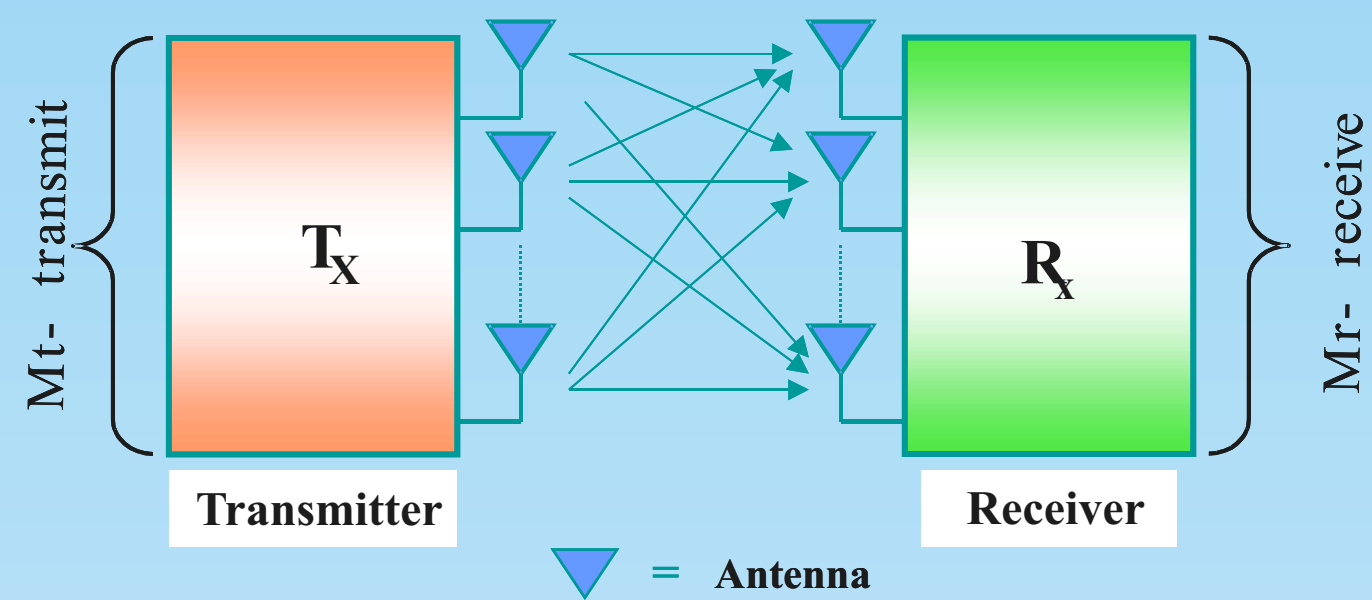


## Introduction

- **Multiple Input Multiple Output (MIMO) technique** benefits from the spatial diversity that can be obtained with the spatially separated antennas in a dense multipath scattering environment.
- **Orthogonal Frequency Division Multiplexing (OFDM)** is an attractive modulation scheme used in broadband wireless systems which encounter large delay spread.
- Thus, **MIMO-OFDM** is a very promising candidate for 4G broadband wireless communications
- However, similar to OFDM, **MIMO-OFDM** suffers severe performance degradation due to the presence of phase noise.

## Channel Model

A MIMO Communication System:



- Each channel is characterized by a Complex fading Coefficient
- $h_{ij}$  represents the channel between the  $i^{\text{th}}$  Receiver and  $j^{\text{th}}$  transmitter
- With OFDM/CP technique, we have a Flat Fading Channel Matrix  $H$



$$Y(k) = H(k)X(k) + N(k)$$

where

$$H(k) = \begin{bmatrix} H_{11}(k) & H_{12}(k) & \dots & H_{1M_T}(k) \\ H_{21}(k) & H_{22}(k) & \dots & H_{2M_T}(k) \\ \vdots & \vdots & \ddots & \vdots \\ H_{M_R1}(k) & H_{M_R2}(k) & \dots & H_{M_R M_T}(k) \end{bmatrix}$$

## Coding Scheme

In MIMO-OFDM, one can use different kinds of coding schemes:

- SFBC (Space Frequency Block Coding)
- STBC (Space Time Block Coding)
- STTC (Space Time Trellis Coding)
- Spatial Multiplexing

