Multi-user FSO Communication Link

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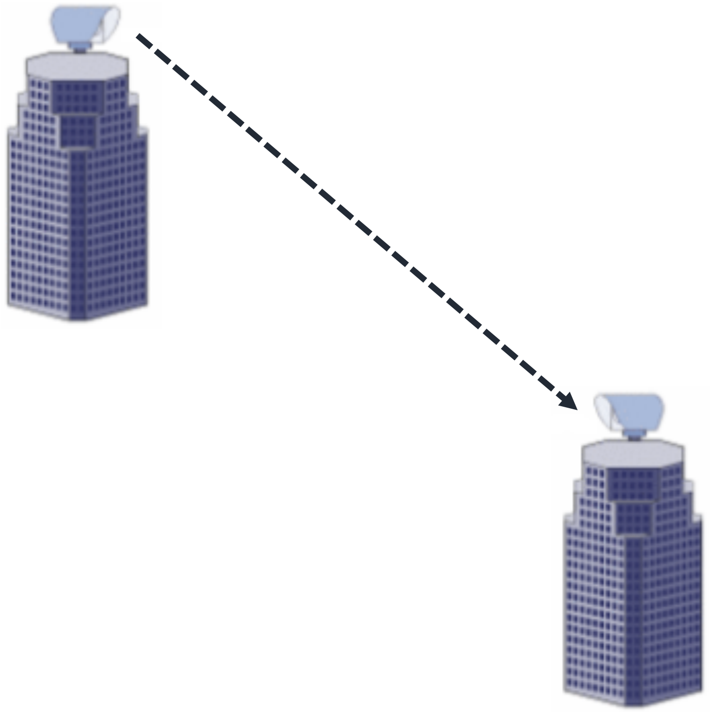
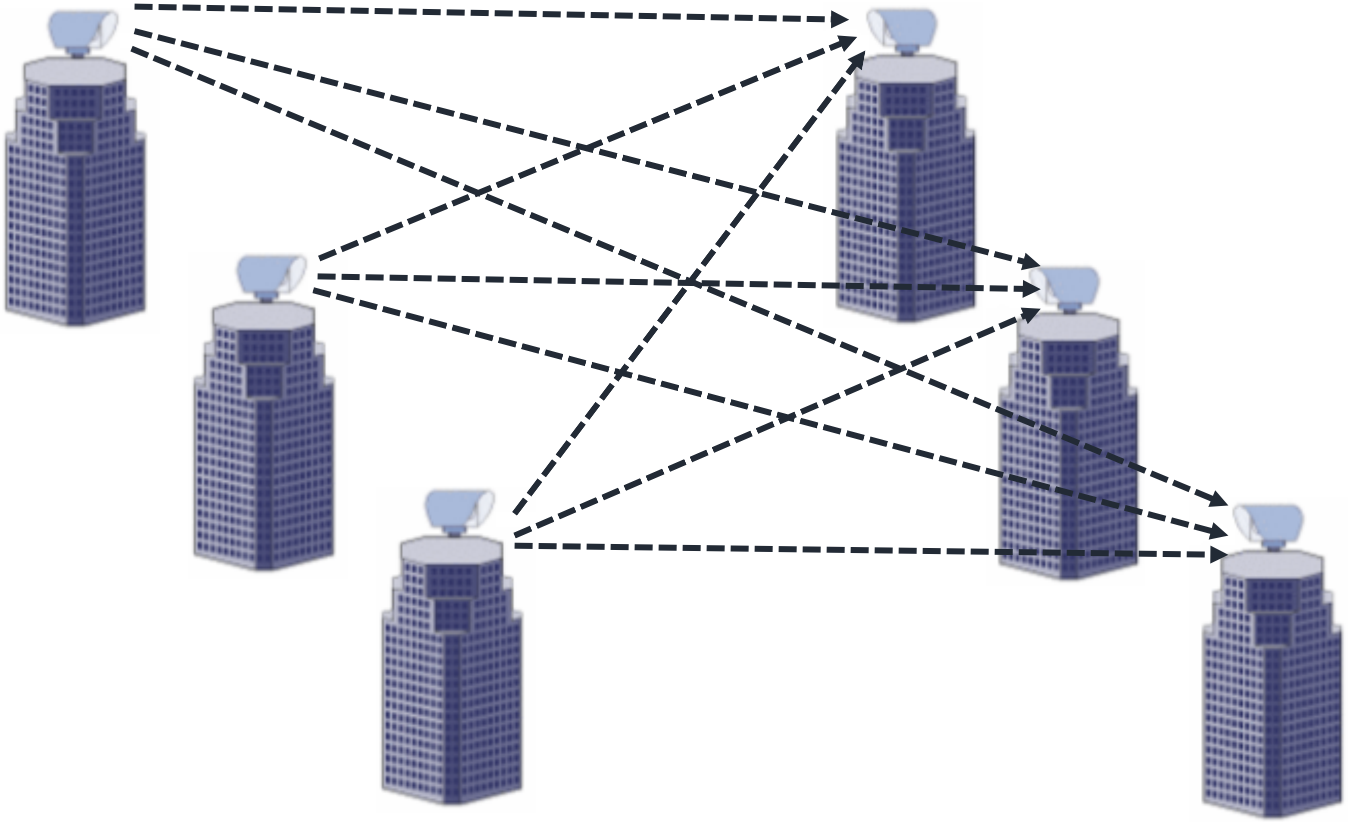
Outline

- ❑ **MOTIVATION**
- ❑ **BLIND SOURCE SEPARATION**
- ❑ **INDEPENDENT COMPONENT ANALYSIS**
  - ➢ FastICA ALGORITHM
- ❑ **1°SYSTEM SETUP**
  - ➢ NO TURBULENCE CASE
  - ➢ HIGH TURBULENCE CASE
- ❑ **2°SYSTEM SETUP**
  - ➢ NO TURBULENCE CASE
  - ➢ HIGH TURBULENCE CASE
- ❑ **PERFORMANCE ANALYSIS**

