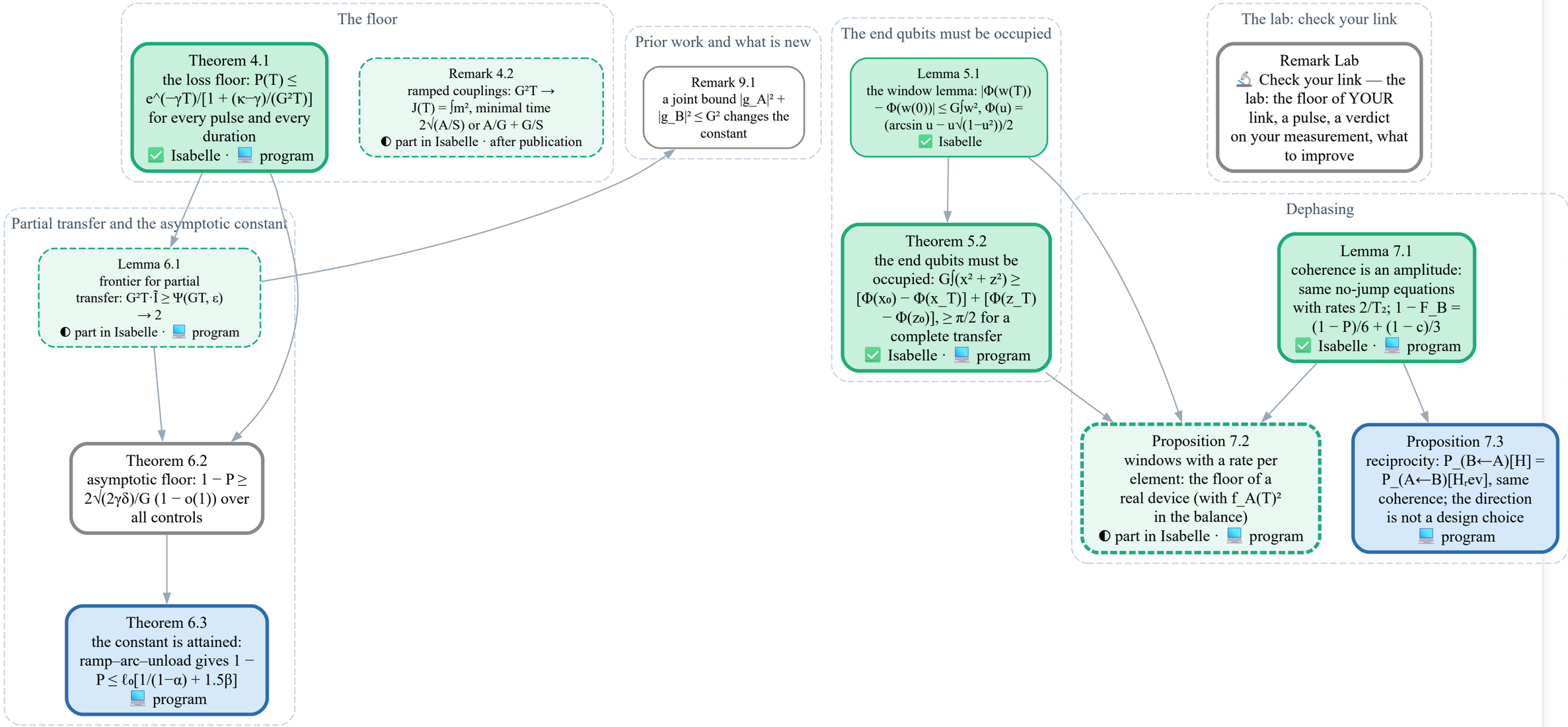
Map of *Quantum state transfer through a lossy bus: fundamental error limits for every control pulse, with application to IBM's meter-scale interconnects*

Quantum state transfer · quantum interconnects · optimal control bounds

12 results | ✅ **0** entirely in Lean | ◐ **3** partly in Lean | ✅ **4** in Isabelle | 💻 **7** checked by a program | written proof only | (a result can carry several tags)

Dependencies in the written proof: an arrow A → B means that this proof of B uses A. Every result rests on its written proof; the tags record what was checked besides, and each statement's "Evidence & scope" block says how far. The colour of a box is its strongest tag, in the order above; the tags in the box give the rest. Boxes with a thick border are the main results; click a box to read the statement.