We concentrate on SFBC as an example and for simplicity, we assume 2 transmit antennas and  $M_R$  receive antennas. Hence the transmitted OFDM symbols can be written as:

$$X_1 = [X(0), X^*(1), \dots, X(N-2), X^*(N-1)]^T$$

$$X_2 = [X(1), X^*(0), \dots, X(N-1), X^*(N-2)]^T$$

## System Model with Phase Noise

The term phase noise is widely used for describing short term random frequency fluctuations of a signal. It is caused by both transmitter and receiver oscillators and can be described as a continuous Brownian motion process. Since phase noise is multiplicative, the time domain multiplication between received signal and phase noise turns into convolution in frequency domain.

Hence the system model with phase noise is modified as:

$$Y(k) = H(k)X(k)C(0) + \underbrace{\sum_{n=0, n \neq k}^{N-1} H(n)X(n)C(k-n)}_{ICI(k)} + N(k)$$

Note that phase noise contributes to:

- Common Phase Error (CPE), indicated by  $C(0)$ , which causes the rotation of the desired signals;
- Intercarrier Interference (ICI), indicated by the term  $ICI(k)$ , which causes interference on the desired signals.

## MMSE-based CPE Estimator

$$Y = SC(0) + N$$

$$\begin{bmatrix} Y(k_1) \\ Y(k_2) \\ \vdots \\ Y(k_{N_p}) \end{bmatrix} = \begin{bmatrix} S(k_1) \\ S(k_2) \\ \vdots \\ S(k_{N_p}) \end{bmatrix} C(0) + \begin{bmatrix} N(k_1) \\ N(k_2) \\ \vdots \\ N(k_{N_p}) \end{bmatrix}$$

where

$$S(k_i) = \begin{bmatrix} H(k_i)X(k_i) \\ \vdots \\ H(k_i)X(k_i) \end{bmatrix}, \quad N(k_i) = \begin{bmatrix} N(k_i) \\ \vdots \\ N(k_i) \end{bmatrix}$$

The MMSE-based cost function for CPE estimation is minimized by finding an appropriate coefficient vector  $W$ :

$$W = (S^H S + \frac{1}{E_C} I_{M_R N_p})^{-1} S^H Y$$

Which give rise to the MMSE estimate of CPE:

$$\tilde{C}(0) = W^H Y = S^H (S^H S + \frac{1}{E_C} I_{M_R N_p})^{-1} Y$$

## Residual MMSE After Estimation

Residual MMSE estimation can be expressed as a function of parameters, such as the **number of antennas**, **signal to noise ratio (SNR)**, **the number of pilots**, **subcarrier number**, **variance of phase noise**, **CPE energy**, etc. Since MMSE depicts the effectiveness of noise mitigation, this expression can be used in the design of the system to satisfy given requirements.

This can be shown to give:

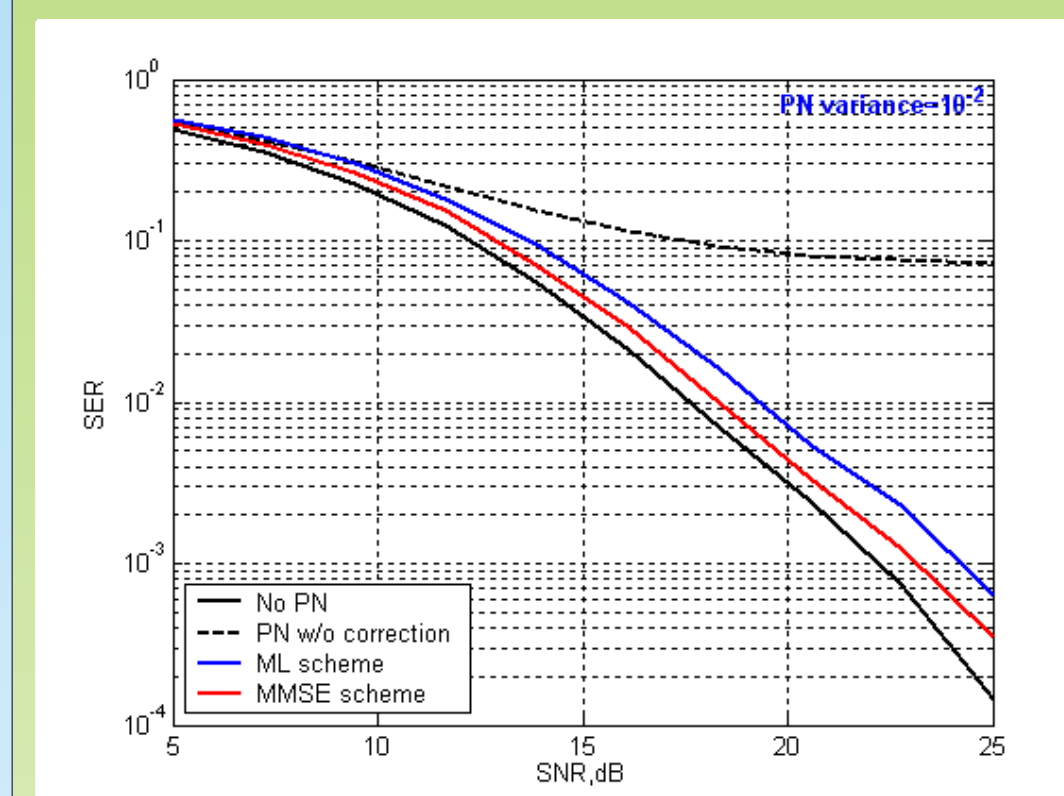
$$MMSE = E \left| C(0) - \tilde{C}(0) \right|^2$$

