Impact of the ERL Beam Loading Patterns on the RF system and BBU Instabilities

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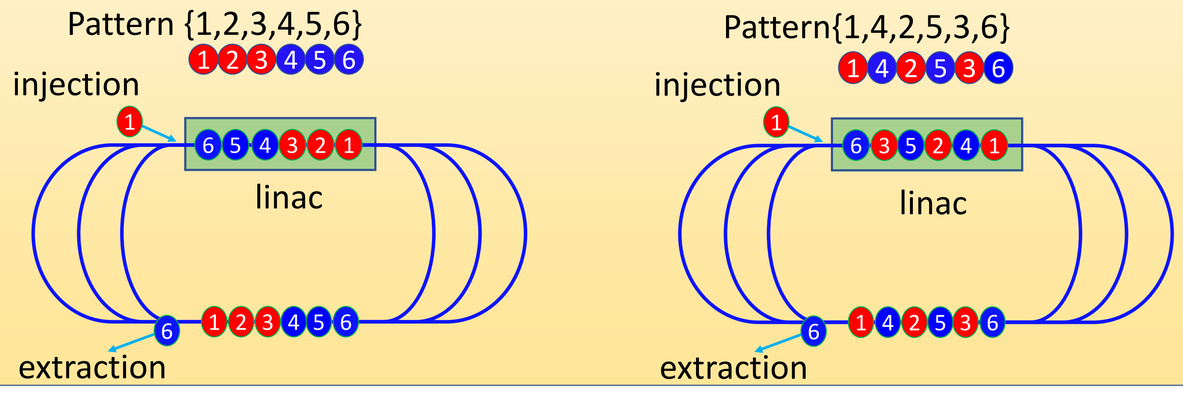
ERL cavity voltage, RF power, and BBU threshold currents are beam loading pattern dependent

Optimal pattern can lower cavity voltage fluctuation and power consumption and increase threshold current

Beam loading pattern

The order bunches pass through the cavity



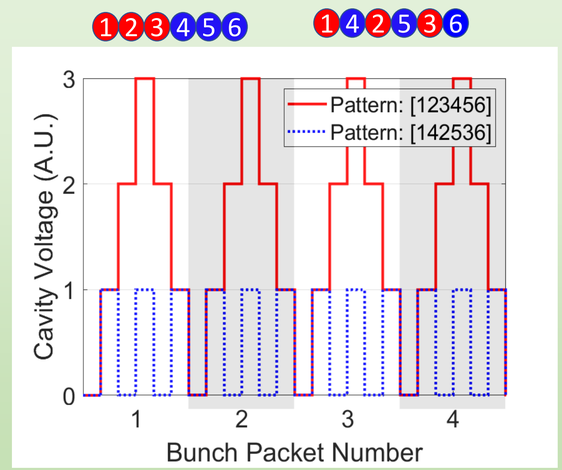
Cavity voltage

$$\delta V_{cav} = -\frac{q_{bunch}}{2}\omega\left(\frac{R}{Q}\right)\cos(\phi)$$

