Revealing Development Trends and Key 5G Photonic Technologies Using Patent Analysis

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Featured Application: This study explores the development trend of 5G photonic technologies, thereby providing a reference for the government to promote these emerging technologies.

Abstract: In recent years, 5G photonic technology has gradually gained increased attention from scholars. However, studies on 5G photonic technology have mostly focused on technological discussions or market development research, but have failed to identify the relevant key technologies from a comprehensive perspective. In particular, 5G photonic technology is an interdisciplinary technology that could create considerable potential business opportunities in the future, therefore, identifying related key technologies is crucial. Accordingly, the patents of 5G photonic technologies were used as the basis for analysis in this study, and a patent technology network for such technologies was constructed using network analysis. The results showed that the key technologies of 5G photonic technology are mainly related to optics, nanostructures, semiconductors, and material analysis, indicating an interdisciplinary feature instead of focusing only on one specific technological field. Additionally, the relevant technologies that have seen active development in recent years are mainly related to optical elements and semiconductor devices. Finally, a patentee analysis demonstrated that information technology companies were the key players in the development of 5G photonic technologies, and the semiconductor industry will have a crucial role in the development of such technologies. In this study, a patent technology network model was constructed to explore the development trend of 5G photonic technologies, thereby providing a reference for the government to promote these emerging technologies.

Keywords: fifth-generation mobile communication system; photonic technology; patent; key technology; network analysis

1. Introduction

Photonics is a science that explores the use of photons as information and energy carriers [1]. Photons are characterized by a lack of electric charge and mass, low energy consumption, and insusceptibility to external influences. They can solve problems related to electromagnetic interference-induced operation delays and energy loss due to the shortened distance between components and wires arising from the miniaturization of semiconductors. Accordingly, photons have become a crucial emerging technology in the post Moore’s Law era, with photonic technology being one of the five technologies proposed as key enabling technologies by the European Union’s Horizon 2020 program [2]. Electric signals can be converted into optical signals through photonic technology to transmit data in order to increase transmission distance and data bandwidth while reducing energy consumption, all of which are huge potential advantages in cloud computing, the Internet of Things (IoT), and 5G networks [3–6].
The development of 5G satisfies the requirements of the connection between people and the connection between objects. 5G communication is 100 times faster than 4G communication, with only one-tenth of 4G’s delay time. The other benefits of 5G over 4G can be further defined in three application scenarios. The first of these scenarios is enhanced mobile broadband that supports more efficient data transmission through improved network coverage and capacity, such as virtual reality, augmented reality, and other computationally intensive experiences [7]. The second benefit is the promotion of massive IoT application services in fields such as smart homes and smart cities [8,9]. According to Gartner, a global research and advisory firm, the world is expected to have over 20 billion connected objects in use by 2020 [10]. Finally, 5G is a key technology in many growth sectors that provide key services, such as autonomous vehicles, smart factories, and smart healthcare [11–13]. These service applications, which were previously constrained in speed and stability under 4G networks, could be implemented following the advent of 5G.

Preliminary discussions have been conducted with regard to the use of 5G photonic technology [4,14,15]. Because next-generation (5G) wireless communication systems require the high-speed processing of considerable amounts of data and a wider bandwidth, bandwidth has become increasingly important; transmission technologies require a substantial number of antennas [14]. Photonic technology is the key technology for the future of 5G. The realization of 5G network infrastructure will considerably benefit from advanced photonic technologies to fulfill those requirements [16]. In the future, the long-distance transmission of considerable amounts of data will directly enter terminal machines, or even memory or processing chips, in the form of optical signals. Because the application of 5G is not limited to consumer mobile communication (its application includes Internet services such as IoT, automated vehicles, and smart homes) and photonic technology is the key technology for the implementation of 5G, this study focused on 5G photonic technology and explored the relevant key technologies and their development trends. The study results may serve as references for governments and the industry for the allocation of research and development resources and the formulation of research and development directions.

Previously, research on 5G photonic technology mainly focused on technical discussion [4,14,17] or market development research [3,16,18]. These studies have not actively discussed the key areas of photonic technology in 5G development. In particular, the development of 5G involves numerous technological fields [12,13,19], and holds the potential for unlimited business opportunities in the future. Patents are the manifestation of technology industrialization, and patent application is conducive to providing business opportunities that monopolize the technology market. Thus, this study focused on patent data and observed the key areas and trends in the technological development of key technologies using network analysis.

