Toward an Optimal Beam-Based Feedback Control for a Continuous-Wave Linear Accelerator

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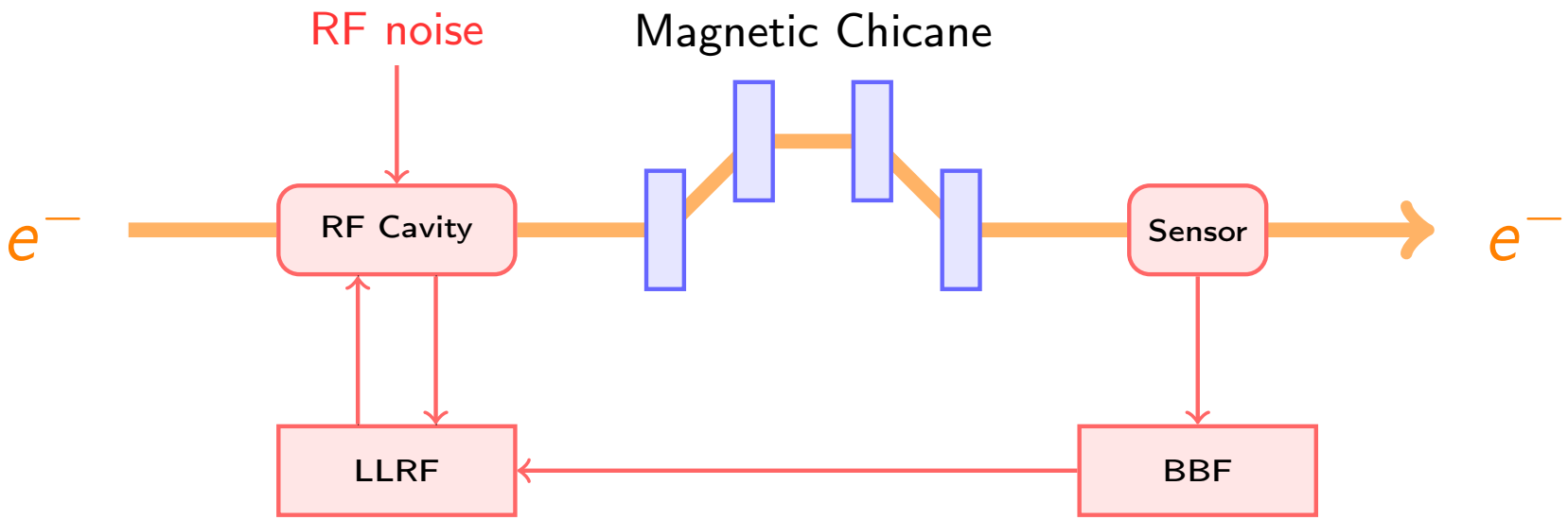
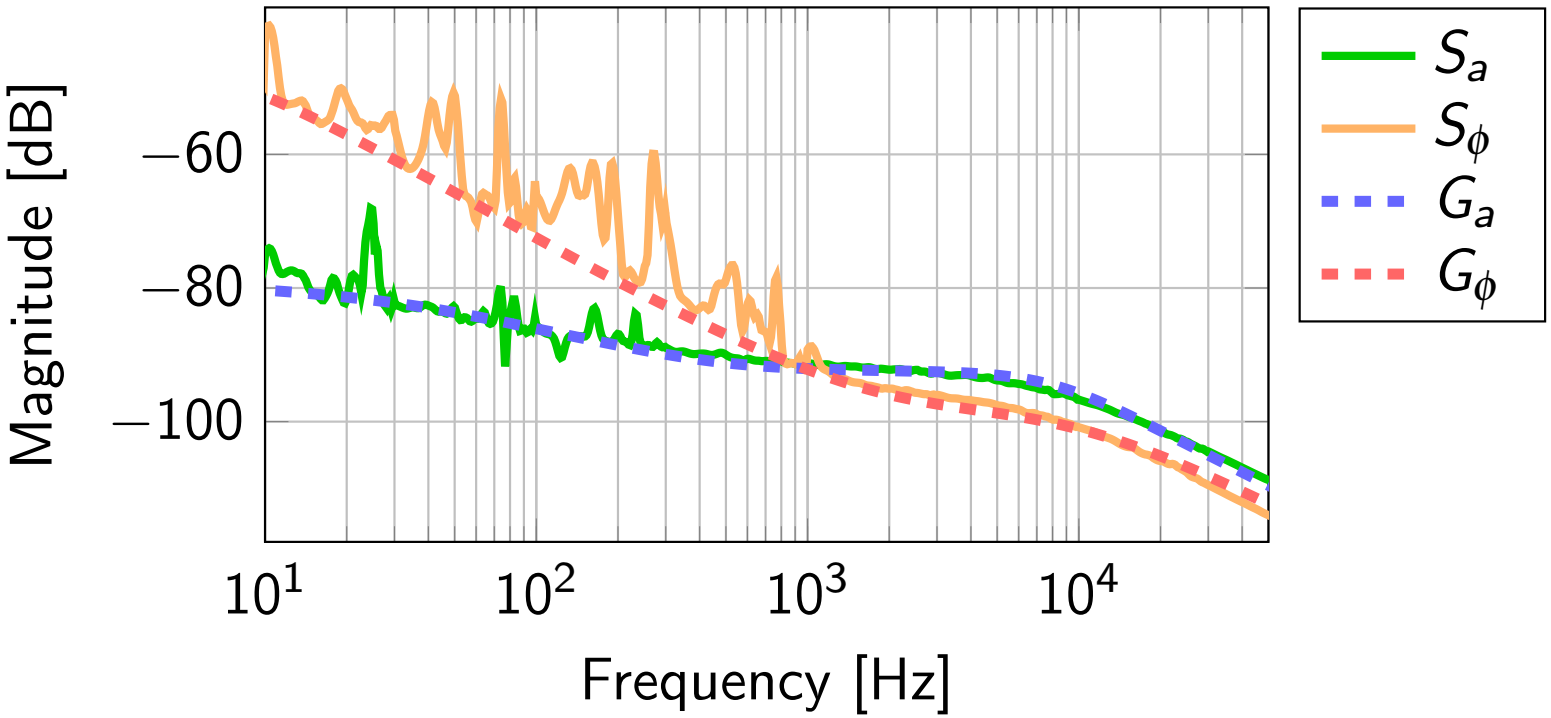
Problem Scope



