



Patenting in the Quantum Era: A Comparative Analysis of Patents in Quantum Technologies in the EU and the U.S.

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I. Introduction

In December 2022, the city of Antwerp was struck by one of the largest cyberattacks to date, shutting down all digital services for a full year, and 500 gigabytes of data were stolen.¹ Situations such as these emphasize the need for more efficient and sustainable security. With 5G slowly emerging, sectors such as platform technologies, finance, mobility, and public health play a vital role in national security and everyday lives. Classical cybersecurity has become vulnerable, and governments are seeking solutions to improve security.

2025 is recognized as the International Year of Quantum Science and Technology by the United Nations, celebrating 100 years of the era of modern quantum mechanics.² Though the history of quantum mechanics can be traced back to the 17th century, it is only when Werner Heisenberg and Max Born developed their matrix formulation of quantum mechanics that the first physical applications were developed. Nowadays, the scientific field is rapidly evolving, and the first devices with quantum parts are being used, such as quantum navigation to replace GPS³ and the first tests around quantum encryption on IP networks.⁴

Quantum technologies ('QT'), which are based on principles of quantum mechanics, seem to be a solution to cyberconcerns. In 1994, Peter Shor proved that a quantum algorithm can disband an integer into prime numbers faster than any classical computer would be able to in a thousand years. Ever since, innovation in quantum tech has been rapidly increasing, with promising inventions regarding the development of quantum computers, cryptography, navigation, and so forth. Authors have predicted groundbreaking possibilities in biochemistry, solving logistical problems, and possibly in machine learning and artificial intelligence,⁵ and quantum computers could theoretically break current encryption methods in just a few hours.⁶

¹ Tim Verheyden, 'Rapport Vlaamse overheid vernietigend voor cyberveiligheid stad Antwerpen vóór grote hack in 2022: "Onvoldoende maatregelen, pijnlijk voor zo'n grote organisatie"' (*VRT NWS*, 25 June 2024) <<https://www.vrt.be/vrtnws/nl/2024/06/25/cyberantwerpen/>> accessed 3 April 2025.

² UNESCO, 'International Year of Quantum Science and Technology' (*UNESCO*, date unknown) <<https://www.unesco.org/en/years/quantum-science-technology>> accessed 26 July 2025.

³ Greg Block, 'Q-CTRL's New Maritime Quantum Navigation Solution Successfully Undergoes First Defense Trials at Sea' (*Quantum Insider*, 16 July 2025) <https://thequantuminsider.com/2025/07/16/q-ctrls-new-maritime-quantum-navigation-solution-successfully-undergoes-first-defense-trials-at-sea/> accessed 25 July 2025.

⁴ Huawei Blog, 'Huawei's Router-Based Quantum Encryption Transmission Solution Passes Testing' (*HuaweiBlog*, 15 April 2025) <<https://blog.huawei.com/en/post/2025/4/15/huawei-router-quantum-encryption-transmission-passes-testing>> accessed 25 July 2025.

⁵ Christopher Monroe, Michael G. Raymer and Jacob Taylor, 'QUANTUM INFORMATION The US National Quantum Initiative: From Act to action' (2019) 364 *SCIENCE* 440, 440.

⁶ Jennifer A Nekuda Malik, 'Science advocacy drives passage of US National Quantum Initiative Act' (2019) 44 *MRS Bulletin* 158, 159, referring to National Academies of Sciences, Engineering, and Medicine, *Quantum Computing: Progress and Prospects* (1st edn, The National Academies Press 2019) 98.

There are multiple ways this innovation thrives besides mere scientific curiosity: private and public funding, R&D collaboration, and the possession of exclusive rights to monetize inventions and prohibit others from unauthorized exploitation: patents. As of 2022, there were 1892 granted patents related to quantum computing.⁷ However, the new, rapidly evolving, and theoretical nature of quantum technologies might clash with the current patent system compared to other technologies, such as telecommunications and the Internet of Things. In both the EU and the U.S., abstract ideas, mathematics, and algorithms are deemed ineligible for patent protection, while technologies such as quantum sensing and communication are leading the field. Error correction techniques to handle one of the largest hurdles in quantum computers, being decoherence and noise, mainly consist of mathematical formulations. At last, both patent examiners and applicants must keep up with the rapid advancements. The question begs whether patents are necessary for innovation in quantum technologies and whether other mechanisms, such as trade secrets, might be more preferable.

With this in mind, the following research questions will lead this paper:

1. What is the current state of affairs in patenting innovations in quantum science, with a comparative analysis between the U.S. and the EU?
2. What are the advantages and disadvantages of patent law as compared to trade secrets in quantum technologies?
3. What are possible solutions found in literature and practice in the U.S. and the EU in neighboring fields, and what can we learn from them for the future in quantum technologies?

The primary objective of this research is to determine whether the current patent policies in the EU and the U.S. remain desirable for incentivizing innovation in quantum technologies. Are patents still important, or do they play a complementary role amongst alternatives, and what are the challenges that patent applicants face when claiming quantum inventions? The research will distinguish between hardware and software, because the answers to the questions may differ.

The research methods that are applied are the classical legal method and the comparative method.

This method is used to become familiar with the existing legislation on patent law and trade secrets law. Case law and scholarship in the EU and the U.S. provide insight into similarities and differences in interpretations in both quantum technologies and similar domains. Reports and studies conducted by working groups are consulted to provide empirical insights into quantum technologies and similar domains.

The classical legal method will be performed comparatively by comparing the patent examination processes of the EU and the U.S. Patent files and representative examples to

⁷ Mauritz Kop, Mateo Aboy and Timo Minssen, 'Intellectual property in quantum computing and market power: a theoretical discussion and empirical analysis' (2022) 17(8) *Journal of Intellectual Property Law & Practice* 613, 622.

substantiate the theoretical research are chosen through case law found in the official databases of the European Patent Office (the “EPO”) (and the Board of Appeal) and the United States Patent and Trademark Office (the “USPTO”) (and the Patent Trial and Appeal Board) and by searching through specific keywords on patent databases such as Google Patents and Espacenet. The reason behind the choice to compare with the U.S. is that the top patent holders are mostly American, and most patents granted within quantum science happen by the USPTO.⁸

This thesis consists of three parts. The **first part** introduces quantum science to understand its relevance and nature, the current landscape of the global patent developments, and a discussion comparing patents with alternatives clarifies their role in innovation. The **second part** the challenges that the quantum nature poses for patent law regarding patentability requirements with case law and examples. The **third part** provides guidelines around the role of trade secrets in aspects where patents would succeed or fail in quantum technologies and a short overview of emerging challenges and issues regarding quantum patents, looking into the proposed *sui generis* framework, standardization, and open source software.

The main theme throughout the thesis is diving into the peculiarities of quantum technologies and their unique challenges for the current patent systems. The fundamental question of whether patents are necessary and preferable to incentivize innovation in quantum technologies, while looking at both the European and American legal systems.

II. PART I. QUANTUM TECH BACKGROUND

A. Introduction to Quantum Science

It is not within the objectives of this research paper to provide detailed technological insight into quantum technologies. However, to better understand the obstacles that quantum technologies face in acquiring patent protection, a concise introduction to quantum science will be provided in the following subchapters, while focusing on the most evolved quantum areas. First, the key concepts of superposition, measurement, entanglement, and qubits will be explained. Second, the principles of quantum technologies are laid out with specific examples, while distinguishing hardware and software. Third, the government’s interest in quantum tech and an overview of the main funding and R&D projects are laid out.

1. Key concepts

While classical mechanics describes large objects on large scales, such as projectiles on Earth or the workings of the solar system, it cannot describe phenomena on the

⁸ Mateo Aboy, Timo Minssen and Mauritz Kop, ‘Mapping the Patent Landscape of Quantum Technologies: Patenting Trends, Innovation and Policy Implications’ (2022) 53 IIC 853, 962, fig. 2.

(sub)atomic level.⁹ As such, ‘quantum’ refers to the smallest amount of something. Quantum mechanics, or quantum physics,¹⁰ is concerned with predicting and observing fundamental units of matter, energy, and light and their interactions with each other, in particular atoms and molecules, and other atomic-level structures.¹¹ Since this scale is extremely small, quantum physics is not typically observed in our everyday lives,¹² which makes it difficult to grasp its concepts fully. The following key concepts will be explained at an elementary level, without delving into extensive scientific or mathematical detail.

In experiments regarding quantum physics, light waves are often used, which act similarly to particles and vice versa, and the physical processes are influenced by being observed. Although particles on the quantum level are often referred to as ‘quantum systems’ in the research fields, they will simply be described as particles in this paper. Quantum particles move in ways that are impossible to predict. There are only possibilities of positions that these particles can be in. This phenomenon, where a particle can exist in multiple states at the same time, is called a **superposition** of states. When they are observed (or measured), the particles “collapse” into one state.¹³

Furthermore, quantum particles seem to be spinning, either clockwise (referred to as ‘spin up’, symbolized by $|\uparrow\rangle$) or anticlockwise (referred to as ‘spin down’, symbolized by $|\downarrow\rangle$). The direction of spinning can only be found by **measuring** (i.e., observing) them when the particle collapses in one direction.¹⁴ **Measurement** outcomes of large quantum systems are, ~~as such,~~ always probabilistic,¹⁵ and while cloning is impossible, the collapse of a particle is definite.¹⁶

Another key concept is **quantum entanglement**, which opposes the idea that an object can only be directly influenced by its immediate surroundings. The measurement of a particle not only determines the state of that particle, but also of a particle it is connected to or entangled with, regardless of the distance between them. As such, information can be retrieved from one about the other through their entangled state.¹⁷ Preskill has

⁹ Yehuda B. Band and Yshai Avishai, *Quantum Mechanics With Applications To Nanotechnology And Information Science* (Elsevier Science 2013) 2.

¹⁰ The terms “quantum mechanics” and “quantum physics” are each other’s synonyms, though quantum mechanics can be considered a subfield of quantum physics. Within the scope of this paper, these terms will be used interchangeably.

¹¹ Yehuda B. Band and Yshai Avishai (n 9) 2.

¹² Eduardo J S Villaseñor, ‘Introduction to Quantum Mechanics’ (2008) 1023 *Geometry and Physics XVI International Fall Workshop* 107, 107.

¹³ National Academies of Sciences, Engineering, and Medicine (n 6) 28.

¹⁴ The spinning of particles is demonstrated by the Stern-Gerlach experiment. See: Michael A. Nielsen and Isaac L. Chuang, *Quantum computation and quantum information*, (2010) 10th anniversary ed. Cambridge, New York, Cambridge University Press, 43.

¹⁵ Jayakumar Abhijith and others, ‘Quantum Algorithm Implementations for Beginners’ (2022) 3(4) *ACM Transactions on Quantum Computing* 1, 7.

¹⁶ Eleanor Rieffel and Wolfgang Polak ‘An Introduction to Quantum Computing for Non-Physicists’ (2000) 32 *ACM Computing Surveys* 300, 306-307.

¹⁷ M.A.B. Whitaker, ‘Theory and experiment in the foundations of quantum theory’ (2000) 24(1-2) *Progress in Quantum Electronics* 1, 52.

provided a simple analogy, comparing reading a normal book to a quantum book, where pages represent bits and qubits, respectively. The information in a normal book can be understood when read page by page; a quantum book, on the other hand, is not understandable when the pages are read separately. This is because the information is not imprinted on each page individually, but can only be understood when the pages are read simultaneously, as they are linked to each other.¹⁸

At last, **quantum interference** is a phenomenon that arises from the wave-like nature of quantum particles. The multiple states that a particle is in superposition can interfere with each other, resulting in certain patterns of outcomes after measurement. Interference is a key component of quantum algorithms because manipulation tactics can be encoded to control the states of qubits. Applications of this are Grover's algorithm and the Quantum Fourier Transform. It is also used in quantum phase estimation, in which quantum algorithms estimate the phase of a quantum state.¹⁹

2. Qubits

When information is linked to quantum particles, it can move through spaces in different ways than in classical computing. In classical computers, the smallest sources of information are **bits** (short for 'binary digit'), which can only exist in one of two states: 0 or 1,²⁰ and they are both equally likely to occur. These states are translated through electrical signals, which go through transistors and store information: 0 means that there is no to little voltage, and 1 means a high voltage.²¹ Thus, the state of the transistor is always known. Long strings of zeros and ones represent all types of information. For classical computers to solve problems, they process all possible combinations of bits.²²

Quantum computing uses **quantum bits**, or **qubits**, as fundamental units of information.²³ Qubits exist in a superposition of both 0 and 1 simultaneously. While they do not hold more information than classical bits, quantum computers can solve problems much faster than classical computers because the former require half the number of bits to form a variety of possibilities.²⁴ However, retrieving information from a qubit involves measuring it, which makes the qubit collapse into a definite state (0 or 1).²⁵ Thus, qubits do not hold more information than classical bits.²⁶

¹⁸ John Preskill, 'Quantum Computing in the NISQ era and beyond' (2018) 2 *Quantum* 79, 80.

¹⁹ Quantum Microsoft, 'Interference' (*Microsoft*) <<https://quantum.microsoft.com/en-us/insights/education/concepts/interference>> accessed 29 July 2025.

²⁰ Marshall Brain, 'How Bits and Bytes Work' (*HowStuffWorks*, date unknown) <<https://computer.howstuffworks.com/bytes.htm>> accessed 23 March 2025 and Charles E. MacKenzie, *Coded Character Sets, History and Development* (Addison-Wesley Pub. Co. 1980) 12.

²¹ Robert B. Ash, *Information Theory* (Dover Publications Inc. 1965) 2.

²² Charles E. MacKenzie (n 20) 12-15.

²³ Jayakumar Abhijith and others (n 15) 4.

²⁴ Daniel Claudino, 'The Basics of Quantum Computing for Chemists' (2022) 122 *International Journal of Quantum Chemistry* 1, 3 <<https://doi.org/10.1002/qua.26990>> accessed 2 October 2024 and Eleanor Rieffel and Wolfgang Polak (n 16) 306-307.

²⁵ Eleanor Rieffel and Wolfgang Polak (n 16) 306-307.

²⁶ Jayakumar Abhijith and others (n 15) 7.

However, there are several issues. Quantum systems also use strings of qubits, but they are coherent and entangled. At the moment, qubits in quantum processors can currently interact with their nearest neighbors without fail.²⁷ Entanglement makes them very sensitive to the slightest interaction with the environment, which causes **decoherence**, unwanted collapses,²⁸ resulting **errors**, and incorrect answers.²⁹ Therefore, dilution refrigerators or adiabatic demagnetization refrigerators and active error-correcting detecting and correcting techniques are used to manipulate and control qubits.³⁰

There are two types of qubits: logical qubits consist of groups of coherent physical qubits and are abstract concepts. Physical qubits can be represented by particles such as electrons and photons.³¹ There is a variety of types of qubits used in different quantum computers, them being superconducting (e.g., IBM's Eagle Processor),³² photonic (e.g., PsiQuantum),³³ trapped ion qubits (e.g., IonQ's Aria),³⁴ and topological (e.g., Microsoft's Majorana 1 processor).³⁵ The latter is the most error-resistant option, but the advanced materials hinder current large-scale applications.

3. Quantum technologies

In the past two decades, quantum science has rapidly developed into a technology whose applications are not yet commercialized,³⁶ which is arguably the largest hurdle to quantum computing today. Quantum technologies would be useful for numerical optimization, the modeling of molecules (development of new drugs, fertilizers, and batteries), replication of

²⁷ Carmen G. Almudever and others, 'Realizing Quantum Algorithms on Real Quantum Computing Devices' (Design, Automation & Test in Europe Conference & Exhibition (DATE), France, 2020), 864, 867 <<http://dx.doi.org/10.23919/DATE48585.2020.9116240>> accessed 3 April 2025.

²⁸ Lucjan Pielka, *Ideas of Quantum Chemistry* (Elsevier Science 2007) 50.

²⁹ Antonio D. Córcoles and others, 'Challenges and Opportunities of Near-Term Quantum Computing Systems' (2020) 108 Proceedings of the IEEE 1338, 1339.

³⁰ James Dargan, 'Cryogenics: A Short History & The Implications it Has on The QC Industry' (*Quantum Insider*, 13 April 2024) <<https://thequantuminsider.com/2023/09/12/cryogenics-a-short-history-the-implications-it-has-on-the-qc-industry/>> accessed 11 August 2025.

³¹ Michael A. Nielsen and Isaac L. Chuang, *Quantum computation and quantum information*, (Cambridge University Press 2010) 287.

³² Oliver Dial, 'Eagle's quantum performance progress' (*ibm.com*, 23 March 2022) <<https://www.ibm.com/quantum/blog/eagle-quantum-processor-performance>> accessed 10 August 2025.

³³ Psiquantum, 'Homepage' (*psiquantum.com*) <<https://www.psiquantum.com/>> accessed 28 July 2025.

³⁴ IonQ, 'IonQ Aria Furthers Lead As World's Most Powerful Quantum Computer.' (*ionq.com*, 23 February 2022) <<https://ionq.com/news/february-23-2022-ionq-aria-furthers-lead>> accessed 28 July 2025.

³⁵ Chetan Nayak, 'Microsoft unveils Majorana 1, the world's first quantum processor powered by topological qubits' (*azure.microsoft.com*, 19 February 2025) <<https://azure.microsoft.com/en-us/blog/quantum/2025/02/19/microsoft-unveils-majorana-1-the-worlds-first-quantum-processor-powered-by-topological-qubits/>> accessed 28 July 2025.

³⁶ European Commission, Joint Research Centre, *#Standards4Quantum Making Quantum Technology Ready for Industry* (Publications Office of the European Union 2020), 7.

complex systems (weather), cryptography,³⁷ and lower power consumption.³⁸ **Quantum optimization** is a process that reduces computational complexity to reach solutions more efficiently.³⁹

There are four major segments: **quantum computing, communication, sensing, and simulation.**

Half of quantum patents surround **quantum dots**, which are low-dimensional nanostructures. These are atomic materials and are used in applications in LEDs, displays, lasers, and biological imaging, to link information to qubits in LEDs.⁴⁰

The history of **quantum computing** is fairly short. In the early 1980s, Richard Feynman discovered that classical computers were unable to simulate quantum mechanics, a task that would require a computer composed of quantum elements, known as a **quantum computer**. A quantum computer operates on the principles of superposition and entanglement, solving complex puzzles. The **quantum processor** is the brain of a quantum computer and contains qubits and thus, information.⁴¹ It further consists of the most notable **quantum gates**, which perform operations on qubits by changing the probability of their states (e.g., Hadamard and CNOT gates)⁴² and a **quantum circuit** that consists of qubits, instructions that act upon them, and hardware-guided simplification (for which quantum compilers are used to translate quantum algorithms into clearer machine instructions to execute on hardware).⁴³

There are several types of quantum computers:

- Noise Intermediate Scale Quantum ('NISQ') computers are hybrid computers with classical elements that have between 50-100 qubits with high-fidelity quantum gates.⁴⁴
- Experimental quantum computers, which are used for research purposes: increasing qubit counts, improving stability for future commercialization. Examples of these include Google's Willow chips (105 qubits), IBM's Eagle, Osprey, and Condor processors (1.121 qubits).

³⁷ Muhammad Zia-Ul-Haq and Ghulam Mujtaba, 'Legal Challenges of Intellectual Property Rights for Quantum Computing' (2024) 1 Trends in Intellectual Property Research 1, 2.

³⁸ Oskar van Deventer and others, 'Towards European standards for quantum technologies' (2022) 9 EPJ Quantum Technology 33, 34.

³⁹ Deborah Volpe, Giacomo Orlandi and Giovanna Turvani, 'Improving the Solving of Optimization Problems: A Comprehensive Review of Quantum Approaches' (2025) 7 Quantum Rep. 3, 3.

⁴⁰ Mathew Alex, 'Quantum Technologies: A Review of the Patent Landscape' (2021) ArXiv 1, 14.

⁴¹ Chris Jay Hoofnagle and Simson L. Garfinkel, *Law and Policy for the Quantum Age* (Cambridge University Press 2022), 144.

⁴² MathWorks, 'What are Quantum Gates?' (*mathworks.com*, date unknown) <<https://www.mathworks.com/discovery/quantum-gates.html>> accessed 29 July 2025.

⁴³ Hayk Tepanyan, 'Introduction to the Quantum Circuit: Everything You Need to Know' (*BlueQubit*, 24 February 2025) <<https://www.bluequbit.io/quantum-circuit>> accessed 29 July 2025.

⁴⁴ Alan Ho, 'Announcing Cirq: An Open Source Framework for NISQ Algorithms' (*Google Research*, 18 July 2018) <<https://research.google/blog/announcing-cirq-an-open-source-framework-for-nisq-algorithms/>> accessed 3 April 2025. See: <https://quantumai.google/cirq>.

- Commercial quantum computers, which are used in the real world, such as cryptography and AI.

Quantum decoherence,⁴⁵ quantum noise, and quantum control inaccuracies are major issues in the field⁴⁶ because, in practice, complete isolation of the quantum system from its environment is impossible.⁴⁷ Because of this, the current quantum computers are not strong enough to demonstrate quantum advantage.⁴⁸ As such, **error-mitigating techniques**⁴⁹, such as fault-tolerant computation and quantum error correction,⁵⁰ are being developed to solve these issues.⁵¹ They are also encoded as circuit instructions.

Essentially, quantum algorithms are mathematical codes consisting of instructions for a variety of tasks and calculations, and which contain at least one quantum phenomenon.⁵² In the scope of this thesis, **quantum algorithms** can be divided into two types:

1. Quantum algorithms that demonstrate the quantum computing advantage over classical computers. E.g., Peter Shor developed Shor's Algorithm (1994), a quantum algorithm that can find the prime factors of an integer, which otherwise would take a classical computer significantly more time to do.⁵³ Other examples are Grover's algorithm⁵⁴ and Hamiltonian simulation.
2. Error mitigation and correction codes that are used to solve the decoherence and noise issues in quantum computing to upscale the qubit count and control over them, and can be highly mathematical algorithms.⁵⁵ Examples of these are algorithms that optimize quantum gate sequences to minimize decoherence in quantum processes. Examples are Shor code and Steane codes.⁵⁶

⁴⁵ Lucjan Piela (n 28) 50 and see **Error! Reference source not found.**

⁴⁶ IonQ Staff, 'How We Achieved a Significant Breakthrough in the Performance of Quantum Systems' (*IonQ*, 26 January 2023) <<https://ionq.com/blog/how-we-achieved-a-significant-breakthrough-in-the-performance-of-quantum>> accessed 2 May 2025.

