Multi-Cavity Complex Controller for Low Level Radio Frequency System

Accelerator studies - September 2007, January 2008

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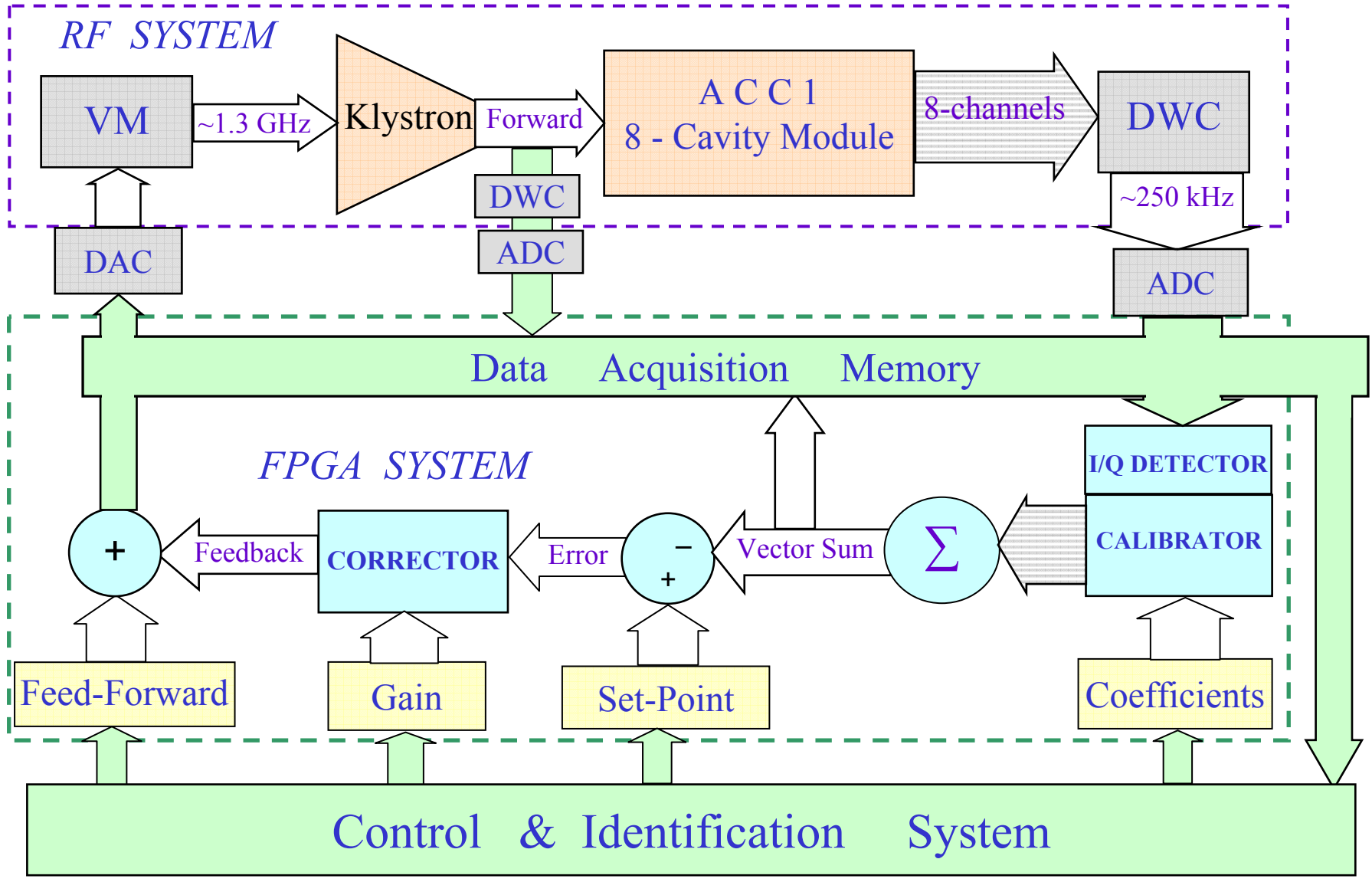
Motivation and goal of the experiments

Development of the Multi-Cavity Complex Controller based on the system parameters identification