In summary, this study differs from previous research on 5G photonic technology and the related market. In particular, a comprehensive examination was conducted of the layout of 5G technologies and an overall picture of photonic technology in 5G was presented from a macro perspective, focusing on the establishment of a technology network model and the analysis of technology development trends. This can provide a valuable reference for the government, researchers, and industry professionals.

2. Literature Review

2.1. Development of 5G

IoT is a new communications paradigm that will expand current Internet technologies and enable machine to machine (M2M) communication. The next-generation 5G radio access technology will be a key component of the networked society. 5G will support considerable numbers of connected devices and meet the real-time and high-reliability communication needs of mission-critical applications [9]. 5G will provide wireless connectivity for a range of new applications, such as cloud-based image computing, the Internet of Vehicles, smart manufacturing, smart energy, wireless
healthcare, unlimited home entertainment, the Internet of Drones, social livestreaming networks, personal artificial intelligence assistance, and smart cities.

5G-related investments are constantly growing. According to a recent report by TechNavio, the global market size of 5G equipment will grow by US$16.28 billion from 2019 to 2023, with a compound annual growth rate of approximately 71% [20]. Currently, numerous countries are planning to use the expired 3G spectrum for the development of 5G. For example, China has planned for its 5G system to use the 4800–5000 MHz and 300–3600 MHz bands, in addition to millimeter waves, to comply with the International Telecommunication Union’s IMT-2020 standards. The United Kingdom announced the 5G Testbeds and Trials Programme in 2018, which involved launching large-scale 5G trials in the United Kingdom [21]. Private companies (e.g., Gigaclear) have begun to allow large- and medium-sized enterprises to use paid trials for high-speed 5G networks. Verizon Wireless, a wireless communication service provider in the United States, has collaborated with Samsung (South Korea) to deploy and test 5G networks in five U.S. cities. These cases suggest that 5G technology is receiving increasing attention from governments and technology companies.

The increased global attention toward 5G technology is primarily because of its higher data transmission rate and faster response time. The long-distance transmission of a large amount of data to modems in buildings is currently achieved using optical signals transmitted through fiber optics. These signals are then converted into electric signals. In the future, the optical signals will directly enter terminal machines and even memory and processing chips. This will require the close integration of photonic components and complementary metal-oxide-semiconductors. Therefore, photonic technology in 5G has recently been given increased attention [4,16–18]. The importance of photonic technology in 5G is explained further in the following section.

2.2. The Importance of Photonic Technology to 5G Networks

Photonic technologies are largely used in optical communication systems and networks due to their unique characteristics in term of bandwidth, immunity to electromagnetic fields, compatibility with optical fiber, and flexibility [18]. Applications involving the use of photonic technologies have thus far been applied extensively in long-distance and metro transportation systems and in passive optical network (PON)-based access systems [16]. In the development of 5G technology, passive optical networks have become an attractive option due to their effective use of fiber resources and point-to-multipoint topology. In addition, 5G wireless communication technology requires each user or object to have an increase in bandwidth of three orders of magnitude (>500 Mb s$^{-1}$). Thus, the satisfaction of requirements in bandwidth and power consumption is urgently needed. Photonic technology is expected to have an increasingly important role in information and communications technology, because fixed high-capacity links are largely based on this technology [18].

Following the increase of mobile data traffic, the requirements of high-quality network services and user experiences can be met by photonic technology. For example, the application of optical networks as the fronthaul in mobile communication networks has been receiving academic attention [22,23]. Additionally, the standards for 5G fronthaul optical networks are being discussed. In terms of the development potential of 5G photonic technology, this study mainly focused on photonic technology in 5G and determined its key technologies through patent analysis. Searching for key technologies was performed using network analysis. The following section further illustrates this analysis approach.

2.3. Patent Technology Network Analysis

In recent years, studies have explored the development path of specific technologies using network analysis [24–26], through which the knowledge map and technology positioning of a country can be determined [27,28]. Moreover, the current state of technology transfer and technology industrialization has been explored through patent analysis [29–31]. Network analysis can accurately display the evolution pattern of technologies and communication paths of information. The analysis of patent data can provide objective and feasible information, including the number of patents, year of patent
approval, and technology type [29]. Accordingly, analyzing the development of specific technologies through patent data is valuable. Therefore, this study explored the connectivity and co-occurrence between technology nodes using network analysis. The division of technology nodes was based on the studies of Kim and Bae [32] and Park and Yoon [33]. Mature patent classification structures were used as the foundation of our analysis and the key players in the application of photonic technology in 5G technology were analyzed through patent technology network analysis to observe the areas of focus of 5G photonic technology and to understand technology development trends.

