink signal are reduced using standard diversity schemes.

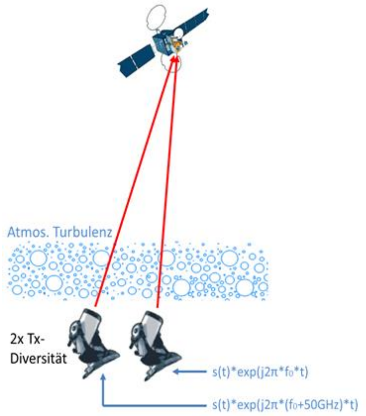

Figure 1: Spatial diversity scheme with two transmitters in a GEO feeder uplink

In this paper, the implementation of transmitter diversity using one data signal with data rate R_b=10Gbps and a wavelength division scheme with two wavelengths in a GEO feeder uplink is presented.

The German Aerospace Center's Institute of Communications and Navigation is pursuing research in a number of different projects in this context including downlink and uplink applications [2], [3].

2 Transmitter Diversity Scheme

Figure 2 describes the transmitter diversity scheme with wavelength division multiplexing (WDM). The two optical transmitters are fed by the same 10Gbps data signal. The frequency separation between the two optical signals is 50GHz. This minimum separation is kept to avoid optical interference between the two signals by keeping the optical spectrums separate enough to avoid overlapping. The two signals separately go through the uncorrelated fading testbeds which emulate the effect of atmospheric turbulence on the optical signal. The two signals are combined at the 10Gbps direct detection receiver where a more stable signal is achieved. Moreover, it reduces the depth and outage probability of the fades as verified by the transmission diversity experiment ArtemEx on ARTEMIS geostationary satellite [4].

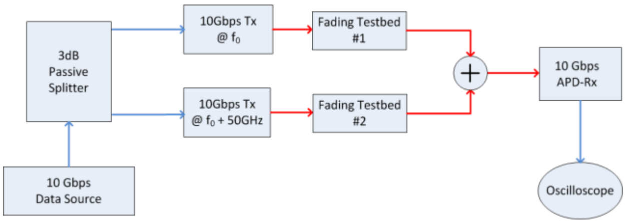

Figure 2: Block diagram of transmitter diversity scheme using one 10Gbps data channel and two wavelengths with 50GHz frequency separation

To demonstrate the concept, intensity modulated direct detection (IM/DD) scheme is deployed in this experiment because of its simplicity and ease of implementation.

3 Experimental Setup

A 10Gbps pattern generator with PRBS7 is used as data source. A 3dB power splitter splits the 10Gbps data signal into two to drive the two optical transmitters. The optical transmitters in use are tunable XFP transceivers which can be tuned on ITU-T 50GHz grid. The minimum frequency separation of 50GHz between the two transmitters is limited by the technological constraints of tunable XFP transceiver modules. The 10Gbps modulated optical signals with 1mW power each go into the two fading testbeds (FTB).

The FTBs are in-house built statistically independent fading emulators that can emulate the scintillation effects of the turbulent atmosphere. **Figure 3** shows the block diagram of the FTB.

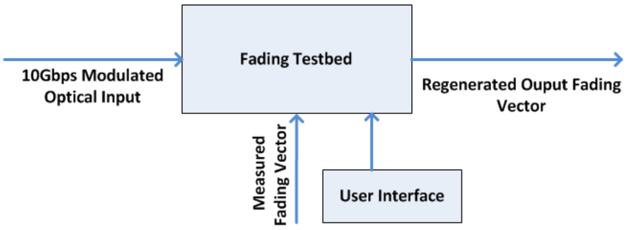

Figure 3: Block diagram of the Fading Testbed

The testbed uses an input file having a normalized vector which can be either taken from measured satellite uplink fading vector or from any other additional user defined realistic fading behavior. The output is the regenerated fading vector with a user defined mean power which follows the power statistics of the loaded fading vector. Fading vectors used in this experiment are obtained from the ArtemEx measurement campaign carried out for the uplink GEO feeder link [4]. The sampling rate of the fading vector is 8kS/s. **Figure 4** shows the fading vector measured in the ArtemEx campaign.