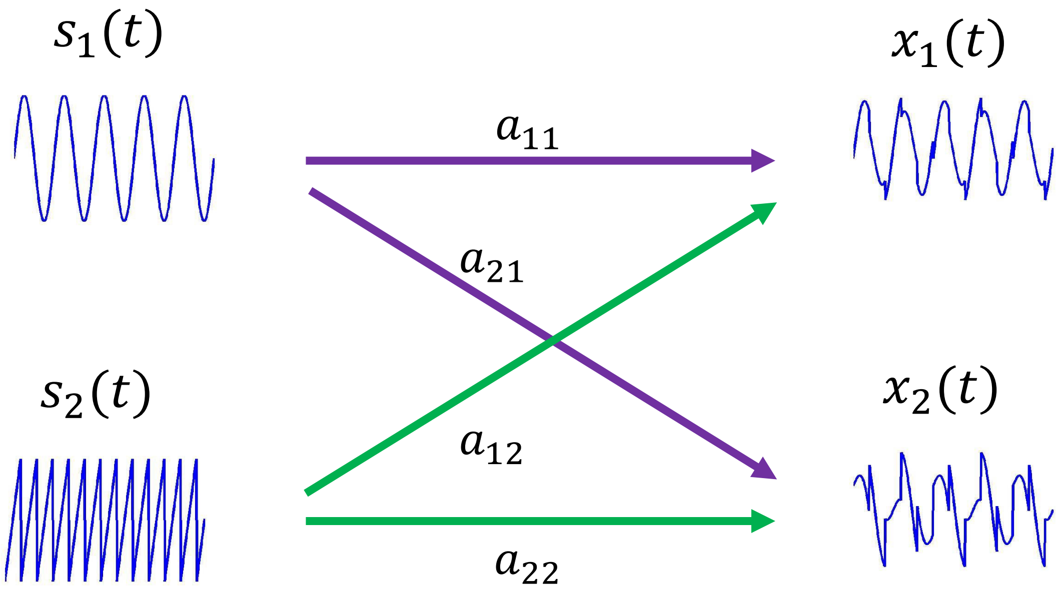
Motivation

FSO *point to point* topology → **FSO *multipoint* topology**





Blind Source Separation



$$\begin{cases} x_1(t) = a_{11}s_1(t) + a_{12}s_2(t) \\ x_2(t) = a_{21}s_1(t) + a_{22}s_2(t) \end{cases}$$

$$\boldsymbol{x} = \boldsymbol{A}\,\boldsymbol{s}$$

KNOWN MIXED SIGNALS ($\boldsymbol{x}$)

UNKNOWN SOURCE SIGNALS ($\boldsymbol{s}$)

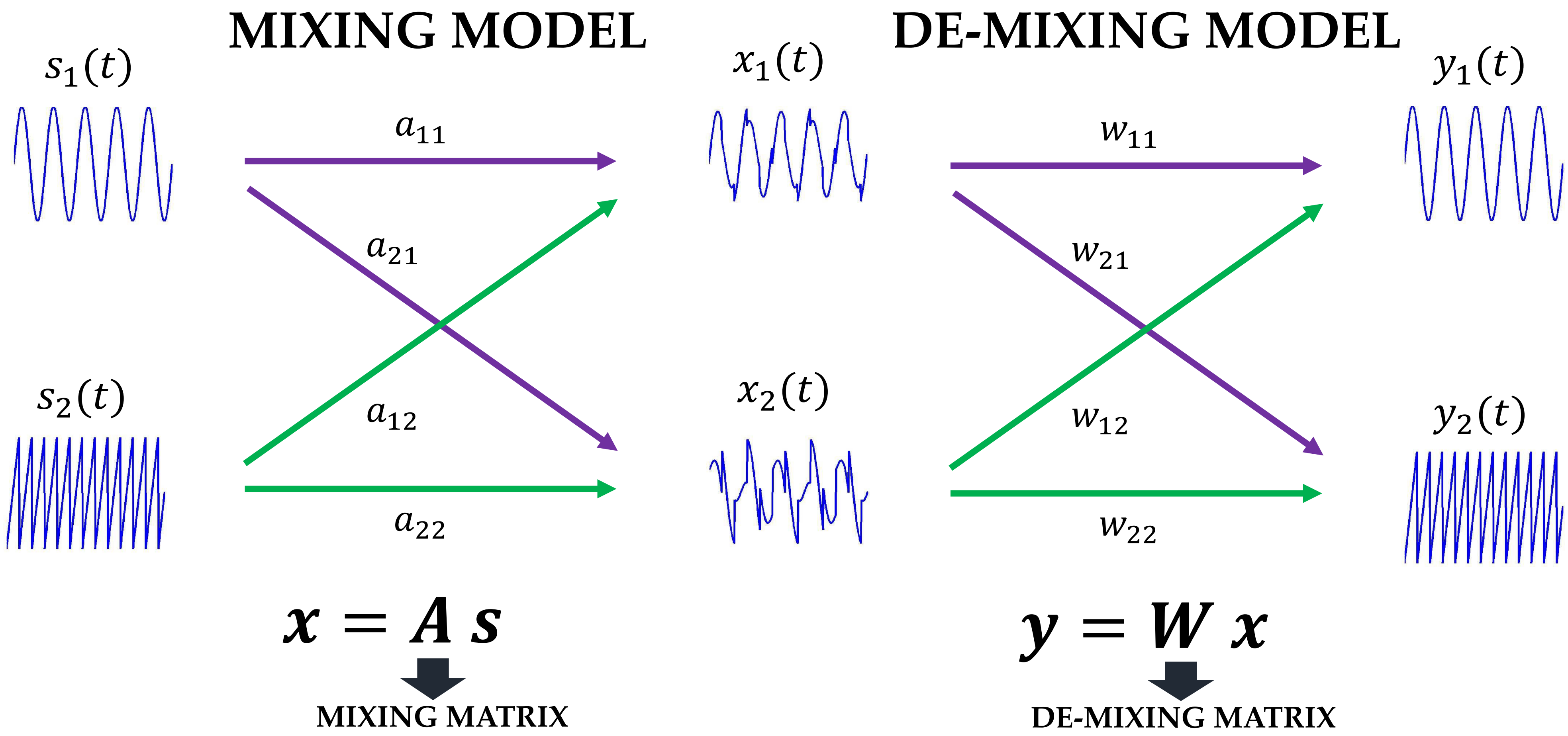
UNKNOWN MIXING MATRIX ($\boldsymbol{A}$)

We need to estimate source signals $\boldsymbol{s}$ from their observed mixtures $\boldsymbol{x}$ sans information about the mixing process and original signals.