- Accelerated electron beam e^- must remain stable.
- RF cavity controlled by a dedicated LLRF controller.
- Ultimately design a beam-based feedback controller.
- Start by analyzing RF noise.

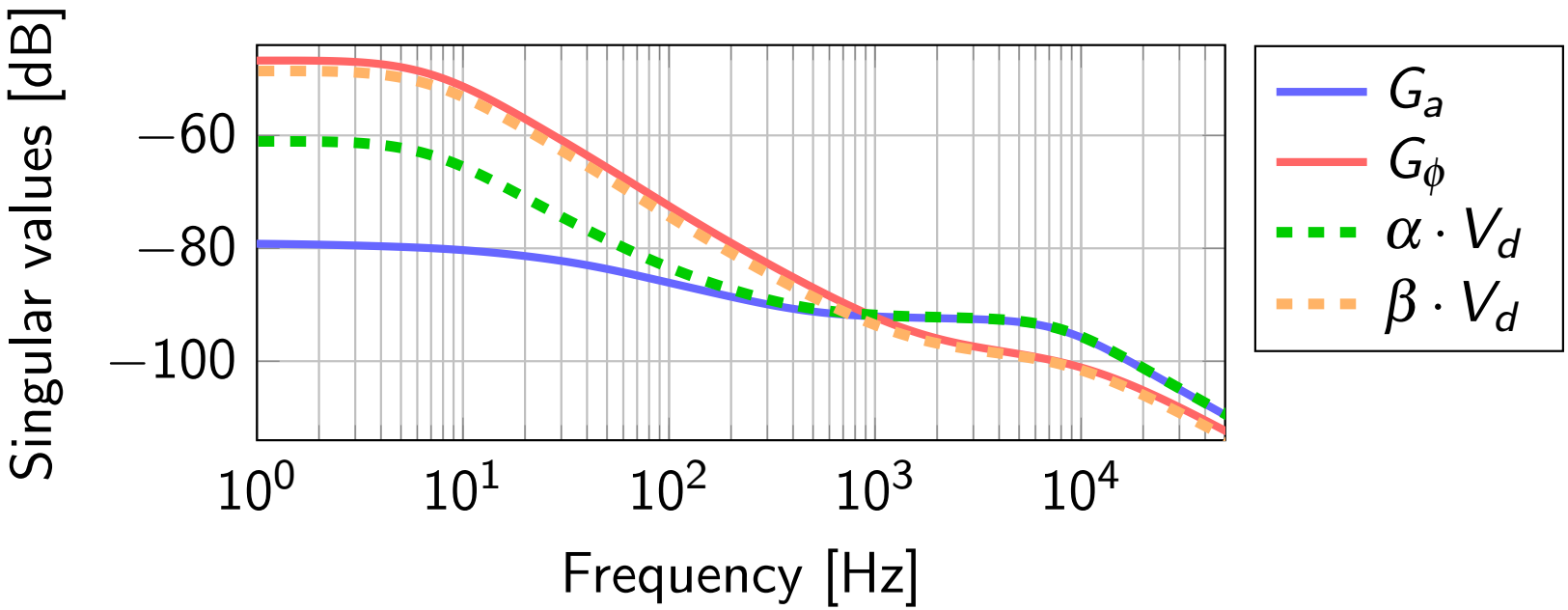
Frequency Domain Definition of RF Noise



- Measure RF noise at a superconducting RF cavity at ELBE.
- Approximate measured shapes using linear time-invariant systems.
- Use developed LTI filters in simulations to analyze beam noise.

