

Quantum simulation

Insight report

June 2023

Executive summary

This report is the eighth patent insight report published by the European Patent Office (EPO), and the fourth report related to quantum technologies.¹ Its objective is to provide an overview of important patent trends in the field of second-generation (2G) quantum simulation technologies.

The report summarises the results of patent analyses which were carried out jointly by subject-matter specialists and patent knowledge experts at the EPO. For this study, publicly available patent information drawn from the EPO's databases of worldwide patent data was analysed. Patent information constitutes a very rich source of technical information on inventions for which patent protection was sought based on the commercial expectations of the applicants. Patent information often includes technical and other information that is not available from any other source.

This report may be helpful as a source of information on quantum simulation. The methodology on which this report is based can be used freely, i.e. everyone can adapt the chosen search and analysis approach to their needs, for example to follow trends and developments in other established or emerging technical fields.

While the number of inventions in the field of 2G quantum simulation is still rather low, it has increased dynamically over the last decade at a rate which is well above the increase generally observed across all fields of technology. The figure on the next page shows the number of so-called International Patent Families relating to 2G quantum simulation technologies and the number in all technical fields by the year when the underlying inventions were made publicly available for the first time and could influence the activities of competitors and other researchers.

The EPO patent insight report on quantum simulation in a nutshell:

- Number of inventions in the field of second-generation quantum simulation multiplied over the last decade
- Higher growth rate than across all fields of technology in general
- High proportion of International patent applications, suggesting high economic expectations with regard to the technologies in question and multinational commercialisation strategy
- The most active patent applicants in the field of quantum simulation are companies. The majority of them are located in the United States, followed by Canada, Europe, China, and Japan. Some US-based universities also played an important role

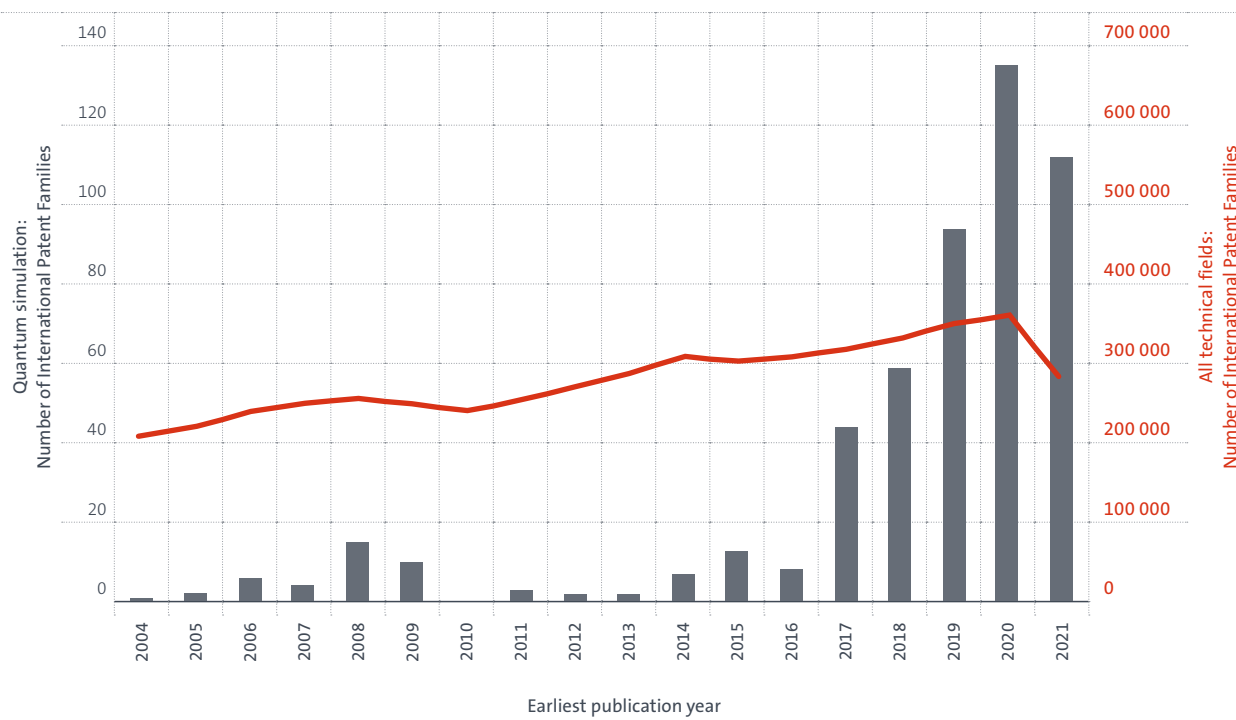
Patent applicants in the field of quantum simulation relied heavily on the following patent application routes: International patent applications that may result in patent protection in more than 150 countries worldwide, US applications, JP applications, EP applications, CN applications and CA applications. The high proportion of International patent applications may be interpreted as an indication of the significant economic expectations of the patent applicants with regard to the technologies in question, as well as a corresponding multinational commercialisation strategy.

¹ More information about EPO patent insight reports and the list of currently available reports is available at epo.org/insight-reports

Figure

Quantum simulation: Number of International Patent Families per earliest publication year.

Number of inventions by earliest publication year in the field of 2G quantum simulation technologies, limited to International Patent Families. International Patent Families group together patent documents relating to the same or similar inventions published by at least two patent authorities. It is generally assumed that patent applicants attribute greater economic potential to the underlying inventions of these patent families, and that they tend to seek more extensive commercialisation from a geographical point of view.



The most active applicants in the field of 2G quantum simulation are companies. Most of them are located in the United States of America, followed by Canada, Europe, China and Japan. The exceptions to this are a small number of US-based universities, such as the University of Maryland and Harvard University. The list of most active applicants in the field since 2004 is headed by Google, followed by IBM. The picture becomes more nuanced when looking at development over the last few years in more detail. The situation in the 2010s was compared to the period 2020-2021. Whereas Google, IBM and Microsoft head the list in both periods, the rest of the applicants are quite different, suggesting a realignment of research and development activities in the field.

In view of the high momentum in the field of quantum simulation, the EPO intends to update this report in the future and to take a closer look into how sub-sectors in the field of quantum simulation have developed and diversified.

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Abbreviations

2G	Second-generation
CA	Two-letter code used to label patent applications processed and published by the Canadian Intellectual Property Office
CN	Two-letter code used to label patent applications processed and published by the China National Intellectual Property Administration
CPC	Cooperative Patent Classification
DE	Two-letter code used to label patent applications processed and published by the German Patent and Trade Mark Office
DOCDB	EPO worldwide bibliographic data
EP	Two-letter code used to label patent applications processed and published by the European Patent Office
EPO	European Patent Office
EPC	European Patent Convention
GB	Two-letter code used to label patent applications processed and published by the Intellectual Property Office (United Kingdom)
IPC	International Patent Classification
JP	Two-letter code used to label patent applications processed and published by the Japan Patent Office
KR	Two-letter code used to label patent applications processed and published by the Korean Intellectual Property Office
PCT	Patent Cooperation Treaty
US	Two-letter code used to label patent applications processed and published by the United States Patent and Trademark Office
WIPO	World Intellectual Property Organization
WO	Two-letter code used to label patent applications processed and published by the World Intellectual Property Organization under the Patent Cooperation Treaty

Glossary

Espacenet	Free online patent searching service developed by the EPO. Includes information on more than 140 million documents from 100 patent offices. Espacenet is available at worldwide.espacenet.com .
International patent application	Patent application filed under the Patent Cooperation Treaty. An International patent application may result in patent protection in more than 150 countries.
International Patent Family	A patent family having patent family members published by at least two different patent authorities.
Invention	A practical technical solution to a problem.
Jurisdiction	Country (territory) for which a patent or related intellectual property right may be granted by the corresponding intellectual property office.
Patent	Legal title giving the patent owner(s) the right to exclude others from using the protected invention in a commercial context. A patent builds on what is called the “patent specification”, which discloses the relevant details defining the protected invention along with other relevant information.
Patent application	In the field of patent information, the expression “patent application” is used for both the patent application itself and the patent application published as a document.
Patent classification system	The set of patent classification symbols assigned to categorise the technical subject-matter of a patent or utility model. There are various patent classification systems used today by national, regional and international patent offices.
Patent family	<p>A set of patent documents covering the same or similar technical content, depending on the patent family definition.</p> <p>The size of a patent family (family size) refers to the number of patent documents in that patent family.</p> <p>A DOCDB patent family is a set of patent documents relating to patent applications claiming priority of the same earlier applications. The technical content covered by the patent applications in a DOCDB patent family is considered to be identical.</p>
Priority application	Inventions can be protected by patents and utility models in more than one country. Once an applicant has filed a first application, called the priority application, in a member state of the Paris Convention, the applicant has 12 months to file applications for the same invention in other member states of the convention. During this period, the original filing date can be claimed as the effective filing date, or “priority date”, for subsequent applications.
Quantum simulation	Quantum simulation is the modelling of a complex quantum mechanical system by another system under controlled conditions to systematically study and predict the behaviour of the simulated system.

1. Introduction

1.1 About this report

This report is the eighth patent insight report published by the EPO, and the fourth report related to quantum technologies.² It summarises the results of patent analyses in the field of quantum simulation which were carried out jointly by subject-matter specialists and patent knowledge experts at the EPO.

