Cavity Controller Simulations

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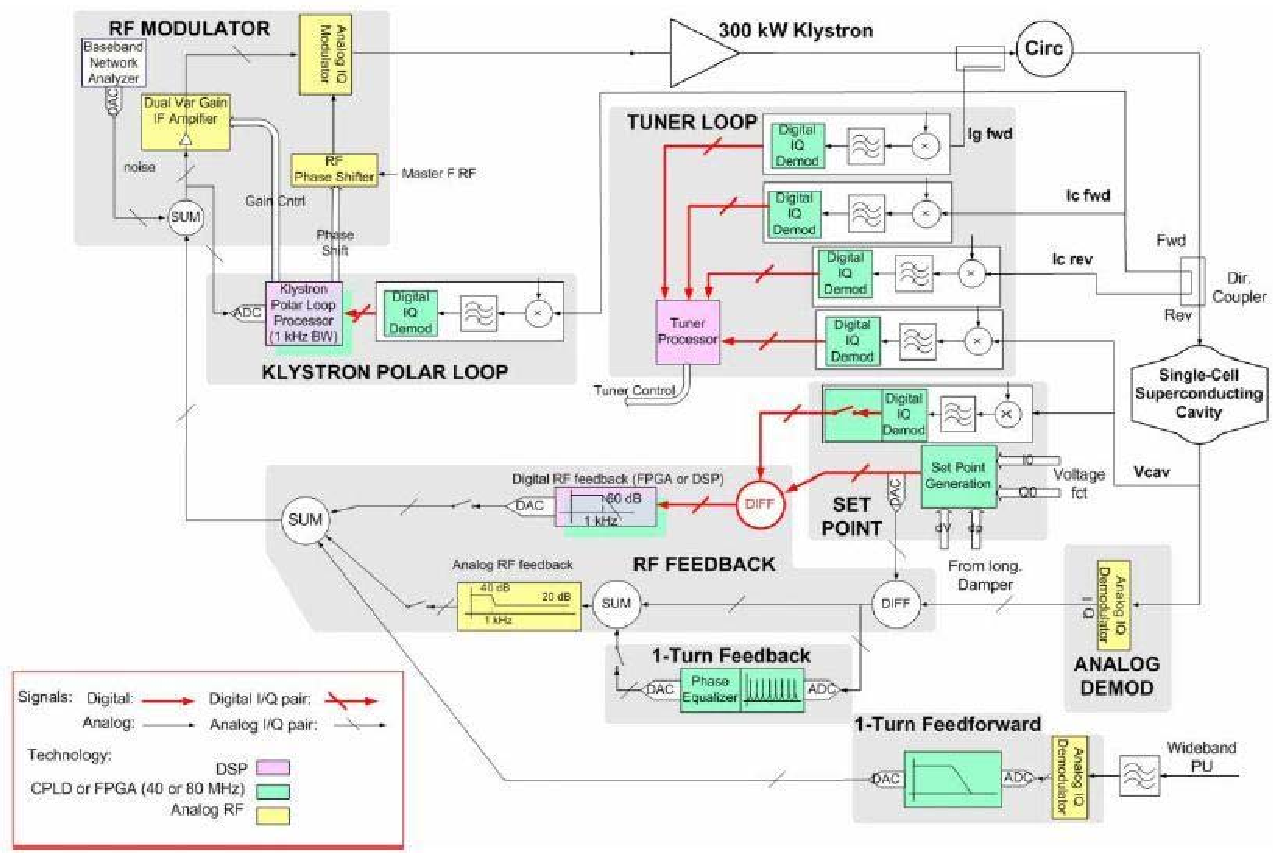
Topics

1. The Aim of the Simulations
2. The Present Model of the Cavity Controller
3. The Model of the Klystron
4. The Model of the Cavity
5. The Other Functional Blocks
6. Results and Notations
7. Next Steps

The Aim of the Simulations

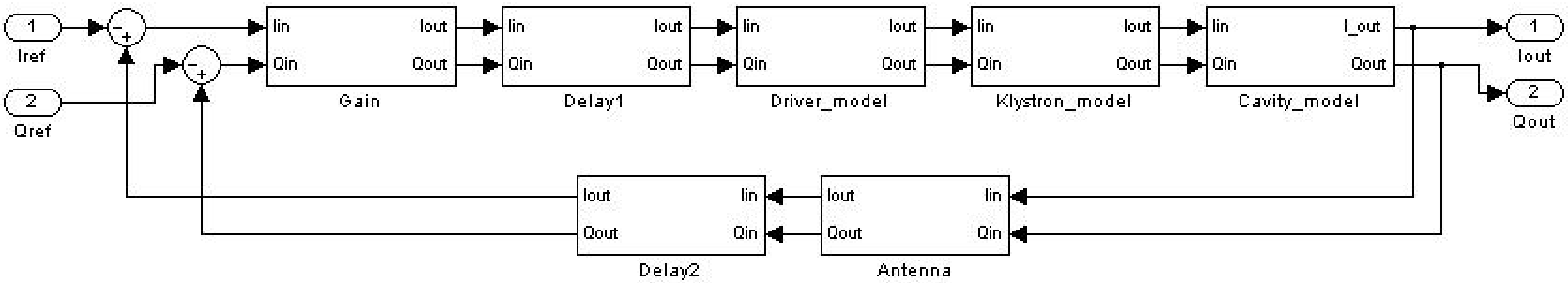


The cavity controller

The Aim of the Simulations

- The cavity controller includes a klystron which has very non-linear behavior
- Linear control theory does not necessary give optimal settings for the controller
- The simulation model will be used in designing control algorithms for the cavity controller: everything is not needed to be tested with hardware
- MATLAB and Simulink are used as tools

The Present Model of the Cavity Controller

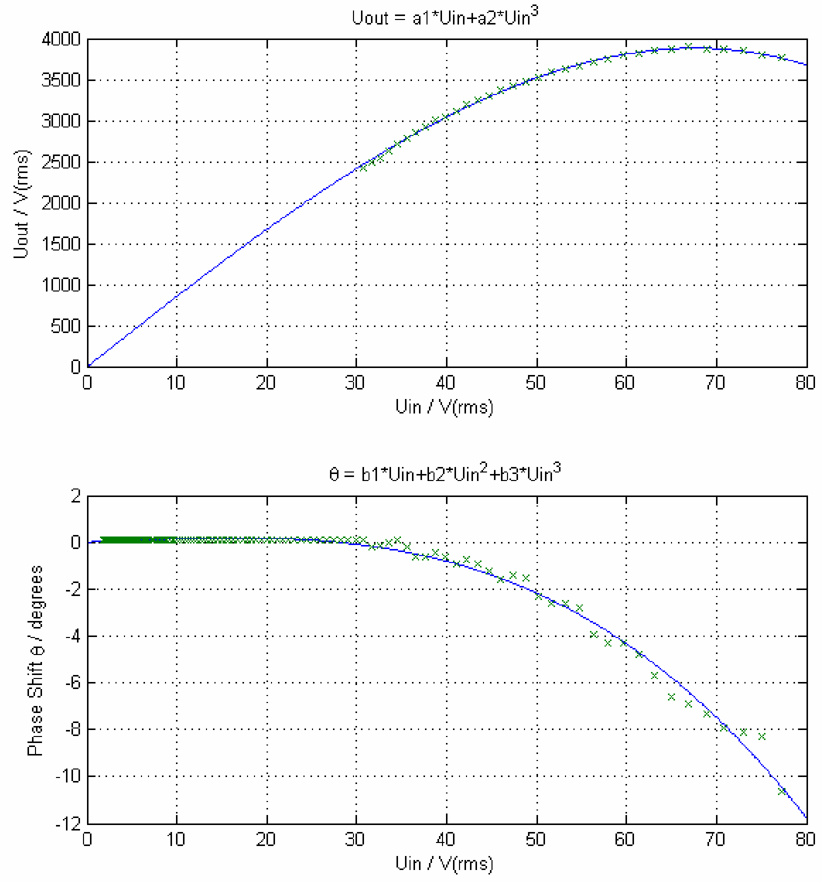


The simulation model of the cavity controller

- The models of the klystron, the cavity and the driver have been designed and implemented
- The other blocks perform basic functionalities: delay and gain