⁴⁷ Dave Morris Bacon, 'Decoherence, Control, and Symmetry in Quantum Computers' (2001), 13 <<https://doi.org/10.48550/arXiv.quant-ph/0305025>> accessed 1 April 2025.

⁴⁸ Carmen G. Almudever and others (n 27) 4 and - Frederiksen A K, 'The quantum computer exists, but is not all that powerful' (Technical University of Denmark, 16 May 2023) (<https://www.dtu.dk/english/newsarchive/2023/05/the-quantum-computer-exists-but-is-not-all-that-powerful>) accessed 25 March 2025.

⁴⁹ Ivan B. Djordjevic, *Quantum Communication, Quantum Networks, and Quantum Sensing* (Academic Press 2022) 15.

⁵⁰ Dave Morris Bacon (n 47) 9.

⁵¹ *ibid* 9.

⁵² Surya Teja Marella and Hemanth Sai Kumar Parisa, 'Introduction to Quantum Computing' in Yongli Zhao (ed.), *Quantum Computing and Communications* (BoD – Books on Demand 2022) 70.

⁵³ Wolfgang Polak (n 16) 300 and for Shor's Algorithm: Arthur O Pittenger, *An Introduction to Quantum Computing Algorithms* (Xth edn, Springer Science & Business Media 2012) vii preface.

⁵⁴ Sudbudhirishika, 'Math Matters: Quantum Computing and the math behind it' (*thestemachive.com*, 20 February 2025) <<https://www.thestemachive.com/post/math-matters-quantum-computing-and-the-math-behind-it>> accessed 29 July 2025.

⁵⁵ Surya Teja Marella and Hemanth Sai Kumar Parisa (n 52) 70.

⁵⁶ Muhammad Tuhin, 'Scientists Solve Longstanding Quantum Error Problem Unlocking New Path to Practical Quantum Computers' (*Science News Today*, 20 June 2025)

Next, another large category within quantum technologies is **quantum communication**, which combines quantum sensing and computing,⁵⁷ where tools are developed to transmit information between remote destinations. These transmissions can be limited to short distances or extended to the development of the quantum internet and satellites.⁵⁸ This field relies heavily on hybrid quantum-classical algorithms, by doing classical computation (on a classical computer) on logical qubits (in a quantum computer) (e.g., the Variational Quantum Eigensolver, which can be used in chemistry, nuclear physics, and materials science).⁵⁹

Quantum cryptography, or more specifically, quantum key distribution ('QKD'), is used to secure the transmission of information by encrypting the data using a private key.⁶⁰ Two components are needed: a key to encrypt a message, which usually happens by randomly selecting a number, and a quantum key distribution channel to transmit the key.⁶¹ By doing so, the information is hidden from any unauthorized party⁶² through entanglement; when an unauthorized party tries to acquire information, the collapse of the system notifies their measurement.⁶³ Furthermore, hackers cannot duplicate the transmitted quantum system and forward a perfect copy because of the no-cloning theorem of quantum mechanics. Several QKD protocols describe how the bit values are encoded on quantum systems and how the emitter and the receiver cooperate. The most commonly used protocol is the Bennett-Brassard 84 protocol.⁶⁴ The design of secure cryptographic schemes has already been put on the market.⁶⁵ Quantum communication and cryptography can provide resistance against cyberattacks and secure hospitals, energy grids, and connected technologies.⁶⁶ Post-quantum cryptography is another area that assumes hackers use quantum computers themselves to plan cyberattacks.⁶⁷

<<https://www.sciencenewstoday.org/scientists-solve-longstanding-quantum-error-problem-unlocking-new-path-to-practical-quantum-computers>> accessed 28 July 2025.

⁵⁷ Chris Jay Hoofnagle and Simson L. Garfinkel (n 41) 15.

⁵⁸ European Quantum Industry Consortium, 'A portrait of the global patent landscape in quantum technologies' (2025) 4 <<https://www.euroquic.org/wp-content/uploads/2025/02/A-Portrait-of-The-Global-Patent-Landscape-in-Quantum-Technologies-2025.pdf>> accessed 2 April 2025.

⁵⁹ IonQ, 'What is Hybrid Quantum Computing?' (*IonQ*, 8 January 2025) <<https://ionq.com/resources/what-is-hybrid-quantum-computing>> accessed 28 July 2025.

⁶⁰ Ivan B. Djordjevic (n 49) 18.

⁶¹ European Commission, Joint Research Centre (n 36) 14.

⁶² Hugo Zbinden and others, 'Post-quantum cryptography' (1998) 67 *Applied Physics B*, 743.

⁶³ *ibid* 744.

⁶⁴ Misra Shreshtha and others, 'Exploring The Quantum Frontier: Applications, Challenges, and Future Directions In Quantum Communication Technologies' [2024] *ITU Kaleidoscope: Innovation and Digital Transformation for a Sustainable World* 1, 3.

⁶⁵ European Quantum Industry Consortium (n 58) 5.

⁶⁶ CEN CENELEC, *Standardization Roadmap on Quantum Technologies* (CEN CENELEC, March 2023) <<https://www.cenelec.eu/areas-of-work/cen-cenelec-topics/quantum-technologies/>> accessed 16 March 2025, 22.

⁶⁷ ENISA, *Post-Quantum Cryptography* (May 2021) <<https://www.enisa.europa.eu/publications/post-quantum-cryptography-integration-study>> 1.

Another category is **quantum sensing**, which refers to measuring a physical quantity using quantum phenomena⁶⁸ by coupling the quantum system to an external physical quantity.⁶⁹ **Quantum metrology** is related to quantum sensing and is focused on improving the quality of measurement.⁷⁰ More usable applications can be found here compared to quantum computing, such as, magnetometers based on atomic vapours or superconducting quantum interference devices ('SQUID') are well-established products⁷¹ that are used in research in biomedics and geophysics in warfare.⁷²

At last, **quantum simulation** models complex quantum mechanical systems, such as molecules and their chemical reactions, under controlled conditions to study and predict their behavior. Classical computers are not able to accurately simulate quantum systems, but quantum computers provide a solution because they are quantum systems themselves. They would be useful to study chemical reactions and materials to create drugs and manufacture fertilizers.⁷³ An example is the Fermi-Hubbard model that shows how electrons move in a solid while carrying electricity, but around 50 to 100 qubits are needed for the model to work better than a classical computer.⁷⁴

⁶⁸ C. L. Degen, F. Reinhard and P. Cappellaro, 'Quantum sensing' (2017) 89 *Reviews of Modern Physics* 1.

⁶⁹ European Quantum Industry Consortium (n 58) 6.

⁷⁰ Jiahao Huang and others, 'Quantum Metrology Assisted by Machine Learning' (2024) 2300329 *Advanced Quantum Technologies* 1, 1.

⁷¹ CEN-CENELEC (n 66) 17.

⁷² Anne Fabricant, Irina Novikova and George Bison, 'How to build a magnetometer with thermal atomic vapor: a tutorial' (2023) 25 *New. J. Phys.* 1, 20.

⁷³ TUDelft, 'Quantum simulation' (*tudelft.nl*, date unknown) <<https://www.tudelft.nl/over-tudelft/strategie/vision-teams/quantum-computing/applications/quantum-simulation>> accessed 15 July 2025.

⁷⁴ Surya Teja Marella and Hemanth Sai Kumar Parisa (n 52) 11.

4. Government interest and funding

Governments are aware of the evolving relevance of quantum technologies and are funding projects and initiatives to research the landscape in quantum technologies. For example, quantum cryptography is essential for improving national security.

A study conducted by McKinsey and Company shows that private and public investors have noticed the quantum possibilities.⁷⁵

G7 and the Council of Europe have published statements recognizing the importance of quantum technologies and have expressed commitment regarding efforts to advance quantum technologies for R&D, commercialization, and security, while also establishing a Joint Working Group to guide cooperation in standards, risk management, and future applications.⁷⁶

In 2018, the European Commission launched its 1 billion EUR ‘Quantum Technologies Flagship’ 10-year project to sponsor quantum R&D, through which 5,000 peer-reviewed research projects will be funded.⁷⁷ Notable examples of these projects are the Coordination and Support Action, responsible for identifying and coordinating the relevant standardization and IP protection actions in most mature technologies,⁷⁸ and the Gen-Q international program for PhD candidates in quantum science and technologies.⁷⁹ The European Research Area Cofunded Action in Quantum Technologies (QuantERA) supports international research projects in the field of QT.⁸⁰ In 2025, the Commission invested 3 million EUR to develop a more efficient quantum chip combining technologies of light and electronics.⁸¹

Public investment in quantum technology start-ups increased 19 percentage points from 2023 to 2024.

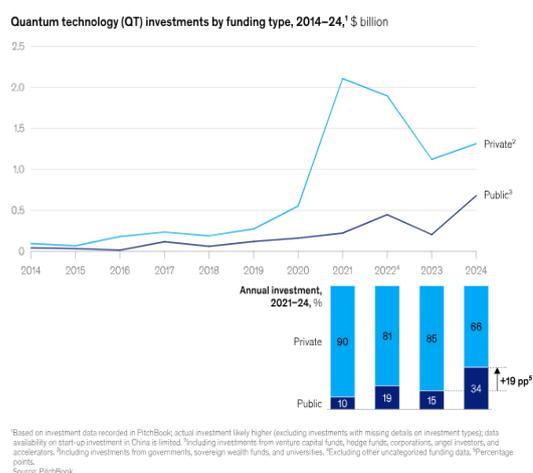


Figure 1 Funding projects in quantum tech. Source: Henning Soller (n 75).

⁷⁵ Henning Soller, ‘The Year of Quantum: From concept to reality in 2025’ (*mckinsey.com*, 23 June 2025) <<https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-year-of-quantum-from-concept-to-reality-in-2025>> accessed 22 July 2025.

⁷⁶ European Commission, *European Declaration on Quantum Technologies* (European Commission, 6 December 2013) <<https://ec.europa.eu/newsroom/dae/redirection/document/100585>> accessed 15 April 2025, 1.

⁷⁷ European Commission, Joint Research Centre (n 36) 7.

⁷⁸ CEN CENELEC (n 66) 19.

⁷⁹ EUCOR, ‘Generation Quantum: 12 million euros for a doctoral programme in quantum science’ (*eucom*, 25 February 2025) <<https://www.eucom-uni.org/en/news/generation-quantum-12-million-euros-for-a-doctoral-programme-in-quantum-science>> accessed 4 May 2025.

⁸⁰ CEN CENELEC (n 66) 19.

⁸¹ Quantum Flagship, ‘New chip to solve quantum computing roadblocks’ (*Quantum Flagship*, 23 January 2025) <https://qt.eu/news/2025/2025-01-23_new-chip-to-solve-quantum-computing-roadblocks> accessed 5 May 2025.

Also in 2018, the U.S. adopted the National Quantum Initiative Act ('NQI') to fund quantum computing projects in the next ten years, over 1.2 billion USD, with a focus on national security and accelerating R&D and its commercialization.⁸² Since 2020, three new 'Quantum Leap Challenges' research institutes have been established by the National Science Foundation for quantum information science. The U.S. is characterized by private and public funding, including military agencies. In 2023 alone, 70% of investments in quantum tech were private. Examples of these funding agencies are IBM, Microsoft, Google, Intel, and Honeywell.⁸³

However, supply chains for QT are emerging, commercial products are becoming available, and published standards are being developed on quantum cryptography.⁸⁴ Due to the emerging complexity of quantum technologies, the number of patents and participants will increase as time goes on.

Furthermore, large companies, such as IBM, Google, and Microsoft, not only operate on public and private funding, but they also have sufficient internal sources, not only monetary, but also access to more experts and know-how, compared to smaller entities, which are dependent on external investors, such as venture and government funding. Attracting external investors also depends on their IP portfolio. An example of private funding is when Rigetti became a publicly traded company on NASDAQ, a new company that focuses on quantum computing.⁸⁵

5. Projects in Quantum Tech

IBM has multiple active working groups, specializing in high-energy experiments, materials science (for which quantum simulation is central), health care and life science, and optimization. This includes collaboration with other companies and academic institutions.⁸⁶

Moreover, the European Quantum Industry Consortium ('QuIC') has various quantum working groups, some of which research standards, challenges, and solutions in patents and other IPs, and sources of funding for R&D and commercialization of quantum tech.⁸⁷ The Quantum Flagship has multiple working groups too, one of which organizes the EQTC, and others monitor the developments of quantum tech in Europe and develop

⁸² European Commission, Joint Research Centre (n 36) 7.

⁸³ CEN CENELEC (n 66) 18.

⁸⁴ Oskar van Deventer and others (n 38) 25.

⁸⁵ Mauritz Kop, Mateo Aboy and Timo Minssen (n 7) 623.

⁸⁶ IBM, 'Quantum working groups push for near-term use cases' (*ibm.com*, 22 May 2024) <<https://www.ibm.com/quantum/blog/quantum-working-groups>> accessed 16 July 2025.

⁸⁷ QuIC, 'Working Groups' (*euroquic.org*, date unknown) <<https://www.euroquic.org/working-groups/>> accessed 20 July 2025.

standards.⁸⁸ Here, the Joint Technical Committee 22 ‘Quantum Technologies’ has been established,⁸⁹ which is relevant in the early standardization projects.

6. Conclusion

Quantum technologies combine physics with math, chemistry, and engineering to explore atomic levels that have never been explored before. While there is much excitement around their possibilities, the field is also characterized by abstract mathematics and theories, natural phenomena such as superposition and entanglement, and experimental hardware. Their applications and future possibilities are promising, though their practical use is currently very limited ~~at the moment~~.⁹⁰ The most patented quantum technologies, being quantum computing, communication, and sensing, and the main distinction, and the interoperability, between hardware and software, are explained.

B. Overview of the Patent Landscape

It is not feasible to make an extensive overview of the patent landscape, for databases often lie behind paywalls. Therefore, this chapter provides a concise, global overview supported by tables and figures based on the latest reports from working groups and independent researchers.

First, a global overview of granted patents in quantum technologies is provided, focused on the key patent families within QT, being quantum computing, quantum cryptography, and quantum sensing. The second subchapter provides an overview of the global evolution within quantum computing specifically. The third chapter delves deeper into the European and American patenting activities. The last subchapter concludes by comparing patenting activities at the EPO and the USPTO.

⁸⁸ Quantum Flagship, ‘Working Groups’ (*qt.eu*, date unknown) <<https://qt.eu/working-groups/>> accessed 20 July 2025.

⁸⁹ Quantum Flagship, ‘Standardization’ (*qt.eu*, date unknown) <<https://qt.eu/working-groups/standardization>> accessed 20 July 2025.

⁹⁰ Vikas Hassija and others, ‘Present landscape of quantum computing’ (2020) 1 IET Quantum Communication 42, 43.

1. Global overview of granted QT

(a) General segmentation of quantum technologies

A report by the QuIC mainly covers the largest segments of patent families, being quantum computing, communication, and sensing. Globally, quantum communication consists of a large part of patents. Within software, the largest patent families include cryptography and optimization. Algorithms, including qubits, error-correcting codes,

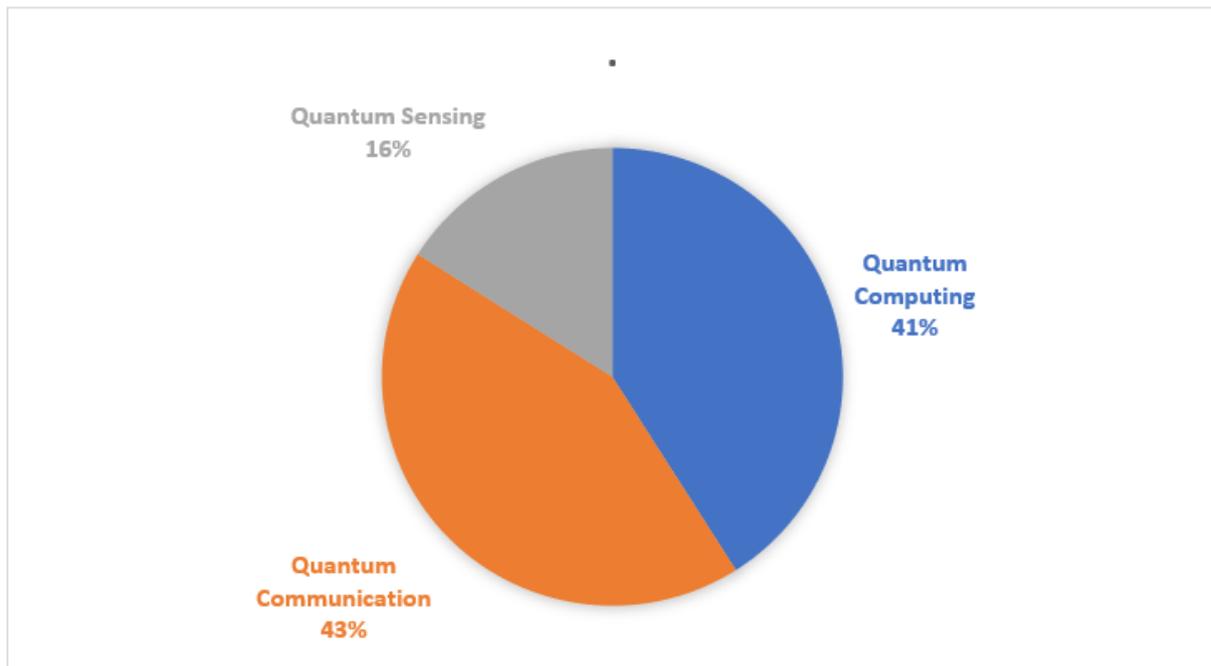


Figure 2 Weight of most active patent families. Source: European Quantum Industry Consortium (n 58) 8.

circuits, and quantum logic gates, are mentioned.⁹¹

In quantum communication, the top 20 patent assignees consist exclusively of Chinese companies and academic institutions, with two exceptions: Toshiba and NEC, which are Japanese enterprises. Around 80% of quantum communication patents are related to quantum cryptography.⁹² In quantum sensing, the majority of patent assignees consist globally of (academic) research institutions, of which 75% are Chinese entities, 30% are American, and 20% are European entities.⁹³

⁹¹ Michel Kurek, 'Quantum Technologies: Patents, Publication and Investments Landscapes' (2020), 23 <<https://zenodo.org/records/7473989>> accessed 17 February 2025.

⁹² European Quantum Industry Consortium (n 58) 15, fig. 7.

⁹³ European Quantum Industry Consortium (n 58) 16, fig. 8.

Figure 3 shows that the largest growth is in the fields of quantum computing (more than fifty percent for the period from 2016 to 2021) and quantum communication,⁹⁴ that have been funded privately and publicly.⁹⁵

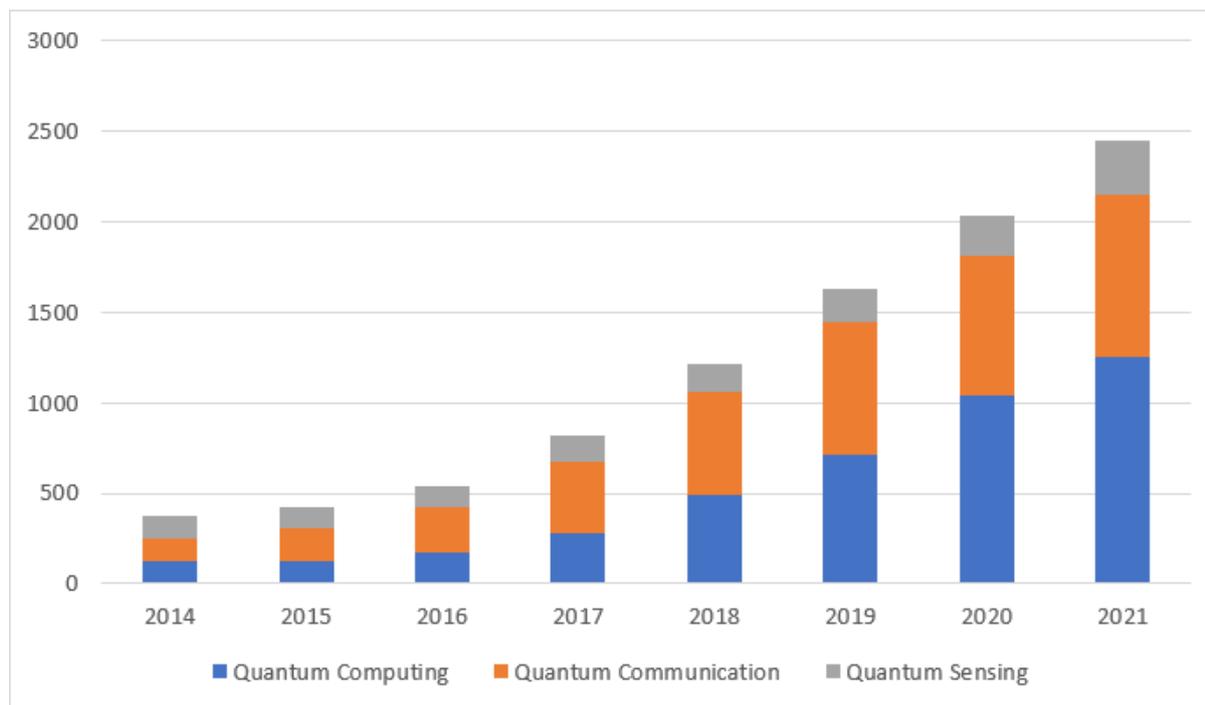


Figure 3 International patent activity by priority date 2014-2021. Source: European Quantum Industry Consortium (n 58) 9.

2. Overview of evolution within quantum computing

To provide a general overview of quantum computing, only International Patent Families⁹⁶ will be considered. These data are used in the referenced reports, as they serve a useful role in this paper by offering an insight into the patentees seeking global protection.

(a) Global evolution within quantum computing

⁹⁴ *ibid* 9.

⁹⁵ For instance, the National Quantum Initiative Act established the National Quantum Coordination Office which will coordinate the development provided by the NIST, the NSF, and the DOE. See: National Quantum Initiative, 'About the National Quantum Initiative' (*quantum | gov*) <<https://www.quantum.gov/about/#LEGISLATION>> accessed 8 April 2025.

⁹⁶ These are patent applications that are internationally filed based on the Patent Cooperation Treaty.

