

# Control System Modeling for SC Cavity

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Experimental results for ACC1 module  
driven with the SIMCON board

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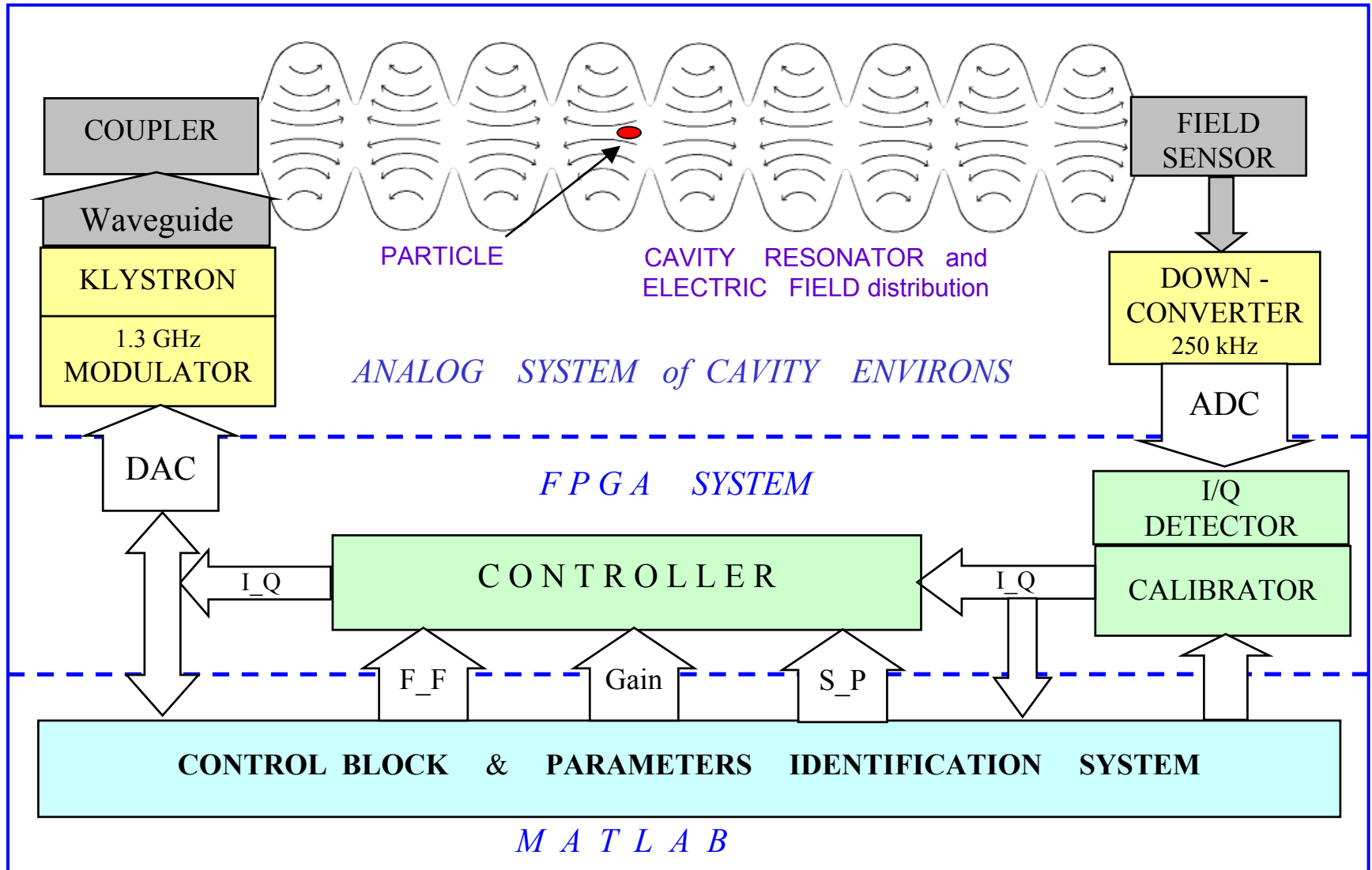
Warsaw University of Technology  
*Institute of Electronic Systems*  
ELHEP-DESY Group



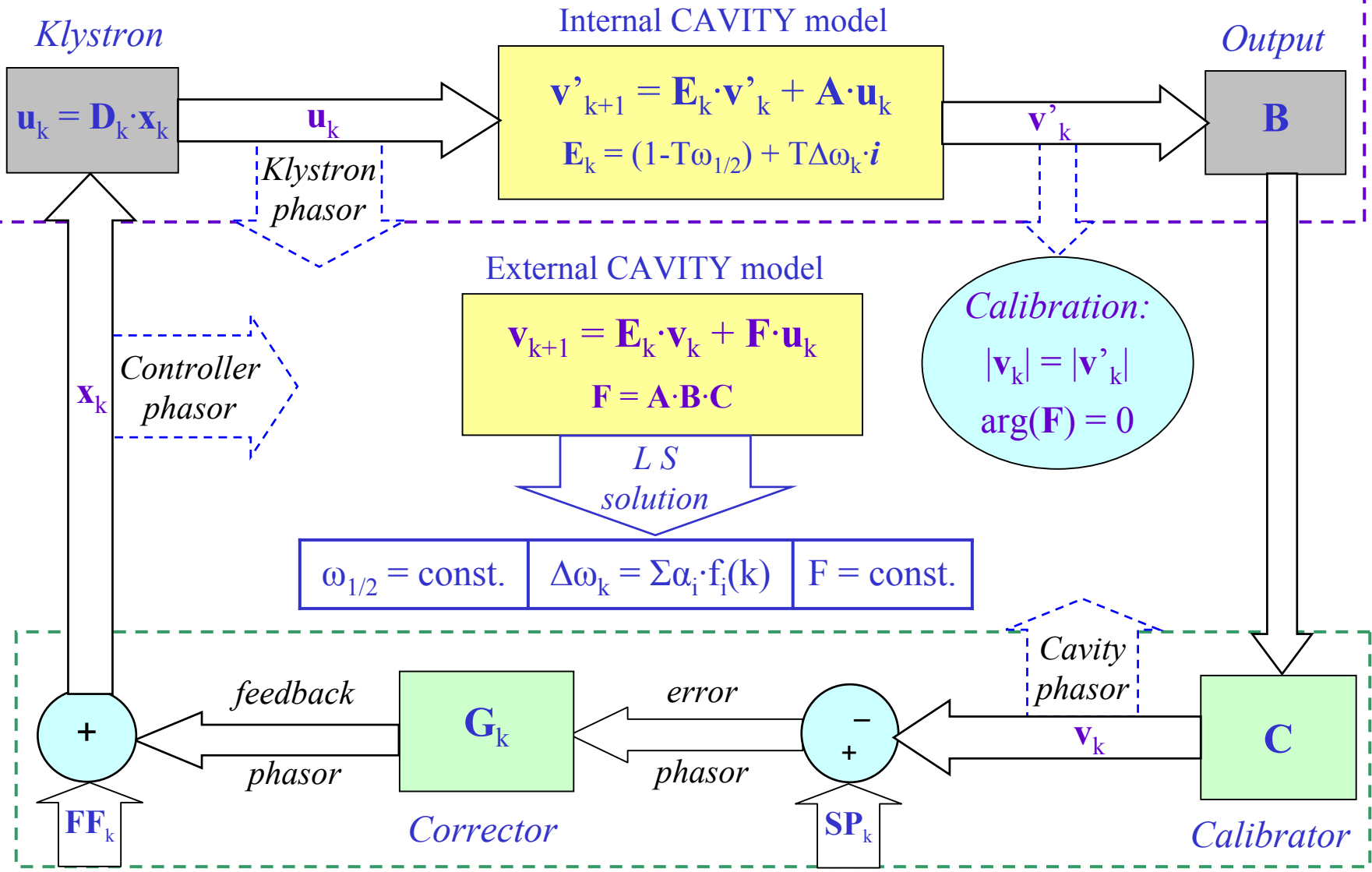
# Main topics of the presentation

- Low Level Radio Frequency system introduction
- Algebraic model of the LLRF control system
- Calibration and correction procedure
- Cavity parameters identification
- Control system algorithm
- Experimental results
- Summary

# Functional block diagram of Low Level Radio Frequency Cavity Control System



# Algebraic model of the LLRF control system



# Parameters identification of cavity system in noisy and no stationary condition

External CAVITY model

$$\mathbf{v}_{k+1} = \mathbf{E}_k \cdot \mathbf{v}_k + F \cdot \mathbf{u}_k \quad \mathbf{E}_k = (1 - T\omega_{1/2}) + T\Delta\omega_k \cdot \mathbf{i}$$

Parameters:  $F$ ,  $\omega_{1/2}$ ,  $\Delta\omega_k = \sum \alpha_i \cdot f_i(k)$

Approximation of time-varying detuning by series of **base functions**:

**Linear decomposition:**  $\Delta\omega = \mathbf{W}^* \boldsymbol{\alpha}$

$\mathbf{W}$  – matrix of base functions: *polynomial* or *cubic B-spline set*

$\boldsymbol{\alpha}$  – unknown vector of series coefficients

**Over-determined matrix equation** for measurement range:

$$\mathbf{V} = \mathbf{Z}^* \mathbf{z}$$

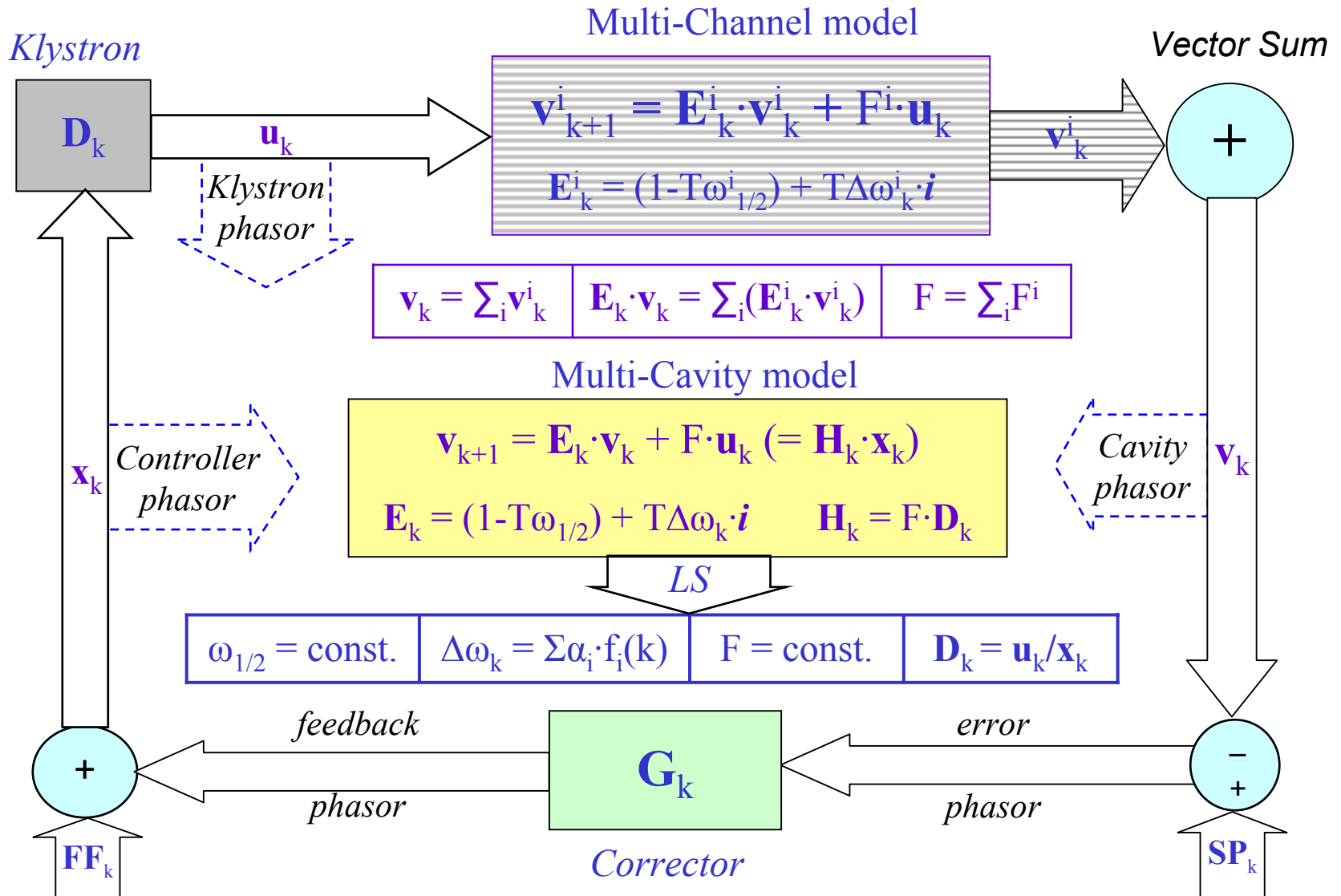
$\mathbf{V}$  – total output vector,  $\mathbf{Z}$  – total structure matrix

$\mathbf{z} = [F; (1-T\omega_{1/2}); \boldsymbol{\alpha}]$  - total vector of unknown values

**Least square (LS)** solution for minimum RMS error:

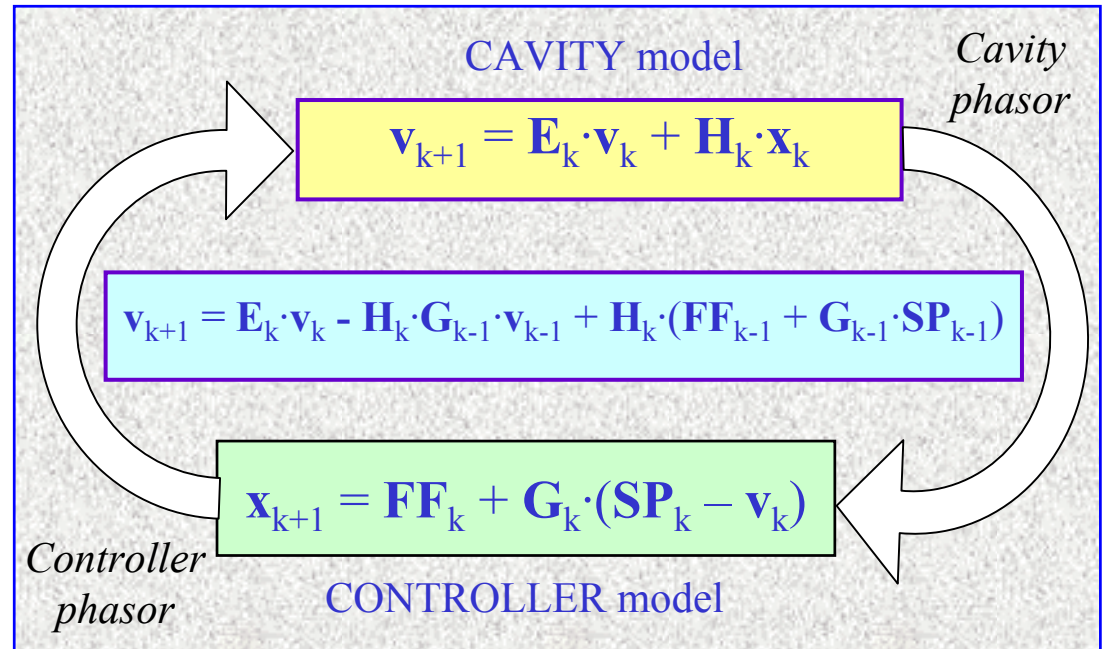
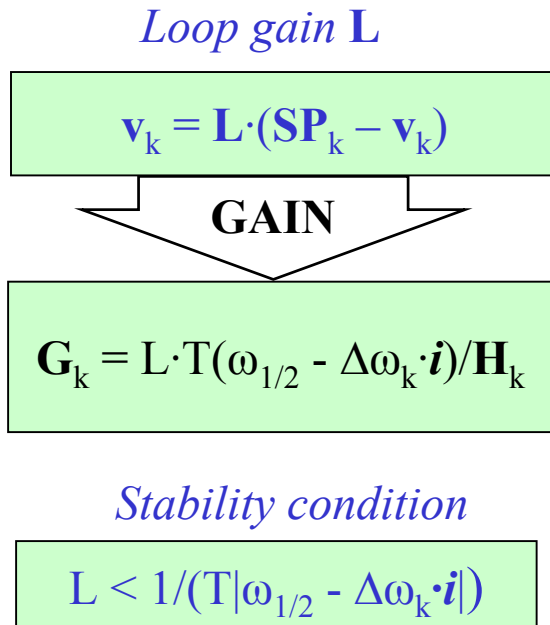
$$\mathbf{z} = (\mathbf{Z}^T * \mathbf{Z})^{-1} * \mathbf{Z}^T * \mathbf{V}$$