The Model of the Klystron

- Klystron is very non-linear device: its gain and phase shift depends on the amplitude of the input signal
- The model is based on measured AM-AM and AM-PM curves (with the CW 400.8 MHz signal) [1]



AM-AM and AM-PM curves of a klystron

The Model of the Klystron

- For an input $x(t) = A\cos(\omega_0 t)$
  the output is $y(t) = f(A)\cos(\omega_0 t) + g(A))$,
  in which *f(A)* describes AM-AM characteristics
  and *g(A)* AM-PM characteristics of the klystron
- The klystron is assumed to be frequency independent because of its large bandwidth (>10 MHz)
- A band-limited signal *x(t)* centered on a carrier frequency ω_o can be expressed as

$$x(t) = I(t)\cos(\omega_0 t) - Q(t)\sin(\omega_0 t)$$

The Model of the Klystron

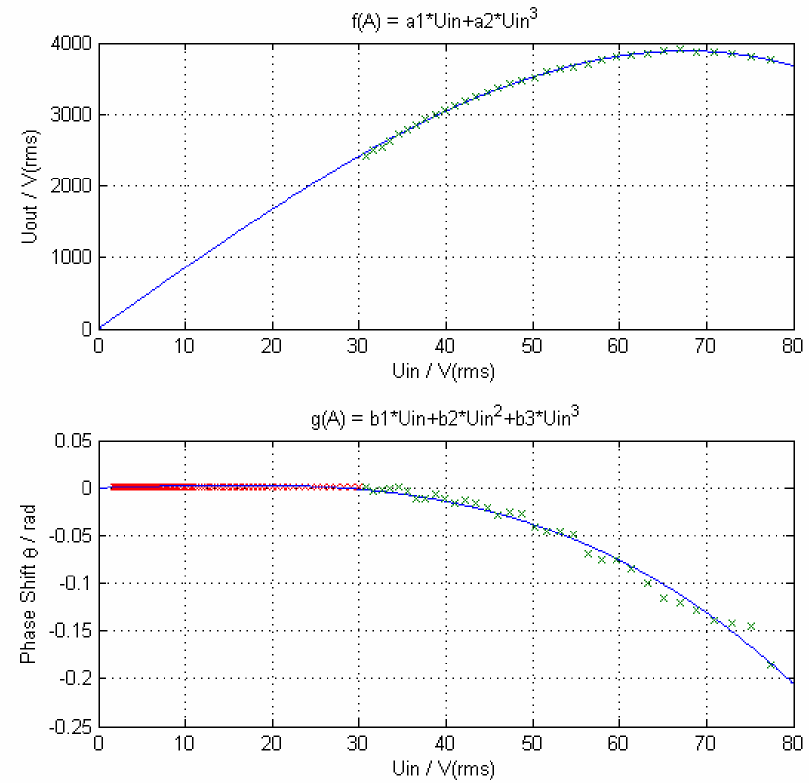
- In Cartesian coordinates the klystron can be presented as

$$\begin{bmatrix} I' \\ Q' \end{bmatrix} = f(A) \begin{bmatrix} \cos(g(A)) & -\sin(g(A)) \\ \sin(g(A)) & \cos(g(A)) \end{bmatrix} \begin{bmatrix} I \\ Q \end{bmatrix}$$

  in which I and Q are the base band input signals, I' and Q' the outputs and

$$A = \sqrt{I^2 + Q^2}$$

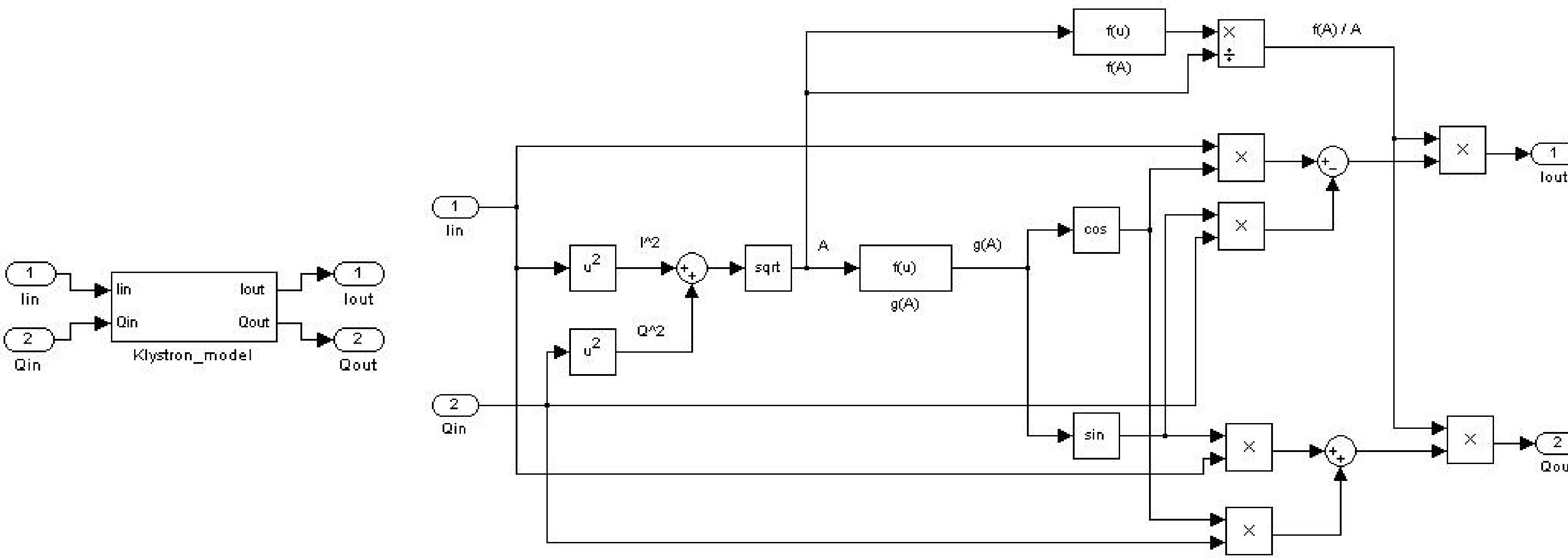
- The equations for f(A) and g(A) are found with the means of regression analysis



The fitted curves for f(A) and g(A)

The Model of the Klystron

- Implementation of the model in Simulink



The model of the klystron in Simulink

The Model of the Cavity

- Contradictory to the klystron, the cavity is assumed to be purely linear but it has very narrow bandwidth (3 – 20 kHz)
- The cavity can be presented as an RLC resonator and the model is based on the transfer functions which have been derived in [2]

- In Cartesian coordinates, the transfer functions are the followings:

$$\begin{bmatrix} I' \\ Q' \end{bmatrix} = \begin{bmatrix} H_S(s) & -H_C(s) \\ H_C(s) & H_S(s) \end{bmatrix} \begin{bmatrix} I \\ Q \end{bmatrix}$$

in which

$$H_S(s) = \sigma R \left[\frac{s + \sigma\left(1 - \frac{\Delta\omega}{\omega_D}\right)}{(s+\sigma)^2 + (\Delta\omega)^2} \right]$$

and

$$H_C(s) = \frac{\sigma^2 R}{\omega_D} \left[\frac{s + \left(\sigma + \frac{\omega_D \Delta\omega}{\sigma}\right)}{(s+\sigma)^2 + (\Delta\omega)^2} \right]$$

The Model of the Cavity

- The transfer functions:

$$\begin{bmatrix} I' \\ Q' \end{bmatrix} = \begin{bmatrix} H_S(s) & -H_C(s) \\ H_C(s) & H_S(s) \end{bmatrix} \begin{bmatrix} I \\ Q \end{bmatrix}$$

$$H_S(s) = \sigma R \left[\frac{s + \sigma\left(1 - \frac{\Delta\omega}{\omega_D}\right)}{(s+\sigma)^2 + (\Delta\omega)^2} \right]$$

$$H_C(s) = \frac{\sigma^2 R}{\omega_D} \left[\frac{s + \left(\sigma + \frac{\omega_D \Delta\omega}{\sigma}\right)}{(s+\sigma)^2 + (\Delta\omega)^2} \right]$$