BLIND SOURCE SEPARATION

Independent Component Analysis

ICA is the most used method for BSS and it aims to estimate the **DE-MIXING MATRIX**



Independent Component Analysis

ICA assumptions:

- Original sources s_i should be statistically independent
- At most one Gaussian distribution (not assumed to be known)
- Same number of transmitters and receivers (A is a square and non singular matrix)

ICA ambiguities:

$$x = \sum_i \left(\frac{1}{\alpha_i} a_i\right)(\alpha_i s_i)$$

- We cannot determine the order of the independent components
- We cannot determine the variance of the independent components:
  - Ambiguity of magnitude
  - Ambiguity of sign

FastICA algorithm

- The most used and high-performing algorithm is the **FastICA** algorithm
- This is a high order statistic (**HOS**) methods that wants to maximize the non-Gaussianity of the data
- A measure of non-Gaussianity used is the **NEGENTROPY:** $J(y) = H(y_{gauss}) - H(y)$ that is zero for Gaussian variables and non negative for non Gaussian variables.
- The following approximation of **NEGENTROPY** is used: $J(y) \propto \left(E\left(G(y)\right) - E\left(G(v)\right)\right)^2$ where G is a non quadratic function

ADVANTAGES OF THE ALGORITHM

- Fast convergence (cubic or at least quadratic)
- Valid for any non-Gaussian distribution (no estimation of the probability distribution is required)
- Robust and easy to use

FastICA algorithm

This is a ***two-step*** algorithm:

1. **Pre-processing:**

   ➢ **Centering:** $\boldsymbol{x}$ became a *zero-mean* variable and this implies $\boldsymbol{s}$ is *zero-mean* too

   ➢ **Whitening:** $\boldsymbol{x}$ is linearly transformed (EVD) in a new vector $\tilde{\boldsymbol{x}}$ that is *white* ($E\{\tilde{x}\tilde{x}^T\}=I$) and A is transformed in a new *orthogonal* matrix $\tilde{\mathbf{A}}$ ($\tilde{A}\tilde{A}^T = I$)

   Lower solution complexity from n^2 to $n(n-1)/2$ parameters should be estimated

2. **Algorithm:**

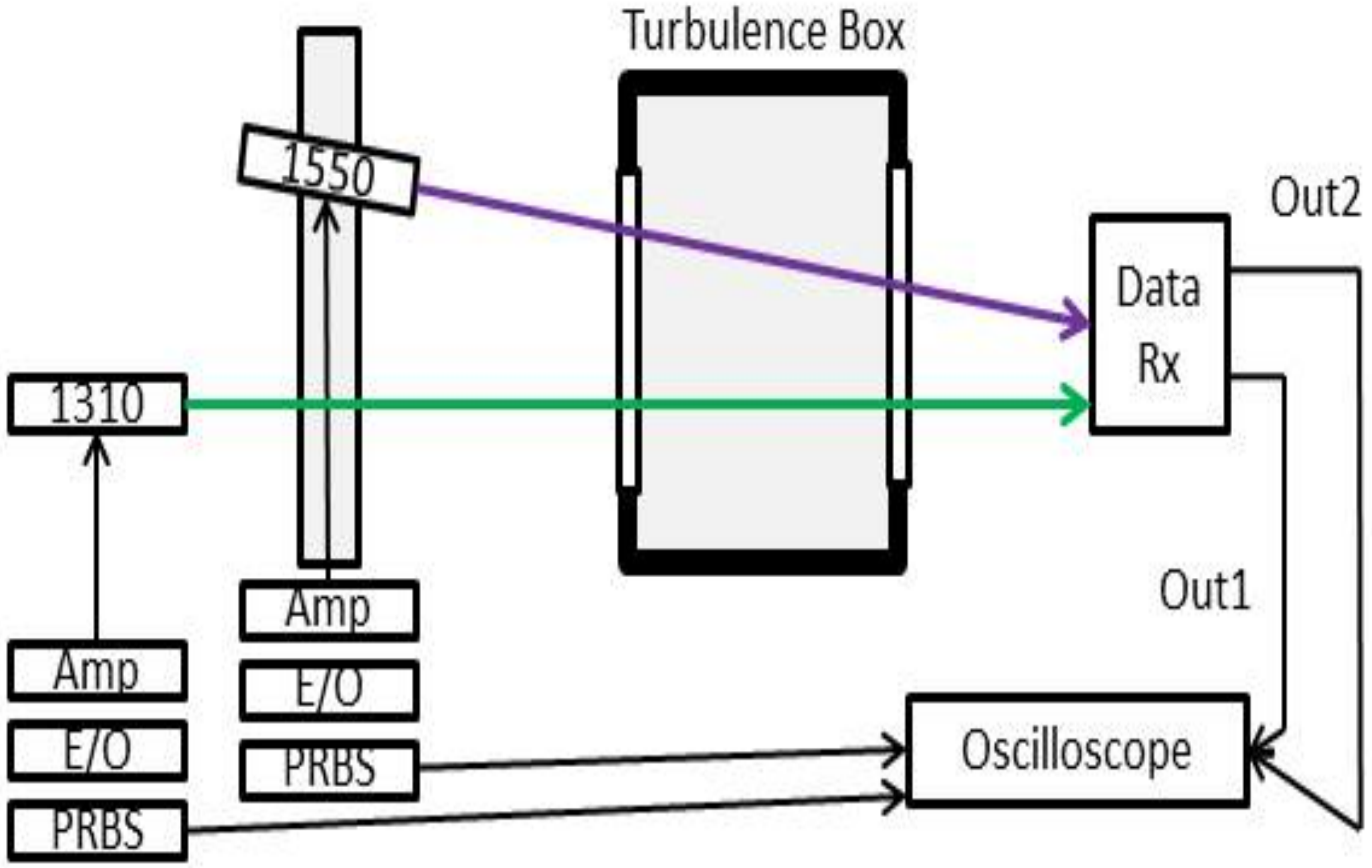
   ➢ The optimum $E\{G(w^T x)\}$ that maximizes $J(w^T x)$ is found using Lagrange:

   1) $\mathcal{L} = E\{xg(w^T x)\} + \lambda w$

   2) $\frac{d\mathcal{L}}{dw} = E\{xx^T g'(w^T x)\} + \lambda I = 0$

   3) $w = E\{xg(w^T x)\} - E\{g'(w^T x)\} w$ ➡ Iterate until convergence

1° System Setup



Tx_1 1310 nm (θ_{Tx1} =0°)

