

svd in decoupled control for nm-level positioning with coupled dynamics.

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USE CASE

- Control a nm-precision 6-DoF stage (Figure 1) with crosstalk.
- Goal:** use decoupled (SISO) control: **simple** and **well-known**.
- Challenge:** coupling causes.
 - SISO stability analysis to be invalid.
 - SISO performance predictions to be unreliable.
- Solution:** design **notches for crosstalk** modes **within SISO** architecture **using SVD** (Singular Value Decomposition).

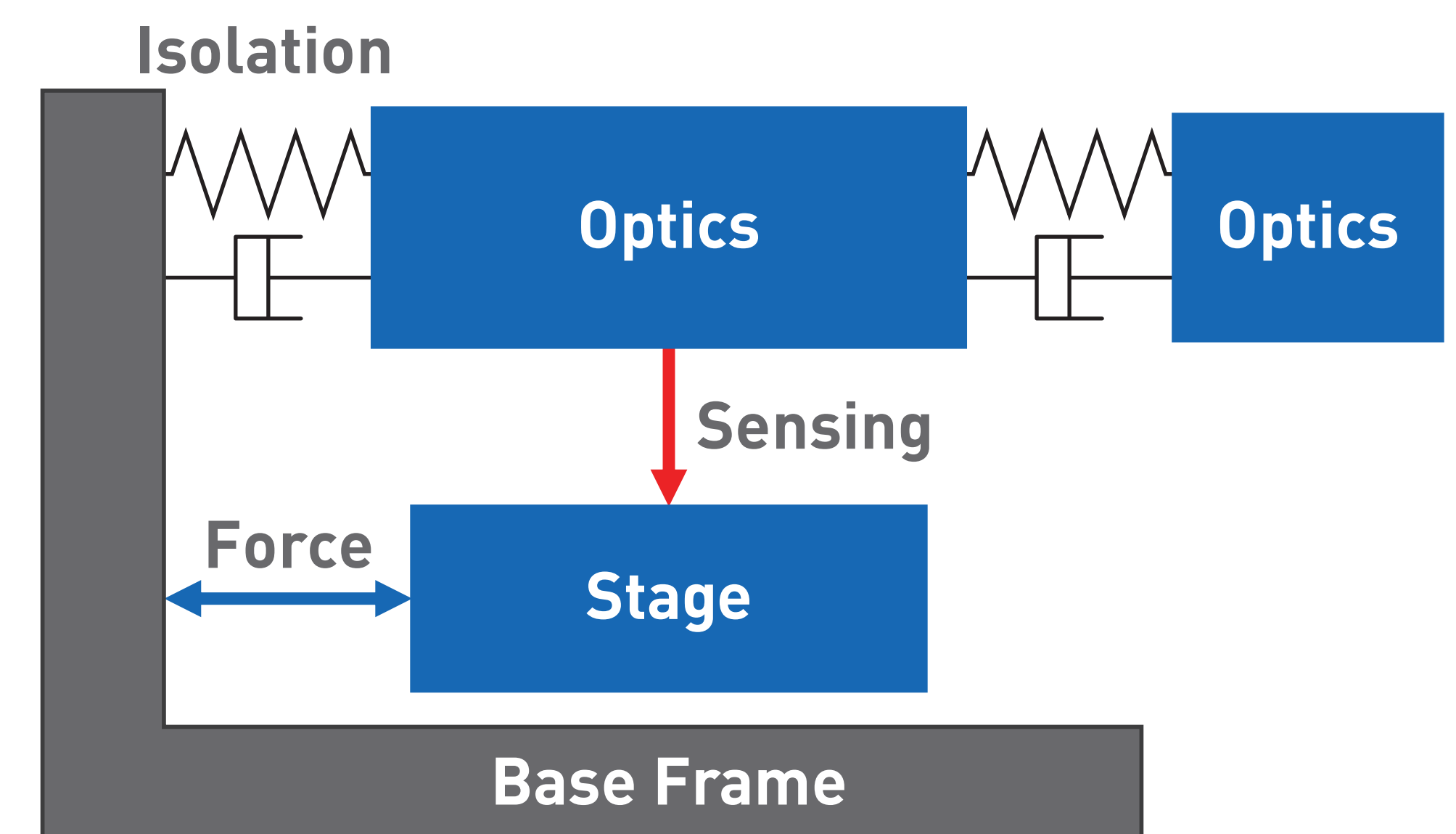


Figure 1: Schematic lithography stage illustrating crosstalk effects.

