



OptiSystem Software Enabling Machine Learning Capabilities and Optical Satellite Communication Systems

Ahmad Atieh, Ph.D.



- Optiwave overview
- Software product line
- Weather, temporal and spatial scintillation effects in the channel
- Showcase optical satellite communication system
- Adaptive optics in OptiSystem software
- Machine Learning control for a FSO Systems
- Q&A



General Information

- Optiwave established in 1994 in **Ottawa, Ontario, Canada**
- Optiwave develops innovative **software tools** that offer **design**, simulation, and **optimization capabilities** for components, links, systems and networks
- Optiwave's software **offers** users a **distinct competitive advantage** through
 - **shortening product time introduction** to the market
 - improving **product quality**
 - **enhancing** productivity and **cost-effectiveness**

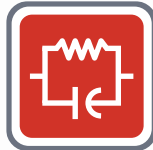


System-Level



OptiSystem

Optical Communication System
Amplifier Design Suite



OptiSPICE

Opto-Electronic Circuit Design
Software

Component-Level



OptiBPM

Waveguide Optics Design Software



OptiFDTD

Finite-Difference Time-Domain
Design Software



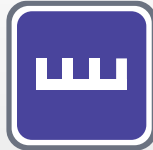
OptiMode

Waveguide and Modal Analysis
Software



OptiFiber

Optical Fiber Design Software



OptiGrating

Integrated Fiber Optical Gratings
Design Software



OptiOmega

Photonics Device and Circuit Design
Software Package

Instrumentation-Level

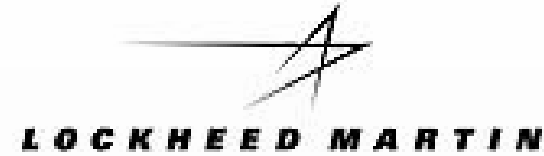


OptiInstrument

Instruments Communication and Control Tool



Optiwave Key Customers



CORNING



NOKIA



SONY



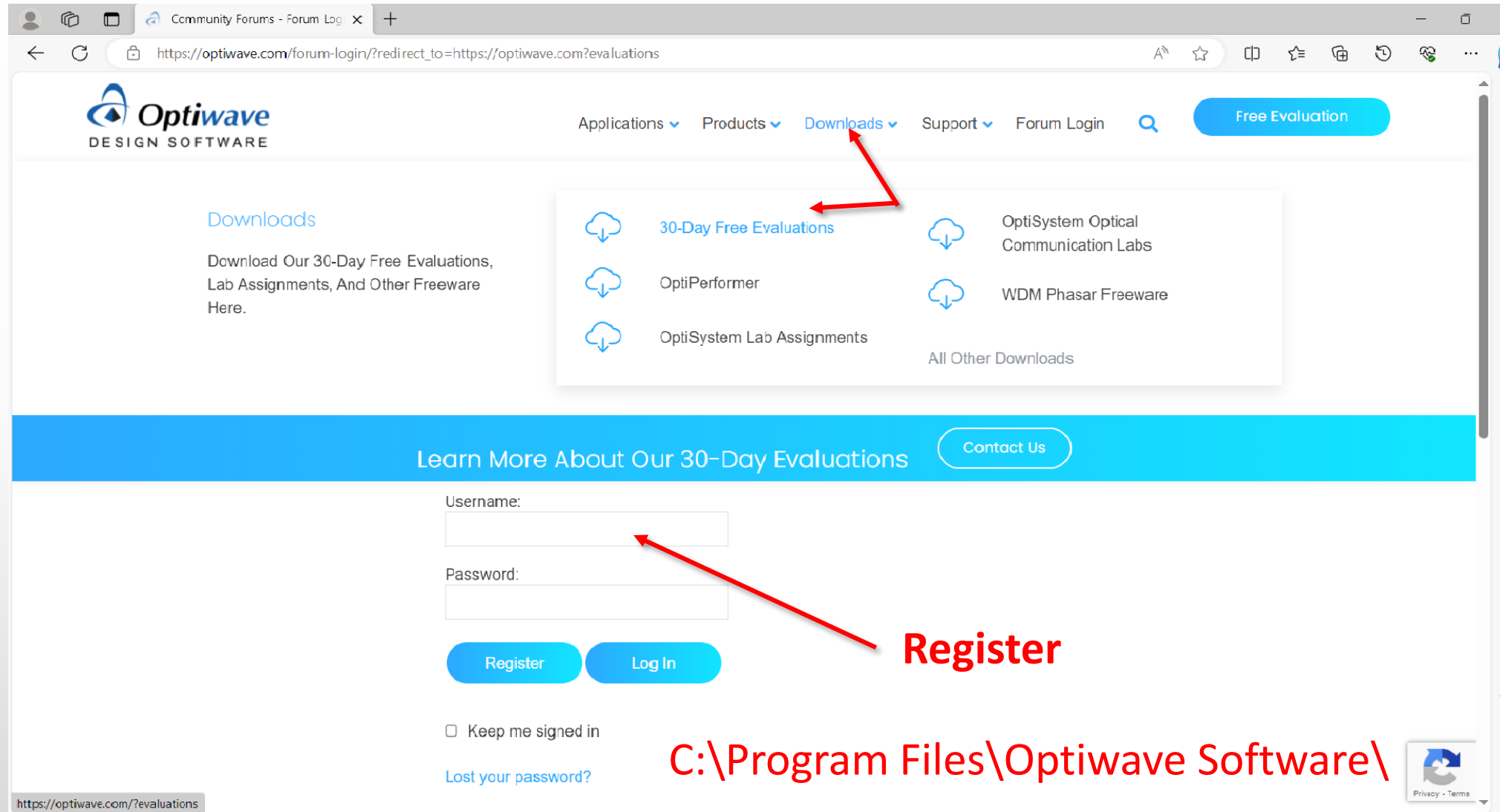
THALES

NORTHROP
GRUMMAN

IBM



Optiwave Software Download



The screenshot shows the Optiwave website's 'Downloads' page. The navigation bar includes 'Applications', 'Products', 'Downloads' (highlighted with a red arrow), 'Support', and 'Forum Login'. A 'Free Evaluation' button is also present. The main content area features a 'Downloads' section with the text: 'Download Our 30-Day Free Evaluations, Lab Assignments, And Other Freeware Here.' Below this, a list of download options is shown, including '30-Day Free Evaluations' (highlighted with a red arrow), 'OptiPerformer', 'OptiSystem Lab Assignments', 'OptiSystem Optical Communication Labs', and 'WDM Phasar Freeware'. A 'Contact Us' button is located in the top right of the main content area. Below the main content, there is a blue banner with the text 'Learn More About Our 30-Day Evaluations' and a 'Contact Us' button. The registration form below the banner includes fields for 'Username:' and 'Password:', a 'Register' button (highlighted with a red arrow), a 'Log In' button, a checkbox for 'Keep me signed in', and a link for 'Lost your password?'. The URL bar shows 'https://optiwave.com/forum-login/?redirect_to=https://optiwave.com/evaluations'.

Downloads

Download Our 30-Day Free Evaluations, Lab Assignments, And Other Freeware Here.