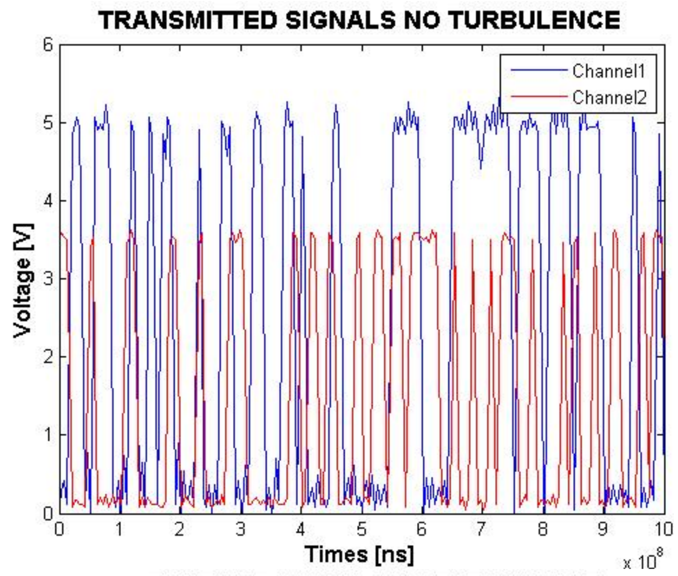
Tx_2 1550 nm (θ_{Tx2} =15°)

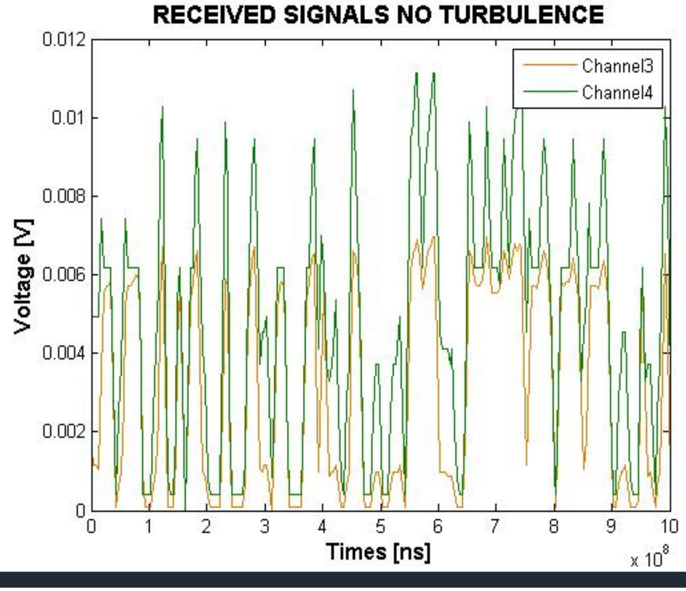
$$\begin{cases} Out_1 = a_{11}Tx_1 + a_{12}Tx_2 \\ Out_2 = a_{22}Tx_2 \end{cases}$$

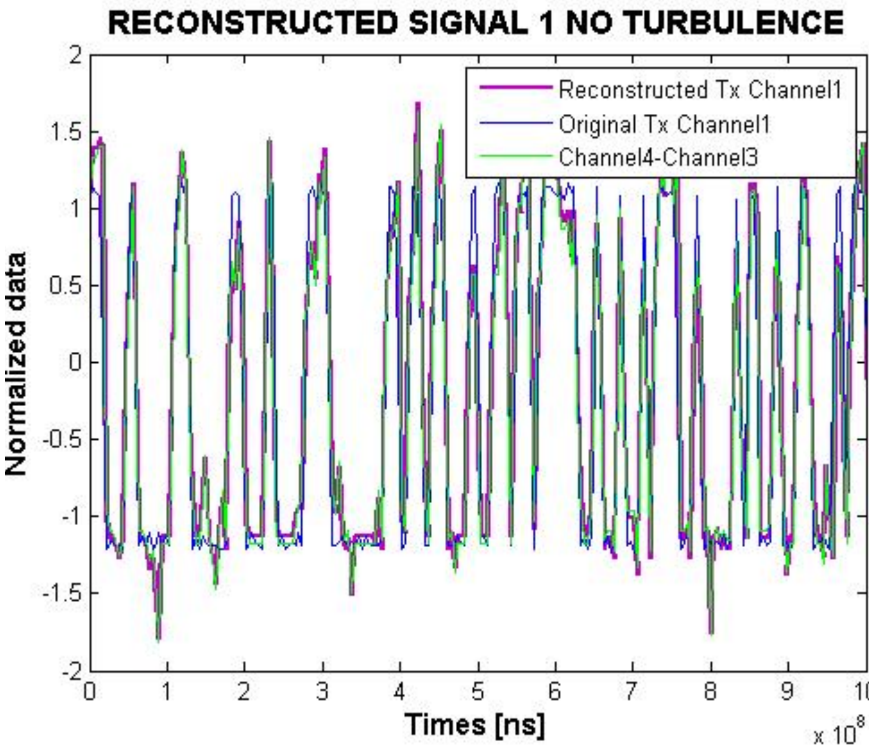
DIFFERENT LEVELS OF TURBULENCE:

