Low-cost, home-made Quantum Computer

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Introduction

Among all quantum technologies currently available, quantum computers remain the most controversial. After over 100 years of quantum science in 2025, numerous applications were developed, such as quantum sensors and quantum networks. With these technologies used across medicine, military, and enterprises, quantum computers remain active mostly in the laboratories. Their applications are limited to validating fundamental laws of physics, where the number of logical qubits remains low. This feature of the so-called Noisy Intermediate Scale Quantum (NISQ) computers makes them rather of a teaching tool than real-world problem solvers. Because of that, the following research focuses on an engineering approach that allows a student to create such a tool in a low-cost manner, to discover computational quantum mechanics at home.

Deutsch-Jozsa Algorithm

One common approach to benchmarking an NISQ computer is to utilise its ability to implement the Deutsch-Jozsa algorithm, which determines whether a given function is balanced or constant in a single run, demonstrating quantum advantage over classical logic-based methods that require multiple evaluations. The following mathematical steps represent physical operations on a gate-based NISQ device to assess its foundational computational capabilities: initialising the qubits, applying Hadamard gates to create superposition, using an oracle to encode the function, applying Hadamard gates again to generate interference, and finally measuring the output to distinguish between balanced and constant functions[5].

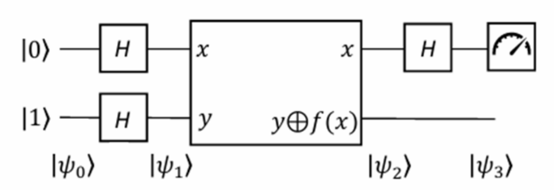


Figure 1. Gate-based implementation in Quantum Information framework.

Step 1: Initial State and First Hadamard Transformation

$$\begin{aligned}|\psi_0\rangle &= |01\rangle\\ |\psi_1\rangle &= \left(\frac{|0\rangle+|1\rangle}{\sqrt{2}}\right)\otimes\left(\frac{|0\rangle-|1\rangle}{\sqrt{2}}\right)\\ &= \frac{1}{2}(|00\rangle-|01\rangle+|10\rangle-|11\rangle)\end{aligned}$$

Step 2: Oracle Function Evaluation

For $f(x)=0$: $|\psi_2\rangle=\frac{1}{2}(|00\rangle-|01\rangle+|10\rangle-|11\rangle)$
For $f(x)=1$: $|\psi_2\rangle=\frac{1}{2}(|01\rangle-|00\rangle+|11\rangle-|10\rangle)$
For $f(x)=x$: $|\psi_2\rangle=\frac{1}{2}(|00\rangle-|01\rangle+|11\rangle-|10\rangle)$
For $f(x)=x\oplus 1$: $|\psi_2\rangle=\frac{1}{2}(|01\rangle-|00\rangle+|10\rangle-|11\rangle)$

Step 3: Final State Analysis

For $|\psi_2\rangle$:

$$|\psi_2\rangle=\begin{cases}\pm\left(\frac{|0\rangle+|1\rangle}{\sqrt{2}}\right)\otimes\left(\frac{|0\rangle-|1\rangle}{\sqrt{2}}\right) & \text{if } f(0)=f(1)\\ \pm\left(\frac{|0\rangle-|1\rangle}{\sqrt{2}}\right)\otimes\left(\frac{|0\rangle-|1\rangle}{\sqrt{2}}\right) & \text{if } f(0)\neq f(1)\end{cases}$$

After the final Hadamard on the first qubit, for $|\psi_3\rangle$:

$$|\psi_3\rangle=\begin{cases}\pm|0\rangle\otimes\left(\frac{|0\rangle-|1\rangle}{\sqrt{2}}\right) & \text{if } f(0)=f(1) \text{ (constant)}\\ \pm|1\rangle\otimes\left(\frac{|0\rangle-|1\rangle}{\sqrt{2}}\right) & \text{if } f(0)\neq f(1) \text{ (balanced)}\end{cases}$$

The measurement result of the first qubit determines the function type:

- Measure $|0\rangle \Rightarrow$ Function is constant
- Measure $|1\rangle \Rightarrow$ Function is balanced

Benchmarking 2-qubit NISQ computers

The following table compares 2-qubit, NISQ computers, quantifying their effectiveness through measured fidelity rates to assess adherence to expected balanced/constant function results, dependent on qubit infrastructure choice.

