Knowledge and technology building blocks for space access architectures

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Knowledge and Technology Building Blocks for Space Access Architectures

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Abstract

Gateway Earth Development Group (GEDG) is proposing to develop a technically and economically viable architecture for interplanetary space exploration. It also proposes to utilize on-orbit satellite servicing manufacturing, and space tourism as enablers for the development of a space station (Gateway Earth) in Earth's geostationary orbit (GEO). At this station, interplanetary spacecraft could be built and serviced to take astronauts on missions across the Solar System.

This paper, which is a part of an existing draft architecture design, analyses the available knowledge and technology landscape to enable architectural solutions to modular access to space. In particular, it maps all available papers and patents on component modules of the station, focusing on the core of the business model of Gateway Earth – in-orbit satellite repair and manufacturing.

The paper aims to provide the various stakeholders in the field of space access with a broad overview of their position, with respect to ownership of IP, in their particular domain. It will help them strategize their research efforts by identifying white spaces and areas where substantial work is needed. It can also be a useful tool in identifying the right partners to collaborate and minimize the duplication of efforts.

Since the technology blocks for space access can be quite broad, this paper will utilize WIPO's (World Intellectual Property Organization) International Patent Classification system to classify the technologies for analyses and providing intelligible insights.

Keywords: Space Access, Modular Architecture, Future, Space Exploration

Acronyms/Abbreviations

ARIPO	African Regional IP Organization
EVA	Extra-Vehicular Activity
GEDG	Gateway Earth Development Group
GEO	Geostationary Orbit
GTO	Geostationary Transfer Orbit
ISS	International Space Station
JAXA	Japanese Aerospace Exploration Agency
LEO	Low Earth Orbit
SRMF	Satellite Repair and Manufacture Facility
WIPO	World Intellectual Property Organisation

1. Introduction

Gateway Earth Development Group (GEDG) is proposing a modular space access architecture pivoted around a crewed space station just above Geostationary Orbit (GEO) [1]. From there critical new missions can be launched into the Deep Space, in particular (back) to the Moon and further to Mars, as well as hosting space travellers and tourists [2].

However, critical for the (economic) viability of such an outpost is the potential for in-orbit satellite maintenance (life extension) and manufacturing, with potential markets in the billions of USD [3].

Unlike other key functions of the Gateway Earth station, the satellite repair and development require new technologies and operational protocols to be established. Here, work by the GEDG has been underway to specify the required configuration of on-board equipment and patent landscape analysis as to its current state of development and future potential.

In this paper, we first outline the key premises behind the Gateway Earth station design, before exploring in more detail the Satellite Repair and Manufacture Facility (SRMF) and GEO satellites repair/release operations requirements (satellite freighters), before analysing the patent landscape of the core required technologies.

2. Gateway Earth Station and In-Orbit Satellite Repair and Manufacture

The baseline Gateway Earth design was proposed to comprise of Bigelow B330-type inflatable modules for living quarters with additional connecting modules, cupola and research/satellite repair/manufacture facility and antenna farm [3]. However, an updated module has been developed to remove the antenna farm (as the station location was revaluated to above GEO) and expand on the details about the component modules and programme (in particular in satellite repair and manufacture), as seen in the schema in Fig. 1.

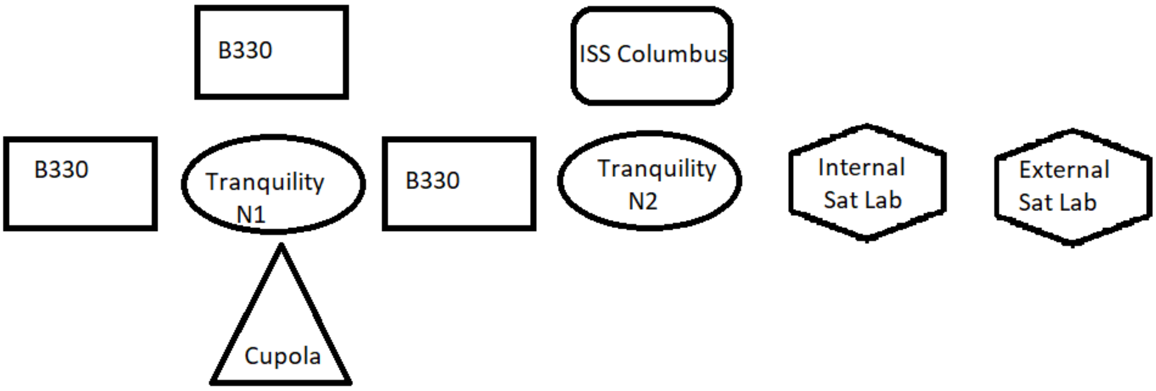

Fig. 1 – Schematic Gateway Earth Modules Design

The main premise behind the satellite servicing in orbit is based on the ability of using freighters to tow an existing GEO satellite to either refurbish faulty components or re-fuel its orbit positioning thrusters. Most of the satellites in GEO are communications or weather satellites, which potentially require upgrades or refurbishments to equipment, such as transponders or visible/IR imagers. Therefore, the space station should come equipped with replacement parts for satellites, or these could be ferried up with cargo deliveries prior to satellite interception by the tug.

Defunct GEO satellites could be cannibalised for solar panels or other useful parts, for example the US weather satellite GOES-15, retired in July 2019, which orbits in the equatorial plane at a height of 35,791.0 km perigee, 35,800.4 km apogee. GOES-15 has a single 2.3kW Gallium-Arsenide solar panel, which could be reused.

Other components could also be useful, e.g. the vis/IR multispectral imager on board GOES-15 or instruments used to measure magnetic fields, solar activity and cosmic radiation. If the satellite in question is beyond repair, the cannibalised components could be used to refurbish other satellites of the same type, should they need parts that would otherwise be too costly to manufacture and launch from Earth, and are already in orbit.

However, most of the electronic components of these systems would likely be degraded beyond use by the harsh radiation environment. Even without salvaging any sensor or processing equipment, cannibalising the bus platforms to build new satellite systems could greatly reduce the cost of satellite manufacture (in-orbit), as well as cap the amount of space junk in GEO and graveyard orbits.

Hence, a suitable facility on Gateway Earth would therefore require the ability to manipulate and deconstruct satellites, in the event of mechanical cannibalism and the capability to perform precise surgery on these devices, in the event that only a single/few piece(s) need to be repaired or replaced, although this may be better suited to human hands in the pressurised lab.