$$= E_C^{-1} S^H (S^H S + \frac{1}{E_C} I_{M_R N_p})^{-1} S$$

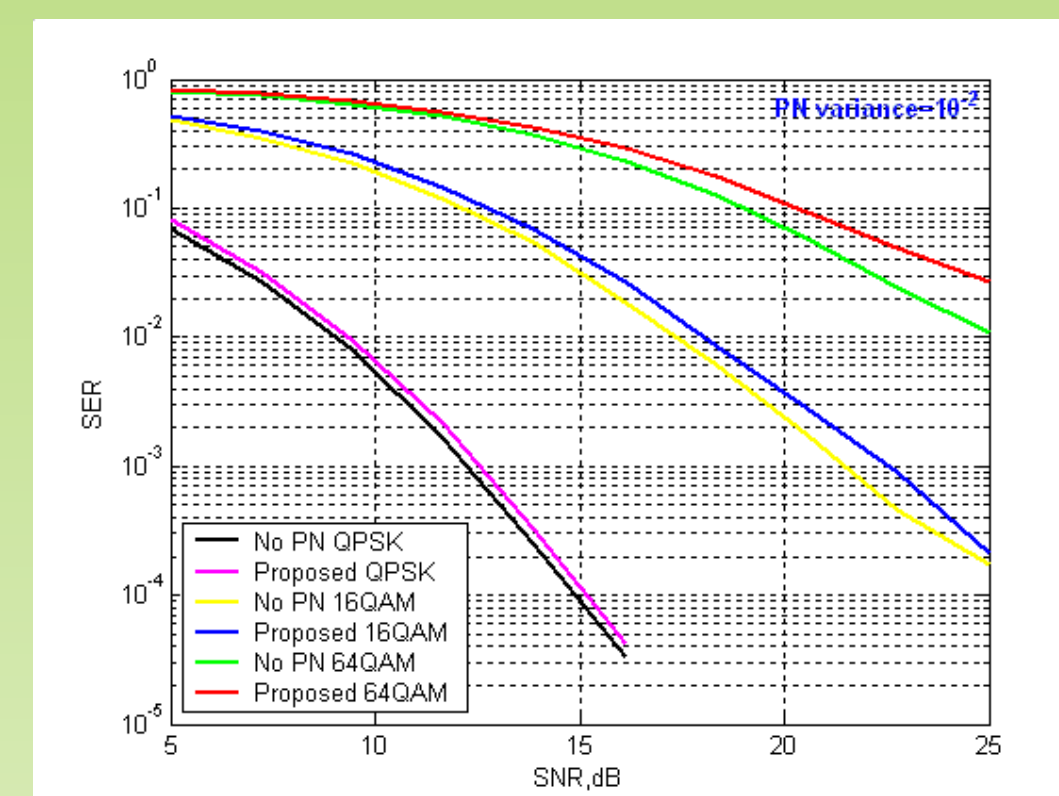
$$= E_C^{-1} \frac{E_C E(S^H S)}{M_T N_p^2 E_X + \frac{1}{SNR}}$$