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Register

C:\Program Files\Optiwave Software\



Knowledge Base

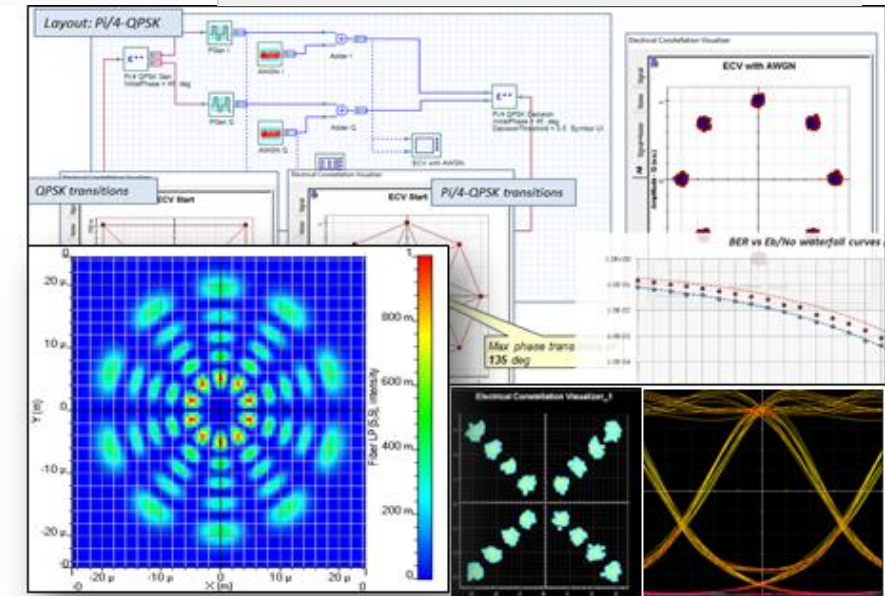
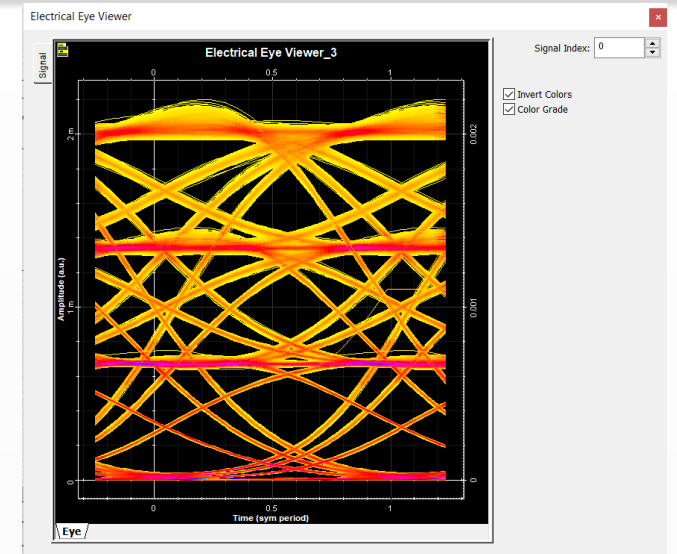
- www.Optiwave.com
- Three types of articles
 - Fundamental theory
 - General structures without paper confirmation
 - Paper reproductions
- Growing number of articles

YouTube Channel

- OptiwaveHD - <https://www.youtube.com/@OPTIWAVEHD>
- Playlists for each product
- Wide range of applications and tutorials



- OptiSystem has over **630** components and visualizers (**optical, electrical, Binary, and M-ary**)
- OptiSystem Example Library has over **1100 examples** demonstrating the different applications



OptiSystem Optical Wireless Components

Component Library

Default/

- Visualizer Library
- Sensors
- Transmitters Library
- WDM Multiplexe...
- Optical Fibers...
- Amplifiers Library
- Multimode Library
- Filters Library
- Receivers Library
- PAS Library
- Passives Library
- Optiwave Softwar...
- Signal Processin...
- Optical Switches
- Tools Library
- External Softwa...
- Free Space Optics

Layout: Layout 1

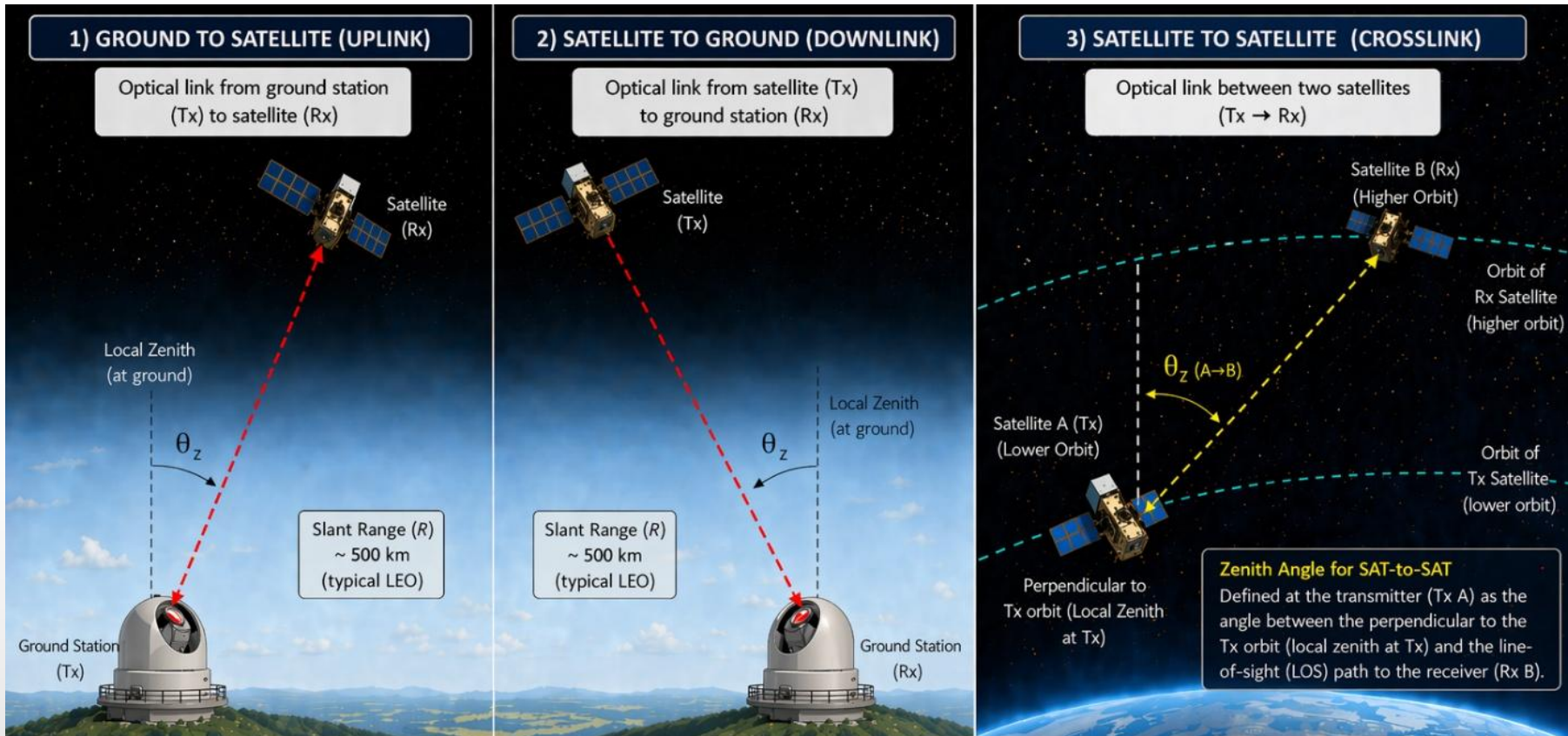
Bit rate (bits/sec): 1e+10 Sequence length (bits): 1024 Samples per bit: 32 Sample rate (Hz):