RF to Beam Noise Transfer Function

$$V_d = \begin{bmatrix} m_{11} & m_{12} \end{bmatrix} \begin{bmatrix} G_a & 0 \\ 0 & G_\phi \end{bmatrix}$$

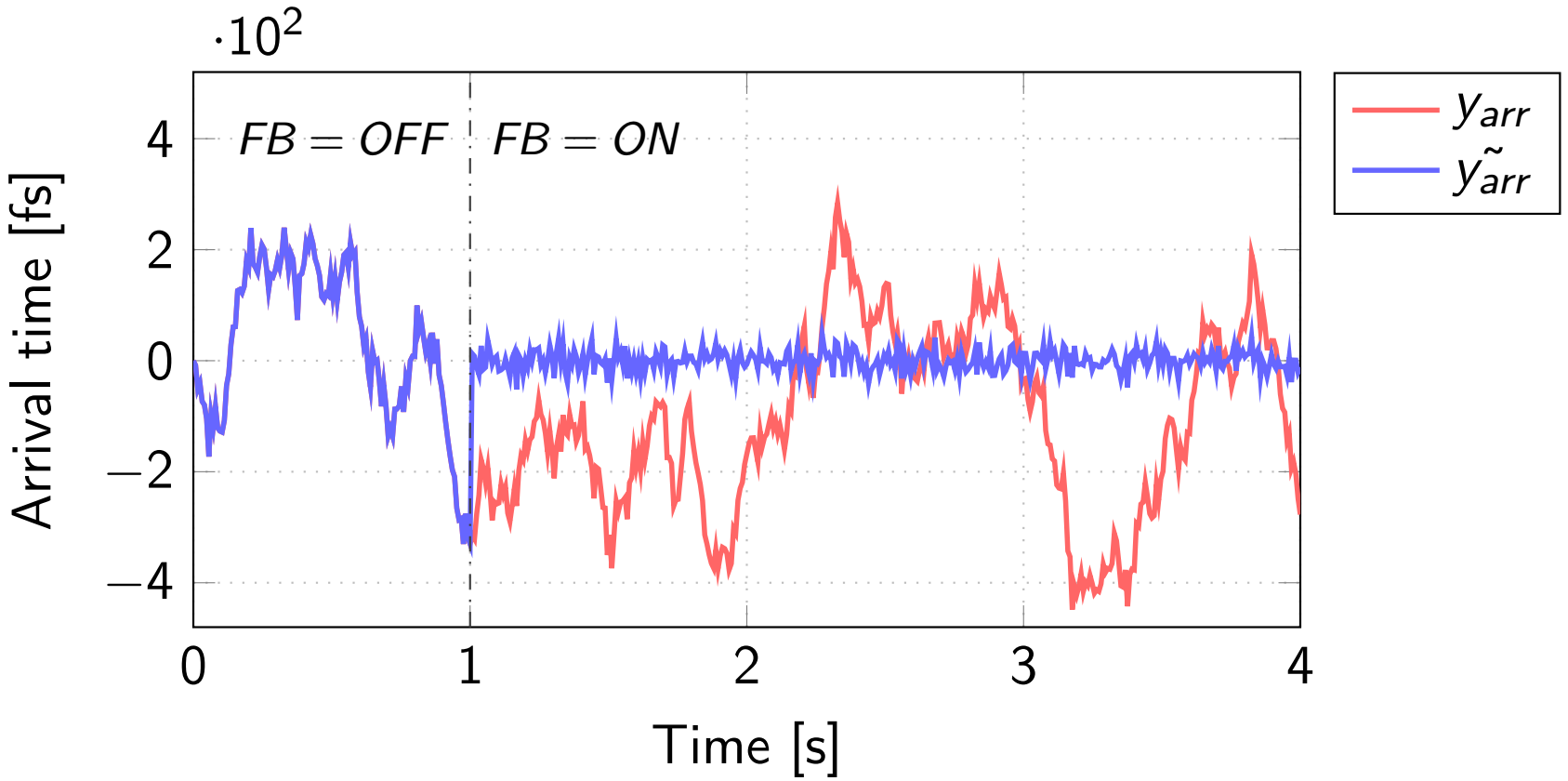


- Assume static propagation of RF noise to electron beam [1].
- Define transfer function V_d to analyze beam arrival time noise.
- Noise shape depends on sensitivity parameters m_{11} and m_{12}.

Optimal Control Problem Formulation

- Process disturbance has stochastic nature.
- $\mathscr{H}_2$ norm shows the rms response of a system driven by white noise.
- CW allows treating the plant as operating in a steady-state mode.
- Focus on disturbance rejection using $\mathscr{H}_2$ optimal control.

Control Performance



- Simulate V_d to produce beam arrival time fluctuations y_{arr}.
- Turn feedback on to compensate y_{arr}.

Next Steps

- Implement the designed control law on a FPGA.
  - Express controller in observer form (LQR + Kalman filter).
  - Use DESY VHDL framework.
  - Target DAMC-TCK7 board by MicroTCA Technology Lab.
- Perform hardware verification.
- Validate the designed beam-based feedback at ELBE.

References

[1] A. Maalberg, M. Kuntzsch, and E. Petlenkov, "Simulation of RF Noise Propagation to Relativistic Electron Beam Properties in a Linear Accelerator," in Proceedings of the 21st IFAC World Congress, 2020, Accepted for publication