- In those equations,

$$\sigma = \frac{\omega_0}{2Q_L}$$

$$R = 2\sqrt{\frac{R/Q * Q_L}{Z_0}}$$

$$\omega_D = \sqrt{\omega_R^2 - \sigma^2}$$

$$\Delta\omega = \omega_D - \omega_0$$

- Observing that Q_L>>1, ω_D and $\Delta\omega$ can be simplified:

$$\omega_D \approx \omega_R = \Delta\omega_R + \omega_0$$

$$\Delta\omega \approx \omega_R - \omega_0 = \Delta\omega_R$$

The Model of the Cavity

- The parameters needed for the model are the followings:

  Q_L, the quality factor of the cavity (20 000 – 180 000)

  Z_0, the characteristic impedance of the system (50 Ω)

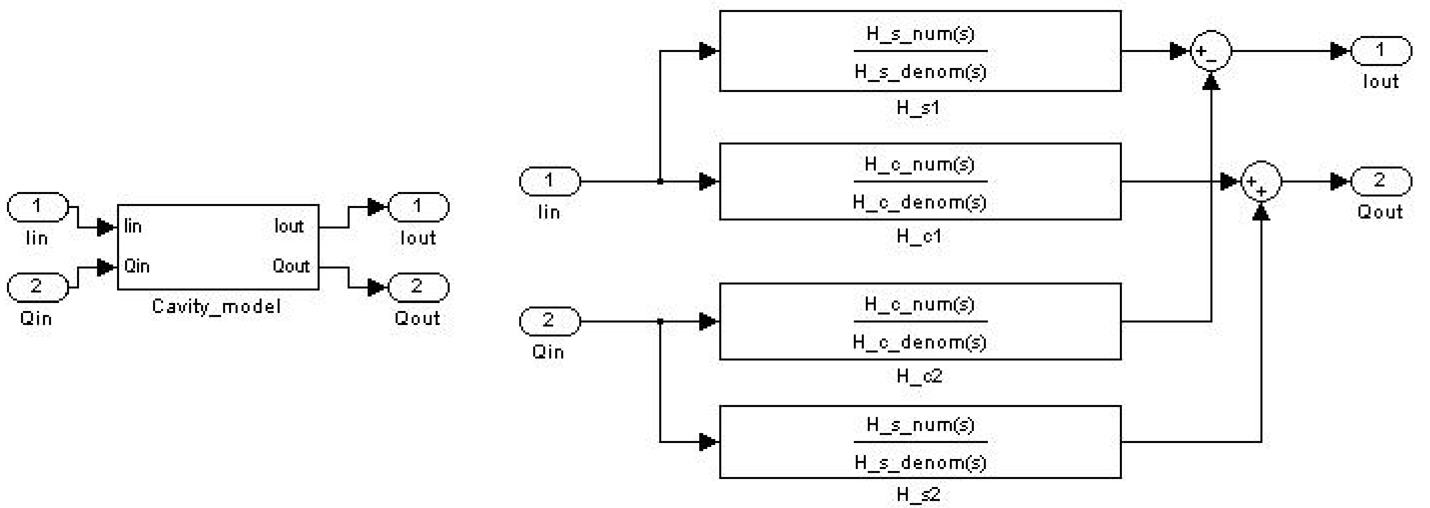
  ω_0, the RF center frequency (400.8 MHz)

  R/Q, the cavity R-over-Q (45 Ω)

  $\Delta\omega_R$, the detuning frequency of the cavity

The Model of the Cavity

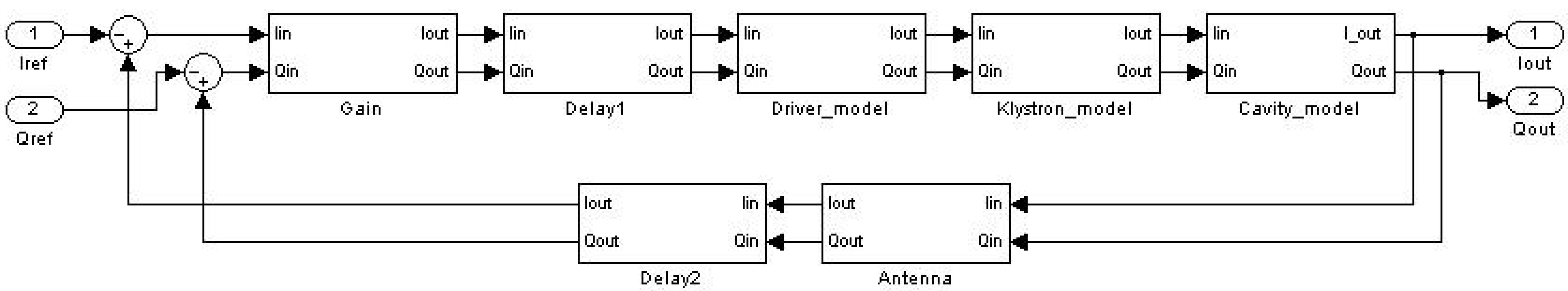
- Implementation of the model in Simulink



The model of the cavity in Simulink

The Other Functional Blocks

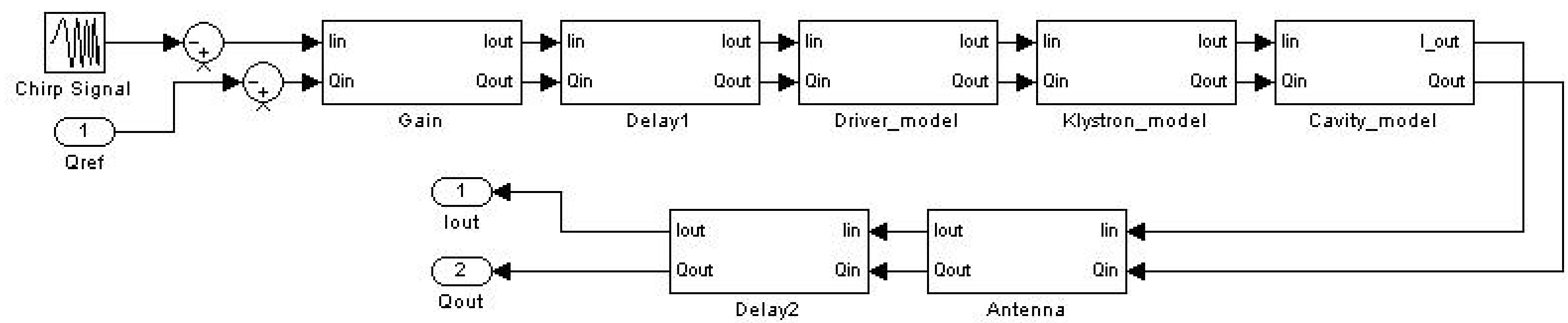
- The driver (preamplifier) sets saturation limits for the klystron
- The antenna measures cavity voltage (gain)
- Delays of the klystron and other components
- The actual value of gain was not known, but it was defined to be optimal