Infra.	ID⇒0	NOT⇒0	CNOT⇒1	Z-CNOT⇒1
Supercond.[1]	93%	94%	91%	84%
Silicon[7]	98%	96%	95%	93%
Ion-Trap[2]	98.1%	91.3%	97.5%	97.5%

Table 1. Fidelity scores for 2-qubit Deutsch-Jozsa implementations.

Design of Experiment

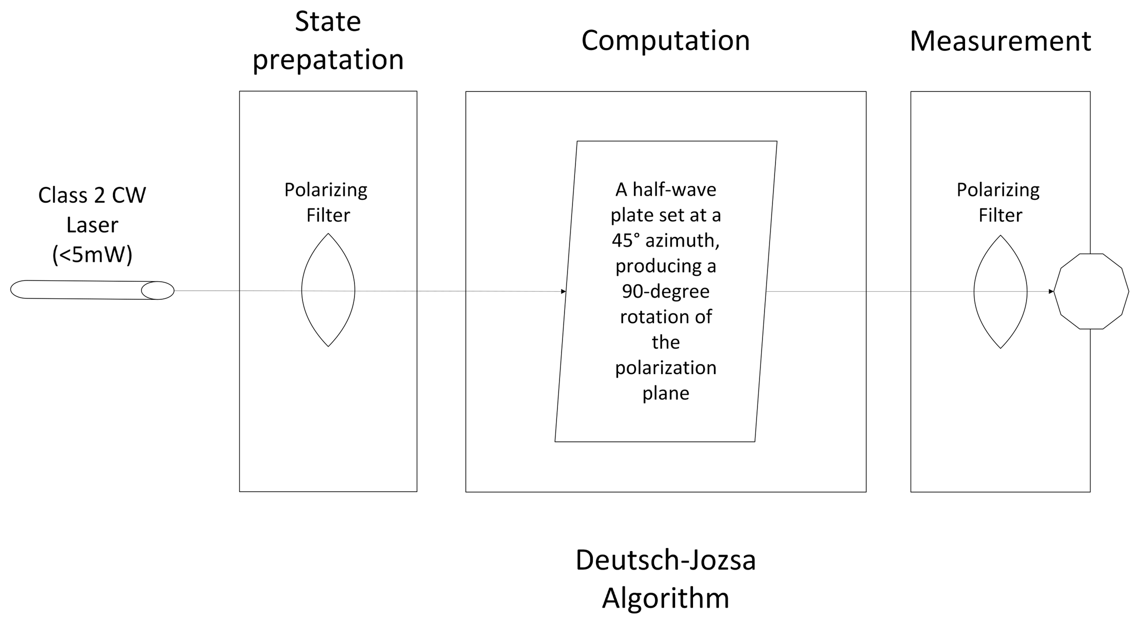


Figure 2. Project Architecture[6].

Polarisation-encoded qubits via half-wave plates[4].

Step 1: State Preparation

1. Laser
2. Polariser (as a Hadamard gate)
3. Laser intensity stabilisation (combination of half-wave plates and polarisers)

Step 2: Computation (Oracle)

- ID gate: Beam passing through a polarisation-neutral medium.
- NOT gate: half-wave plate set at a 45° azimuth.
- CNOT gate: encode control qubit in polarisation, and target in spatial degree of freedom with a polarising beamsplitter.
- Z-CNOT gate: a half-wave plate at 45° to the control qubit, send this photon through PBS, apply another half-wave plate on the control qubit.

Step 3: Measurement

- Polariser (Analyser)
- Intensity correlation measurements using balanced photodetectors connected to oscilloscopes.
- Function determination via intensity threshold analysis:

$$\text{Outcome}=\begin{cases}\text{Total intensity} > \eta & \text{Constant}\\ \text{Modulated intensity distribution} & \text{Balanced}\end{cases}$$

where η is the intensity threshold from calibration.