$$= \frac{E_C}{6} \frac{E_C M_T M_R N_p}{M_T N_p^2 + \frac{1}{SNR}}$$

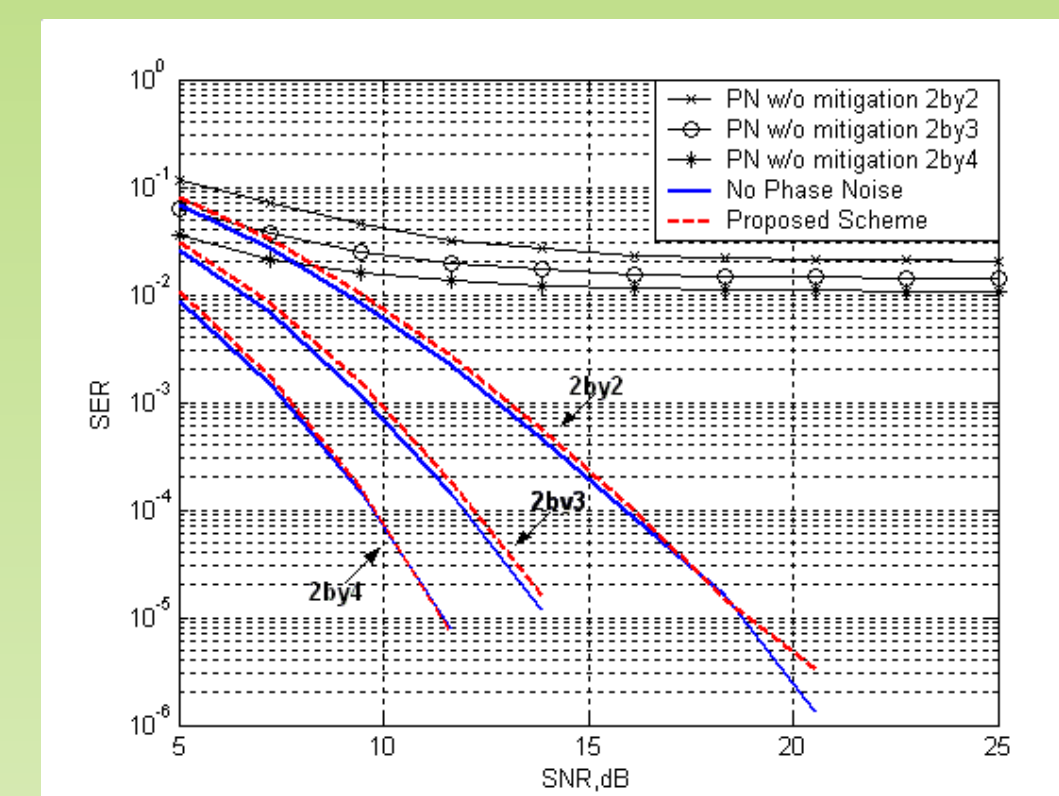
## Simulation Results



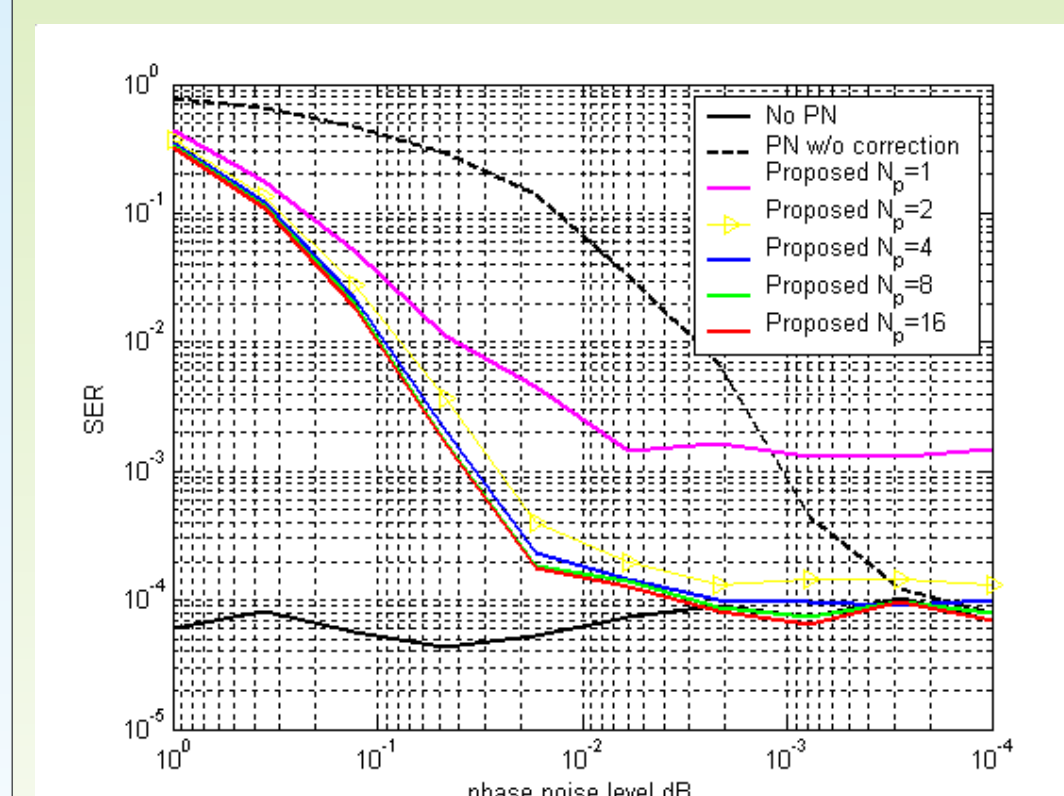