In principle, there are precedents for developing such solutions. For instance, the OSAM-1 mission [4] is set to demonstrate many of the technologies and techniques necessary to make this servicing function practically applicable:

1. An autonomous, real-time relative navigation system that allows the spacecraft to safely rendezvous with target satellites, which could be applied to the satellite tugs
2. Avionics systems designed to both process sensor data and control robotic tasks.
3. Two dexterous robotic arms that are capable of precisely performing servicing assignments, with included software, which could be adapted to the in-vacuum part of the satellite lab.
4. Advanced multifunction tools created with the task of satellite servicing in mind.
5. A propellant transfer system that delivers controlled, measured amounts of fuel to the satellite at the correct rate, temperature and pressure. This is even applicable to satellites never designed to be serviced.

The OSAM-1 mission is also an experiment to test the feasibility of large-scale material printing and assembly in space. In this case, the spacecraft also contains a payload, known as Space Infrastructure Dexterous Robot, or SPIDER, which will manufacture a 10-metre lightweight composite beam, and assemble from seven elements a 3-metre functional Ka-band communications antenna. The technologies demonstrated by this mission, if successful, will facilitate a new era of astro-engineering, in some cases removing the need for ground-based construction of certain elements, instead allowing the payload to consist of only "raw" construction materials to be assembled in-orbit. The application of these technologies and techniques will allow serviced satellites to be expanded beyond their original capacities, equipping them with more powerful communications arrays, power generation facilities, and processing power, further improving the cost effectiveness of initial investments.

3. SRMF Components and Design

As discussed, a major component of the station's operation and commercial viability will be the proposed refurbishment of satellites in GEO. Many of these satellites are communications satellites, launched in some cases decades ago. In such cases, the station could be responsible for correctly refuelling, repairing and occasionally expanding the satellite beyond its original capabilities. This function effectively extends the operational lifetime of satellites to a great extent, increasing the cost effectiveness of these assets.

The SRMF would require many specialised tools to service client satellites. A summary of some of these tools is provided below in Table 1.

Needed Equipment for Sat Labs	**Use on GE**	**Current deployment**	**Notes**
EVA "power screwdriver" -pistol grip tool	Removing panels from satellites to fix, general maintenance	Used on the ISS for fixing	Can withstand heat fluctuations for space. Another model is used for HST that is faster for larger panels
Crane \ Robotic arm	Maneuvering large items, Capture of satellites	KIBO Module arms, Canadarm 2	Canadarm 2 used to help build ISS and is on rails, making it possibly more useful. Also has force sensors
Tethers for EVA suits	Connect astronauts to the ship so we don't have a Gravity-esque incident	Extravehicular mobility unit ISS	EVA ports should be located on opposite ends of the station for ease of access to all locations on the exterior
3D Printer	To print parts or rapid prototype in space	ISS	Can print specific tools for any job. Terrestrial ones can print both plastics and metals
General tool kit	General maintenance	ISS tool box	An earth training set of the same things on the ISS
Astrobee	Helpful hands, can hold tools or bring operators things	Took over from SPHERES. Inside the ISS	Cubic robots for holding things, free floating in space

Table 1 – The breakdown of the critical components of internal and external satellite repair and manufacturing tools and facilities.

The so-called satellite laboratories are currently designed to consist of an interior, pressurised module for human use, and an exterior, unpressurised module for robotic manipulation via computer-controlled dexterous grappling limbs and other tools. The pressurised compartment will largely comprise computer monitors to allow human control of the robotic section from a safe enclosure. The SRMF module could conceivably be modelled after the JAXA's KIBO [5] module on the International Space Station (ISS), which already demonstrates the capability to control exterior components, in the case of the JEM-EF, or Exposed Facility (commonly referred to as Terrace).

4.1. KIBO Module Baseline Assessment

The KIBO module [5–7] would be a useful module to use as a the baseline for the design of a satellite repair module. The external section is well sized for satellite repairs and maintenance at 5.6x5x4m, fitting in satellites with room to manoeuvre. The external section also has the robotic arms that are well suited to the job. In their current implementation on the ISS, astronauts control both a heavy arm for big lifting, and a fine arm that is more suited to more intricate jobs. These are on rails to be able to access the whole external section, minimising the need for space walks or unnecessary complications in manipulating large objects. These would provide useful for larger repairs on satellites such as panel replacing.

The downside to the KIBO module as a satellite repair facility is that the satellites cannot be brought to the internal part of the facility for more precise disassembly and procedures. A larger module with more extensive air-lock would be more optimal.

However, even with EVA disassembly and integration, the module is a suitable minimum-viable proposition for satellite repair and manufacture.

Regarding the other external fittings, non-proprietary grapple fixtures would be preferable to the current grapple fixtures on the ISS. On the ISS, the external robotic arms are anchored and confined to their own section of the space station [8], since the Russians use different grapple fixtures than do the Canadian or Japanese sections of the station [9]. The Gateway Earth should incorporate standardised grapple fixtures to remediate this. The flexibility afforded by this would allow the robotic arm(s) greater freedom and mobility on the exterior of the station, to more effectively assist with incoming satellites or payloads.

4.2 GEO Satellite Capture/Release Operations

The cost of launching a payload to Low Earth Orbit (LEO) is significantly less than that of launching to Geostationary Equatorial Orbit (GEO), or to Geosynchronous Transfer Orbit (GTO) on the way to GEO. Once the payload is in a stable orbit, the orbit can be raised by very low-thrust means for relatively little fuel.

This is the concept behind the Cannae Space Freighter [10], an ion drive powered cargo freighter capable of grappling to a payload in LEO and raising the orbit to GEO with almost zero propellant. The freighter, which has a mass of approximately 10 tons, is also capable of continuously accelerating indefinitely. This spacecraft could conceivably save up to $240M per GEO payload launch by eliminating the need for the payload to reach GTO from the ground.

However, another use for this freighter, would be to intercept satellites already in GEO for maintenance and upgrades by SRMF. This is the single viable and thus critical option for satellite capture and release in the correct orbital slot in GEO, for the Gateway Earth station in orbit above GEO [1].

5. Patent Landscape

The technical fields and technologies contributing to the establishment of GEO satellite repair and manufacturing operations on the Gateway Earth station were broadly classified into the following for patent analysis: In-space Manufacturing, Satellite Payload Health Monitoring, Satellite Payload Performance Monitoring, Satellite Freighters, and In-Space Recycling and Reuse Technology.