Quantum simulation technologies are developing dynamically, with hundreds of scientific and technical publications and patent protection being sought for numerous inventions. This development is being spurred

on by a large number of active companies, including leading technology companies and funding programmes. The Quantum Flagship initiative, which was set up by the European Commission and makes an important contribution to research and the commercialisation of quantum technologies, may be mentioned here as an important example (see Figure 1).

The objective of this report is to provide an overview of important patent trends in the field of second-generation quantum simulation technologies.³ For this study, publicly available patent information drawn from the EPO's databases of worldwide patent data was analysed.

Figure 1

The Quantum Flagship initiative



Launched in 2018, the Quantum Flagship initiative is one of the largest and most ambitious research initiatives established by the European Union. It aims to consolidate and expand scientific excellence and leadership in Europe in the area of quantum technologies. The initiative brings together more than 5 000 scientists and engineers, entrepreneurs and policymakers..

With a budget of more than €1 billion over a period of more than 10 years, the initiative aims to reinforce Europe's role as a leader in the field of quantum technologies. For this purpose, it has the following goals:

- to foster a competitive European quantum industry
- to expand scientific excellence in the field of quantum research
- to make Europe an attractive region for businesses and investments in quantum technologies
- to use quantum technologies for better solutions to important challenges, e.g. in the areas of the environment, health and data security.

The activities of the Quantum Flagship initiative centre around the following main fields: basic quantum research, quantum computing, quantum simulation, quantum metrology and sensing, and quantum communication.

Valuing the important role of the Quantum Flagship initiative and of quantum technologies for society and the economy in Europe, the EPO has developed a series of EPO patent insight reports on quantum technologies aligned with the main topics of the initiative.

Topic	Publication year
Quantum metrology and sensing	2019
Quantum computing	2023
Quantum simulation (this report)	2023
Quantum communication	2024 (planned)

Once published, these reports and supplementary information are made available at epo.org/insight-reports.

² More information about EPO patent insight reports and the list of currently available reports is available at epo.org/insight-reports

³ More information about 2G quantum technologies and the differences between these technologies and earlier developments is available in J.P. Dowling and G.J. Milburn, "Quantum technology: the second quantum revolution", *Philosophical Transactions of the Royal Society A* 361, 2003, 1655-74.

Patent information constitutes a very rich source of technical information on inventions for which patent protection was sought based on the commercial expectations of the applicants. Patent information often includes technical and other information that is not available from any other source.

To gather relevant patent information as the basis for this report, search strategies were developed using meaningful keywords and appropriate patent classification symbols. These search strategies, which were designed to strike a balance between completeness and capturing as few unrelated documents as possible in the result sets, were then used to create a basic data set of suitable patent documents from the EPO's databases of worldwide patent data. This basic data set formed the basis for the subsequent patent analyses.

This report may be helpful as a source of information on quantum simulation. The methodology on which this report is based can be used freely, i.e. everyone can adapt the chosen search and analysis approach to their needs, for example to follow trends and developments in other established or emerging technical fields.

1.2 Introduction to quantum simulation

Quantum effects, such as those giving rise to the colours of everyday materials, have played an important role in the life of humans since ancient times, but it was not until the 19th century that quantum effects and their physical foundations developed into a key focus of research. With the establishment of quantum physics at the end of that century, it became possible to describe matter and electromagnetic radiation, such as visible light, accurately on the atomic scale.

Numerous technologies that have become an integral part of modern life build on these achievements. Examples include lasers and semiconductors, which are a firmly established part of nearly all electrical appliances and devices. It has become difficult to imagine a life without mobile phones or computers.

These technologies belong to the first generation of quantum technologies, which began in the middle of the 20th century. The advent of a new, second, generation of quantum technologies has raised a great deal of interest. With precise control of the quantum-physical properties and behaviour of individual or a small number of particles

such as atoms and photons becoming possible, a wave of new applications is on the horizon.

In the last two decades, research into quantum technologies has made remarkable progress, enabling its implementation in cross-disciplinary fields of applied research, and consequently its industrialisation. Estimates suggest that quantum technologies will become part of major industries in the short to medium term, depending on their nature.^{4 5}

Quantum technologies will have an impact on many technical fields and industry sectors. One domain that has received particular attention is quantum computing. This is no surprise, as this technology promises major advances in many technical areas such as drug development and materials research.⁶ Quantum computing is developing more and more dynamically, with a large number of active companies and funding programmes, such as the Quantum Flagship initiative, at the national and international level.

Other domains covered by the Quantum Flagship initiative include quantum communication, with potential applications for secure IT architectures, and metrology and sensing, which are expected to lead to better sensors and measuring devices.⁷

A domain of specific interest is quantum simulation. Quantum simulation is the modelling of a complex quantum mechanical system by another system under controlled conditions to systematically study and predict the behaviour of the simulated system.

Quantum simulation is distinguished from universally programmable quantum computing, which is computing using quantum phenomena. In contrast to what happens in a universally programmable quantum computer, the relationship and interactions of individual elements in quantum simulators are determined by hardware structures. Box 1 illustrates the nature of quantum simulators using the examples of two inventions disclosed in patent documents.

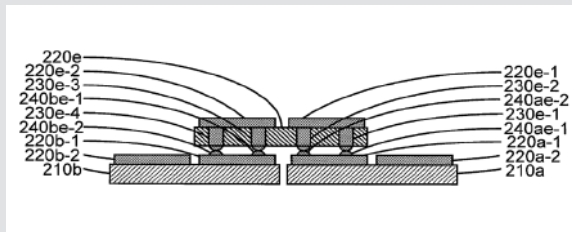
4 See [Quantum Manifesto: a new era of technology, 2016](#).

5 See A.M. Lewis et al., "Quantum technologies: implications for European policy. Issues for debate", 2016.

6 See the [EPO patent insight report on quantum computing](#) for a detailed overview of patent filing trends in this field.

7 See the [EPO patent insight report on quantum metrology and sensing](#) for more information on patent filing trends in this field.

Box 1: Examples of quantum simulation



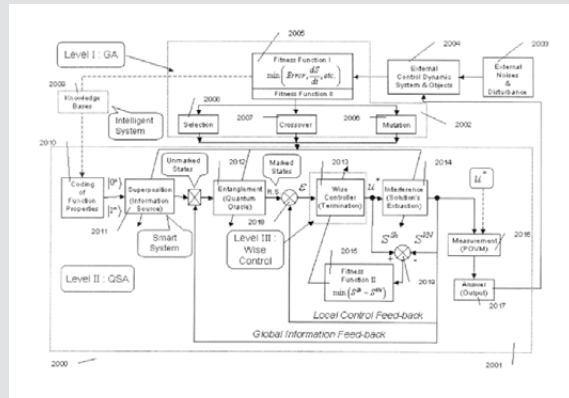
US2009173936A1:
 Quantum processor

This patent application presents a multi-chip processor comprising a connection between different portions of the integrated circuit. This connection is suitable for a coherent transfer of quantum information between different parts of a quantum information processing unit.

In this patent application, quantum simulation is mentioned as a possible area of application, along with other ways of quantum information processing such as freely programmable quantum computing.

The patent application illustrates the challenges that need to be overcome at the hardware level for a successful implementation of quantum simulation. The invention presented addresses basic problems in the physical realisation of quantum simulators that arose at an early stage of development of the relevant technology.

The patent application also illustrates the interrelationship between quantum simulation and other kinds of quantum information processing that share similar problems to be addressed. The fact that the patent applicant made an explicit reference to quantum simulation in this context indicates the applicant's commercial interest in quantum simulation.



EP1672569A1:
 A method of performing a quantum algorithm for simulating a genetic algorithm

This patent application presents a genetic algorithm to be performed on quantum information processing devices. One of these devices is described as a hardware implementation of the algorithm, i.e. a quantum simulator according to the definition used for this report.

The patent application is an example of how quantum simulation may be considered at an algorithmic level in the context of different possible ways of implementation but without a detailed description of the hardware. Again, the fact that the patent applicants explicitly refer to quantum simulation indicates their awareness of quantum simulation and their commercial interest in this technology.

Box 2: The European patent system and inventions in the field of quantum simulation

The European patent system and inventions in the field of quantum simulation

The European patent system makes it possible to obtain European patents valid in up to 39 member states of the European Patent Convention (EPC) on the basis of a single application.¹ European patents have the same legal effects as national patents in each country for which they are granted. As of 2023, it will be possible to request unitary effect for a granted EP patent, which provides uniform patent protection in up to 25 member states of the European Union.

European patents are granted by the European Patent Office in a centralised, cost-effective and time-saving procedure conducted in either English, French or German.

Every patent application undergoes substantive examination before a European patent is granted to make sure that inventions for which patent protection is sought meet all legal requirements set out in the EPC. Patents are granted for inventions across all fields of technology if they are new, involve an inventive step and are industrially applicable. An invention meets these requirements if it was not known to the public in any form prior to the (earliest) filing date, was not obvious to a skilled person and can be manufactured or used industrially. Inventions in the field of quantum simulation are not an exception to this.

Inventions directed to methods of simulation typically comprise features which fall under the category of mathematical methods. If patent protection was sought for these activities as such, i.e. without any technical aspect, they would be excluded from patent protection under the EPC. Methods related to quantum simulation are at least partially computer-implemented and do not fall under this exclusion criterion if they provide a further technical effect, i.e. have technical character.