# Multi-Channel System modeling



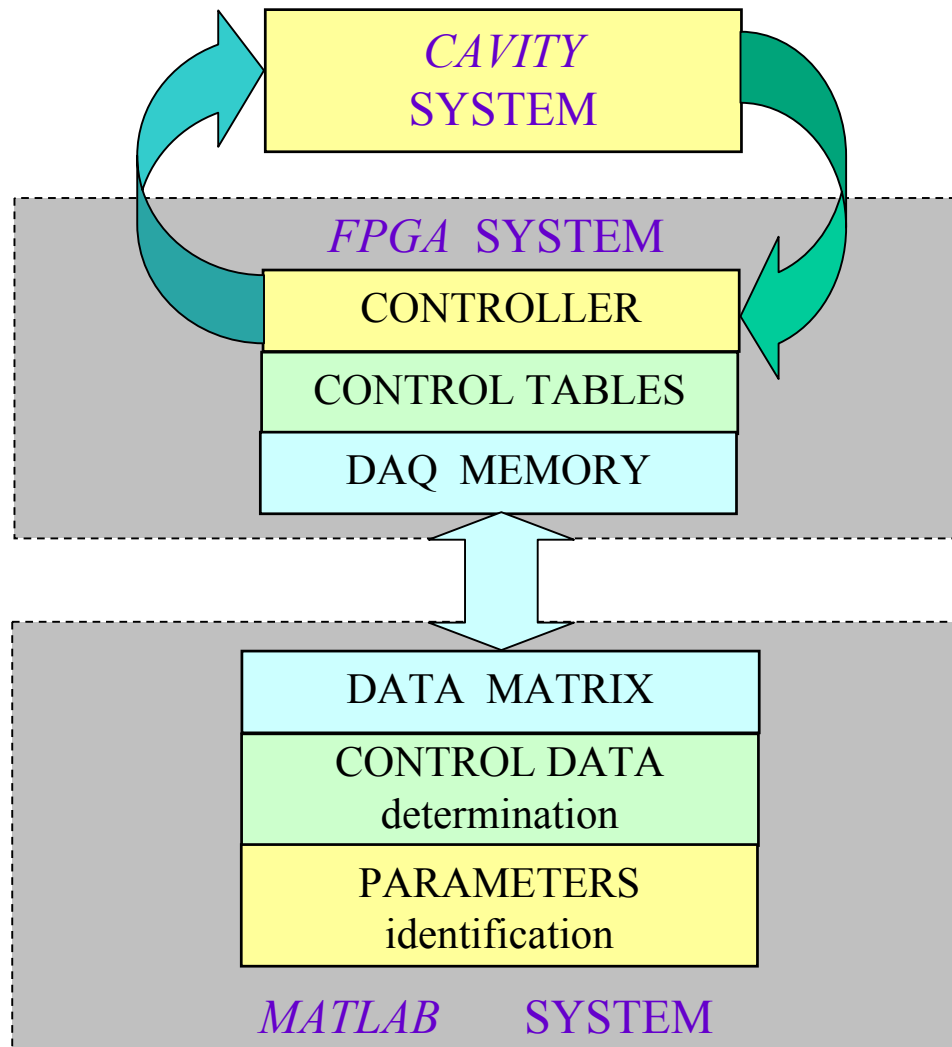
# Control Algorithm

## Determination of Control Tables : F\_F S\_P GAIN



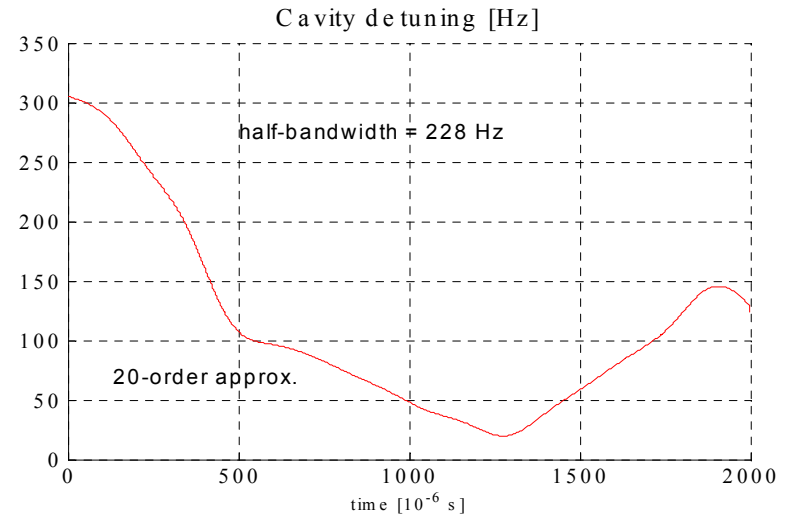
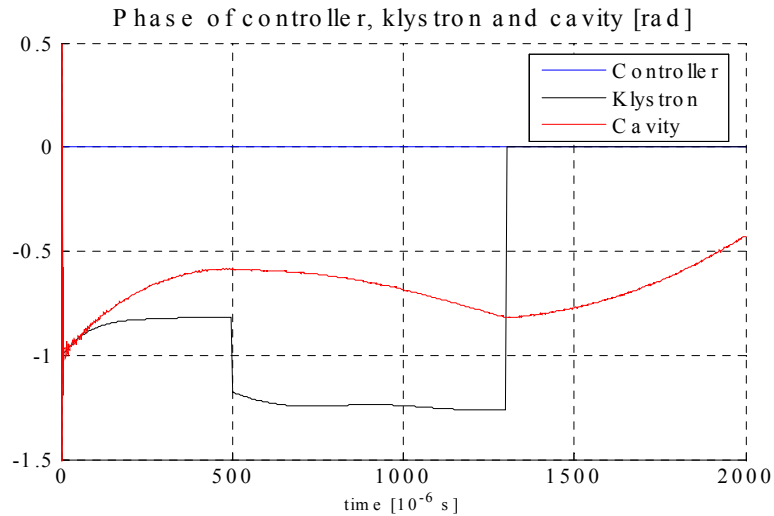
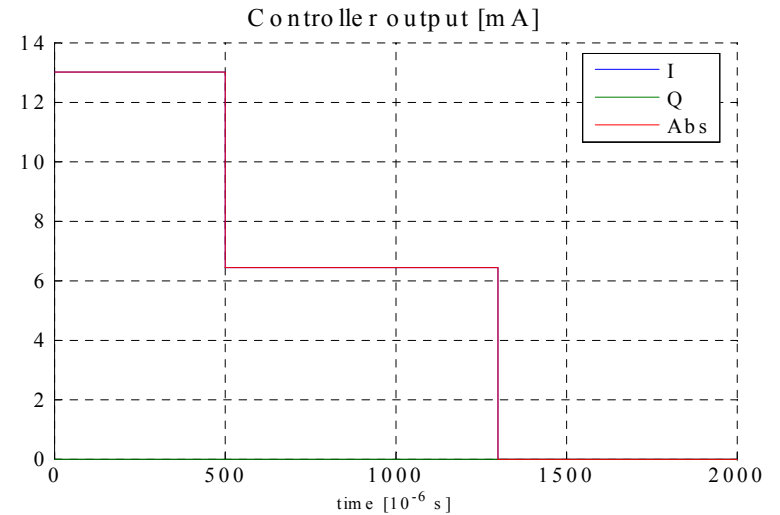
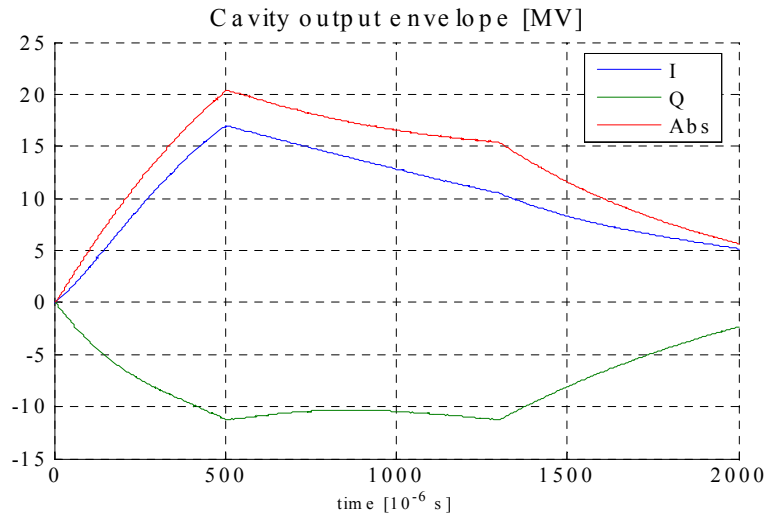
<i>MODE</i> <i>RANGE</i>	FEED-FORWARD	SET-POINT
<i>Filling</i>	$\mathbf{FF}_k = \mathbf{T}\omega_{1/2} \cdot \mathbf{v} \cdot \exp(\mathbf{i}\varphi_k) / \mathbf{H}_k$ $\varphi_k = \varphi_{k-1} + \mathbf{T}\Delta\omega_k$	$\mathbf{SP}_k = \mathbf{v} \cdot [1 - \exp(-k \cdot \mathbf{T}\omega_{1/2})] \cdot \exp(\mathbf{i}\varphi_k)$ $(\mathbf{SP}_{end} = \mathbf{V}) \rightarrow \mathbf{u}, \varphi_1$
<i>Flattop</i>	$\mathbf{FF}_k = \mathbf{V} \cdot \mathbf{T}(\omega_{1/2} - \Delta\omega_k \cdot \mathbf{i}) / \mathbf{H}_k$	$\mathbf{SP}_k = \mathbf{V} = \mathbf{V} \cdot \exp(\mathbf{i}\Phi)$

