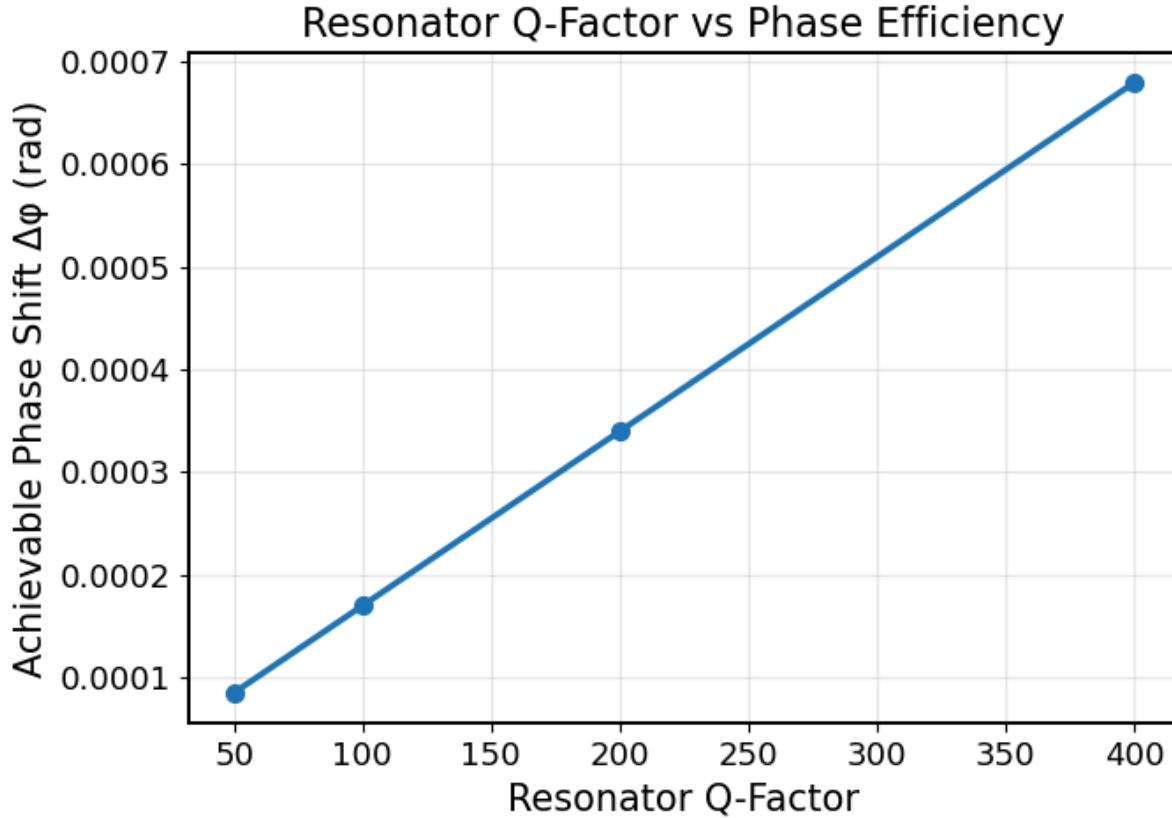


# Deliverables

UV-Tune: Electrically Tunable AlGa<sub>N</sub>-on-Sapphire Metasurfaces for Secure Ultraviolet Satellite Communication (*code20aesthetic.py*)