Globally, Figure 4 shows a rapid increase in published inventions in quantum computing since 2016. The increasing interest, funding, and development in the field explain this observation, as illustrated by the high public and private investments.⁹⁷ For example, while the leading quantum processor had a qubit count of 20 in 2017, it increased to 128

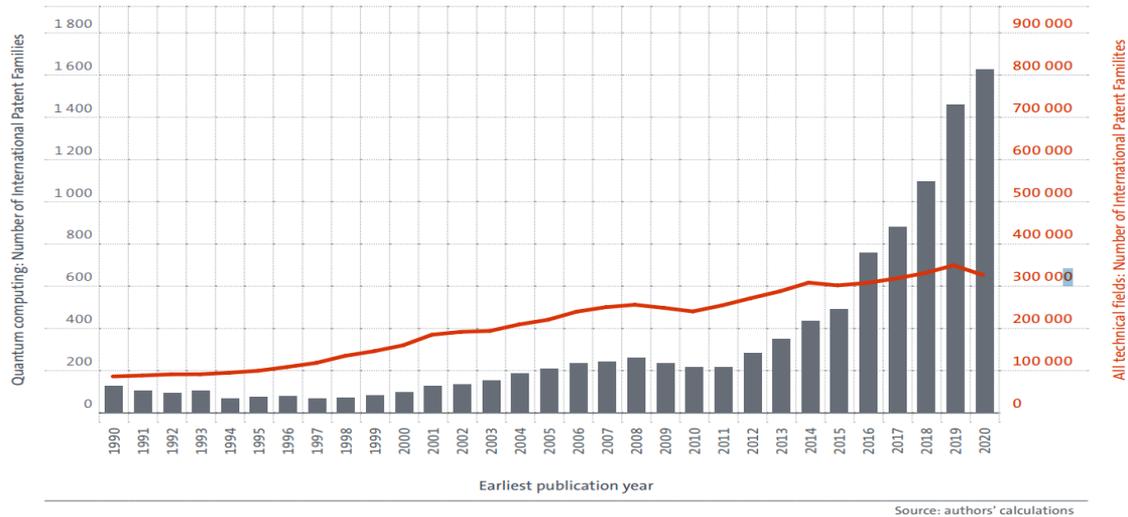


Figure 4 Number of inventions per earliest publication year in the field of quantum computing, limited to International Patent Families. Source: EPO, Quantum computing - Insight report (EPO, January 2023) <<https://www.epo.org>> accessed 8 April 2025. 17, fig. 3

qubits in 2020 with IBM's Eagle processor. As of July 2024, IBM's Heron processor has a qubit count of 156 qubits.⁹⁸

(b) Global top assignees

Figure 5 shows that the top patent owners are primarily private companies, with IBM leading the field as of 2023.⁹⁹ Only a few academic institutes and other public research institutions are top assignees, which suggests that most innovations happen more privately. This could raise problems regarding access, public disclosure, and standardization in the future. However, the role of academic institutions remains important for collaboration with the industry.¹⁰⁰

⁹⁷ See Figure 1 in chapter **Error! Reference source not found.**

⁹⁸ IBM Quantum Platform, 'Processor types' (*IBM Quantum Platform*, date unknown) <<https://docs.quantum.ibm.com/guides/processor-types>> accessed 27 July 2025.

⁹⁹ European Quantum Industry Consortium (n 58) 6.

¹⁰⁰ Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) 862.

Companies specialize in various technologies. For example, IBM focuses on superconducting qubits and quantum algorithms, D-Wave Systems on quantum annealing, Microsoft specializes in topological quantum computing and quantum software, Google advances quantum supremacy and quantum processors, Intel invests in quantum dot technologies and Silicon-based qubits, and lastly, academics, including universities and other research groups, are defined by research and early-stage innovations.¹⁰¹

As such, each entity owns up to its role in the context of the overall technological innovation. Furthermore, these data illustrate a competitive landscape that is U.S.-dominated, for other countries such as Japan (Toshiba), China (Baidu, Benyuan Quantum Computing, and Origin Quantum), and Canada (D-Wave Systems) are in the minority. New ventures are also among the top assignees, such as Rigetti, D-Wave, and IonQ, which are fairly young and specialized in quantum technologies.¹⁰²

Figure 6 illustrates a steady increase in international patent applications with a drastic spike in 2023 compared to 2022.



Figure 5 Main assignees in quantum computing. Source: European Quantum Industry Consortium (n 58) 6.

¹⁰¹ Clint Brown, ‘Exploring Quantum Computing Patents Trends’ (*Augmented Qubit*, 5 March 2024) <<https://augmentedqubit.com/quantum-computing-patents/#identifying-key-quantum-computing-modalities>> accessed 27 July 2025.

¹⁰² Mauritz Kop, Mateo Aboy and Timo Minssen (n 7) 624.

Table 1

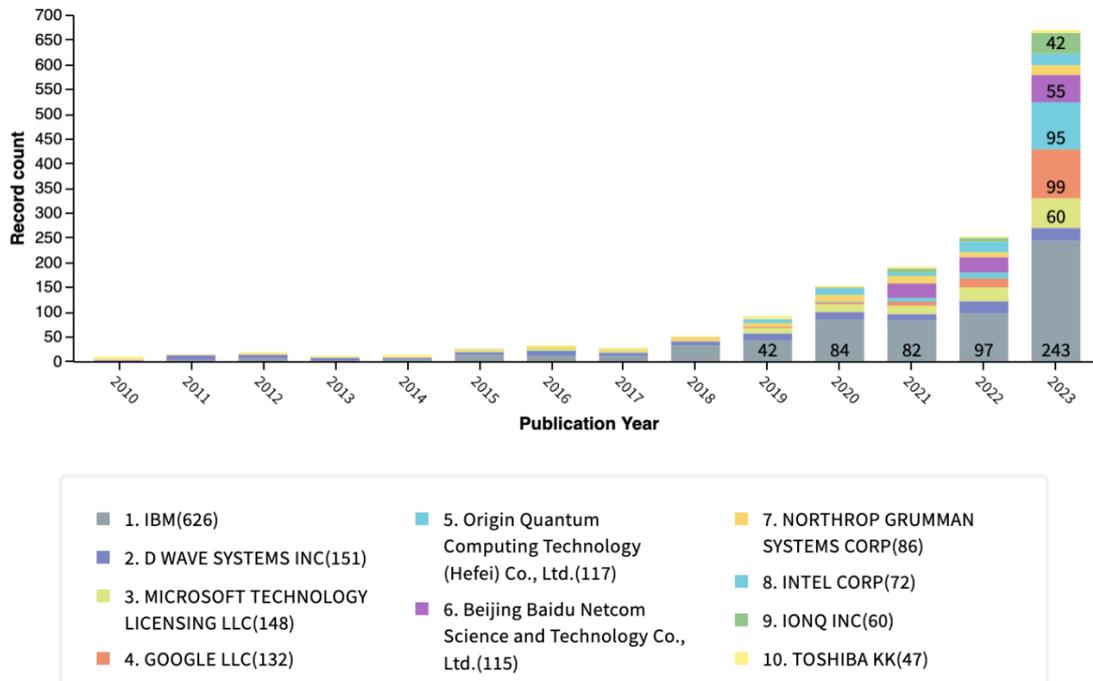


Figure 4 International quantum computing patents 2010-2023 with top 10 patent holders. Source: Elliot J. Mason, 'State of Quantum Industry Innovation – What Patents Tell us' (QED-C) <<https://quantumconsortium.org/blog/state-of-quantum-industry-innovation-what-patents-tell-us/>> accessed 4 May 2025.

Table 1 Total of quantum computing patents by EPO and USPTO as of 2022. Source: Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) Table 1, 858.

Search Concept	Applications	Granted	Percentage (~ %)
Quantum related patents	236,642	178,033	75.23%
Quantum patents (TAC)	34,402	20,581	59.82%
Quantum Devices	14,243	8965	62.94%
Nanostructures/Q.Optics	4917	3282	66.75%
Q. Information Processing	3331	2057	61.75%
Quantum Computing	3042	1603	52.70%
Quantum Cryptography	1219	736	60.38%
Quantum Communication	1057	632	59.79%

focus overall.¹⁰³ However, only 31% of the European patents and patent applications originate from European applicants, while U.S. entities have received and filed 46% of

shows the number of applications compared to the number of patents eventually granted. While the percentage of granted quantum computing patents is lower than most other concepts, the overall granting rates remain relatively high.

3. Comparison of patenting activities: Europe vs. the U.S.

The U.S. is leading in its investments in quantum technologies. Figure 7 shows that the U.S. is primarily investing in quantum computing, while in Europe, there is no particular

¹⁰³ European Quantum Industry Consortium (n 58) 24.

patents and patent applications.¹⁰⁴ This could hinder business for European companies and impede European innovation. More European government funding could boost European innovation and IP portfolios.¹⁰⁵ Some examples of recent quantum innovations developed by European entities are the project to create the first portable quantum computer¹⁰⁶ and Rigetti's launch of the 84qubit quantum computer.¹⁰⁷

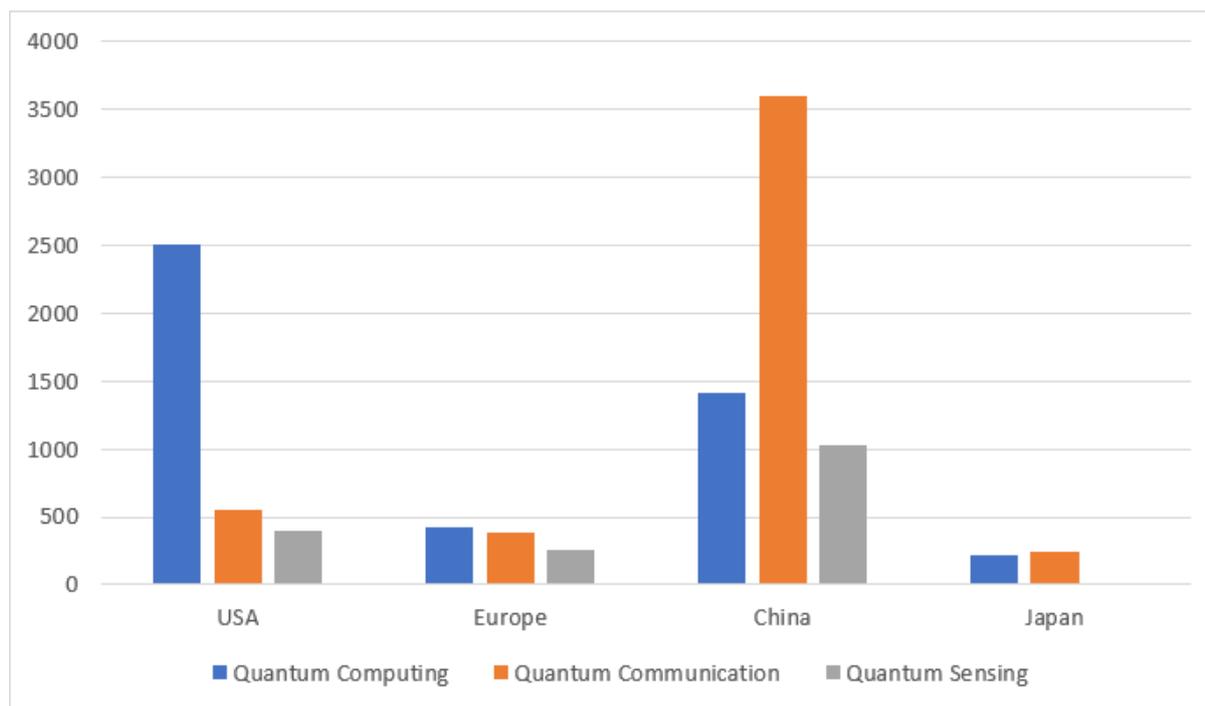


Figure 5 Global number of investments per quantum technology per country/region. Source: European Quantum Industry Consortium (n 58) 10, fig. 3.

¹⁰⁴ *ibid* 22.

¹⁰⁵ *ibid* 27.

¹⁰⁶ Nick Flaherty, '€35m to develop first portable quantum computer' (*eeneews*, 18 September 2024) <<https://www.eenewseurope.com/en/e35m-to-develop-first-portable-quantum-computer/>> accessed 17 July 2025.

¹⁰⁷ Nick Flaherty, 'Rigetti launches 84qubit Ankaa-3 quantum computer' (*eeneews*, 23 December 2024) <<https://www.eenewseurope.com/en/rigetti-launches-84qubit-ankaa-3-quantum-computer/>> accessed 17 July 2025.

4. Comparison of patenting activities: EPO vs. USPTO

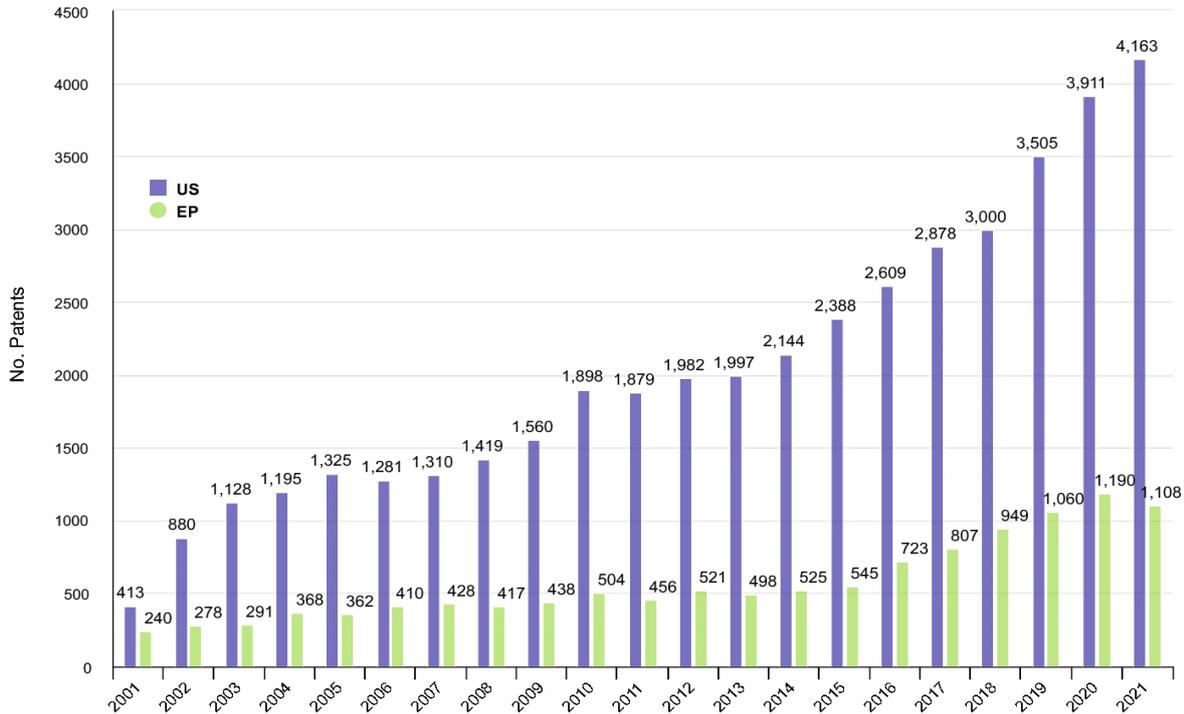


Figure 6. Choice of patent office for quantum technologies, EPO versus USPTO. Source: Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) 862, fig. 2.

Figure 8 illustrates the U.S.’s leading position as the primary patent office for quantum technologies.¹⁰⁸ In 2021 alone, the USPTO received four times as many patent applications in quantum computing as the EPO, which can be explained by the importance of quantum science in the U.S., both in research and development and commercially.

5. Conclusion

This overview of the patent landscape illustrates the global increase in patent filings, though heavily fragmented, and the dominance of the USPTO as a patent office, and the dominance of large American companies in quantum technologies. The major patented topics are placed within quantum computing, quantum communication, and quantum sensing. The growing relevance of quantum computing is evident not only in science but also in patent applications.

Leading assignees seem to favor the USPTO and its jurisdiction over the EPO, due to the U.S. patent system and market situation.¹⁰⁹ And thus, the following question arises: in what aspects does the U.S. patent landscape differ from that of the EU?

¹⁰⁸ Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) 862, fig. 2.

¹⁰⁹ EPO, *Quantum computing - Insight report* (EPO, January 2023) <<https://www.epo.org>> accessed 8 April 2025, 15.

C. Desirability of protecting quantum tech through patents

Quantum technologies are rapidly evolving scientifically in various areas, along with the number of patent grants yearly. Both European and American patents share the primary goal of incentivizing innovation and rewarding innovators with exclusive rights in exchange for public disclosure of inventions. However, the legal problem lies in the fact that quantum tech can challenge patent law as they have barely or never been seen before. This chapter addresses the question of whether patent law is necessary for quantum tech or whether there are better alternatives that incentivize innovation anyhow.

Public and private funding, return on investment, and scientific enthusiasm are important besides exclusive rights. The latter is proven by the large companies providing open-source software, allowing individuals to experiment on quantum processors through cloud computing. Leading companies also collaborate with academic institutions and other specialized research entities to share R&D knowledge and costs, whether through funding, privately, or in working groups. Examples of these collaborations are IBM with Lockheed¹¹⁰ and the University of Chicago¹¹¹ for quantum chemistry for incorporating quantum computers in biotech. At last, trade secrets are a common alternative in technologies for strategic purposes, but perhaps they are also necessary for unpatentable inventions.

Although funding and collaboration support a lot of monetary investments by sharing R&D costs and transferring information, especially for smaller projects, the duration of experimentation and investment remains a long-term commitment, which cannot be encouraged by enthusiasm and short-term funding alone. For example, governments are investing in quantum cryptography to enhance national security and quantum sensing to use in the military¹¹² and commercialization. Quantum algorithms that cannot be operated are underdeveloped or researched, specifically because they do not guarantee short-term profits, which is not attractive for lucrative research, nor are their applications interesting to authorities to utilize.

Considering that there are alternatives to patent protection and innovation is not particularly incentivized by patents alone, arguments can be made that patents still matter to shape the emerging field. Patents provide legal certainty and return on investment for entities that do not rely on funding and collaboration, and for unprofitable and inoperable¹¹³ inventions. They set up possibilities such as high patent value in a cumulated chain of inventions, licensing agreements, attracting venture capital by the

¹¹⁰ Javier Robledo-Moreno and others, 'Lockheed Martin & IBM combine quantum computing with classical HPC in new research' (*ibm.com*, 22 May 2025) <<https://www.ibm.com/quantum/blog/lockheed-martin-sqd>> accessed 16 July 2025.

¹¹¹ University of Chicago, 'IBM and University of Chicago Collaborate to Advance Quantum Computing, Including Innovations in Quantum Chemistry' (*chemistry.uchicago.edu*, 25 April 2025) <<https://chemistry.uchicago.edu/news/ibm-and-university-chicago-collaborate-advance-quantum-computing-including-innovations-quantum>> accessed 16 July 2025.

¹¹² See chapter I. **Error! Reference source not found.**

¹¹³ In this hypothesis, which discusses the objective of patents, the patentability criteria are not taken into account.

legal certainty around royalties, and future standardization and SEPs. Cross-licensing becomes an easier and attractive possibility besides R&D collaboration.¹¹⁴

In contrast to more mature fields such as telecommunications and biotechnology,¹¹⁵ quantum technologies have not established patent pools,¹¹⁶ widely adopted standards and standard essential patents (“SEPs”).¹¹⁷ This suggests that there are no disruptive overlapping patents that disincentivize innovation yet.¹¹⁸ More so, the Antitrust Guidelines for the Licensing of Intellectual Property by the DOJ and FTC¹¹⁹ acknowledge that patent pools and standards can affect innovation by establishing premature commercial products and hindering the development of new products in a geographical market without actual (or potential) competition in those products.¹²⁰

Therefore, patents still serve as the only IP mechanism to incentivize disclosure which in turn pushes innovation forward, to attract investment, and to continue follow-up innovation without taking into account legally complex frameworks, such as licensing negotiations and royalty stacking. This was apparent considering both large, established companies (such as IBM, Google, and Microsoft) and fairly new, specialized companies (such as D-Wave, Rigetti, and IonQ) are among the top patent assignees.¹²¹ Together, they continue to build a strong foundation for future quantum applications, and collaboration is more likely incentivized through high R&D costs and know-how. Nonetheless, as the quantum field continues to mature, patent thicket issues might emerge, and patent pools

¹¹⁴ **Cross-licensing** is a practice where patent owners grant each other the right to practice the other’s patents, and this might solve the issues with complementary R&D. See: Carl Shapiro, ‘Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard-Setting’, (2000) 1 Innovation Policy and the Economy 1, 127.

¹¹⁵ See: Birgit Verbeure and others, ‘Patent pools and diagnostic testing’ (2006) 24 Trends in Biotechnology 115.

¹¹⁶ A **patent pool** involves a single entity that licenses the patents of multiple companies to third parties as a package. They have become common in complex technological fields with widely adopted standards, where pool members can profit from low royalty rates due to the compliance with standards, but they can lead to price fixing and hinder market entry. See: Carl Shapiro (n 114) 130.

¹¹⁷ The IP Guidelines by the Quantum Flagship discuss the future role of patent pools and acknowledge the lack of maturity of the field to form patent pools at the moment. Jari Rantala and Mattia Giardini, *IP Guidelines for Quantum Technologists* (March 2025) <https://qt.eu/media/pdf/IP_Guidelines_for_Quantum_Technologists_2024.pdf> accessed 15 July 2025, 39-40.

¹¹⁸ **Patent thickets** are a large number of patents tied to an accumulated invention to the point that there is a high risk of unintentionally infringing someone else’s patent, particularly when improvements are limited to minimal changes. These hinder innovation when entrants are required to acquire many complementary licenses to participate in the market. See: Mario Coccia and Saeed Roshani, ‘Path-Breaking Directions in Quantum Computing Technology: A Patent Analysis with Multiple Techniques’ [2024] Journal of the Knowledge Economy 1, 27 and Michael Noel and Mark Schankerman, ‘Strategic Patenting and Software Innovation’ (2013) 61(3) J. Ind. Econ. 469, 483.

¹¹⁹ U.S. Department of Justice and the Federal Trade Commission, *Antitrust Guidelines for the Licensing of Intellectual Property* (12 January 2017) <<https://www.justice.gov/atr/IPguidelines/download>> accessed 10 August 2025.

¹²⁰ U.S. Department of Justice and the Federal Trade Commission (n 119) 11.

¹²¹ See **I.Error! Reference source not found.**

would be more beneficial than individual R&D and patents. Until then, as the quantum field stands currently, the absence of patent protection can impede innovation, slowing down follow-up innovation. While patents are not the sole, but complementary elements to other drivers by ensuring commerciality, providing legal protection, and helping IP and collaboration, and innovation in a rapidly developing field without excluding new entrants. Having established the complementary nature of patents, the next subchapter delves into the way the nature of quantum technologies challenges the current patent system.

