System Identification in the cERL LLRF system

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Main Content

- System Identification
- Models Analysis
  I. Black Model and White Model (Grey Model)
  II. Model comparison (Model output vs. Meas.)
- Model-based Application
  I. Improved FF / FB
- Summary and future plan

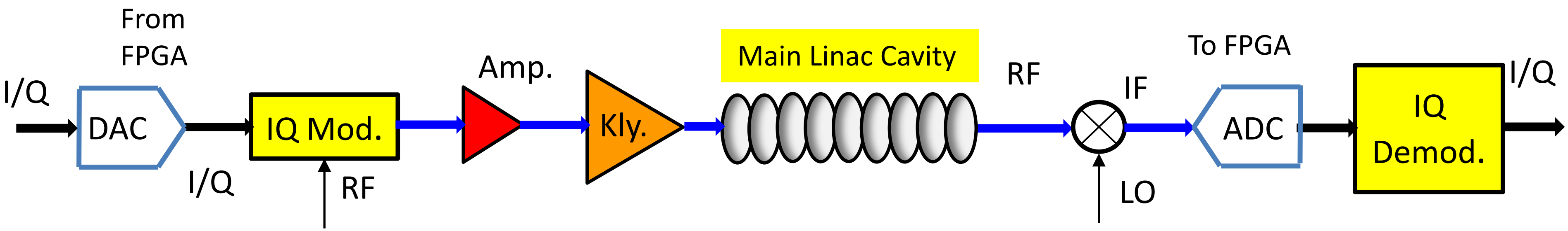
System Identification

- Why we need the model of the system?

I. Understand the system well (Loaded Q, Phase calibration, Loop Gain, mathematic model, etl.)

II. For some more complex application (Adaptive feed forward, MIMO controller, etl.)

- How to "know" the model of the system? (System Identification)



It is either difficult and time-consuming to analyze every component of the RF system

System Identification

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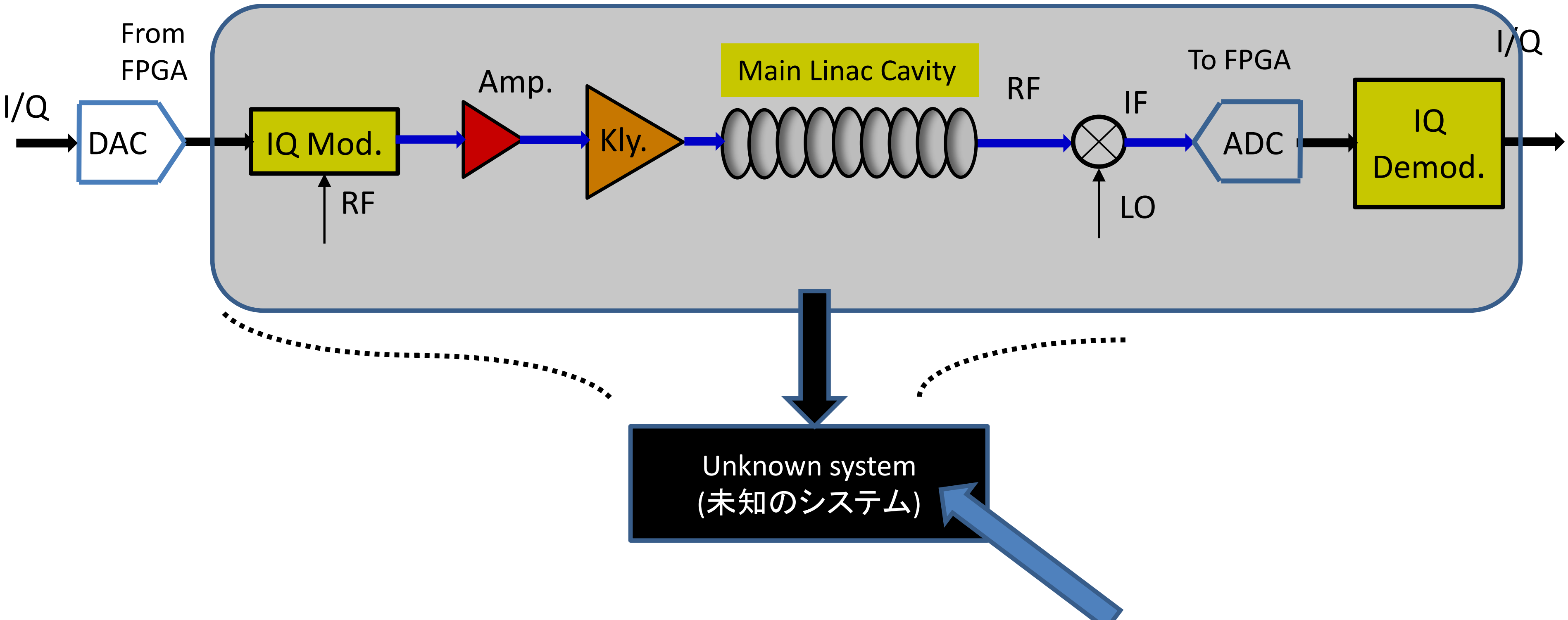
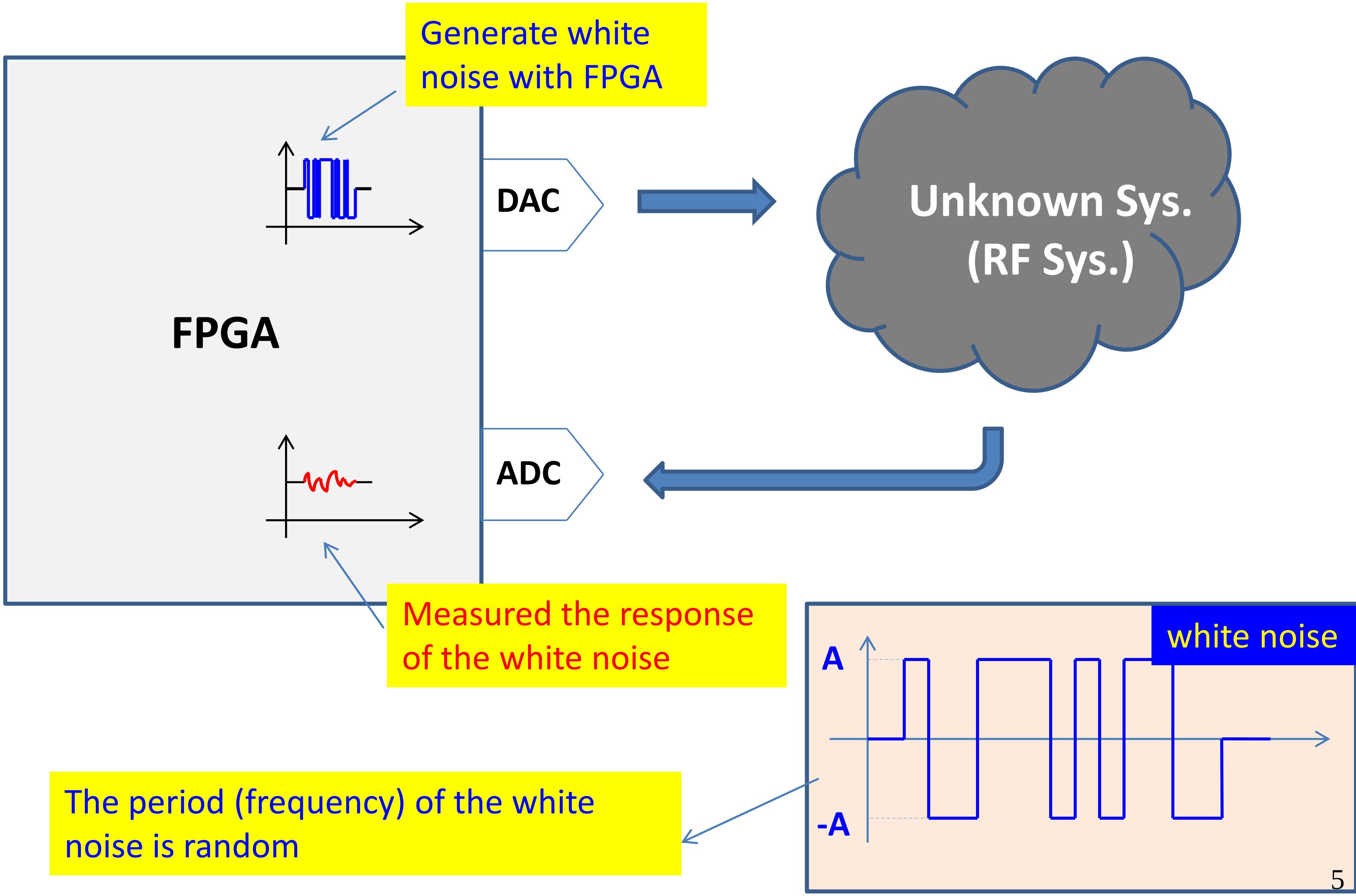