3. Research Design

3.1. Search Strategy and Data Source

This study mainly collected data from the U.S. Patent and Trademark Office (USPTO) database for patent analysis. The main reason for this was that the United States is the world’s largest commercial trading market, and inventors often apply for patents in the United States while applying for patents in other countries. Additionally, researchers generally use the USPTO database for measuring global innovation activities [34,35]. The patent data were U.S. patents issued between 1 January 2014 and 30 April 2019. Derwent smart search, a precise search method, was employed to conduct patent searches. As a key word search method that involves manual reading and organization, Derwent smart search first requires the complete reading of official patent disclosures in the database by hundreds of experts. Subsequently, translation, abstract rewriting, content debugging, and the normalization of patentee information were conducted, after which the rewritten and normalized data were stored in the database. The search criteria of this study were as follows: (SSTO/5th-Generation) AND (SSTO/photonic). A total of 24 patents were retrieved. For the classification of technology networks, the USPTO and the European Patent Office implemented the Cooperative Patent Classification (CPC) system in 2013. Thus, the CPC system was used as the basis for the analysis framework of this study.

3.2. Key Technology Analysis

A participant can be defined as a star or gatekeeper through network analysis, thereby determining whether the said participant is a key player [36,37]. Previous studies have adopted the network centric analytic approach to identify key players in a network [38,39], with participants in a network center having a greater influence on other participants [36]. Because each patent can belong to multiple CPCs, a larger number of different CPCs appearing in the same patent indicates a strong technological correlation between CPCs. Accordingly, the relationship between the CPC (node) and the frequency of patent occurrence between CPCs (edge) can be used to construct a patent technology network. The participant at the center of the network is known as the key node, that is, the node that receives a high level of attention. According to social capital theory, the value of a network node depends on the centrality of the node within the network [40]. This approach was applied in this study, where the key technologies within the patent technology network were identified through network centrality. The following section further describes the measurement of network centrality.

3.2.1. Closeness Centrality

Closeness centrality refers to the reciprocal of the sum of the shortest distance between a particular node and other nodes. A closer distance between a particular node and other nodes indicates that the node has a higher degree of closeness or proximity. In technology networks, closeness centrality can measure the global centrality of a particular technology, thereby determining its linkage with other technologies.

$$C_C(i) = \left[ \sum_{j=1}^{n} d(i, j) \right]^{-1}$$  \hspace{1cm} (1)

where $d(i, j)$ denotes the distance from nodes $i$ to $j$. 
3.2.2. Betweenness Centrality

Betweenness centrality refers to some nodes within the network that must depend on other nodes, that is, mediators, to connect with other nodes in the network. It can be used to measure the importance of nodes for data transmission. Within a technology network, a node with higher betweenness centrality indicates that the technology node occupies a key position in the network structure, and the connection and circulation between other technology nodes must depend on that particular technology node.

$$C_b(i) = \sum_{i\neq j \neq k} d_{jk}(i)/d_{jk}$$  \hspace{1cm} (2)

where $d_{jk}$ denotes the number of shortest paths from nodes $j$ to $k$; $d_{jk}(i)$ represents the number of shortest paths from nodes $j$ to $k$ that must pass through node $i$.

3.2.3. Structural Holes

In addition to betweenness centrality, another alternative that can measure node mediators is a structural hole. A structural hole describes the characteristics of a particular node that occupies the main channel of the network communication message. This is termed the hole effect [41], that is, the degree of dependence of the connection between the clusters on a particular node. Burt [42] noted that the hole effect could be measured through reinforced structural holes (RSHs), ranging from 0 to 1. A high value of RSHs indicated a superior hole effect.

$$C_{ij} = \sum_k (1 - m_{ij}) p_{ik} (1 - m_{kj})$$  \hspace{1cm} (3)

$C_{ij}$ denotes multiplying the sum by the extent to which there is an $i$-$j$ structural hole for $i$ to define a variable RSH that varies from 0 to 1 with the extent to which the network around $i$ reinforces an $i$-$j$ structural hole; $p_{ik}$ is the proportional strength for $i$ of this connection with $k$ (the connection between $j$ and $i$ divided by the sum of $i$'s other connections); $m_{ij}$ represents the marginal strength of $i$'s connection with $j$ (the connection between $j$ and $i$ divided by $i$'s maximum connection in $i$'s network); $m_{kj}$ denotes the marginal strength of $k$'s connection with $j$ where the summation is across all of $i$'s contacts $k$, $k \neq i$, $j$. The expression $C_{ij}$ is zero when no $i$-$j$ structural hole exists for $i$ ($m_{ij}$ equals one) or all of $i$'s other contacts are bridges to $j$ (all $m_{kj}$ equal one). The index approaches 1 to the extent that $j$ is disconnected from $j$, and $i$’s closest contacts are also disconnected from $j$.