III. PART II. PATENT LAW AND QUANTUM TECH

A. Basics of Patent Law

1. EU

Article 52(1) EPC states that any invention in all fields of technology can be protected by a patent, provided it meets four independent requirements: it must be an invention, new, involve an inventive step, and be susceptible to industrial application.¹²² Although the EPC does not define inventions, it does define what is not considered as such, and is ineligible subject-matter: discoveries, scientific theories and mathematical methods,¹²³ aesthetic creations, schemes, rules and methods for performing mental acts, playing games or doing business, and programs for computers and presentations of information.¹²⁴ However, only subject matter or activities *as such* are excluded from patentability.¹²⁵ When they have a technical effect, by linking them with hardware, for instance, they can be eligible subject-matter.¹²⁶ The patent offers the assignee exclusive rights for producing, using, or selling the claimed invention for 20 years.¹²⁷

In addition to the patentability requirements, the examiner looks at the technical field to which the invention is related.¹²⁸ The invention must concern a technical problem,¹²⁹ and it must have technical features that can be defined in the claim.¹³⁰ However, according to the Guidelines of the EPO, technical progress or any useful effect is not necessary for the claim to be considered an invention, though it is important to assess inventive step.¹³¹

¹²² See also Art. 57 EPC and EPO, *Case Law of the Boards of Appeal* (11th edition, July 2025) <<https://www.epo.org/en/legal/case-law/2025/index.html>> accessed 14 July 2025, Part I-E, 1.1.

¹²³ EPO, *Guidelines for Examination in the European Patent Office* (April 2025) <<https://www.epo.org/en/legal/guidelines-epc/2025/index.html>> accessed 14 July 2025, Part G-II, 3.3.

¹²⁴ Art. 52(2) EPC.

¹²⁵ Art. 52(3) EPC.

¹²⁶ EPO (n 123) Part G-II, 3.6.

¹²⁷ Art. 63 EPC.

¹²⁸ EPO, *Implementing Regulations to the Convention on the Grant of European Patents of 5 October 1973* (EPO, 2002) <<https://www.epo.org/en/legal/epc/2020/r43.html>> accessed 3 May 2025, Rule 42(1)(a).

¹²⁹ *ibid* Rule 42(1)(c).

¹³⁰ *ibid* Rule 43(1).

¹³¹ EPO (n 123) Part G-I, 2.

At last, the patent claim must be clear, as required by Article 84 EPC, so that a skilled person in the art could reproduce the invention based on the patent alone.

2. The U.S.

In the U.S., patentability criteria are federally regulated in Title 35 of the U.S. As opposed to the EPO, the U.S. code distinguishes several types of patents: utility,¹³² design,¹³³ and plant patents.¹³⁴ For patenting quantum technologies, all of them consist of utility patents. The USPTO Manual of Patent Examining Procedure provides thorough guidelines for patent examiners when examining patent applications and offers inventors a clear, referenced insight into the required conditions and (precedential) case law.

Generally, patent claims can be divided into **four statutory patent-eligible subject matter categories**, which are process, machine, manufacture, or composition of matter, as long as they are new,¹³⁵ useful,¹³⁶ not obvious compared to prior art,¹³⁷ and are industrially applicable.¹³⁸ The invention can include the improvement of other inventions and even patents.¹³⁹ The U.S. patent law also offers exclusive rights for 20 years.¹⁴⁰

U.S. case law has also defined ineligible subject matter. These are claims regarding laws of nature, natural phenomena, mental processes performed on a computer that can be done by a human,¹⁴¹ and abstract ideas, including mathematical concepts.¹⁴² Yet, if a claim includes additional proof that is eligible for patentability, certain ineligible features, such as mathematics,¹⁴³ matter less when a sufficient degree of technical effect is proven.

These eligibility criteria must be differentiated from the requirements for a valid application, such as sufficient disclosure, which requires a clear description of how to make and use the invention,¹⁴⁴ which at the USPTO is defined as **enablement**.¹⁴⁵ The invention must therefore work and be replicable.

Prima facie, the legal frameworks of the EPC and the U.S. Code are similar, having similar requirements and exclusions. These legal frameworks will be compared in more detail in

¹³² 35 U.S.C. §101.

¹³³ 35 U.S.C. §171.

¹³⁴ 35 U.S.C. §161.

¹³⁵ 35 U.S.C. §102.

¹³⁶ 35 U.S.C. § 101.

¹³⁷ 35 U.S.C. §103.

¹³⁸ Art. 57 EPC.

¹³⁹ 35 U.S.C. §101.

¹⁴⁰ 35 U.S.C. § 154(a)(2), (c)(1).

¹⁴¹ USPTO, *Manual of patent examining procedure* (9th edition, November 2024) <<https://www.uspto.gov/web/offices/pac/mpep/index.html>> accessed 19 April 2025, 2106 and Alain Strowel and Sinan Utku, 'The trends and current practices in the area of patentability of computer implemented inventions within the EU and the U.S. (Final Report)' (2016) 3, 12.

¹⁴² USPTO (n 141) 2106.

¹⁴³ *ibid* 2106.5.

¹⁴⁴ 35 U.S.C. §112.

¹⁴⁵ See: case 2023-002850 *Ex parte Aaron K. Baughman and others* (PTAB 2100, 19 January 2024).

the following subchapters by applying them to quantum technologies and what challenges quantum tech might face when applying for patent protection.

B. Introduction to Patenting Quantum Technologies

Within the scope of this paper, aiming to research how the unique characteristics of quantum science challenge patent law, ‘quantum technology patents’ and inventions are defined as those inventions that use quantum mechanical phenomena, to target the challenging components of quantum inventions.

Within the CPC class for quantum computing, being G06N10/00, patent claims can be divided into various areas,¹⁴⁶ such as building blocks, quantum error correction, models of quantum circuits, applications of quantum algorithms, such as quantum optimization, and platforms to access quantum computers, f.e, for simulation.

The following patents illustrate the focus and the range of subject matter of recent quantum tech patents. The method to acquire this information is by using the search engine of Google Patents,¹⁴⁷ and using the keywords ‘quantum’ and the CPC-class corresponding to the quantum field. For quantum computing, it is G06N10/00, for quantum algorithms it is G06N10/60, for quantum communication, it is H04B10, and for quantum cryptography, it is H04L9/08.¹⁴⁸ The advanced search options chosen were ‘country: US,EP’, ‘status:GRANT’, and ‘type:PATENT’.

The following quantum computing patents have been granted between September 2024 and June 2025.

*Table 2*Titles of some of the most recent quantum computing patents granted

Title	Assignee
Quantum noise process analysis method and apparatus, device, and storage medium	Tencent Technology Shenzhen Co Ltd
Qubit control electronics	Google LLC
Constructing quantum processes for quantum processors	Rigetti and Co LLC
Quantum annealing debugging systems and methods	D Wave Systems Inc
Methods and devices for decoding quantum states	Psiquantum Corp
Quantum computer architecture system	Origin Quantum Computing Technology Hefei Co Ltd

¹⁴⁶ Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) 864-865.

¹⁴⁷ See: Google Patents, <patents.google.com>.

¹⁴⁸ Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) 858.

The following patents have been granted between January 2025 and July 2025.

Table 3 Titles of the most recent quantum algorithm patents granted

Title	Assignee
Calculation control for hybrid computing of hamiltonian eigensolutions	Qunova Computing Inc
Variational quantum state preparation	Google LLC
Reducing unitary error in a quantum computation system	Rigetti and Co LLC
Quantum statistic machine	Google LLC
Weighted alternating paths in graphs for quantum computing	Google LLC
Error corrected variational algorithms	Google LLC

The following patents have been granted between March 2022 and July 2025.

Table 4 Titles of the most recent quantum communication patents granted

Title	Assignee
Systems and methods for disparate quantum computing threat detection	Wells Fargo Bank NA
Quantum communication transceiver based on quantum entangled atomic states	Hughes Network Systems LLC
Physical electromagnetics simulator for design optimization of photonic devices	X Development LLC
Transmitter for a quantum communication system, a receiver for a quantum communication system and a method of controlling a quantum communication system	Toshiba Corp

The following patents have been granted between February 2023 and July 2025.

Table 5 Titles of the 5 most recent quantum cryptography patents granted

I. Title	Assignee
Systems and methods for disparate quantum computing threat detection	Wells Fargo Bank NA

Systems and methods for quantum entanglement authentication	Wells Fargo Bank NA
Cryptographic system for post-quantum cryptographic operations	PQshield Ltd
Method and apparatus for enhancing security of quantum key distribution network	Tsinghua University
System and method for flexible post-quantum trust provisioning and updating	NXP BV
Communication device, communication method, and communication method for performing communication using shared quantum key	Toshiba Corp

There are some challenges that patent applicants might face in quantum tech. First, essential quantum inventions are excluded from the subject matter, and second, the unpredictable nature of quantum science, its experimental hardware, and core principles of quantum mechanics challenge technical effects in patentability.

Figure 7 illustrates the distribution of various rejection types for quantum computing patents as reported by the USPTO. Overall, the vast majority of patent rejections are based on non-obviousness, though subject matter eligibility, novelty, and clear and precise definition of the scope of quantum inventions represent a large number of rejections.¹⁴⁹

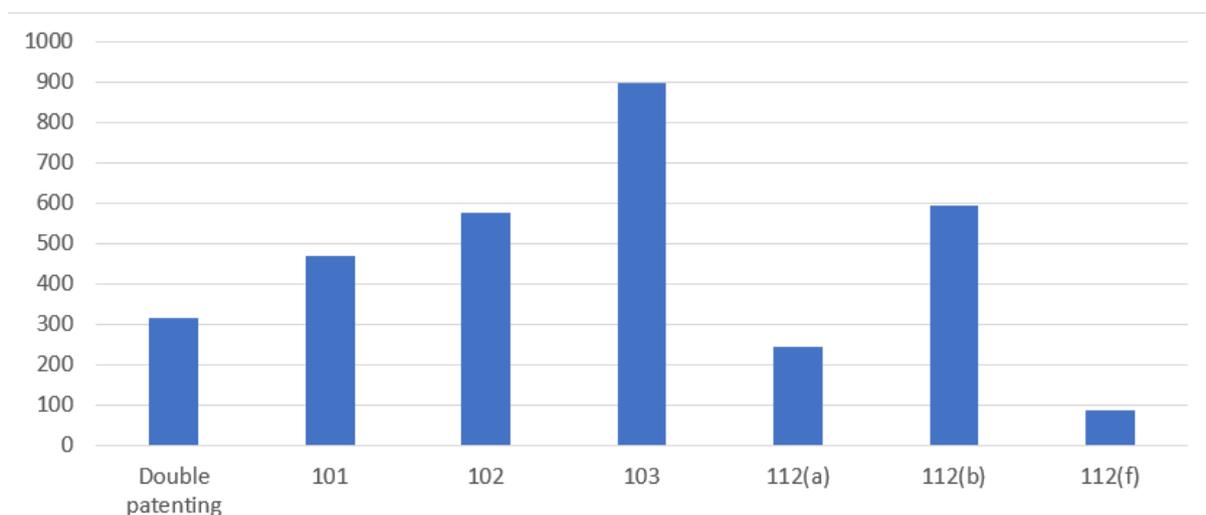


Figure 7 Distribution of rejection types for quantum computing patent applications as of 2024. Source: Matt Nealon (n 149).

¹⁴⁹ Matt Nealon, ‘Quantum Computing Patent Trends in the US: Are Breakthroughs Just Around the Corner?’ (*PatentNext*, 14 March 2025) <<https://www.patentnext.com/2025/03/quantum-computing-patent-trends-in-the-us-are-breakthroughs-just-around-the-corner/>> accessed 8 April 2025. This study used data and information provided by Juristat.

Issues regarding novelty and non-obviousness are common in new emerging technology fields.¹⁵⁰

Quantum algorithms and simulations are highly mathematical, and can be excluded as such, and future inventions around chemical bonds through quantum simulation can equally be considered projections of information. Furthermore, quantum computations are probabilistic and less deterministic than classical deterministic systems. Identical inputs do not consistently yield the same results because of the extremely sensitive nature of quantum states. Also, the difficulty in arranging qubits contributes to vastly different outcomes.¹⁵¹ Such unpredictability complicates providing sufficient¹⁵² and comprehensive¹⁵³ information to replicate the invention, which requires sufficient, multidisciplinary knowledge of the patent examiner¹⁵⁴ and operability of the invention. Current quantum computers do not have a sufficient number of qubits and control, which makes meeting the disclosure requirement an issue. Given that the necessity of patent protection in quantum innovation is complex, the following subchapters delve deeper into the introduced challenges and explore the current legal frameworks, considering the unique characteristics of quantum tech.

C. Treatment of Abstract Ideas

Hardware quantum inventions are mostly patent-eligible, such as qubits, quantum gates, decoders, simulators, and quantum processors.¹⁵⁵ However, both at the EPO (under Art. 52(2)(3) EPC) and the USPTO (*Diamond v. Diehr*),¹⁵⁶ abstract ideas are excluded from eligible subject-matter. Despite the *prima facie* exclusion of quantum algorithms, optimization, and error-mitigating codes and programs, both institutions have established their approach to patent applications with ineligible subject matter.

1. EPO: the two-hurdle test

At the EPO, the requirement of subject-matter eligibility is separate from inventive step, but the EPO's approach to determine subject-matter eligibility for inventions with non-technical features overlaps with its inventive step requirement.¹⁵⁷ Therefore, both requirements are discussed in the following chapter.

¹⁵⁰ Victoria Carrington and Michael Mauriel, 'Quantum computing patents: early 101 guidance from PTAB decisions' (2025) 77 *The Patent Lawyer* 44, 44.

¹⁵¹ Bao Tran, 'Inside IBM's Quantum Computing Patents: What Lawyers Need To Know' (*PatentPC*, 21 July 2025) <<https://patentpc.com/blog/inside-ibms-quantum-computing-patents-what-lawyers-need-to-know>> accessed 12 July 2025.

¹⁵² Art. 83 EPC and 35 U.S.C. 112(a).

¹⁵³ Art. 84 EPC and 35 U.S.C. 112(a).

¹⁵⁴ Bao Tran (n 151).

¹⁵⁵ Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) 3.

¹⁵⁶ *Diamond v. Diehr*, 450 U.S. 175 (1981) at 185.

¹⁵⁷ Alain Strowel and Sinan Utku (n 141) 14 and 17.

In the decision by EPO's Boards of Appeal G1/19, the **two-hurdle approach** was established to assess whether the subject-matter in claims with non-technical features is patentable.¹⁵⁸ This case concerned the question of whether a method involving technical means is an invention regarding simulations. The first hurdle, subject-matter eligibility, does not take into account prior art and general knowledge.¹⁵⁹

In summary, the two-hurdle approach consists of three questions:

1. The invention's eligibility under Article 52 EPC.
2. Whether a feature contributes to the technical character of the invention.
3. Whether the invention is based on an inventive step vis-à-vis the closest prior art,¹⁶⁰ following the COMVIK approach.¹⁶¹
 - (a) First hurdle: Subject-Matter Eligibility (Art. 52(2)(3) EPC)

The exclusions of Article 52(2)(3) EPC exclude patent claims for mathematical methods, mental processes, and computer programs *as such*.¹⁶² 'As such' indicates that unless a claim does have *any* technical effect¹⁶³ or at least technical considerations¹⁶⁴ as a whole,¹⁶⁵ it could be patented, even without a technical purpose.¹⁶⁶

However, the mere possibility of serving a technical purpose is not sufficient.¹⁶⁷ This clashes with the nature of quantum inventions that cannot be carried out yet when the apparatus with sufficient qubits has not been invented, such as Shor's algorithm for factoring, which requires more qubits and more control over them to run on. Examples are physical changes, technical signal processing, or improvements in internal device workings.¹⁶⁸

¹⁵⁸ Case G1/19 *Pedestrian simulation* (Enlarged Board of Appeal, 10 March 2021).

¹⁵⁹ G1/19 (n 158) Reason 28, Case T258/03 *Auction method/HITACHI* (Technical Board of Appeal 3.5.1., 21 April 2004) and Case T0388/04 *Undeliverable mail/PITNEY BOWES* (Technical Board of Appeal 3.5.02, 22 March 2006).

¹⁶⁰ EPO (n 122) Part I-A.4.

¹⁶¹ Introduced in Case T641/00 *Two identities/COMVIK* (Technical Board of Appeal 3.5.1., 26 September 2002) OJ EPO 2003, 352 and G1/19 (n 158).

¹⁶² Igor Dydenko, 'Searching claims comprising non-technical features at the European Patent Office' (2018) 54 *World Patent Information* 44, 45.

¹⁶³ Opinion G3/08 *Programs for computers* (Enlarged Board of Appeal, 12 May 2010).

¹⁶⁴ Case T931/95 *Controlling pension benefits system* (Technical Board of Appeal 3.5.1., 8 September 2000) OJ 2001, Reason 2.

¹⁶⁵ EPO (n 123) Part G-II, 3.3. See: Case T0208/84 *Computer-related invention* (Technical Board of Appeal 3.5.1., 15 July 1986), OJ 1987, 14.

¹⁶⁶ T258/03 (n 159) and T931/95 (n 164) Reason 2.

¹⁶⁷ Case T-306/04 (Technical Board of Appeal, 27 September 2004).

¹⁶⁸ Hendrik Vanhees, *Handboek intellectuele rechten* (Intersentia 2020) 559.

The same applies to methods for performing **mental acts**.¹⁶⁹ However, technical considerations do not suffice if the process can be carried out exclusively mentally; tangible, technical effects are still required.¹⁷⁰

Algorithms can be seen in two ways, either as a pure mathematical exercise, or as defining a procedure to make a machine carry out a certain task. Because all computer programs are deemed to have technical effects, they must have a “further” technical effect.¹⁷¹ As such, abstract quantum principles, algorithms, programs, and codes (e.g., quantum error-correcting codes), that are essential aspects to ensure the proper functioning of quantum computers,¹⁷² could be classified as **computer-implemented inventions (‘CIIs’)**.¹⁷³ These are inventions that include features that can only or partly be realized through a computer program and the use of a computer or something alike.¹⁷⁴ They are patentable if the claim describes computer-executable steps or executes a specific functionality when installed by a processor on a computer-readable medium hosting a computer program.¹⁷⁵ Simulations can also be assessed as CIIs.¹⁷⁶ However, quantum algorithms that demonstrate quantum advantage cannot be classified as such, for they are currently inoperable, and as such, impossible to be implemented into a computer because of the requirement of reproducibility.¹⁷⁷ Neither are quantum algorithms which are merely more efficient than prior art, unless it results into a technical effect.¹⁷⁸

However, this classification lowers the threshold for subject-matter eligibility, because the mere reference to an algorithm as ‘a computer-implemented method’ or ‘quantum computing method’ often suffices to pass the first test,¹⁷⁹ as shown by the following examples:

- *A computer-implemented method* of correcting a stream of syndrome measurements produced by a quantum computer using a surface code. The claim consisted of a full integration of the quantum algorithm in the hardware, and the error-correction process was explained fully.¹⁸⁰

¹⁶⁹ Case T38/86 *Text processing* (Technical Board of Appeal 3.5.1., 14 February 1989), OJ 1990, 384 and case T769/92 *General purpose management system* (Technical Board of Appeal 3.5.1., 31 May 1994).

¹⁷⁰ Case T914/02 (Technical Board of Appeal 3.4.1., 12 July 2005).

¹⁷¹ G3/08 (n 163) 13.5.1.

¹⁷² Gabriela Lenarczyk, Timo Minssen and Mateo Aboy, ‘IP In Superposition: Patents, Trade Secrets, and Open Innovation in Quantum Information Technology’ in Mateo Aboy, Marcelo Corrales Compagnucci and Timo Minssen (eds.), *Quantum Technology Governance : Law, Policy, and Ethics in the Quantum Era* (preprint, 2025), 5.

¹⁷³ Alain Strowel and Sinan Utku (n 141) 3.

¹⁷⁴ EPO, *Index for Computer-Implemented Inventions* (EPO, 2025) <<https://www.epo.org/en/legal/guidelines-epc/2025/j.html>> accessed 3 May 2025.

¹⁷⁵ Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) 4.

¹⁷⁶ EPO (n 123) Part G-II, 3.3.

¹⁷⁷ *Infra* chapter II.4.

¹⁷⁸ EPO (n 123) Part G-VII, 5.4.

¹⁷⁹ Alain Strowel and Sinan Utku (n 141) 17.

¹⁸⁰ Google, *Quantum error correction* (EP3682381, 24 July 2024).

- *A computer-implemented method* for integrating post-quantum cryptographic algorithms into transport layer security. All the steps for the integration were written out, and the application also included a hardware system, including one or more processors.¹⁸¹
- *A computer-implemented method* for simulating a quantum circuit, the method comprising receiving data representing the quantum circuit, wherein the quantum circuit comprises multiple quantum logic gates, and generating a simulation of the quantum circuit using the received data.¹⁸²

There is a difference between a CII and a **computer** program. While CIIs refer to a sequence of computer-executable instructions specifying a method, which makes them patent eligible as a whole, programs are methods *performed* on a computer.¹⁸³ The EPO appears to be stricter towards **computer programs** because they all have technical effects.¹⁸⁴ The program must provide a further technical effect than mere normal physical interactions between the program and the computer on which it is run.¹⁸⁵ Providing a faster program is insufficient because it does not achieve a technical effect beyond mere communication with a computer.¹⁸⁶ Algorithms are unlikely to be classified as part of a computer program because they do not increase a computer's inner functionality, nor have a technical effect between software and hardware.¹⁸⁷ This *could* be the case for optimization and error-correction codes.

As such, mixed quantum patent applications must provide sufficient and clear proof that specific hardware cannot operate without the software. In practice, this first hurdle, if not directed to a computer program, imposes a low threshold.¹⁸⁸ For example, in the *Hitachi decision*, concerning a computer-implemented method for carrying out an automatic auction, including terms in the claim such as 'server computer' and a 'network' satisfied the subject-matter eligibility criterion.¹⁸⁹ However, the claim failed at the second hurdle.

(b) Second hurdle: inventive step COMVIK-approach

Although technical advancement or usefulness is required for a claim to be patentable, it plays a major role in determining the inventive step, because the second hurdle of the inventive step only takes into account technical features to establish non-obviousness.

