Low Level RF feedback loop design

Main variables

φ the instantaneous phase deviation of the bunch from the synchronous phase.

δR the variations of the beam radius

ω_{rf} the RF frequency

$\delta\omega_b$ the variations of the beam frequency

φ_b the phase of the beam with respect to the RF

Transfer functions

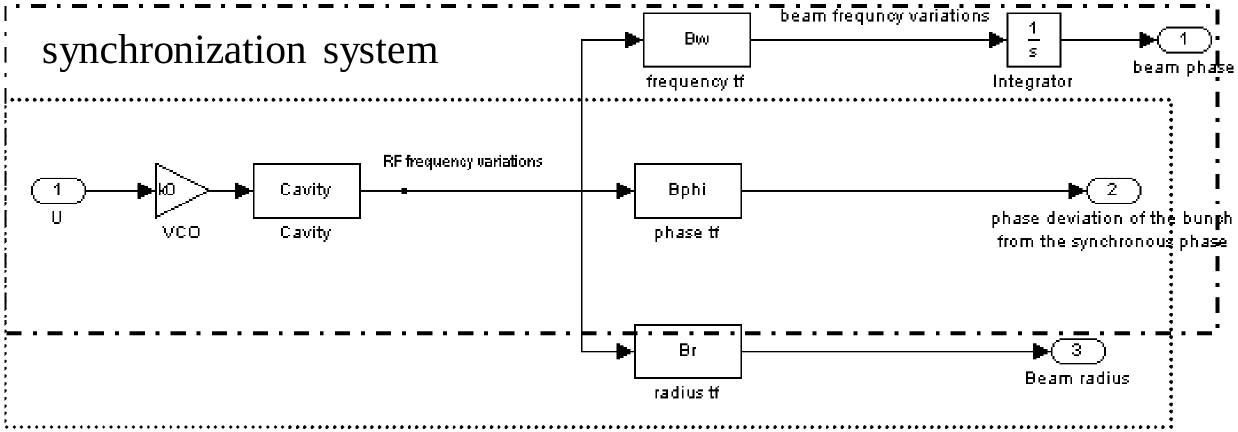
B scaling factor,

ω_s the synchronousfrequency.

$$B_\varphi(s) = \frac{\varphi}{\delta\omega_{rf}} = \frac{s}{s^2 + \omega_s^2}$$

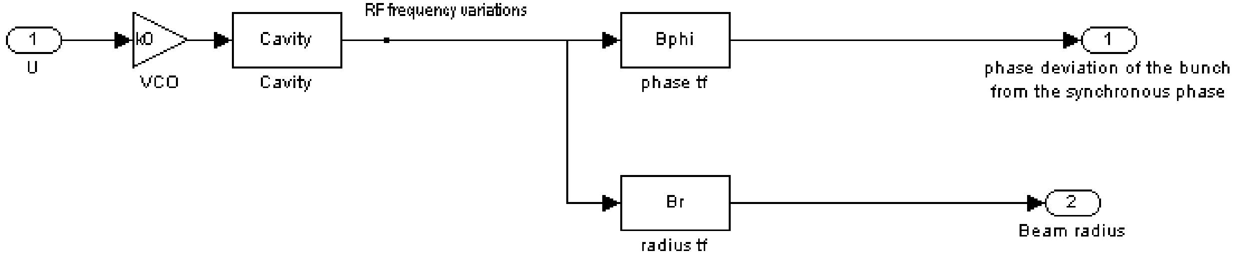
$$B_R(s) = \frac{R}{\delta\omega_{rf}} = \frac{b}{s^2 + \omega_s^2}$$

$$B_\omega(s) = \frac{\delta\omega_{rb}}{\delta\omega_{rf}} = \frac{s}{s^2 + \omega_s^2}$$



Phase and radial system

Phase and radial loop



$$\frac{d}{dt}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \underbrace{\begin{pmatrix} 0 & 1 \\ -\omega_s^2 & 0 \end{pmatrix}}_{A_s}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \underbrace{\begin{pmatrix} 0 \\ k_0 \end{pmatrix}}_{B_s} U$$

$$y = \begin{pmatrix} \varphi \\ R \end{pmatrix} = \underbrace{\begin{pmatrix} 0 & 1 \\ b & 0 \end{pmatrix}}_{C_s}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \underbrace{\begin{pmatrix} 0 \\ 0 \end{pmatrix}}_{D_s} U$$