Physical implementation

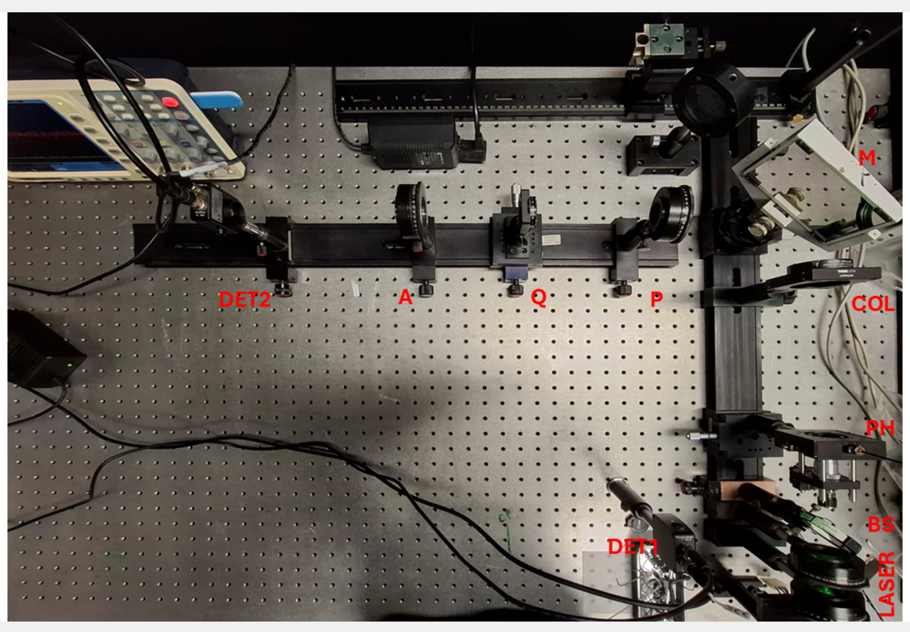
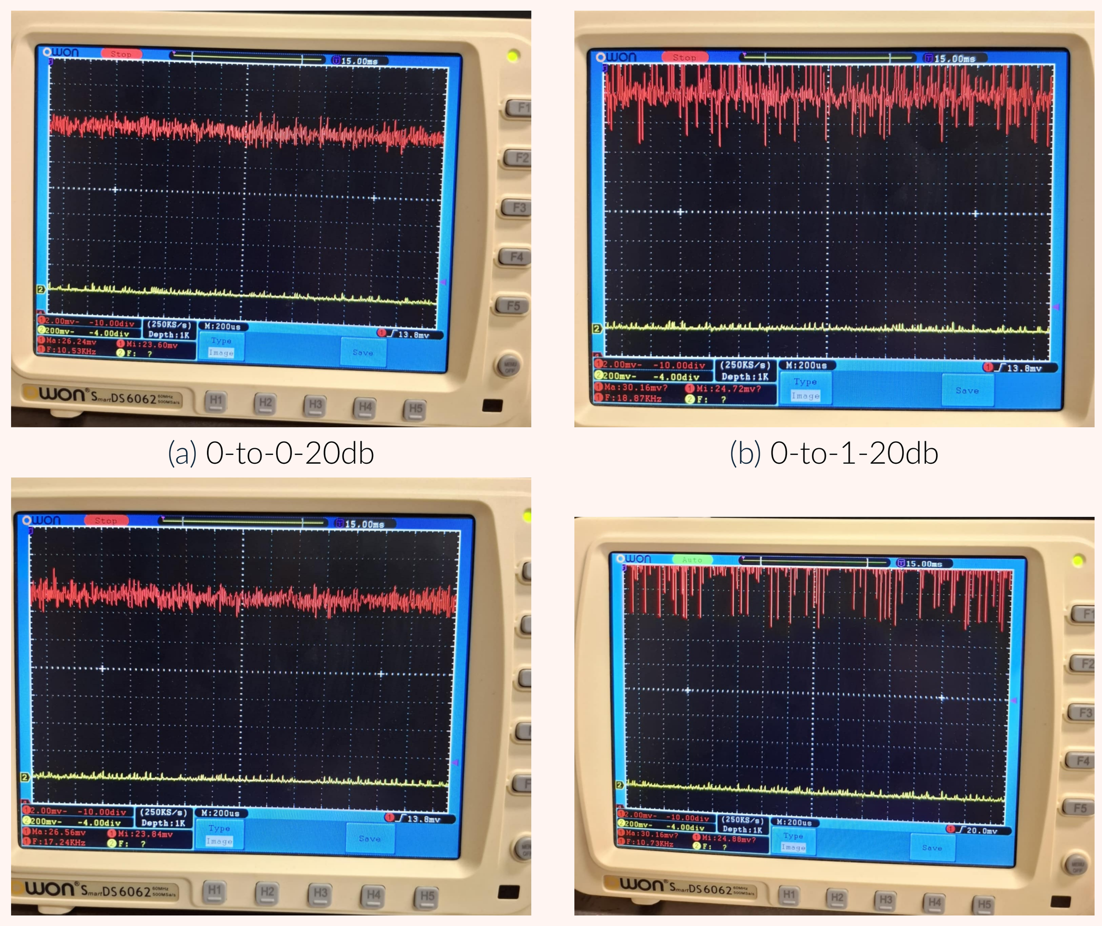