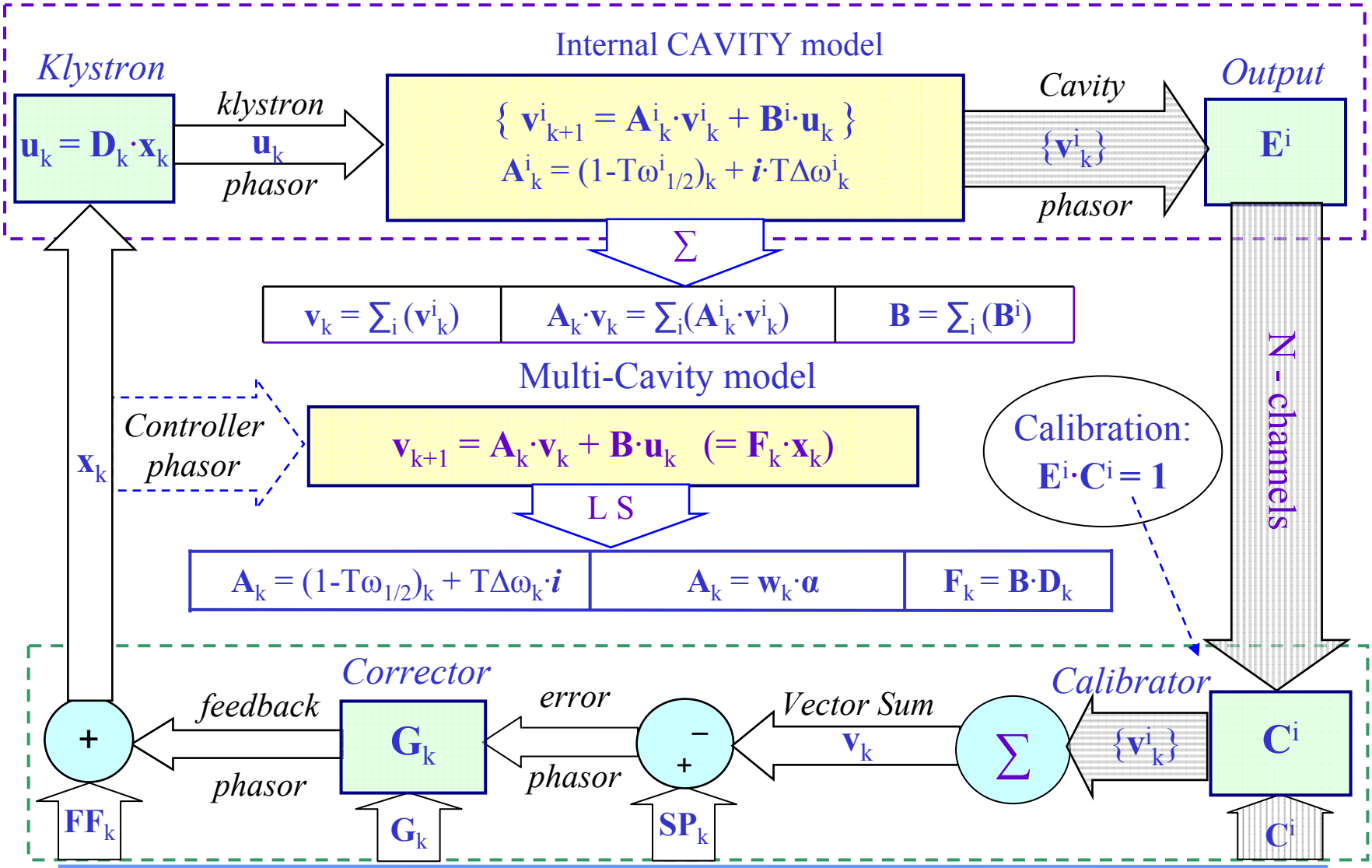
Main topics of the presentation

- System setup
- Control system algorithm
- Experimental results
- Achievements

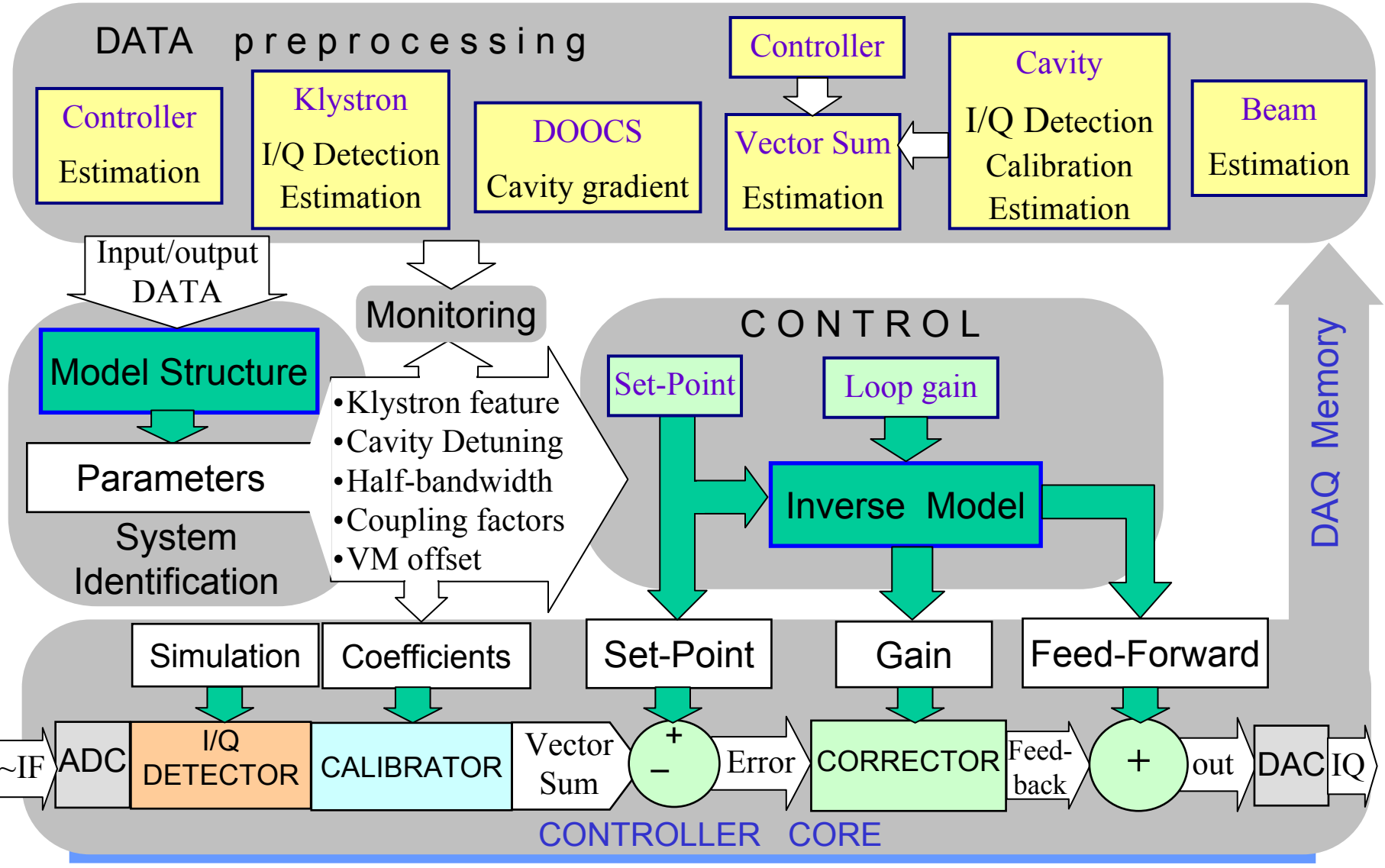
Functional block diagram of Multi-Cavity Control System



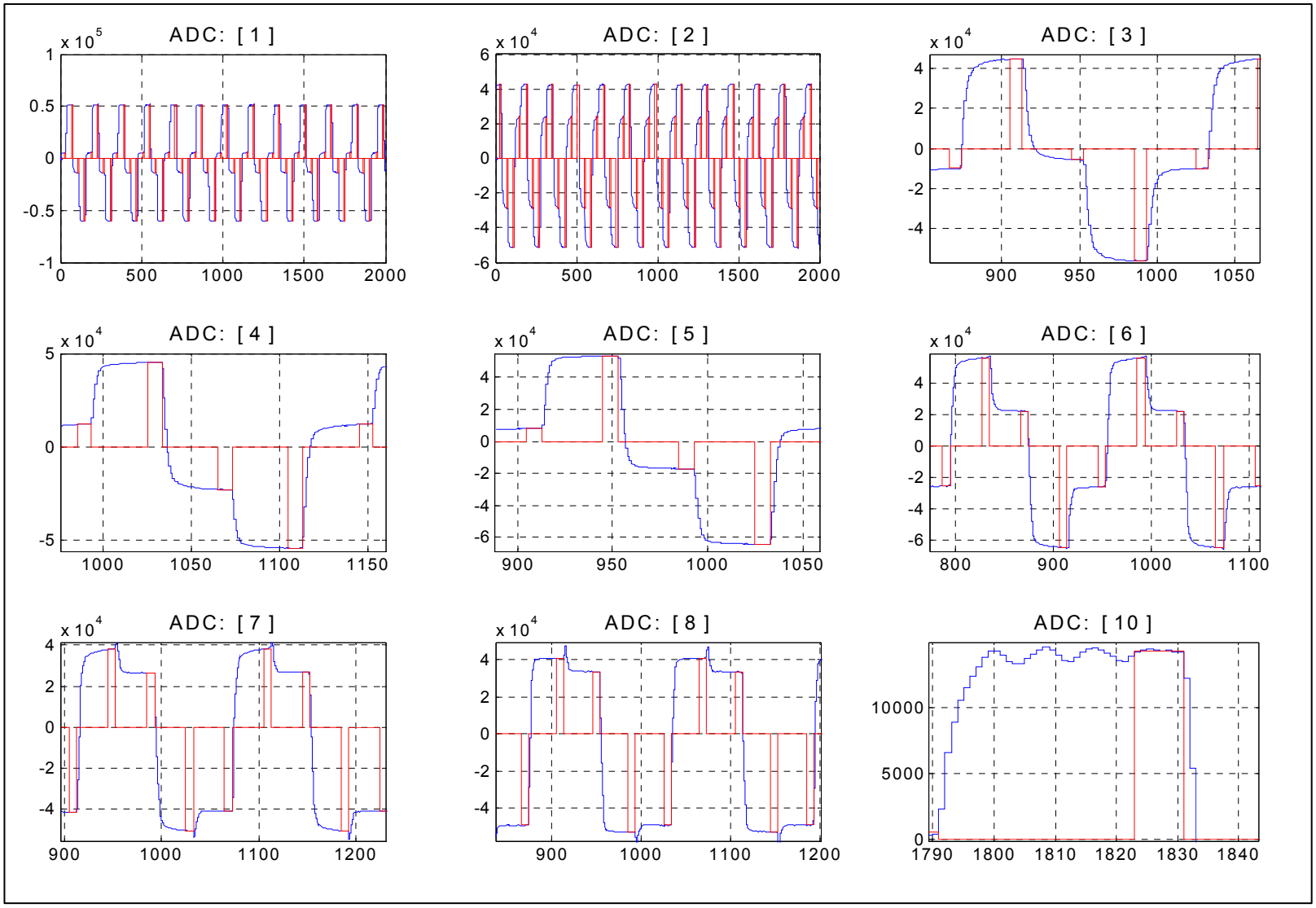
Algebraic model of Multi-Cavity Control System