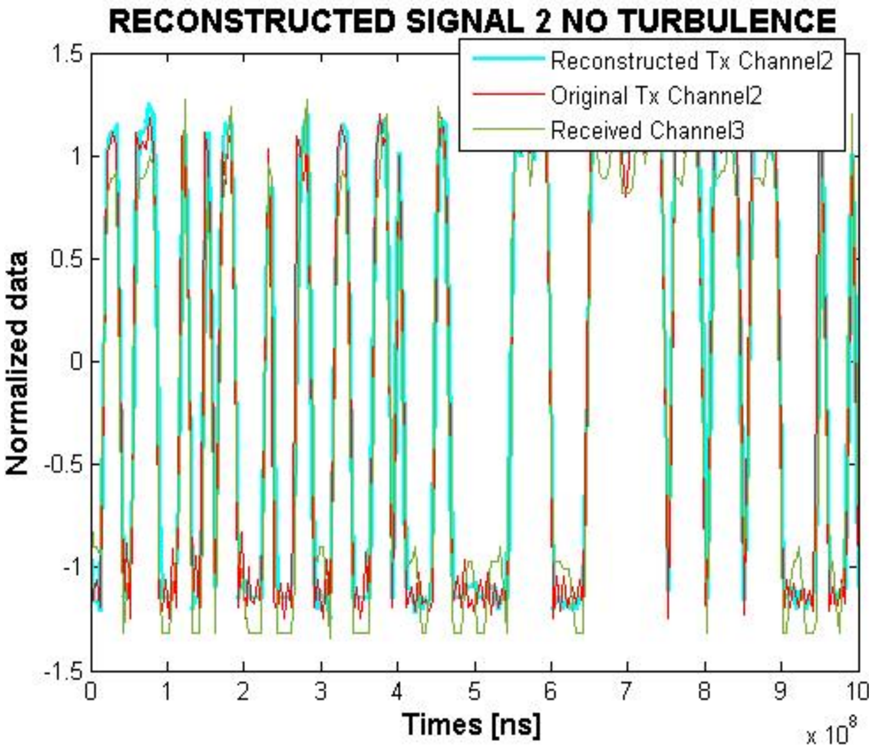
no turbulence, low, medium, high

No turbulence case

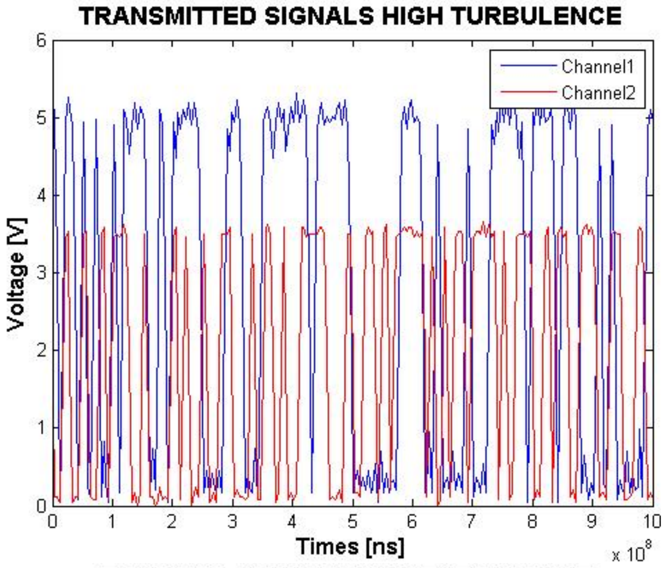


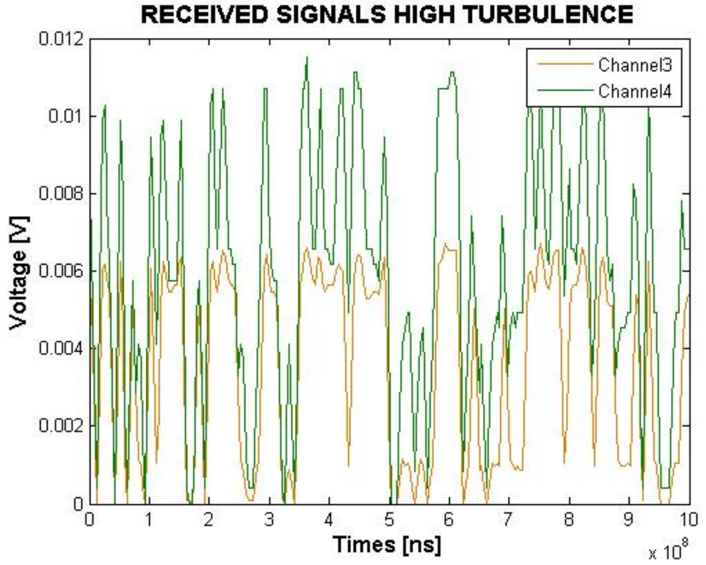


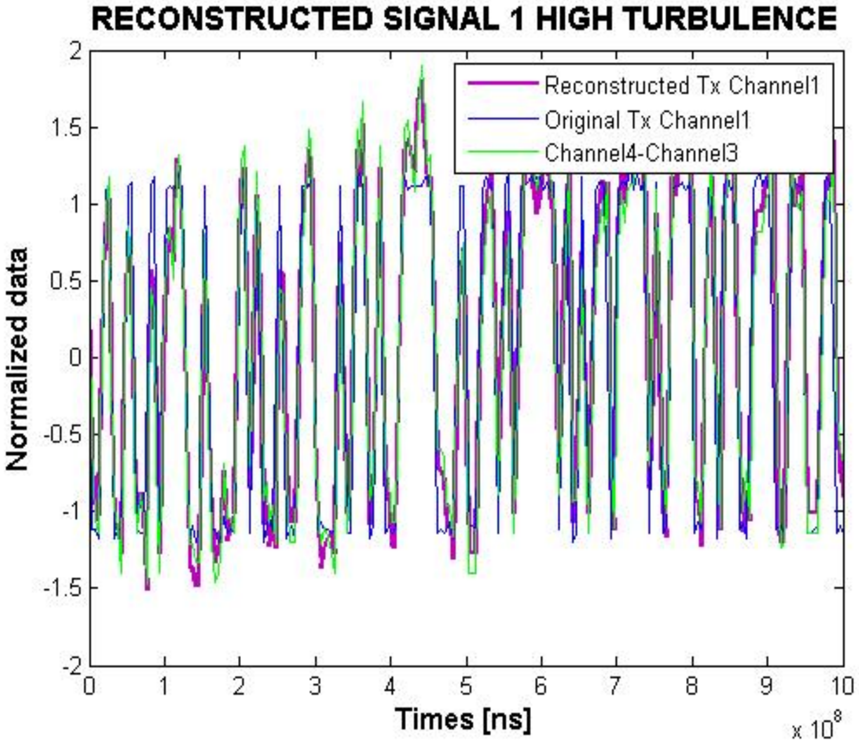