SER Performance for 16QAM with Different Phase Noise Mitigation Schemes (2x2 antennas with 4 pilots)



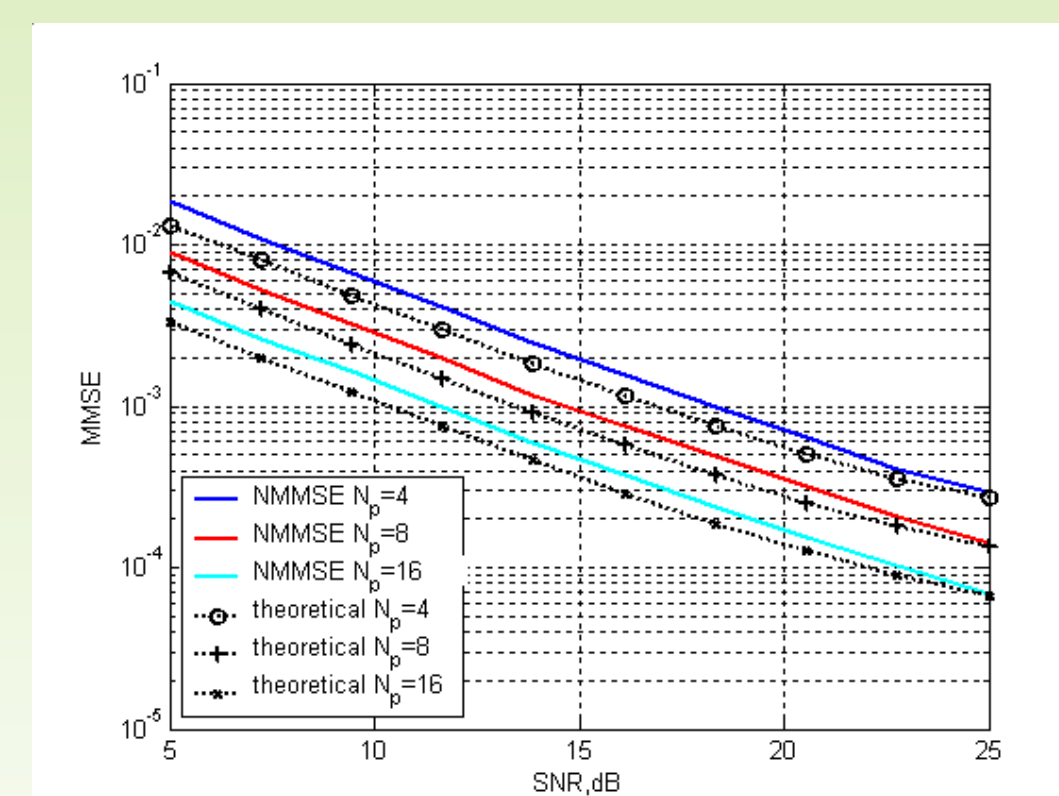
SER Performance for Different Modulation Schemes (2x2 antennas with 4 pilots)