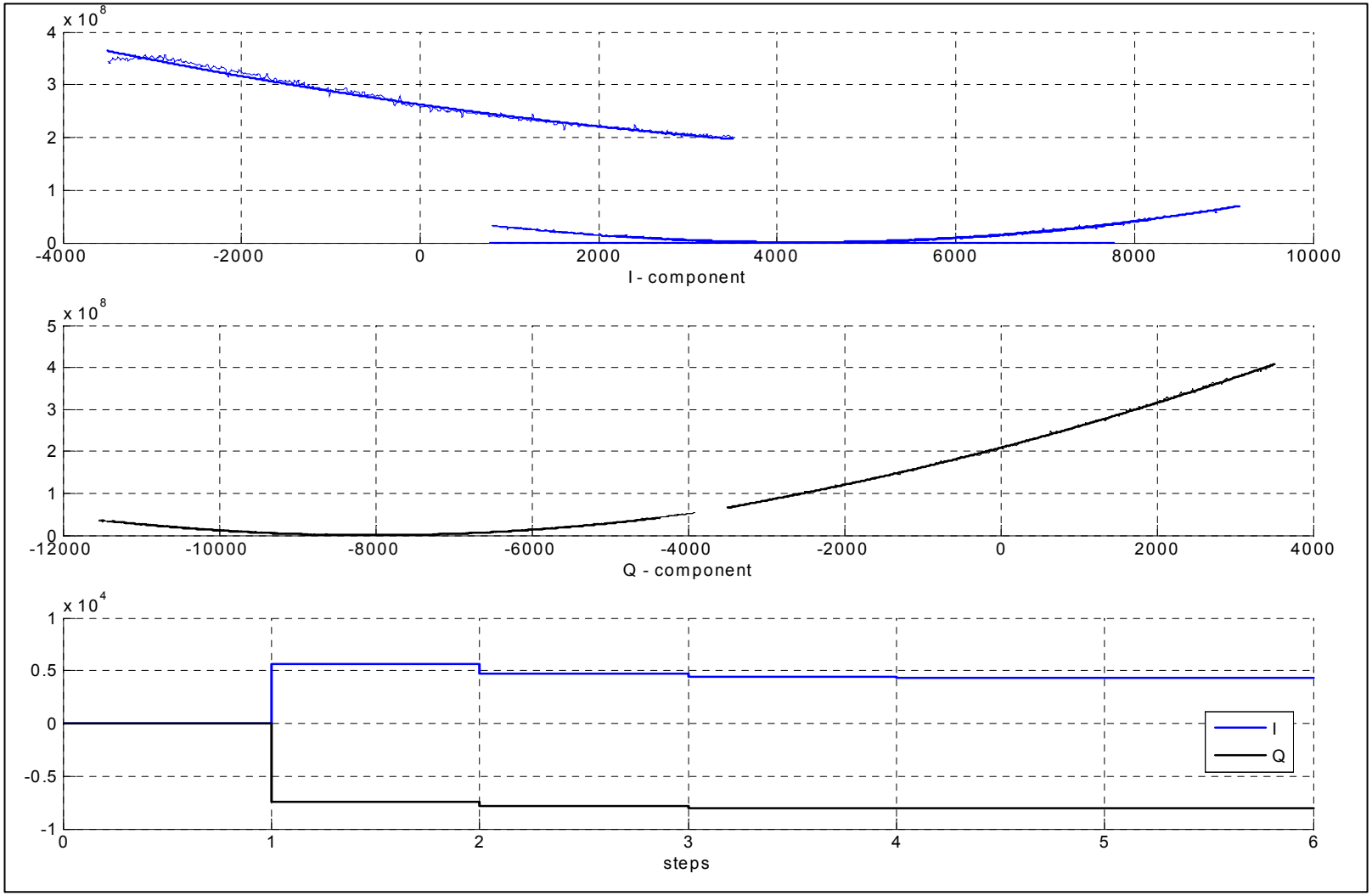
Control & Identification System



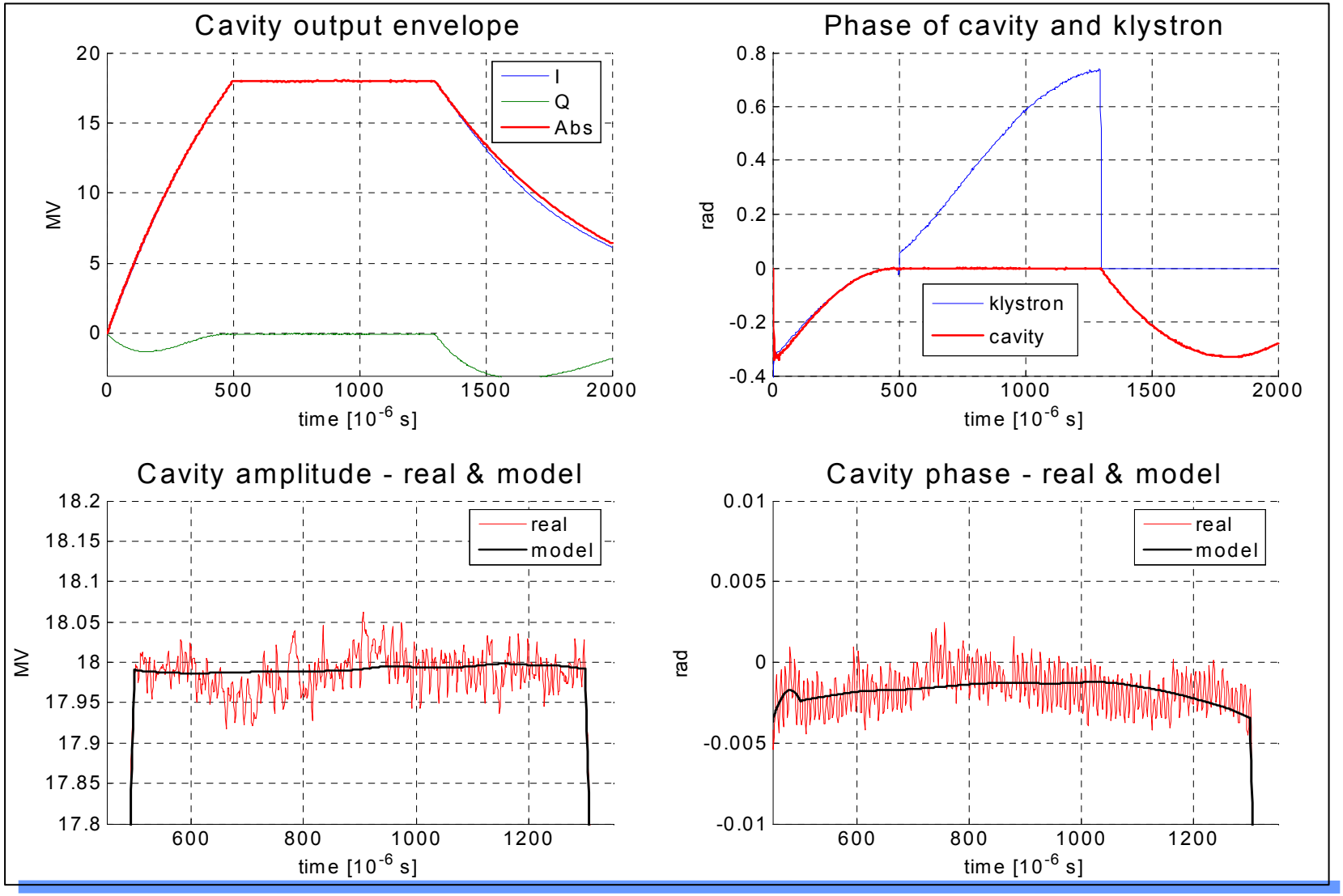
ADC fast readout



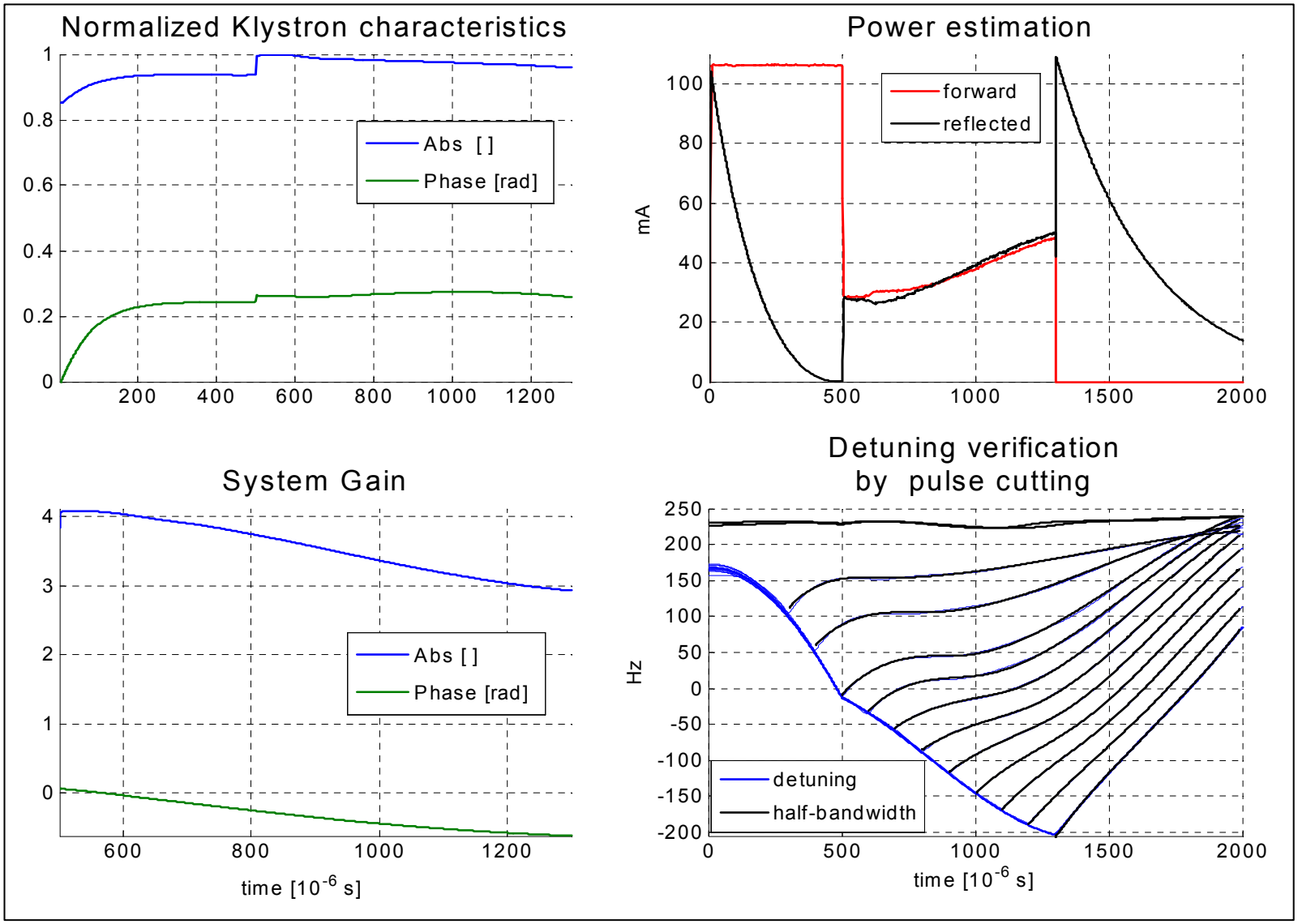
Vector Modulator offset auto-compensation