The layout diagram contains the following components and parameters:

- FSO Channel**: Range = 1 km, Attenuation = 25 dB/km
- OWC Channel**: Frequency = 193.1 THz, Range = 200 km
- LOS Channel**
- Li-Fi Channel**
- FSO Weather Condition**: Wavelength = 1550 nm, Attenuation (dB/km) = 0, Size parameter = 0
- LOS Underwater Channel**: Range = 50 m, Absorption coefficient (a) = 0.0405 1/m, Scattering coefficient (b) = 0.0025 1/m
- NLOS Underwater Channel**: Absorption coefficient (a) = 0.0405 1/m, Scattering coefficient (b) = 0.0025 1/m
- Index Refraction Structure Altitude (Cn²)**: Cn² Index Refraction Structure = 0
- Universal FSO Channel**: Range = 1000 m, Attenuation = 25 dB/km
- UAV Channel**: Range = 6 km, Attenuation = 0.4 dB/km, Beam waist = 50 mm
- SAT Satellite FSO Channel**: Range = 900 km, Beam waist = 35 cm, Transmitter height = 0.01 km, Receiver height = 500 km



Satellite Link Roles and Geometry



For both Ground-to-Satellite (uplink) and Satellite-to-Ground (downlink):
The zenith angle (θ_z) is defined at the ground station as the angle between the local vertical and the line-of-sight (LOS) path.
This is the same physical angle in both cases.

--- Optical Link (LOS Path)
--- Local Zenith / Vertical (Reference)

R : Slant range (link distance along the path)
 θ_z : Zenith angle at ground (angle from local vertical to LOS path)
 $\theta_z (A \rightarrow B)$: Zenith angle in SAT-to-SAT (angle from perpendicular to orbit at Tx to LOS path to Rx)
Tx : Transmitter
Rx : Receiver

Key: SAT-to-SAT Geometry

- Tx (Satellite A) is in a lower orbit.
- Rx (Satellite B) is in a higher orbit.
- Zenith reference is the perpendicular to the Tx orbit at the transmitter (local zenith at Tx).
- The zenith angle depends on relative geometry (along-track, cross-track, and radial separation).
- This definition is independent of any ground point.

- Link power budget
- Spatial input beam
- Plane and spherical beam wavefronts
- Weather conditions
- Temporal and spatial scintillation
- Loading external scintillation phase masks
- Beam propagation evolution
- Receiver capture loss
- Beam wandering
- Satellite dynamics
- Doppler effect
- Blockage and Line-of-sight visibility effects



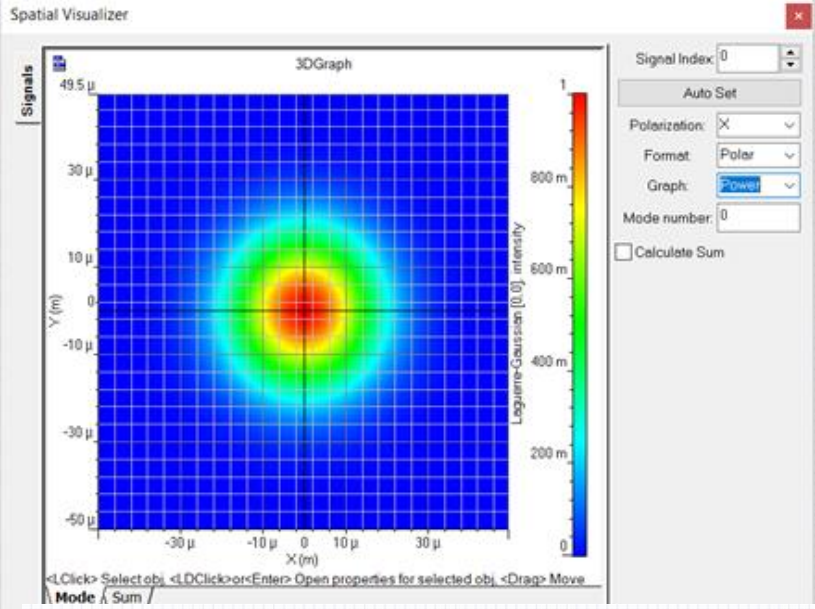
Weather Condition Handling

- **Dry Weather** (Clear, Haze, and Fog)
- **Precipitation** (Rain, Snow (wet and dry))
- **Clouds** (Seven types of clouds including user define)
- Two models **Kim** and **Kruse** are available to determine the related parameters of the visibility used in attenuation calculation

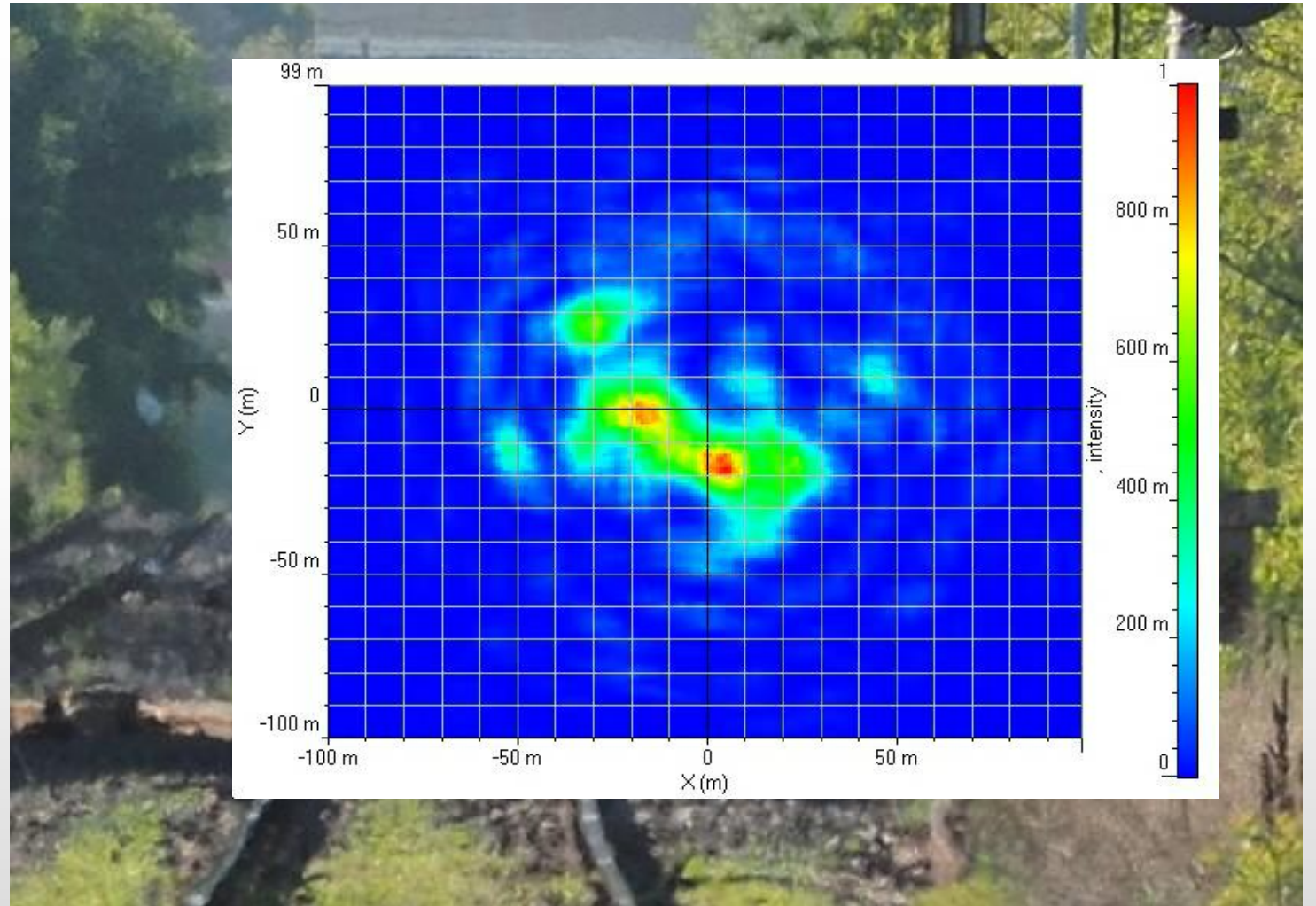
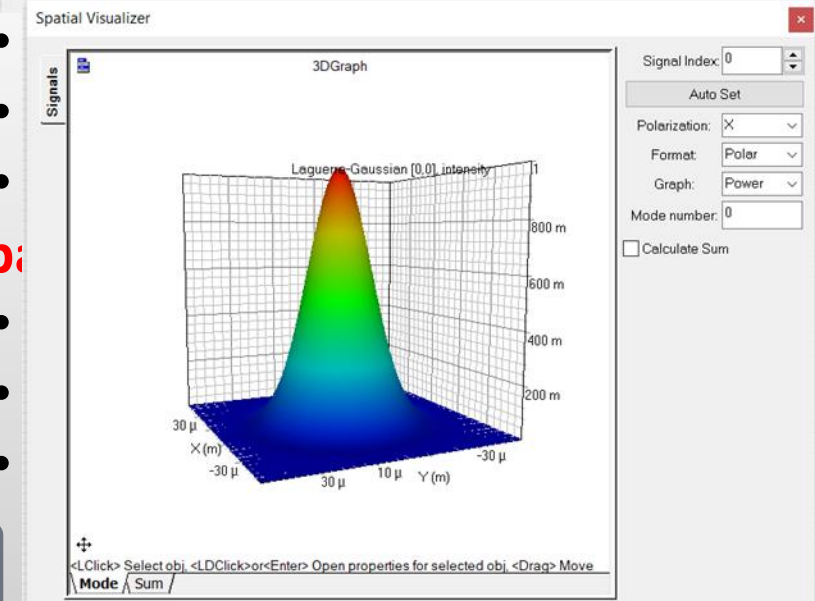


