

iQuHACK 2026 - Superquantum Track

Team: The Q-Factor

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Overview

The goal was to compile quantum unitaries into efficient Clifford+T circuits. Non-Clifford gates (T gates) are expensive in fault-tolerant quantum computing, so minimizing T-count while maintaining accuracy was the key challenge. We used a mix of algebraic insight, KAK decomposition, and gridsynth approximation to achieve competitive results across all 11 challenges.

Challenge 1: Controlled-Y Gate

This was the warm-up to verify our submission pipeline worked. We used the identity $Y = SXS^\dagger$ to express Controlled-Y in terms of Controlled-X (CNOT) with S gates on the target qubit. Since $S = T^2$, this gives an exact Clifford+T implementation with just a few T gates.

Challenge 2: Controlled- $R_y(\pi/7)$

A controlled rotation by an irrational angle. We decomposed it as a controlled-Rz sandwiched between basis changes. The key was isolating the control structure so only one rotation needed gridsynth approximation. We searched for epsilon sweet spots to minimize T-count while hitting the error target.

Challenge 3: $\exp(i\pi/7 \cdot ZZ)$

The ZZ interaction is diagonal in the computational basis. We used the standard CNOT to compute parity, apply Rz on the parity qubit, then CNOT to uncompute. This "CNOT-phase-CNOT" pattern is compact and only requires synthesizing one Rz rotation.

Challenge 4: $\exp(i\pi/7 \cdot (XX + YY))$

The XY interaction has a known structure related to partial SWAP. We decomposed it as $CNOT \rightarrow \text{Controlled-Rz} \rightarrow CNOT \rightarrow \text{single-qubit corrections}$. Recognizing this algebraic structure meant we only needed to synthesize one non-trivial angle ($2\pi/7$) rather than treating it as a generic 2-qubit gate.

Challenge 5: $\exp(i\pi/4 \cdot (XX + YY + ZZ))$

The full Heisenberg interaction with a special angle. The key insight is $XX + YY + ZZ = 2 \cdot \text{SWAP} - I$. With the $\pi/4$ coefficient, this becomes related to $\sqrt{\text{SWAP}}$, which is nearly Clifford. This gave us a very low T-count since the structure is almost exact.

Challenge 6: $\exp(i\pi/7 \cdot (XX + ZI + IZ))$

The transverse field Ising model. We avoided Trotter decomposition (which adds discretization error) and used exact KAK decomposition instead. This gave us 10 non-Clifford rotations. We then searched epsilon values systematically and found spots where gridsynth errors across rotations canceled out. The result was $T=1140$ with error 3×10^{-11} , beating the competition by $10,000\times$ on error.

Challenge 7: State Preparation

Prepare a random 2-qubit state from $|00\rangle$. We used Qiskit's state preparation decomposition which gives 1 CNOT + 6 rotations. The key insight is we only need $U|00\rangle = \text{target}$, not a full unitary. With the 10,000 gate budget, we pushed epsilon to 2×10^{-9} and achieved precise results with only 1,600 gates.

Challenge 8: 2-Qubit QFT

This was an exact synthesis problem, not an approximation problem. QFT_2 decomposes as $H \rightarrow \text{Controlled-S} \rightarrow H \rightarrow \text{SWAP}$. The Controlled-S gate needs just 3 T gates: $T(\text{ctrl}) \rightarrow \text{CNOT} \rightarrow T^\dagger(\text{tgt}) \rightarrow \text{CNOT} \rightarrow T(\text{tgt})$. Total: 3 T gates with zero error.

Challenge 9: Structured Unitary

The "figure out the structure" challenge. We identified this matrix as a controlled operation conjugated by Hadamard: $(H \otimes I) \cdot \text{Controlled-U} \cdot (H \otimes I)$. Recognizing this structure helped us decompose the inner controlled operation efficiently.

Challenge 10: Random Unitary

No exploitable structure here since the unitary is randomly generated. We tried several approaches: naive transpilation left generic single-qubit gates (not true Clifford+T), Solovay-Kitaev worked but produced very deep T-heavy circuits, and manual Weyl/KAK + gridsynth was accurate but overly complex. Our final approach used the Qiskit gridsynth plugin which provides built-in optimal Clifford+T synthesis with error control. The result was 2043 T-gates with $1e-11$ norm distance.

Challenge 11: 4-Qubit Diagonal

All phases were multiples of $\pi/4$, which means exact Clifford+T synthesis is possible. We used phase polynomial decomposition from the workshop, ending up with 3 T-gates in total. We used RMSynth for this challenge, to reduce the number of T-gates in our circuit!