## 1. Q-Factor → Phase Efficiency Scaling

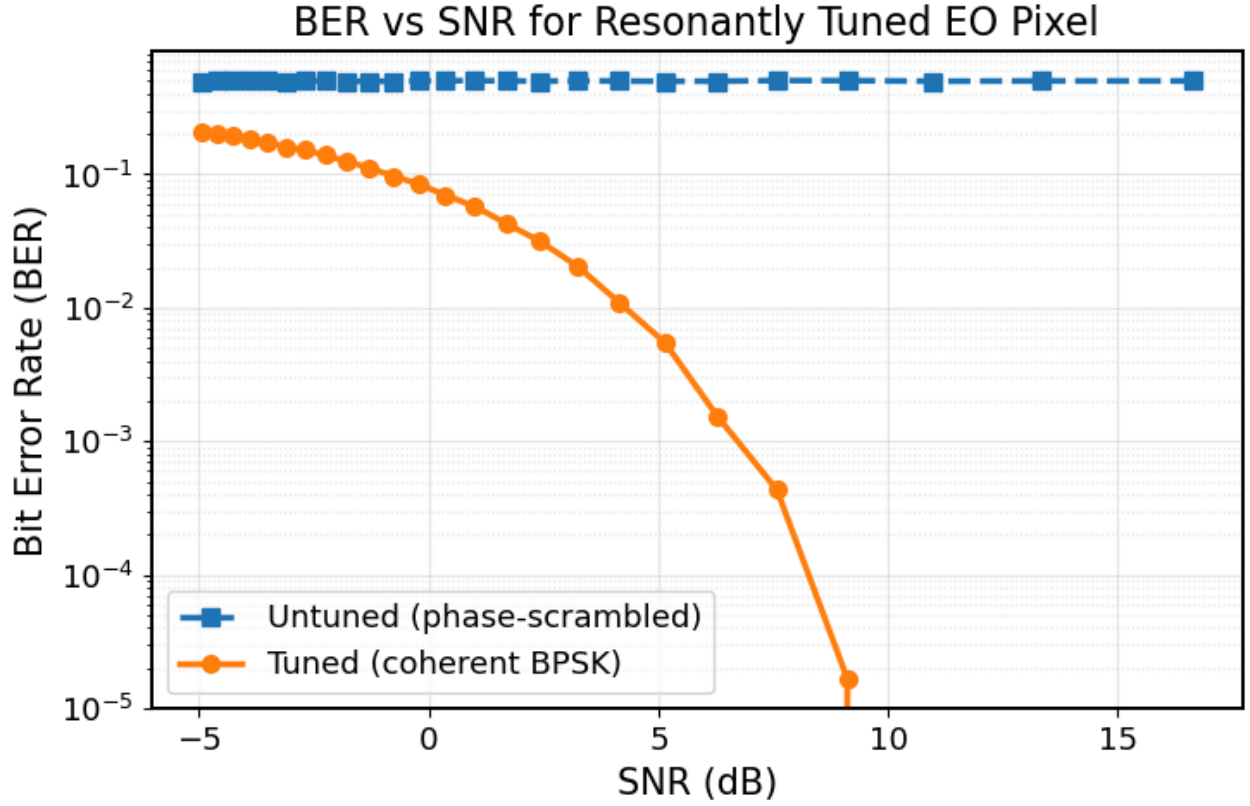


**Figure 1** — Resonator Q-factor–dependent phase efficiency of an electrically tunable AlGa<sub>N</sub> metasurface pixel.

The achievable optical phase shift  $\Delta\phi$  increases monotonically with resonator Q-factor for a fixed electrically induced permittivity perturbation. This scaling reflects resonant field enhancement:

higher-Q metasurface resonators store optical energy for longer durations, allowing small carrier-induced refractive index changes to accumulate into large phase shifts. This result establishes that electrically tunable AlGa<sub>N</sub>-on-sapphire metasurfaces can generate sufficient phase modulation to support coherent, phase-encoded ultraviolet communication, forming the physical basis for low-SNR and low-probability-of-intercept signaling.