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Discrete representation, pole placement

Add an integral action

$$F = \begin{bmatrix} A_{sdiscr} & 0 \\ -C_{sdiscr} & 1 \end{bmatrix}$$

Set of gains

$$\begin{bmatrix} K_{\varphi} & K_R & K_{\text{int}} \end{bmatrix}$$

Feedback: $U = -\left(K_{\varphi}\varphi + K_R R - K_{\text{int}} Z\right)$

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Pole placement

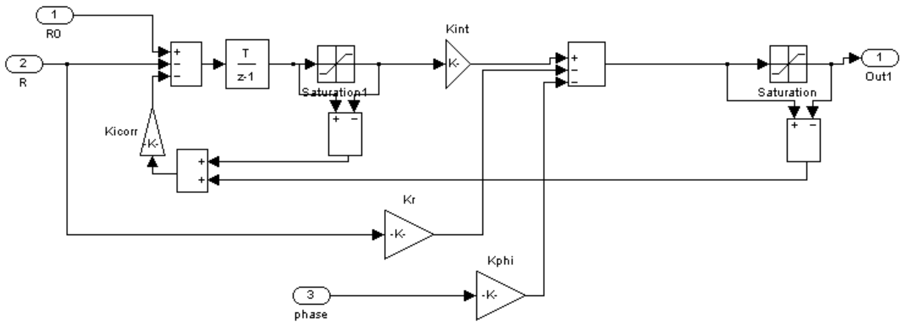
Poles of a 3rd order Bessel filter

Non overshooting behaviour

200 Hz (20 ms)

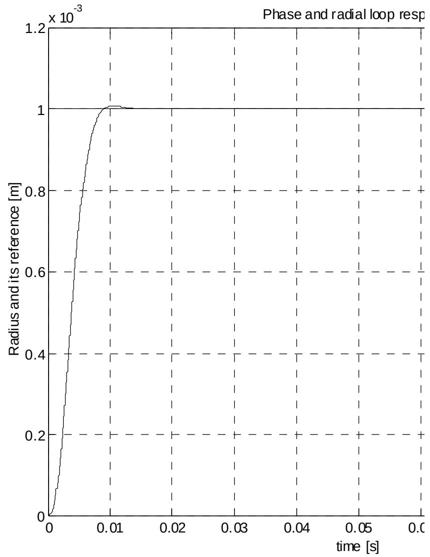
Feedback structure

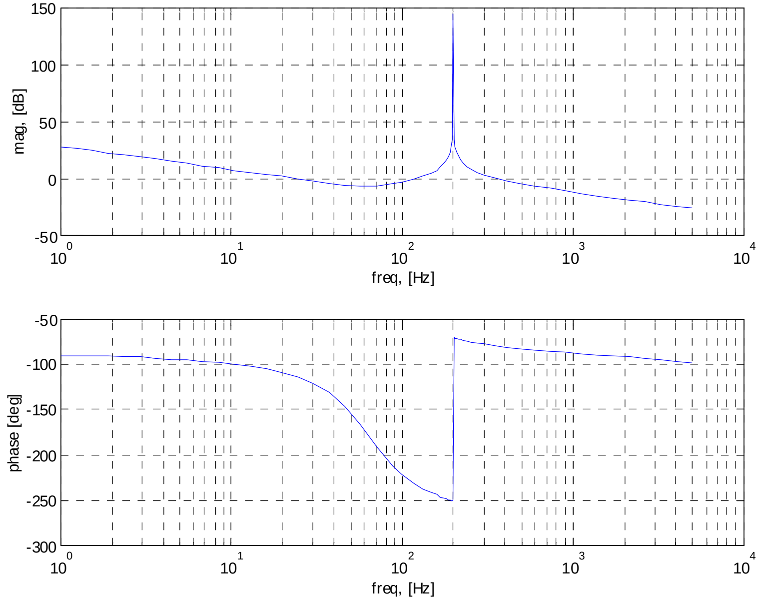
Cascaded implementation plus antiwindup

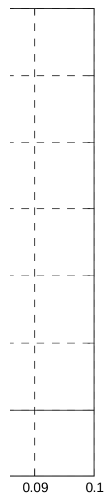


Closed loop response

1 mm step







Synchronization

Beam rigidly phase with its reference

$\varphi_b - \varphi_{ref} = \varphi_{set}$

Phase reference can be incremented at each clock cycle

Output of the phase detector: sawtooth corresponding to the freq difference

Synchronization

Force the output of the phase detector to a ct value during acceleration using an offset