Further to this classification, keywords were formed, and a full-text patent search was conducted in the World Intellectual Property Organization (WIPO) database [11]. (Please note that patent applications are normally published within 18 months from the date of application, which means that the data for the previous 18 months is subject to change as new applications are published.)

While the field of payload performance monitoring has the maximum number of patents, in-space recycling seems to be just picking-up. The field of additive manufacturing is seeing an upward trend in the number of applications and can be attributed to the increasing interest in the field of 3D printing and research on new materials.

Satellite freighters patent data shows an interesting insight; apart from Boeing and Trion World, other top applicants in this field are all individuals and not organizations.

Patent applications are classified based on their technical field of implementation, and they often give a glimpse of the major focus of inventions in our chosen technology. Based on the data collected, we see that most of the patents in monitoring of satellite payload health and performance fall under the category of "Transmission". This indicates that most inventions focus on ICT (Information and Communication Technology), as compared electromechanical inventions.

As seen on Fig. 2, USA leads the pack with the most patent applications among the top jurisdictions, and the UK, Canada and Australia find themselves in three of the five technical fields. China appearing in the list for In-Space Manufacturing and Russia for Satellite Freighters are in-line with the traditional areas of focus of their respective research areas. South Africa and ARIPO (African Regional IP Organization) appear in the list for Payload Performance Monitoring.

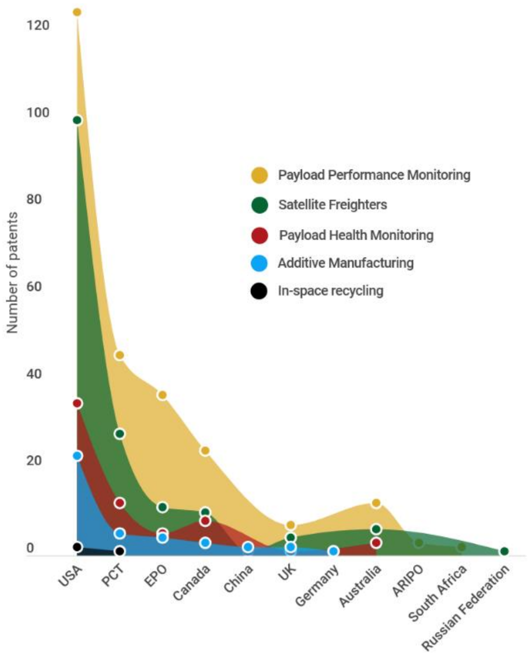

Fig. 2 – Breakdown of patents within the five target technical fields, broken down by jurisdiction.

There is a visible lack of applications from the South American and Asian continents, which can be attributed to the nascent stage of space activities and research in most of the countries there. Also, even among countries that have a history of space activities, such as India and Japan, most of the space-related research and activities are performed only by the state-owned space agencies, which are known to focus on traditional capabilities such as satellite launches. However, an increasing entrepreneurial activity in space research globally and recent developments like India opening the space sector for private players, we can expect the landscape to considerably change over the next decade.

5. Conclusions

The interest in commercial activities in space has seen an upward trend over the last few years. With decreasing launch costs and increasing capabilities of other technologies such as Artificial Intelligence and Robotics, the possibilities of new ventures off-Earth, be it asteroid mining or space tourism, have never seemed more viable. This is very evident from an increased interest in additive manufacturing in space and reusing space resources.

With the number of start-ups and entrepreneurial ventures aimed at commercialization of space on the rise [12], the next few years would see a number of major players and stakeholders emerging from this ecosystem, who could become major partners to an initiative like Gateway Earth.

As this paper analysed, new developments in in-orbit satellite repair and manufacturing could be a game-changing opportunity for commercial activities in GEO, as well as a way to mitigate the accumulation of space junk in high-altitude and graveyard orbits. The current proposal of a crewed space station just above GEO, i.e. the Gateway Earth, has been developed further to include details of the technological systems and tools required for such work.

This was analysed from a patent perspective, too, and there are many untapped areas and technical fields within the broader technologies that enable in-orbit satellite repair and manufacturing in GEO. The Appendix part of this paper illustrates the patent trends in some of those broader technology areas, and it could be used as a baseline for anyone wishing to perform a more detailed analysis before investing time and resources in their ventures.

This paper forms part of the critical development of a holistic Gateway Earth space access architecture proposal [13], which is currently being finalised as part of the GEDG cornerstone White Paper. We believe in the next decades a wealth of specific applications will be brought forward and we welcome partners from around the world in the final research and development of the next stage of space exploration and industry – a human GEO outpost.

Acknowledgements

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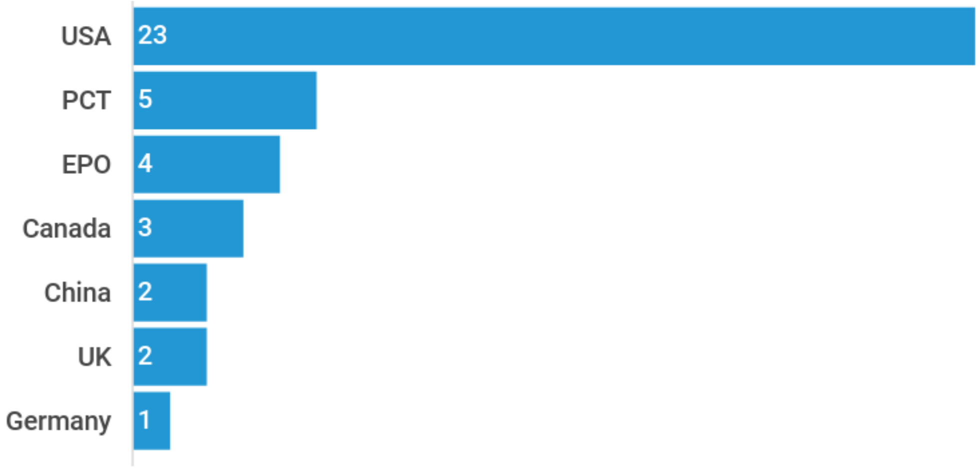
Appendix

Manufacturing in Space
(Key-phrase: in-space manufacturing)