Turbulence Effects In Atmosphere

- From the atmosphere
- Available for simulation
- Temperature



- Spatial



Temporal Scintillation Models

Negative Exponential

$$f(I) = \frac{1}{2\sqrt{\gamma\mu}} \exp\left(-\frac{\gamma}{\mu}\right)$$

$$\gamma = \frac{(\eta I)^2}{N_0}, \text{ Instantaneous SNR}$$

$$\mu = \frac{(\eta \langle I \rangle)^2}{N_0}, \text{ Average SNR}$$

$\langle I \rangle$, mean irradiance

Gamma-Gamma

$$f_{funcGG}(I) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{\alpha+\beta}{2}-1} K_{\alpha-\beta}(2\sqrt{\alpha\beta}I)$$

K-Model

$$f(I) = \frac{2}{\Gamma(\alpha)} \alpha^{\frac{\alpha+1}{2}} I^{\frac{\alpha-1}{2}} K_{\alpha-1}(2\sqrt{\alpha}I), \quad I > 0,$$

Log-Normal

$$f_X(x) = \frac{d}{dx} \mathbb{P}_X[X \leq x]$$

$$= \frac{d}{dx} \mathbb{P}_X[\ln X \leq \ln x]$$

$$= \frac{d}{dx} \Phi\left(\frac{\ln x - \mu}{\sigma}\right)$$

$$= \varphi\left(\frac{\ln x - \mu}{\sigma}\right) \frac{d}{dx} \left(\frac{\ln x - \mu}{\sigma}\right)$$

$$= \varphi\left(\frac{\ln x - \mu}{\sigma}\right) \frac{1}{\sigma x}$$

$$= \frac{1}{x \sigma \sqrt{2\pi}} \exp\left(-\frac{(\ln x - \mu)^2}{2\sigma^2}\right).$$

Malaga (Shadowed Rician) –Option I

$$p(I) = p_{SR}(I)p_{\gamma\gamma}(I)$$

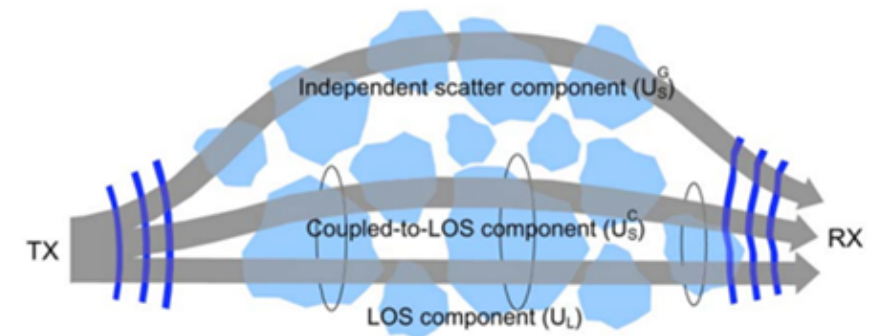
$$p_{SR}(I) = a_1 \lambda \exp(-U_1 \lambda \text{Kummer}(m, 1, b_1 U_1))$$