The simulation model of the cavity controller

The Other Functional Blocks

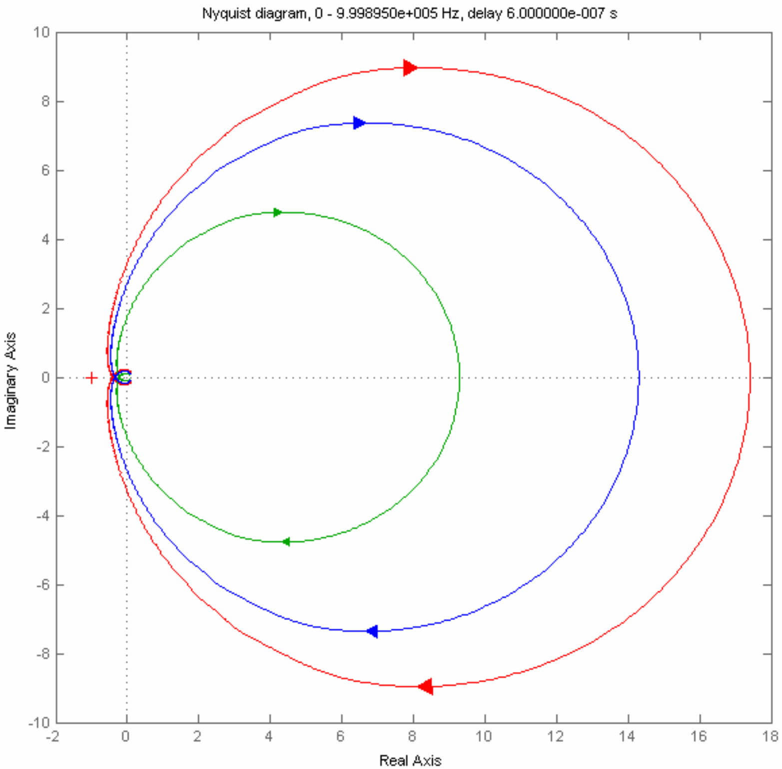
- Defining the gain:
- a chirp signal, the sine wave with changing frequency and small amplitude, was fed into the open loop model
- the ratio of the fast Fourier transforms (FFTs) of the input and the output gave the frequency response of the system
- the gain was increased until the desired gain margin was reached (10 dB)

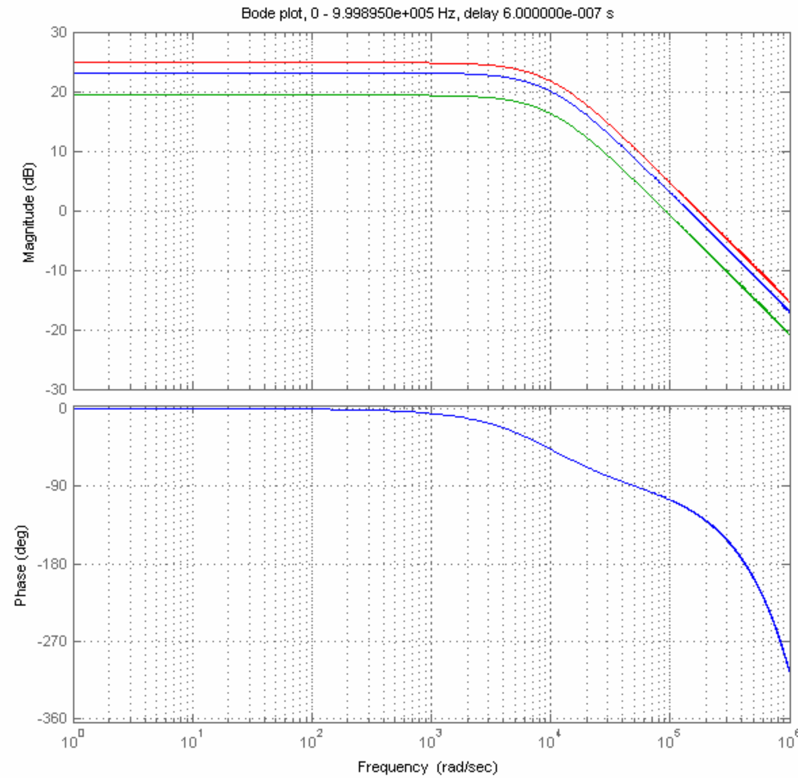


The open loop model

The Other Functional Blocks

- Defining the gain

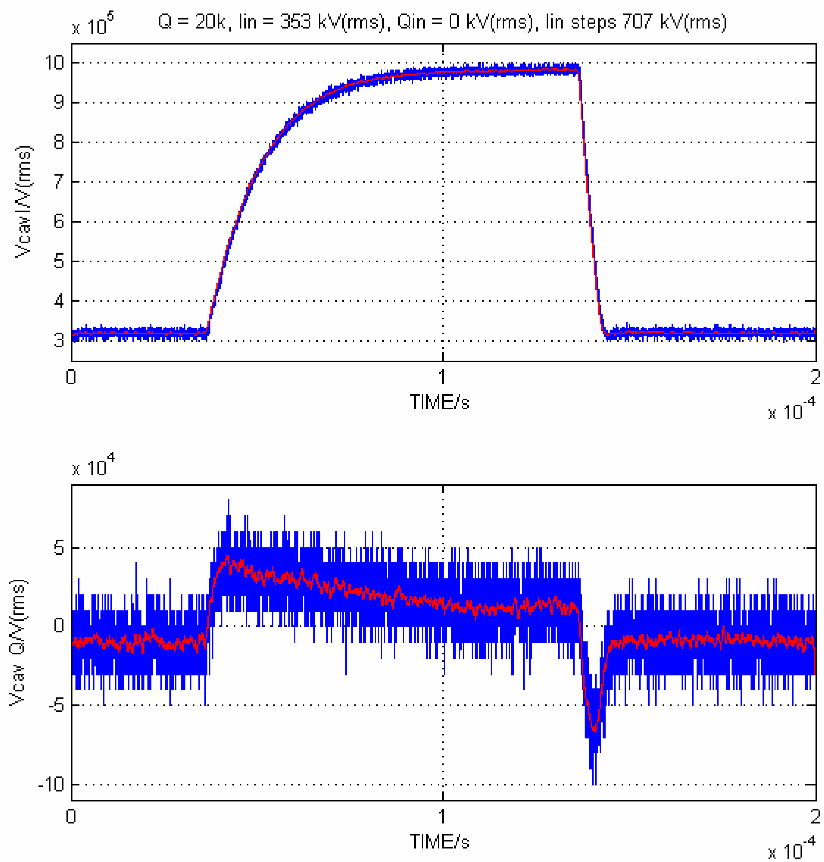




The Nyquist and Bode plots of the open loop model with three values of gain

Results and Notations

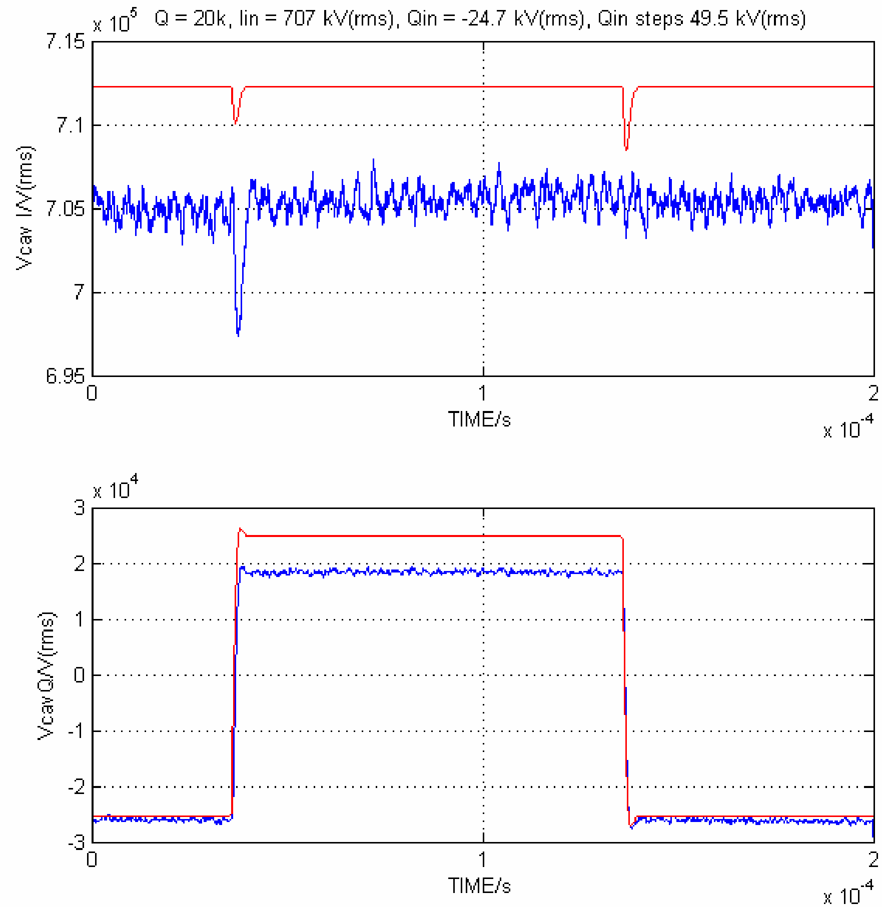
- The simulated step responses have been compared to the measured responses (SM18 tests)
- The measured noisy data has been filtered by sliding average with 600 ns as the window width