What the paper contributes

A qubit hands its state to another qubit through a lossy bus (a resonator, a waveguide or a cable mode), with each coupler bounded by G. The paper gives error floors that hold for *every* control pulse, every duration and any number of bus modes, and applies them to IBM's meter-scale interconnect.

- **A floor at every duration** (Theorem 4.1, Isabelle): $P(T)\le e^{-\gamma T}/[1+(\kappa-\gamma)/(G^2T)]$.
- **The end qubits cannot be bypassed** (Theorem 5.2, Isabelle): the excitation must sit in the end qubits for an integrated time whose lower bound tends to $\pi/(2G)$ for a complete transfer.
- **The asymptotic constant** (Theorems 6.2 and 6.3): the perturbative optimum $2\sqrt{2\gamma(\kappa-\gamma)}/G$ becomes a lower bound over all controls, and an explicit pulse attains it with explicit error terms.
- **Dephasing and real devices** (Section 7): the coherence with the vacuum is an amplitude with rates $2/T_2$; a version with a rate for each element gives the floor of a real device; reciprocity makes the direction irrelevant.
- **IBM's links** (Section 8): floors 6.03–10.05×10^{-4} on $1-F_B$, certified with ball arithmetic, against measured errors 11–16 times larger; which hardware change lowers the floor; three other platforms.

The lab **Check your link** computes the floor of your own link with the same code as the paper's tables.

Open in the laboratory, with the values of the paper: IBM Q240–Q247 · IBM Q241–Q246 · IBM Q242–Q245 · IBM Q243–Q244 · Heya et al. · Chang et al. · Burkhart et al. (1 − P) · unequal couplers (10.9 / 7.1 MHz) · $g/2\pi = 22.5$ MHz · towards 10^{-4} (design map). Each opens the three labs of the section with those values: the floor, the bound at the measured duration, the pulses, the error budget, the design map and the sliders.

🚀 **Start here: Theorem 4.1**: the loss floor: $P(T) \le e^{(-\gamma T)}/[1 + (\kappa-\gamma)/(G^2T)]$ for every pulse and every duration.

Main results:

- **Theorem 4.1**: the loss floor: $P(T) \le e^{(-\gamma T)}/[1 + (\kappa-\gamma)/(G^2T)]$ for every pulse and every duration
- **Theorem 5.2**: the end qubits must be occupied: $G\int(x^2 + z^2) \ge [\Phi(x_0) - \Phi(x_T)] + [\Phi(z_T) - \Phi(z_0)]$, $\ge \pi/2$ for a complete transfer
- **Theorem 6.2**: asymptotic floor: $1 - P \ge 2\sqrt{(2\gamma\delta)}/G\ (1 - o(1))$ over all controls
- **Theorem 6.3**: the constant is attained: ramp–arc–unload gives $1 - P \le \ell_0[1/(1-\alpha) + 1.5\beta]$
- **Lemma 7.1**: coherence is an amplitude: same no-jump equations with rates $2/T_2$; $1 - F_B = (1 - P)/6 + (1 - c)/3$
- **Proposition 7.2**: windows with a rate per element: the floor of a real device (with $f_A(T)^2$ in the balance)
- **Proposition 7.3**: reciprocity: $P_(B\leftarrow A)[H] = P_(A\leftarrow B)[H_rev]$, same coherence; the direction is not a design choice

- **Remark Lab**: 🔬 Check your link — the lab: the floor of YOUR link, a pulse, a verdict on your measurement, what to improve

🧭 Fields: where the paper lives and what it connects

Tools taken from other branches

- **Quantum speed limits and optimal control** → Cauchy–Schwarz on the integrated bus occupation; comparison with ODE windows; a calibration function Φ for the end qubits — Theorem 4.1, Theorem 5.2, Lemma 6.1, Proposition 7.2
- **Open quantum systems** → no-jump evolution, Lindblad dephasing, coherence with the vacuum as an amplitude, reciprocity — Lemma 7.1, Proposition 7.3
- **Formal verification and certified numerics** → Isabelle/HOL-Analysis (entry Quantum_Speed_Limits, public in karlesmarin/formalizations); ball arithmetic (Arb) for the IBM floors — Theorem 4.1, Lemma 5.1, Theorem 5.2, Lemma 6.1, Proposition 7.2

What the results serve

- **Hardware design of modular quantum computers** ← which parameter lowers the floor of a link most (coupling, worse-qubit dephasing, coupler slope), before any pulse is designed — Proposition 7.2, Proposition 7.3