MODELING AND SIMULATION OF INDUS-2 RF FEEDBACK CONTROL SYSTEM
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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 Iₗ through transformer as a coupler.

Cavity gap voltage is given by

\[
i = \frac{1}{j \omega C_0} V + \frac{1}{j \omega L_0} \frac{dV}{dt} + \frac{1}{j \omega C} \int V dt + \frac{1}{j \omega L} \int \frac{dV}{dt} dt
\]

For Indus-2 it becomes

\[
\frac{V(t)}{C(t)} = \frac{0.5235464 \times 10^3 s}{0.3173068 \times 10^3 s + 0.10067984 \times 10^3 s}
\]

Cavity Baseband I/Q Model
Cavity gap voltage can also be represented as follows:

\[
\frac{dV}{dt} + 2\Delta \omega \frac{dV}{dt} + \alpha V = 2\Delta \omega R_c \frac{dI}{dt}
\]

Representing I and V, in terms of vector notations:

\[
\mathbf{I} = \mathbf{I}_P + j \mathbf{I}_Q; \quad \mathbf{V} = \mathbf{V}_P + j \mathbf{V}_Q; \quad \mathbf{V} = \mathbf{V}_P e^{j \theta}
\]

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:

\[
\frac{dV}{dt} \ll \omega V \quad \text{and} \quad \frac{dV}{dt} \ll \omega I
\]

Now cavity gap voltage can be written as:

\[
\frac{dV}{dt} + (\Delta \omega_j) V + \delta V = \Delta \omega \delta R_c \delta I
\]

where \( \delta = (\omega - \omega_0) \) is called “detuning parameter”.

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

\[
\frac{dV_P}{dt} + \Delta \omega \delta V_P + \delta \omega \delta V_Q = \Delta \omega \delta R_c \delta I_P
\]

\[
\frac{dV_Q}{dt} + \Delta \omega \delta V_Q - \delta \omega \delta V_P = \Delta \omega \delta R_c \delta I_Q
\]

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

\[
\frac{dV_P}{dt} = 158.65043 \times 10^4 V_P + \omega V_Q = 26.177321 \times 10^4 I_P
\]

\[
\frac{dV_Q}{dt} = 158.65043 \times 10^4 V_Q - \omega V_P = 26.177321 \times 10^4 I_Q
\]

Different operating conditions can be simulated using different values of detuning parameter \( \delta \).

Comparison of Cavity Models
The baseband transfer function of real (and imaginary) part of cavity baseband model with zero detuning is given by:

\[
V(s) = \frac{1}{\omega_0^2 s^2 + 1}
\]

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.

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.