# Adaptive control for cavity driven with FPGA controller supported by MATLAB system

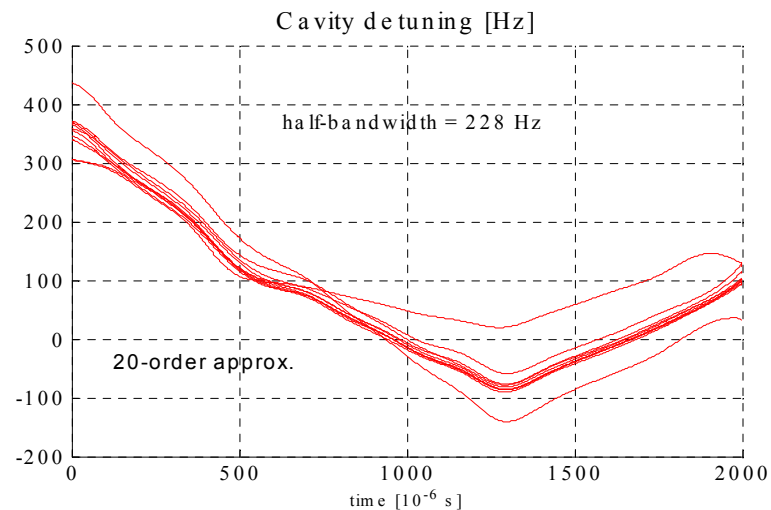
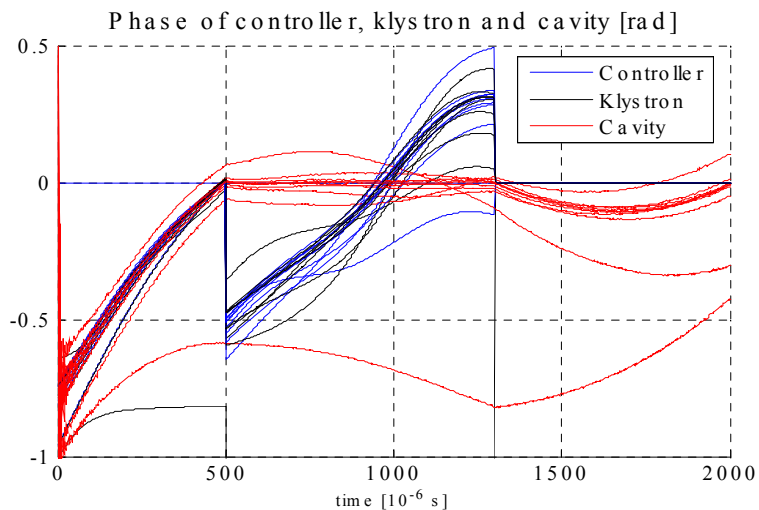
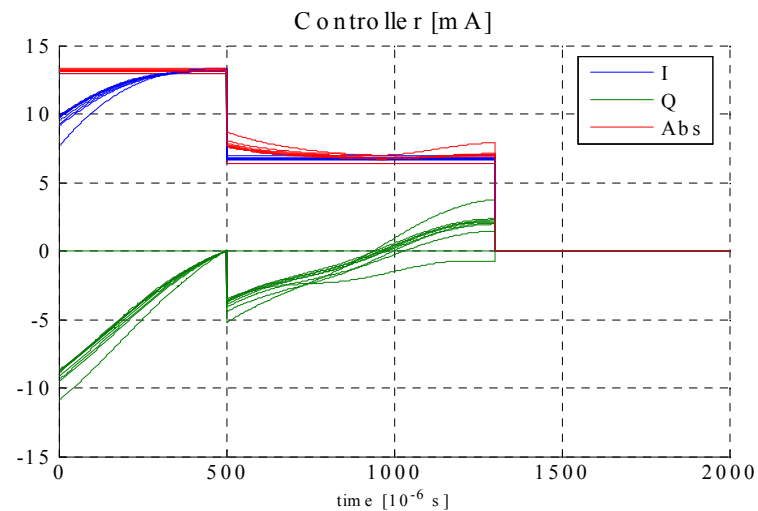
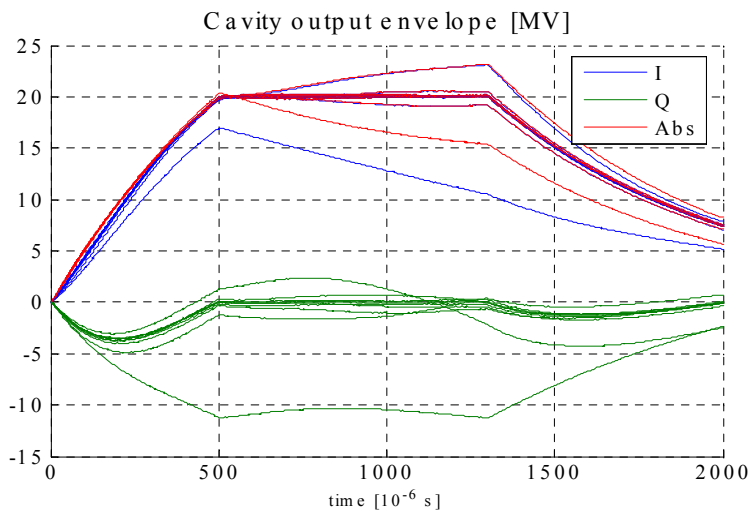




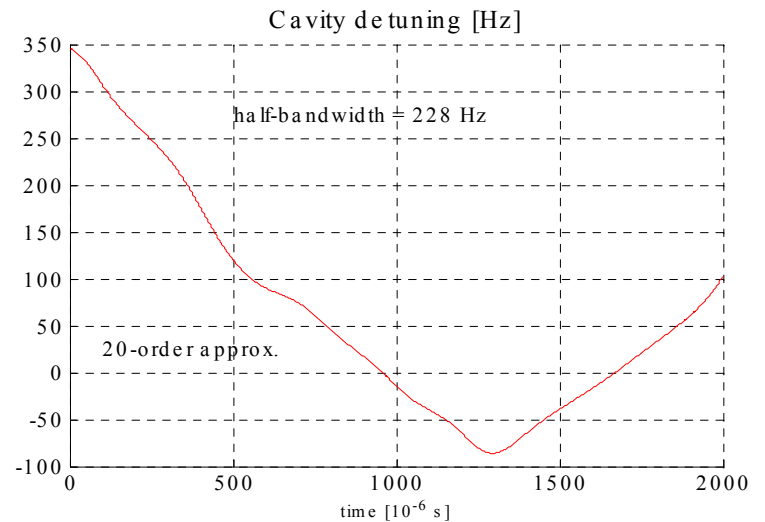
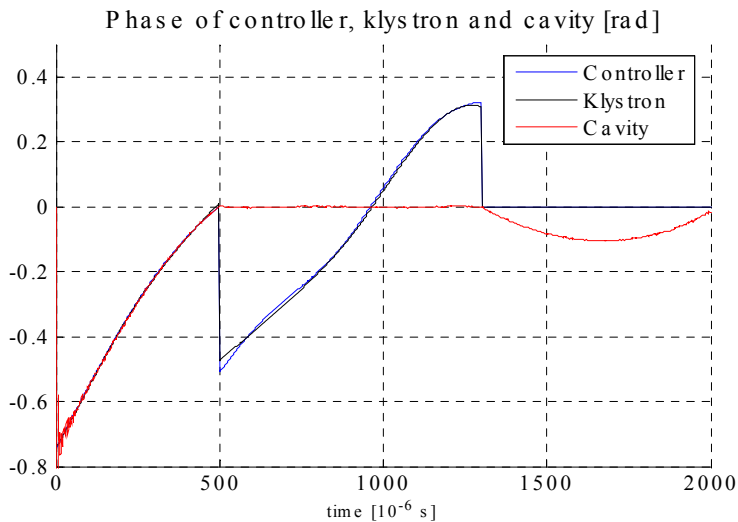
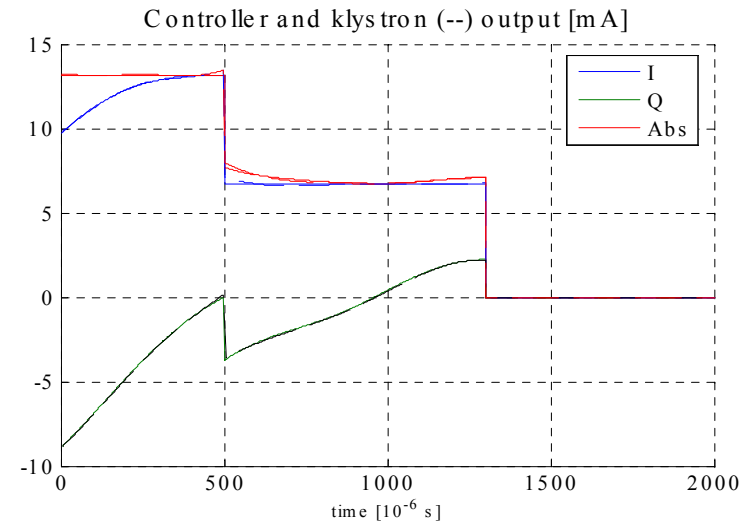
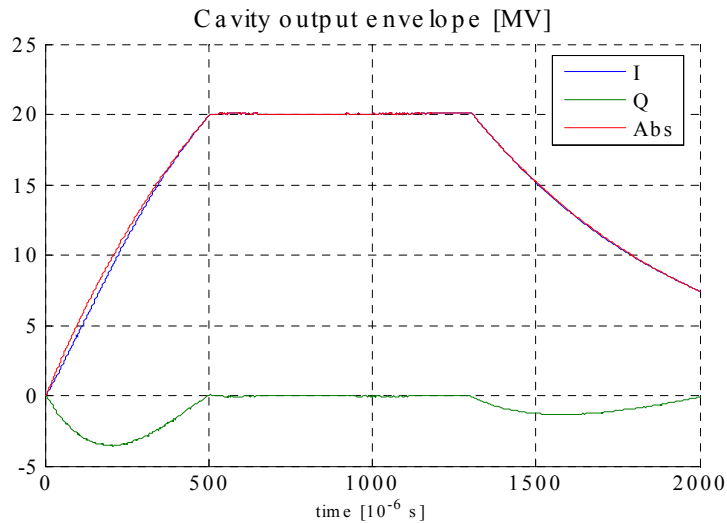
# Adaptive Feed Forward – 1<sub>st</sub> step