For mixed inventions, the Board of Appeal has established the **problem-solution approach**, in which the **COMVIK** approach is conventionally applied. The essence is whether the inventive elements of a claim *themselves* have technical character.

¹⁸¹ IBM, *Tls integration of post quantum cryptographic algorithms* (EP4176563, 14 August 2024).

¹⁸² Google, *Simulation of quantum circuits* (EP3682383, 21 September 2022).

¹⁸³ EPO (n 122) Part I-A, 6.5.2.

¹⁸⁴ Case T1173/97 *Computer program product/IBM* (Technical Board of Appeal 3.5.1., 1 July 1998).

¹⁸⁵ EPO (n 123) Part G-II, 3.6.

¹⁸⁶ EPO (n 128) Rule 43(1).

¹⁸⁷ Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) 3-4.

¹⁸⁸ Alain Strowel and Sinan Utku (n 141) 21.

¹⁸⁹ Case T258/03 (n 159) 3.7 and Alain Strowel and Sinan Utku (n 141) 19.

The problem-solution approach consists of:

1. identifying the *closest prior art*, the most relevant prior art, or at least a realistic starting point;
2. determining the *objective technical problem*, that is, determining, in the view of the closest prior art, the technical problem which the claimed invention addresses and successfully solves; and
3. examining *whether or not the claimed solution* to the objective technical problem *is obvious* for the skilled person, given the state of the art in general.¹⁹⁰

However, non-technical features can nevertheless contribute to the technical *solution* of a technical problem and the technical character of the invention as a whole.¹⁹¹ If an essential idea of the invention lies in a non-technical field, usually excluded subject matter, the objective technical problem is formulated as a constraint that any implementation must meet.¹⁹² As such, only those non-technical features that interact with the technical subject matter will be taken into account.¹⁹³ For example, in the *Hitachi* decision, the Board found that the claims lacked inventive step due to the solution not being technical, but modifications to prior art. The low threshold of the first hurdle for CIIs is compensated by case law regarding the inventive step requirement.

As such, if drafted carefully, quantum algorithms such as Shor's algorithm and Grover's algorithm, that by themselves do not solve a technical problem, nor do error-correction and optimization codes, can be patentable if proven well enough that facilitating qubit coherence and reducing noise constitutes a technical problem,¹⁹⁴ beyond merely carrying out some procedure.¹⁹⁵ Encryption and decryption methods, while mathematical, are deemed technical,¹⁹⁶ and so are methods for operating a computer.¹⁹⁷

For example, the technical effects of the implementation of a Variational Quantum Eigensolver algorithm¹⁹⁸ was described as follows:

“It is an objective of the present disclosure to provide a technical solution that enables accurate calculation of any-order partial derivatives for an objective function without having to change the structure of an ansatz state (and) to improve the efficiency of the VQE algorithm by using these accurately calculated partial derivatives of the objective function.”

¹⁹⁰ EPO (n 123) Part G-VII, 5 and Mateo Aboy and Timo Minssen, ‘The Patentability of Computer Implemented Simulations and Implications for Computer-Implemented Inventions (CIIs)’ (2021) 16(7) *Journal of Intellectual Property Law & Practice* 633.

¹⁹¹ EPO (n 123) Part G-VII, 5.

¹⁹² T641/00 (n 161) headnote 2.

¹⁹³ Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) 4.

¹⁹⁴ EPO (n 128) Rule 43(1).

¹⁹⁵ G3/08 (n 163) 13.5 and see also case T1358/09 *Classification / BDGB ENTERPRISE SOFTWARE* (Technical Board of Appeal 3.5.7., 21 November 2014).

¹⁹⁶ Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) 3.

¹⁹⁷ G3/08 (n 163) 10.7.

¹⁹⁸ See subchapter **Error! Reference source not found.** Huawei, *Implementation of variational quantum eigensolver algorithm by using tensor network framework* (EP4042336, 25 June 2025).

Inventions in **quantum simulation** are typically placed in the category of mathematical methods or mental processes, but technical effects can be established by using external physical apparatuses for the input and the output of the simulation or implementing the simulation using hardware for technical purposes. Mere numerical data reflecting the physical states of a system or models usually do not provide sufficient technical character on their own.¹⁹⁹ However, the Board of Appeal did acknowledge that quantum computers could perform certain simulations that require more computer power than is available from a standard computer.²⁰⁰

If the solution to the objective technical problem provided by the claims is deemed **obvious** to that skilled person, the invention lacks inventive step. This part of inventive step will be discussed in III.D.2.

(c) Examples

The technical effect of quantum algorithms, both with quantum advantages but also error-correcting algorithms, is established when they are used in a technical process. This process is carried out on a physical entity, such as a quantum processor or another device like quantum circuits.²⁰¹ A change in the entity is caused by implementing the method through these technical means.²⁰² For example, in T 323/21, the interaction between an algorithm and a device was not proven sufficiently. Because the algorithm was too mathematical, it was deemed not eligible.²⁰³ Also, encoding and decoding, like in quantum communication, QKD, error-correction algorithms in quantum circuits, are essentially mathematical processes, but they can still be technical.²⁰⁴ Even mathematical steps as a solution for a technical problem in encrypting data must have further, technical context.²⁰⁵

However, merely using hardware to operate a code or an algorithm does not suffice. For instance, in **T 1125/17**,²⁰⁶ an application concerned a method for transforming a computation graph, such as quantum circuit instructions, to make it easier to parallelize. This was rejected because the claim did not explicitly execute the code on parallel hardware, but only referenced to a computer in general. Without it, the claim concerned a well-known idea in the field.²⁰⁷ As such, even internal software improvements a hardware application. This is also placed in the general uncertainty of quantum computing regarding optimization and error-correcting methods without hardware implementation, because it is either not operable yet, or unknown. For example, **quantum circuits defining gate**

¹⁹⁹ G1/19 (n 158) 53.

²⁰⁰ G1/19 (n 158) 115.

²⁰¹ Gabriela Lenarczyk, Timo Minssen and Mateo Aboy (n 172) 5.

²⁰² Case T1814/07 *Index disorder/CARDIAC INTELLIGENCE CORP.* (Technical Board of Appeal 3.5.5., 2 September 2008).

²⁰³ Case T0323/21 *Non-decreasing sequence determining device/Nippon Telegraph and Telephone Corp.* (Technical Board of Appeal 3.4.1., 6 August 2024), 12.

²⁰⁴ Case T1326/06 *RSA-sleutelpaarberekening/GIESECKE & DEVRIENT* (Technical Board of Appeal 3.5.6., 30 November 2010).

²⁰⁵ Jari Rantala and Mattia Giardini (n 117) 11.

²⁰⁶ Case T1125/17 *Parallelizing computation graphs/AB INITIO* (Technical Board of Appeal 3.5.6., 2 April 2019).

²⁰⁷ *ibid* 5.5.

operations need to be defined to be executed within the coherence time of a NISQ quantum computer, so the execution of such a quantum circuit might define a technical solution to a technical problem.²⁰⁸

Nevertheless, the absence of “real external effects” does not exclude the possibility for software and the underlying algorithms to contribute to the technical character of a CII. As such, even technical improvements to simulations and algorithms could be achieved through software that can be patented.²⁰⁹ Especially in error-correction algorithms, the external effects of qubit control and stability might not be apparent, but they have a technical effect.

3. USPTO: the Alice/Mayo framework
(a) Subject Matter Eligibility

Although case law had established that laws of nature, natural phenomena, and abstract ideas are also not patentable subject matter,²¹⁰ the U.S. Court of Appeals for the Federal Circuit (“Fed. Cir.”) has since developed an approach to handle subject matter eligibility of CIIIs. The Court stated in **Mayo Collaborative Services v. Prometheus Laboratories, Inc. (‘Mayo’)**²¹¹ that inventions are human-made, distinguished from discoveries that are natural and already existent, making these claims invalid.²¹² Though this case involved biology, and it had mainly consequences in biotech and medicine at the time of the ruling, this can also be applicable in quantum physics, a field that also involves the continuous discoveries of quantum phenomena.

²⁰⁸ Jari Rantala and Mattia Giardini (n 117) 11-12.

²⁰⁹ G1/19 (n 158) 115.

²¹⁰ Alain Strowel and Sinan Utku (n 141) 21; *Diamond v. Diehr* (n 156) at 185.

²¹¹ *Mayo Collaborative Services v. Prometheus Laboratories, Inc.* 566 U.S. 66 (2012), 74, 83-84.

²¹² *Mayo* (n 211156) 8, 17 and 18.

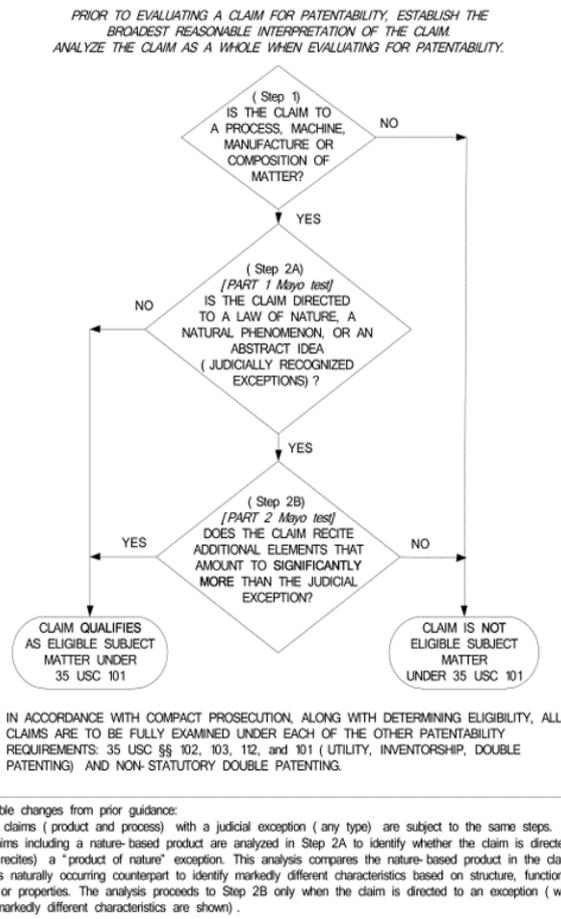


Figure 8 PTO Guidance on subject-matter eligibility. Source: Alain Strowel and Sinan Utku (n 141) 24.

the exception is integrated into a practical application by proving that the invention improves the functioning of a computer or improves another technology or technical field.²¹⁷ The applicant must have additional features²¹⁸ that amount the claim to significantly more than the judicial exception, for example, by proving that the invention sufficiently transforms an abstract idea into a real-life, practical application.²¹⁹ However, merely adding the words ‘apply it’ does not suffice.²²⁰

In *Gottschalk v. Benson*, the Supreme Court determined that a mathematical algorithms for converting binary coded decimal to pure binary within a computer’s shift register was an abstract idea, because the algorithm could be carried out mentally.²²¹ However, in a patent examination regarding a modified VQE process to determine the

The Supreme Court applied the *Mayo* framework in *Alice Corp. v. CLS Bank Int. (‘Alice’)*.²¹³ The case concerned electronic methods for financial-trade systems that mitigated settlement risk, and a computer acts as a third-party intermediary.²¹⁴ Along with USPTO’s memorandum of June 25, 2014, the *Alice* case provides a two-part test to determine the subject matter eligibility in a claim when the claimed invention is directed at one of the four statutory patent-eligible matter categories,²¹⁵ considering the broadest reasonable interpretation of the claim.²¹⁶

The following elements are assessed:

- Whether the invention involves one or more judicial exceptions.
- Whether the claim as a whole recites something more than the judicial exception(s).

The USPTO will therefore examine the claim as a whole to determine whether

²¹³ *Alice Corp. v. CLS Bank International* 583 U.S. 208 (2014).

²¹⁴ Alain Strowel and Sinan Utku (n 141) 21.

²¹⁵ USPTO (n 141) 61.

²¹⁶ *MyMail, Ltd. v. ooVoo, LLC*, 934 F.3d 1373, 1379 (2019).

²¹⁷ USPTO (n 141) 2106.04(d)(1).

²¹⁸ *Alice* (n 213) at 2357.

²¹⁹ Alain Strowel and Sinan Utku (n 141) 21.

²²⁰ *Alice* (n 213) at 1982-83.

²²¹ *Gottschalk v. Benson* 409 U.S. 63, at 67.

ground state of a quantum Hamiltonian,²²² many claims were initially considered mental processes, but the patent was eventually granted. One of the applicant's final arguments before issue was that the human mind is not capable of detecting quantum phenomena to determine the ground state like a quantum computer does.²²³

If abstract ideas and principles are integrated into practical applications, and the claim is not directed to those principles as such, then it would not require further analysis.²²⁴ In the *Benson* case, it was established that merely implementing a mathematical formulation in a computer does not suffice to elevate the claim above abstract. Relevant considerations to evaluate the required additional elements include an improvement in the functioning of a computer or another technology.²²⁵ An error correction device with an error correction code, that could be attached to a quantum system to detect and correct errors, does improve the functioning of a computer, and pass this requirement.²²⁶ Furthermore, claims that are directed to clear improvement to a (computer-related) technology, do not need the full eligibility analysis.²²⁷

However, in June 2023, the Patent Eligibility Restoration Act was introduced to amend 35 U.S.C. §101, including the elimination of exclusions for mathematical formulas, mental processes (though only those performed solely in the human mind), and natural processes occurring in nature absent human activity.²²⁸

(b) Examples in Quantum Tech

In the U.S., there has been more case law activity regarding quantum inventions. For example, in *(in) re Huping Hu*, the Federal Circuit sustained a rejection based on the fact that quantum entanglement is not an invention, but a natural phenomenon.²²⁹ At the PTAB, there are three interesting quantum cases around subject matter eligibility, being: *Ex Parte Alexei Ashikhmin* (2017)²³⁰, *Ex Parte Yudong Cao* (2025)²³¹, and *Ex Parte Yili Zhang and others* (2024)²³².

²²² IBM, *Iterative energy-scaled variational quantum eigensolver* (US201916691941, 5 April 2022).

²²³ Applicants Arguments/Remarks Made In an Amendment (US201916691941, 12 January 2022), 3.

²²⁴ *Mayo* (n 211156) 80 and 84.

²²⁵ USPTO (n 141) 2106.04(d)(1) and 2106.05(a).

²²⁶ Quantum Corp, *Error correction algorithm using interleaved parity check and reed-solomon code* (US31343805, 21 June 2007).

²²⁷ *Enfish, LLC v. Microsoft Corp.*, 822 F.3d 1327, 1339.

²²⁸ Patent Eligibility Restoration Act of 2023, S.2140, 118th Cong. (2023).

²²⁹ *In re Huping Hu*, 848 F. App'x 416 (Fed. Cir. 2021) 420; Kaya Derose, 'Establishing the Legal Framework to Regulate Quantum Computing Technology' (2023) 31 Catholic University Journal of Law and Technology 145, 168.

²³⁰ Case 2017-006572 *Ex parte Alexei Ashikhmin* (PTAB 2100, 4 December 2017).

²³¹ Case 2024-002159 *Ex parte Yudong Cao* (PTAB 2100, 11 February 2025).

²³² Case 2024-000512 *Ex parte Yili Zhang and others* (PTAB 3600, 29 November 2024).

Although error correction techniques are methods that, as such, could be deemed ineligible subject matter, in *Ex Parte Alexei Ashikmin*, an application dated to 2013, a technique was successfully linked to hardware. This application is related to a quantum device designed to measure syndromes and parity-check bits to identify and possibly correct quantum errors. Errors can occur during computation or transmission of data, for example, due to decoherence and noise. Syndromes are sets of measurements that identify errors and are frequently used in quantum error correction.

The claim proposed a technique to check whether the syndromes themselves contained errors with the use of a quantum circuit consisting of preset qubits that are used as test or reference qubits, of which the state can be manipulated depending on the states of other qubits that might contain an error. The measurement of these preset qubits

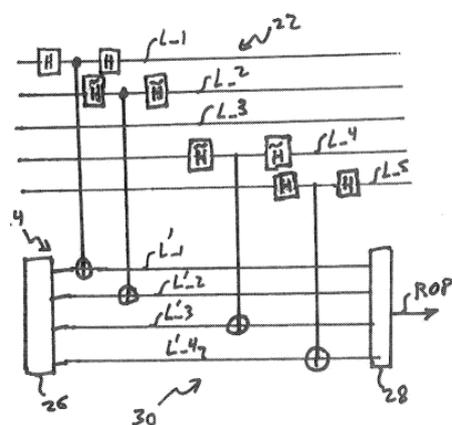


Fig. 7

12(7)

provides information about error qubits. Then, parity check bits are used to determine the reliability of the syndromes. This entire process preserves the quantum states. This is situated in the battle against decoherence and error, making the quantum systems more controlled.

The examiner found that the syndromes were abstract and mathematical. The PTAB reversed the rejection, stating that:

“(q)uantum processing using quantum bits or ‘qubits’ and measuring physical states and syndromes associated therewith, may be esoteric technology, but this does not make the claimed invention abstract...”

Techniques for virus detection and data integrity checking have been well-established in telecommunications and data processing, including their improvements. Error-correcting techniques, being their quantum equivalent, must be eligible as well.²³³

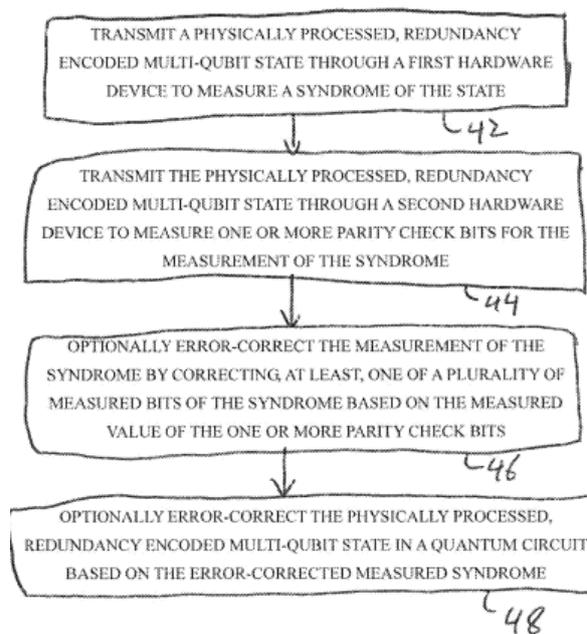


Fig. 10

²³³ *Ex parte Yili Zhang and others* (n 232) 4 and *Victoria Carrington and Michael Mauriel* (n 150) 46.

*Ex Parte Yudong Cao*²³⁴ concerned a hybrid quantum-classical computer system that solves linear systems. The technical problem is that noise makes solving linear systems difficult, and so, this invention proposes improvements to quantum computers for solving linear systems. It splits the linear system to be solved into subsystems that are small enough to be solved by the quantum computer, under the control of the classical computer. Then, the classical computer synthesizes the outputs of the quantum computer to generate the complete solution to the linear system.

The examiner has rejected the application on various bases, but the most importantly because it is directed to an abstract idea without significantly more after doing the *Alice* test. Most of the claims either did not reflect an improvement to the technology or lacked additional elements. The abstract idea in question was gathering data from qubits through the claimed method of preparing a quantum state on a set of qubits.

On appeal, the PTAB disagreed and explained that the step:

“represents the focus of the invention and integrates the recited abstract idea [of mathematical relationships] into a practical application[...] enabling noisy quantum computers, which have limited circuit depth, to practically solve linear systems - a technology improvement.”

The applicant’s approach to drafting the patent claim sufficiently explains what the technical problem is on quantum computers, the necessity for a solution, and connects the two by the invention.

This decision has multiple important conclusions. First, this decision may be cited from now on to argue that techniques involving the application of quantum circuits to prepare quantum states are eligible for patent protection. Second, this decision may end the trend of rejecting claims because encoding information into bits was previously considered a mental act. As such, the PTAB has recognized the unique nature of quantum algorithms, and provides a guideline for their patentability. However, it is still unclear whether this would be sufficient in and of itself for patent eligibility. As such, the PTAB has recognized the unique nature of quantum algorithms and provides a guideline for their patentability.²³⁵

At last, in *Ex Parte Yili Zhang and others*, the PTAB decided that merely involving quantum processing in the claims does not suffice as an additional element to transform an abstract idea into patent-eligible subject matter. The claim involved calculating credit risk factors by using a discrete probabilistic wave function representing a superposition state of scores. Quantum hardware would be used, but it was not specified. This case demonstrates that generally referring to using quantum computers to solve a non-technological problem, in this case being risk analysis, remains too abstract for patent eligibility.²³⁶

²³⁴ *Ex parte Yudong Cao* (n 231).

²³⁵ Victoria Carrington and Michael Mauriel (n 150) 46.

²³⁶ *ibid* 46.

3. Comparative analysis

Generally, both at the EPO and the USPTO, patent applicants avoid using the limitation ‘algorithm’ in the patent claims. And yet, it has been reported that from 2010 to 2021, there was an increase in patents using that limitation. Nonetheless, it remains a minority compared to other patent claims,²³⁷ which is apparent on how the offices treat algorithms and ‘computer-implemented methods’.

While at the USPTO, the discussion around technical effect happens in the subject matter

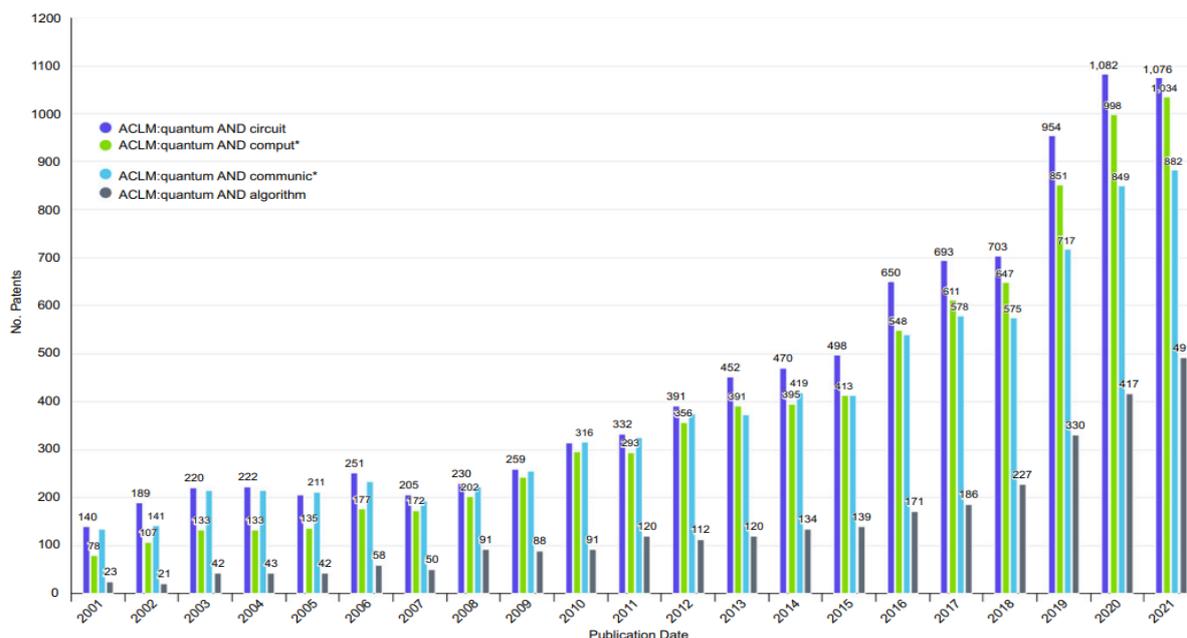


Figure 9 Relative prevalence of USPTO and EPO quantum technology patent claims directed to quantum circuit, quantum computing, quantum communication, and quantum algorithms. Source: Mauritz Kop, Mateo Aboy and Timo Minssen (n 8102) 863.

eligibility requirement, the EPO’s approach has spread the analysis over both subject-matter eligibility and inventive step.