Identify the unknown system by modern system identification

System Identification

- Input white noise in the DAC output and read the response from the ADC?



System Identification

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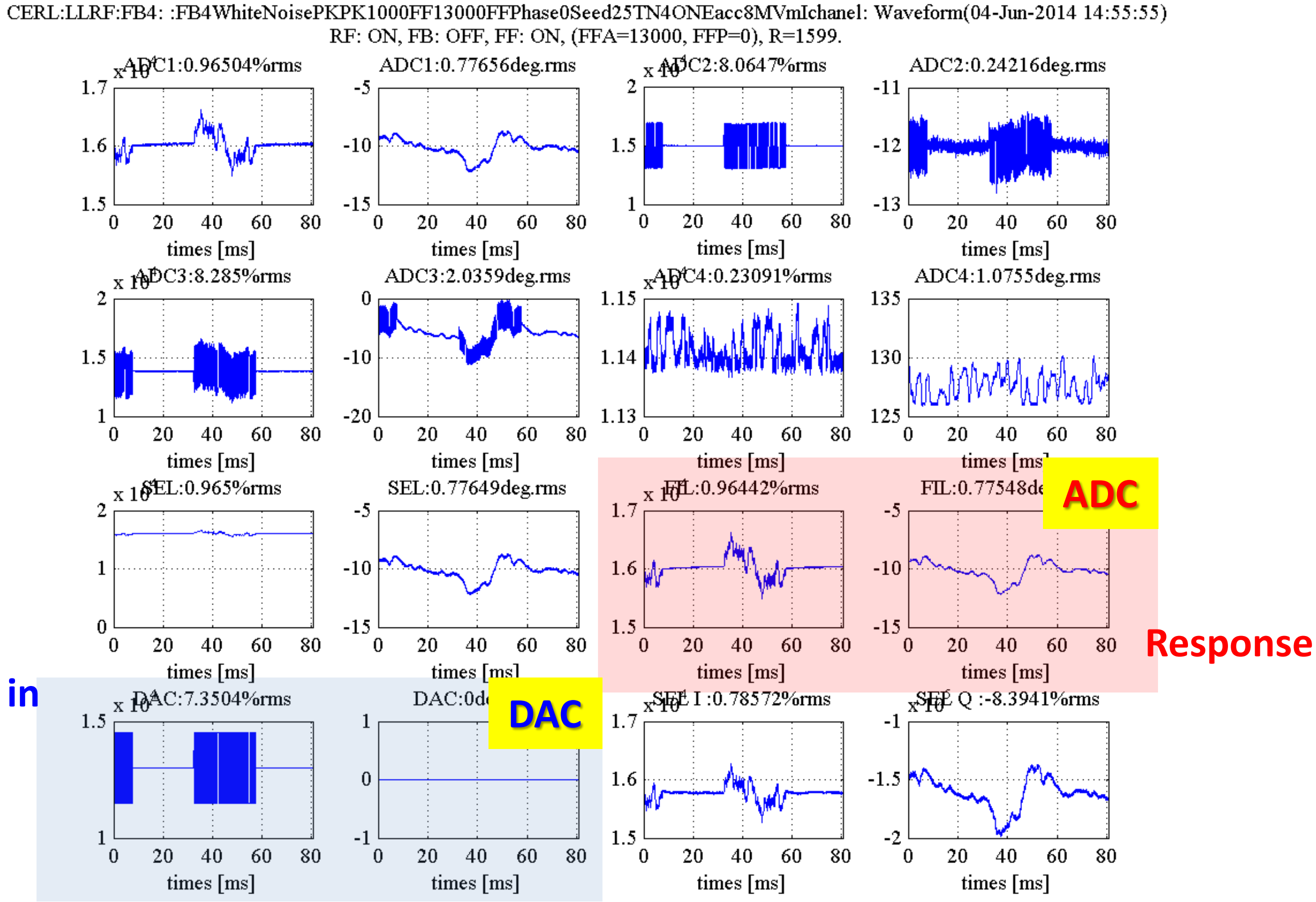