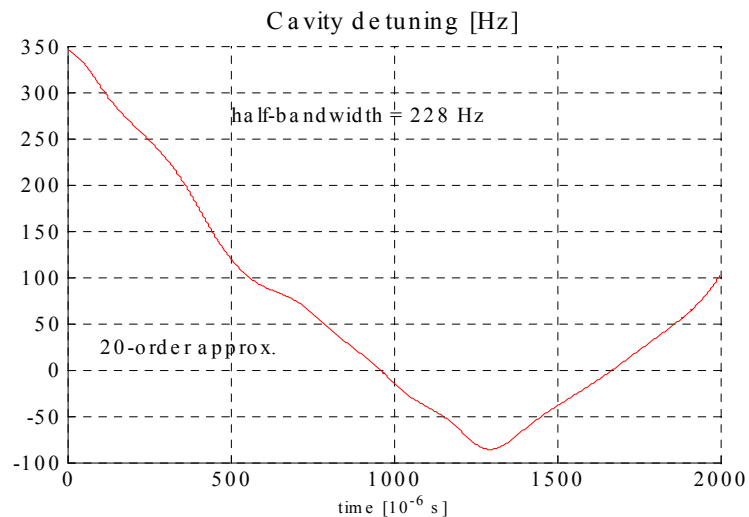
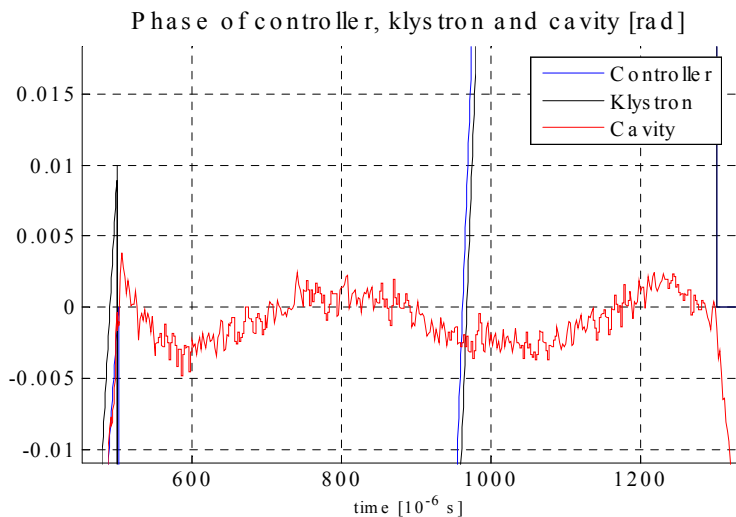
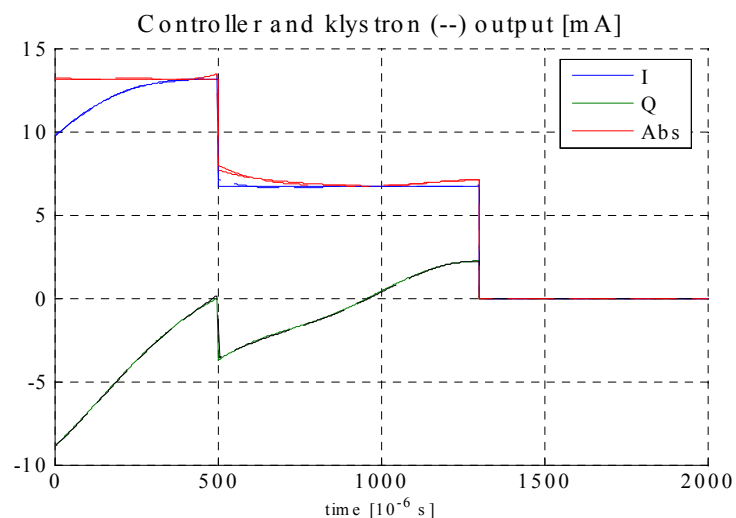
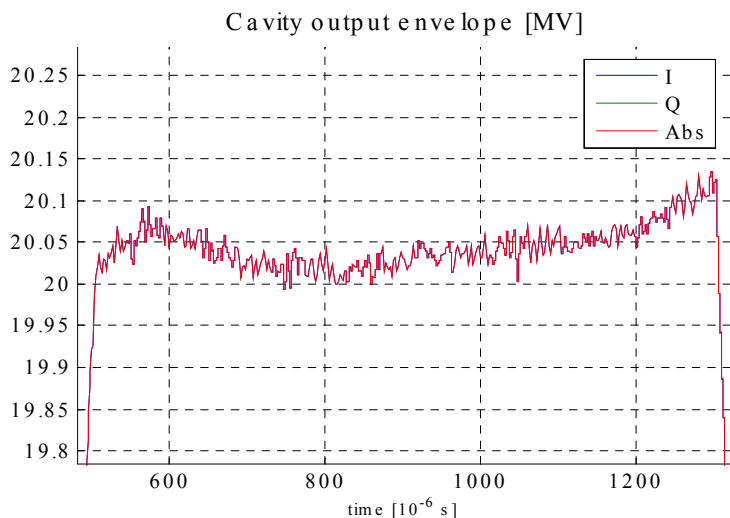
# Adaptive Feed Forward – 10 steps



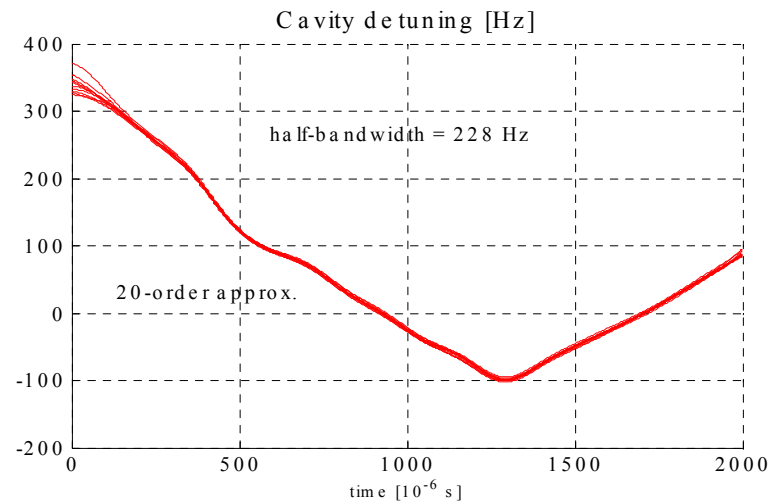
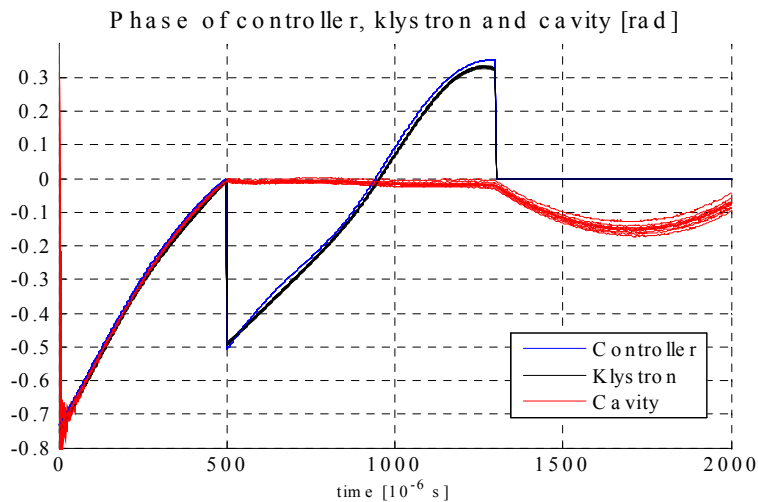
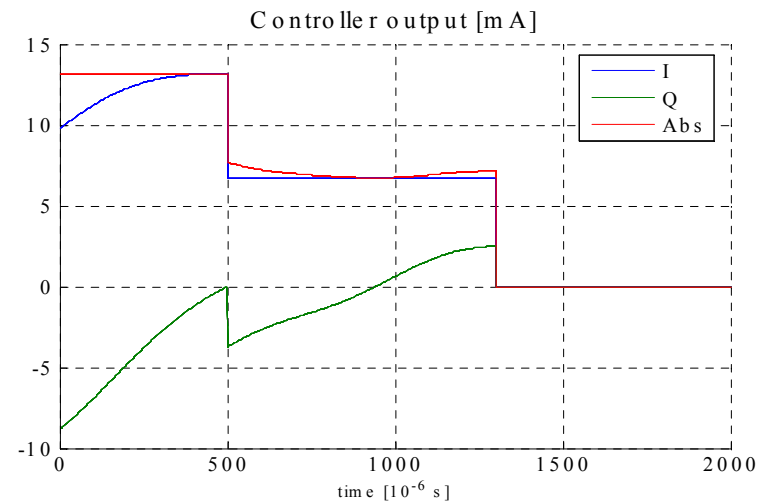
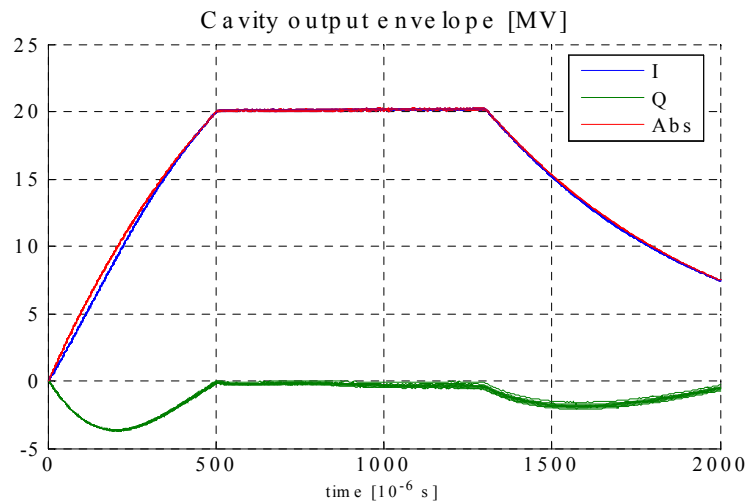
# Adaptive Feed Forward – 10\_th step