The technical character of quantum simulation, as a specific kind of simulation, may be established by the interaction with an external physical entity at the input or output side of the simulation. The technical character may also be established by a specific implementation of the simulation, including hardware implementation, or by an intended technical use of simulation data. By contrast, calculated numerical data reflecting the physical state or the behaviour of a system or process existing only as a model in a computer (in the quantum simulator) usually cannot contribute to the technical character of the invention, even if it reflects the behaviour of the real system or process adequately.

The technical or non-technical nature of features of the invention for which patent protection is sought also plays a role during the assessment of the inventive step. Applicants cannot rely on non-technical features to establish an inventive step, but these features may be used in formulating the objective technical problem to be used when the existence of an inventive step is assessed.

More information relevant for the assessment of inventions related to simulations under the EPC is available in the Guidelines for Examination in the European Patent Office² and in the Case Law of the Boards of Appeal.³

¹ European patents may also be effective in some countries that have not acceded to the EPC (i.e. in extension and validation states).

² See [epo.org/law-practice/legal-texts/guidelines.html](https://www.epo.org/law-practice/legal-texts/guidelines.html), in particular sections G-II, 3.3.2 and G-VII, 5.4.

³ See in particular cases G 1/19 relating to the patentability of computer-implemented simulations, and T 641/00 relating to the treatment of non-technical aspects in the problem-solution approach for the assessment of the inventive step.

While a quantum computer executes a series of instructions, a model system is prepared in a quantum simulator in a particular state and then left to develop according to the laws of quantum mechanics under the conditions determined by the structure and the set-up of the simulator. In a quantum simulator, there is no need for intervention during the time in which the model system develops. Accordingly, coherence problems are less complex to manage than in a universally programmable quantum computer.

Quantum simulators based on the laws of quantum physics may make it possible to overcome the shortcomings of conventional supercomputers. With these devices, the physical and chemical properties of complex structures and chemical compounds may be simulated, leading to new products and applications in the fields of pharmacy and chemistry and physics and engineering.

Further reading

J.P. Dowling and G.J. Milburn, "Quantum technology: the second quantum revolution", *Philosophical Transactions of the Royal Society A* 361, 2003, 1655-74.

D. Hangleiter et al., "Analogue Quantum Simulation. A New Instrument for Scientific Understanding", Springer Cham, 2022.

T.H. Johnson et al., "What is a quantum simulator?", *EPJ Quantum Technology* 1, 2014, 1-10.

2. Methodology and sources of patent information used

2.1 Using patent information

In essence, patents are legal rights which confer on patent holders the right to exclude others from commercially using the patented invention. Patents are commercial assets which can help to attract investment, secure licensing deals and provide market exclusivity.

Patent systems foster innovation, technology diffusion and economic growth by allowing patent holders to secure investments in research and development, education and infrastructure while requiring them to disclose their inventions to the public in return. To this end, patent information is at the core of any patent system.

Patent information enables others to build on the published inventions of other inventors and also to avoid the mistake of investing in developing a solution for a problem that has already been solved by others and is potentially protected. Patent information contains a wealth of technical and other information, much of which cannot be found in any other source.

The EPO alone, as the leading provider of high-quality patent information worldwide, has collected, standardised and harmonised information on more than 140 million patent documents from more than 100 countries in its databases, amounting to more than one billion records. These databases continue to grow by tens of millions of records every year.

Patent information from these databases is available via numerous free and commercial patent information services provided by patent offices and service providers worldwide. The information may be used for various analyses, e.g. to explore technical trends and the filing strategies of applicants, or to calculate indicators for innovation activity, commercialisation and knowledge transfer.

2.2 Methodology of this EPO patent insight report

This EPO patent insight report is designed to provide useful insights into the field of 2G quantum simulation. It is based on publicly available patent information and acts as a snapshot of the technologies, taken in the light of patent information.

The methodology of this report is based on a three-step process.

Step 1: Creating and tuning a basic data set

A basic data set is created, usually based on various individual search concepts, e.g. building on keywords and on patent classification symbols for specific technologies.

Typically, unrelated patent documents will have to be removed from the resulting data set in an automated or manual manner to increase the quality of the basic data set.

The creation of a meaningful basic data set is critical to providing a reliable basis for sound patent analysis in Step 2.

Step 2: Patent data analysis

In this second step, analyses are performed on the basic data set, e.g. by aggregating the data to patent families as a representative of inventions, by creating descriptive statistics, testing hypotheses or recognising patterns in the data.

Step 3: Further processing and visualisation

In this third step, the data is further analysed and processed. Results are visualised and summarised.

The methodology underlying this report and the details are free to use. As a result, anyone can apply the proposed analytical approach to reveal trends and prospects in the same or other areas of technology and adapt the approach to their own needs.

2.2 Patent retrieval

For this report, EPO subject-matter experts developed dedicated search strategies to identify patent documents that relate to 2G quantum simulation technologies. The search strategies combine relevant keywords and patent classification symbols (see Box 2) and include a restriction to patent applications filed in 2004 at the earliest. The search strategies were optimised for the EPO's in-house search tools (see section 2.3.1).

The patent classification symbols and keywords used for this report efficiently capture documents with a focus on 2G quantum simulation, as opposed to, for example, more general technical improvements that may be useful in the field of quantum simulation as well as in other technical domains and thus extend beyond the field of quantum simulation. Such technical improvements with a broader scope may be discussed in the context of “quantum technologies” in general, but that is beyond the scope of this report.

The volume of search results retrieved using the search methodology will grow over time due to the dynamic nature of the technical field and of the patent databases, as patent documents relating to quantum simulation are continuously being added to these databases. Accordingly, we intend to update this report in the future, which would also give an opportunity to produce an analysis of patent trends in sub-sectors of the quantum simulation domain.

The dedicated search strategies developed for this report will be made available as part of the supplementary materials which accompany it. The search strategies may be translated into search statements for other patent search tools which are publicly available on the internet, such as the EPO's search interface Espacenet.⁸

Box 3: Quantum simulation and patent classification schemes

Patent offices assign patent classification symbols to categorise the technical subject-matter of a patent or utility model. Patent classification symbols are defined as part of what are known as “patent classification systems”. There are various patent classification systems used today by national, regional and international patent offices.

Two patent classification systems are of particular importance.

The **International Patent Classification (IPC)** system is a hierarchical patent classification system which is used by more than 100 patent offices on all continents, including the EPO. It breaks technologies down into eight sections with several hierarchical sub-levels. The IPC system has approximately 75 000 subdivisions and is updated on an annual basis. Further information about the IPC system is available on a [dedicated website](#).

The **Cooperative Patent Classification (CPC)** system builds on the IPC system and provides a more granular and detailed classification structure. The CPC system has more than 250 000 sub-divisions and is updated four times a year. It is used by more than 30 patent offices worldwide, including the EPO. Further information about the CPC system is available on the [CPC website](#).

IPC and CPC classification symbols can be used to quickly retrieve relevant patent documents using search interfaces such as the EPO's free search interface Espacenet, for example.

For the purposes of this study, sub-divisions in the IPC and the CPC systems were used and combined with other search terms to restrict the resulting data set to patent documents closely related to 2G quantum simulation. The following table shows a selection of the IPC and CPC sub-divisions used.

⁸ Available at worldwide.espacenet.com.

Sub-division	Description
B82Y10	Nanotechnology for information processing, storage or transmission, e.g. quantum computing or single electron logic
G01L21/30	Vacuum gauges, by making use of ionisation effects
G06N10	Quantum computing, i.e. information processing based on quantum-mechanical phenomena
H10B61	Magnetic memory devices, e.g. magnetoresistive RAM devices
H10N50	Galvanomagnetic devices
H10N60	Superconducting devices
H10N69	Integrated devices, or assemblies of multiple devices, comprising at least one superconducting element covered by group H10N60
H01L29/122	Single quantum well structures
H01L29/125	Quantum wire structures
H01L29/127	Quantum box structures
H01L29/66977	Quantum effect devices, e.g. using quantum reflection, diffraction or interference effects, i.e. Bragg- or Aharonov-Bohm effects
H01L29/7613	Single electron transistors; Coulomb blockade devices

2.2.1 Data sources and tools used

The quality of the patent data analysis largely depends on the completeness, correctness and timely availability of relevant patent information in the patent databases from which the basic data set for the subsequent analysis is extracted.

Absolute completeness of the relevant patent information is not possible as not all data is available from all patent offices.

However, there are several patent databases that have very good or excellent coverage of patent information from the main patent offices. These patent databases mostly rely on EPO worldwide patent data as a central source of prior art patent information.

EPO worldwide patent data includes bibliographic and other information on more than 140 million patent documents from more than 100 patent authorities on all continents. It is available via the EPO patent information products and services,⁹ and via other major free and commercial search interfaces for patent information.

For this EPO patent insight report, patent searches were carried out using EPO worldwide patent data via the EPO's internal data platforms and search interfaces such as ANSERA¹⁰ to create the basic data set for subsequent patent analyses.

The resulting basic data set was combined with added value data contained in the EPO's PATSTAT product line,¹¹ which provided the advanced basis for the patent data analysis step and was used for further processing and visualisation of the data.

⁹ More information is available at epo.org/searching-for-patents.html.