Original (blue) and filtered (red) step response data

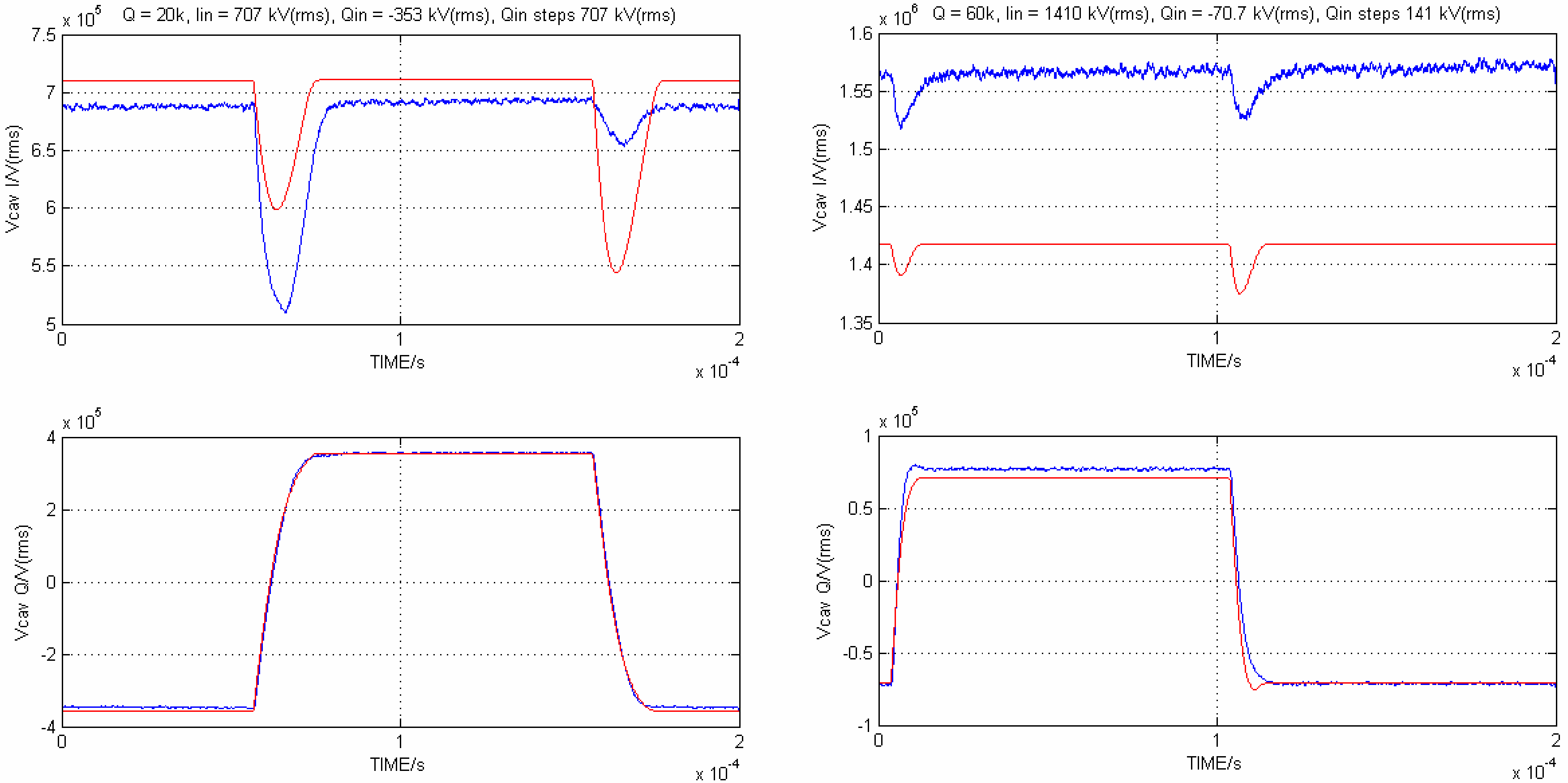
Results and Notations

- When input signals are fed in both inputs Iin and Qin, and Qin steps, the simulated and measured responses are quite similar
- Time constants of the stepping VcavQ signals are of the same scale
- The responses of VcavI differ more from each other: the relative sizes of the spikes which are caused by fast changes of Qin do not fit well