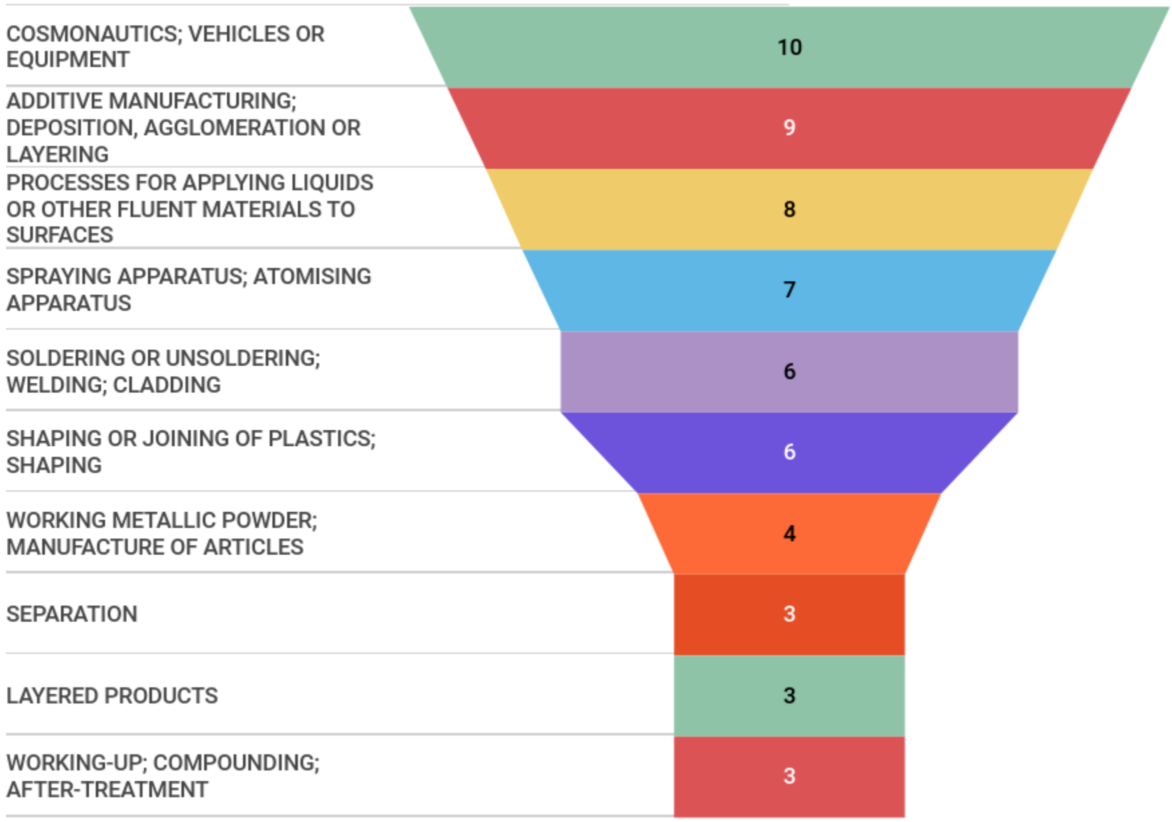
Top Jurisdictions



Top Applicants

Manufacturing in Space

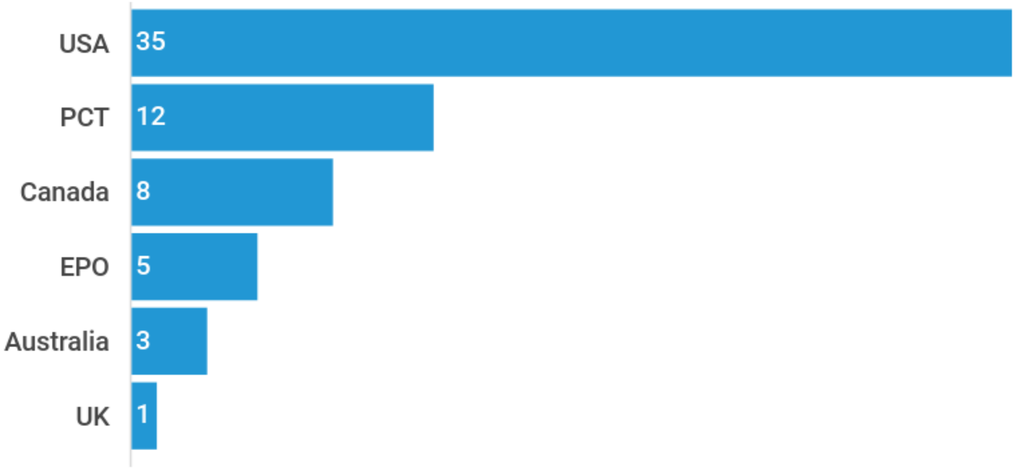
Top technical fields (As per IPC Codes)



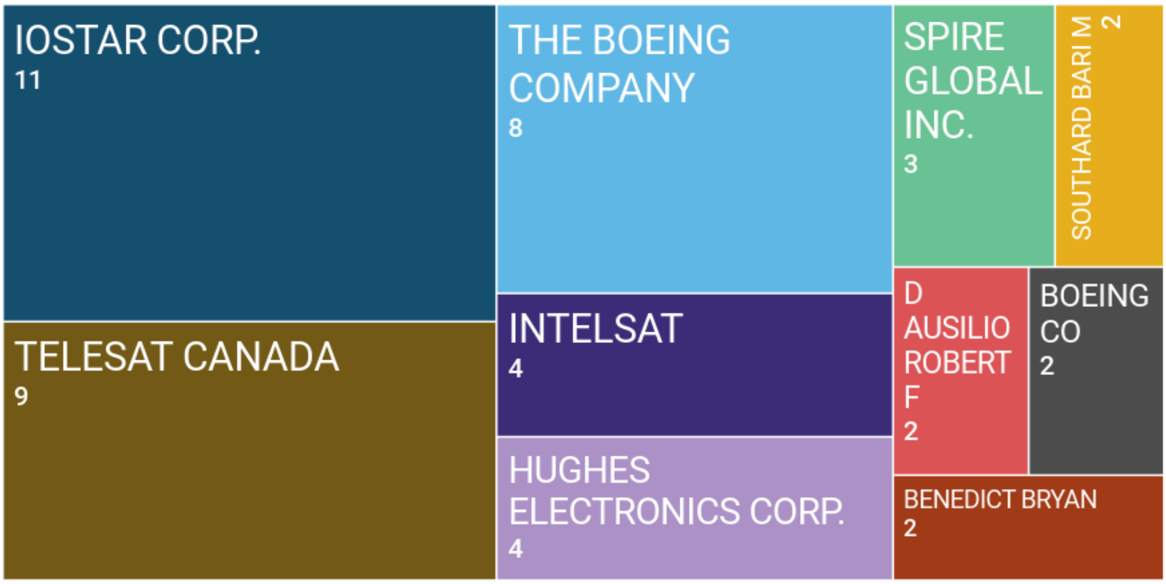
Applications trend over the last decade

Satellite Payload Health Monitoring
(Key-phrase: "satellite payload" "in orbit" health monitoring)