The EPO’s approach to determining which non-technical features are taken into account for inventive step is similar the *Alice*-requirement of determining whether the claims include additional elements that elevate them beyond the mere abstract. However, while for the EPO it suffices to refer to the use of a computer, references to ‘generic computers’ is insufficient for the *Alice*-test, which requires more additional elements.²³⁸

Regarding quantum inventions, the PTAB has decided mainly on quantum subject matter and acknowledged the unique characteristic of the field, while the Board of Appeal at the EPO has not done so explicitly yet. More so, decisions on quantum patent applications

²³⁷ Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) 863.

²³⁸ Alain Strowel and Sinan Utku (n 141) 31.

have not been reported on at the EPO. This indicates that the Board of Appeal has not treated them much differently compared to classical technologies.

Quantum hardware does not specifically struggle with being applications of quantum mechanics. Quantum software, however, depends on the success of the two-hurdle step.

Amongst the most difficult software inventions are the following. First, quantum algorithms require technical applications to be patentable as the patent system currently stands. As such, to comply with the first hurdle, the patent claim must include hardware and a computer-implemented method that is executed on a quantum computer, because the EPO has a more clearly established framework. To address the second hurdle, the technical problem and the technical impact of each feature, even non-technical ones, must be specifically described to resolve the issue. In the case of quantum algorithms and codes, the *technical* application or implementation of it in a computer to solve a *technical* problem is required. In practice, this is similarly treated at the USPTO. However, future quantum case law would determine how the Boards of Appeal would continue applying their approaches to quantum tech, but the high granting rates do suggest that in practice, the applicants are able to adjust their claims to the requirements.

D. Disclosure in Quantum Tech

Considering the complex nature of quantum tech, both the EPO (Article 83 EPC) and the USPTO (Article 35 U.S.C. §112(a), first paragraph) require sufficient disclosure of the invention for a valid patent claim. This requirement must be distinguished from eligible subject matter and the patentability criteria, such as non-obviousness and clarity. However, highly mathematical algorithms, unstandardized terminology, and complex hardware could cause issues for the ordinary skilled person in the art in a rapidly developing, multidisciplinary field. This means that both applicants and examiners must have sufficient knowledge of physics, chemistry, maths, engineering, and their quantum counterparts, and must be up to date with the latest developments and general knowledge.

This chapter delves into the broad challenges regarding disclosure in quantum tech in the requirements of novelty, non-obviousness, and enablement. It is important to note that these are distinct requirements, and they will be discussed as such, but they might face overlapping hurdles.

1. Novelty

(a) Definition

Both the EPC and the U.S. code require the patent claim to be new.²³⁹ Any specific public disclosure before the application is prohibited. Regarding digital disclosure, any prior-art document must be read on the relevant date for a skilled person in the art. Both at the

²³⁹ Art. 54(2) EPC and 35 U.S.C. §102.

EPO and the USPTO, applicants can claim priority to their earliest year of disclosure,²⁴⁰ but if the patent is eventually granted, the term starts counting from the priority date, not the filing date. This affects the effective term of the patent.²⁴¹ When determining novelty, only features that are distinctive for a particular use must be taken into account, as well as those that are implicitly present.²⁴²

(b) Challenges in quantum tech

Any generic disclosure is permitted,²⁴³ such as a press release around the invention or the basic principles on which the invention is based. Examples of this are Microsoft's Majorana 1 announcement on Microsoft's blog, though no patent claim has been applied for the processor yet,²⁴⁴ and IBM sharing the underlying systems of planned quantum processors in their press release and academic papers.²⁴⁵

Rejections based on novelty could be the result of insufficient research on prior art or the nature of the fast availability of information through digital means, combined with rapid advancements. Frequent, small improvements that are detrimental in quantum tech for enhancing coherence in quantum computers, optimization, and hardware might fail to be novel if they are disclosed in other channels.²⁴⁶

In both the Board of Appeal and PTAB decisions, the lack of novelty is often combined with failure in subject matter and inventive step or non-obviousness, because non-technical features are more often described more abstractly, while referring to their achieved effect using non-technical language instead of precise, technical ones. When the examiner cannot find prior art that match as closely as possible the underlying invention by directing the concrete embodiments disclosed in the description, the searcher interpret the claim in its broadest technically sensible meaning.²⁴⁷

For example, in **T1448/23**,²⁴⁸ the patent of Rigetti related to a quantum processor including 144 qubits, 142 coupled quantum devices, and 146 read-out devices to each qubit for reading its state, which are all arranged within an electromagnetic waveguide system. A third party opposed the patent grant, and the case ended up before the Board of Appeal, with the main request opposing novelty compared to one prior document. The differences regarded terminology and clarity of the previously disclosed document. Regarding terminology, the opposed patent was deemed novel because the term was not used as such

²⁴⁰ Art. 87 and 89 EPC and 35 U.S.C. §119

²⁴¹ Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) 869.

²⁴² EPO (n 123) Part G-VI, 2.

²⁴³ *ibid* Part G-VI, 4.

²⁴⁴ Chetan Nayak (n 35).

²⁴⁵ See: IBM, 'IBM Sets the Course to Build World's First Large-Scale, Fault-Tolerant Quantum Computer at New IBM Quantum Data Center' (IBM, 10 June 2025) <<https://newsroom.ibm.com/2025-06-10-IBM-Sets-the-Course-to-Build-Worlds-First-Large-Scale,-Fault-Tolerant-Quantum-Computer-at-New-IBM-Quantum-Data-Center>> accessed 21 July 2025.

²⁴⁶ Kaya Derose (n 229) 168.

²⁴⁷ Igor Dydenko (n 162) 46 and case T79/96 *Granulation by spray drying/APV ANHYDRO* (Technical Board of Appeal 3.3.5., 20 October 1998), 2.1.3.

²⁴⁸ Case T1448/23 *Transmon qubits/RIGETTI* (Technical Board of Appeal 3.5.6., 20 March 2025).

in the prior art document, and regarding the novelty of the solution, the prior art document only proposed a similar solution as one of many alternatives to the problem. Because the patented solution was not described as a clear solution by the prior art document, the opposed patent was deemed sufficiently novel. However, the U.S. parallel application was rejected due to being obvious after assessing it with the *Graham v. John Deere Co.* framework.²⁴⁹

Nowadays, information can be disclosed not only through academic papers and patents, but also through forums, social media discussions, and videos. The rise of open-source code databases, such as GitHub, and freely accessible academic reprints on arXiv may publish prior art before the application has been submitted because of the low accessibility threshold. Even informal discussions on technical blogs and forums, such as Stack Overflow, Medium, and Reddit posts, may disclose inventions, the same as API documentation, developer guides, conference presentations and recordings, and educational videos on YouTube might reverse engineer or reveal major aspects of an invention. While there are no known cases yet, disclosures without deep experimental data could be obstacles in patent applications.

(c) Conclusion

While not much case law exists around novelty in emerging technologies, the fast pace of quantum technologies and the rise of digital disclosure could be an issue for both patent applicants and examiners to establish prior art. Small improvements, though vital for quantum tech, risk not being novel enough for patentability.

2. Non-obviousness

The inventive step consists of two questions: whether something is obvious compared to prior art to an ordinary skilled person in the art, but when software is involved, it also begs the question of whether the invention has a sufficient technical effect. As such, the second hurdle of the two-hurdle test at the EPO is introduced, and the *Alice/Mayo* framework is involved when determining patent eligibility. However, both institutions treat inventive step and subject matter eligibility as not entirely independent, as part of the work of subject matter is done through establishing inventive step.²⁵⁰

(a) Legal frameworks

At the EPO, non-obviousness²⁵¹ is examined from the perspective of a skilled person in the art who has common, general knowledge of the technological field and has access to the prior art.²⁵²

²⁴⁹ Rigetti, *Housing Qubit Devices in an Electromagnetic Waveguide System* (US20200258003A1, 13 August 2020).

²⁵⁰ Alain Strowel and Sinan Utku (n 141) 17.

²⁵¹ Art. 56 EPC and 35 U.S.C. §103.

²⁵² EPO (n 123) Part G-VII, 3.1.

At the USPTO, the leading case law that sets forth rules to determine obviousness to a person of ordinary skill is **Graham v. John Deere Co.**²⁵³ and **KSR**.²⁵⁴ An obvious invention provides predictable results through the combination of familiar elements and according to known methods.²⁵⁵

The **Graham v. John Deere Co.** framework²⁵⁶ examines obviousness by making factual inquiries by determining the scope and the contents of the prior art, comparing the prior art and the claims at issue, resolving the level of ordinary skill in the pertinent art, and considering objective evidence present in the application²⁵⁷ before the effective filing date of the claimed invention, based on available prior art and solutions. For a claim to be obvious, the whole invention must be obvious, not only the differences between the prior art and the claims,²⁵⁸ while also taking into account non-technical features. Regarding quantum improvements, they are considered obvious if it is likely not the product of innovation, but of ordinary skill and common sense.²⁵⁹

At the EPO, a skilled person is presumed to be a skilled practitioner in the relevant field of technology who has average knowledge and ability, has common general knowledge in the art at the relevant date, and must be involved in constant development in the relevant technical field.²⁶⁰ The level of knowledge is general and common and can be found in handbooks.²⁶¹ At the USPTO, the level of ordinary skill in the art of a hypothetical person at the relevant time is determined based on various factors, such as the prior art solutions to those problems, the rapidity with which innovations are made, and the sophistication of the technology.²⁶²

(b) Skilled person in the art of quantum tech

Both systems have a similar hypothetical person in the art. Based on the factors of both, the unique, multidisciplinary, and fast-evolving character of quantum science must be taken into account when drafting patent applications and when examining non-obviousness. Applicants must stay aware that the ordinary person might not be up to date with the latest developments. The guidelines of the USPTO do not specify what type of knowledge can be considered common knowledge, but define it based on the field itself.²⁶³ Nonetheless, a higher standard of knowledge might be expected from examiners at the USPTO compared to those at the EPO in quantum tech. Examiners must have common knowledge in physics, chemistry, math, engineering, computing, and their quantum

²⁵³ *Graham v. John Deere Co.* 383 U.S. 1 (1966).

²⁵⁴ *KSR International Co. v. Teleflex Inc.* (“KSR”) 550 U.S. 398 (2007).

²⁵⁵ KSR (n 254) at 415-416.

²⁵⁶ *Graham v. John Deere Co.* (n 253).

²⁵⁷ *ibid* at 17-18.

²⁵⁸ *Stratoflex, Inc. v. Aeroquip Corp.*, 713 F.2d 1530, 218 USPQ 871 (Fed. Cir. 1983) at 785 and *Schenck v. Nortron Corp.*, 713 F.2d 782, 218 USPQ 698 (Fed. Cir. 1983) at 700.

²⁵⁹ KSR (n 254) at 127.

²⁶⁰ EPO (n 123) Part G-VII, 3.

²⁶¹ *ibid* Part G-VII, 3.1.

²⁶² More examples of knowledge level are found in: USPTO (n 141) 2141.03.

²⁶³ USPTO (n 141) 2141.03.

counterparts. For instance, Shor's algorithm, though being taught as one of the basics in quantum computing, is already quite sophisticated for an average person with average knowledge in math, computing, and physics. Complex hardware architecture might also be considered common knowledge by scientists and engineers in quantum tech, but it is not a common understanding for average people in the field who have average knowledge of physics and chemistry, and would be able to determine obviousness based on that knowledge.

In *Ex Parte Yudong Cao*, a lack of enablement and written description was also one of the initial rejections by using the class of 'objective functions'. The PTAB reversed the rejection, stating that a skilled person in the art of quantum science would know what the term means, though broadly and generally described.²⁶⁴

In **T1914/19**,²⁶⁵ an application concerned a method and a device for generating true random numbers and a gaming system through a quantum optic process. However, when compared to prior art, it was found that the differences by using a truly quantum state-based random number generator only provided more reliability without needing substantial correction mechanisms, though without linking them to a concrete technical effect, and as such, they were not considered when assessing inventive step. Because these were non-technical differences that did not contribute to the technical effect on their own, it was established that the skilled person would have solved the issue from available and known alternatives.

The skilled person in the art can also combine prior art to come to an obvious solution. This was the case in a claim regarding multiple quantum computing methods involving encoding qubit devices in a waveguide system with a quantum processor that houses the qubit devices and coupler devices.²⁶⁶

At last, quantum patents are characterized by unusual drawings, which are difficult to understand, even for the average skilled person in the quantum field. When patent applicants also omit certain features of the technology, it adds to the complexity of reproducing it.²⁶⁷

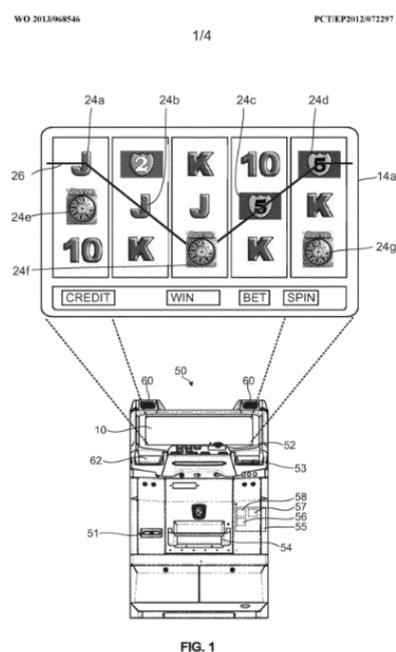
3. Sufficient Disclosure

²⁶⁴ Victoria Carrington and Michael Mauriel (n 150) 46.

²⁶⁵ Case T1914/19 *Quantum dots/NOVOMATIC* (Technical Board of Appeal 3.5.6., 15 November 2023).

²⁶⁶ Rigetti, *Housing Qubit Devices in an Electromagnetic Waveguide System* (US201916682793, 13 August 2020).

²⁶⁷ Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) and USPTO (n 141) 2141.03



(a) Legal framework

Article 83 EPC requires that the disclosure of the application as a whole²⁶⁸ happens in a manner sufficiently clear and complete for it to be carried out by a person skilled in the art without undue burden,²⁶⁹ and Rule 42(1)(c) of the EPC requires the description to disclose the invention, such that the technical problem and its solution can be identified. The level of skill is equal to that of assessing inventive step, taking into account the common general knowledge of the skilled person.²⁷⁰

Enablement (Article 35 U.S.C. §112(a), first^{268t} paragraph) requires a person skilled in the art to make and use the invention without undue experimentation, even if the experimentation is complex,²⁷¹ by the instructions laid out in the application. The standard is the answer to the question of whether experimentation that is needed to practice the invention is undue or unreasonable,²⁷² coupled with information known in the art.²⁷³

The **Wands factors** are used to assess whether any necessary experimentation required by the specification is reasonable or undue, regardless of the technology field. Some factors are the nature of the invention, the state of the prior art, the level of predictability in the art, and the existence of working examples.²⁷⁴

Enablement must be distinguished from written description, which aims to prove that the applicant has invented the claimed subject matter²⁷⁵ and to obligate the patentee to disclose the invention and all its technological knowledge to the public.²⁷⁶ However, these criteria often come together,²⁷⁷ because a failure in enablement can support the lack of written description from the point of view of a skilled person in the art. Written description requires that the disclosure must convey to those skilled in the art that the inventor had possession of the claimed subject matter as of the filing date.²⁷⁸

(b) Disclosure of Quantum Tech

However, an important characteristic of quantum tech is the fact that a large amount of hardware is experimental rather than commercial, such as the existing quantum computers. Quantum algorithms, such as Shor's algorithm and Grover's algorithm, are not yet performable on quantum computers because of decoherence

²⁶⁸ EPO (n 122) Part C.3.1.

²⁶⁹ EPO (n 123) Part F-III, 3.

²⁷⁰ EPO (n 122) Part C.3.1.

²⁷¹ USPTO (n 141) 10.

²⁷² *Minerals Separation Ltd. v. Hyde* 242 U.S. 261, 270 (1916).

²⁷³ *United States v. Telectronics, Inc.*, 857 F.2d 778, 785, 8 USPQ2d 1217, 1223 (Fed. Cir. 1988).

²⁷⁴ *In re Wands* 858 F.2d 731, 737, 8 USPQ2d 1400, 1404 (Fed. Cir. 1988)

²⁷⁵ *In re Barker* 559 F.2d 588, 592 n.4, 194 USPQ 470, 473 n.4 (CCPA 1977)

²⁷⁶ *Capon v. Eshhar* 418 F.3d 1349, 1357, 76 USPQ2d 1078, 1084 (Fed. Cir. 2005).

²⁷⁷ *Ariad Pharmaceuticals, Inc. v. Eli Lilly & Co. "Ariad Pharm."*, 598 F.3d 1336, 1352 (Fed. Cir. 2010).

²⁷⁸ *Ariad Pharm.* (n 277) 1351.

and noise, which prohibit a sufficient number of coherent physical qubits. As such, inventions that cannot be practically executed would fail the disclosure requirement while simultaneously lacking inventive step.

Moreover, methods to optimize coherence or to detect and correct errors might be at risk of failing the sufficiency disclosure, as reproducing them and getting the results as described in the patent application require large engineering efforts that are not disclosed. Qubits, for instance, are inherently probabilistic and are disclosed as such. A patent on certain quantum error-correction might describe the theoretical protocol, but reproducing the invention would require months of laboratory calibration and engineering methods not disclosed in the patent application.²⁷⁹ The efforts of reproducing quantum inventions that are required often exceed those expected of the hypothetical person who should determine whether the invention can be performed and repeated to achieve the desired technical result, considering that the current patent system and guidelines are written based on classical technology with less technological and physical frailty.²⁸⁰ If the results have limited chances of success, even when following the instructions, the invention is fundamentally insufficient.²⁸¹ Software and algorithms must be explained in enough detail so that the technical effects and advantages produced by algorithms and software are sufficiently supported by the disclosure. Data such as simulations and measurements can be used.²⁸² In *Re Huping Hu*, one of the claims lacked operability because the applicant not only did not explain the operability, but there were no test data that would support a result.²⁸³

However, it has been observed that in contrast to artificial intelligence and machine learning patents, quantum patent applications, while based on quantum mechanics, generally exceed the minimal threshold of sufficiency.²⁸⁴ This is because applicants often consist of highly experienced engineers and academic physicists, who, despite the unique quantum character of the claims, can thoroughly draft patent applications. Some authors even argue that there is no structural incompatibility between quantum tech and disclosure and enablement.²⁸⁵

Disclosing quantum processors would include specifying the materials, qubit architecture, control hardware, and fabrication processes required to reproduce the device. Quantum algorithms are disclosed with executable circuit diagrams, gate sequences, or mathematical descriptions tied to specific computation tasks.²⁸⁶

²⁸⁶ ²⁷⁹ Gabriela Lenarczyk, Timo Minssen and Mateo Aboy (n 172201) 2.

²⁸⁰ EPO (n 123) Part F-II, 5.1.

²⁸¹ *ibid* Part F-III, 3.

²⁸² Jari Rantala and Mattia Giardini (n 117) 12.

²⁸³ *In re Huping Hu* (n 229) 8.

²⁸⁴ Gabriela Lenarczyk, Timo Minssen and Mateo Aboy (n 172201) 4.

²⁸⁵ *ibid* 4.

²⁸⁶ *ibid* 4.

²⁸⁷ T1914/19 (n 265).

²⁸⁸ *ibid* 3.1-3.3.

In **T1914/19**,²⁸⁷ the Board of Appeal decided that the intended meaning of the term ‘substantially equivalent’ when referring to the spatial positions of detectors was not clear. It could mean that the distances between them are substantially the same, but it did not clarify what other conditions could lead to the spatial positions being ‘substantially equivalent’ apart from distance.²⁸⁸ This failure to fully disclose the invention affects the clarity of the invention, because even a small part of the invention was not deemed sufficiently clear for a skilled person in the art.

In **EP3018840**,²⁸⁹ although the patent was eventually granted, one of the hurdles was clarity, while simultaneously lacking all essential features of the invention. This application concerned a method of a quantum key distribution system with only two communication channels between a transmitter and a receiver, one quantum communication channel transmitting quantum particles or states, and the other one, a service channel, transmitting classical data. Both channels are continuously ‘self-synchronized’, which was deemed unclear.

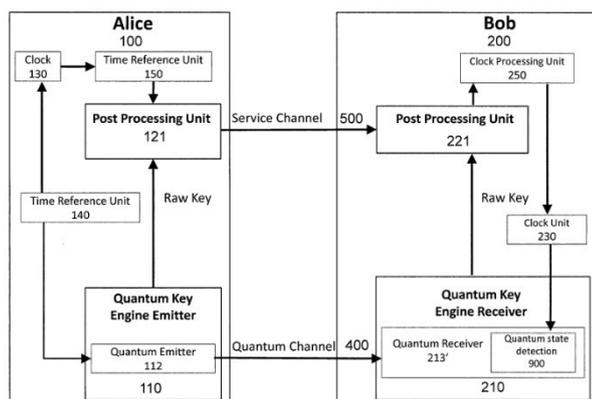
In *Ex parte Aaron K. Baughman and others*,²⁹⁰ a patent by IBM regarding a method directed to deep learning using quantum entanglement was initially rejected by the examiner based on failing to distinctly claim the subject matter, written description, and enablement.