4. Empirical Study

4.1. Patent Search Results

The patent search results were first analyzed before a technology network analysis was conducted to preliminarily understand the relevant technology development. Research indicates that a third-order patent technology classification code is sufficient to represent the technological characteristics of the patent in its relevant fields and is also close to industry classifications [43–45]. Table 1 shows the top five third-order CPCs of 5G photonic technology.

| Ranking | CPC Classification Number | Frequency of Appearance | Percentage |
|---------|---------------------------|-------------------------|------------|
| 1       | H04B                      | 19                      | 25.33%     |
| 2       | H04W                      | 12                      | 16.00%     |
| 3       | G02B                      | 8                       | 10.67%     |
| 4       | H01Q                      | 3                       | 4.00%      |
| 5       | H04Q                      | 3                       | 4.00%      |

Note: Frequency of appearance denotes the number of times a patent appears in the CPC.
A total of 30 third-order CPC technologies were observed in the third-order CPC distribution in this study. According to Table 1, 5G photonic technology is mostly concentrated technology in H04B, H04W, G02B, H01Q, and H04Q (definitions of each CPC code are presented in Appendix A). In the CPC system, H04B relates to data transmission; H04W relates to wireless communication networks; G02B relates to optical elements, systems, or apparatuses; H01Q pertains to antennas (i.e., radio aerials); and H04Q relates to details of selecting apparatuses or arrangements.

The aforementioned analysis revealed that 5G photonic technology was mainly related to data transmission, wireless communication networks, and optical components. Table 2 shows the analysis results for the top five patentees. According to Table 2, the patentee with the most patents is CommScope Technologies LLC., which has benefited from the development of recent key industry trends such as fiber optics and mobile communications, 5G, and the Internet of Things.

### Table 2. Number of approvals of the top ten patentees.

| Ranking | Patentee                        | Number of Patents | Percentage |
|---------|---------------------------------|-------------------|------------|
| 1       | CommScope Technologies LLC.     | 8                 | 22.86%     |
| 2       | Redwood Systems INC.            | 3                 | 8.57%      |
| 3       | Allen Telecom LLC.              | 3                 | 8.57%      |
| 4       | Andrew LLC.                     | 2                 | 5.71%      |
| 5       | Lockheed Martin Corporation     | 2                 | 5.71%      |

Note: A patent may have more than two assignees.

### 4.2. Key Technology Network Analysis

In terms of the key technologies of patents, this study focused on third-order CPCs. The network model results of the key technologies are shown in Figure 1 and the key CPCs are shown in Table 3.
Accordingly, the most important 5G photonic technologies mainly involve applying optical elements, systems, or apparatuses (G02B), indicating the gradual maturation of wireless communication networks (H04W), antennas (H01Q), the transmission of digital information (H04L), and devices or arrangements. The optical operation of such devices and arrangements was modified by changing their optical properties to control the intensity, color, phase, polarization, or direction of light (G02F). Furthermore, optical elements, systems, or apparatuses (G02B) were altered using the process of light amplification through the stimulated emission of radiation (laser) to amplify or generate light (H01S). Accordingly, the most important 5G photonic technologies mainly involve applying optical and electrical communication techniques, all of which are indispensable for conducting related interdisciplinary research.

4.3. Postanalysis: Changes in the Key 5G Photonic Technologies Over Time

Changes in the key technologies related to CPC codes H04B, H04W, H01Q, H04L, G02F, G02B, and H01S in each country over the past decade were further analyzed to understand the trends related to 5G photonic technologies. The analysis results are shown in Figure 2.