System Identification

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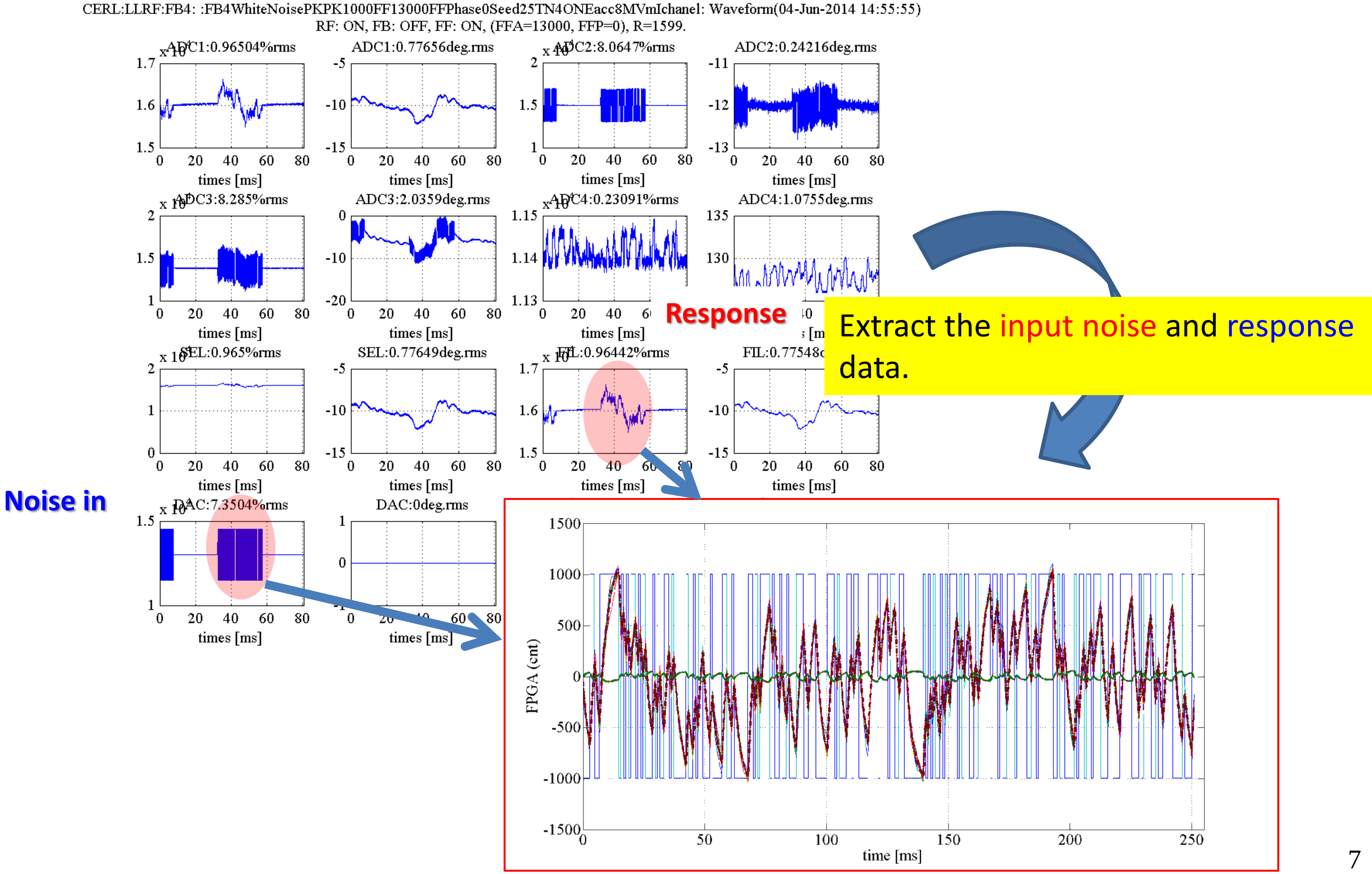
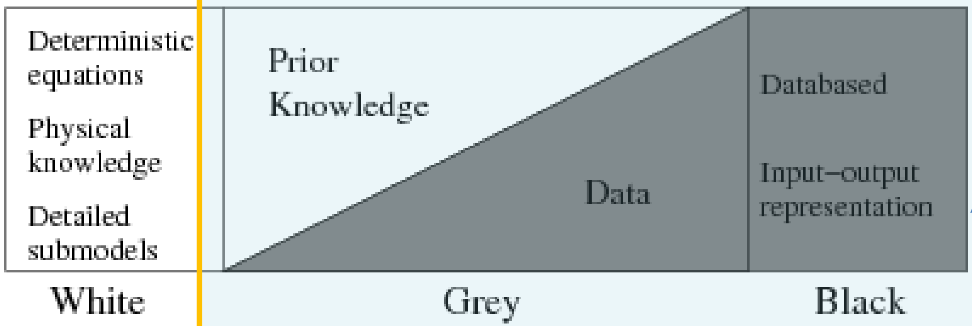


Model choice



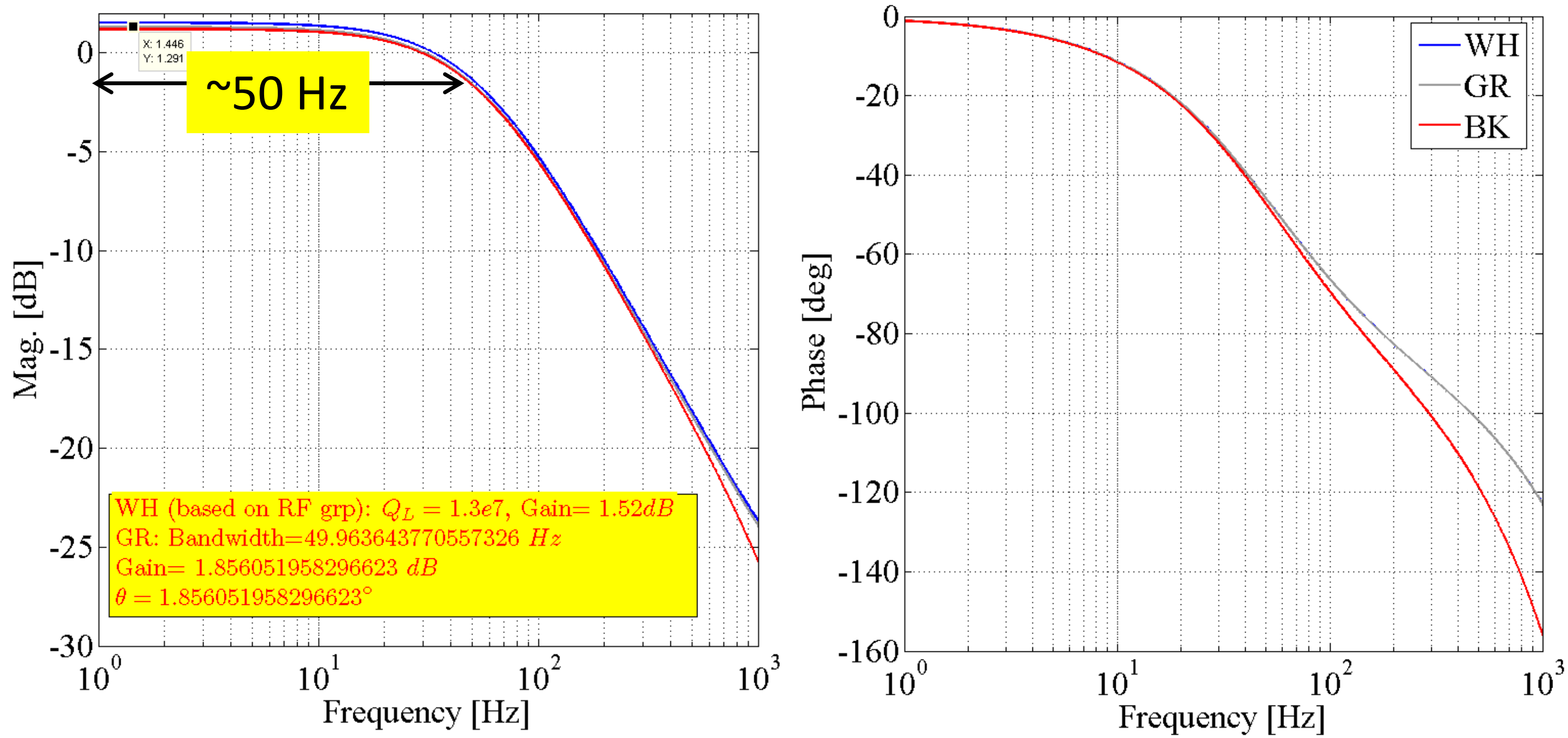
System ID can do

Type	Advantages	Disadvantages
White	I. Know the system in detail	I. Complexity Model II. Need prior knowledge about the system in detail
Black	I. Easy to identify II. Do not need priory information	I. Non-physical
Grey	I. The structure of the system can be identified	I. Still require some prior knowledge