¹⁰ See Y.Tang Demey and D. Golzio, "Search strategies at the European Patent Office", World Patent Information 63, 2020.

¹¹ The Autumn 2022 edition of the PATSTAT product line was used for this study.

3. Analysis

This chapter presents the results of the analyses regarding the field of 2G quantum simulation technologies. For this purpose, filing trends in the field of 2G quantum simulation are first considered and then the findings are compared with the overall situation across all fields of technology. Then, the main jurisdictions for which protection was sought are looked at as well as the jurisdiction where the earliest application for an invention was filed. This chapter will end with an analysis of applicant networks in the field of quantum simulation.

The number of patent applications in the field of 2G quantum simulation has increased dynamically over the last decade. Figure 2 shows the number of inventions, approximated by DOCDB simple patent families,¹² in the field of quantum simulation, by the earliest publication date. This date was chosen to represent the moment when the invention was first available to the public and could stimulate research activities by others and influence the commercial strategy of competitors. In this case, the earliest publication date is of fundamental importance for the technical and economic development of a technical field.

The figure shows a steep increase in the number of inventions over the last decade, starting from around 2017. This increase is above the generally observed increase in the number of inventions across all fields of technology (see right-hand scale in Figure 2).

Figure 2 discloses minimal filing activity in the 2000s in the field of quantum simulation, suggesting that it was at an early stage of development. This observation corresponds to a similar observation in the field of quantum computing, which may have been triggered by certain scientific publications or inventions related to a specific concept in this field.¹³

Figure 2 takes into account patent families with patent applications which have been filed in a single national jurisdiction as well as in multiple jurisdictions. For the latter kind of patent families, the International Patent

Families, it is generally assumed that patent applicants attribute greater economic potential to the underlying inventions, and that they tend to seek more extensive commercialisation from a geographical point of view.¹⁴

In light of the significance of International Patent Families, the analysis focused on this category of patent families. When plotting the number of International Patent Families in the field of 2G quantum simulation technologies by the earliest publication year, the dynamics described earlier become even more apparent. While the number of inventions is continuously increasing for all fields of technology, the increase in the field of quantum simulation is clearly above average (Figure 3).

Notably, Figure 3 shows a decrease in the number of International Patent Families in the field of 2G quantum simulation technologies in 2021 of about one-fifth compared to the situation one year before. Although this decrease is remarkable when taken alone, it corresponds to an even larger decrease of about one-fourth across all fields of technology in the same period. These observations were not considered to be sufficient to judge whether the filing trend has recently reversed, or whether the observation is for example due to a temporary incomplete data stock in the underlying patent database for the very recent past, or to the ample time limits for International patent applications for the entry into the national phase.¹⁵

¹² A DOCDB simple patent family is essentially a set of patent documents relating to patent applications claiming priority from the same earlier applications. The technical content covered by the patent applications in a DOCDB simple patent family is considered to be identical.

¹³ See section 3.1 of the [EPO patent insight report on quantum computing](#) (2023) for more information.

¹⁴ In this context, the centralised application and granting procedure under the European Patent Convention may lead to patent applicants and inventions with an exclusive focus on Europe being under-represented in the report. By default, patent applications using the European route, and the patents granted, are only published as EP documents although these patents may be valid in more than one country and accordingly reflect a multinational strategy. This means that inventions for which protection was exclusively sought using the European procedure may not be mapped as International Patent Families in the analyses despite the multinational filing strategy behind them.

¹⁵ In view of the high momentum in the field of quantum simulation, the EPO intends to update this report in the future, which will also help to clarify the situation on this subject.

A closer look at International Patent Families in the field of 2G quantum simulation, and at which patent authorities published the patent documents in these patent families, shows that the patent documents are not evenly distributed across all patent authorities. Rather, it can be seen that patent applicants focus strongly on the following patent application routes: International applications,¹⁶ US applications, JP applications, EP applications, CN applications and CA applications (see Figure 4).

Figure 5 shows the percentages of these patent application routes for 2G quantum simulation inventions. Despite the range of the observed values due to the rather small number of inventions, the chart shows the high proportion of US patent applications in recent years, reflecting the importance of the United States in the field of quantum simulation both in terms of the development of 2G quantum simulation technologies and as an important market for these technologies.

The proportion of International patent applications in this field is above average if compared with the proportion attributed to the International patent application route across all fields of technology (see Figure 6), which is in line with similar analyses for the field of quantum computing. This higher proportion may be interpreted as an indication of the high economic expectations of patent applicants with regard to 2G quantum simulation technologies, as well as a corresponding multinational commercialisation strategy.

As described above, analysis of the patent authorities which published the patent documents in a patent family can shed light on potential markets for quantum simulation technologies. In contrast, a closer look at the earliest patent applications related to inventions in that field can give an idea of where the inventions were potentially made. For this reason, the patent authorities with which these earliest patent applications were filed was analysed. Figure 11 shows a breakdown of the filing statistics with regard to these patent authorities by the earliest publication year. While the observed pattern remains rather varied due to the low number of

inventions in the field,¹⁷ the dominance of earliest patent applications originating from the United States is clearly visible. The proportion of these applications was greater than 50% in the recent past, which is clearly higher than the proportion of earliest patent applications originating from the United States in all technical fields (Figure 12).

An important indicator of the strategic orientation and success of patent filing strategies in the field of 2G quantum computing is the proportion of granted IP rights in a specific country or region. Figure 8 shows the proportion of International Patent Families in that field for which an IP right was granted in a specific jurisdiction. For more than 37% of these International Patent Families, at least one IP right was granted for the United States, underlining its important role in the field of quantum simulation. For other legislations, the proportion is also substantial but significantly lower than in the United States. Examples of important markets include Japan (14%), Australia (12%), China (9%) and Europe (8%, based on granted European patents).

EP applications are a special case. The European Patent Convention (EPC) has established a single application procedure for obtaining patent protection in Europe. With just one patent application, applicants can protect their invention not only in all of the 39 contracting states that have acceded to the EPC but also in one extension state and four validation states.¹⁸

Figure 7 shows the percentage of EP patents in International Patent Families in the field of 2G quantum simulation that were validated and maintained in an EPC member state, extension state or validation state. The figure provides an indication of the importance of a country as a location for research and production, and as a market in the field of quantum simulation, according to patent holders in that field.¹⁹ EP patents in the field of 2G quantum simulation technologies have mainly been validated and maintained in France, Germany and the United Kingdom.

¹⁶ I.e. patent applications filed under the Patent Cooperation Treaty (PCT). Correspondingly, these patent applications are often referred to as PCT, or International, applications. See wipo.int/pct/en for more information.

¹⁷ The scattering is particularly apparent in 2013 as earliest publication year, with its significant deviation from other years corresponding to the particularly low number of inventions for this year.

¹⁸ See epo.org/applying/european.html for more information about the European patent application route.

¹⁹ This figure is based on procedural information related to the payment of maintenance fees for EP patents in these countries, as available via the EPO worldwide legal event data (INPADOC) service.

This limitation to a small number of European countries with a large gross domestic product differs to some extent from the situation in the field of quantum computing (see [EPO patent insight report on quantum computing](#), Figure 7), which may be due to the different stages of development of these two technical domains.

The analysis also looked at active patent applicants in the field of 2G quantum simulation technologies. For this purpose, patent applicant data was consolidated in the basic data set for this report by aggregating patent applicants belonging to the same corporate tree.¹⁹ Individuals jointly listed with legal entities as patent applicants were also aggregated with these.

The most active applicants in the field of 2G quantum simulation are companies. Most of them are located in the United States, followed by Canada, Europe, China and Japan (Table 1). The exceptions to this are a small number of US-based universities, such as the University of Maryland and Harvard University. The list of most active applicants in the field is headed by Google, followed by IBM and D-Wave Systems.

The picture becomes more nuanced when looking at development over the last few years in more detail. The situation in the 2010s was compared with the period 2020-2021 (Table 2). Whereas Google, IBM and Microsoft head the list in both periods, the rest of the applicants are quite different, suggesting a realignment of research and development activities in the field. In this context, D-Wave Systems was identified as an important example. While they were by far the most active applicant before 2010, the number of inventions from them decreased considerably in the 2010s and even more so in the recent past with respect to 2G quantum simulation technologies.

A closer look at the International Patent Families in the field of 2G quantum simulation technologies shows that most patent applications in these families were filed by a single patent applicant. Although International Patent Families with patent applications filed by more than one patent applicant are in the minority (about one-fifth of all patent families), these cases are of particular interest as they provide indications of collaboration between different companies or between companies and academic institutions, either within the same country or across national borders.

Figure 9 shows co-applicant behaviour in the field as an indication of co-ownership of the invention. The chart is helpful in identifying collaboration between applicants. Collaboration can be mainly observed between research institutions and between specific companies and research institutions. A prominent example is the US-based company IonQ, which is a spin-off of the University of Maryland and Duke University, another academic institution in the United States. IonQ applied for patent protection jointly with both universities.

The country of residence is another interesting aspect when looking at co-applicant behaviour in the field because it helps to understand whether collaboration is taking place among applicants in the same country or region, or over greater distances. Figure 10 shows the co-applicant pattern in the field of 2G quantum simulation, with a breakdown by country of residence of the applicants. Collaboration can be identified both between applicants in the same country, such as mainly in the case of European applicants, and between applicants in different countries. A prominent example of the latter are joint activities between applicants in the United States and Japan.

