MODELING AND SIMULATION OF INDUS-2 RF FEEDBACK CONTROL SYSTEM

Radio Frequency System Division
Raja Ramanna Centre For Advanced Technology Indore, India.
Dheeraj Sharma, Pritam S. Bagduwal, Nitesh Tiwari, M. Lad, P. R. Hannurkar

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Introduction

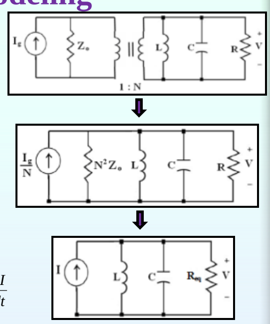
For higher beam current and better performance of LLRF feedback control loop it is being upgraded to digital feedback system. Inphase and Quadrature (I/Q) modulation technique is being implemented. To understand the behavior of I/Q based feedback LLRF control system under different operating conditions, modeling and simulation is done.

Modeling and simulation also helps in algorithm study, controller design and optimization. Baseband simulation has been performed because of its close correspondence with the actual implementation and making the simulation faster due to better computational efficiency. A description of the models and corresponding results are discussed.

RF Cavity Modeling

Cavity RF Model

Resonant modes of cavity can be described by means of resonant LCR circuits. The power source feeding power to RF cavity can be modeled as an LCR circuit driven by a current source I_g through transformer as a coupler.



Cavity gap voltage is given by

$$I = \frac{1}{L}\int V dt + C\frac{dV}{dt} + \frac{V}{R_{eq}} \Rightarrow \frac{d^2V}{dt^2} + \Delta\omega\frac{dV}{dt} + \omega_0^2 V = \frac{1}{C}\frac{dI}{dt}$$

$$\boxed{\frac{V(s)}{I(s)} = \frac{s/C}{s^2 + \Delta\omega s + \omega_0^2}}$$

For Indus-2 it becomes

$$\boxed{\frac{V(s)}{I(s)} = \frac{0.5235464 \times 10^{12} s}{s^2 + 0.3173008 \times 10^6 s + 0.10067984 \times 10^{20}}}$$

Table 1: Indus-2 RF Cavity Parameters

Parameter	Symbol	Value
Unloaded Quality Factor	Q	40000
Loaded Quality Factor	Q_L	10000
Resonant Frequency	f_0	505.812 MHz
Shunt Impedance	R	6.6 MΩ

Cavity Baseband I/Q Model

Cavity gap voltage can also be represented as follows:

$$\frac{d^2V}{dt^2} + 2\Delta\omega_{1/2}\frac{dV}{dt} + \omega_0^2 V = 2\Delta\omega_{1/2} R_{eq}\frac{dI}{dt}$$

Representing *I*, and *V*, in terms of vector notations:

$$I = \vec{I}e^{j\omega t} = (I_r + jI_i)e^{j\omega t} \quad \& \quad V = \vec{V}e^{j\omega t} = (V_r + jV_i)e^{j\omega t}$$

The envelope of the cavity voltage *V*, is a slowly varying function of time compared to the time period of the RF oscillations, hence following assumptions can be made: $\frac{d\vec{V}}{dt} << \omega\vec{V}$ & $\frac{d^2\vec{V}}{dt^2} << \omega\frac{d\vec{V}}{dt}$.

Now cavity gap voltage can be written as:

$$\frac{d\vec{V}}{dt} + \left(\Delta\omega_{1/2} - j\,d\omega\right)\vec{V} = \Delta\omega_{1/2} R_{eq}\vec{I}$$

where ***dω* (= *ω*$_o$- *ω*)** is called "detuning parameter".

Separating real and imaginary part, baseband I/Q model is given by:

$$\frac{dV_r}{dt} + \Delta\omega_{1/2} V_r + d\omega\, V_i = \Delta\omega_{1/2} R_{eq} I_r \quad \& \quad \frac{dV_i}{dt} + \Delta\omega_{1/2} V_i - d\omega\, V_r = \Delta\omega_{1/2} R_{eq} I_i$$

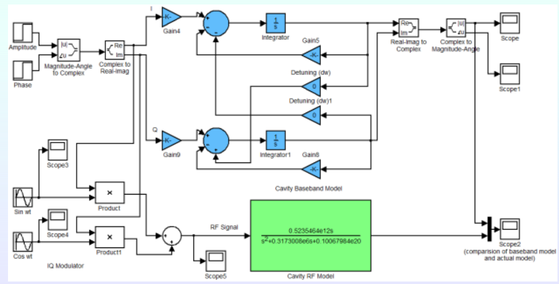
For Indus-2 baseband I/Q model is given by:

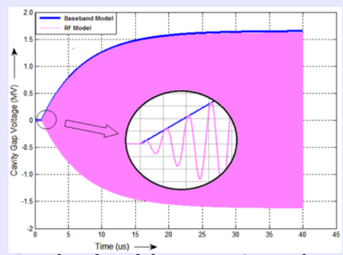
$$\boxed{\frac{dV_r}{dt} + 158.65043 \times 10^3 V_r + d\omega\, V_i = 26.177321 \times 10^{10} I_r}$$

$$\boxed{\frac{dV_i}{dt} + 158.65043 \times 10^3 V_i - d\omega\, V_r = 26.177321 \times 10^{10} I_i}$$

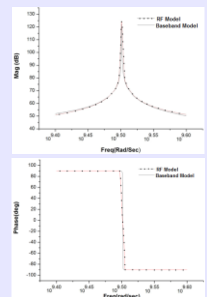
Different operating conditions can be simulated using different values of detuning parameter *dω*.

Comparison of Cavity Models





Baseband model response is envelope of RF model response

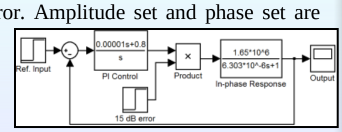


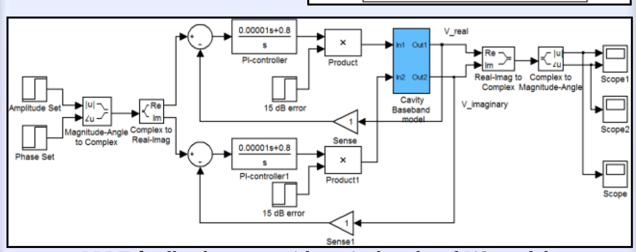
Bode plots of cavity models

LLRF Feedback System Modeling

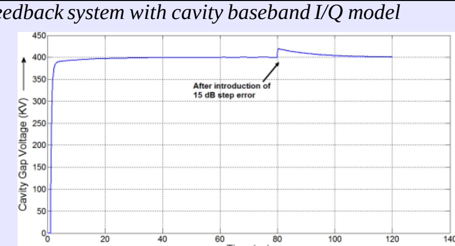
The baseband transfer function of real (and imaginary) part of cavity baseband model with zero detuning is given by: $\frac{V_r(s)}{I_r(s)} = \frac{R_{eq}}{(\frac{1}{\Delta\omega_{1/2}})s + 1}$

A PI controller has been designed for inphase and quadrature response of cavity. Design constraint has been taken as 5% peak overshoot for 15 dB step error. Amplitude set and phase set are kept as 400 kV and 45° respectively.





LLRF feedback system with cavity baseband I/Q model



Response of LLRF feedback model with 15 dB step error

Conclusion

This simulation is a helpful tool to model, design and optimize the closed loop LLRF control system under different operating conditions of RF cavity. Similar model will also help in studying the behavior of I/Q based digital LLRF system for various controlling algorithms.