(Moving reference)

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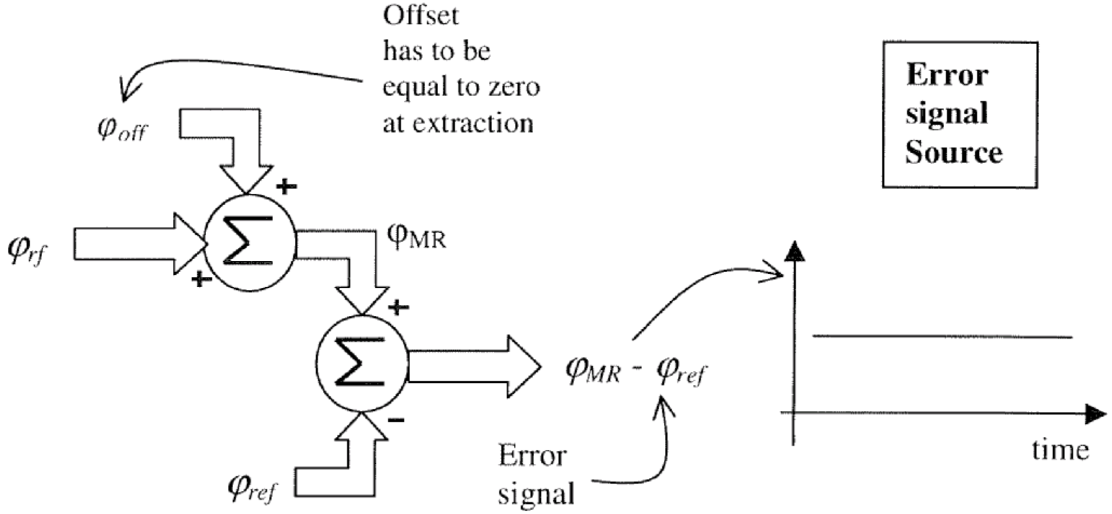
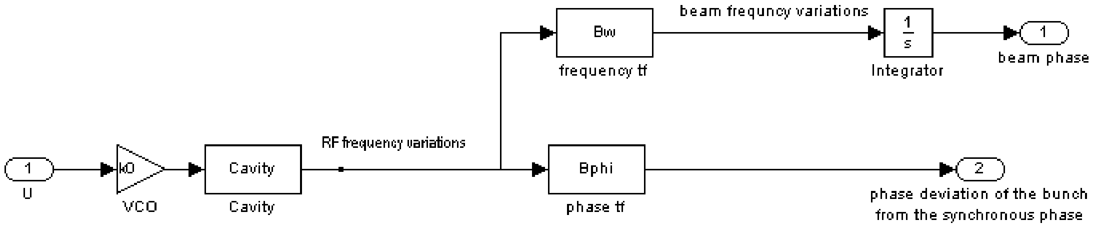
Synchronization

Moving reference



Error: diff between an extrapolated rf phase and the ref. Allows the closing of the synchron

State space model



$$\begin{cases} x_1 = \varphi_b = \dfrac{1}{s}\omega_b \\ x_2 = \omega_b = \dfrac{\omega_s^2}{s^2 + \omega_s^2}\omega_{rf} \\ x_3 = \varphi = \dfrac{s}{s^2 + \omega_s^2}\omega_{rf} \end{cases}$$

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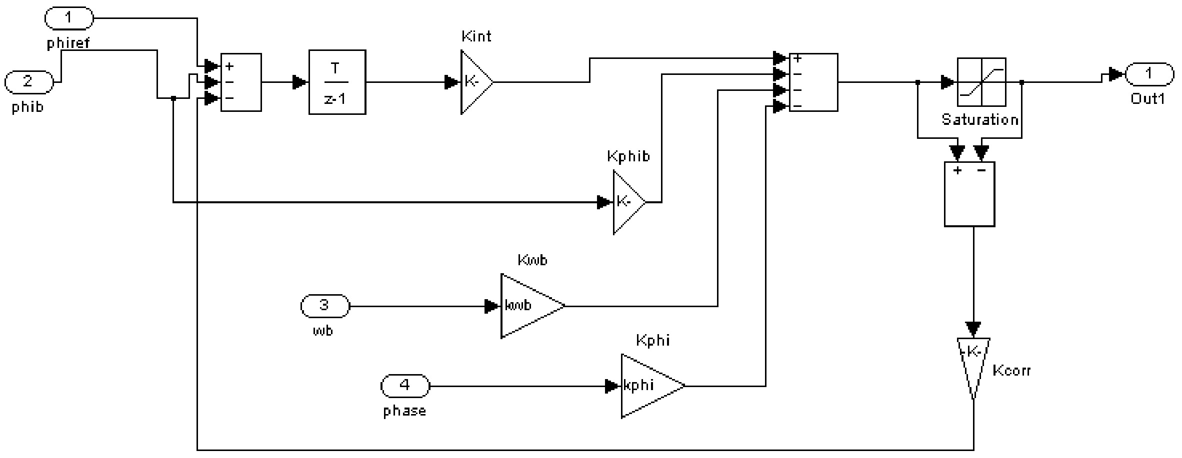
Loop gains