SVD

Open-loop $L(j\omega) = U(j\omega)S(j\omega)V(j\omega)^*$ Frequency Decomposition

NOTCH DESIGN FOR CLOSED-LOOP

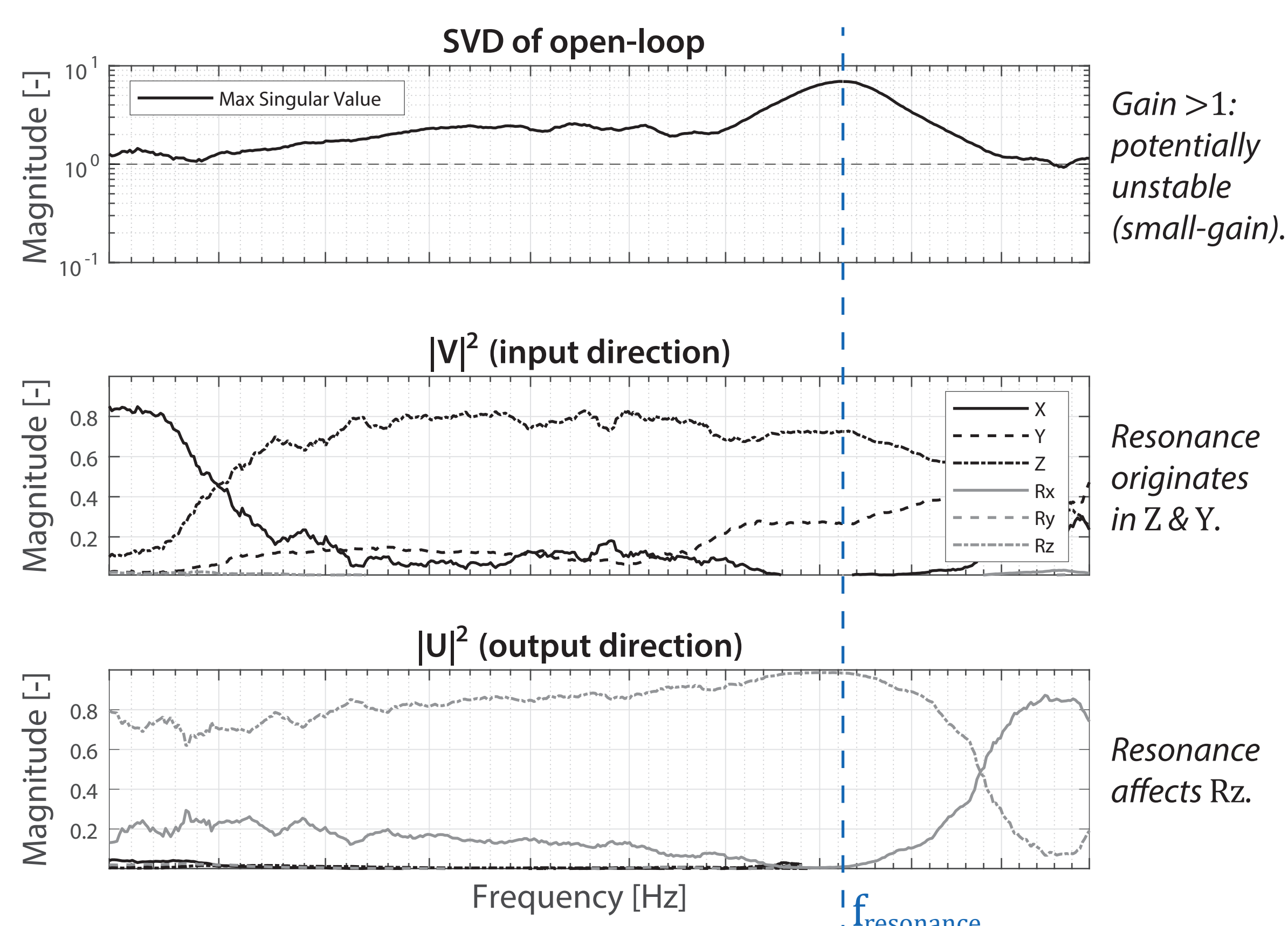


Figure 2: Open-loop SVD. Top: max. singular value σ . Mid and bottom: the in- and output vector corresponding to σ , respectively.

- Figure 2 gives **insight** into **open-loop resonance directions**.
- Open-loop is conservative due to small-gain stability.
- Improve using **D-scaling** (from H_∞ synthesis D-K iterations) to assess **closed-loop behaviour**:
 - Augment the loop (Figure 3).
 - Open the loop between $D(j\omega)$ and $D^{-1}(j\omega)$ for small-gain.
 - Optimize $D(j\omega)$ to minimize the max. singular value.
- SVD with D-scaling approximates closed-loop behaviour, **avoiding unnecessary notches**.

D-SCALING

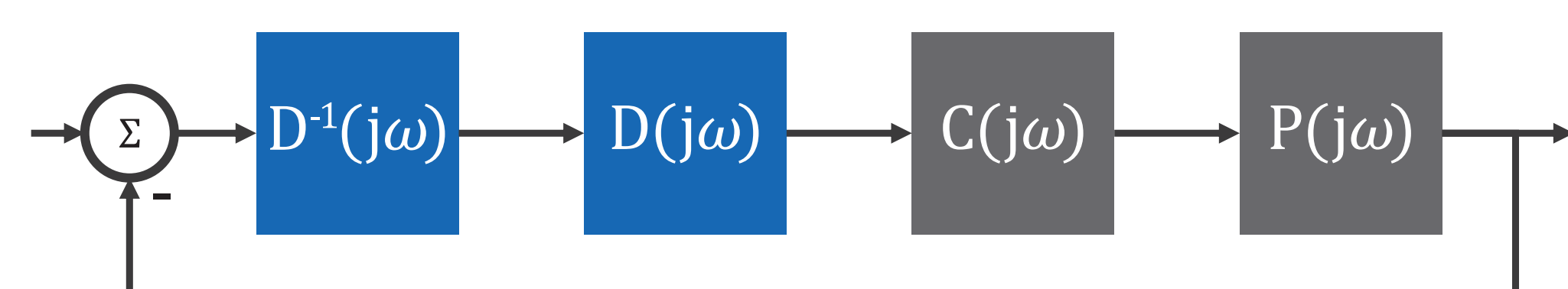


Figure 3: Augmented closed-loop used for D-scaling analysis.