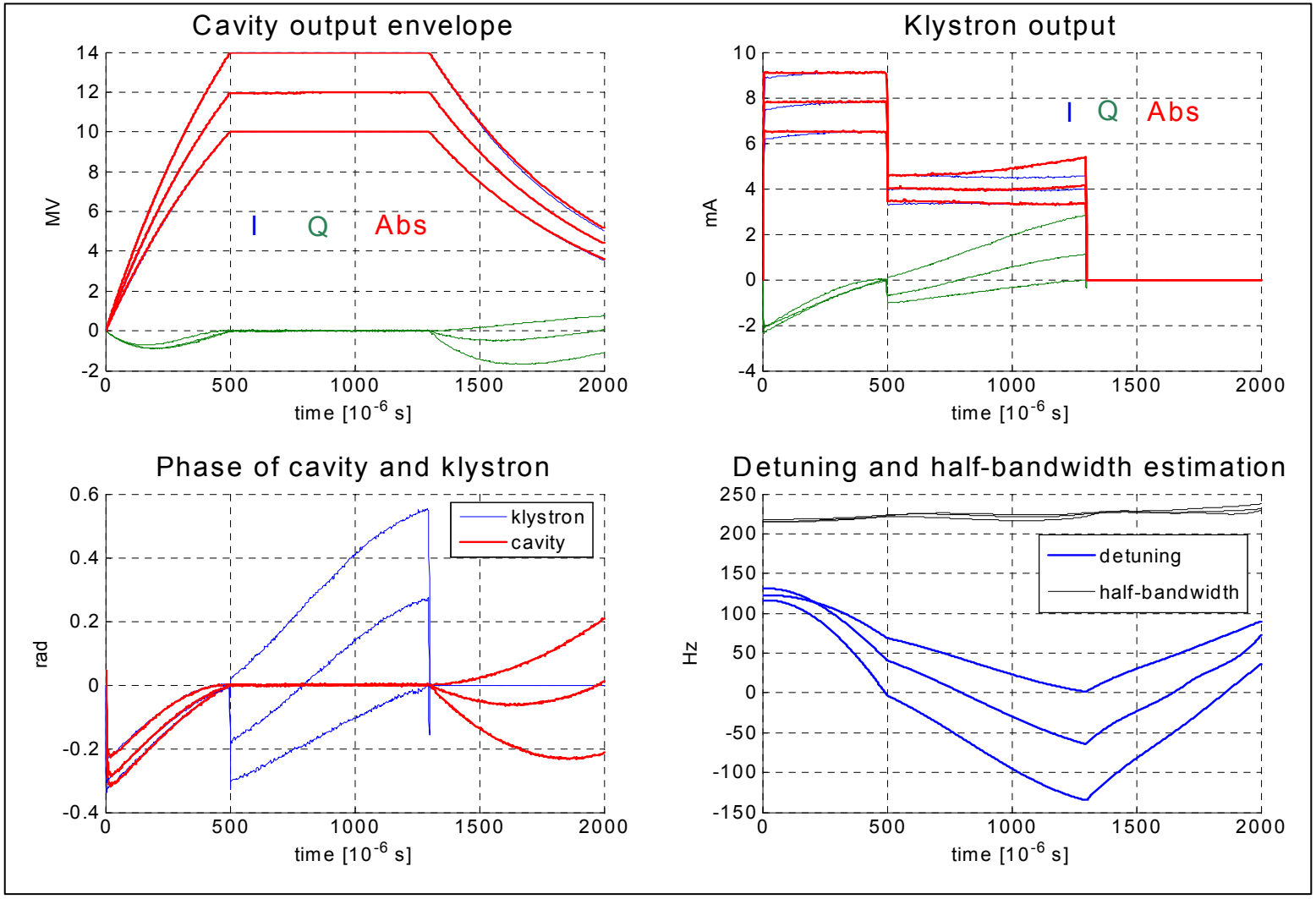
System Identification - Model verification
Cavity 8 – Adaptive Feed-forward (gain=0)



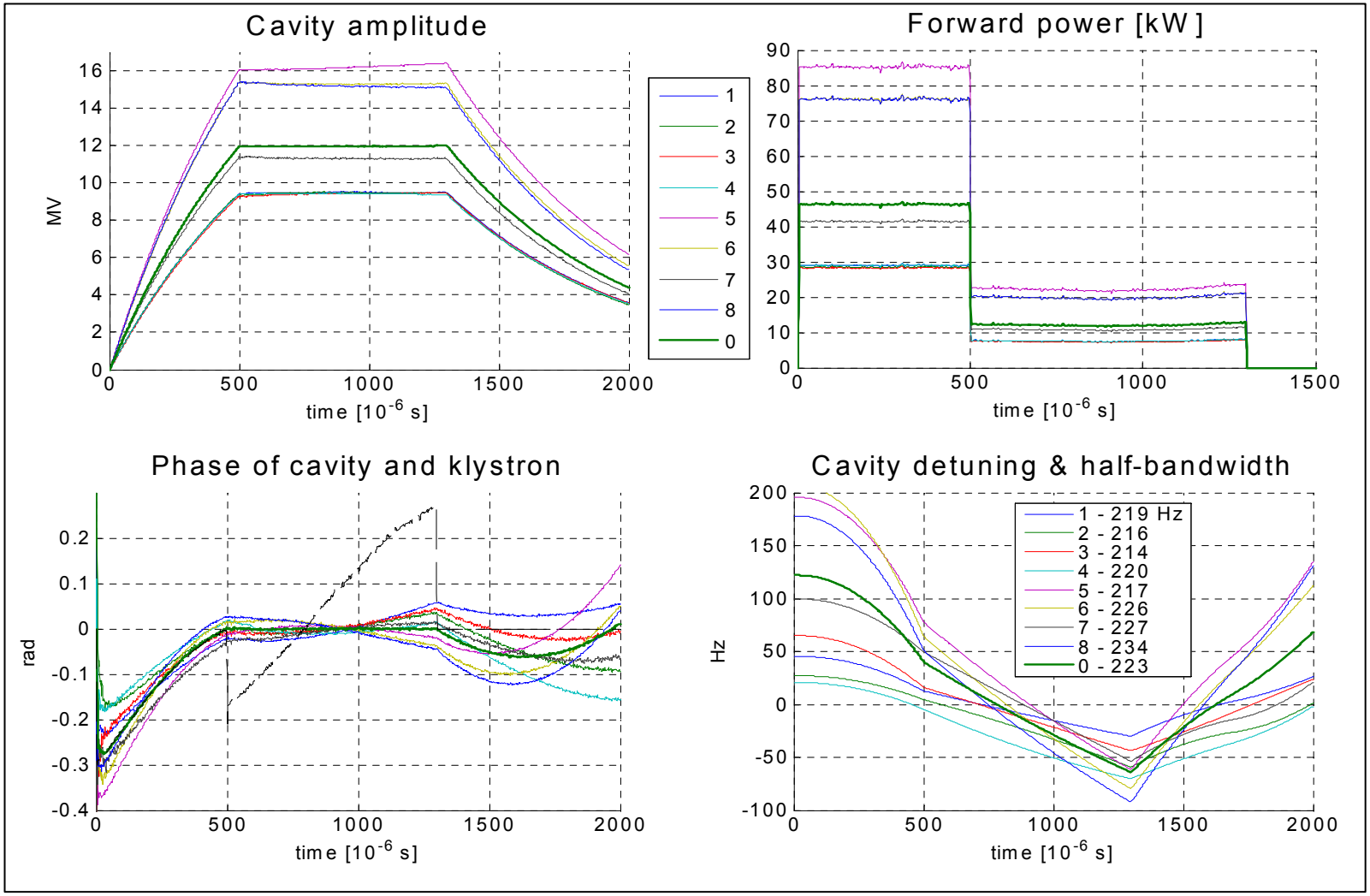
Results from System Identification - Cavity 8