$$p_{\gamma\gamma}(I) = \gamma(I|\alpha, \gamma(I|\beta, (\alpha\beta)^{-1}),)$$

$$\Omega_x = \Omega + \rho 2b_0 + 2\sqrt{\rho 2b_0 \Omega}$$

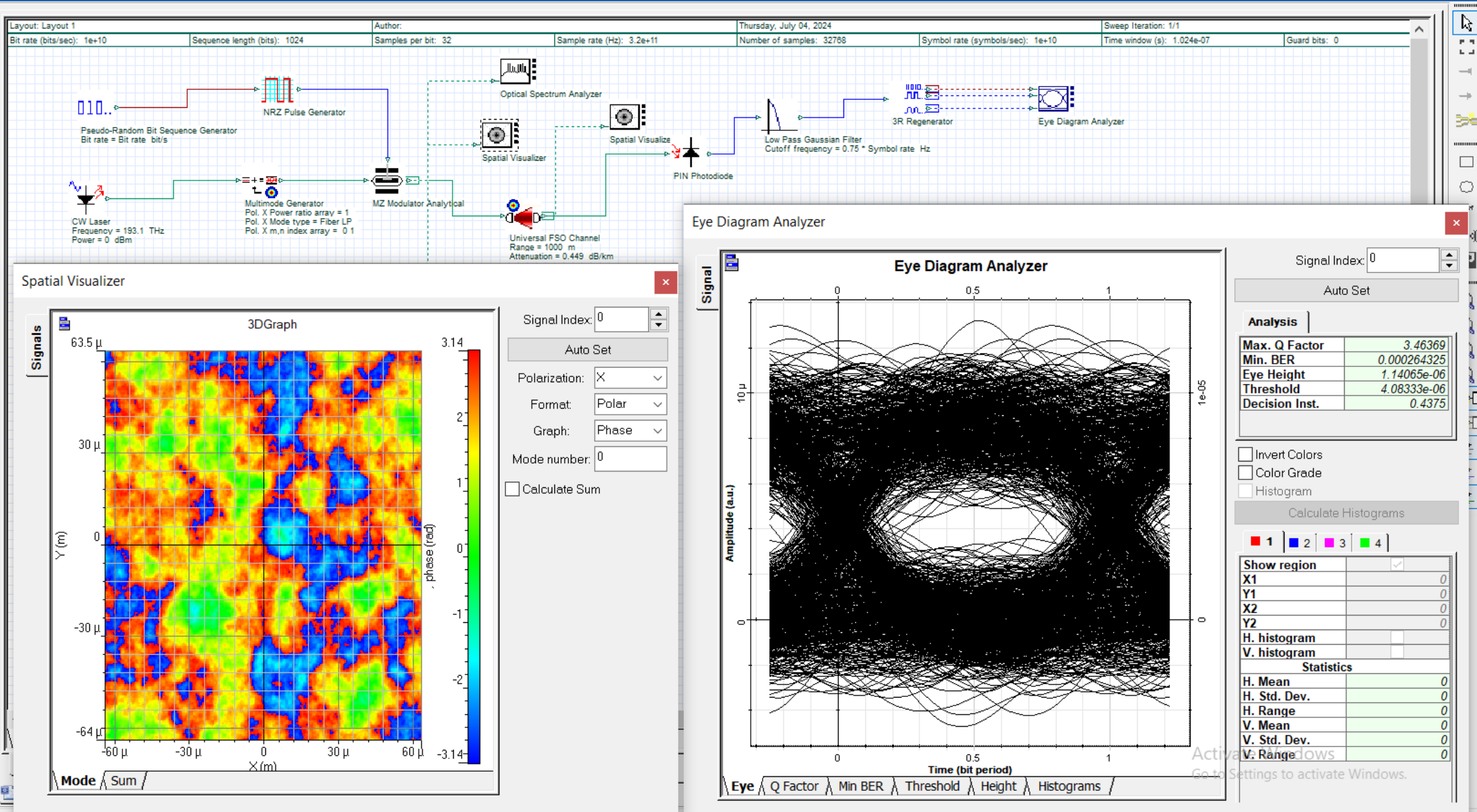
$$a_1 = \left(\frac{\rho 2b_0 m}{\rho 2b_0 m + \Omega_x}\right)^m \quad b_1 = \frac{\Omega}{(\rho 2b_0 m)(\rho 2b_0 m + \Omega)}$$

$$\lambda = \frac{1}{\rho 2b_0}$$

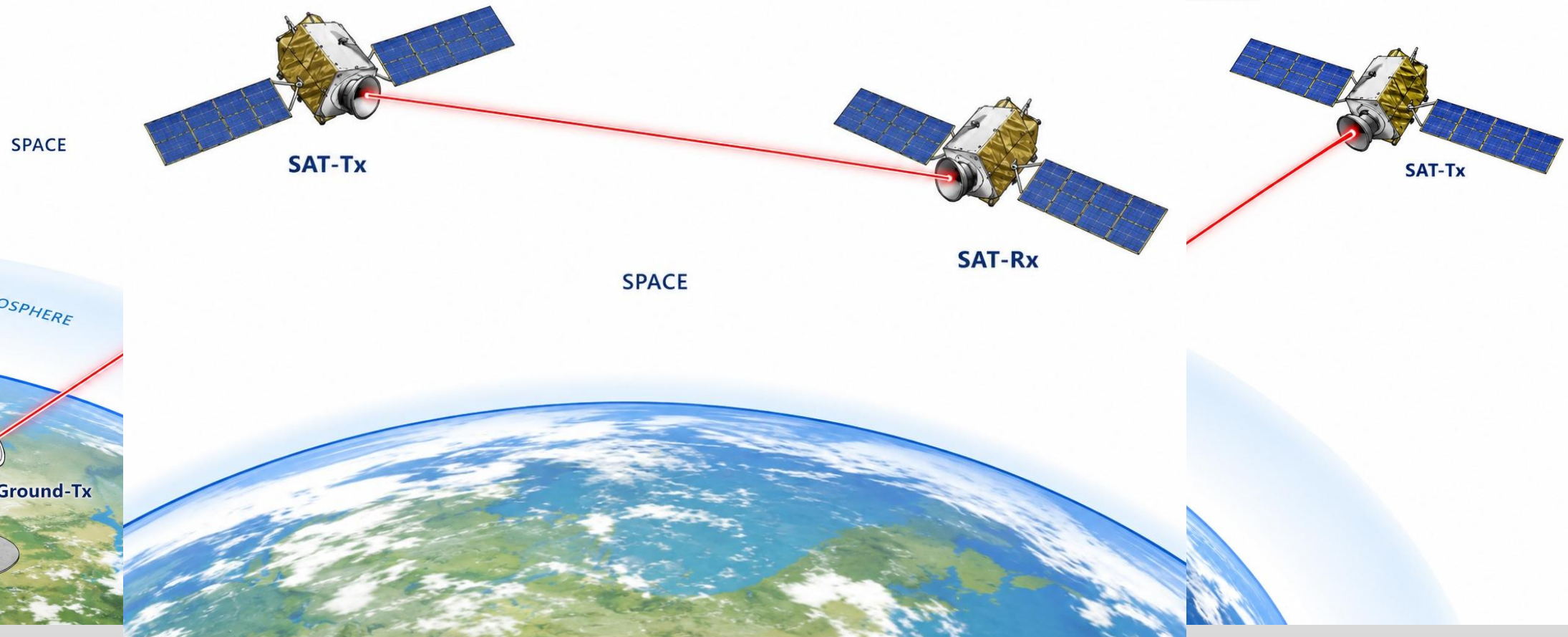


- [1] Nistazakis, H. E., et. al. "Performance estimation of free space optical links over negative exponential atmospheric turbulence channels." *Optik* 122, no. 24 (2011): 2191-2194.
- [2] A. Abdi, et. al., "A new simple model for land mobile satellite channels: First- and second-order statistics," *IEEE Trans. Wireless Commun.*, 2(3), pp. 519-528, (2003).
- [3] Antonio Jurado-Navas, et. al., "General analytical expressions for the bit error rate of atmospheric optical communication systems," *Opt. Lett.* 36, 4095-4097 (2011)
- [4] V. Srivastava, A. Mandloi, D. Patel and P. Shah, "Performance Analysis of Negative Exponential Turbulent FSO Links with Wavelength Diversity," *2020 12th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP)*, Porto, Portugal, 2020, pp. 1-5, doi: 10.1109/CSNDSP49049.2020.9249618.