Measured (blue) and simulated (red) step responses

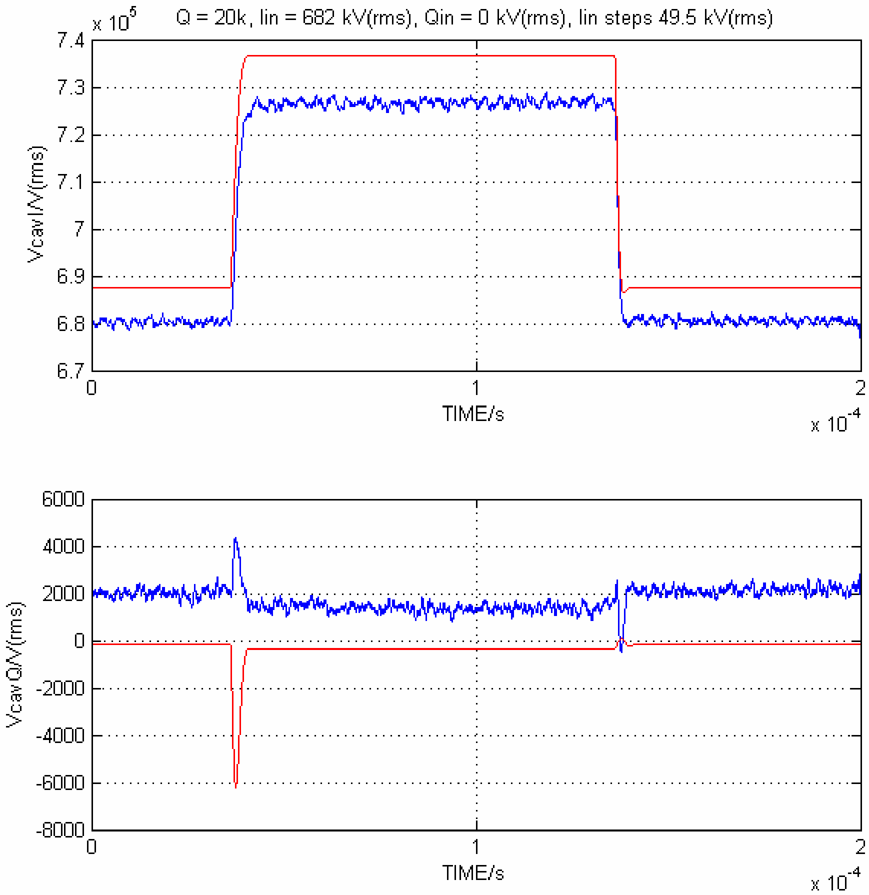
Results and Notations



Measured (blue) and simulated (red) step responses

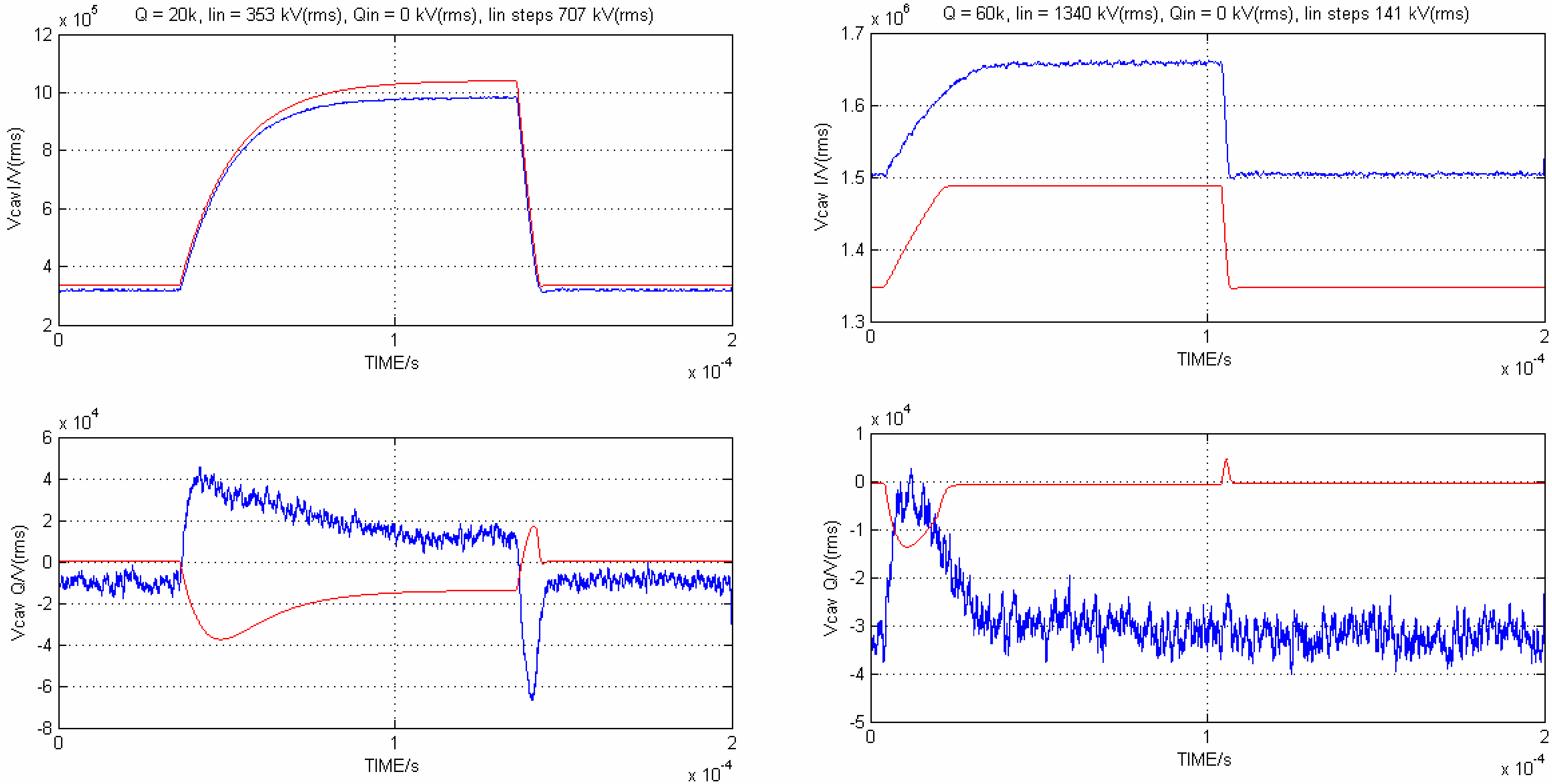
Results and Notations

- When Iin is fed only and the input of Qin is zero, the responses are more different
- Time constants of the stepping VcavI signals are still quite the same, but the responses of VcavQ signals are as if they had been inverted
- The absolute amplitudes of the non-matching signals are quite small