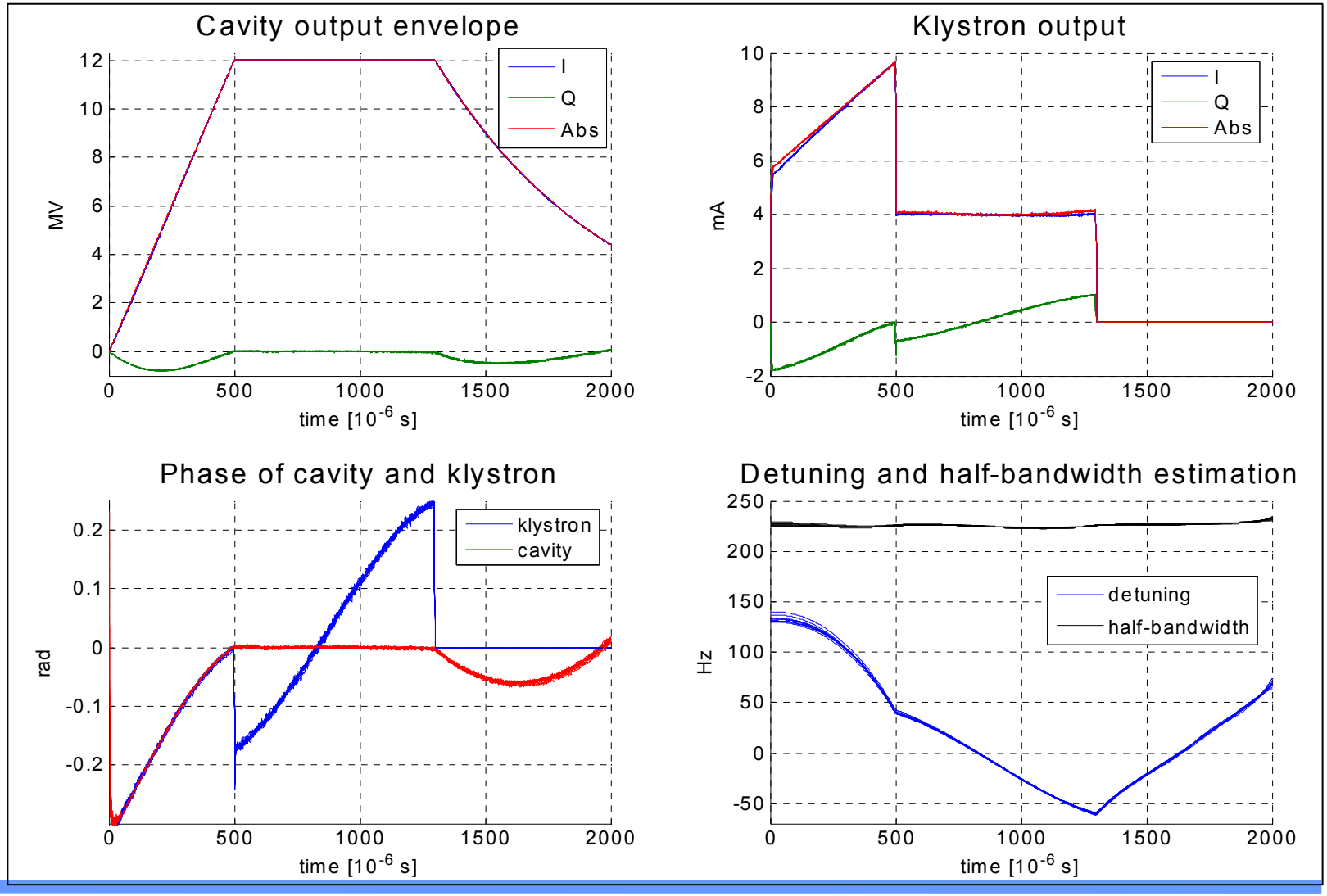
Vector sum control of 8 cavities ACC1
Adaptive Feed Forward (gain=0) for three gradient levels



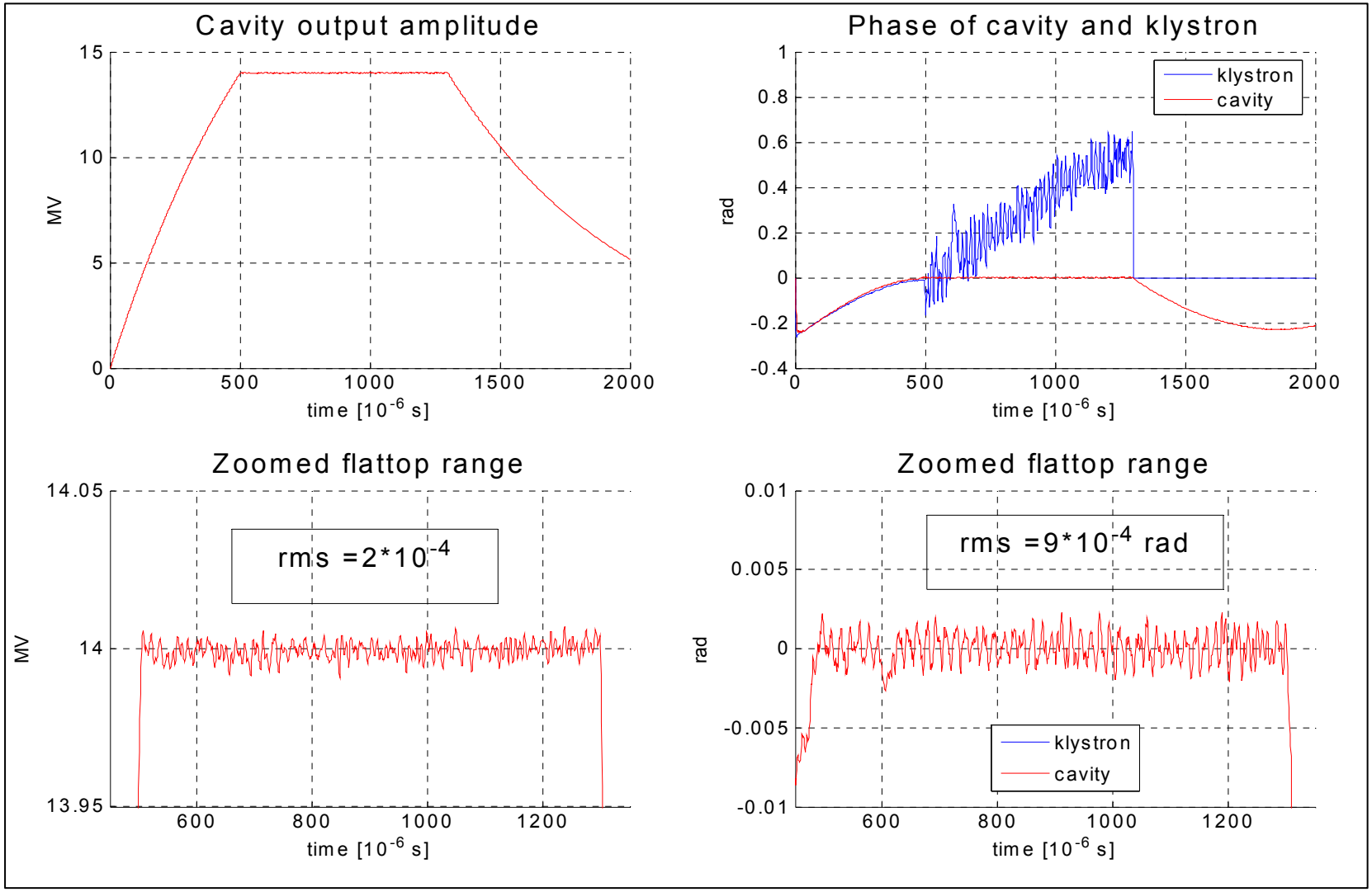
Vector sum control of 8 cavities
Adaptive Feed Forward – all cavities monitoring



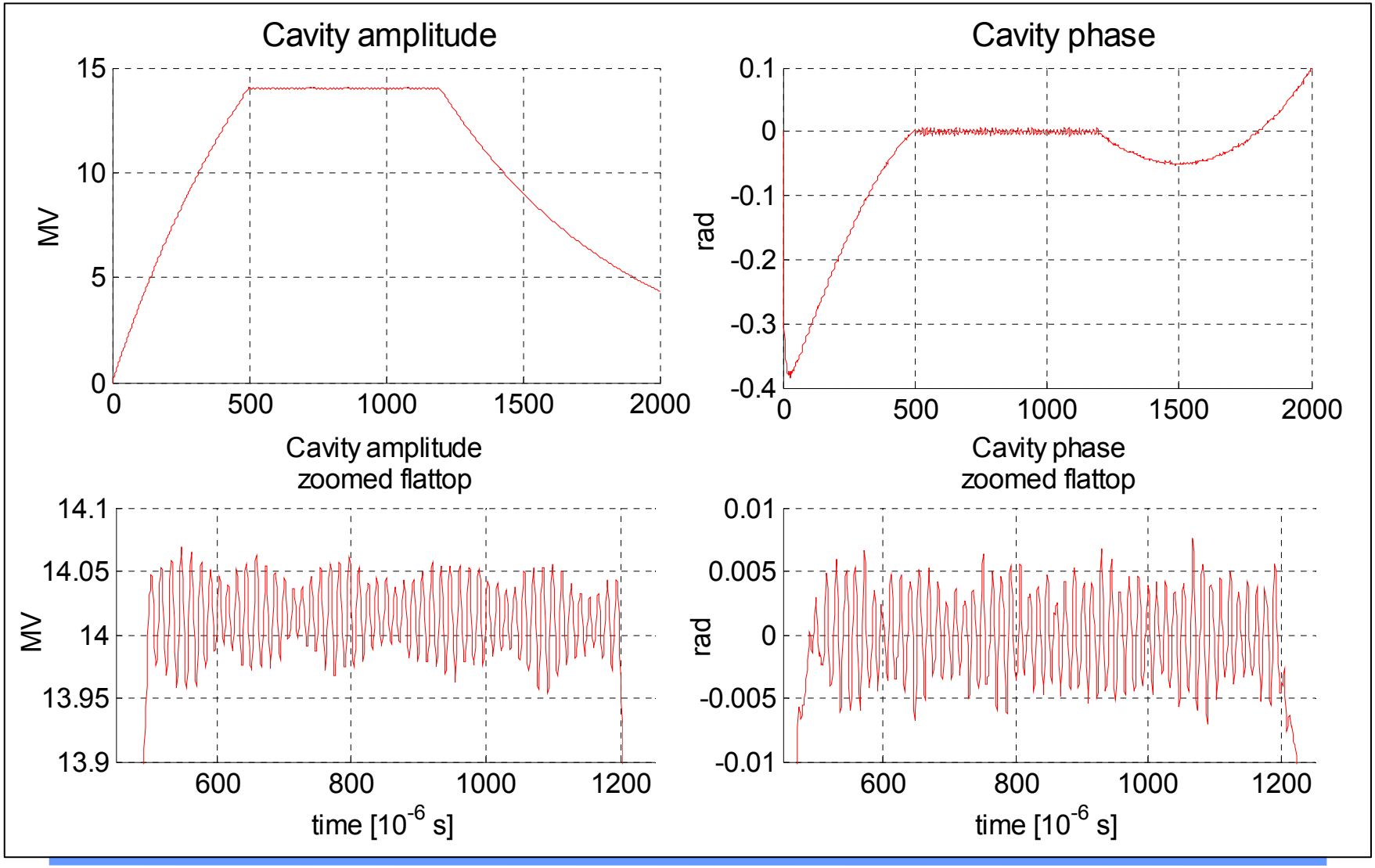
Vector sum control of 8 cavities ACC1
Adaptive Feed Forward (gain=0) - 10 repetition readouts