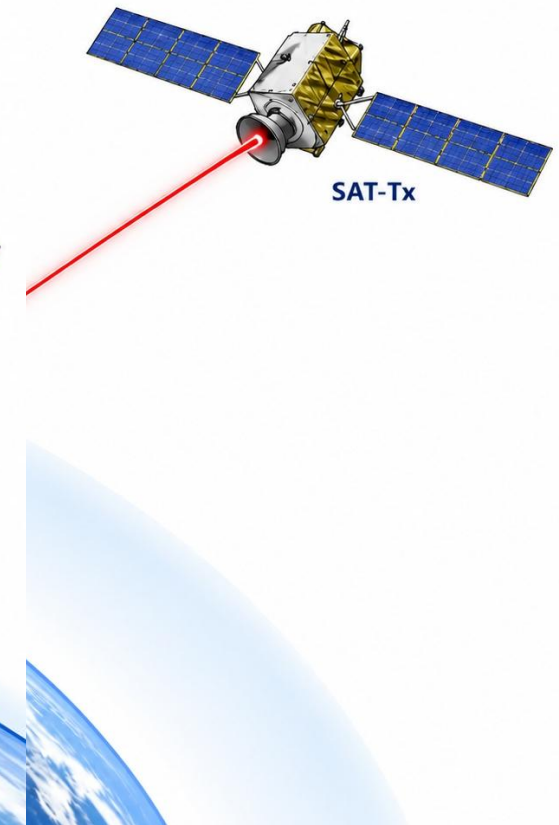
Spatial Scintillation



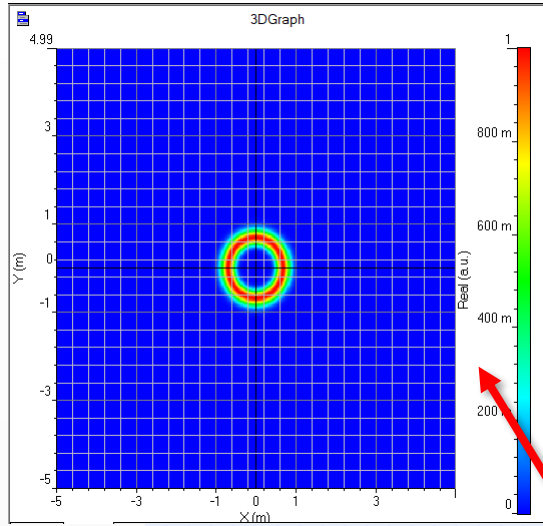
SAT-Tx to SAT-Rx



Ground-Rx



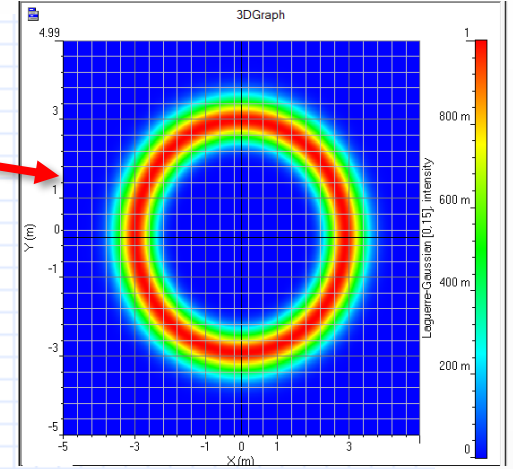
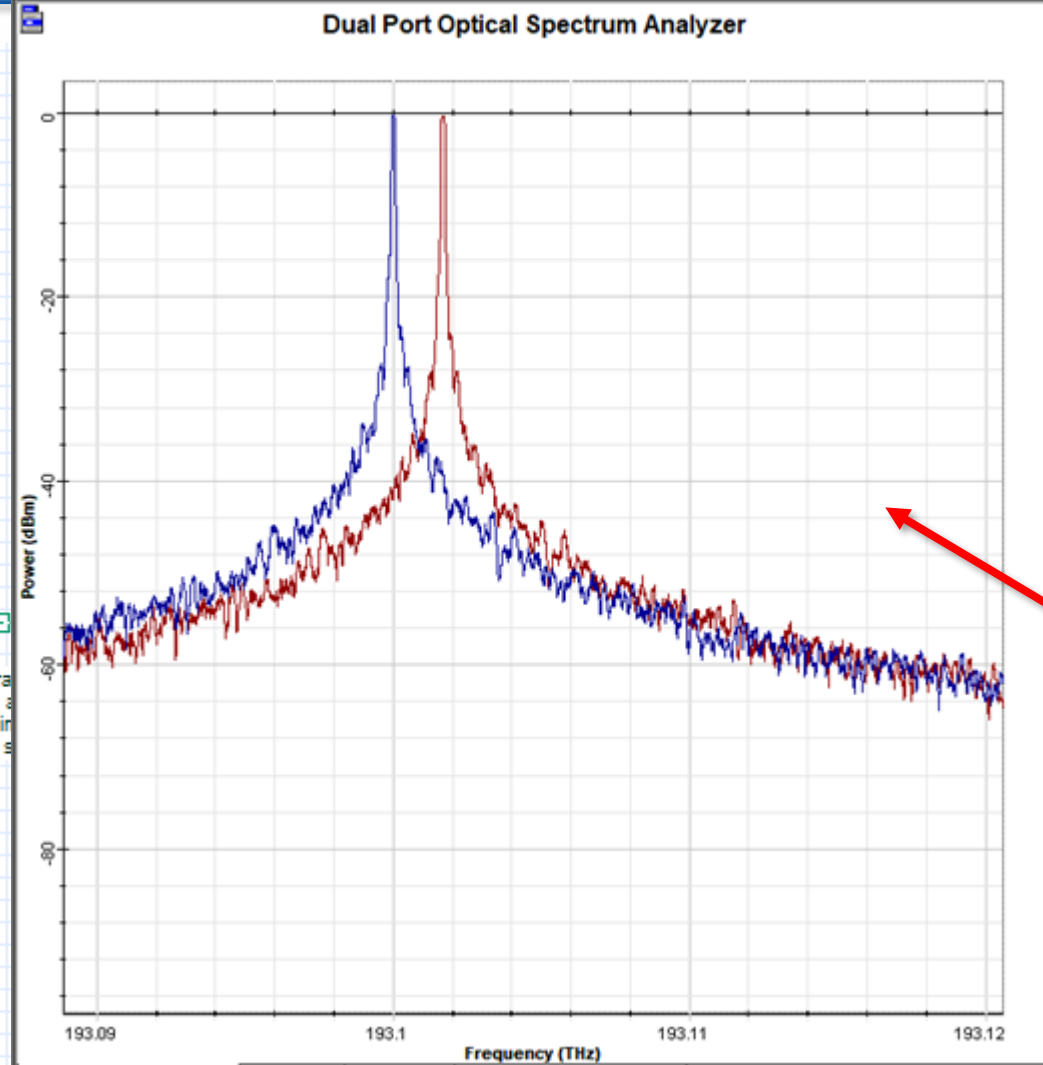
Spatial Scintillation