¹⁹ The corporate tree covers the subsidiaries and companies (legal entities) in a holding structure.

Figure 2

Number of DOCDB patent families per earliest publication year related to 2G quantum simulation technologies

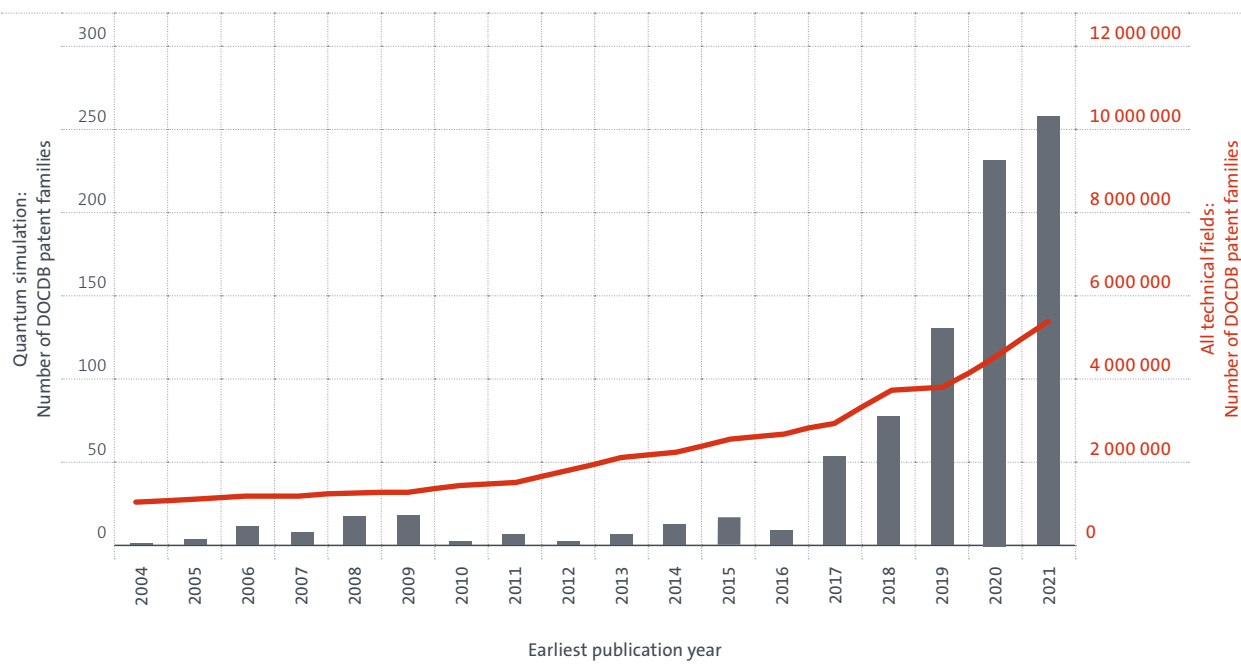


Figure 3

Number of inventions per earliest publication year in the field of 2G quantum simulation, with limitation to International Patent Families

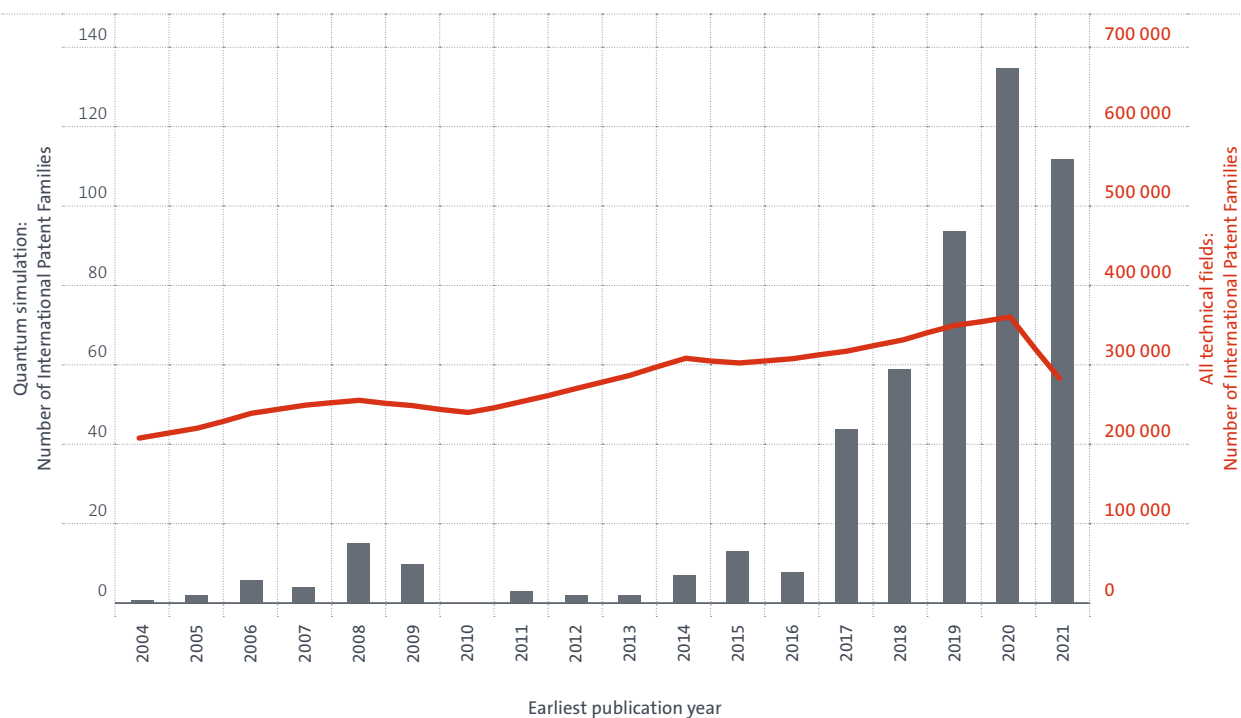


Figure 4

Breakdown of filing statistics in the field of 2G quantum simulation by publishing patent authority and by earliest publication year

The chart below shows the proportion of International Patent Families with patent family members published by specific patent authorities.

Fractional counting by patent authority was used. For each patent authority, only one patent publication in the patent was counted, which helps to avoid double counting and over-representing the patent authority.

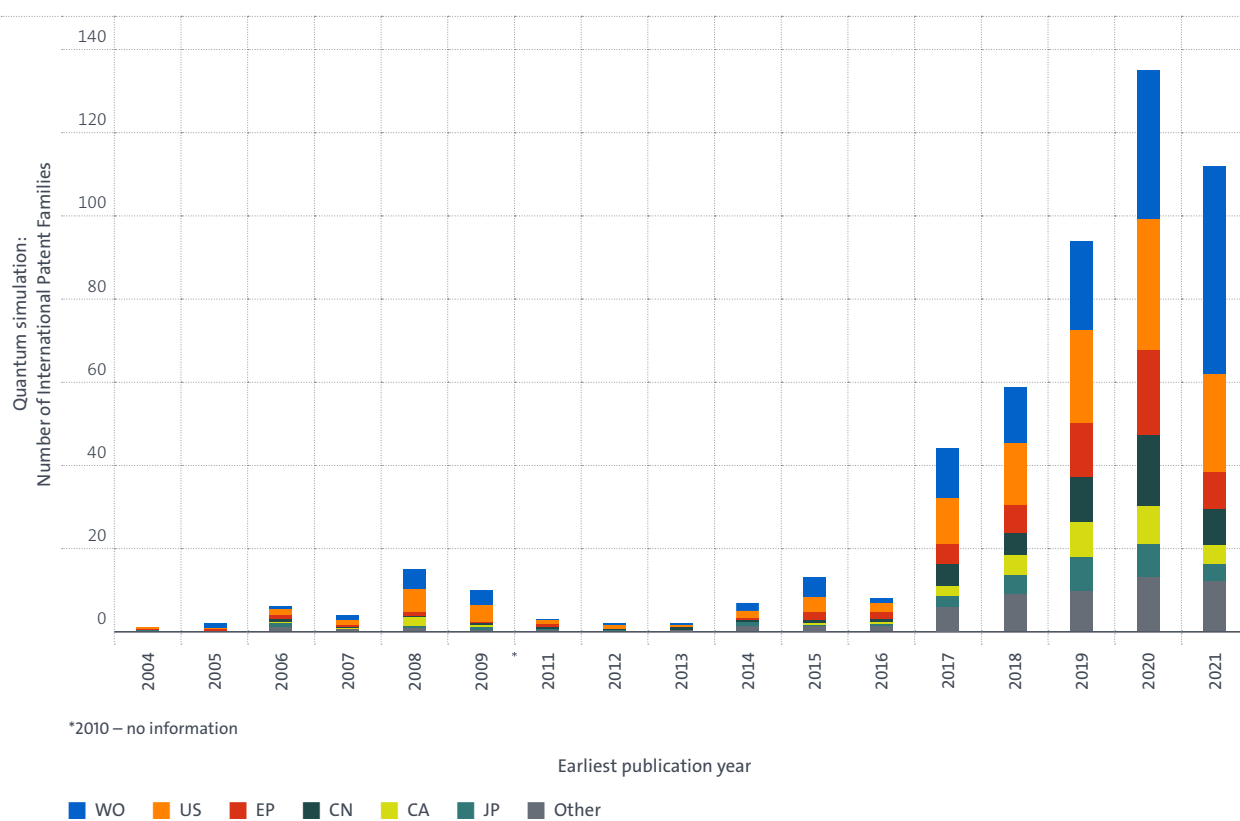


Figure 5

Breakdown of filing statistics in the field of 2G quantum simulation as to publishing authorities, per earliest publication year