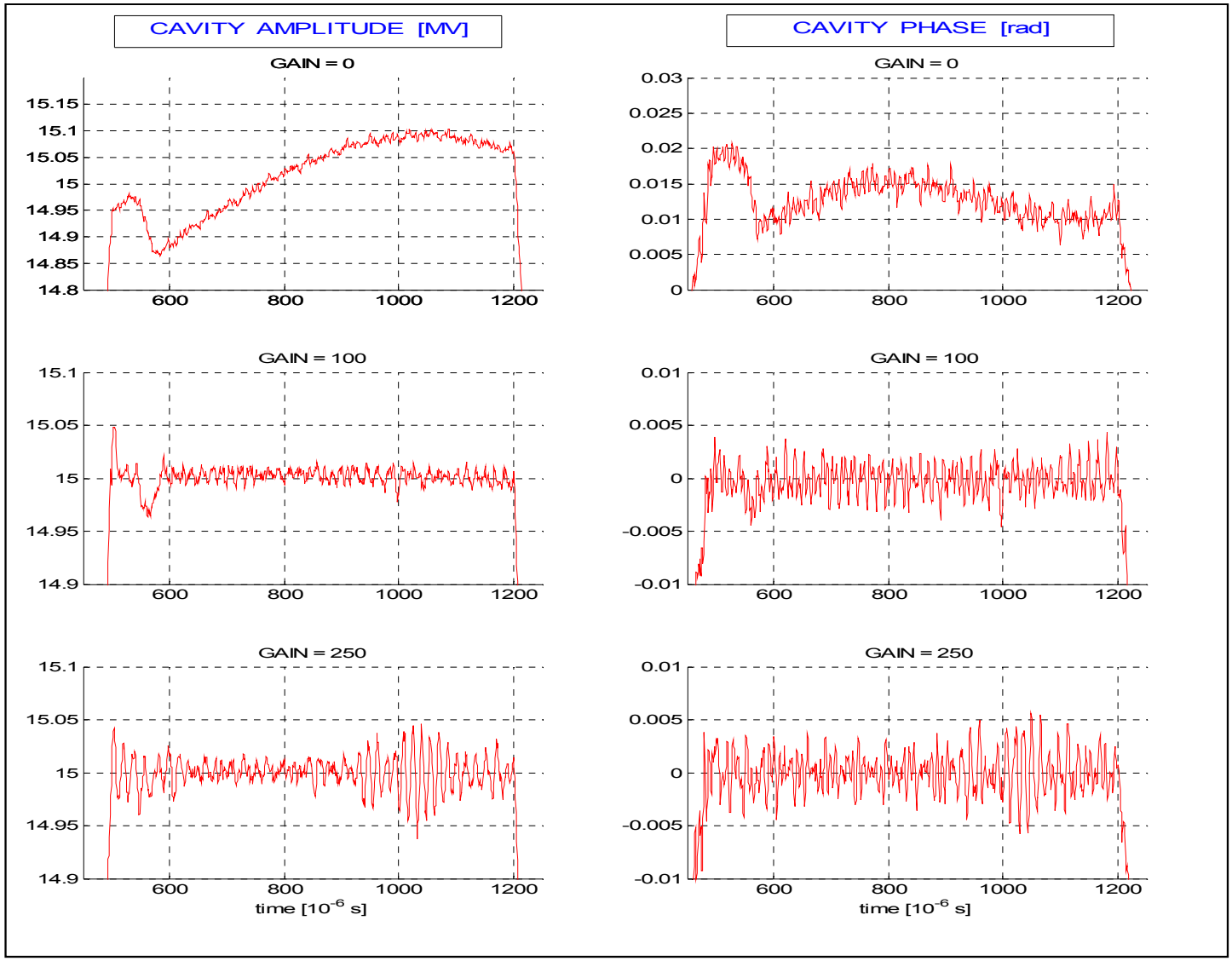
Vector sum control of 8 cavities – ACC1
Feed Forward and feedback (gain=100)



Vector sum control of 8 cavities – ACC1
Feed Forward and feedback (gain = 300)



Beam loading testing



Cavity filling optimization

The *energy efficiency* η_f for filling range t_f

$$\eta_f = \frac{\text{stored energy}}{\text{expended energy}} = \frac{W(t_f)}{\int_0^{t_f} P_f(t)dt}$$

Optimal condition for cavity model

$$\frac{d}{dt}\mathbf{v}(t) = \left(-\omega_{1/2} + \boldsymbol{j}\Delta\omega(t)\right)\cdot \mathbf{v}(t) + \mathbf{u}(t)$$

- phase

$$\angle\mathbf{u}(t) = \angle\mathbf{v}(t) = \varphi(t) \Leftrightarrow \frac{d}{dt}\varphi(t) = \Delta\omega(t)$$