Input mode
LG 0 15

CW Laser
Frequency = 193.1 THz
Power = 0 dBm

Laquerre Tra
Power ratio a
Pol. X m,n in
Pol. X spot s

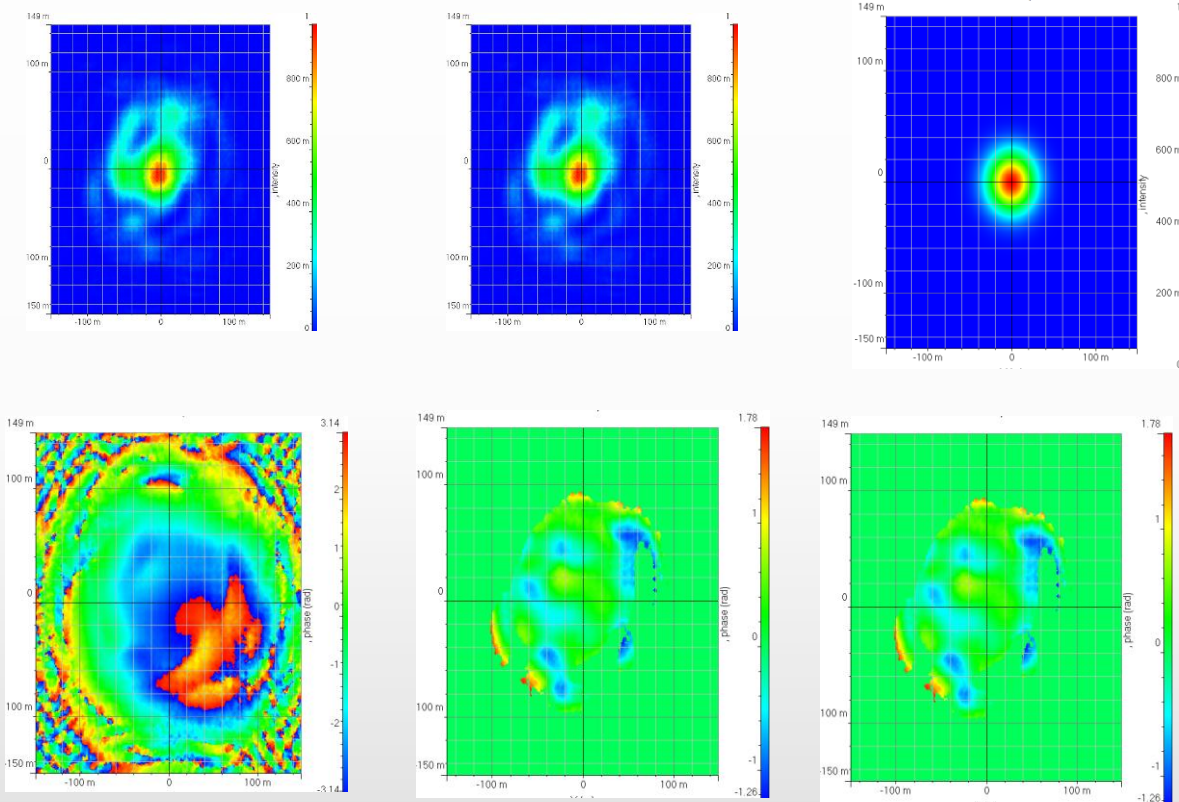


Output

Dual Port Optical Spectrum Analyzer



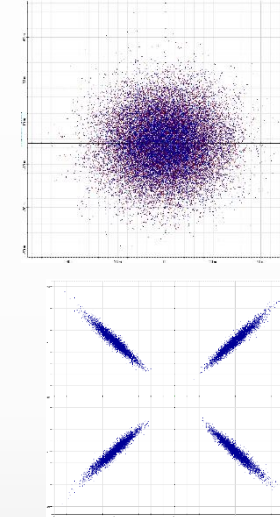
QPSK at 112 Gbps $C_n^2 = 10^{-6}$



Power:-2.960 dBm

Power:-4.788 dBm

Power:-4.430 dBm



BER=0
EVM%=19.323
SER=0

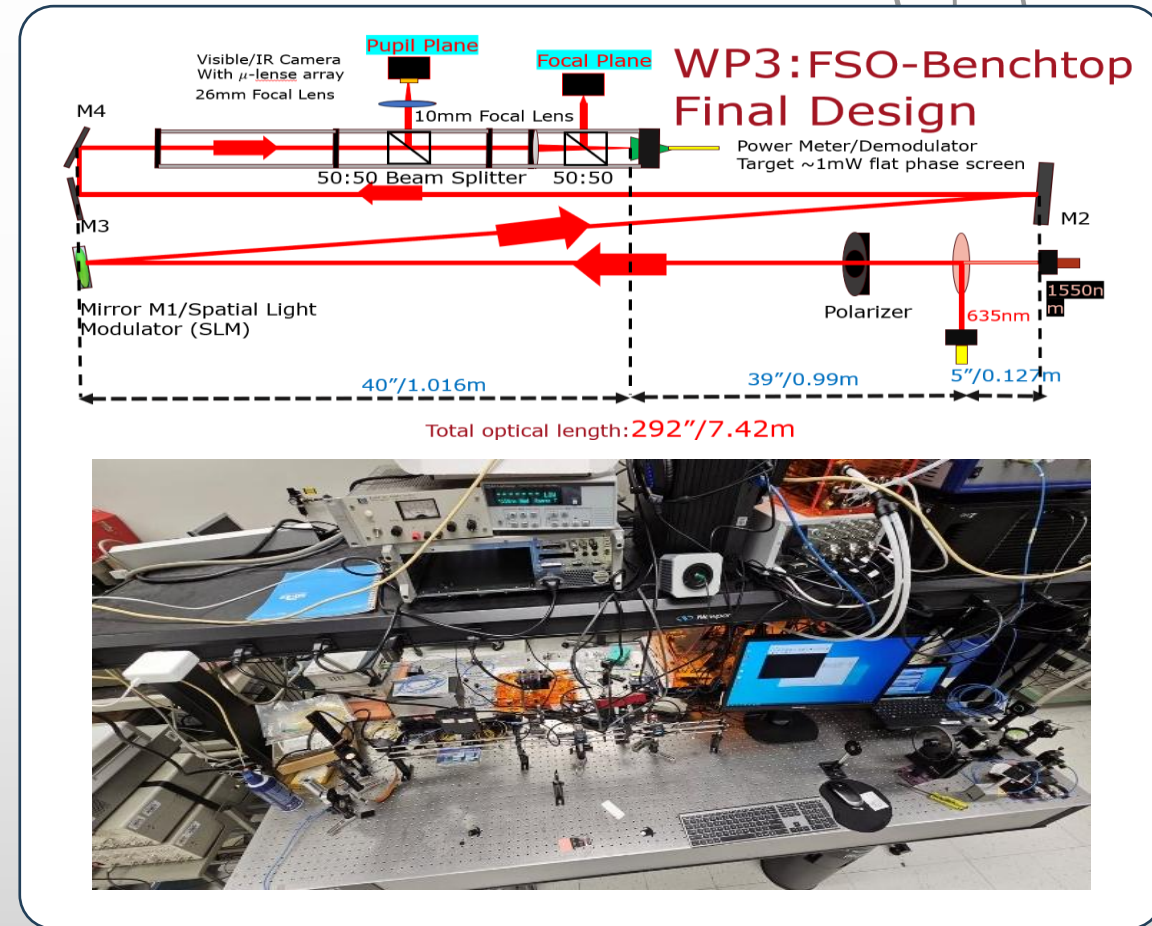
Configured number of speckle	30
Configured speckle threshold	0.0001
ModeX Effective angle(c) (deg)	-68.78533660711251
ModeX Effective angle(c) (rad)	-1.199921983035185
ModeX Effective eta = c ^2	0.5370780163732668
ModeX Effective c	0.7328560679787449
ModeX lma(c)	-0.6830297797864391
ModeX Real(c)	0.2656093678659608
ModeX coupling after (%)	53.70780163732668
ModeX coupling before (%)	32.44182085321091
ModeX coupling gain (dB)	2.189321544876399
ModeX mean speckles process	30
ModeX phase PV after AO (rad)	6.281358658823942
ModeX phase PV before AO (rad)	6.277950902076832
ModeX phase PV reduction (%)	-0.05428135390455405
ModeX phase RMS after AO (rad)	0.7885917980838187
ModeX phase RMS before AO (rad)	1.190542764978805
ModeX phase RMS reduction (%)	33.76199316134116
ModeX phase coherence after	0.7711074670820584
ModeX phase coherence before	0.5100044755257058
ModeX phase coherence improvement (%)	1.511962157365798
ModeX selected speckles (%)	100