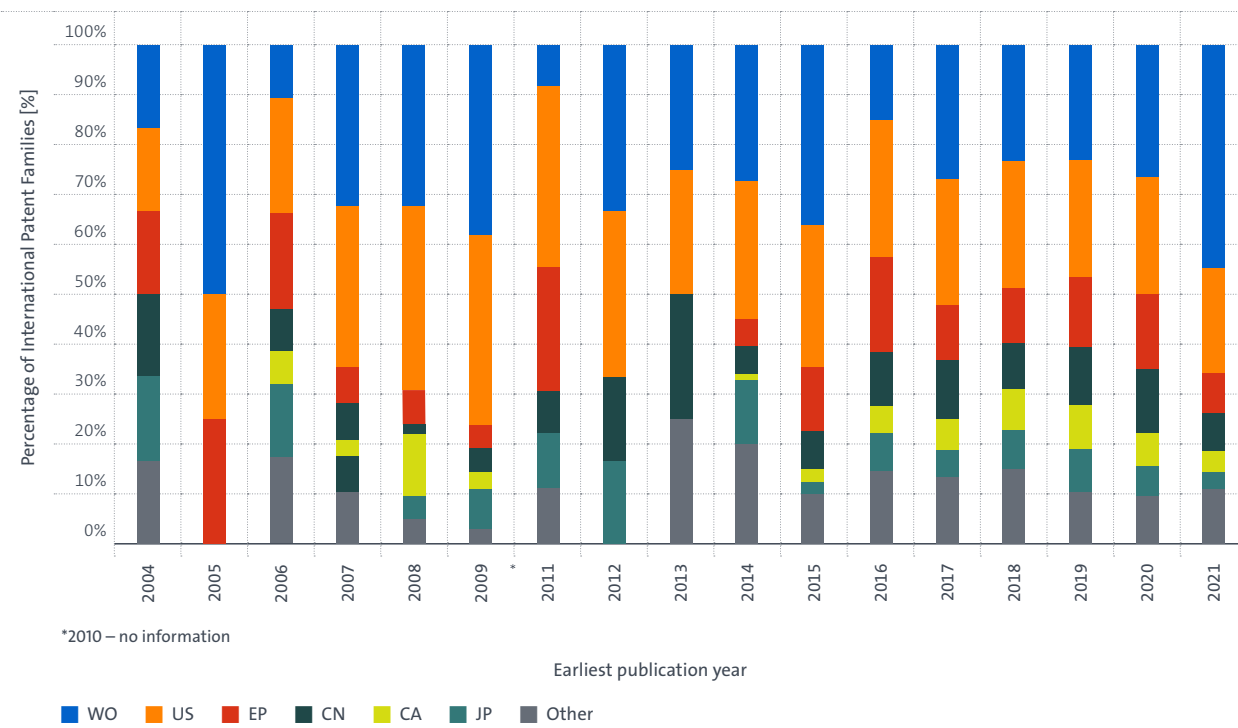


Figure 6

Breakdown of filing statistics in all technical fields by publishing authority and by earliest publication year

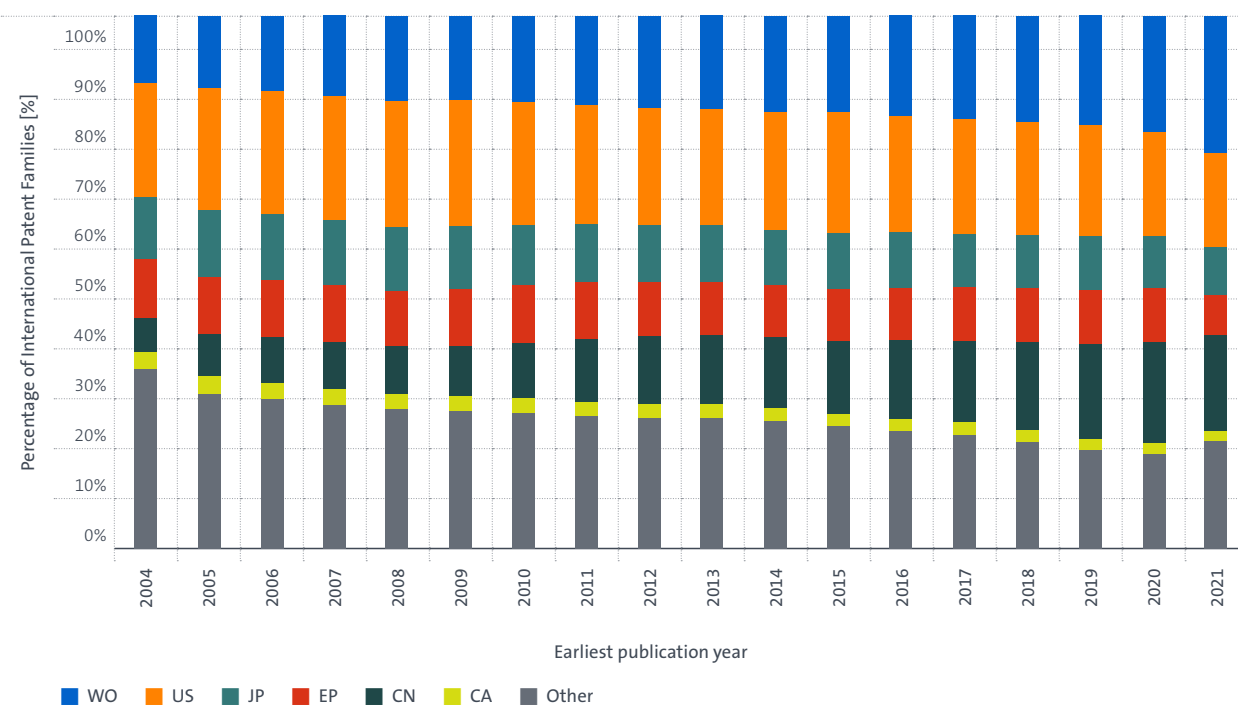


Figure 7

Proportion of granted EP patents in International Patent Families in the field of 2G quantum simulation technologies which were validated and maintained in a member state of the European Patent Convention, in an extension state or in a validation state

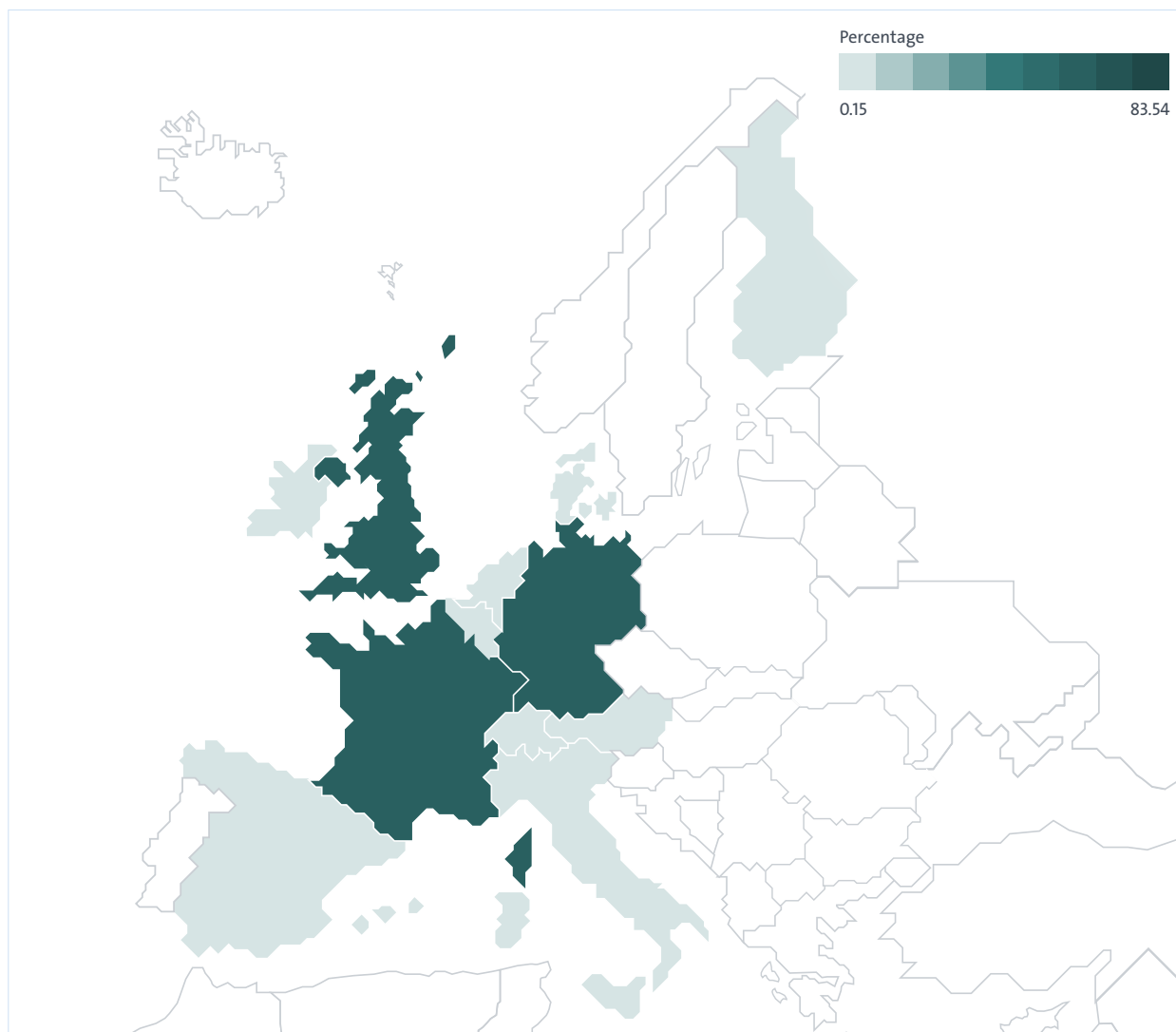


Figure 8

Proportion of patent applications in the field of 2G quantum simulation for which a patent was granted. See section 3 for information on the proportion of EP applications for which a patent was granted