Data-based

Model Comparison

- The comparison of different models



$$WH: Loaded\ Q\ (Q_L), Loop\ Gain\ (G), Loop\ Delay, Loop\ Phase, Klystron\ nonlinear, etl$$

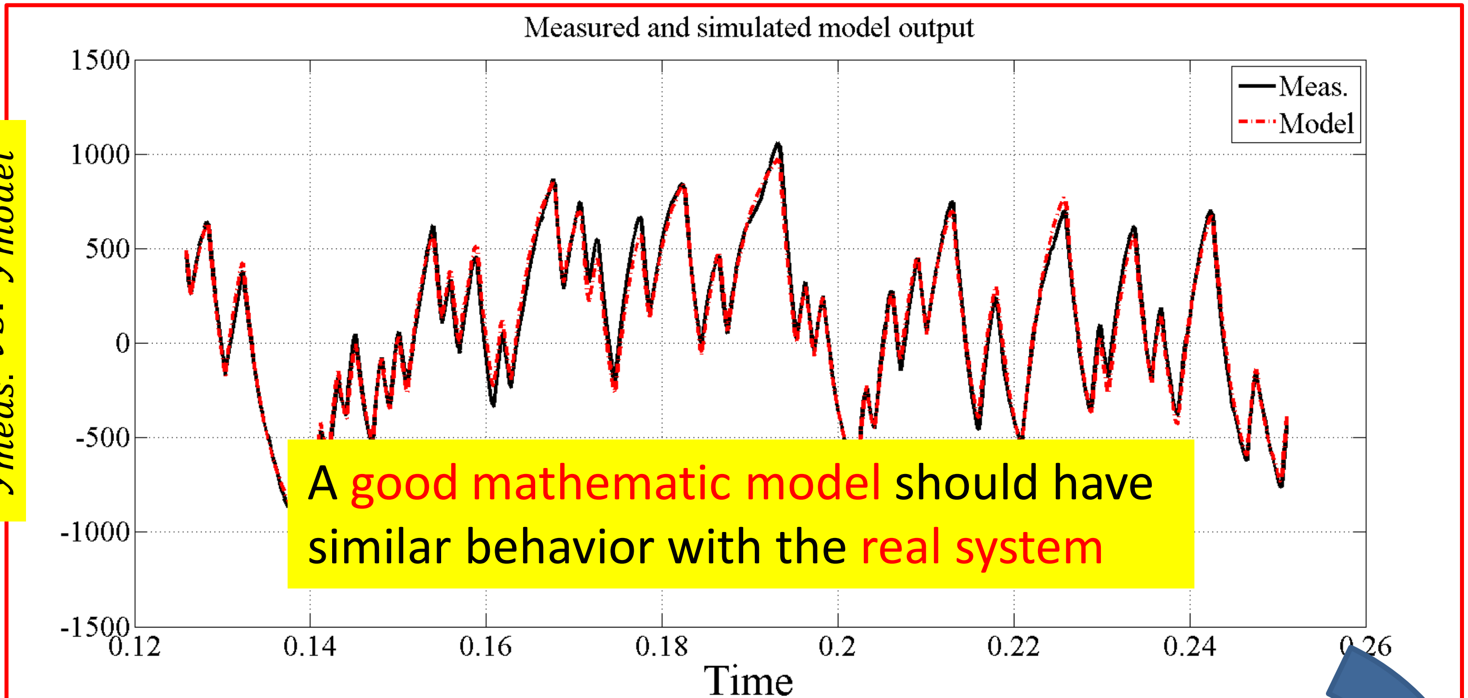
$$GR: \begin{pmatrix} y_I(n) \\ y_Q(n) \end{pmatrix} = \begin{pmatrix} 1 - T\omega_{0.5} & -T\Delta\omega \\ T\Delta\omega & 1 - T\omega_{0.5} \end{pmatrix} \begin{pmatrix} y_I(n-1) \\ y_Q(n-1) \end{pmatrix} + G \begin{pmatrix} cos\alpha & -sin\alpha \\ sin\alpha & cos\alpha \end{pmatrix} \begin{pmatrix} u_I(n-1) \\ u_Q(n-1) \end{pmatrix}$$

$$BK: H_{11}(z) = \frac{Y_{11}(z)}{X_{11}(z)} = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}}$$

Performance comparison

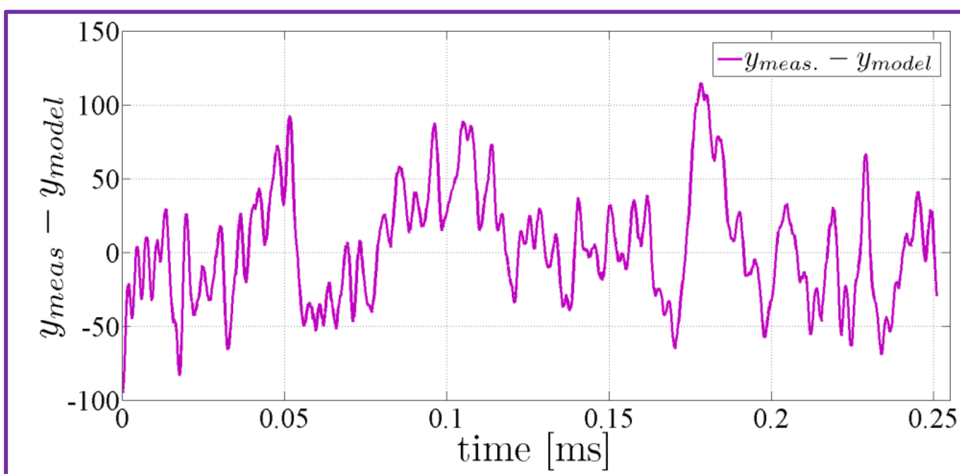
- How to evaluate the identified models?