CONCLUSIONS

- SVD-approach **halved cumulative control error** on Demcon's levitating stage (Figure 3).
- D-scaling enables **targeted notch placement**.
- Achieved high-performance control for a coupled system **without** resorting to full **MIMO complexity**.

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- Focus on collaboration with our customers to deliver the best results within the project's constraints.

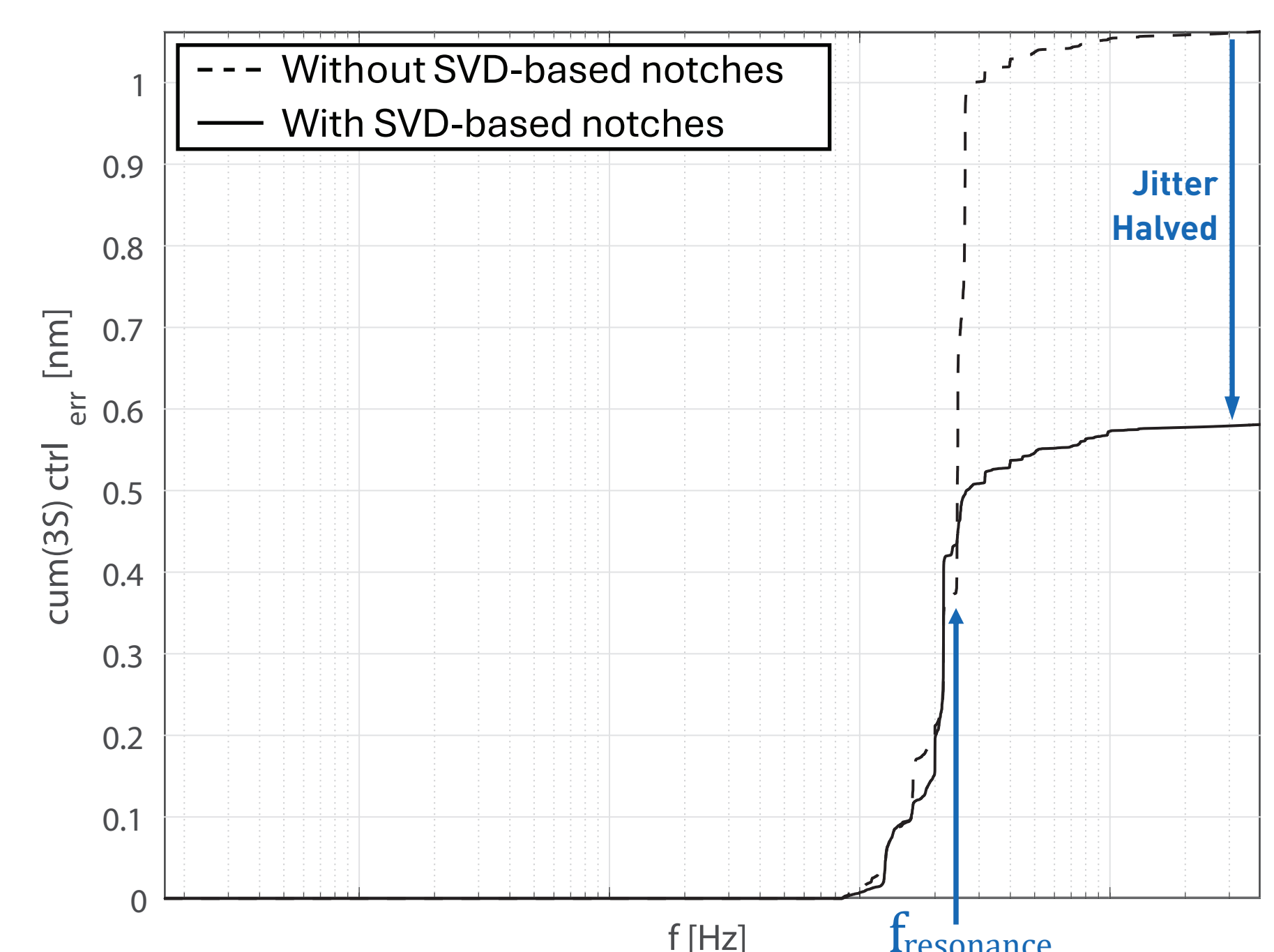


Figure 4: Cumulative controller error (3σ) for control design based on (1) SISO metrics and (2) SISO and SVD metrics.