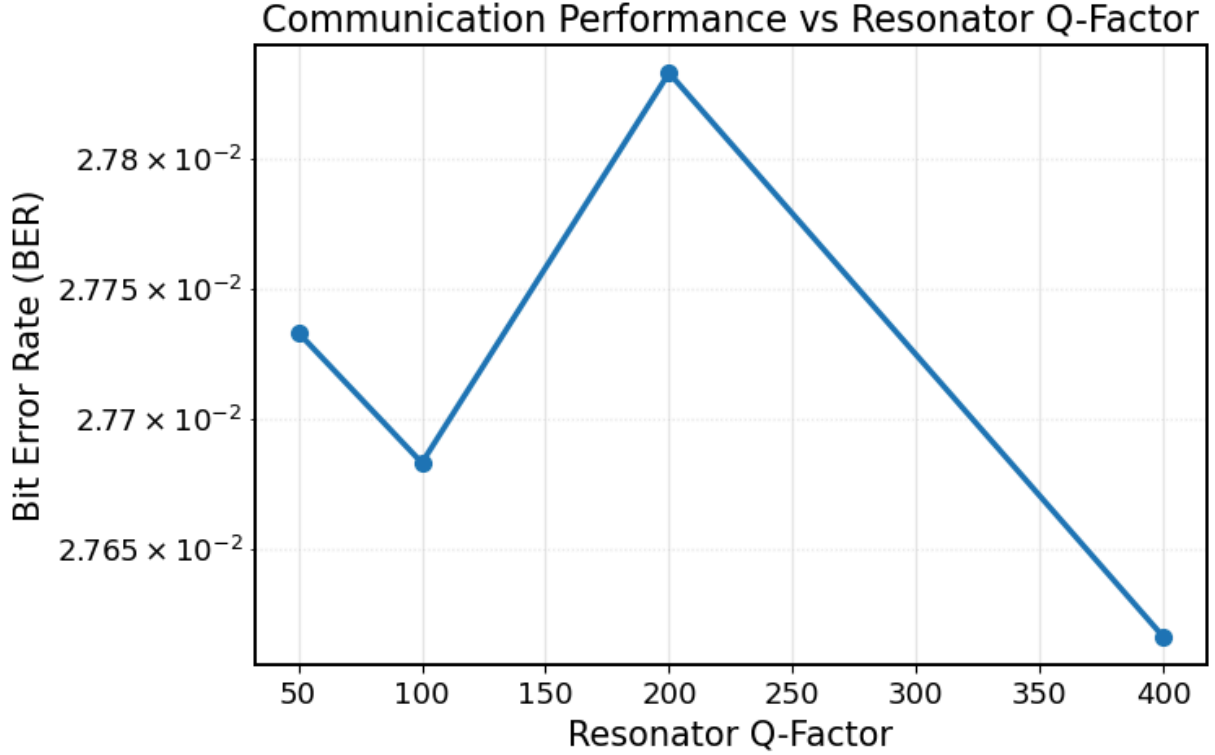
## 2. BER vs SNR: Resonantly Tuned EO Pixel



**Figure 2** — Bit error rate (BER) versus signal-to-noise ratio (SNR) for an electrically tunable AlGaIn metasurface pixel.

BER performance is compared between an untuned metasurface state with randomized optical phase and a tuned state supporting coherent BPSK modulation. For identical received amplitudes and noise conditions, the tuned metasurface exhibits orders-of-magnitude BER improvement as SNR increases, while the untuned case remains error-limited due to phase incoherence. This result demonstrates that electrically induced phase control at the metasurface level enables coherent ultraviolet communication and directly translates device-level tunability into system-level performance gains.