Figure 3. LASER - 523 nm laser with polariser and half-wave plate for intensity and polarisation control. BS - 50:50 beam-splitter. DET1 - irradiance detector, fixed gain. PH - pinhole with microscope objective. COL - collimating lens f=200 mm. M - mirror. P - linear polariser. Q - half-wave plate. A - analyser (linear polariser). DET2 - irradiance detector, variable gain (20 db).

Technical implementation: The experimental setup employs a 523 nm diode laser with initial polarisation control via a linear polariser (P) and half-wave plate (Q), enabling precise intensity modulation and polarisation rotation. A 50:50 beam splitter (BS) divides the beam, directing 50% to a reference irradiance detector (DET1, fixed gain) for power stabilization, while the transmitted portion passes through a spatial filtering stage comprising a microscope objective-integrated pinhole (PH, Ø 10-50 µm) and collimating lens (COL, $f = 200$ mm) to generate a diffraction-limited plane wave. A steering mirror (M) guides the collimated beam through a polariser (P), and then through a waveplate as a computation, to be encoded by an analyser (A) - a rotatable linear polariser - before detection by a variable-gain irradiance sensor (DET2, 20 dB).

Results

The oscilloscope displays distinct intensity levels after 20 dB gain application, clearly reflecting the encoding of NOT and ID gates. These intensity variations directly correspond to binary outputs: lower intensity represents "0" while higher intensity represents "1" across the 2 implemented gates.



(a) 0-to-0-20db
(b) 0-to-1-20db
(c) 1-to-0-20db
(d) 1-to-1-20db

Figure 4. Results of implementation ID and NOT gates with optics.

Numerical implementation

The proposed experiment was modelled using the Jones matrix formalism, with QuTiP's built-in unitary transformations enabling accurate simulation of arbitrary polarisation rotations. We defined custom quantum operations corresponding to each oracle function for the Deutsch-Jozsa algorithm implementation. We tracked the system's evolution using QuTiP's quantum dynamics solvers to extend the functionality beyond the possibilities of the proposed architecture, such as CNOT and Z-CNOT gates. Figure 3 presents Bloch sphere reflecting polarisation results:

$|\mathrm{H}\rangle = 0.5157 - 0.0000j; |V\rangle = 0.4843 + 0.0000j$

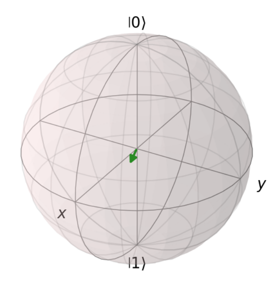


Figure 5. Bloch sphere representing 45 degrees polarisation[3].

Summary

The project detailed specific implementation steps including state preparation through polarizers and half-waveplates, computation via various optical configurations, and measurement using intensity correlation with balanced photodetectors. Experimental results validated the theoretical framework, showing the feasibility of implementing fundamental quantum operations with accessible optical components. This research underscores the potential for democratizing access to quantum technologies by enabling students and hobbyists to build functional, albeit limited, optical computing systems outside specialized laboratories.

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