Regarding enablement, the claim lacked a description of any specific starting material or of any conditions under which quantum entanglement of deep learning layers can be carried out.²⁹¹ The examiner, affirmed by the PTAB, assessed based on the Wands factors that there was a lack of guidance and working examples for a person of *ordinary* skill to follow. The patent also lacked sufficiency of the written description due to referring to ‘a desired result’ and ‘quantum enablement’ without, supposedly, using qubits.²⁹² As such, this case also showcases the disadvantages of the lack of standardized or clarity of quantum terminology.

In *Ex parte Ali Javadiabhari* of IBM,²⁹³ a claim of a method of implementing a quantum algorithm in a quantum processor was rejected due to failing to comply with the written description requirement. In the disclosure, no specific quantum algorithm was disclosed without specific instructions. While IBM claimed that that was not the core of the invention, it being a method that can transform any quantum algorithm, the patent remained refused.²⁹⁴

However, both the examiner and the PTAB acknowledge the complex and early-

Fig. 2



stage character of quantum computing and the fact that quantum algorithms are complex to develop and difficult to debug, and recognize that there is still a gap between current quantum computing hardware and quantum algorithms. They recognize that the applicant must have used this nature in their favor and provided more detail to demonstrate this complexity.²⁹⁵ But the applicant was being too broad in using *any* known algorithm and simulation, which failed the test of whether the disclosure itself conveys that the applicant had possession of the later-claimed subject matter, including all its limitations.²⁹⁶

4. Conclusion

In general, the new, fast-moving nature of quantum tech could result in issues regarding small but important improvements that may not be sufficiently novel, issues with reproducing groundbreaking algorithms without operable hardware and complex architectures would fail the disclosure requirement, but mainly, mathematical methods regarding quantum algorithms, error-correction, and optimization, need hardware implementation and explicit steps to be disclosed sufficiently. The skilled person in the art must have multidisciplinary knowledge, which requires a thorough drafting of the patent claims.

IV. PART III: CHALLENGES

A. Patent and Trade Secrets

The previous chapter concluded with the statement that quantum technology indeed challenges patent law, as well as applicants and examiners, due to its unique characteristics, both in patentability criteria and sufficient disclosure. If a quantum invention is patented, are the exclusive rights worth it, or are alternatives like trade secrets more attractive to avoid the patenting challenges? Or are patents and trade secrets complementary? Given the uncertainty around patentability and disclosure in quantum technologies, can trade secrets or know-how serve as an attractive alternative, or complement, to patents?²⁶⁹

The first subchapter offers a short legal framework of trade secrets. The second subchapter describes the legal problem and the necessity to discuss trade secrets as an alternative to patents in quantum tech. The third discusses the advantages and disadvantages of patents compared to trade secrets. The fourth subchapter provides a concise yet qualitative description of the role of know-how in QT. At last, a summary is provided of preferences for patents, trade secrets, or both.

1. Legal framework

²⁶⁹ European Commission, *Trade secrets – Managing confidential business information* (EC Publications Office, 2021) <<https://data.europa.eu/doi/10.2826/449107>> accessed 14 July 2025, 4.

Generally, trade secrets protect all types of commercially valuable information,²⁷⁰ such as early-stage inventions, manufacturing processes, and know-how, which is not protectable by any means, even patents.²⁷¹ The information must be secret,²⁷² have commercial value, tangible or intangible, and reasonable measures have been taken to keep secret.²⁷³ Unlike patents, trade secrets do not require novelty or registration.²⁷⁴ If so, the protection lasts indefinitely (as long as the conditions are met)²⁷⁵ and protects against ‘unlawful acquisition, use or disclosure of a trade secret.’²⁷⁶ This includes theft and hacking,²⁷⁷ but also breaches of duty or contract by using or disclosing information that is the object of confidentiality obligations, such as NDAs, or other agreements,²⁷⁸ and conduct that is contrary to fair commercial practices.²⁷⁹ Reverse engineering is not prohibited, unless contractually prohibited,²⁸⁰ nor is independent discovery or creation.²⁸¹ As such, trade secrets do not provide exclusive rights. In contrast to patents, trade secrets prohibit disclosure to enjoy their protection²⁸² and are protected for an unlimited time.²⁸³

Reasonable precautions can include: restricting access to trade secret information, writing NDAs or other confidentiality contracts, labeling files and databases, or posting signs at areas that contain secret information, conducting post-departure investigations of employees, using a password, encrypting data, installing physical surveillance, physical barriers, guards, etc.²⁸⁴

To claim misappropriation of secret information, the holder must prove that the information is eligible for trade secret information, the applicant is the rightful holder of

²⁷⁰ David S Almeling, ‘Seven Reasons Why Trade Secrets Are Increasingly Important’ (2012) 27 BTLJ 1091, 1107 <<https://www.jstor.org/stable/24119482>> accessed 8 September 2024.

²⁷¹ In the EU: Directive (EU) 2016/943 of the European Parliament and of the Council of 8 June 2016 on the protection of undisclosed know-how and business information (trade secrets) against their unlawful acquisition, use and disclosure (“**Trade Secrets Directive**”) [2016] OJ L157/1. In the U.S.: **18 U.S. Code §1839(3)**, see also the preceding statutes from §1832 and onwards and the Third Restatement of Unfair Competition 1995, s 39.

²⁷² Art. 2(1): “it is not (...) generally known among or readily accessible to people within the circles that normally deal with the kind of information”.

²⁷³ Art. 2(1) Trade Secrets Directive and 18 U.S. Code §1839(3), see also the preceding statutes from §1832 and onwards and the Third Restatement of Unfair Competition 1995, s 39.

²⁷⁴ European Commission (n 269) 6.

²⁷⁵ Mauritz Kop, ‘Quantum Computing and Intellectual Property Law’ (2021) 35 BTLJ 1, 10.

²⁷⁶ Art. 4 Trade Secrets Directive.

²⁷⁷ *ibid* Art. 4(2)(a).

²⁷⁸ *ibid* Art. 4(3).

²⁷⁹ *ibid* Art. 4(2)(b).

²⁸⁰ Art. 3(1) Trade Secrets Directive; Mateo Aboy, Timo Minssen and Mauritz Kop (n 78) 620.

²⁸¹ Art. 3(1)(a), Consideration 16 Trade Secrets Directive; Mauritz Kop (n 275) 10.

²⁸² Art. 2(1)(c) and 11(2)(b) Trade Secrets Directive.

²⁸³ Mauritz Kop, Mateo Aboy and Timo Minssen (n 7) 619.

²⁸⁴ Robert McHale, ‘Trade Secrets Protection in the Digital Age: What Every Business and Entrepreneur Needs to Know’ (*R McHale Law*, 2013) <<http://rmchale.com/>> accessed 19 April 2025, 3-7.

it, reasonable measures were taken to keep the information secret, and the information was misappropriated or wrongfully taken.²⁸⁵

2. Legal problem

Trade secrets are commonly used in technologies. Both patents and trade secrets are commonly used in technological fields, such as telecommunications and IoT, to protect intellectual property. The Executive Agency for SMEs of the European Commission has provided a comparative analysis between trade secrets and patents, as both have advantages and disadvantages.²⁸⁶ While they offer protection for an unlimited time, they can also be used in the short term, for example, to protect ongoing R&D from publication before any intention to apply for a patent, which requires no prior publication.²⁸⁷

This subchapter compares both protection mechanisms, with a focus on the hurdles experienced in quantum innovations, and aims to offer guidance without giving a general overview of intellectual property law.

3. Comparative analysis of trade secrets and patents

Patents and trade secrets have different objectives. While patents focus on a limited-term exclusivity in exchange for public disclosure of the invention, trade secrets provide unlimited secrecy. Trade secrets are considered to limit innovation,²⁸⁸ while patents are created to encourage it, but as the previous chapters have concluded, patents are often either not optional, or the nature of quantum inventions does not make patent protection attractive. For instance, where quantum algorithms were eligible subject matter, the twenty-year patent protection is too short as they are not operable yet. If Shor's algorithm were protected in 1994, the patent would have expired before it was executed as intended.²⁸⁹

In contrast to patents, secret information should not be novel nor registered anywhere, but it cannot be disclosed. Furthermore, inventions that are ineligible for patent protection, either because they do not meet the requirements of Article 52(1) EPC (yet) or are considered excluded subject matter of Article 52(2)(3) EPC, can be protected by trade secrets.²⁹⁰

²⁸⁵ Art. 11 Trade Secrets Directive and Cornell Law School, Legal Information Institute, 'Trade Secret' (*law.cornell.edu*, June 2024) <https://www.law.cornell.edu/wex/trade_secret> accessed 18 August 2024.

²⁸⁶ European Commission (n 269).

²⁸⁷ European Union, 'Trade Secrets' (*europa.eu*, 3 February 2025) <https://europa.eu/youreurope/business/running-business/intellectual-property/trade-secrets/index_en.htm> accessed 14 July 2025.

²⁸⁸ A study found that secrecy does impede follow-up invention, see: G. De Rassenfosse, G Pellegrino and E Raiteri, 'Do patents enable disclosure? Evidence from the invention secrecy act' (2024) 92(103044) *IJIO* 1 <<https://doi.org/10.1016/j.ijindorg.2023.103044>> accessed 5 Jan 2024, 11.

²⁸⁹ Aaron Hall, 'Quantum Computing Trade Secret Protection' (*aaronhall.com*, date unknown) <<https://aaronhall.com/quantum-computing-trade-secret-protection/>> accessed 15 July 2025.

²⁹⁰ European Commission (n 269) 11.

However, the degree of protection that trade secrets offer depends on the efforts of the owner of that information to keep it confidential. Reverse engineering and independent discovery are still lawful. Any other lawful public disclosure of that information not only takes away future trade secret protection, but also patent protection, either due to the public disclosure or due to another entity claiming the patent first.²⁹¹

However, trade secrets could hinder innovation because information does not get disclosed to the public and other smaller entities involved in quantum R&D, which impedes follow-on innovation and technology transfer to the market.²⁹² While patents are considered to hinder further innovation due to exclusivity, R&D collaboration and licensing mitigate the uncertainty of accidentally breaching anyone's rights. Nonetheless, secret information can also be shared through R&D collaboration with confidentiality contracts.

4. Know-how

Generally, know-how refers to any non-public information that entities acquire by being in the business.²⁹³ If it meets the requirements of trade secrets, it can be protected as such, being included in the Trade Secrets Directive, for instance.²⁹⁴ There is generally no uniform definition of 'know-how'. Some scholars consider it a synonym for trade secrets, while others tend to use it to refer to the personal skills of an employee.²⁹⁵ It does contain trivial knowledge, skills, and experiences, while generally known information and information that is readily accessible to persons within the circles that normally deal with the kind of information in question is excluded.²⁹⁶ If a company or an individual has information that cannot be protected through trade secrets, confidentiality contracts can be signed as well. As such, know-how can be shared, licensed, and transferred.²⁹⁷ When quantum inventions include certain know-how, most likely owned by specialized applicants, that too must be disclosed to comply with sufficient disclosure. However, due to the complex and rapidly moving nature of quantum tech, the examiners themselves, being the skilled people in the art, must remain familiar with what information must be disclosed in detail to avoid early rejections.

5. Applied to quantum patents

The fundamental question is whether public disclosure is necessary, desirable, and possible. The following factors can be considered when choosing between trade secrets and patents.

The **type of technology** can be decisive in choosing secrecy. Either because it is not patentable due to patent law limitations, because the invention is difficult to reverse

²⁹¹ *ibid* 11.

²⁹² Mauritz Kop, Mateo Aboy and Timo Minssen (n 7) 620.

²⁹³ Cornell Law School, Legal Information Institute, 'Know-how' (*law.cornell.edu*, March 2022) <<https://www.law.cornell.edu/wex/know-how>> accessed 15 July 2025.

²⁹⁴ Consideration 14 Trade Secrets Directive.

²⁹⁵ Suzana Nashkova, 'Defining Trade Secrets in the United States: Past and Present Challenges - A Way Forward?' (2023) 54 *IIC* 634, 661.

²⁹⁶ Consideration 14 Trade Secrets Directive.

²⁹⁷ Cornell Law School (n 293).

engineer or to be discovered by others,²⁹⁸ or because an entity's competitive advantages come from its market position and resources. Quantum research often happens in dilution refrigerators, ion-trap vacuum systems, and gate-kept cloud-access interfaces,²⁹⁹ which impedes reverse engineer due to physical accessibility and the required costs and expertise (re)produce them, if that aligns with the business strategy. As such, small monopolies can be created around quantum computers. This is evident because the leading companies are specializing in a variety of quantum hardware. For instance, D-Wave, that produces quantum processors based on quantum annealing, might benefit for longer-term protection to keep their position.³⁰⁰ For example, a company that offers quantum cloud computing as a service might benefit from keeping commercially valuable information secret, compared to competitors.³⁰¹ At last, cybersecurity law and other national security considerations could impose trade secrets.³⁰²

Sometimes, the type of technology does not propose a technical problem or R&D is not develop sufficiently to be inventive. Examples of quantum inventions that may have subject matter eligibility issues due to lack of technical effect: new quantum states in exotic materials,³⁰³ discoveries of antimatter, black holes, breakthroughs in mysteries and phenomena on the quantum level (discoveries), new quantum theories, e.g. progress in quantum field theories (scientific theories), quantum algorithms, error-mitigating and qubit manipulation codes, methods for developing and optimizing quantum algorithms, quantum cryptography, new quantum programs regarding quantum simulation, optimization, and error detection and correction, programming languages and quantum simulations in chemistry and materials (presentations of information).³⁰⁴

Other quantum inventions would benefit from being patented, for example if they are simple to reverse engineer or be discovered independently, or if they are commercially applicable and valuable for follow-up innovation.

Examples of quantum inventions and elements that are eligible for patent protection are quantum hardware, such as technology building blocks (such as qubits), quantum gates, circuit ships, processors, compiler devices, decoders, microarchitecture, and quantum-classical interface.³⁰⁵

²⁹⁸ WilsonGunn, 'Patents vs Trade Secrets: Choosing the right path for intellectual property protection' (*WilsonGunn*, date unknown) <<https://www.wilsongunn.com/resource/ip-insights/patents-vs-trade-secrets-choosing-the-right-path-for-intellectual-property-protection>> accessed 14 July 2025.

²⁹⁹ Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) 877.

³⁰⁰ WilsonGunn (n 298).

³⁰¹ Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) 14.

³⁰² Mauritz Kop, Mateo Aboy and Timo Minssen (n 7) 816.

³⁰³ Nagaland Post, 'Scientists discover new quantum state in exotic materials' (*NagalandPost*, 1 August 2025) <<https://nagalandpost.com/scientists-discover-new-quantum-state-in-exotic-materials/>> accessed 4 August 2025.

³⁰⁴ Mauritz Kop (n 275) 5.

³⁰⁵ *ibid* 5.

The quantum computing process can also be patented, as long as it is sufficiently inventive, industrially applicable, and has a technical effect. Part of the quantum computing process is qubit control. As such, dilution refrigerators as a whole are patentable, including their components such as quantum amplifiers, mixing chambers, and cryogenic isolators.³⁰⁶

Generally, any commercially immature inventions might not benefit from patent protection.³⁰⁷ As such, the desired **term of protection**, whether due to being advantageous compared to other firms or because certain technologies are inoperable yet, such as Shor's algorithm, that has would have been expired if patented in 1994 without being executed.³⁰⁸

R&D entities do not only consist of large companies and academic institutions, but also new entrants and SMEs, such as IonQ and D-Wave, contribute to quantum developments. A large hurdle that they might face is the **costs and resources** that are available. While private and public funding assist in bearing the costs of R&D, patents themselves can be expensive to obtain and maintain.

However, if the invention would possibly attract competitors, combined with the degree of reverse engineering and independent development, patent protection could be a better option in the enforcement, licensing, or transfer of intellectual property rights.³⁰⁹ At last, start-ups do not have sufficient monetary resources and know-how to have a competitive advantage, so they are more incentivized to patent their inventions to both secure the exclusive property rights and help attract venture funding in a deep tech environment where profits are far in the future. Nevertheless, this creates a risk for inventors who are then also incentivized to disclose their inventions through the patent system as opposed to keeping them as trade secrets.³¹⁰

At last, large companies with sufficient internal sources and an established market position can bear the high-risk and costly quantum R&D, while new entrants, such as D-Wave and Rigetti, would benefit from patenting to obtain broad, valuable patents while the field is still in its early stage with limited prior art. This can strengthen their IP portfolio to attract venture capital funding. As such, their position might force them to disclose their inventions while they would prefer to keep them secret. They can specialize in certain technologies compared to the larger companies,³¹¹ just like D-Wave focuses on developing quantum computers based on quantum annealing. At the end of the day, this forced disclosure does benefit society.

³⁰⁶ Mauritz Kop (n 275) 5.

³⁰⁷ Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) 6.

³⁰⁸ Gabriela Lenarczyk, Timo Minssen and Mateo Aboy (n 172201) 2.

³⁰⁹ WilsonGunn (n 298).

³¹⁰ Mauritz Kop, Mateo Aboy and Timo Minssen (n 7102) 624.

³¹¹ Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) 878.

The Executive Agency for SMEs of the European Commission has published a short comparison with advantages and disadvantages.³¹²

	PROS	CONS
Patents	<ul style="list-style-type: none"> - Exclusive rights - Court actions - Base for loans - Involuntary infringement - Secure protection 	<ul style="list-style-type: none"> - High cost - 20 years of limited protection - Disclosure requirement - Lengthy procedures - The scope of protection is limited
Trade secrets	<ul style="list-style-type: none"> - No registration costs - Long-term protection - No disclosure requirement - Immediate effect - Broader scope of protection 	<ul style="list-style-type: none"> - Not easily enforceable - Voluntary infringement - Can be reverse-engineered - Non-secure protection - Limited remedies

Nonetheless, a study has found that the patent system supports public disclosure, even when trade secrets would be commercially more beneficial. Certain technologies that are easy to limit access to are being made accessible through clouds, such as quantum computers that are kept private in facilities but can be experimented on through open-source software, and technologies of which commercial value is far into the future, are being applied for patent protection.³¹³ This is also supported by the increase in patent grants in Chapter I.2.

6. Conclusion

The choice between patents and trade secret protection comes down to three factors: the nature of innovations, the duration of protection, and the costs and resources available to the owner of the information. In general, patents are preferred when innovations are prone to reverse engineering, while trade secrets are better suited for long-term protection. The high R&D costs might force new entrants into patenting.

Quantum inventions that struggle to meet the patentability criteria, such as quantum algorithms and error-correction techniques, are sometimes compelled to remain secret due to their complexity, inoperability, and that are difficult to reverse engineer or be discovered by others.

Secrecy does hinder innovation, while patents do not force patent owners to stay exclusive either; R&D collaboration, technology transfers, and licensing agreements are common and beneficial for both patent owners and other research entities. This is evident in

³¹² European Commission (n 269) 11.

³¹³ Mauritz Kop, Mateo Aboy and Timo Minssen (n 7102) 624.

collaboration between the leading companies and smaller companies or academic institutions.

B. Emerging Challenges in Quantum Tech

In this last chapter, emerging challenges, such as *sui generis* protection proposals, standardization, the role of open source innovation, and more gaps that remain for further research are discussed.

1. Establishing a *sui generis* legal framework

There have been proposals for a *sui generis* patent system for quantum patents.³¹⁴ However, various factors must be taken into consideration, because existing legal frameworks seem to be sufficiently adaptable to quantum technologies.³¹⁵

First, it is essential to define the scope of quantum patents, avoiding both over-inclusion and under-inclusion of certain technologies. Will this include all inventions on the atomic scale? Will that be inventions that exploit the principles of quantum mechanics? Are quantum principles, such as superposition and entanglement, mandatory? When limiting it to any invention that is operable at the scale of 10 nm or less, whose operation is governed by quantum mechanics, would include classical computers that use the current CPUs and GPUs. However, defining it as any technology that exploits quantum principles would also target many current mass-produced technologies, such as semiconductor technologies, electron microscopes, lasers, and nuclear magnetic resonance (NMR). At last, including only inventions that use quantum mechanical phenomena such as superposition and entanglement would be disadvantageous, as patent attorneys would draft claims to achieve the desired classification to either avoid or aim to be classified as a quantum patent, depending on the objective of the patent applicant. The current patent system does not discriminate between types of technologies, but any changes to examining proposals must be mindful of classifying quantum patent applications.³¹⁶

Second, the duration of patent protection has been proposed to be reduced to 10 years for reliability, but this would potentially discourage patenting inoperable quantum inventions.³¹⁷

Third, the subject matter eligibility criteria could be amended to include abstract ideas, such as mathematics and mental processes *as such*, to encourage the development of quantum algorithms, optimization techniques and error-mitigating codes, by focusing less on the abstract idea limitation, and more on the utility of the invention.³¹⁸

³¹⁴ Mauritz Kop, Mateo Aboy and Timo Minssen (n 7102) 623 and Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) 5.

³¹⁵ Gabriela Lenarczyk, Timo Minssen and Mateo Aboy (n 172201) 15.

³¹⁶ Mateo Aboy, Timo Minssen and Mauritz Kop (n 8) 870.

³¹⁷ Mauritz Kop (n 275) 9 and Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) 5.

³¹⁸ Muhammad Zia-Ul-Haq and Ghulam Mujtaba (n 37) 5.

2. Standardization

A standard is a non-obligatory technical specification, adopted by a recognized standardization body, for repeated or continuous application.³¹⁹ Complex technological fields, such as telecommunications and IOT, have grown dependent on agreements around the technical requirements of their technologies to ensure interoperability.³²⁰ This happens through **standardization**. This facilitates competition by reducing R&D costs for developers and consequently lowering market entry barriers, besides lowering prices for consumers,³²¹ since they are not obliged to buy parallel devices and technologies.³²²

Standards might guide innovation and be useful for more efficient communication and collaboration, due to interoperability and harmonization of terminology, and interchangeability of components among researchers. Standardized technologies form the baseline for further improvements,³²³ incentivizing better quality, R&D collaboration, and ensuring safety, but they can also limit adaptability, flexibility, and the uniqueness of quantum science by enforcing certain technologies.³²⁴

(a) Standardization and Quantum Communication

Standards are documents that set out specifications and other technical information to ensure the interoperability of various components, products, and services³²⁵ amongst different developers and locations, and they are negotiated and agreed on by market participants that are members of a **standard-setting organization**³²⁶ (**'SSO'**).³²⁷ These are organizations whose primary activity is to develop and maintain standards by bringing

³¹⁹ Regulation (EU) 1025/2012 of the European Parliament and of the Council of 25 October 2012 on European standardisation, amending Council Directives 89/686/EEC and 93/15/EEC and Directives 94/9/EC, 94/25/EC, 95/16/EC, 97/23/EC, 98/34/EC, 2004/22/EC, 2007/23/EC, 2009/23/EC and 2009/105/EC of the European Parliament and of the Council and repealing Council Decision 87/95/EEC and Decision No 1673/2006/EC of the European Parliament and of the Council Text with EEA relevance [2012] OJ L316/12, art. 2(1)(a)(b)(c).

