

The Quantum System Engineering Roadmap: FAQ

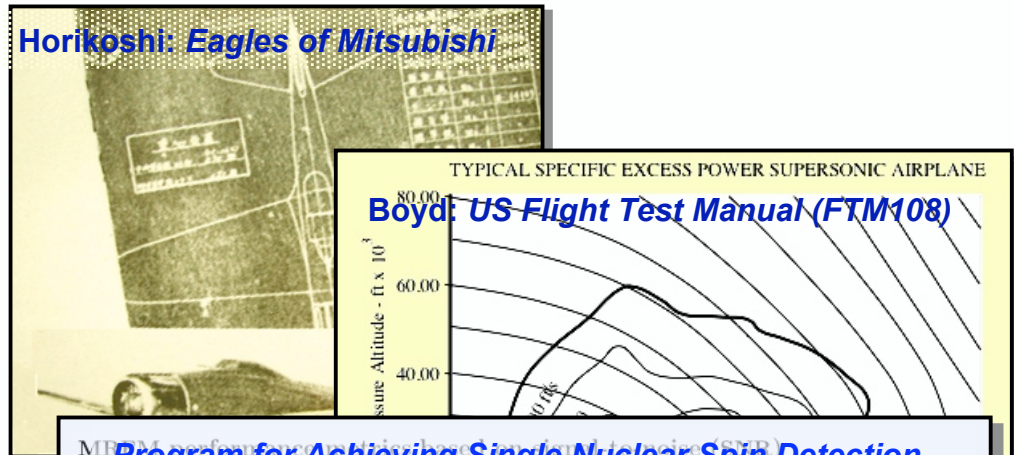
Q3: What is a reliable technical path to practical quantum spin microscopy?

A3: The metric is bits-per-second received from each target spin

- Jiro Horikoshi and John Boyd



Good design metrics reflect the overall mission



Program for Achieving Single Nuclear Spin Detection

$$\left. \begin{array}{l} \text{IOSCAR SNR}^* \text{ for phase-} \\ \text{lock-loop time constant } \tau \end{array} \right\} \text{SNR} = \frac{\partial \mathcal{L} / \partial \tau}{\pi^2 [S_f^{\text{net}} + (2m\omega_0/\tau)^2 S_q]}$$

$$\text{rms force noise in 1 Hz} \quad f_{\min} = (2S_f^{\text{net}} / (1 \text{ second}))^{1/2}$$

$$\left. \begin{array}{l} \text{heuristic MRFM capacity,} \\ \text{as estimated from } f_{\min} \end{array} \right\} C^f = \frac{n_s}{\ln 2} \frac{f_{\text{sig}}^2}{2S_f^{\text{net}}} = \frac{n_s}{\ln 2} \frac{f_{\text{sig}}^2}{f_{\min}^2} \times \frac{1 \text{ bit}}{\text{second}}$$

MRFM performance metrics based on channel capacity

$$\left. \begin{array}{l} \text{net Shannon-Hartley} \\ \text{MRFM capacity} \end{array} \right\} C^{\text{S-H}} = C^{\text{QCL}} \times \mathcal{D}^{\text{loss}}$$

$$\text{quantum capacity limit (QCL)} \quad C^{\text{QCL}} = 0.4758 \times f_{\text{sig}} [n_s / (m\omega_0 \hbar)]^{1/2}$$

$$\left. \begin{array}{l} \text{loss}^b \text{ to excess noise (i.e., } \mathcal{R}^{\text{net}} > 1) \\ \text{and noise imbalance (i.e., } \mathcal{R}^{\text{bal}} \neq 1) \end{array} \right\} \mathcal{D}^{\text{loss}} = \frac{1.6413}{(\mathcal{R}^{\text{net}} \mathcal{R}^{\text{bal}})^{1/6}}$$

$$- \frac{0.5038}{(\mathcal{R}^{\text{bal}})^{1/2}} \times \arctan \left[3.2579 \times \frac{(\mathcal{R}^{\text{bal}})^{1/3}}{(\mathcal{R}^{\text{net}})^{1/6}} \right]$$

$$\left. \begin{array}{l} \text{approximate capacity, valid for all} \\ \text{devices to the left of the } \mathcal{R}\text{-line}^c \end{array} \right\} C^{\text{S-H}} \simeq C^f$$

- Channel capacity is a good choice for an MRFM design metric because it:

- Directly reflects the mission, (gain information from spins)
- Provides strategic guidance for device design
- Establishes fundamental physical bounds on performance