Top Jurisdictions

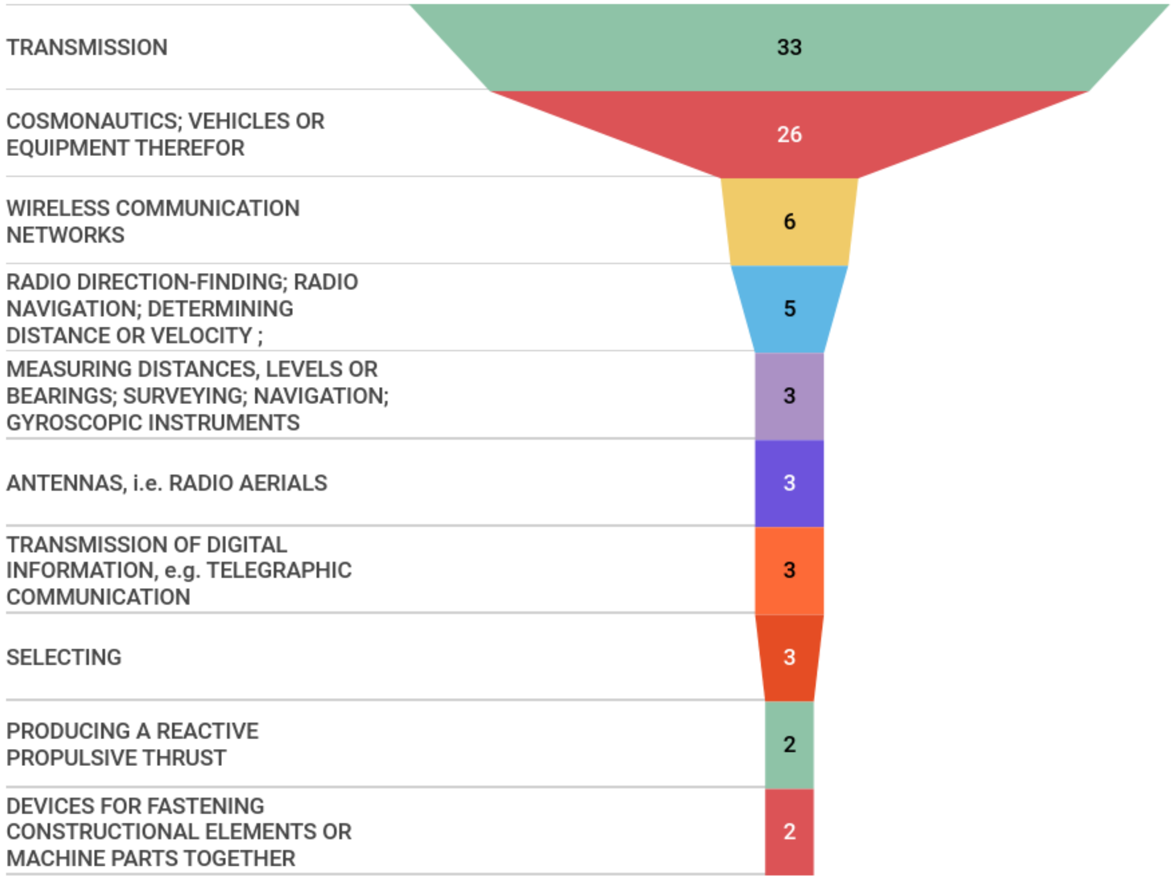


Top Applicants

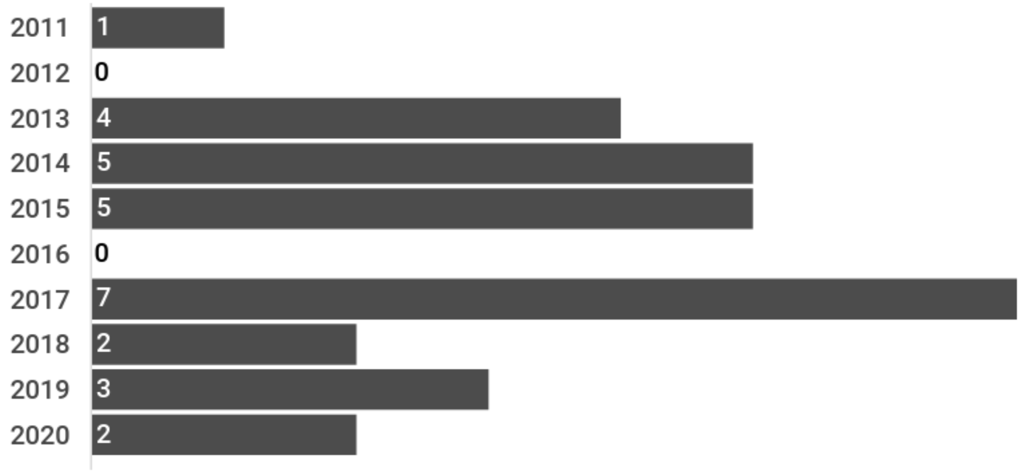


Satellite Payload Health Monitoring

Top technical fields (As per IPC Codes)