$y_{meas.}$ *vs.* y_{model}



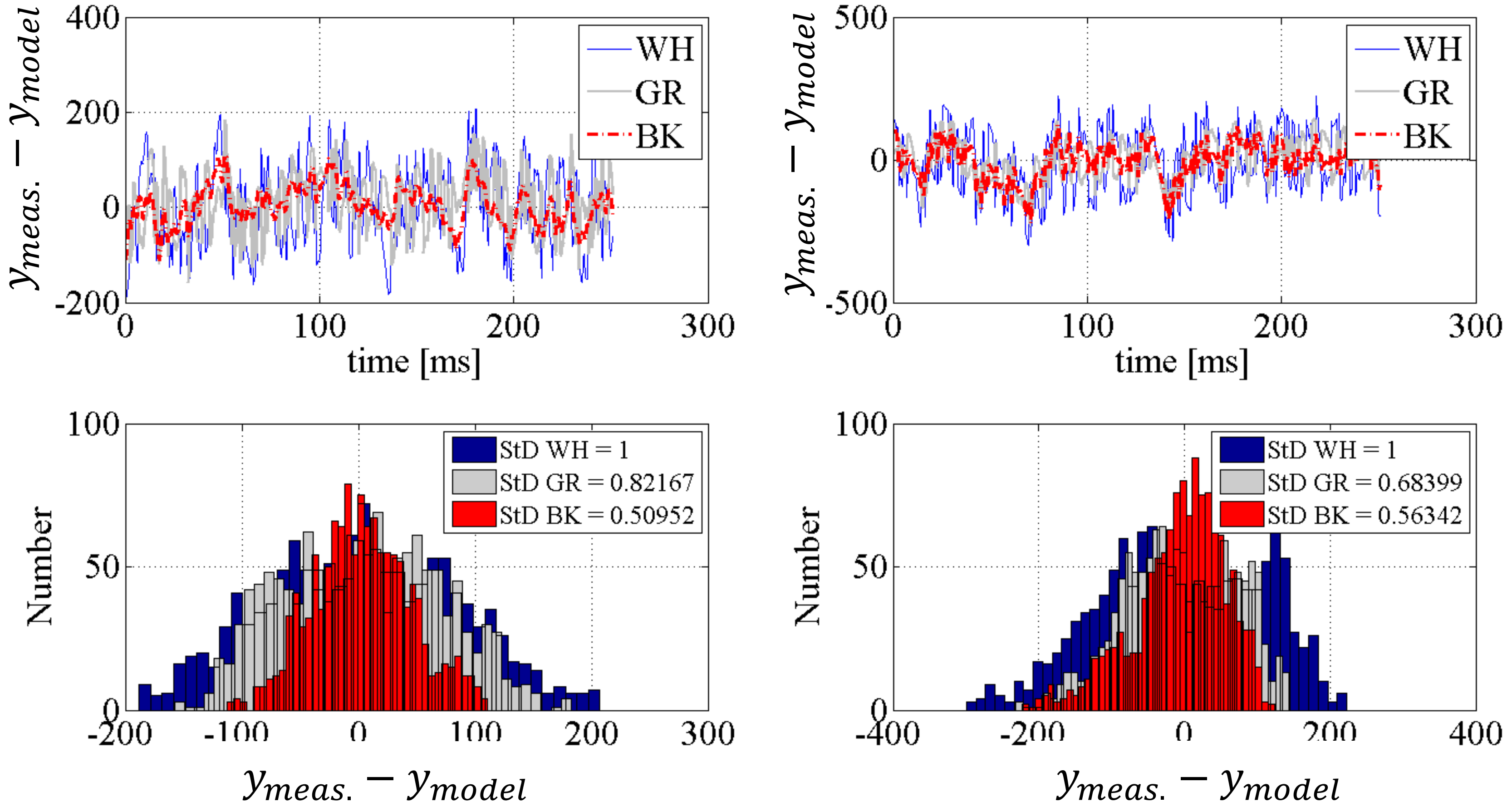
Residual Errors

$y_{meas.} - y_{model}$



Performance comparison

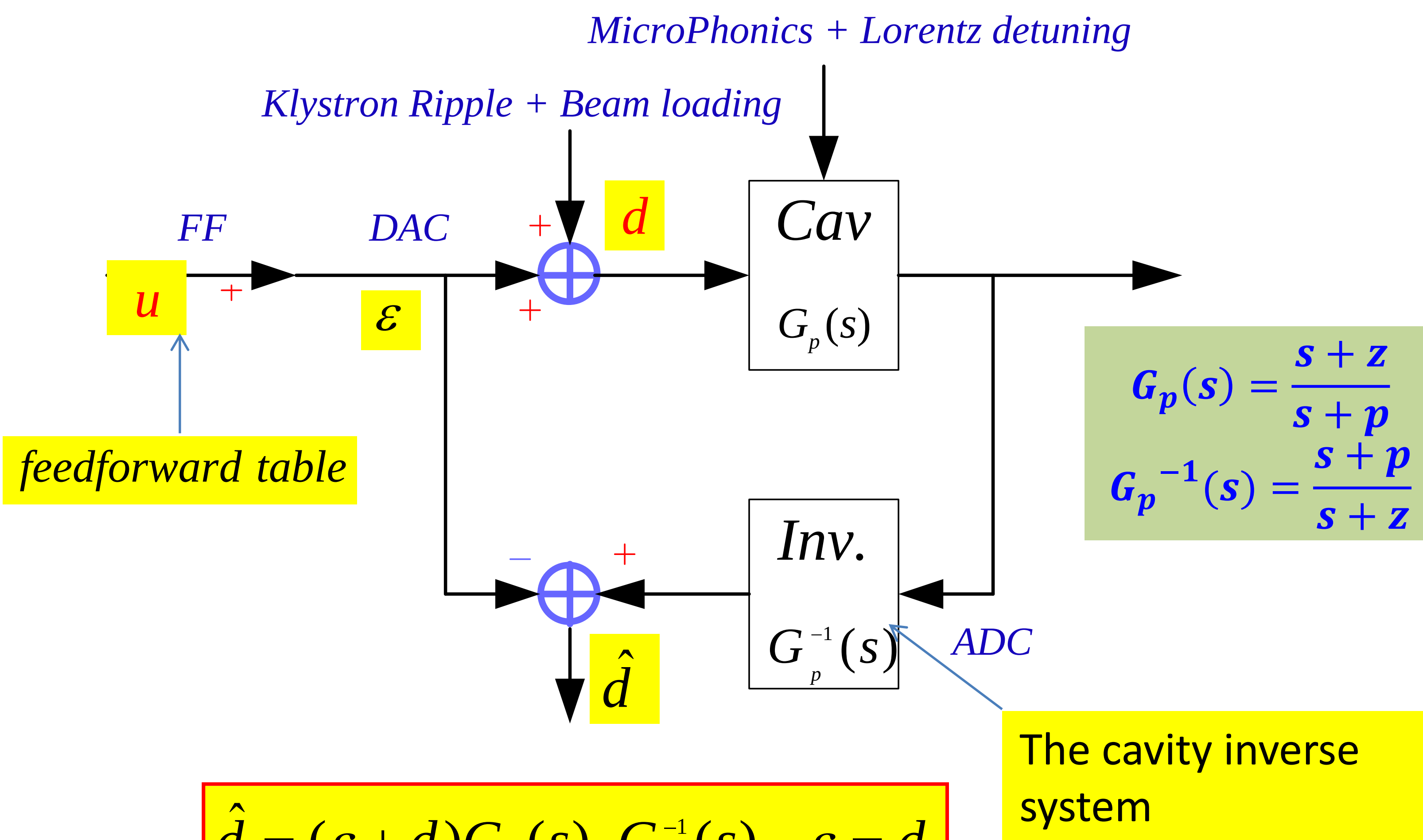
➢ Which model can represent the system behavior best ?