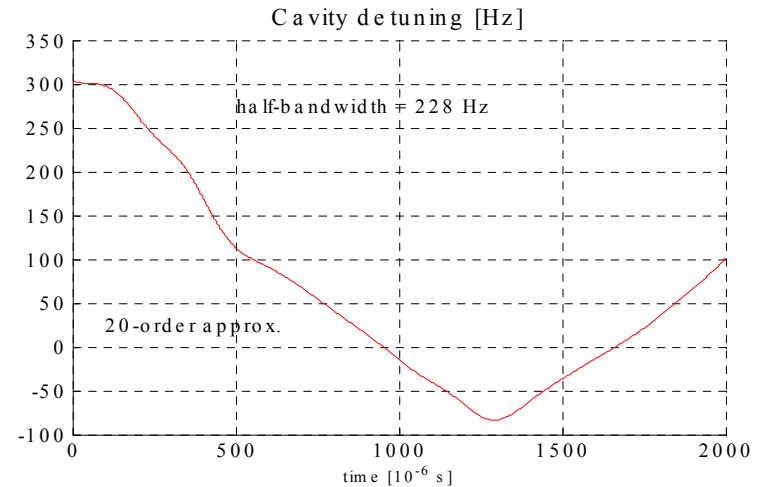
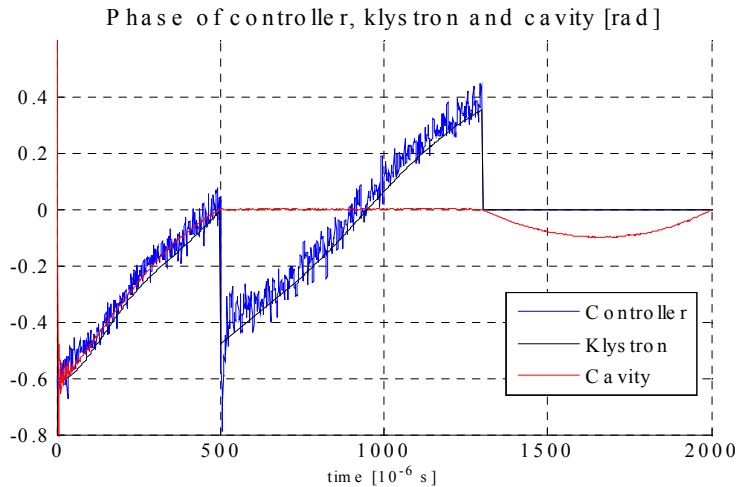
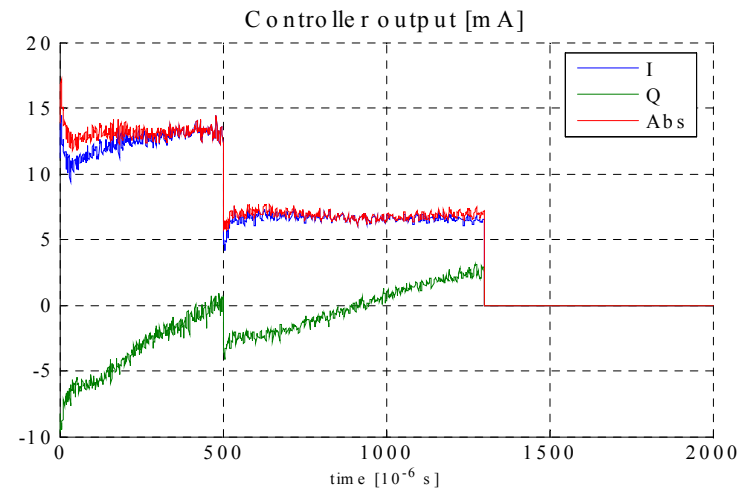
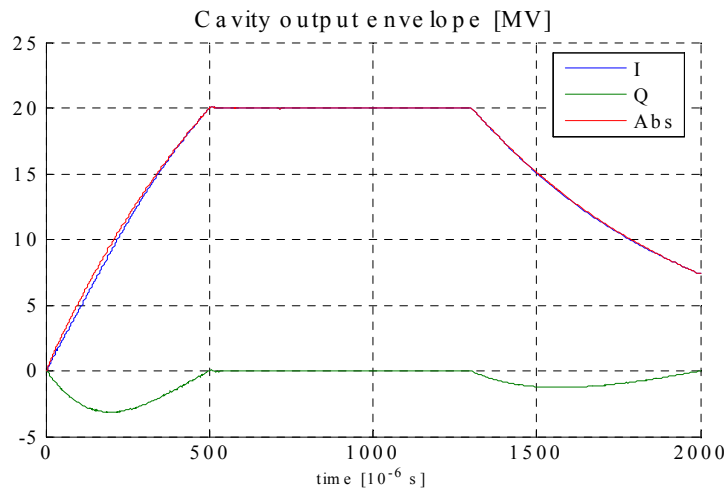
# Adaptive Feed Forward – 10\_th step – zoomed flattop



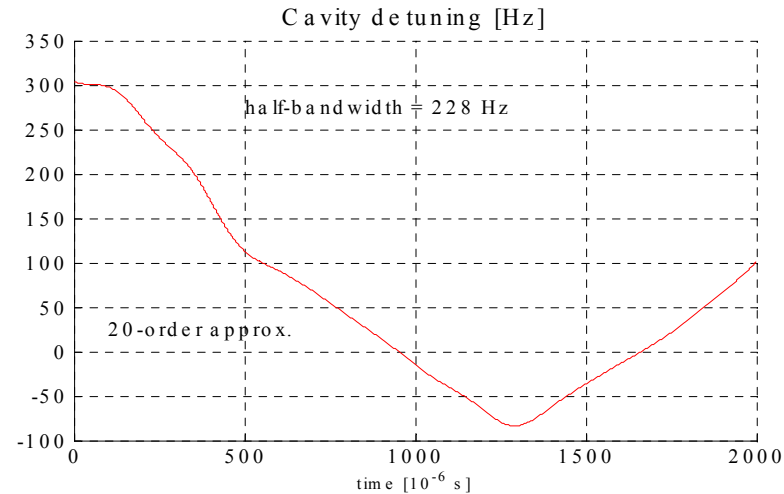
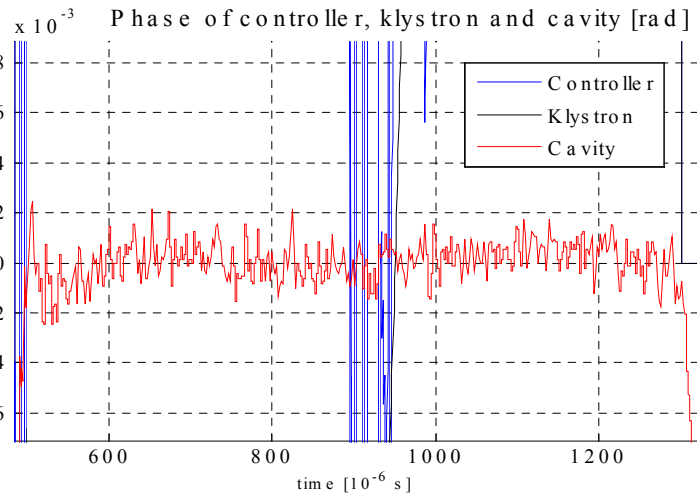
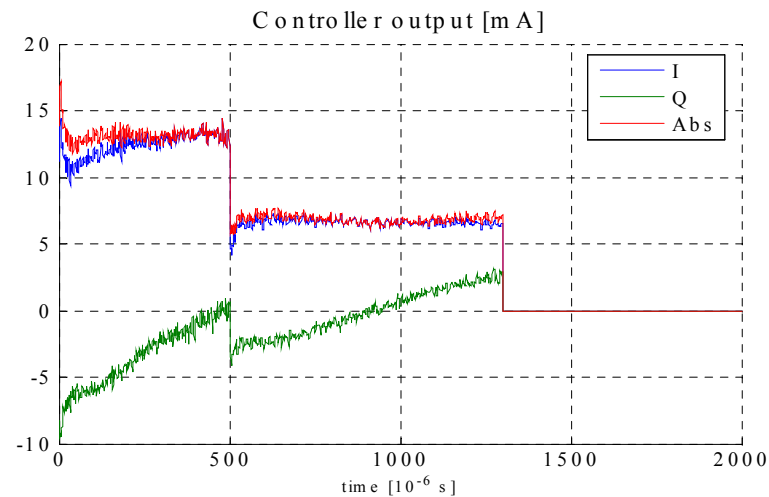
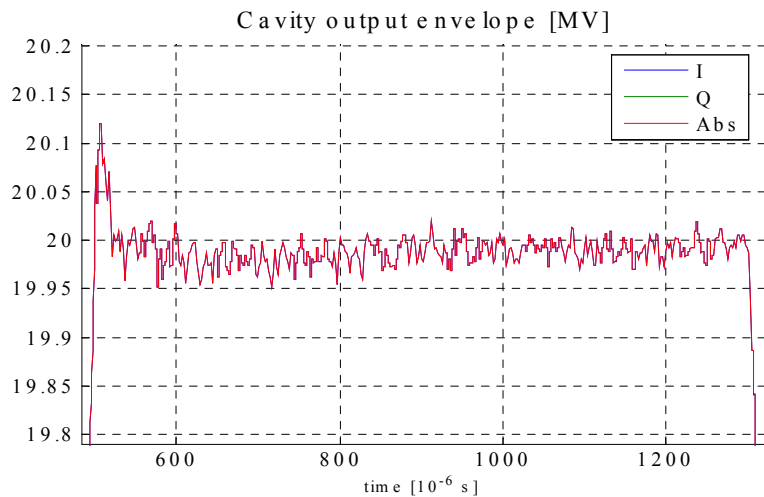
# Feed Forward driving – 10 repetition readout