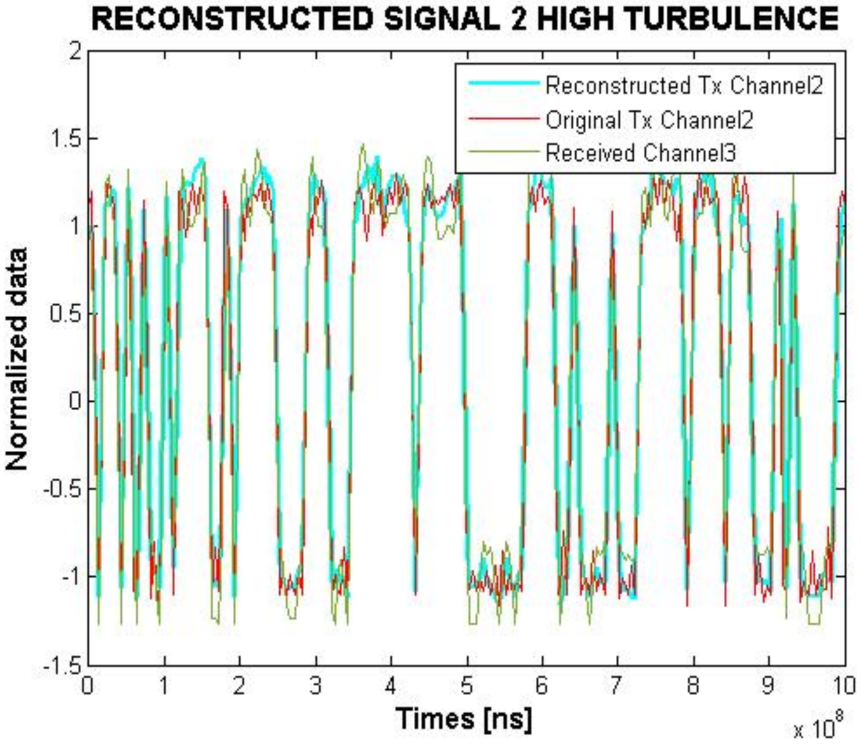


High turbulence case

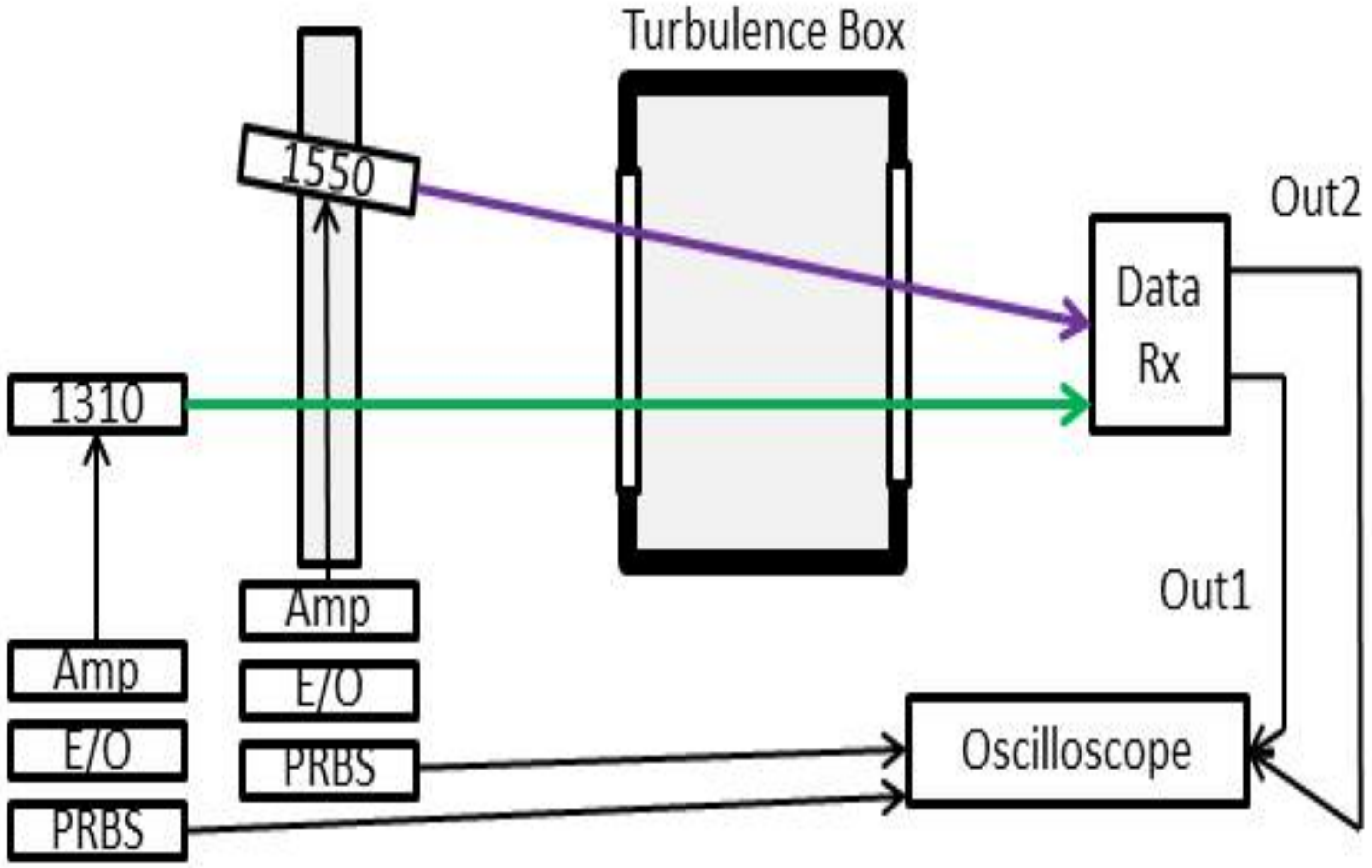








2° System Setup



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