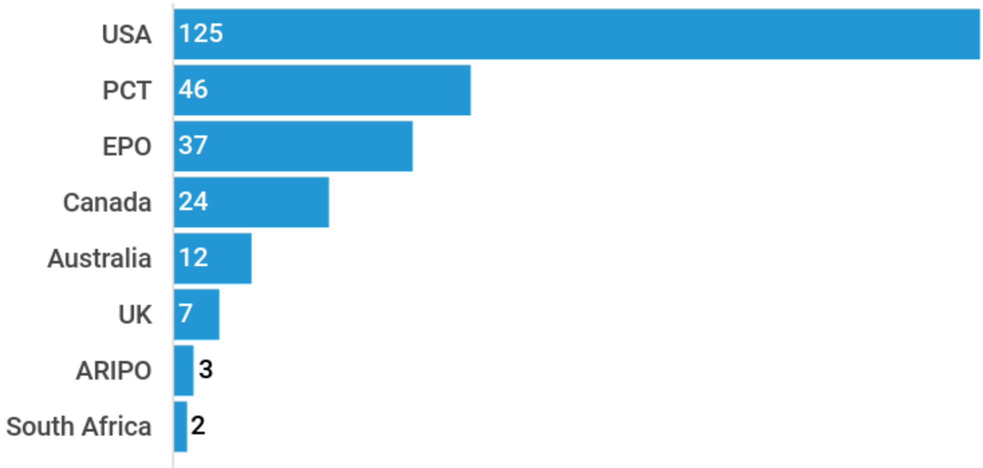


Applications trend over the last decade

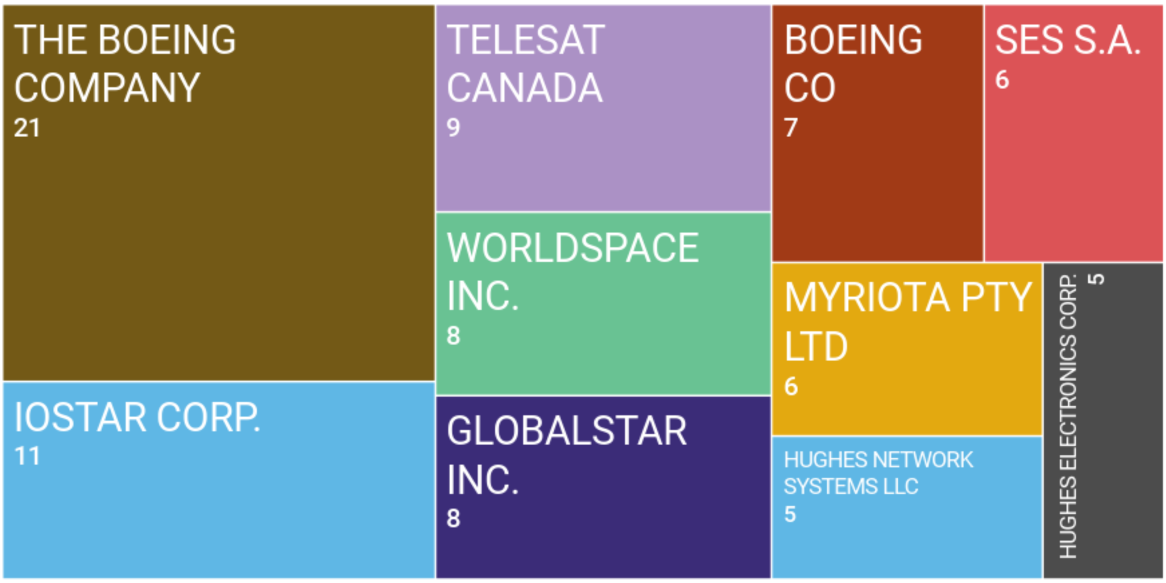


Satellite Payload Performance Monitoring
(Key-phrase: "satellite payload" "in orbit" performance monitoring)