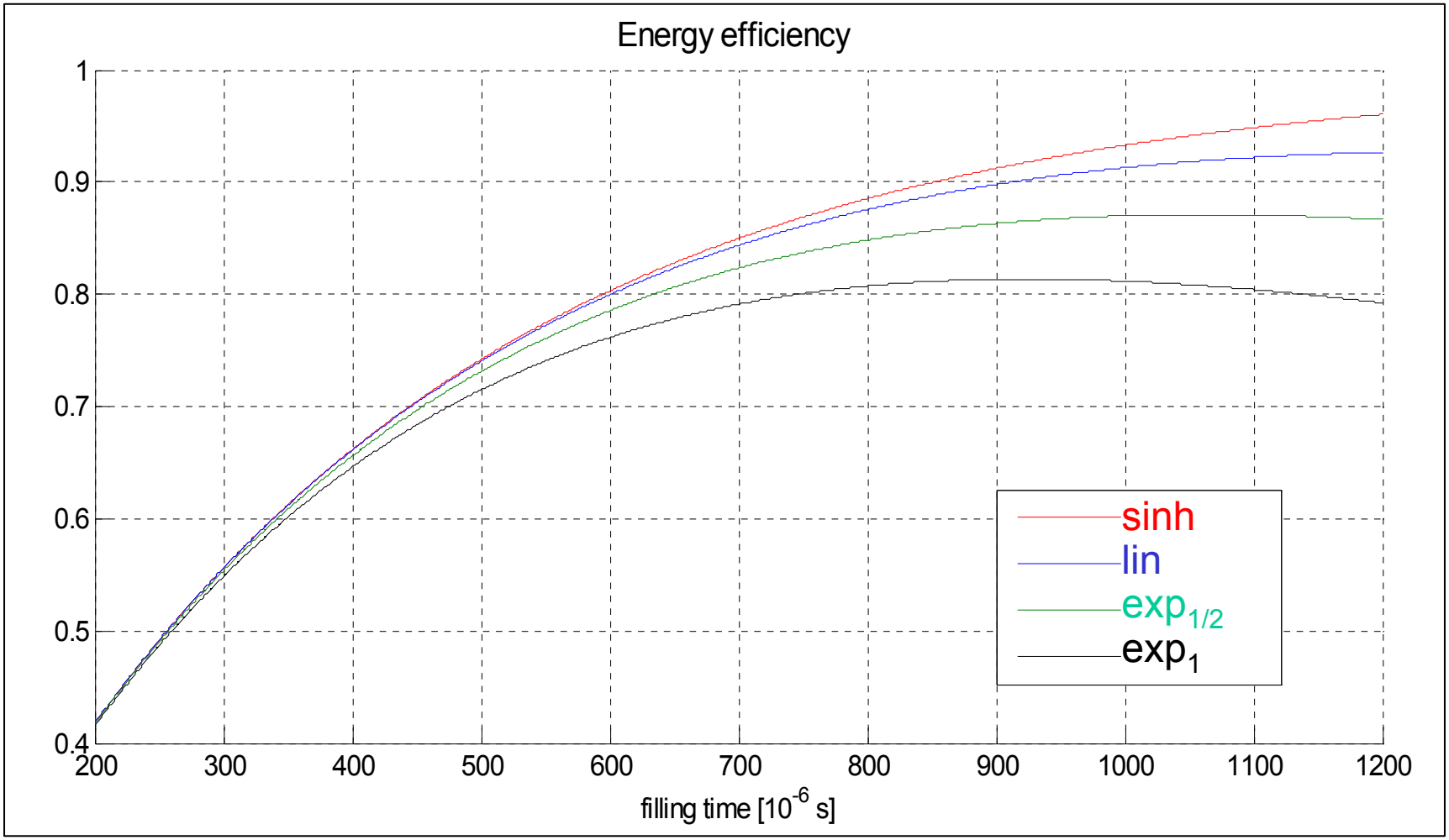
- amplitude

$$v(t) = v(t_f)\cdot\frac{\sinh(\omega_{1/2}t)}{\sinh(\omega_{1/2}t_f)}$$

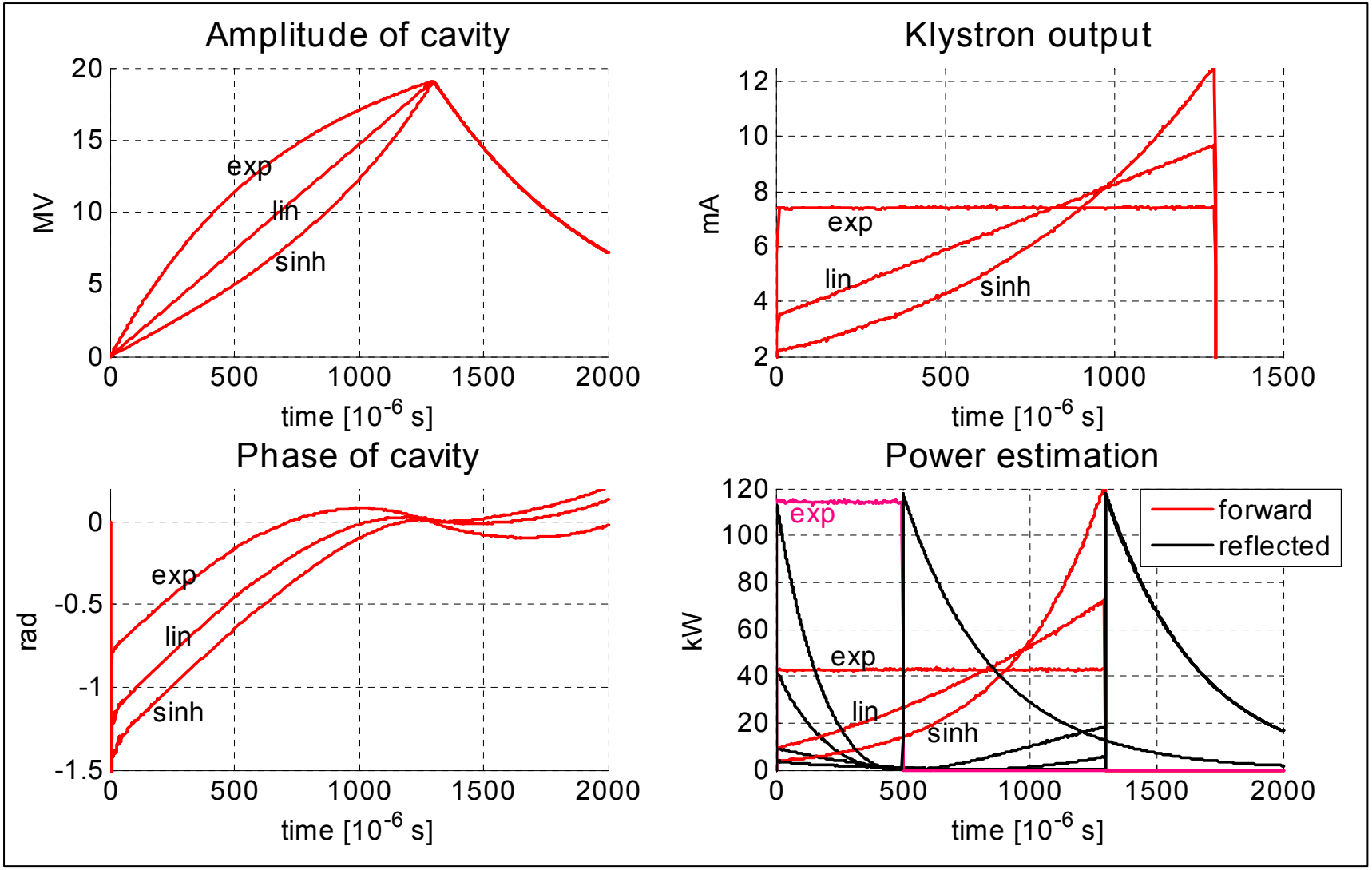
Optimal energy efficiency

$$\eta_{fo} = 1 - \exp(-2\omega_{1/2}t_f)$$

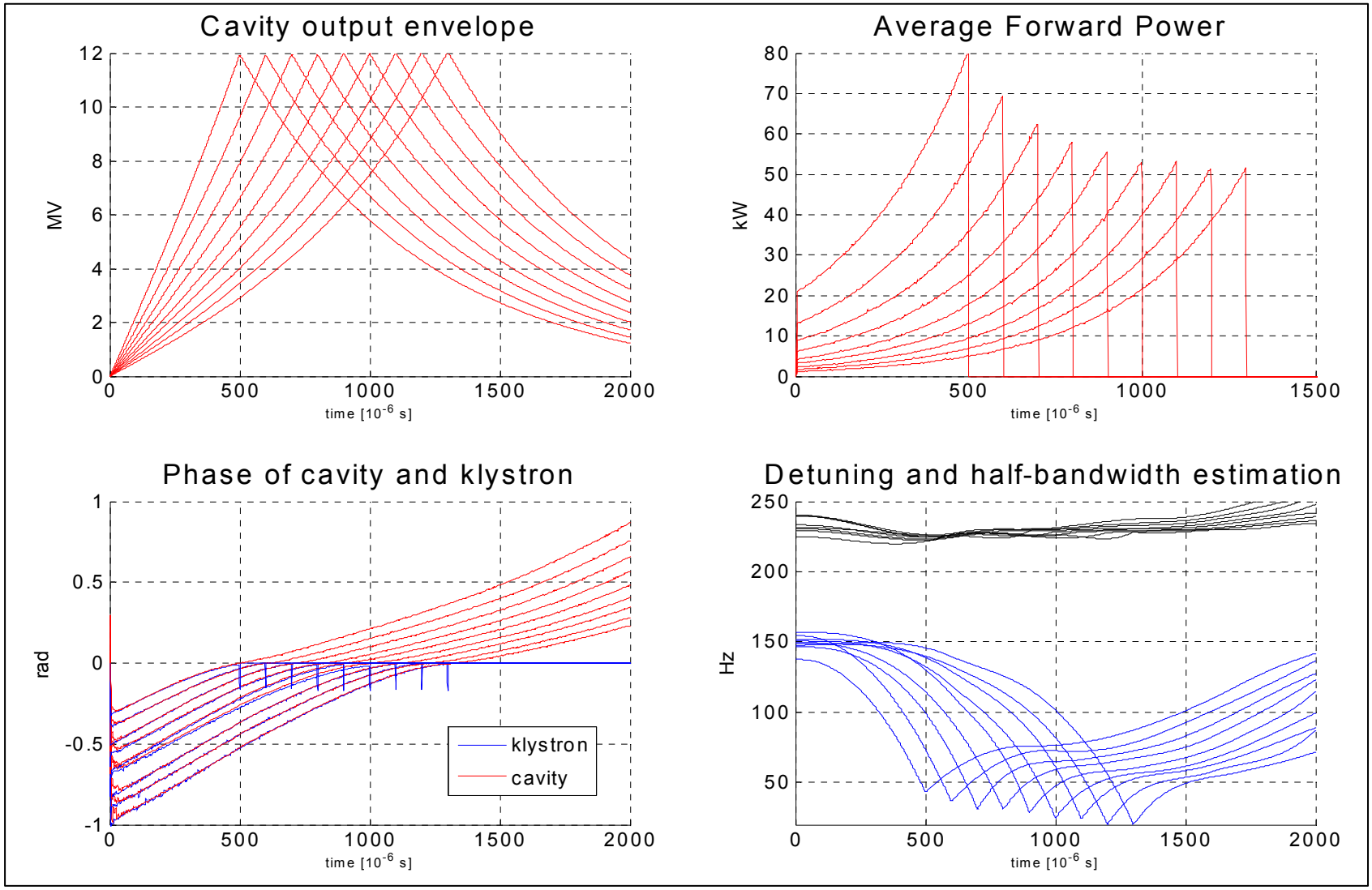
The energy efficiency as a function of filling time for different amplitude trajectories of cavity model