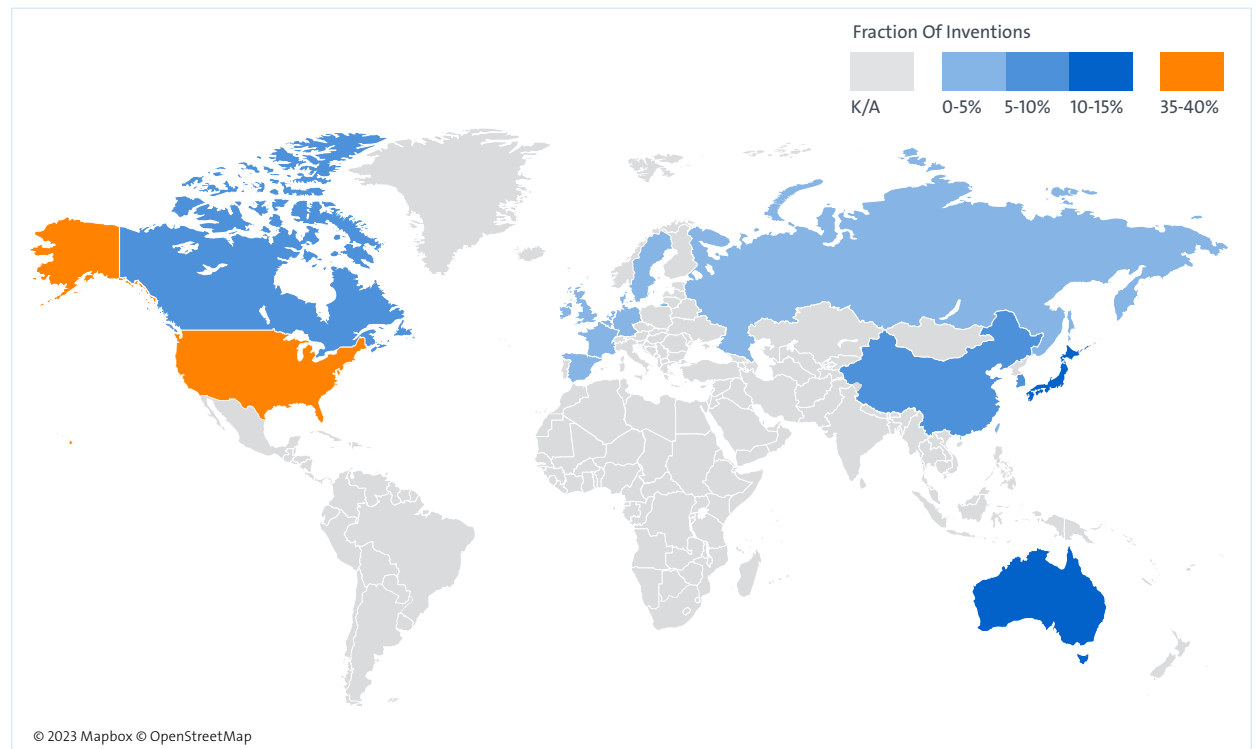
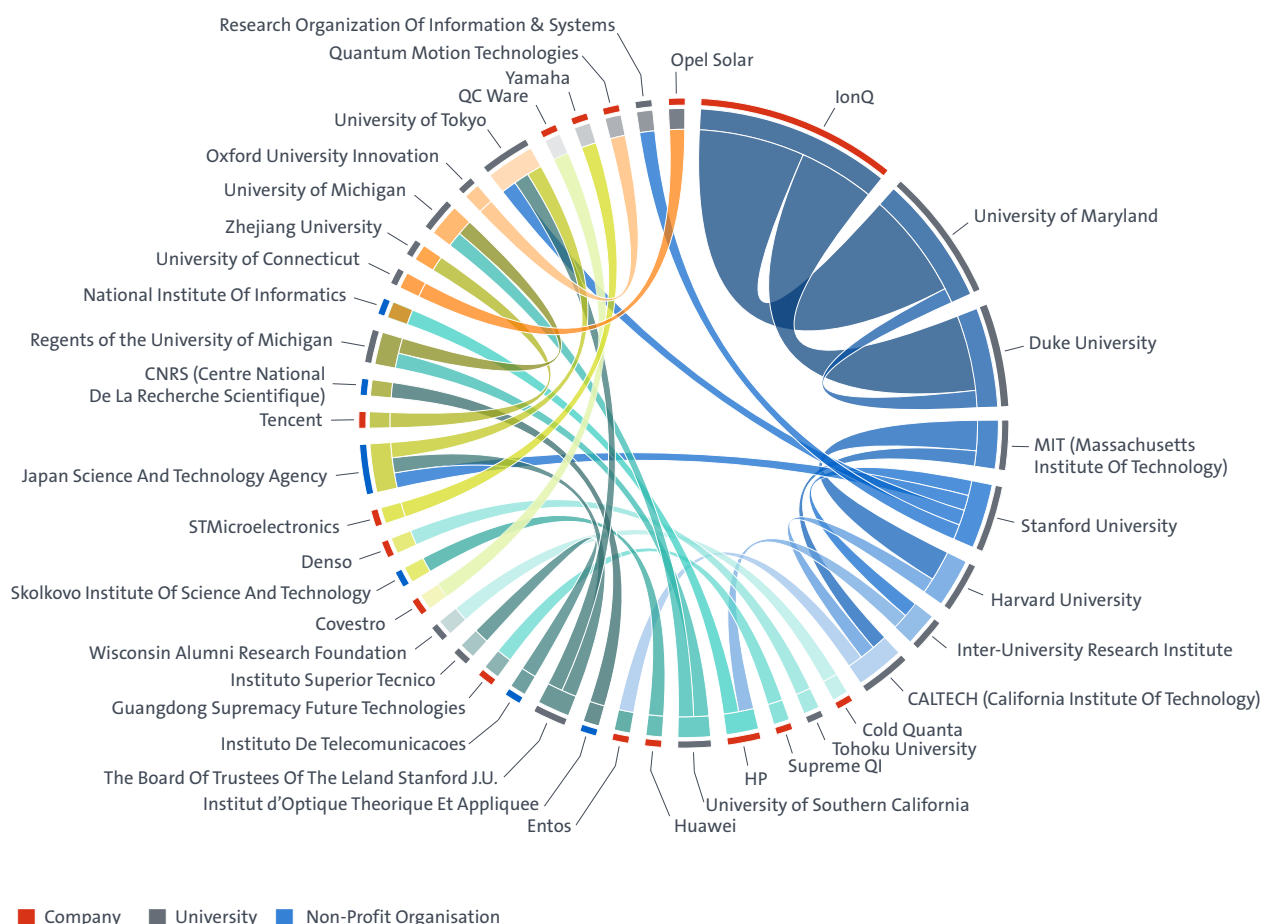


Figure 9

Co-applicant pattern in the field of 2G quantum simulation for International Patent Families, broken down by applicant and displayed as a chord diagram



This chord diagram represents the inter-relationships between applicants in the light of joint patent applications in International Patent Families in the field of quantum simulation.

Each applicant is represented by a segment around the circumference of the circle, which are in different colours to make the diagram easier to read. The chords between the segments represent the number of joint applications. Their thickness reflects the number of International Patent Families with patent applications filed by applicants that are connected by the chord. The thicker the chord, the higher the number of International Patent Families.