Top Jurisdictions

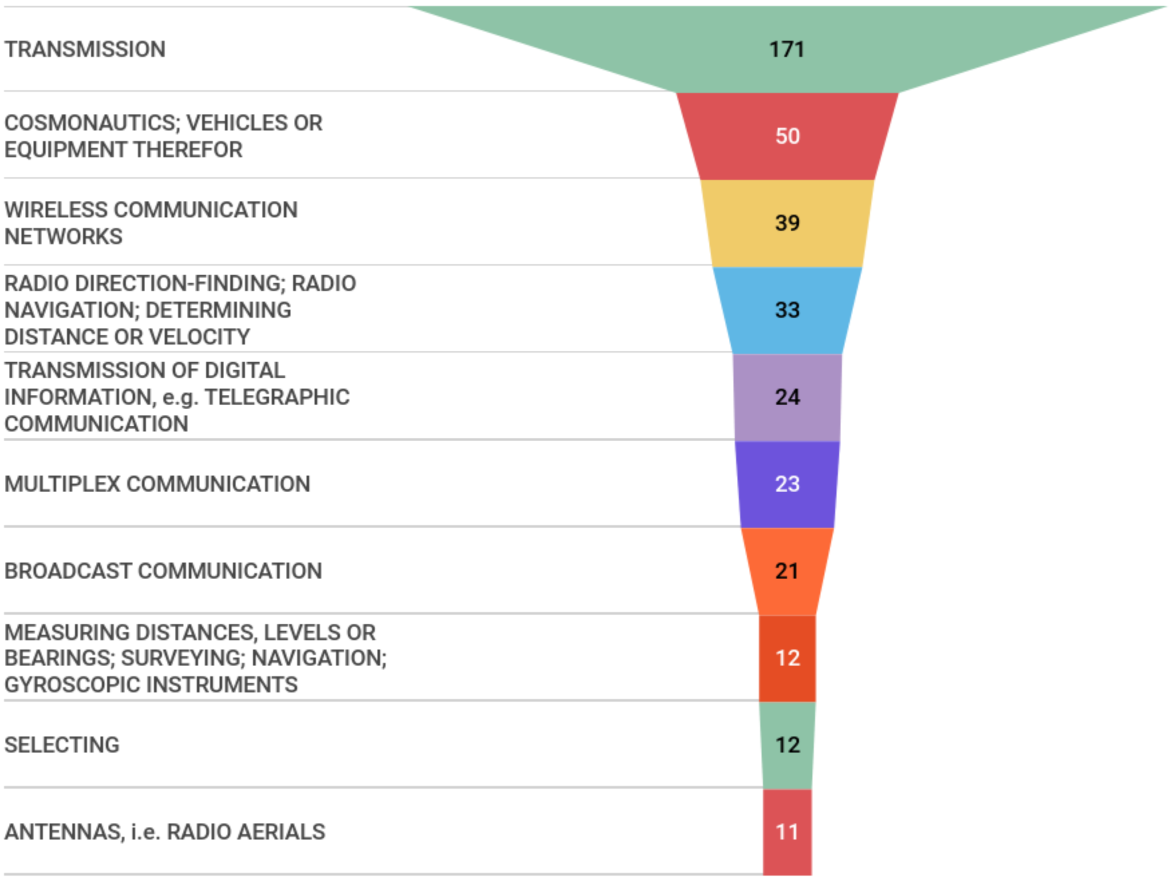


Top Applicants



Satellite Payload Performance Monitoring

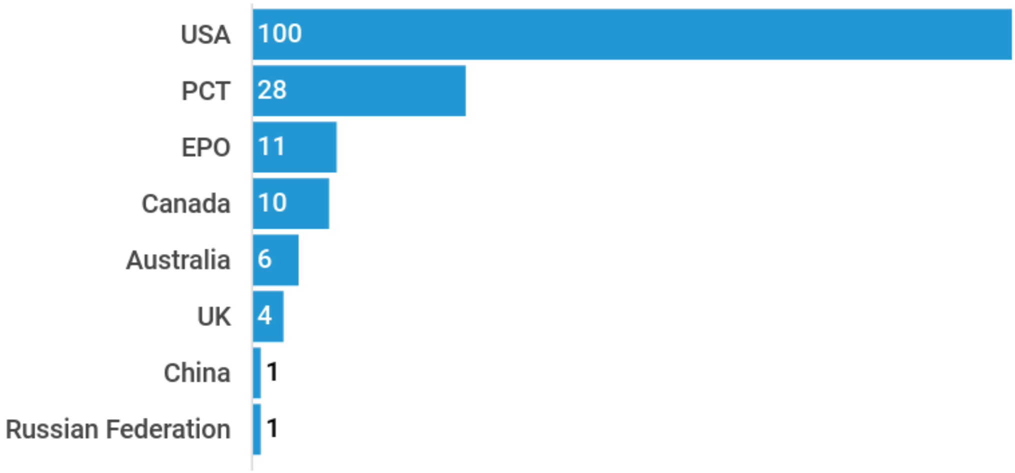
Top technical fields (As per IPC Codes)



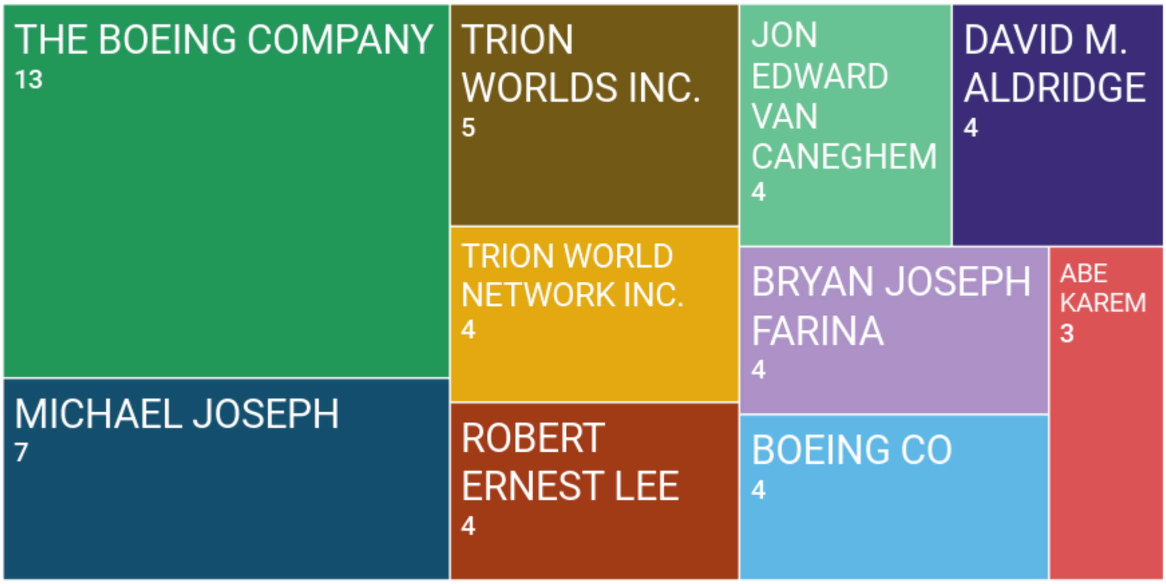
Applications trend over the last decade

Satellite Freighters
(Key-phrase: satellite freighters)