Table 3 shows that codes H04B, H04W, H01Q, H04L, G02F, G02B, and H01S relate to the top three technological fields in terms of closeness centrality, betweenness centrality, and RSHs. This illustrates that the key 5G photonic technologies relate to data transmission (H04B), wireless communication networks (H04W), antennas (H01Q), the transmission of digital information (H04L), and devices or arrangements. The optical operation of such devices and arrangements was modified by changing their optical properties to control the intensity, color, phase, polarization, or direction of light (G02F). Furthermore, optical elements, systems, or apparatuses (G02B) were altered using the process of light amplification through the stimulated emission of radiation (laser) to amplify or generate light (H01S). Accordingly, the most important 5G photonic technologies mainly involve applying optical and electrical communication techniques, all of which are indispensable for conducting related interdisciplinary research.

Table 3. 5G Photonic technology for the top 4 Cooperative Patent Classification (CPC codes).

| CPC   | Closeness Centrality | CPC   | Betweenness Centrality | CPC   | Reinforced Structural Holes |
|-------|----------------------|-------|------------------------|-------|----------------------------|
| H04B  | 18.000               | H04B  | 112                    | H04B  | 0.707                      |
| H04W  | 16.167               | G02F  | 36                     | H04W  | 0.612                      |
| H01Q  | 12.667               | H04W  | 33.833                 | H01S  | 0.437                      |
| H04L  | 12.167               | G02B  | 8.833                  | G02B  | 0.435                      |

Table 3 shows that codes H04B, H04W, H01Q, H04L, G02F, G02B, and H01S relate to the top three technological fields in terms of closeness centrality, betweenness centrality, and RSHs. This illustrates that the key 5G photonic technologies relate to data transmission (H04B), wireless communication networks (H04W), antennas (H01Q), the transmission of digital information (H04L), and devices or arrangements. The optical operation of such devices and arrangements was modified by changing their optical properties to control the intensity, color, phase, polarization, or direction of light (G02F). Furthermore, optical elements, systems, or apparatuses (G02B) were altered using the process of light amplification through the stimulated emission of radiation (laser) to amplify or generate light (H01S). Accordingly, the most important 5G photonic technologies mainly involve applying optical and electrical communication techniques, all of which are indispensable for conducting related interdisciplinary research.

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Figure 2. Changes in the key 5G photonic technologies from 2014 to 2019. Note: The 2019 statistics only contain data until 30 April 2019.

According to Figure 2, most patents in 2015 were related to wireless communication networks (H04W). However, the technologies developed in the past two years have mostly been related to optical elements, systems, or apparatuses (G02B), indicating the gradual maturation of wireless communication network-related technologies and the year-on-year growth of optic-related technologies. Additionally, the development of data transmission–related technologies (H04B) has been relatively strong, suggesting...
that improving the data transmission rate has always been crucial to the development of optical communication technology. In the future, data transmission-related technologies and patents will assume a pivotal role as the amount of data continues to grow.

5. Conclusions

5.1. Discussion

Key 5G photonic technologies were explored using network analysis. The empirical results show that such technologies are mainly related to data transmission, wireless communication networks, and optical components instead of being solely concentrated in a specific field, indicating that the related application and technological development of this technology for 5G networks requires interdisciplinary collaboration. Moreover, an analysis of the major patentees revealed that CommScope Technologies LLC holds numerous patents, indicating that compared with universities and governmental departments, IT companies are the major players in the development of relevant 5G photonic technologies. This also illustrates the potential for 5G photonic technologies in future market development. Driven by market demand, private companies have been conducting research and development in 5G photonic technologies, which is expected to be introduced into the market for commercial application in the near future.

In terms of technological trends, this study revealed that in addition to code H04W components (wireless communication networks), the key 5G photonic technologies have mainly been related to code G02B (optical elements, systems, or apparatuses) components and H04B (data transmission) in recent years, that is, the improvement of data transmission rates through optical communication has become one of the key technologies for the future development of 5G. For example, silicon photonics is used to change electric signals into optical signals to transmit data in order to increase transmission distance and data bandwidth as well as reduce unit energy consumption. The introduction of silicon photonics into the existing complementary metal-oxide-semiconductor fabrication process has become a critical research direction in the related industry. This development trend is similar to that predicted by certain scholars [18,46]. The results of this study also showed the consistency in the current development trends of emerging fields.

Finally, in terms of theoretical contributions, previous research on 5G photonic technologies has mostly focused on technological discussion [4,14,17] or market development research [3,16,18]. However, these researchers were unable to identify the major technological areas, technological development trends, and network distributions between 5G photonic technology domains. This study addressed the aforementioned shortcomings and adopted a novel perspective, namely that which was related to technological areas, to make observations.