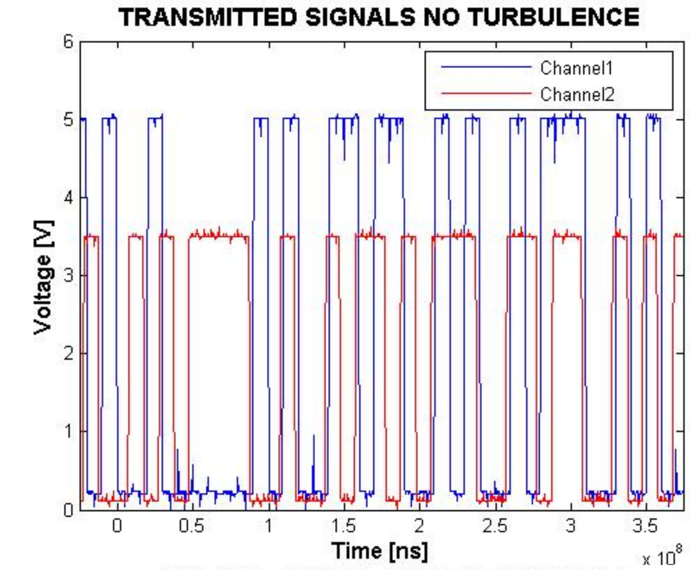
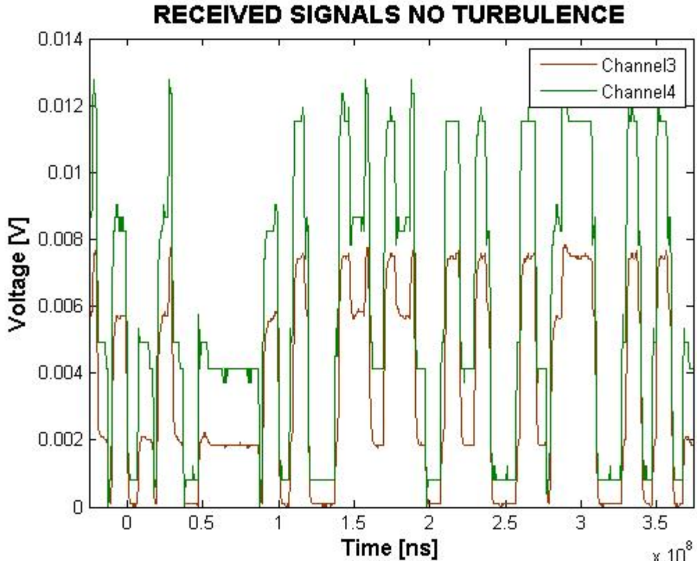
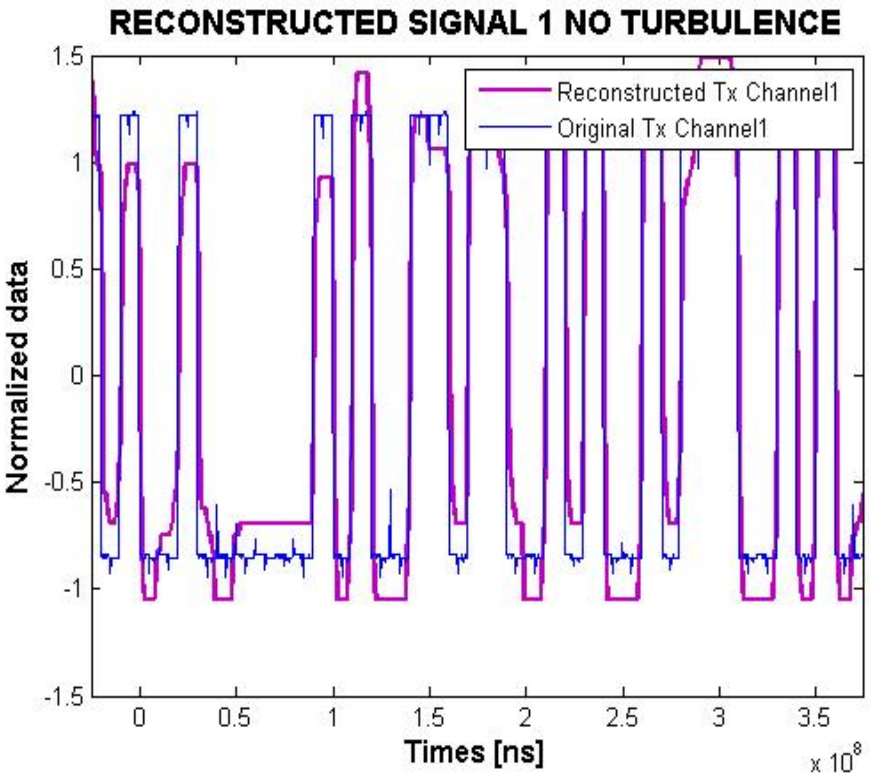
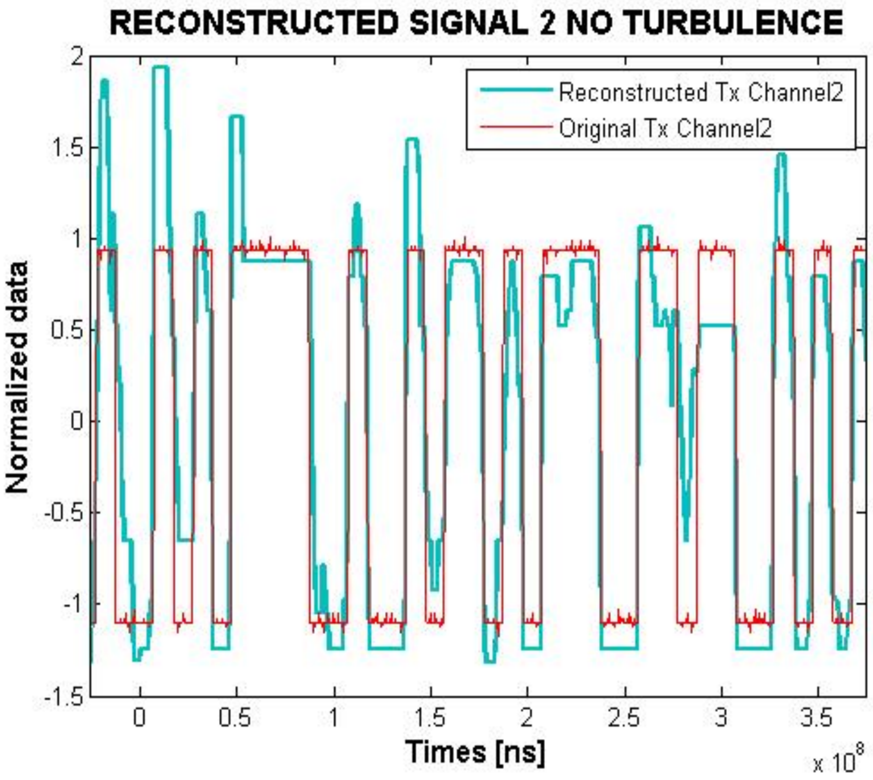
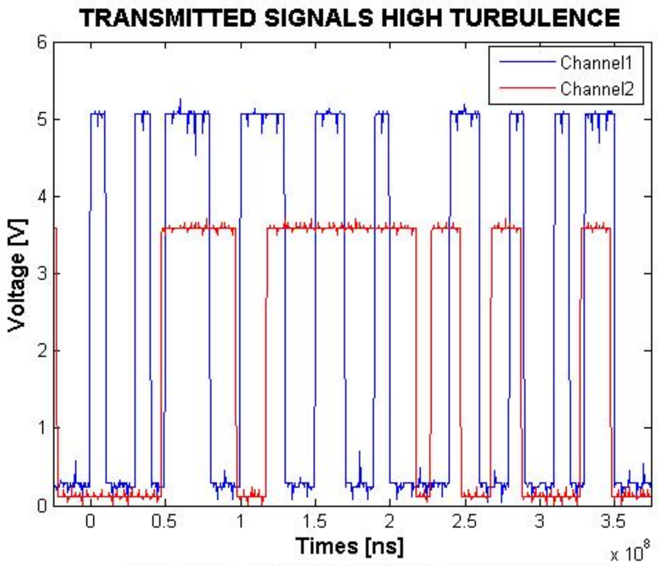