Top Jurisdictions



Top Applicants



Satellite Freighters

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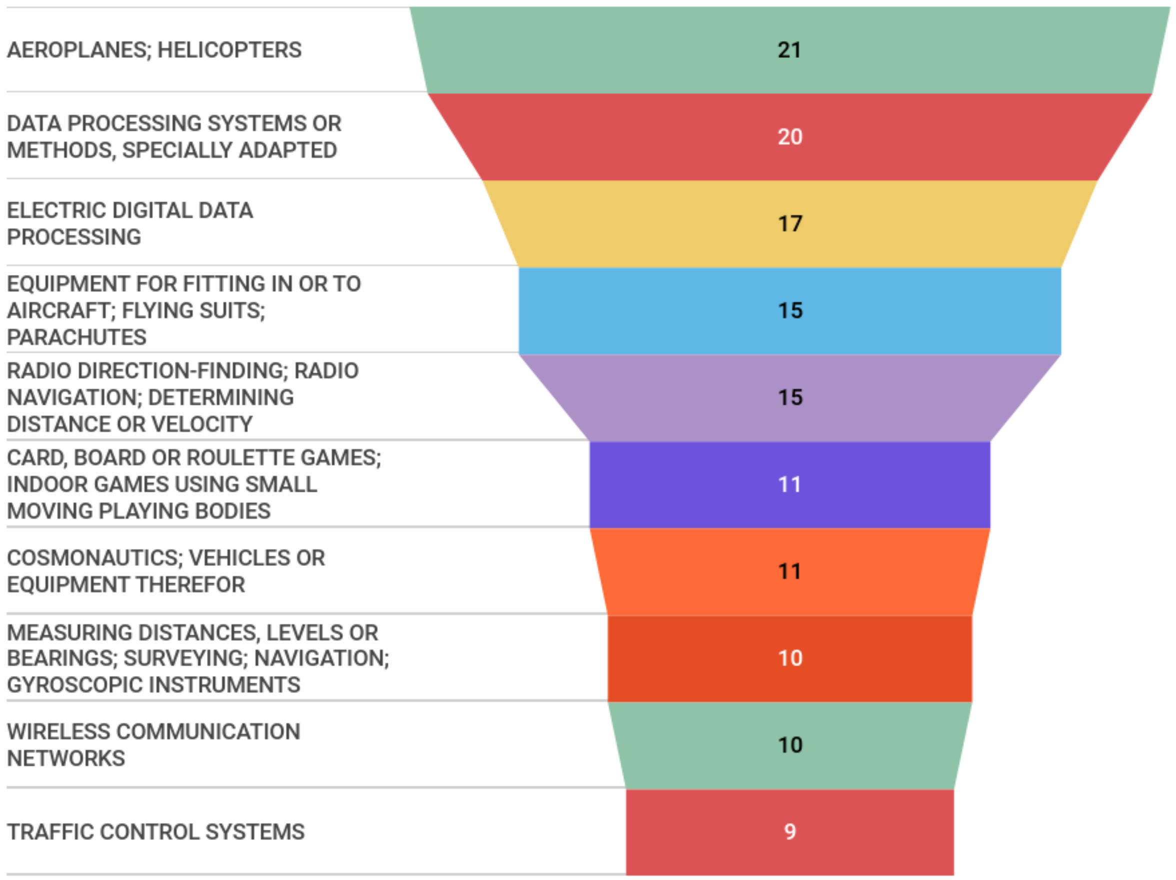
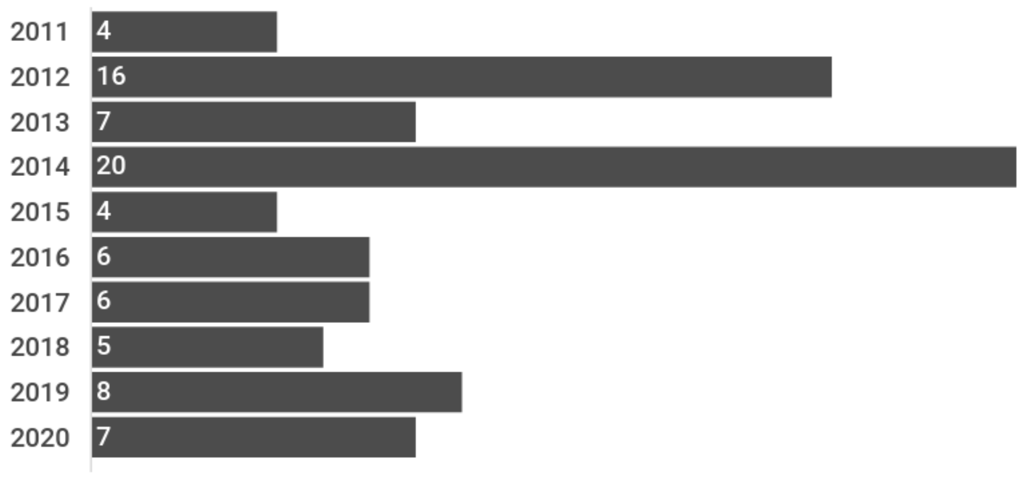


Applications trend over the last decade



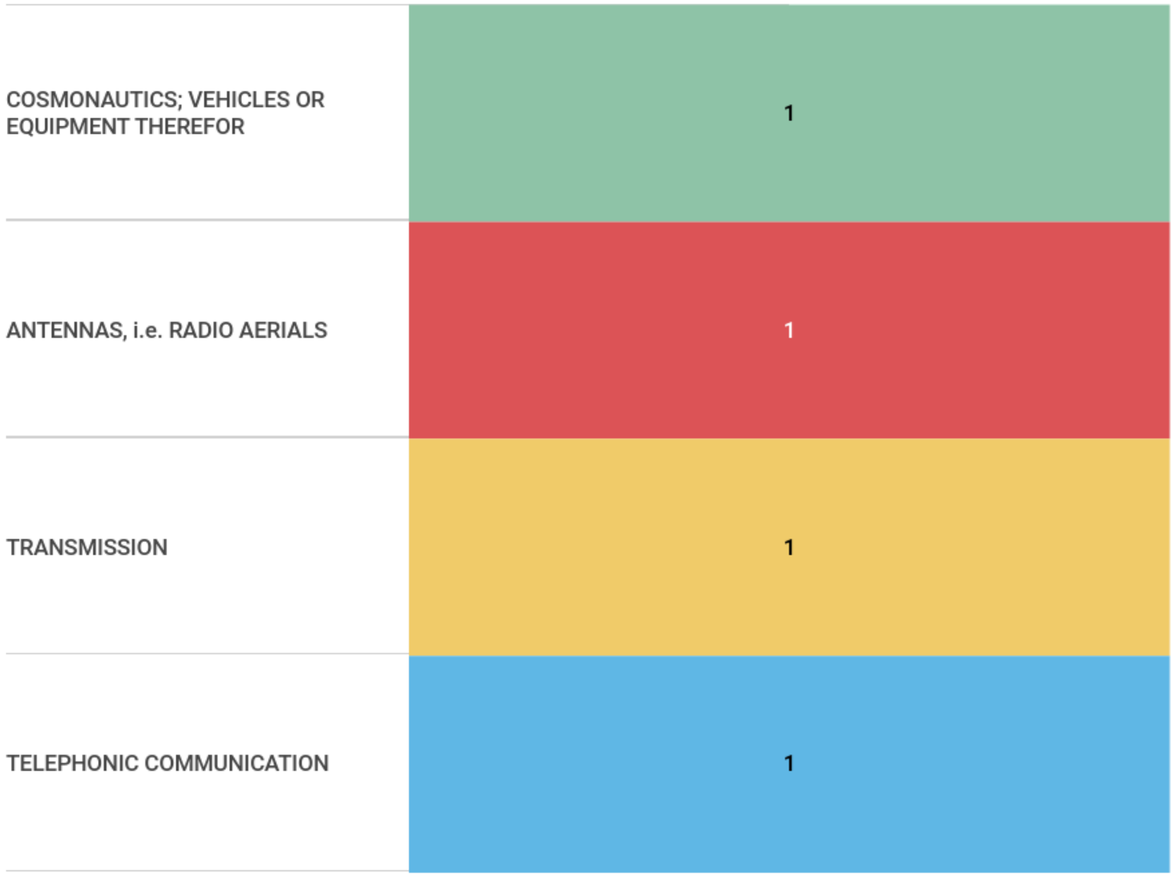
In-Space Recycling & Reuse Technology
(Key-phrase: in-space recycling)

Top Jurisdictions

Top Applicants

In-Space Recycling & Reuse Technology

Top technical fields (As per IPC Codes)



Applications trend over the last decade