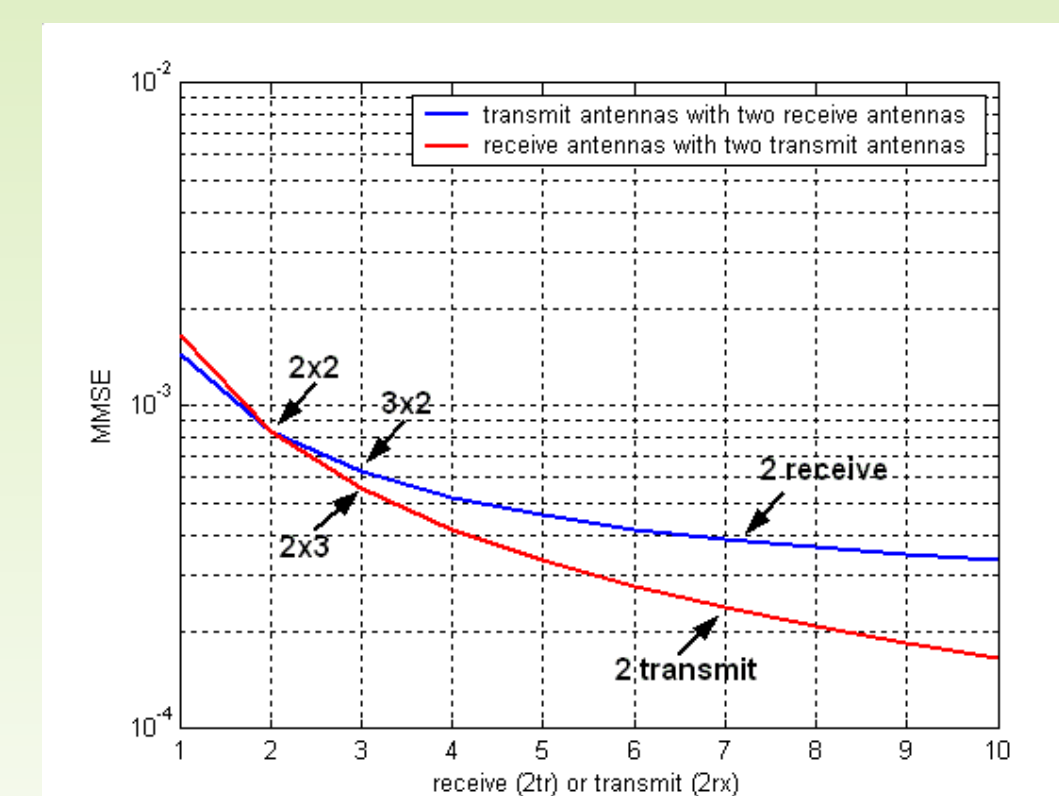
SER Performance for QPSK with different Antenna Deployments (Multiple antennas with 4 pilots)



SER Performance for Different Phase Noise Levels (2 transmit and 2 receive antennas)



Effect of pilot number Theoretical VS. Numerical results of MMSE (2 transmit and 3 receive antennas)



MMSE for Different Antenna Deployments (Multiple antennas)

## Conclusions

- Phase noise causes severe performance degradation of MIMO-OFDM systems. Although several methods have been developed in the literature to mitigate phase noise for single antenna, none except for a recently proposed **ML** approach is applied in MIMO scenario.
- We proposed a **generalized MMSE-based phase noise mitigation scheme for any  $M_T$  by  $M_R$  MIMO-OFDM systems**. The scheme depicts better performance than what was obtained with **ML**-based mitigation scheme, and shows robustness to common modulation methods and SNR levels. Since the result is independent to coding scheme, it can be used in various applications, such as **BLAST** and **space time coding**.
- Furthermore, we also provide an **exact form of the estimation error (MMSE) of the CPE**, which helps in the selection of various key parameters of MIMO-OFDM system under specific requirement with phase noise.

## Future Work

- **Multuser phase noise mitigation in V-BLAST system.**
- **Phase noise impact for MIMO-OFDM cross layer design.**
- **Complexity Reduction for phase noise mitigation scheme.**
- **Comparison between different phase noise models.**