- Channel length = 6 km, attenuation = 0.4 dBm
- Scintillation ' $C_n^2 = 10^{-6}$ '
- Spatial phase noise is corrected based on speckles
- Amplitude is corrected based on the ideal case



Indoor FSO Demonstration

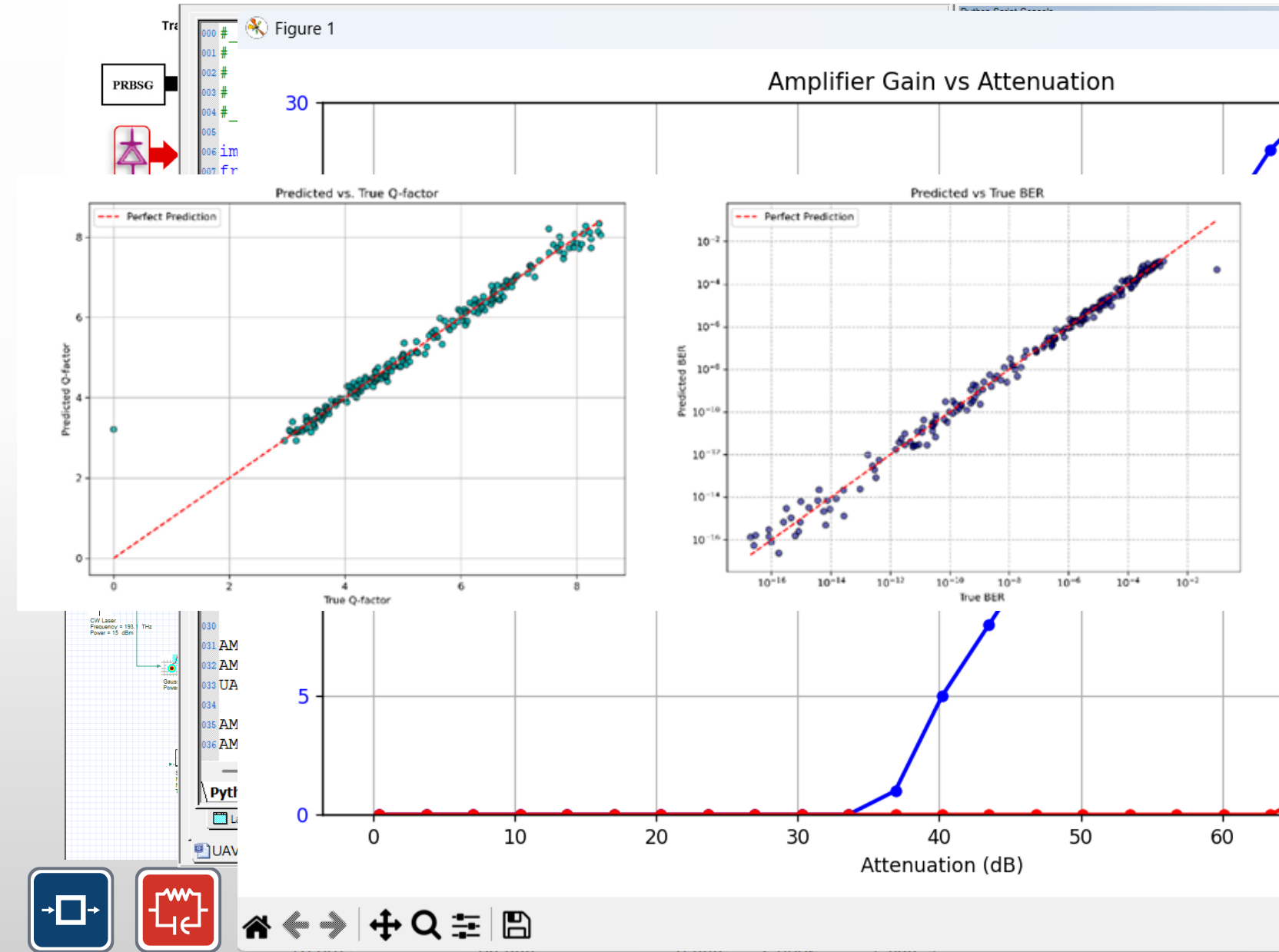
- Turbulence Implementation via Spatial Light Modulation (SLM).
- Integration of custom-built VIS/SWIR Shack-Hartmann wavefront sensor.
- Characterization of the applied C_n^2 via focal plane power measurements (scintillation effects).
- Integration between Photonics lab optical system characterization and OptiSystem software.



Optical Wireless Experiments



Machine Learning FSO System



Article

Real-Time Signal Quality Assessment and Power Adaptation of FSO Links Operating Under All-Weather Conditions Using Deep Learning Exploiting Eye Diagrams

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Abstract

This paper proposes an intelligent power adaptation framework for Free-Space Optics (FSO) communication systems operating under different weather conditions exploiting a deep learning (DL) analysis of received eye diagram images. The system incorporates two Convolutional Neural Network (CNN) architectures, LeNet and Wide Residual Network (Wide ResNet) algorithms to perform regression tasks that predict received signal quality metrics such as the Quality Factor (Q-factor) and Bit Error Rate (BER) from the received eye diagram. These models are evaluated using Mean Squared Error (MSE) and the coefficient of determination (R^2 score) to assess prediction accuracy. Additionally, a custom CNN-based classifier is trained to determine whether the BER reading from the eye diagram exceeds a critical threshold of 10^{-4} ; this classifier achieves an overall accuracy of 99%, correctly detecting 194/195 “acceptable” and 4/5 “unacceptable” instances. Based on the predicted signal quality, the framework activates a dual-amplifier configuration comprising a pre-channel amplifier with a maximum gain of 25 dB and a post-channel amplifier with a maximum gain of 10 dB. The total gain of the amplifiers is adjusted to support the operation of the FSO system under all-weather conditions. The FSO system uses a 15 dBm laser source at 1550 nm. The DL models are tested on both internal and external datasets to validate their generalization capability. The results show that the regression models achieve strong predictive performance, and the classifier reliably detects degraded signal conditions, enabling the real-time gain control of the amplifiers to achieve the quality of transmission. The proposed solution supports robust FSO communication under challenging atmospheric conditions including dry snow, making it suitable for deployment in regions like Northern Europe, Canada, and Northern Japan.

Keywords: free-space optics; LeNet regression; wide ResNet regression; CNN classifier; eye diagrams; real-time signal quality prediction

1. Introduction

Over the past several decades, mobile communication systems have undergone a rapid evolution, with each generation emerging roughly every ten years since the introduction of first-generation (1G) networks in the 1980s. The allocated carrier frequency spectrum of 1G to fourth-generation (4G) technologies has primarily ranged from 700 MHz to 2.6 GHz [1]. However, the limited bandwidth within this range, coupled with the exponential increase in mobile device penetration and global data traffic, has resulted in persistent challenges



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FSO Links Operating Under

All-Weather Conditions Using Deep

Learning Exploiting Eye Diagrams.

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Summary

- OptiSystem Software enables data and quantum communication for ground to satellite, satellite to satellite, and satellite to ground systems
- Do not hesitate to contact Optiwave at info@optiwave.com to request demo or discuss your requirements



Thank You

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