The black model has the best performance

Model-based Applications

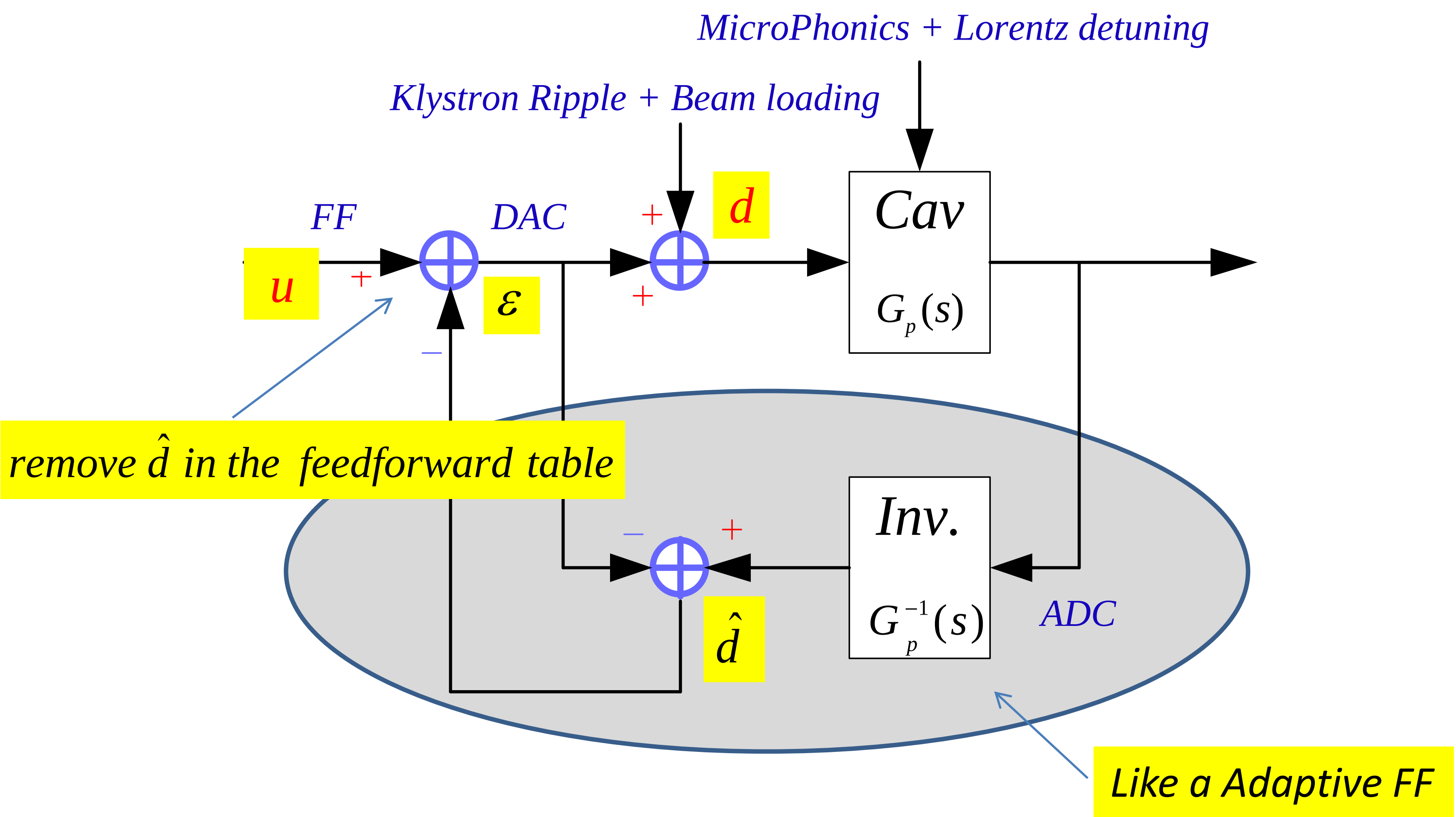
- What we can do if we "know" the system well?
- Can we evaluate the disturbing signal



$$\hat{d} = (\varepsilon + d) G_p(s) \cdot G_P^{-1}(s) - \varepsilon = d$$

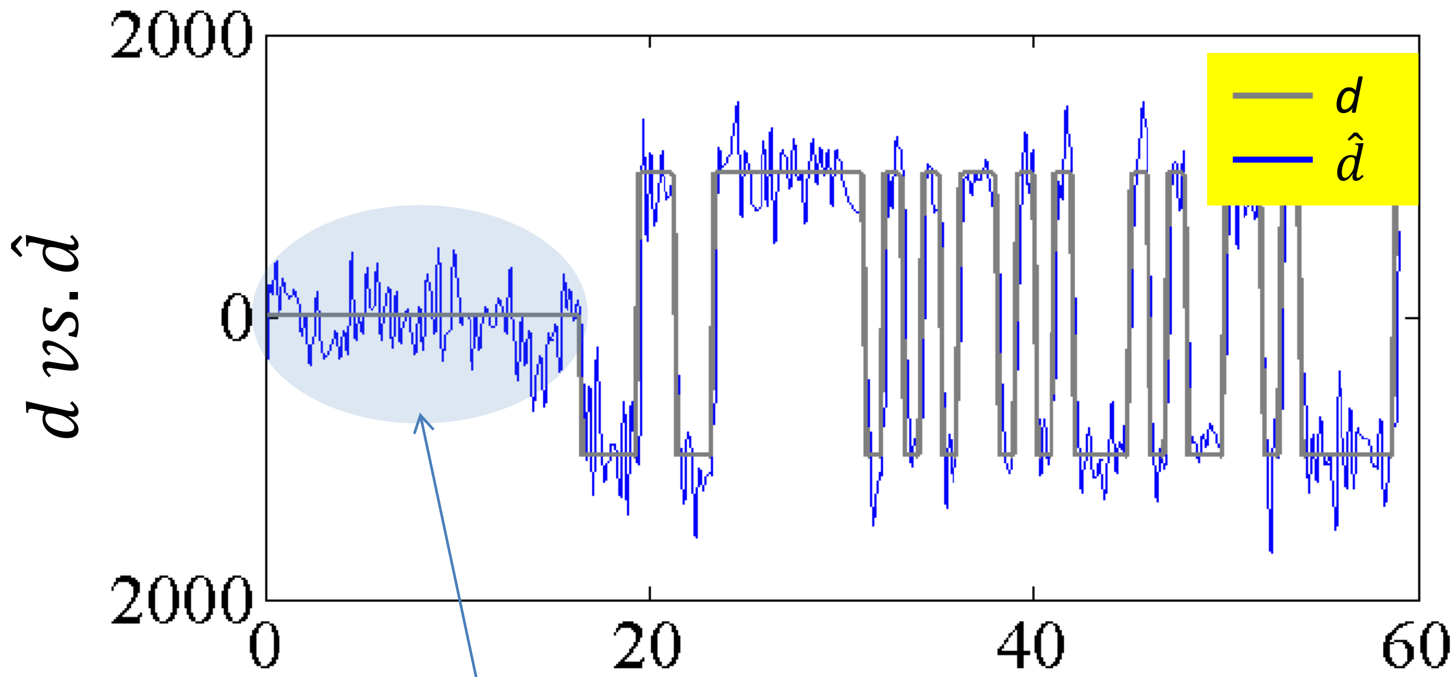
Model-based Applications

- Remove the evaluated disturbing signal $\hat{d}$ from FF table (Ripples, Beam Loading)