ϕ: bunch phase

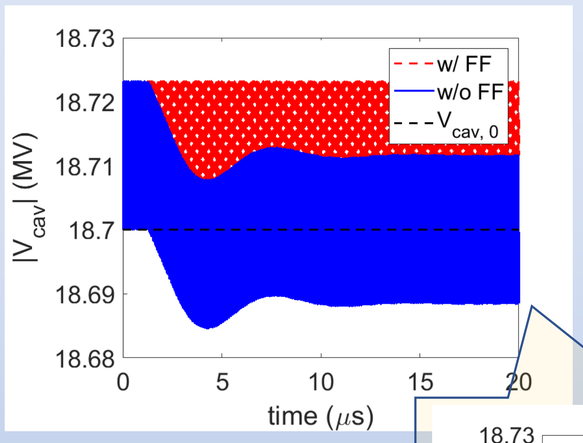
Accelerating: $\phi = 0°$

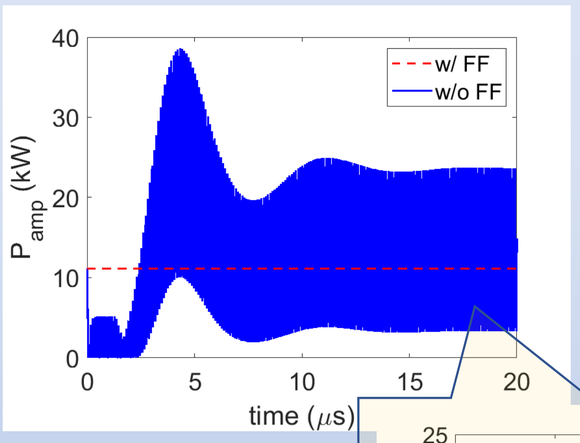
Decelerating: $\phi = 180°$

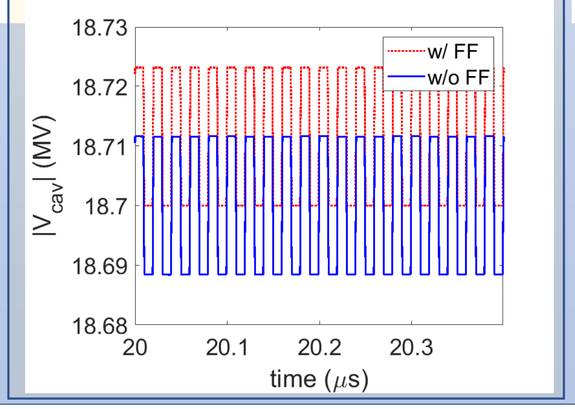


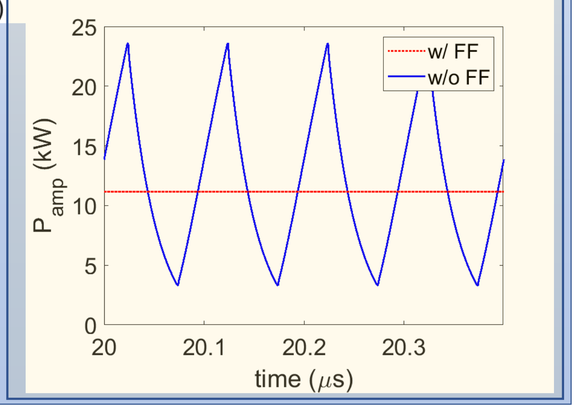
LLRF Feed forward

- ERL net beam loading = 0.
- No need for bunch-to-bunch correction.
- A feed forward (FF) to LLRF can prevent bunch-to-bunch correction.
- Without FF, the LLRF can trigger amplifier and cause fluctuation.
- FF stabilizes V_{cav} and P_{amp}.



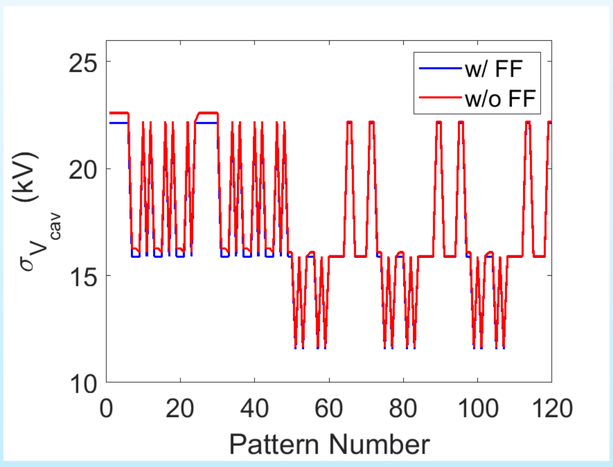


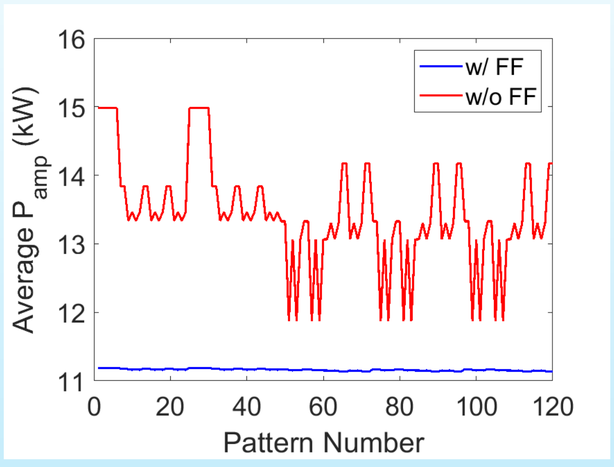




Pattern dependance

- V_{cav} and P_{amp} are pattern dependent
- Some patterns have stabler cavity voltage and requires less amplifier powers
- FF lowers power consumption