Measured (blue) and simulated (red) step responses

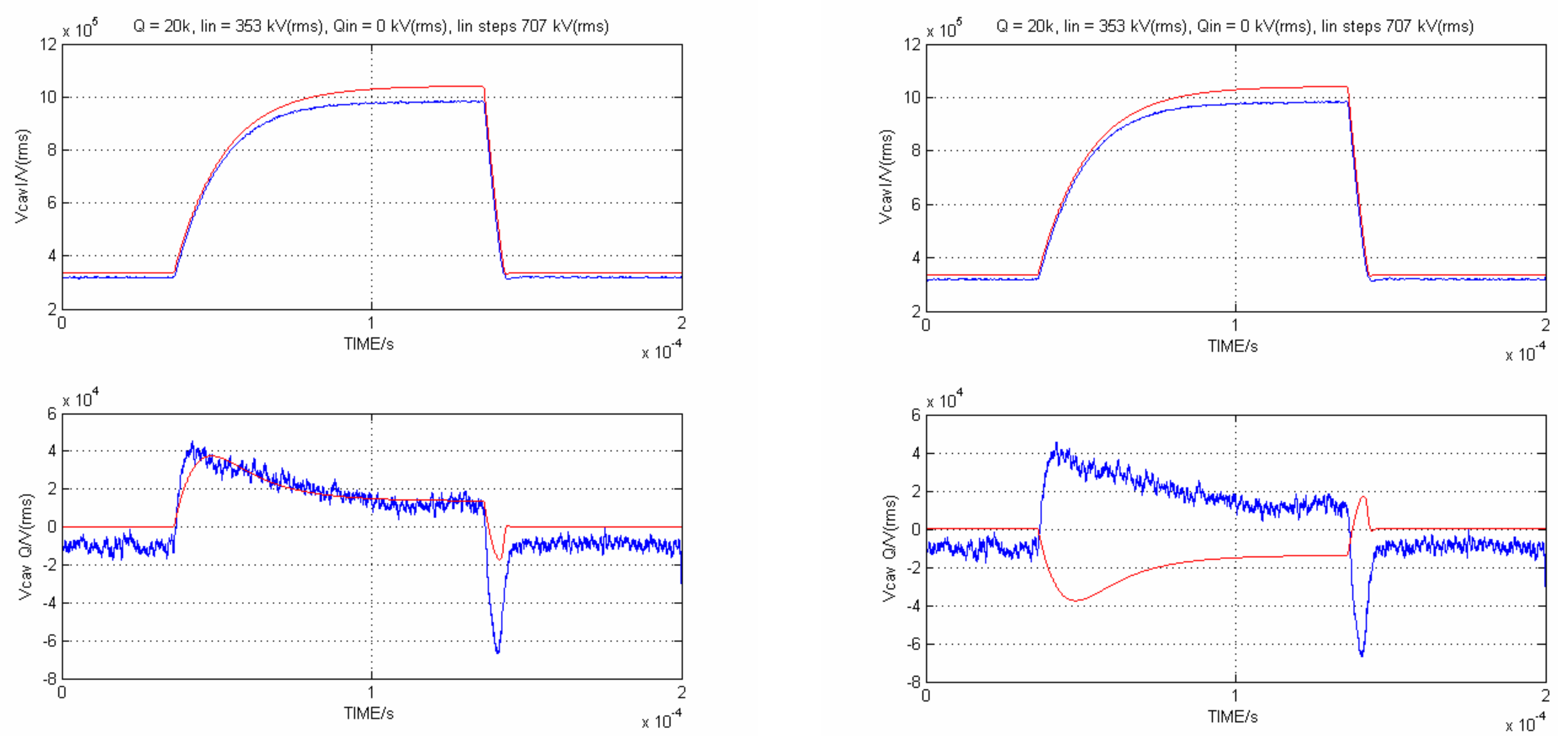
Results and Notations



Measured (blue) and simulated (red) step responses

Results and Notations

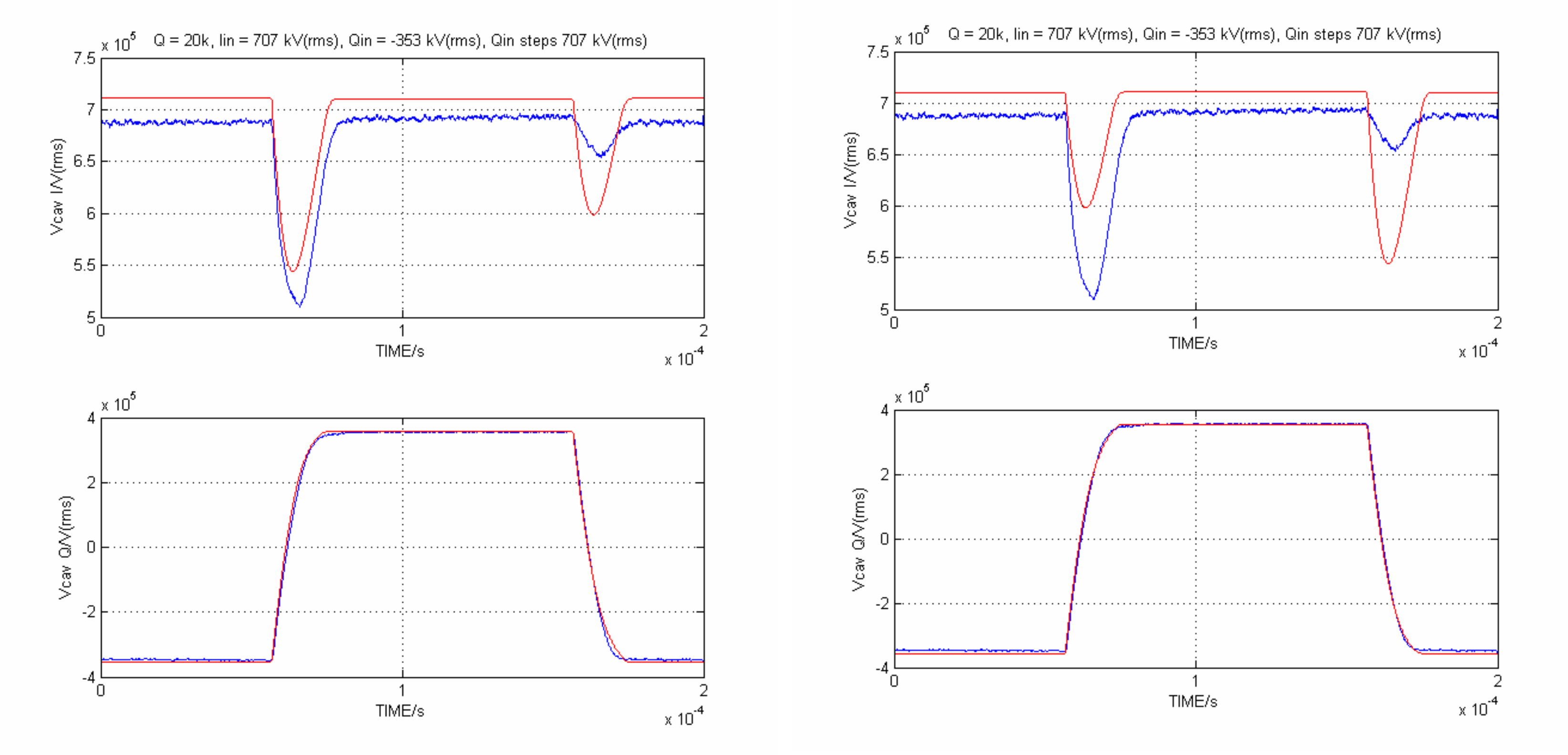
- Surprisingly, if the phase response of the klystron is inverted, the simulated responses are very similar with the measured ones



Measured (blue) and simulated (red) step responses in the cases of the inverted and non-inverted phase shift of the klystron

Results and Notations

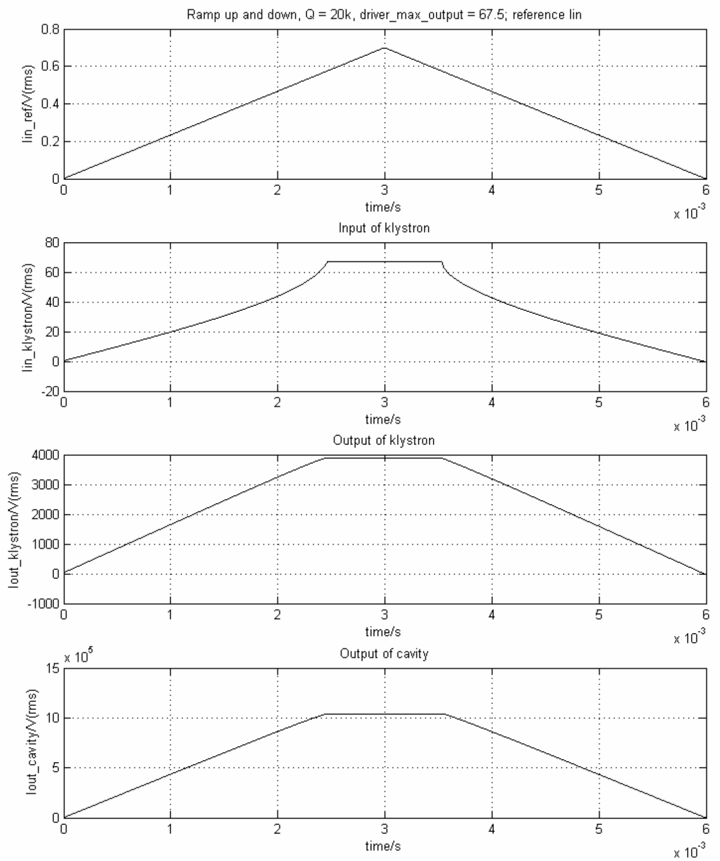
- There can be an error in the model, though, it has not been found yet

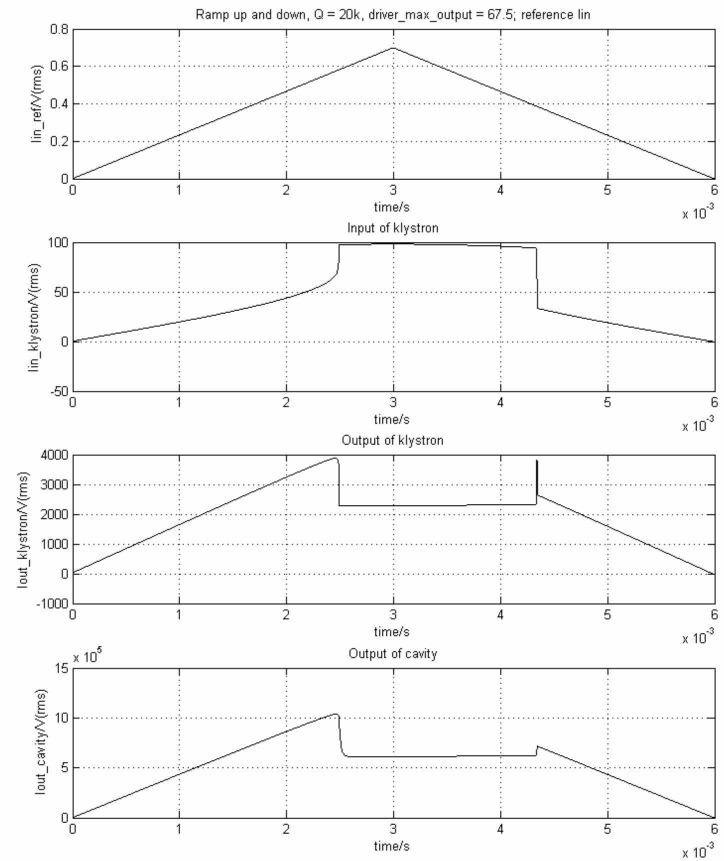


Measured (blue) and simulated (red) step responses in the cases of the inverted and non-inverted phase shift of the klystron