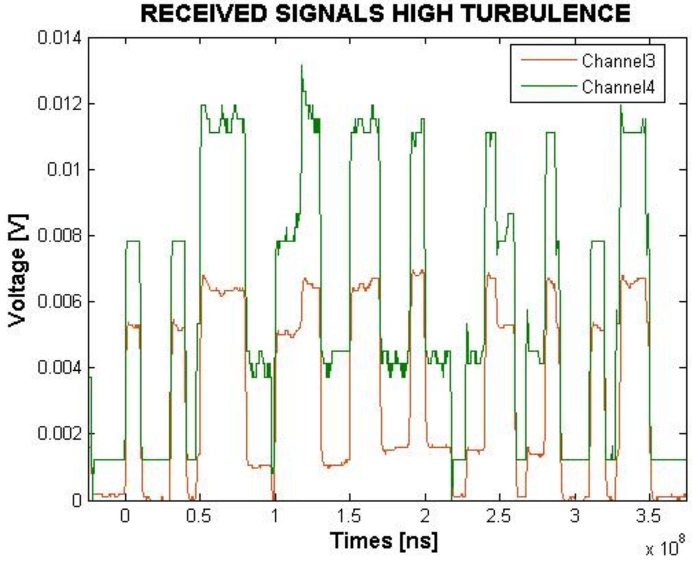


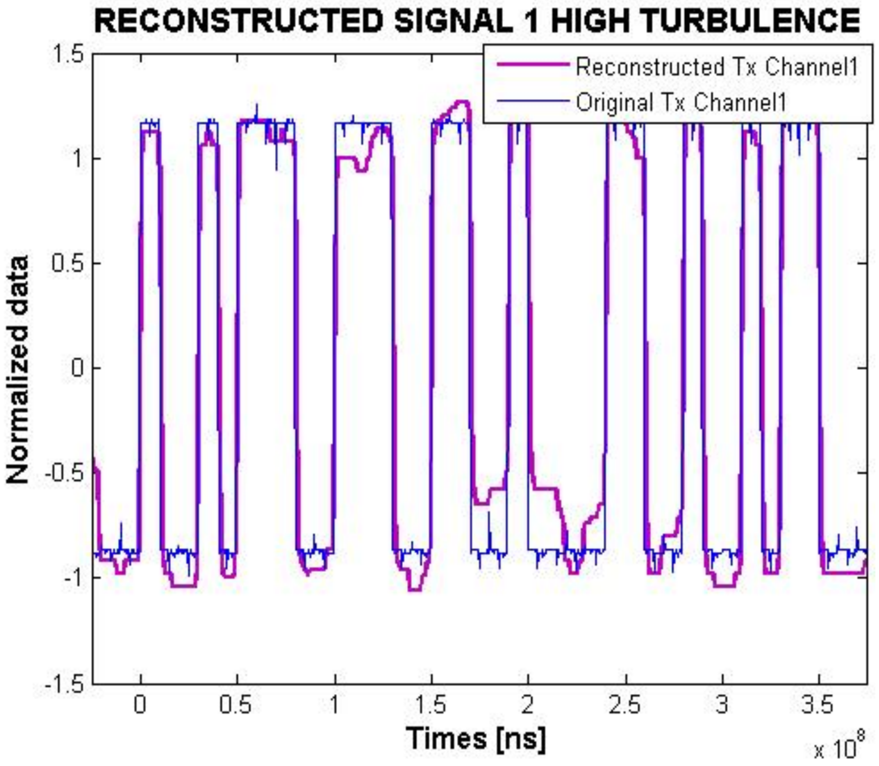


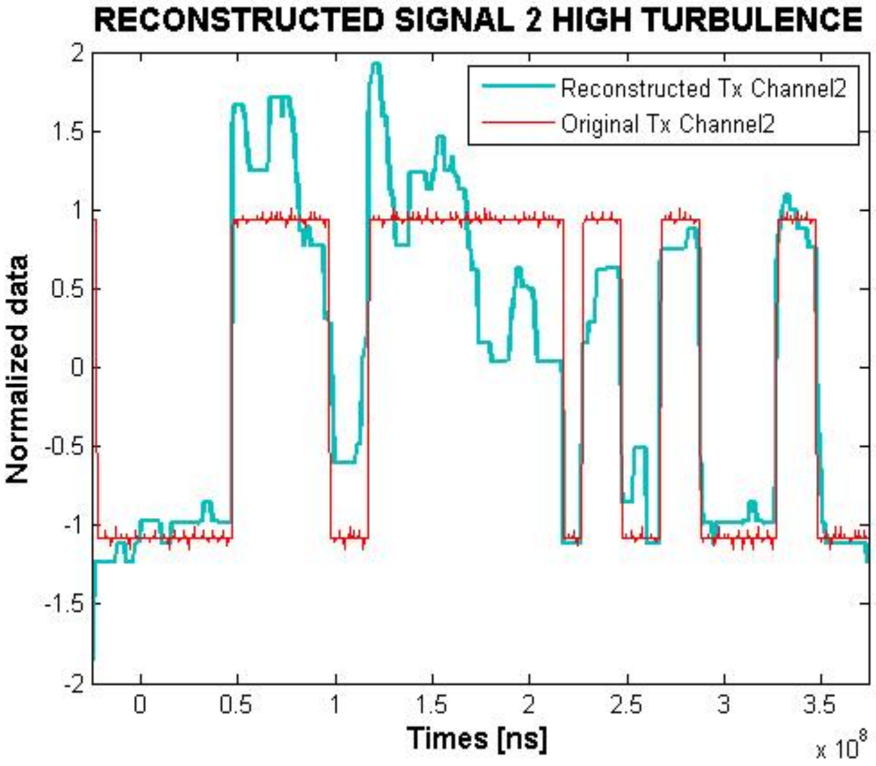


High turbulence case









Performance Analysis

PERFORMANCE INDEX ➔

$$PI = \sum_{i=1}^{N}\left(\frac{\sum_{k=1}^{N}|q_{ik}|^2}{\max_{p}\left[|q_{ip}|^2\right]}-1\right)+\sum_{k=1}^{N}\left(\frac{\sum_{i=1}^{N}|q_{ik}|^2}{\max_{p}\left[|q_{pk}|^2\right]}-1\right)$$

where $Q = WA$

In the Second System Setup the PI was evaluated:

NO TURBULENCE
PI=0.301

GOOD SEPARATION!!!

HIGH TURBULENCE
PI=1.834

ACCEPTABLE SEPARATION!!!

Thanks!!!