Pattern #1: {1,2,3,4,5,6}

Pattern #2: {1,2,3,4,6,5}

…

Pattern #120: {1,6,5,4,2,1}

Beam Breakup (BBU) instabilities

1. Offset x_n causes HOM:

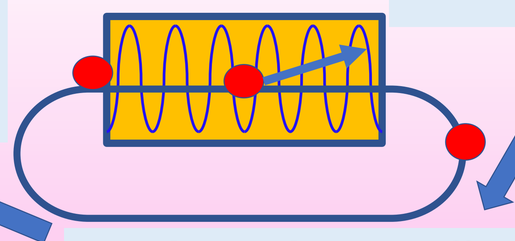
$$V_{HOM,R} = \frac{\omega_{HOM}^2}{2c} q_b \left(\frac{R}{Q}\right)_{HOM} x_n$$

2. $V_{HOM,i}$ kicks the beam:

$$x_n' = \frac{V_{HOM,i}}{V_{beam}}$$

3. Kick translates to offset

$$x_{n+1} = x_n + R_{12} x_n'$$

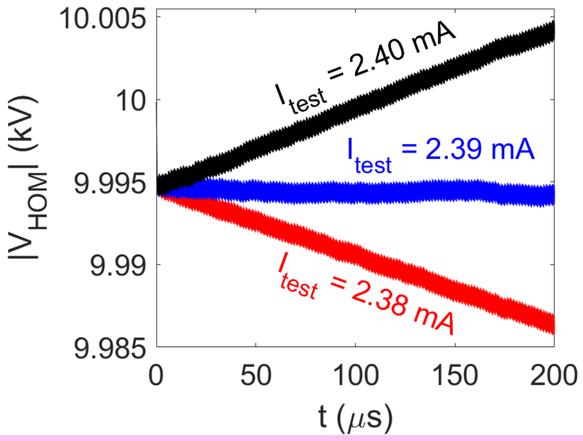


BBU Positive feedback loop:

Offset → HOMs → Kick → Off-set → …

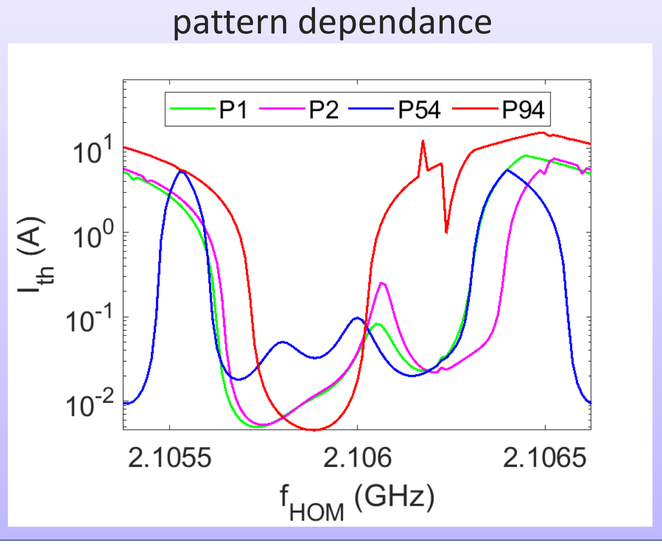
BBU threshold current I_{th}:

- $I_{test} > I_{th}$ → V_{HOM} increases
- $I_{test} > I_{th}$ → V_{HOM} decreases
- $I_{test} = I_{th}$ → V_{HOM} stable

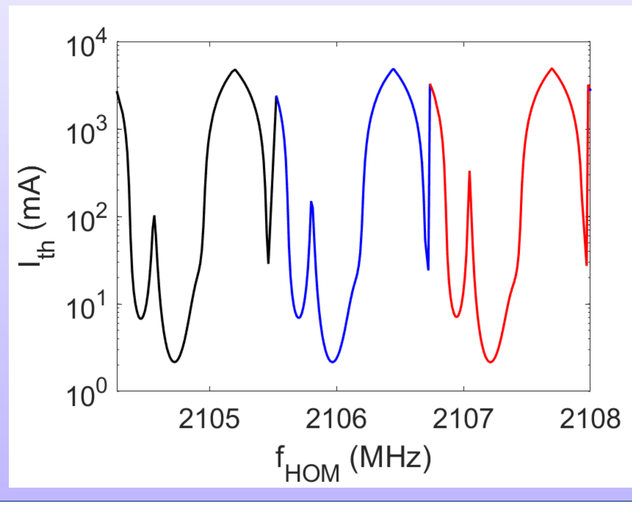


BBU pattern dependance

pattern dependance



Periodic



Threshold current I_{th} is higher when $\mu = n\pi$