Results and Notations

- Simulated ramp responses

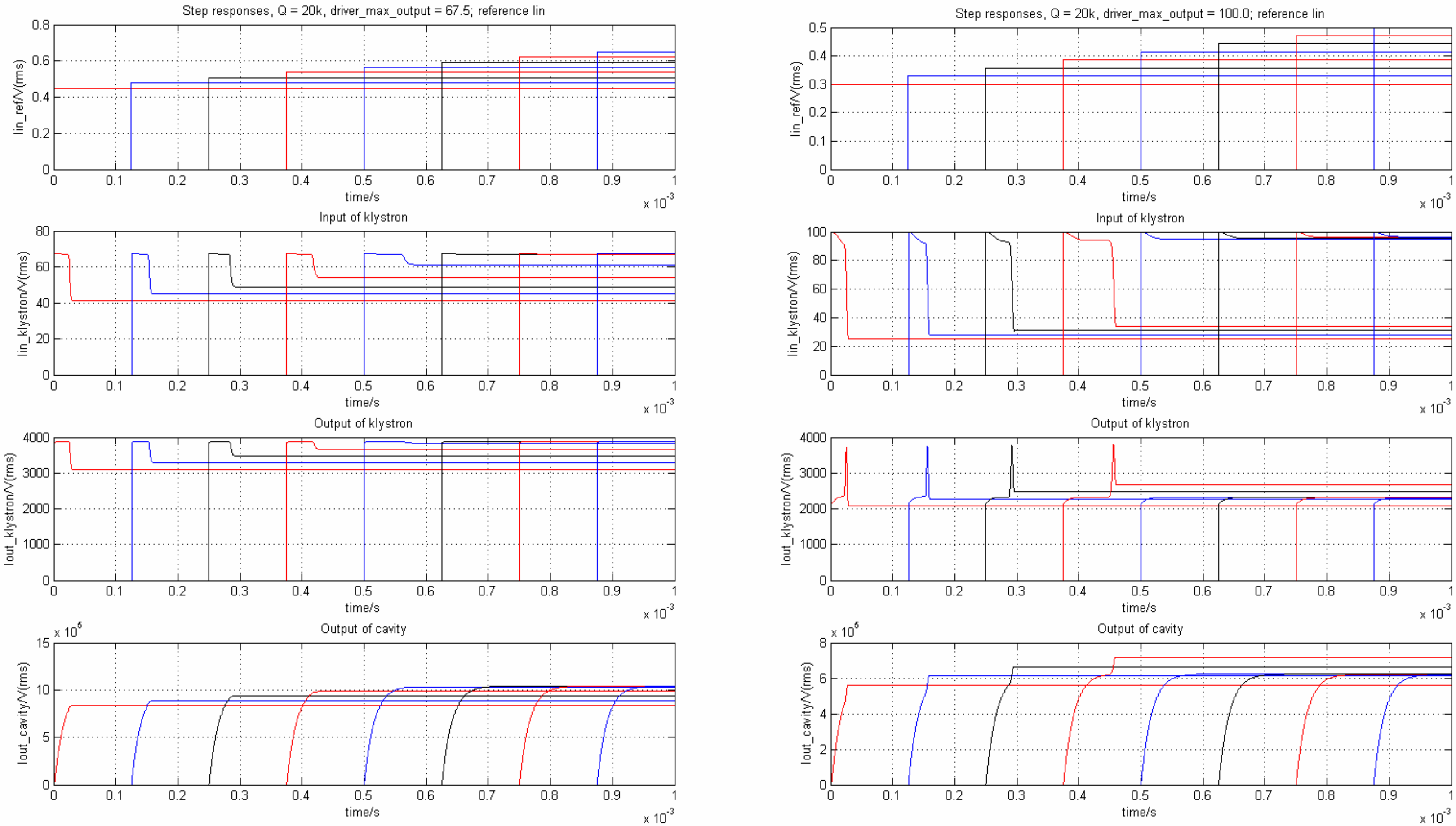




The ramp responses of the model with a clamped and overdriven klystron

Results and Notations

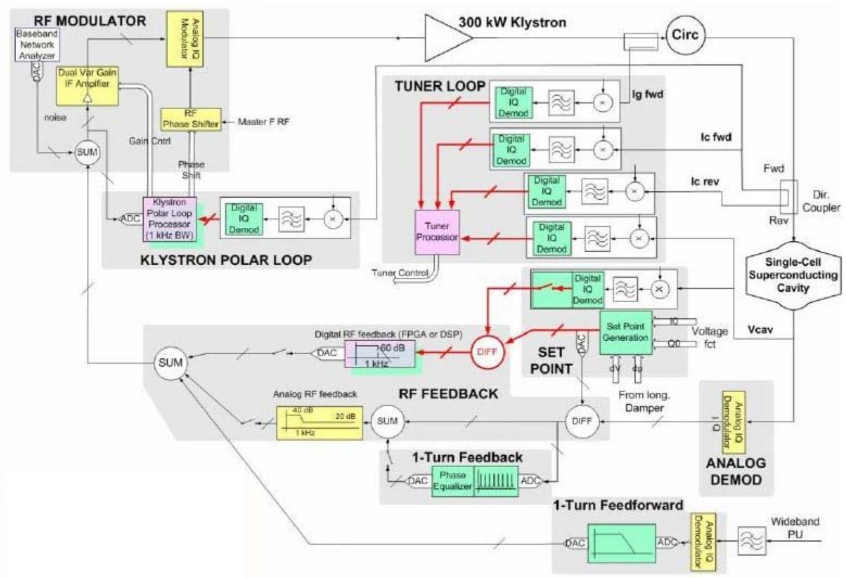
- Simulated series of step responses



The series of step responses of the model with a clamped and overdriven klystron

Next Steps

1. Increased gain at the RF frequency (Digital feedback)
2. The tuner loop
3. The klystron polar loop
4. The beam
5. The GUI

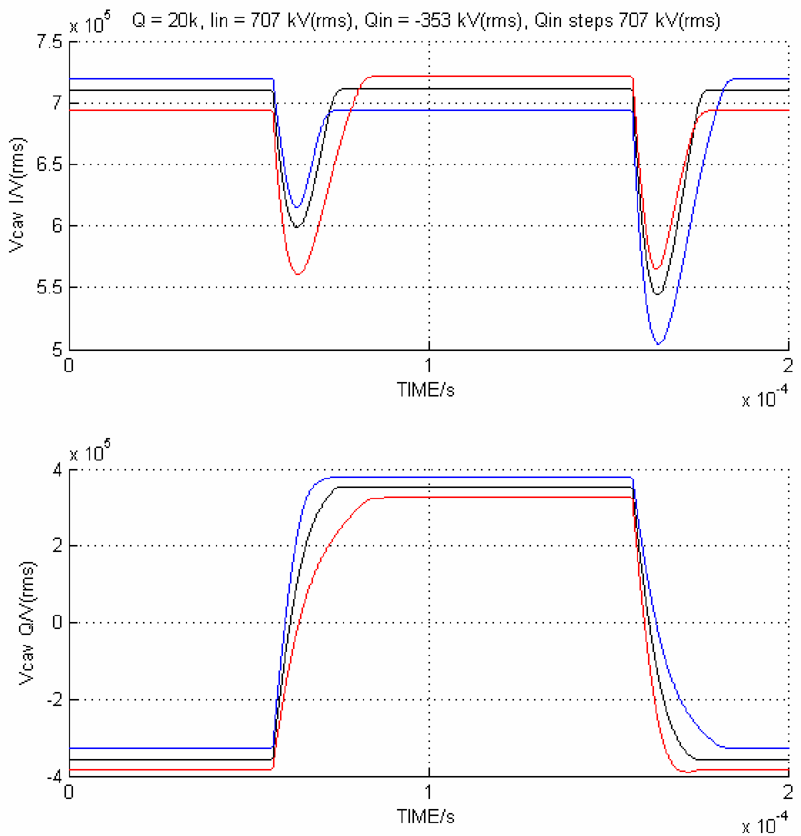


The cavity controller

Next Steps

- Effect of detuning

  - until now, the klystron has been supposed to be on tune all the time



Simulations with detuning of ±5 kHz (blue and red) and without detuning (black)

References

[1] Peter B. Kennigton: High-linearity RF Amplifier Design. Artech House 2000.

[2] Roland Garoby: Low Level RF and Feedback. CERN PS/RF 1997.
http://doc.cern.ch/archive/electronic/cern/preprints/ps/ps-97-034.pdf

Questions?

Comments?