In terms of policy recommendations, this study provides valuable information and a technology roadmap of 5G photonic technologies for the government. Key 5G photonic technology developments were studied through a technology network analysis, thus providing relevant information on the promotion of emerging technologies. Specifically, the analysis results revealed information related to the allocation of vital research and development resources and key technologies. For example, this study found that the data transmission field has been the most crucial research field over the past two years, and China has been constantly improving its 5G system spectrum in recent years to comply with the International Telecommunication Union’s IMT-2020 Standards, a technology development direction that is consistent with the research results of this study. Additionally, the 5G Testbeds and Trials Programme in the United Kingdom places considerable emphasis on erecting reliable wireless communication equipment to meet the needs of 5G test sites. Furthermore, the technological development of wireless communication networks is one of the focuses of 5G photonic technology in this study. Verizon Wireless and Samsung have devoted substantial efforts to the deployment of 5G systems in U.S. cities. In particular, Samsung has laid a solid technological foundation in optical communications, such as that related to fiber optic cables as well as other optical communication
components, modules, and equipment. The company’s research focus on photonic technologies may be further applied to the deployment of 5G in the future. The results of this study also demonstrate the importance of optical components in the construction of 5G technologies in the future.

Finally, this study found that 5G photonic technology–related patents have not focused solely on a single field; rather, they are indicative of cross-domain technological development. Studies have noted that an open innovation system is conducive to the development of new technologies, the improvement of innovative performance, and the accumulation of knowledge among different stakeholders [47–49]. Therefore, the government can assist in the integration of related industries in technology development in the future and establish a platform for collaboration between stakeholders in different industries to facilitate cooperation and exchange in order to enhance technological development and competitiveness in said industries.

5.2. Limitations and Future Research Directions

First, this study only adopted patents as the basis for analyzing technology development trends. Even though the patents reflected the technological development trends in certain markets and that manufacturers had a competitive edge in obtaining valuable technologies, a time gap still existed in the observation of the research frontier. Information related to the latest technologies may be available in different forms, such as theses or technology market reports; however, other forms of information sources were not included in this study, rendering a major research limitation. Second, this study adopted a quantitative approach and may have neglected the depth of a research topic while pursuing a greater breadth. It is recommended that future studies incorporate case studies or other research methods to analyze key 5G photonic technology enterprises, which should increase the academic value of this study. For example, content analysis of patents should continue based on the findings of this study to ensure a more in-depth analysis of related topics. Third, because 5G photonic technology is a recent development, this study only obtained the data of 24 patents using the precise search method, and the search was limited to patents filed in recent years. The lack of data leads to some companies (applicants) only having one or two patents, and the insufficiency hindered this study from performing a more in-depth network analysis such as studying subgroups in social networks. Therefore, this study was unable to perform applicant’s analysis using numerous patents, resulting in the inability to use two-mode network analysis to obtain the layout of each company and the incapability in determining the position of different applicants in various technical fields. Finally, because of personnel and funding limitations, this study only used the CPC system as the basis for technology classifications. However, the CPC approach is overly technology-oriented and incapable of providing scope for an in-depth analysis of the relevant applications and effects of 5G photonic technologies. Therefore, with sufficient personnel resources and funding in the future, a technology-function matrix analysis can be conducted to achieve a more accurate observation of technology trends that satisfy market needs.

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Conflicts of Interest: The author declares no conflict of interest.
Appendix A

Definition of CPC categories.

| CPC Categories | Meaning                                                                 |
|----------------|-------------------------------------------------------------------------|
| G02B           | Optical elements, systems, or apparatus                                 |
| G02F           | Devices or arrangements, the optical operation of which is modified by changing the optical properties of the medium of the devices or arrangements for the control of the intensity, colour, phase, polarisation or direction of light, e.g., switching, gating, modulating or demodulating; techniques or procedures for the operation thereof; frequency-changing; non-linear optics; optical logic elements; optical analogue/digital converters |
| H01Q           | Antennas, i.e., radio aerials                                            |
| H01S           | Devices using the process of light amplification by stimulated emission of radiation [laser] to amplify or generate light; devices using stimulated emission of electromagnetic radiation in wave ranges other than optical |
| H04B           | Transmission                                                             |
| H04L           | Transmission of digital information, e.g., telegraphic communication     |
| H04Q           | Selecting                                                               |
| H04W           | Wireless communication networks                                          |

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