Evaluate the $\hat{d}$

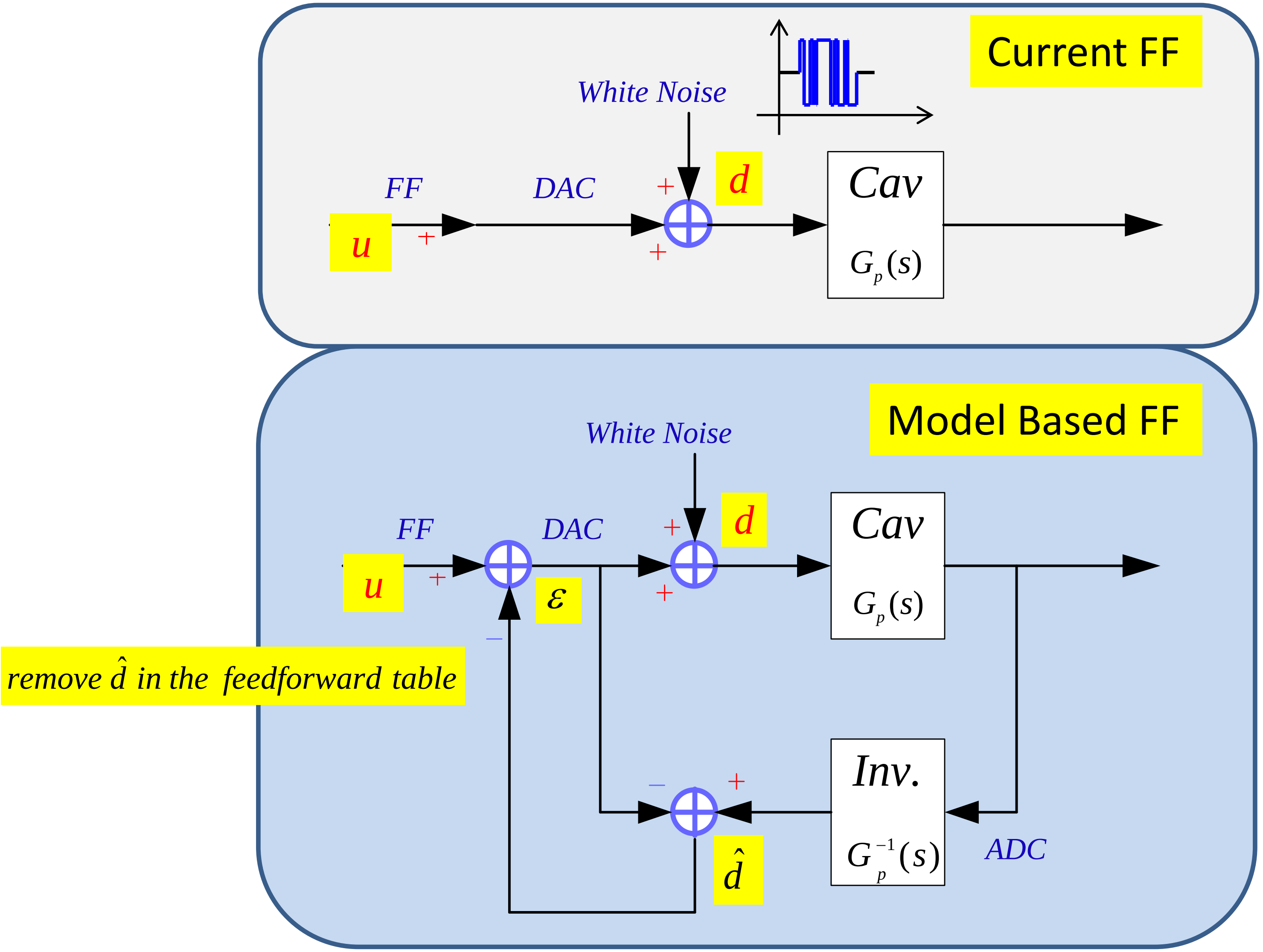
- Examples: recover the white noise during the system identification experiment



The high frequency noise can be removed by cavity itself

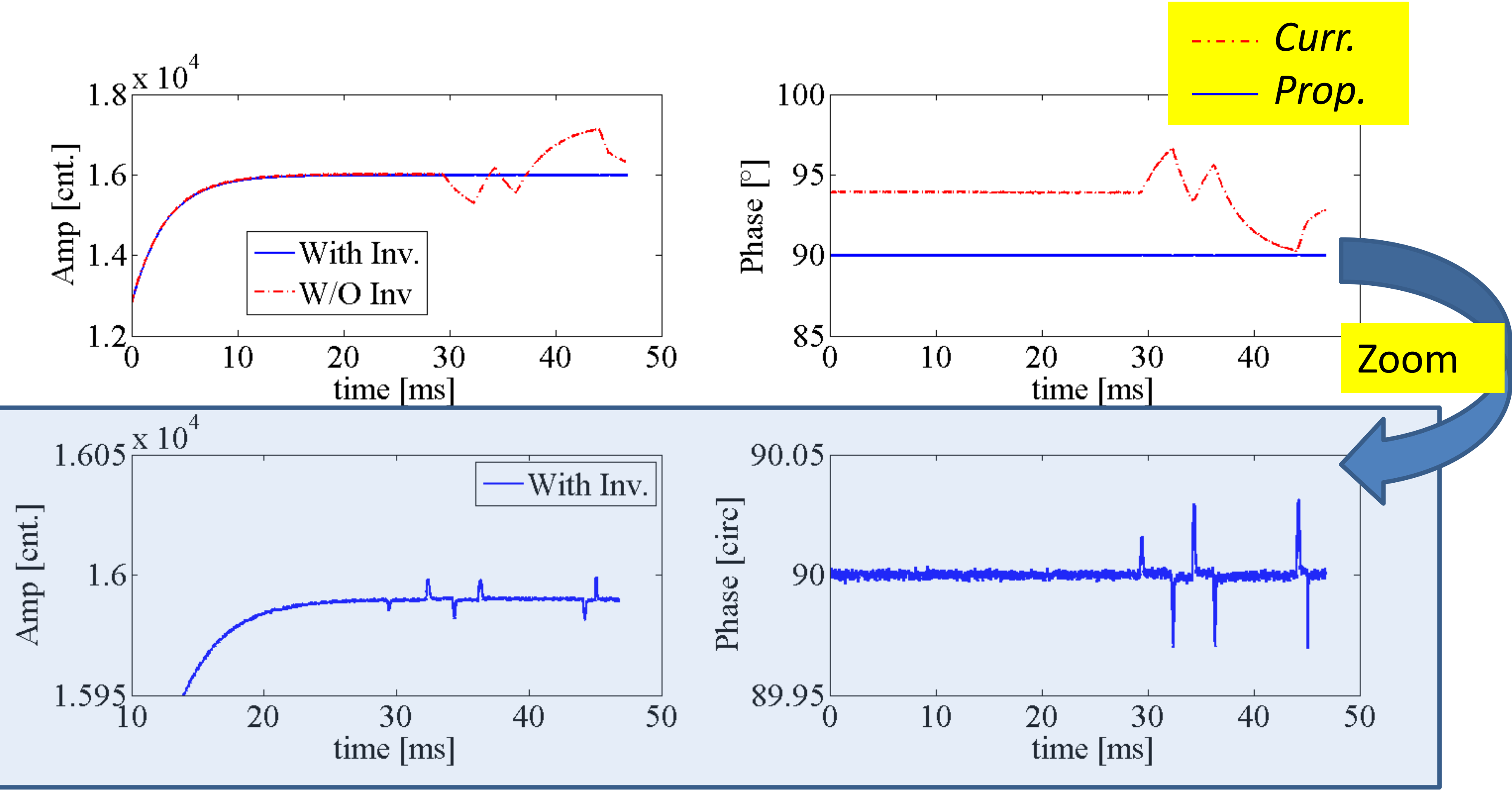
Simulation

- Model-Based feedforward vs current feedforward



Simulation

- Model-Based feedforward vs current feedforward (Matlab / Simulink)



Summary & Plan

Summary

- System Identification experiment for FB4 and FB5
- Comparison of different identified models
- Idea and simulation of some model-based FF

Plan

- Apply the proposed model-based FF in the cERL
- Other Model-based app.