Table 1

Most active applicants in the field of 2G quantum simulation

Applicant	Country of residence	Sector allocation	Number of International Patent Families
Google	US	Company	117
IBM	US	Company	51
D-Wave Systems	CA	Company	37
Microsoft	US	Company	32
Rigetti & Company	US	Company	18
1QB Information Technologies	US	Company	16
IonQ	US	Company	14
Accenture Global Solutions	IE	Company	13
Intel	US	Company	13
Fujitsu	JP	Company	11
University of Maryland	US	University	11
Harvard University	US	University	11
Bull	FR	Company	9
Zapata Computing	US	Company	9
Tencent	CN	Company	8
Ericsson	SE	Company	6
MIT (Massachusetts Institute Of Technology)	US	University	6
Quantum Motion Technologies	GB	Company	5
Northrop Grumman	US	Company	5
Duke University	US	University	5
Huawei	CN	Company	5

Table 2

Breakdown of most active applicants in the field of 2G quantum simulation, for the periods 2010-2019 and 2020-2021

Applicant	Country of residence	Sector allocation	Number of International Patent Families
2010-2019			
Google	US	Company	70
IBM	US	Company	19
Microsoft	US	Company	18
Intel	US	Company	11
Rigetti & Company	US	Company	9
1QB Information Technologies	US	Company	8
D-Wave Systems	CA	Company	6
University of Maryland	US	University	5
Northrop Grumman	US	Company	5
Accenture Global Solutions	IE	Company	5
2020-2021			
Google	US	Company	38
IBM	US	Company	27
Microsoft	US	Company	13
IonQ	US	Company	10
Rigetti & Company	US	Company	8
Tencent	CN	Company	8
Zapata Computing	US	Company	8
Bull	FR	Company	7
University of Maryland	US	University	6
Harvard University	US	University	6

Figure 10

Co-applicant patterns in the field of 2G quantum simulation for International Patent Families, broken down by country of residence, and superimposed onto a world map

The size of the circles in this figure represents the number of International Patent Families with applicants from a specific country. The thickness of a connection between two countries represents the number of International Patent Families which include patent applications where applicants from these countries have jointly filed for patent protection.



Figure 11

Breakdown of filing statistics in the field of 2G quantum simulation by patent authority with which the earliest patent application was filed and by earliest publication year

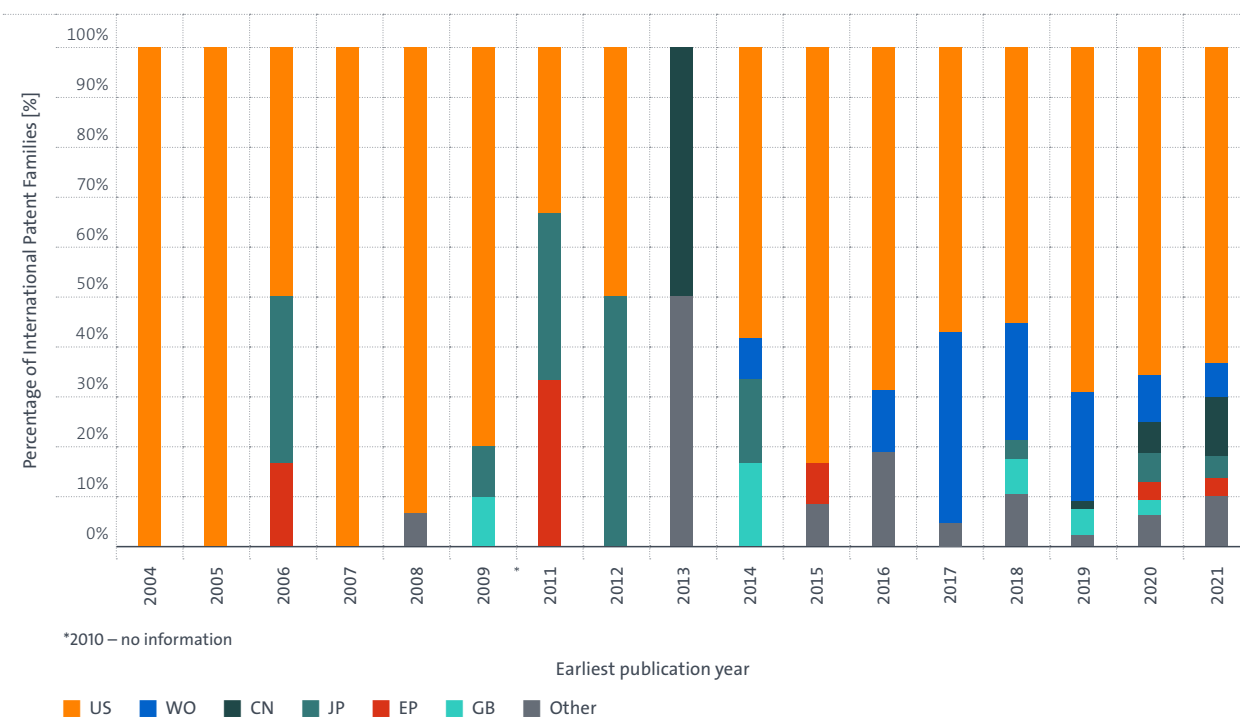
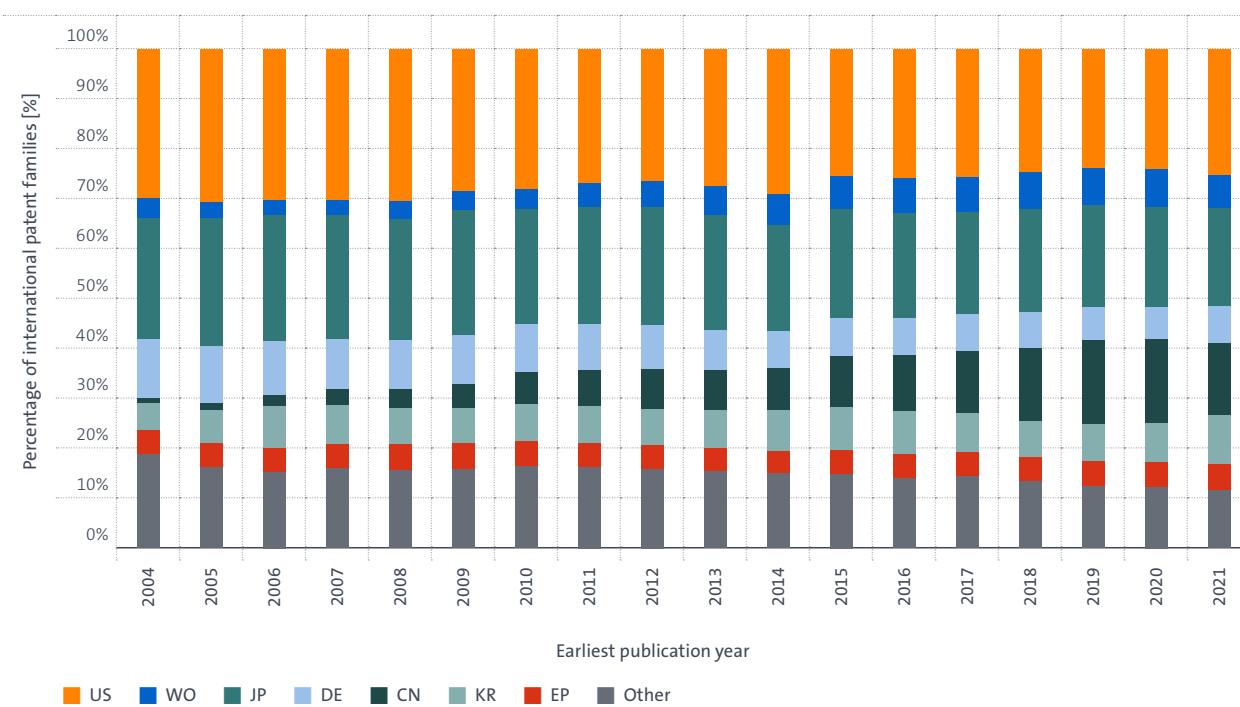


Figure 12

Breakdown of filing statistics in all technical fields by patent authority and by earliest publication year



4. Conclusions and outlook

This report shows that while patent application numbers are still low, the field of 2G quantum technologies is very dynamic, and the momentum in that field is clearly above average compared with the general increase in patent application numbers across all fields of technology in the recent past.

An important finding of the report is the key role of applicants from the United States. The most active applicants in the field of 2G quantum simulation are companies, with Google and IBM heading the list. Most of them are located in the United States, followed by Canada, Europe, China and Japan. The exceptions to this are a small number of US-based universities.

In view of the high momentum in the field of 2G quantum simulation technologies and the high number of exciting inventions in this area, the EPO intends to update this report in the future and take a closer look at how this field has developed and diversified.

Annex

Notes on the limits of the study

This report provides a snapshot of the field of 2G quantum simulation, taken in the light of patent data.²⁰ The methodology on which this report is based can be used freely, i.e. everyone can adapt the chosen search and analysis approach to their needs, for example to follow trends and developments in other established or emerging technical fields.

This report makes use of publicly available EPO worldwide patent data and EPO internal and publicly available search and analysis tools.

Like many patent analyses, this report is based on dedicated search strategies combining keywords and patent classification symbols. The search strategies are included in the supplementary materials document that accompanies this report.

For most patent analyses, it is impossible to simultaneously achieve 100% recall – i.e. to retrieve as many relevant documents as possible – or 100% precision – i.e. to exclude as many non-relevant documents as possible. This study is not an exception. The search queries chosen to create the basic data set for the field of quantum simulation were designed to strike a balance between recall and precision in order to provide a meaningful overview of the field.

²⁰ Date of extraction of the basic data set from the EPO's internal data platform: April 2023. The basic data set was combined with data from the EPO's PATSTAT product line (Autumn 2022 edition), which used backfile data from the EPO's master documentation database (DOCDB) extracted in July 2022.

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