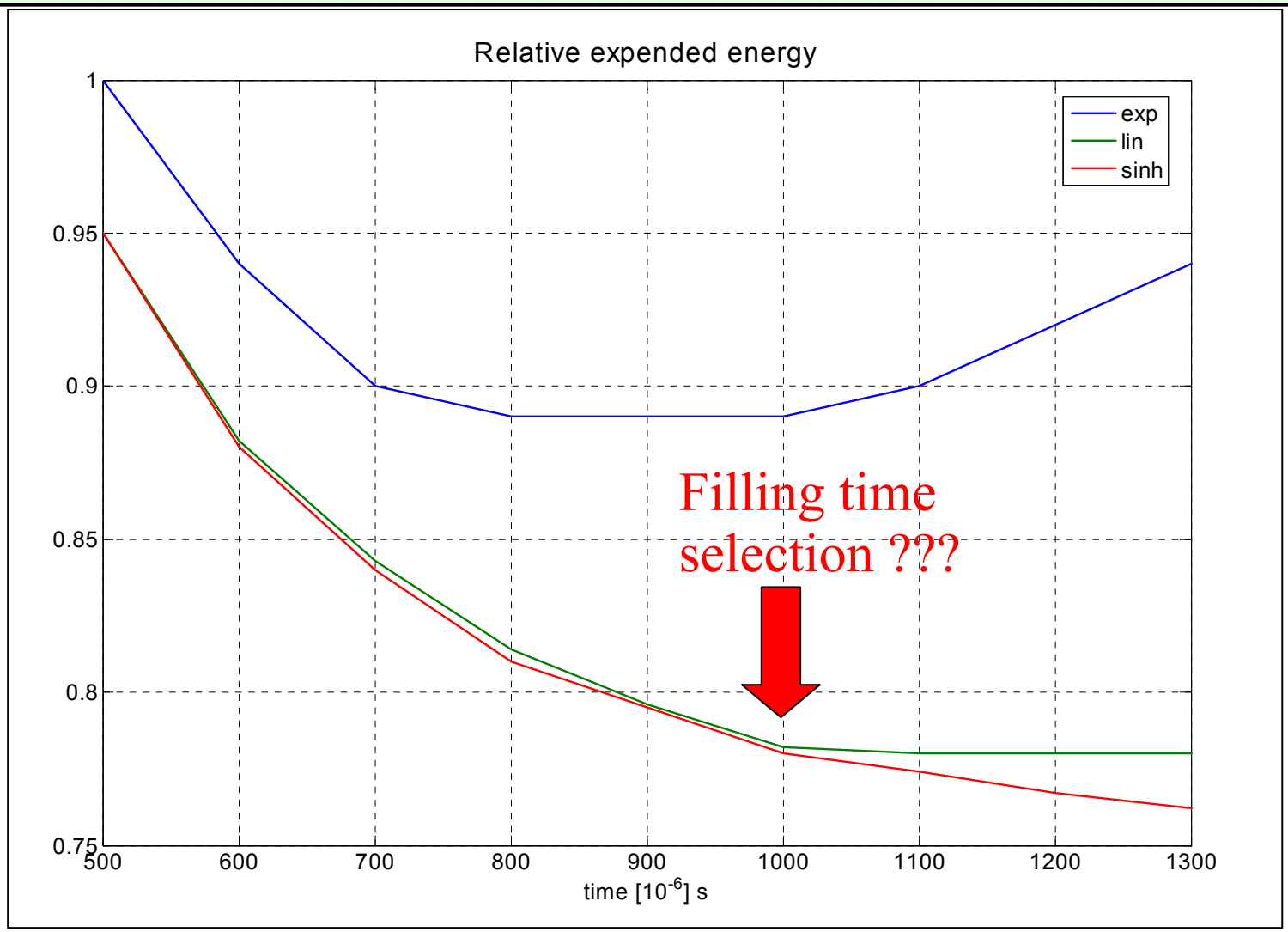
Single cavity filling (Cavity 8) for three trajectories under resonance condition



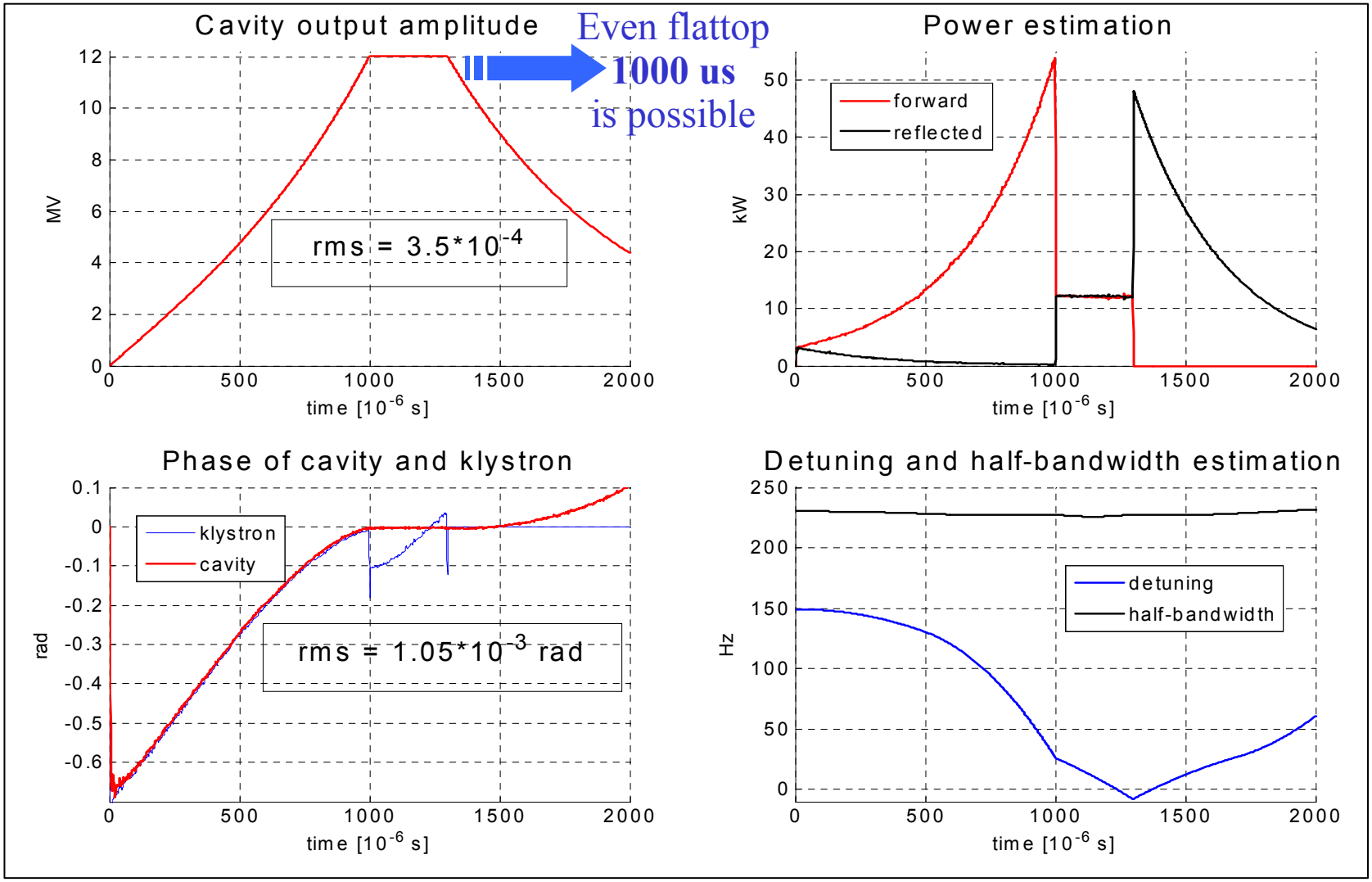
Multi-Cavity (ACC1) optimal (sinh) filling for ranges 500:1300 us



Relative expended energy as a function of filling time for different amplitude trajectories of the Multi-Cavity (ACC1)



Vector Sum Control for optimal filling
Adaptive Feed Forward (gain = 0)



Achievements

- The parameters identification algorithm has been verified
- The control algorithm based on parameters identification has been confirmed for feed-forward and feedback modes for all single cavities and vector sum
- The long flattop range = 800 us was applied in most cases
- The loop gain value of ~300 has been achieved for the vector sum control
- The required cavity performance has been fulfilled : driving under the resonance during filling and field stabilization for the flattop range
- Achieved field stabilization:
  amplitude relative accuracy ~ $2 \cdot 10^{-4}$, phase accuracy ~ $9 \cdot 10^{-4}$ rad.
- The diverse filling ranges have been tested for different output trajectories Adaptive FF and SEL have been applied
- Cavity filling optimal condition has been proposed