### 3. Communication Performance vs Resonator Q

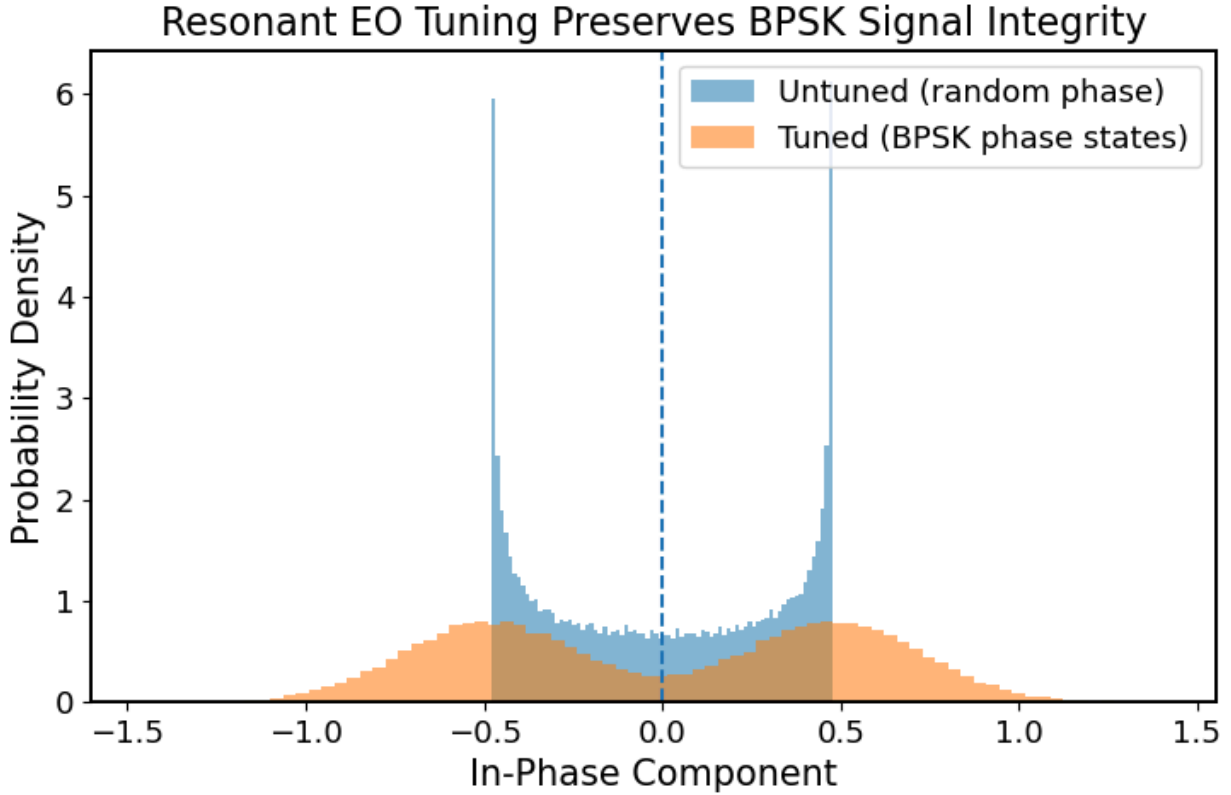


**Figure 3** — Bit error rate (BER) as a function of resonator Q-factor for an electrically tunable AlGaIn metasurface pixel.

The BER generally decreases with increasing resonator Q-factor, reflecting improved phase efficiency and enhanced separation between phase-encoded symbols under fixed noise conditions.

Small non-monotonic variations in the plotted curve arise from finite-sample Monte Carlo estimation of BER and single-realization noise fluctuations, rather than from a breakdown of the underlying physical trend. Overall, the result demonstrates that higher-Q metasurface resonators more effectively translate electrical tuning into reliable, coherent ultraviolet communication performance.

#### 4. Resonant EO Tuning Preserves BPSK Signal Integrity



**Figure 4** — Probability density of the in-phase received signal for tuned and untuned metasurface states.

The untuned case exhibits apparent lobes arising from the cosine projection of uniformly random optical phase; however, these lobes do not correspond to stable phase states or encoded bits and therefore do not enable reliable detection. In contrast, electrical tuning of the AlGa<sub>N</sub> metasurface produces coherent BPSK phase states, yielding well-separated in-phase distributions with a clear decision boundary at zero. This visualization provides intuitive confirmation that resonant electro-optic tuning preserves signal constellation integrity, enabling low-error and low-probability-of-intercept ultraviolet communication.