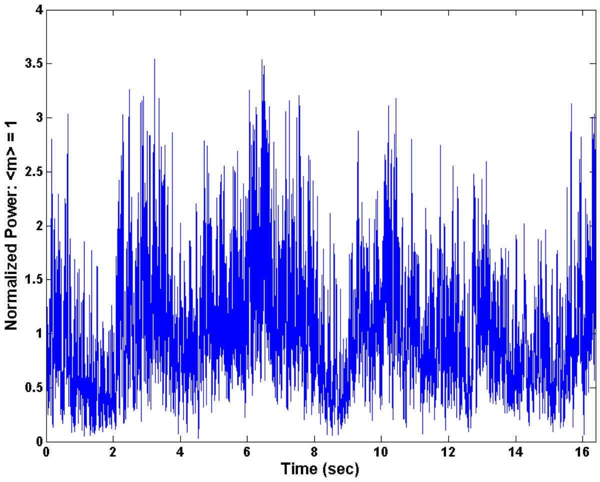

Figure 4: Measured fading vector from ArtemEx campaign. The scintillation index is 0.27 and diameter of the transmitter aperture is 140mm.

Both testbeds are loaded with the same fading vector but with a random non-zero time delay to make the output from the two testbeds completely uncorrelated as it is in the outdoor environment. The two optical signals experience the scintillation effects in the testbed. Direct detection of the optical signal is done by the photoreceiver which converts the optical signal into the baseband 10Gbps signal.

4 Measurement Results

The measurements are repeated by switching on only one transmitter at a time and then switching on both to verify the improvement in signal stability due to diversity. Mean received power in all three cases is kept same to show that the improvement is due to reduced outage probability and not because of higher SNR when using two beams. Performance parameters to verify the effectiveness of this setup are given in the following subsections.

4.1 Received Power Statistics

In **Figure 5** the histogram curves of the intensity distributions of the received powers in the three cases are shown.

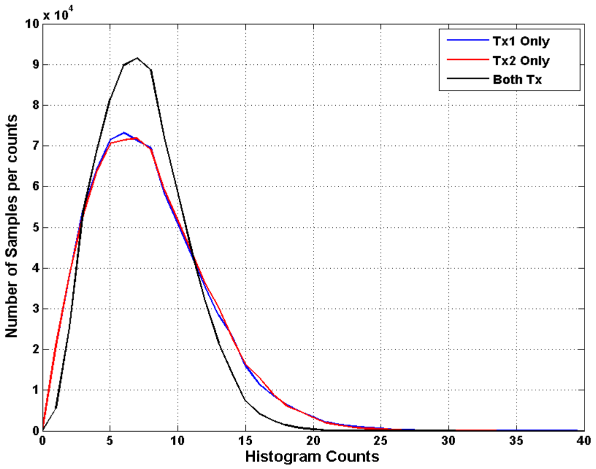

Figure 5: Histogram curves of the received intensity distribution for the three cases at the same mean power

The results show that the sum of the two beams reduces the probability of deep fades compared to the case when only one transmitter is used to send the data signal in uplink.

4.2 Scintillation Index

Scintillation indices are calculated for the three cases and compared with the scintillation index of the used fading signal which is 0.27.

Scintillation is defined as the ratio of variance of the received power to the square of the mean received power [5].

The values of scintillation indices for single beam and with transmitter diversity are included in **Table 1**.

Case	Tx1 only	Tx2 only	Both Tx
Scintillation Index	0.26	0.25	0.13
Relative Error	3.7%	7.4%	3.7%

Table 1: Comparison of the scintillation indices between the measured fading vector used from the ArtemEx campaign and the achieved signals in the lab experiment after fading testbeds

The scintillation indices for the measured signals match closely with the expected 0.27 value when only one beam is transmitted. It can be noted that it is reduced by half when transmitting both beams simultaneously showing the improvement in signal stability with less fluctuations using transmitter diversity scheme.

4.3 Bit Error Rate

Mean BER values for the three cases in transmitter diversity scheme are obtained from the power statistics of the received signal using a typical commercial APD receiver's sensitivity characteristics. The calculated mean BER values are given in **Table 2**.

Case	Tx1 only	Tx2 only	Both Tx
BER	$1.1\cdot10^{-4}$	$1.4\cdot10^{-4}$	$6.3\cdot10^{-6}$

Table 2: Mean BER values calculated from the measured received power statistics

5 Conclusion & Outlook

Transmitter diversity is shown to be a viable mitigation technique to reduce the uplink signal fading. It is tested with a 10Gbps signal using measured satellite uplink fading vectors in the laboratory. Further on, the ability to emulate the atmospheric effects in different turbulence scenarios in the fading testbeds is proven.

Based on these experiments an upgrade of the system, in order to reach throughputs over Tbps is underway. Freely tunable transmitters are part of the follow up experiments to reduce the frequency spacing between the adjacent channels making the system more bandwidth efficient.

6 References

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