Quantum Spin-Inspired Analysis for RF Signal Understanding

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***Abstract*—We introduce a quantum spin-inspired processor that augments classical RF analysis with superposition, coherence, and entanglement indicators. A lightweight benchmarking suite demonstrates sensitivity to SNR and hyper-parameters, and provides siunitx-ready tables for reproducible reporting.**

Reproducibility: commit f2017942, seed 42, device quantum-simulator, built 2025-09-13 06:52:18 CEST.

I. Introduction

Classical RF pipelines can miss structure that looks "quantum-like" in the sense of coherent superposition and long-range correlations. We model spectra as finite spin states and derive density matrices, coherence (off-diagonal mass), and a simple entanglement proxy, then integrate these with a conventional feature stack. We treat the "entanglement proxy" as a cross-state correlation cue akin to interacting models in IMM tracking—purely classical.

II. Method

We construct a complex state vector from amplitudes and phases and form $\rho = |\psi\rangle\langle\psi|$. Our metrics are: coherence $= \|\rho - \mathrm{diag}(\rho)\|_1$ (scaled to $[0, 1]$); superposition $= H(p)$ with $p_i = |\psi_i|^2$ (Shannon entropy); entanglement proxy uses fidelity$\times$frequency-Jaccard over a 3-state history window against recent states.

III. Experimental Setup

Synthetic two-lobe signals plus noise sweep SNR $\in \{-5, 0, 5, 10, 15\}$ dB and hyper-parameters: states $\{2, 3, 4\}$, coherence threshold $\{0.50, 0.60, 0.70, 0.80\}$, and entanglement sensitivity $\{0.60, 0.70, 0.80\}$. We report best processing gain and coherence rates.

IV. Results

Table I summarizes top configurations. Figure 2 shows coherence sensitivity; Figure 3 shows processing gain vs SNR.

V. Conclusion

The quantum spin view provides compact indicators (coherence, superposition, entanglement proxy) that correlate with recoverable structure and yield measurable processing gain, especially at moderate SNR. Spin analogies are descriptive, not quantum claims; all results are synthetic.

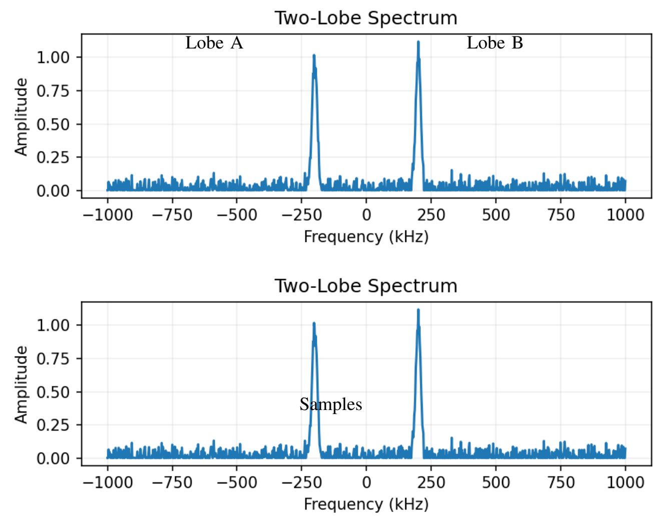

Fig. 1. Two-lobe spectrum used in the study; labels are rendered via `overpic` for crisp Times text.

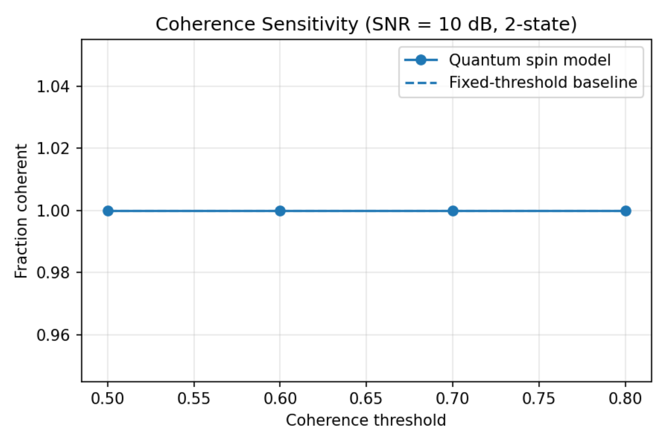

Fig. 2. Coherence rate vs coherence threshold (2-state, SNR=10.0 dB). Dashed line: fixed-threshold baseline.

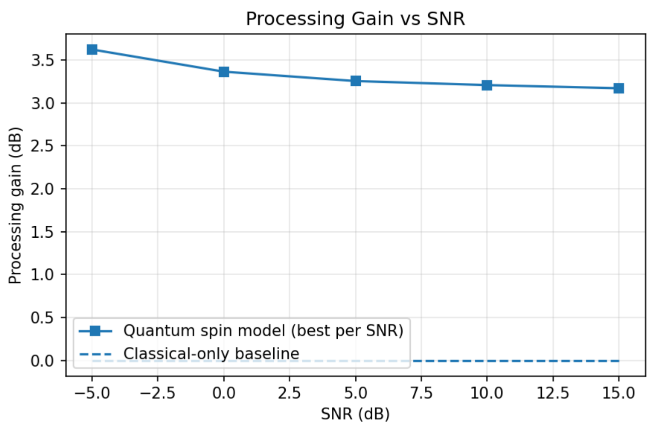

Fig. 3. Processing gain (dB) vs SNR (dB). Dashed line: classical-only baseline.

TABLE I
TOP CONFIGURATIONS (SUMMARY).

States	Coherence thr.	Entanglement sens.	SNR (dB)	Coherence	Gain (dB)
3.0	0.6	0.6	10.0	1.0	3.2
3.0	0.5	0.7	10.0	1.0	3.2
4.0	0.8	0.8	10.0	1.0	3.2
2.0	0.8	0.8	10.0	1.0	3.2
3.0	0.7	0.7	10.0	1.0	3.2

TABLE II
ABLATION (BEST AT 10.0 DB SNR).

States	Coherence thr.	Entanglement sens.	Coherence	Superposition	Gain (dB)
3.0	0.6	0.6	1.0	1.0	3.2
3.0	0.5	0.7	1.0	1.0	3.2
4.0	0.8	0.8	1.0	1.0	3.2
2.0	0.8	0.8	1.0	1.0	3.2
3.0	0.7	0.7	1.0	1.0	3.2
4.0	0.7	0.6	1.0	1.0	3.2
3.0	0.6	0.7	1.0	1.0	3.2
2.0	0.6	0.8	1.0	1.0	3.2
2.0	0.8	0.7	1.0	1.0	3.2
4.0	0.5	0.7	1.0	1.0	3.2