After going to discrete, set of gains:

$$U = -\left(K_{\varphi_b}\varphi_b + K_{\omega_b}\omega_b + K_{\varphi}\varphi - K_{\text{int}}\int(\varphi_{ref} - \varphi_b)\right)$$

Using pole placement



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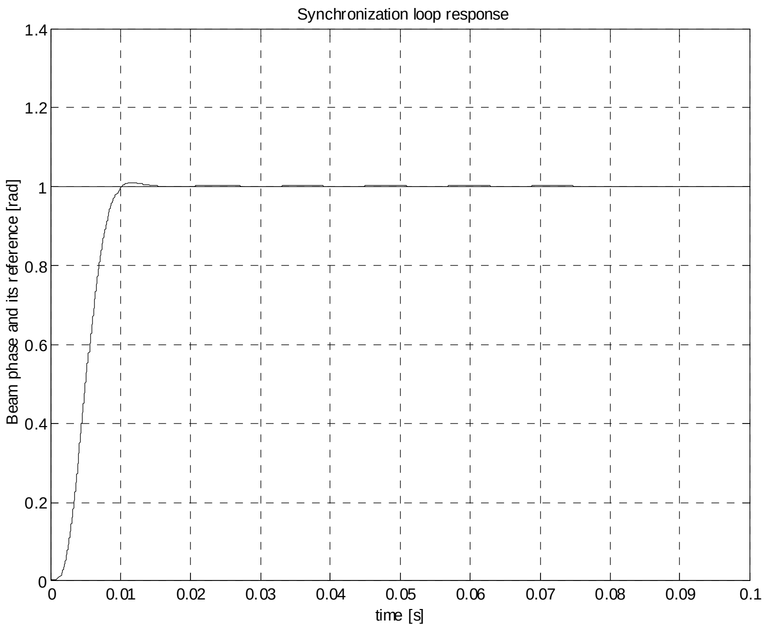
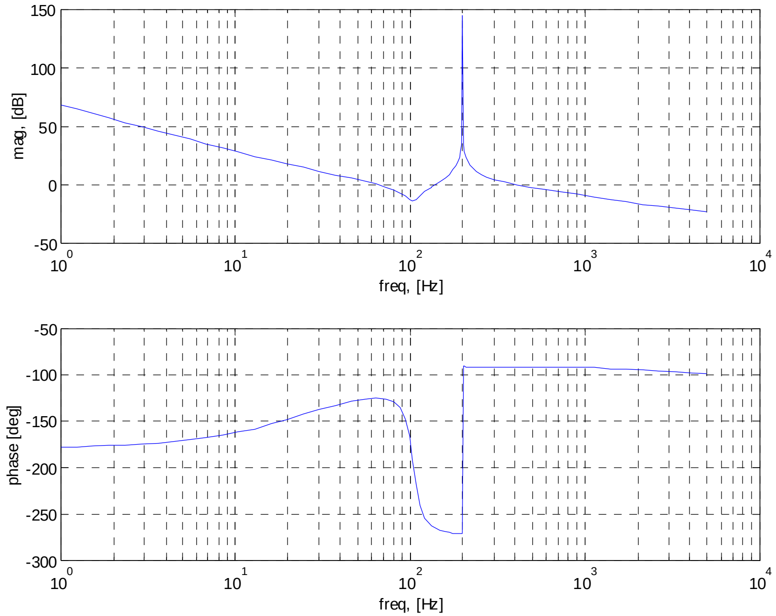
Closed loop behaviour





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