³²⁰ Justus Baron and Tim Pohlmann, 'Mapping standards to patents using declarations of standard-essential patents' (2015) 27 *Journal of Economics & Management Strategy* 3, 505.

³²¹ Tim Pohlmann and Knut Blind, *EU Report Landscaping study on Standard Essential Patents (SEPs)* (12 December 2016) <https://single-market-economy.ec.europa.eu/publications/landscaping-study-standard-essential-patents-europe_en> accessed 18 April 2025, 6.

³²² Tim W. Dornis, 'SEP's and FRAND Licensing - At the crossroads of Economic Theory and Legal Practice' (2020) 11(10) *J. Eur. Comp. L. & Pract.* 575, 575.

³²³ Miroslava Mikva and others, 'Standardization – One of the Tools of Continuous Improvement', (2016) 149 *Procedia Engineering* 329, 329.

³²⁴ Elise Paradis and others, 'Getting standardization right', (2021) 67 *Can Fam Physician* 323, 323.

³²⁵ CEN-CENELEC, 'European Standardization' (*cencenelec.eu*) <<https://www.cencenelec.eu/european-standardization/>> accessed 2 October 2024.

³²⁶ Since it is beyond the scope of this research to make an in-depth discussion on the standard setting process, and because many authors use these terms interchangeably, the term "SSOs" will be used to refer to both.

³²⁷ Nikolaus Thumm and Yann Ménière, *Fair, Reasonable and Non-Discriminatory (FRAND) Licensing Terms* (Publications Office 2015) <<https://data.europa.eu/doi/10.2791/348818>> accessed 9 August 2025, 9.

together industry participants to evaluate competing technologies for inclusion in standards.³²⁸ Examples of these are the European Committee for Standardisation ('CEN'), and the European Committee for Electrotechnical Standardisation ('Cenelec'), and the European Telecommunications Standards Institute ('ETSI') in Europe, and the Institute of Electrical and Electronics Engineers Standards Association ('the IEEE SA')³²⁹, ANSI, and NIST from the U.S.

Most standards currently relate to quantum communication, particularly in post-quantum cryptography and QKD, which focus on security domains. For example, applications in quantum communication lie in areas such as 6G wireless communication that heavily rely on quantum tech, the IoT, and the government and defense industry. Quantum cryptography and QKD will be used in combination for more secure communication, higher data rates, better navigation, defending against cyberattacks, and even protecting the security of voting systems, including the elections.³³⁰ Examples of these are the NIST standards for post-quantum encryption.³³¹ Interoperability between (classical) hardware and quantum software must be ensured over a large geographical territory and between devices from any manufacturer and origin.

However, standardization is still in its early stages in quantum computing and quantum sensing due to the experimental nature of these areas, in which companies are also working on covering the whole production pipeline of quantum computers and sensors themselves without inviting other parties yet.³³²

For example, in June 2022, researchers at the University of Chicago and Argonne were able to create an 89-mile quantum loop that could transmit particles carrying quantum-encoded information from Lemont to the South Side of Chicago. This is a breakthrough for the scale of quantum networks, which in the future could lead to a quantum internet. Interoperability between a variety of systems on a global scale would be standardized to make the quantum internet work.³³³

(b) SSO Initiatives

There are several standardization working groups in the field of quantum technologies, such as the European Committee for Standardization and ETSI. Other standardization

³²⁸ *Motorola - Enforcement of GPRS standard essential patents* (Case AT.39985) Commission Decision C(2014) 2892 (28 April 2014) <https://ec.europa.eu/competition/antitrust/cases/dec_docs/39985/39985_928_16.pdf> accessed 18 April 2025, para 4.2.2.

³²⁹ The IEEE has published a wide range of standards in quantum technologies, see: <<https://quantum.ieee.org/>> and <<https://standards.ieee.org/practices/foundational/quantum-standards-activities/>> accessed 24 April 2025.

³³⁰ Misra Shreshtha and others (n 64) 6.

³³¹ Chad Boutin, 'NIST Releases First 3 Finalized Post-Quantum Encryption Standards' (NIST, 13 August 2024) <<https://www.nist.gov/news-events/news/2024/08/nist-releases-first-3-finalized-post-quantum-encryption-standards>> accessed 1 August 2025.

³³² CEN CENELEC (n 66) 109.

³³³ Andrew Nellis, 'The Quantum Internet, Explained' (*UChicago News*, date unknown) <<https://news.uchicago.edu/explainer/quantum-internet-explained#howfaroff>> accessed 6 August 2025.

groups funded by the European Union exist, such as the European Task Forces ('ETFs')³³⁴ by INSTAR.³³⁵ ETFs have prioritized standardization, focusing on the development of standards to enable the integration of quantum and classical computing systems, metrology standards for QKD devices, the security assessment of QKD devices and networks, the creation of a layer model for quantum computation, and the development of standards for single-photon-based technologies, among others.³³⁶

In June 2020, the CEN-CENELEC launched its Focus Group on Quantum Technologies (FGQT) to develop a Standardization Roadmap on QT and produce standardization deliverables. Their focus is mainly on quantum metrology, sensing and enhanced imaging, quantum computing, quantum simulation, quantum communication, and quantum cryptography. There are four working groups to which organizations and individual experts can join.³³⁷ This focus group will collaborate with experts, NSBs and NCs, and other SDOs, and will get the support of the European Quantum Flagship, QuIC, among other stakeholders.³³⁸

Various SSOs have also initiated standardization practices, workshops, etc. For example, IEEE has initiated multiple projects around standardizing quantum activity, such as standardizing quantum terminology to facilitate clarity,³³⁹ cryptography,³⁴⁰ and network security.³⁴¹

ISO has also launched a technical committee, IEC/ISO JTC 3, to standardize quantum technologies.³⁴² One of the early initiatives focuses on developing a standardized quantum photonic vocabulary to encourage consistent terminology, which is in line with an issue

³³⁴ See an overview of the workgroups: <<https://www.instarstandards.org/task-forces/quantum-technologies>> accessed 3 April 2025.

³³⁵ "INSTAR promotes Europe[']s position as a forerunner in global standards-setting in advanced ICT technologies. The 30-month project shapes the definition & uptake of standards in target countries, delivers studies & analyses on ICT standards, and monitors international standards in trade & cooperation agreements." See <<https://cordis.europa.eu/project/id/101135877>> accessed 3 April 2025.

³³⁶ INSTAR, 'INSTAR Quantum Technologies ETF - Roadmap Factsheet' (*Zenodo*, 29 November 2024) <<https://doi.org/10.5281/zenodo.14620180>> accessed 3 April 2025.

³³⁷ CEN-CENELEC, 'Quantum Technologies (*cencenelec.eu*)' <<https://www.cencenelec.eu/areas-of-work/cen-cenelec-topics/quantum-technologies/>> accessed 19 July 2025.

³³⁸ CEN-CENELEC (n 337).

³³⁹ IEEE, 'P7130' (*standards.ieee.org*) <<https://standards.ieee.org/ieee/7130/10680/>> accessed 19 July 2025.

³⁴⁰ IEEE, 'P3172' (*standards.ieee.org*) <<https://standards.ieee.org/ieee/3172/10926/>> accessed 19 July 2025.

³⁴¹ IEEE, 'P1943' (*standards.ieee.org*) <<https://standards.ieee.org/ieee/1943/10957/>> accessed 19 July 2025.

³⁴² ISO, 'IEC/ISO JTC 3' (*iso.org*) <<https://www.iso.org/committee/10138914.html>> accessed 19 July 2025.

experienced in patent applications.³⁴³ Standards include public-key cryptography, hash functions, and symmetric-key cryptography, such as block ciphers.³⁴⁴

Therefore, currently, standards in quantum tech are the most incentivizing by sharing knowledge and enforcing the applications of cybersecurity, while raising awareness for defense against cyberattacks using quantum mechanisms by demonstrating their effectiveness.

(c) SEPs and FRAND terms

A patent becomes **essential** when it is required to comply with a standard.³⁴⁵ This could lead to monopolistic behavior of the SEP holder, such as demanding excessive royalty rates or other unfavorable conditions, due to a lack of alternatives.³⁴⁶ Therefore, it is often a requirement in SSO policies for the essential patent owners to license their essential patents to implementers on **fair, reasonable and non-discriminatory ('FRAND') terms**. In the EU, the FRAND terms are based on competition law, while in the U.S., they are considered contracts between the SSOs and the participants.³⁴⁷ Currently, there are around 140 known SEPs in the domains of quantum sensing, key distribution, communication, and algorithms, of which ETSI has listed the majority of them.³⁴⁸

However, multiple issues can be identified in SEPs: disclosure issues, essentiality, and the understanding of FRAND terms.

First, most SSO policies require *full* disclosure of information about their technology (and IP rights) within the standardization process to create a standard and have sufficient knowledge on how to comply with the standard.³⁴⁹ Not only must granted patents be fully disclosed, but also patent *applications* and trade secrets. While many quantum communication inventions are patented,³⁵⁰ the secrecy of many algorithms, codes, and other inventions due to patentability issues clashes with this requirement. When standardization procedures end without identifying SEPs, certain secret information might have been disclosed prematurely, unless NDAs are signed.

³⁴³ CEB-BEC, 'Standardization in the Field of Quantum Technologies – ISO/IEC/JTC3' (*ceb-bec.be*, 28 November 2024) <<https://www.ceb-bec.be/nl/nieuws/standardization-in-the-field-of-quantum-technologies-iso-iec-jtc3>> accessed 19 July 2025.

³⁴⁴ Lily Chen, 'Standardization of Quantum-Resistant Cryptography' (ISO/IEC JTC 1 Workshop, 3 April 2023) <https://www.iec.ch/system/files/2023-04/quantumslidesv2_0.pdf> accessed 11 August 2025, 20.

³⁴⁵ Guido Noto La Diega, *Internet of Things and the Law : Legal Strategies for Consumer-Centric Smart Technologies* (1st edn, Taylor & Francis Group 2022), 325.

³⁴⁶ *ibid* 325.

³⁴⁷ See Section 3.1.1.b of Essential Requirements, ANSI.

³⁴⁸ CEN-CENELEC (n 66) 108.

³⁴⁹ ETSI requires that all *potential* essential patents are disclosed in a timely fashion, Clause 4.1. ETSI IPR Policy and ETSI, *Guide on Intellectual Property Rights (IPRs)* (ETSI, 10 June 2021) <<https://www.etsi.org/images/files/IPR/etsi-guide-on-ipr.pdf>> accessed 4 April 2025, 76 *in fine* and Jonathan D. Putnam, 'Economic Determinations in "Frاند Rate"-Setting: A Guide for the Perplexed' (2018) 41 *Fordham International Law Journal* 953, 963.

³⁵⁰ See chapter I.2.1.1., fig. 2.

Second, both in the EU and the U.S., there is major uncertainty about when technologies become *essential*. Some propose to impose essentiality checks,³⁵¹ but they might not fully prevent over-declarations, which inflate patent counts and essentiality rates.³⁵² In a report by the EC, the key issues of SEP licensing are: a lack of **transparency** in the context of SEP licensing frameworks of SSOs, uncertainty around the valuation of FRAND **royalties**, and the scope of the **rights of enforcement** of SEP-owners, in balance with the interests of implementers.³⁵³

Third, while FRAND terms are necessary to ensure that the technology is accessible to all interested parties,³⁵⁴ there is a lack of guidance on *what* FRAND terms *are*. There are no legal frameworks or SSO guidelines, which puts SEPs implementers and holders at risk of engaging in anti-competitive behaviors,³⁵⁵ and courts are tasked with defining what they are.³⁵⁶ *Huawei v. ZTE of the CJEU* is a landmark case regarding avoiding abuse of the dominant position under Article 102 TFEU when licensing under FRAND terms.

As such, while this is not a current challenge for quantum technologies due to limited applications, the current landscape and framework of SEPs is too uncertain to navigate the existing SEPs.

3. Open innovation

³⁵¹ European Commission: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs and Justus Baron, *Essentiality checks for potential SEPs* (Publications Office of the European Union, 2023) <<https://data.europa.eu/doi/10.2873/002897>> accessed 18 April 2025.

³⁵² Keith Mallinson, 'Essentiality Checks Might Foster SEP Licensing, But Do Not Stop Over-Declarations from Inflating Patent Counts and Making Them Unreliable Measures' (2022), 1 <<https://dx.doi.org/10.2139/ssrn.4278639>> accessed 4 May 2025.

³⁵³ Policy Department for Citizens' Rights and Constitutional Affairs, *Standard Essential Patents and the Internet of Things – Legal Affairs* (January 2019) <<http://www.europarl.europa.eu/supporting-analyses>> accessed 18 April 2025, 22.

³⁵⁴ European Commission, MEMO Antitrust: Commission sends Statement of Objections to Motorola Mobility on potential misuse of mobile phone standard-essential patents- Questions and Answers (6 May 2013) <https://ec.europa.eu/commission/presscorner/detail/en/memo_13_403> accessed 3 May 2025.

³⁵⁵ European Commission, *MEMO Antitrust decisions on standard essential patents (SEP)* (29 April 2014) <http://europa.eu/rapid/press-release_MEMO-14-322_en.htm> accessed 4 May 2025.

³⁵⁶ In the EU, the EC had published a proposal on SEPs to provide transparency around SEP portfolios and regulate license negotiations, but it is withdrawn in 2025, see: Stefano De Luca, 'Standard essential patents (SEP) regulation' (*Legislative Train Schedule, EP*, 20 April 2025) <<https://www.europarl.europa.eu/legislative-train/spotlight-JD22/file-patent-licensing-package-1>> accessed 5 May 2025 and EC, 'Standard Essential Patents' (*EC*) <https://single-market-economy.ec.europa.eu/industry/strategy/intellectual-property/patent-protection-eu/standard-essential-patents_en> accessed 5 May 2025. In the U.S., Policy Statements of 2013 and 2019 on FRAND terms are withdrawn, see: USPTO, DOJ and NIST, *Policy Statement On Remedies For Standard-Essential Patents Subject To Voluntary F/RAND Commitments* (19 December 2019) 7 <<https://www.justice.gov/atr/page/file/1228016/dl?inline=>>> accessed 4 May 2025.

Institutions, such as QuIC, have proposed **open innovation** to enhance innovation and commercialization through the sharing of external knowledge, ideas, and resources.³⁵⁷ This is currently developing in software and hardware.

Examples of open source software³⁵⁸ are IBM's Qiskit invites individuals to experiment with quantum technologies themselves or collaborate, and the IBM Quantum Platform, which is an online platform with access to cloud-based quantum computing services. Users are allowed to experiment with real quantum processors and have access to data, results, methodologies, and even a textbook.³⁵⁹ Other examples are Google's Cirq,³⁶⁰ Rigetti's Forest SDK,³⁶¹ QuEra's Bloqade for quantum simulation and execution on neutral atoms,³⁶² and Mitiq. The Unitary Fund has supported the open-source movement by funding open-source projects and has developed a project itself, Mitiq, which is used for quantum error mitigation.³⁶³ Through this, companies attract experts and technological enthusiasts to test the developed hardware, while claiming any breakthroughs made by users and educating future developers. This creates communities and increases publicity, which in turn attracts more experts.³⁶⁴ However, while outputs, databases, and know-how are being openly licensed, not all information is shared, such as raw materials, inputs,³⁶⁵ or key inventions.

Meanwhile, open-source quantum hardware is less advanced. This mainly consists of blueprints for hardware design,³⁶⁶ but it can also include open (remote) laboratories,³⁶⁷ such as superconducting-circuit quantum computers are available online from IBM Quantum Experience and Rigetti Quantum Cloud Services, amongst a few. The European OpenSuperQ has also aimed to develop a public open-access superconducting lab.³⁶⁸ However, the latter are scarce due to the costly maintenance.³⁶⁹

³⁵⁷ European Quantum Industry Consortium, 'Strategic Industry Roadmap 2025' (2025) <<https://www.euroquic.org/strategic-industry-roadmap-2025/>> accessed 9 August 2025, 214.

³⁵⁸ Mauritz Kop (n 275) 10.

³⁵⁹ See: Quantum IBM, <<https://quantum.ibm.com/>> accessed 7 August 2025.

³⁶⁰ Alan Ho (n 44).

³⁶¹ Chad Rigetti, 'Introducing Forest 1.0' (*Medium*, 20 June 2017) <<https://medium.com/rigetti/introducing-forest-f2c806537c6d>> accessed 3 April 2025. See: <https://docs.rigetti.com/qcs/getting-started>.

³⁶² QuEra, 'Bloqade' (*QuEra*, date unknown) <<https://www.quera.com/bloqade>> accessed 8 August 2025.

³⁶³ Unitary Foundation, <<https://unitary.foundation/>> accessed 31 July 2025.

³⁶⁴ Mark Fingerhuth, Tomáš Babej and Peter Wittek, 'Open source software in quantum computing' (2018) 13 PLoS ONE 1, 2.

³⁶⁵ Anushka Mittal, 'Probing the production of quantum technologies to imagine its legal framework' [2025] *Research Directions: Quantum Technologies* 3, 4.

³⁶⁶ Nathan Shammah and others, 'Open Hardware Solutions in Quantum Technology' [2024] *APL Quantum* 1, 3.

³⁶⁷ Nathan Shammah and others (n 366) 12.

³⁶⁸ *ibid* 13.

³⁶⁹ *ibid* 15.

However, sharing resources, data, and research with the public could lead to potential misuse,³⁷⁰ which could, in turn, encourage developers to do unnecessary private R&D, which could impede innovation again.

In conclusion, these enriching and promising projects reflect the enthusiasm of the quantum tech communities to contribute to R&D and the willingness of companies to provide access to their know-how and hardware. Through these means, quantum algorithms might not need patents or be kept secret to advance, but they reward the inventors for publishing them collaboratively and educationally.

4. Remaining gaps

Since quantum technologies are still in development, there have not been many case laws or jurisprudence, or legislation proposals focused on this field. While the PTAB has decided on numerous important quantum cases, they are only situated in the discussion around subject matter. It seems that both applicants and examiners still manage to fit quantum tech in the classical patent approaches, as the number of granted patents lies in the normal range compared to classical technologies.

However, several discussion points fell beyond the scope of this thesis. For example, an in-depth analysis of patent applications was not possible. Therefore, the analyses remained limited to certain representative examples.

Regarding know-how, very little to no reference was made to it in case law and jurisprudence, apart from its definition and distinction from trade secrets. It is, as such, unclear what its role is in patents, trade secrets, and standardization.

Several discussion points remain unanswered regarding quantum technologies:

- The patentability of quantum and AI hybrids.
- The influence of antitrust law on incentivizing innovation and its relationship to IP.
- The definition and the role of know-how.
- What technologies will be the first subjects of patent pools.
- The future role of SEPs.

V. Conclusion

Quantum technologies are a rapidly emerging, complex field based on principles on atomic scales, in which large companies are investing in R&D and their commercialization is being funded by both public and private.

As granted patents are increasing in quantum technologies, both in hardware and software alike, the core question of the thesis arises: are patents necessary to incentivize innovation in quantum tech? If they are not, how are they related to trade secrets, a tool

³⁷⁰ European Quantum Industry Consortium (n 357) 215.

that is very common in complex technologies? How do the patent law and patent application practices differ at the EPO compared to the USPTO?

Patents are complementary to other drivers of innovation, being private and public funding, collaboration with large companies, trade secrets, open source, and high returns on investment. However, due to the field being in its early stages, being a high-risk investment, and the absence of complex mechanisms such as patent pools and SEPs, patents remain an important element to encourage smaller research entities to enter the field, thus participating in innovation. Especially the willingness of large companies to collaborate with specialized entrants encourages new researchers to join the quantum community.

Both at the EPO and the USPTO, quantum tech can face multiple challenges on different levels. First, subject matter eligibility, which excludes quantum algorithms, including vital error-correcting codes, as abstract ideas (mathematics, and mental processes) *as such*. Second, they can be patented only if they show sufficient technical effect based on EPO's two-hurdle test and USPTO's Alice framework, often by integrating them into hardware. This excludes algorithms that are inoperable or merely improve prior art. However, quantum optimization and error-correction are vital parts for quantum applicability, even when improvements seem insignificant, as the field is only in its early stages. Third, the digital era might cause hurdles around novelty. And at last, the skilled person in the art that must be able to execute the invention must have multidisciplinary knowledge and disclosure must be sufficiently complete and understandable and the invention must be operable.

However, studies have shown that patent drafters often have high technological expertise and the number of granted patents is fairly high and increasing each year. Case law at both the EPO and USPTO in classical technologies have shown leniency towards certain technologies and their improvements. Thorough and precise drafting of the claims including their implementation step-by-step, is required to determine a technical effect.

Trade secrets are a common tool to protect inventions besides patents. While trade secrets impede innovation due to secrecy, patents could equally hinder patenting follow-up innovation. Both systems rely on collaboration that enhances further R&D, while the costs of quantum R&D, claiming patents or taking secrecy measurements are high. As such, the choice depends on a variety of factors. Quantum inventions that struggle with patentability (mainly quantum algorithms, or others that are mathematical or mental processes), large companies that seek monopolistic positions, inventions that are difficult to reverse engineer or discover independently, and costs. New entrants without sufficient internal sources and funding may be forced to patent to secure rights and attract more funding, which leads them to invest in patentable innovation or disclose specialized R&D results. Though the systems exclude each other, in the grand scheme of things, they are complementary.

Further emerging challenges are regarding possible *sui generis* legal framework for quantum inventions similar to biotech, the emerging standardization and SEP practices,

open source software and hardware, and the operability of quantum computers in the near future.

In conclusion, quantum technologies challenge patent law by their nature, but the high-granting rates and prior case law showcase that the expertise of the drafters currently suffice to find their way to patent abstract ideas, besides quantum algorithms that show quantum advantage. Due to the lack of complex mechanisms, patents remain important to incentivize innovation by promising more resources for new entrants. However, they remain complementary to other innovation tools.