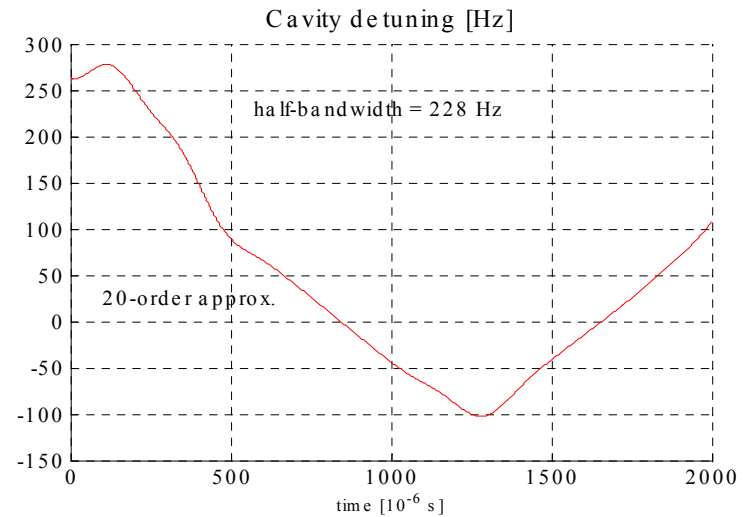
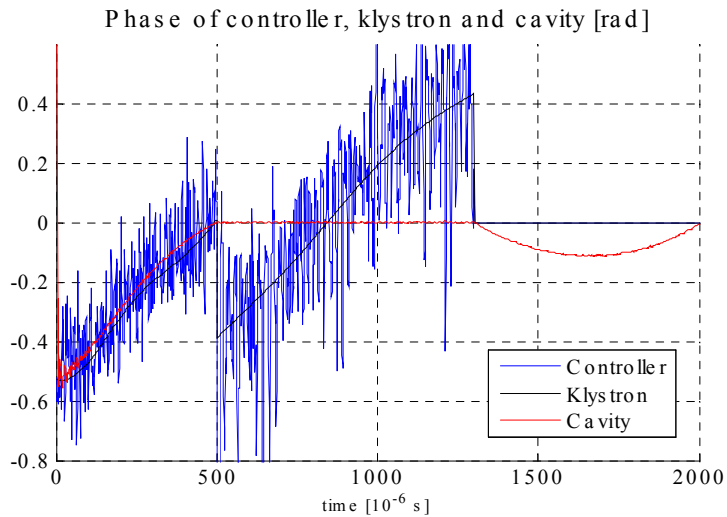
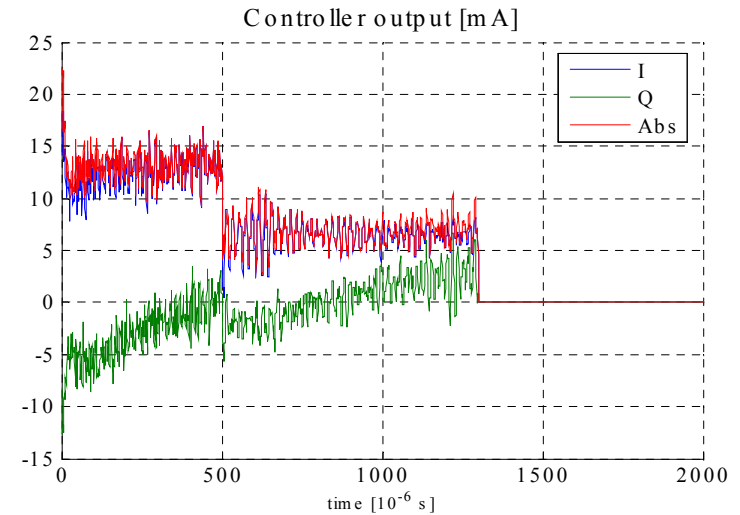
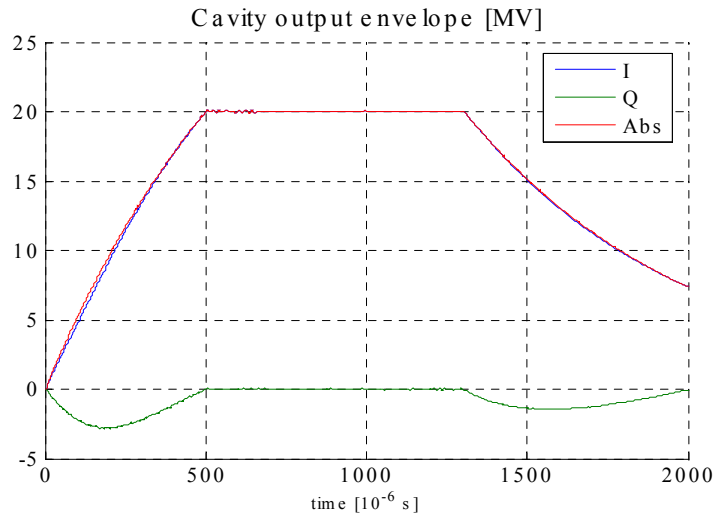
# Single cavity driving: Feed Forward and Feedback mode (gain=100)



# Feed Forward and Feedback mode( gain=100) zoomed flattop area

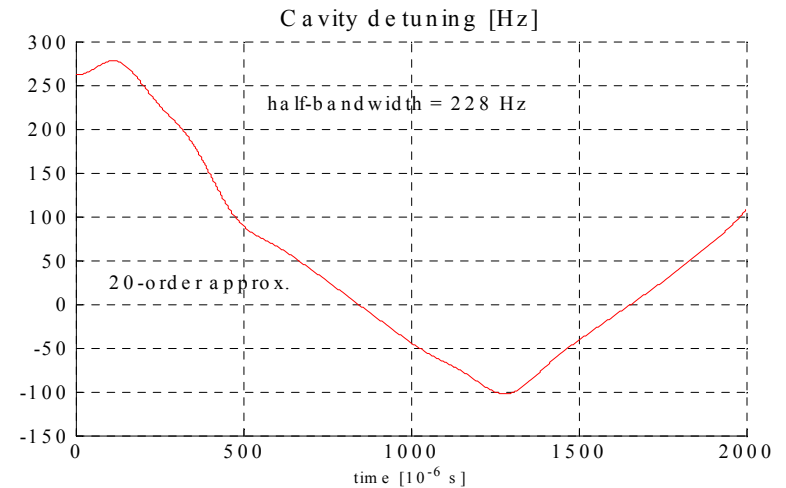
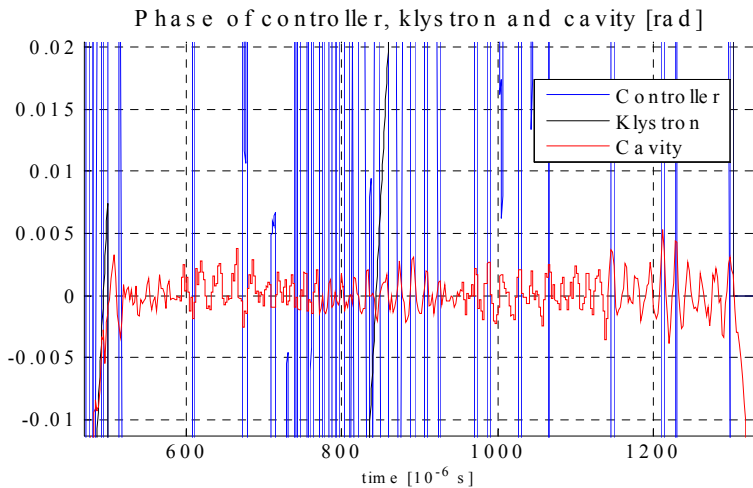
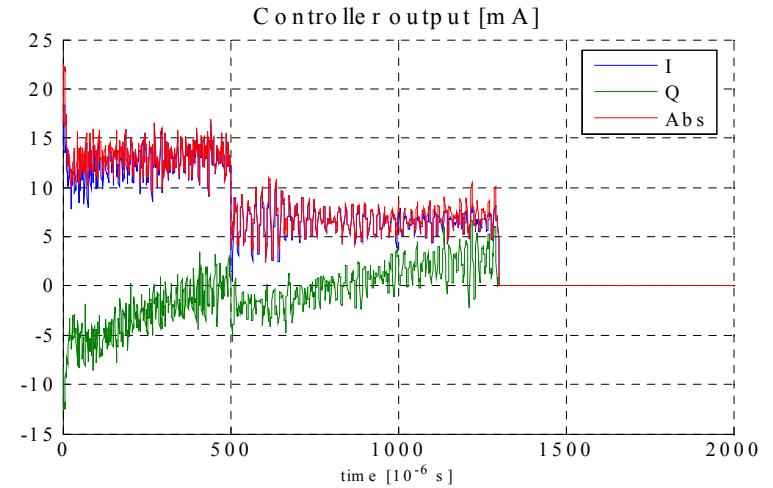
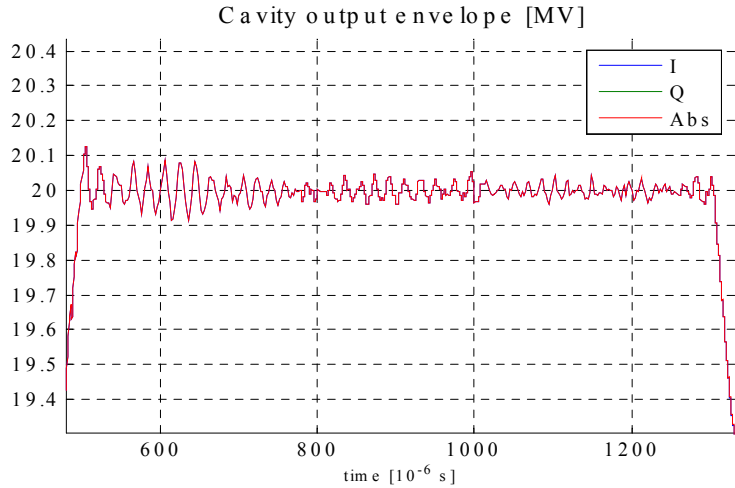