Thank you for your attention

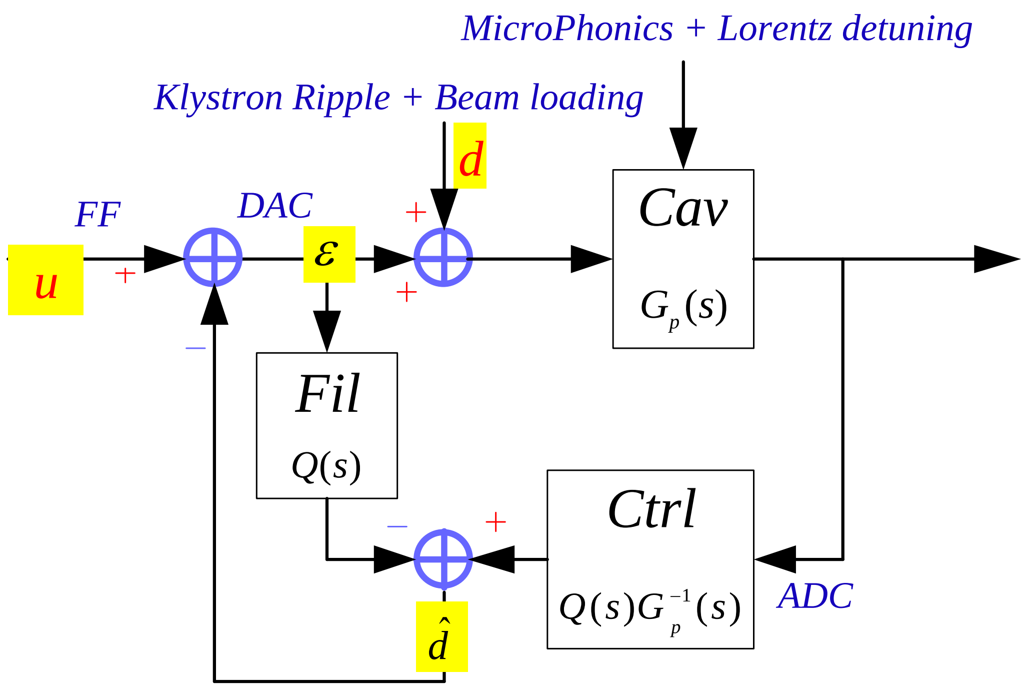
Back up

Model Based FB optimization

- What is the main problem?

I. It is difficult to obtain the inverse transfer function matrix $G_P^{-1}(s)$, too high orders.

II. The $G_P^{-1}(s)$ can not be realized in some case.



Tips

- Connected another system Q(s) with $G_P^{-1}(s)$ to make sure it can be physically realized.
- If the Q(s) is an low-pass filter, then the d can be still evaluated.

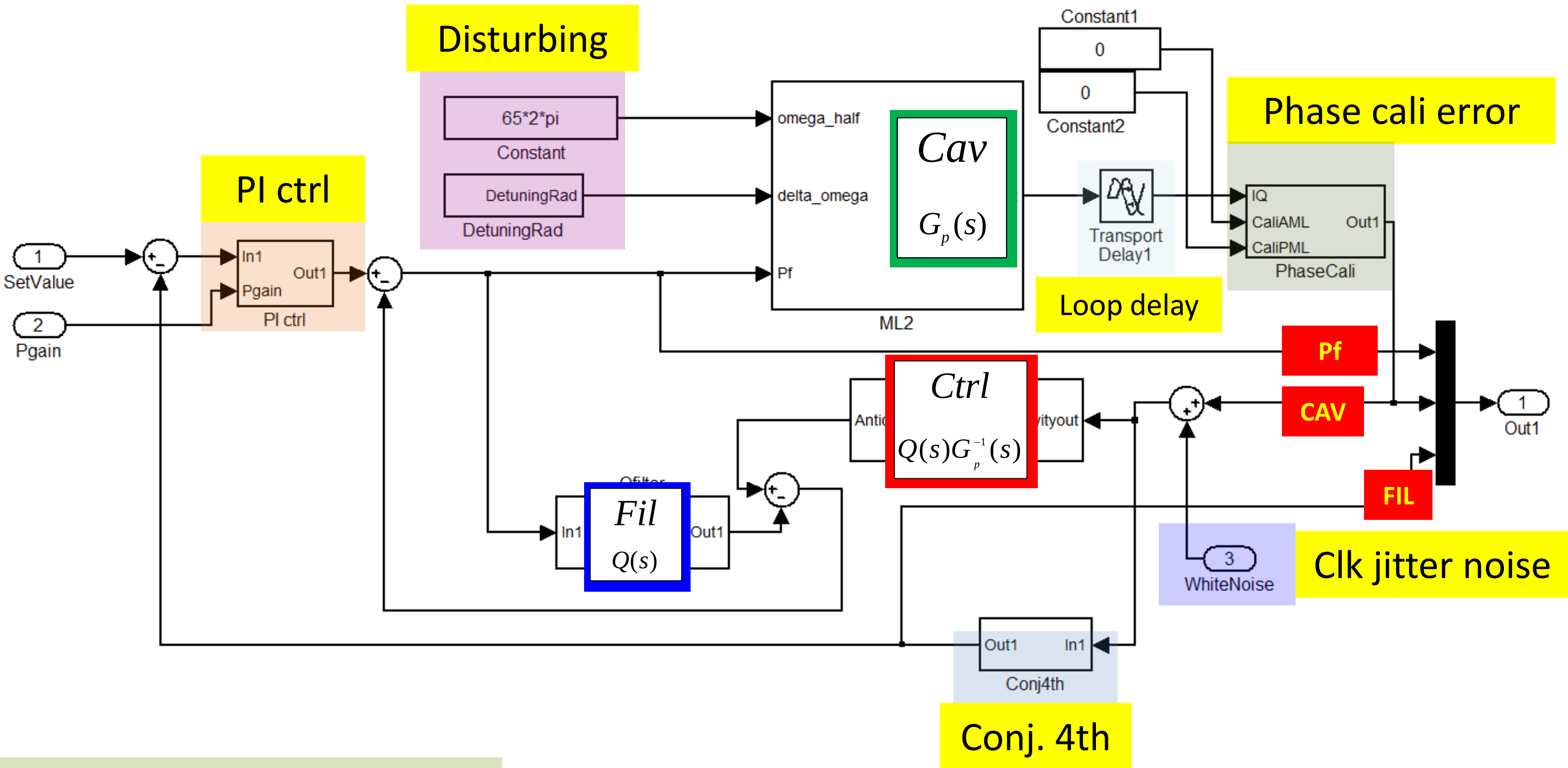
$$\hat{d} = (\varepsilon + d)G_p(s) \cdot G_P^{-1}(s) \cdot Q(s) - \varepsilon \cdot Q(s) = d \cdot Q(s)$$

Simulink Model

- Simulink Model (see AdvancedPIDV1)

I. We input the microphonics data from ML2 as a disturbing.

II. We detect CAV, Pf, and FIL channel in the Simulink model.



PI + Proposed FB controller

System Transformation