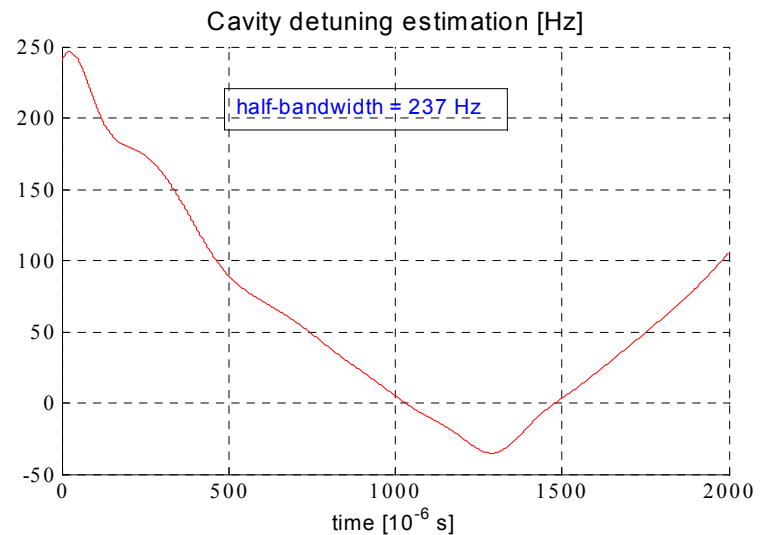
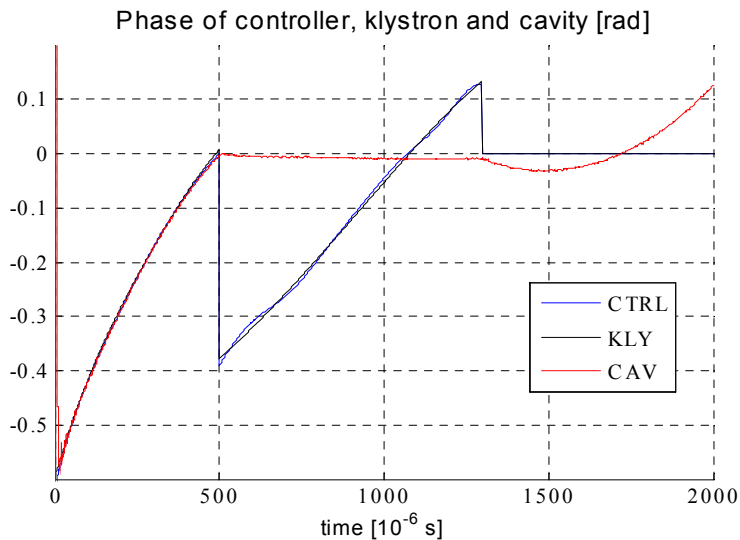
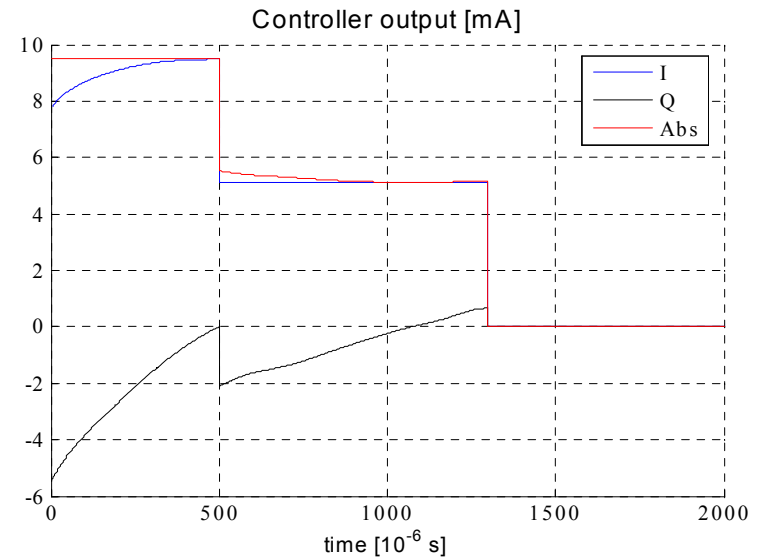
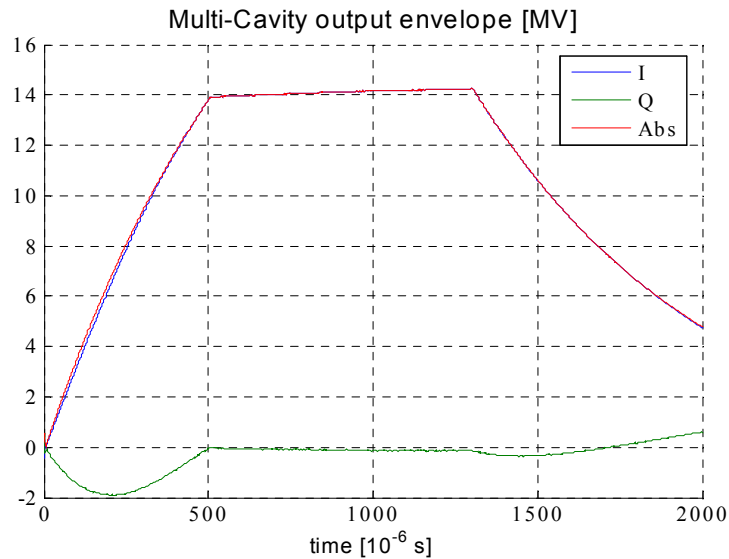
# Feed Forward and Feedback mode ( gain=200)



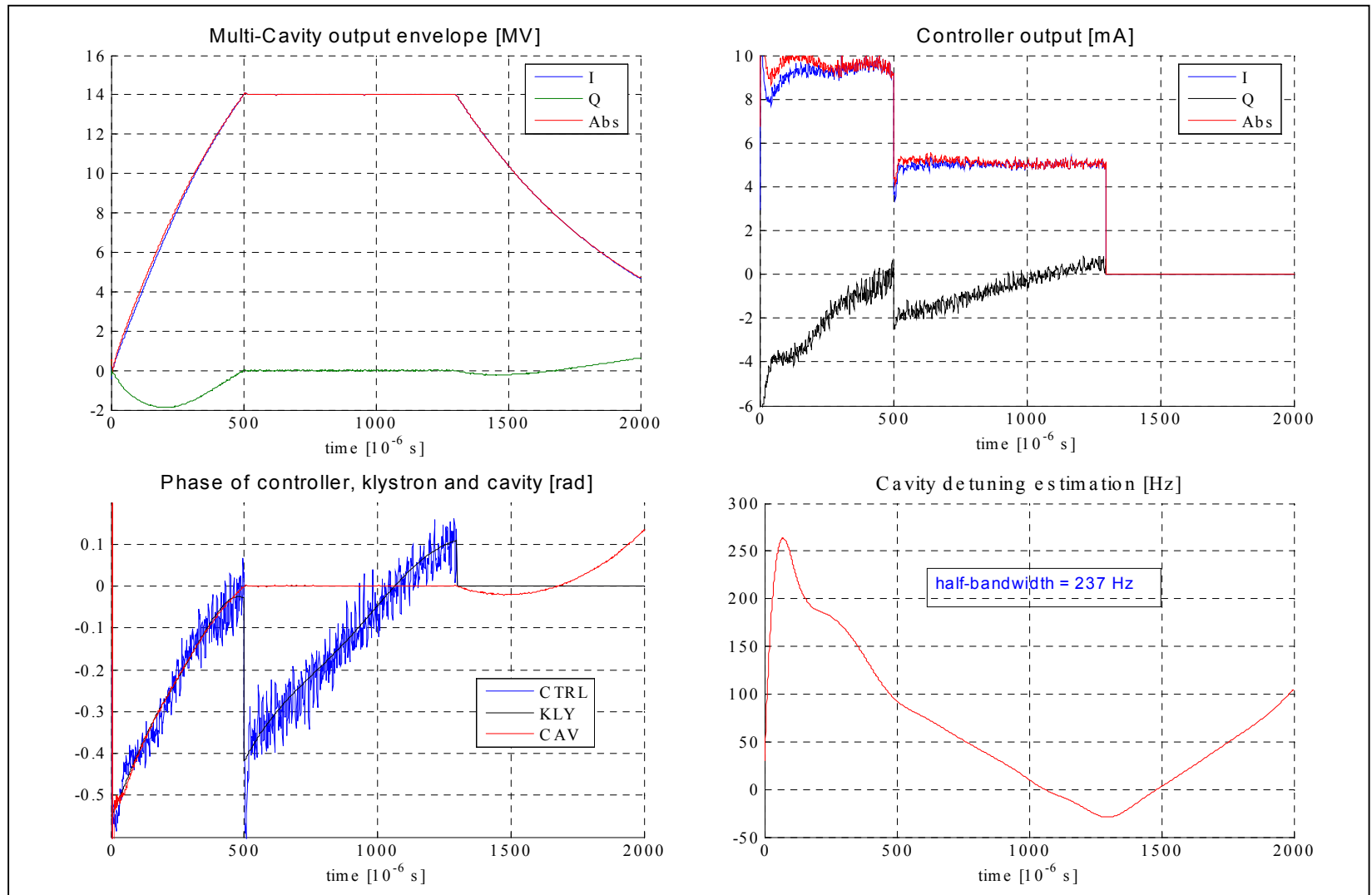


# Feed Forward and Feedback mode ( gain=200) zoomed flattop area





# 8 cavities driving: Feed Forward and Feedback mode (gain=100)



# Summary of Procedures for Control Purpose Implemented in MATLAB System

- Estimation of complex envelope for:  
klystron, each one cavity, multi-cavity module
- Auto compensation of the input offset (DAC, VM)
- Parameters identification for:  
each one cavity, multi-cavity module
- Auto calibration of the cavities channels
- Auto correction of the klystron channel (linearization)
- Control tables determination:  
Set-Point, Feed-Forward, Complex Gain

# CONCLUSION

- Electrical model of the SC cavity has been verified for control purpose
- Algebraic model of the cavity environment has been effectively used for correction and calibration of signal path
- Feed Forward and Feedback control has been performed successfully