ISRO's technical prowess through the prism of patents

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The present article primarily analyses the patenting trends of the Indian Space Research Organization (ISRO) since its formation. The social dimensions and technical prowess of ISRO are well known, but till date no work has been done in analysing its patent portfolio, to let the people be aware of its development, through the prism of patent analysis. This article reports ISRO's patenting activities over the past four decades and has mapped the areas in which patents have been granted. Further, it also discusses how ISRO can be part of the era of open innovation and use its inventions economically.

Keywords: ISRO, open innovation, patent analysis, space research.

OUR nation was still in its infancy when the Indian Space Research Organization (ISRO) had its inception in 1962, to live by its motto 'Space Technology in the Service of Man-kind'; this was one of the earliest endeavours by the Government of India. As the motto would suggest, the mission was to advance the country primarily in the field of space science and technology. India decided to make its ventures in the field of space science and technology with the establishment of the Indian National Committee for Space Research (INCOSPAR). With the visionary Vikram Ambala Sarabhai at its helm, INCOSPAR set up the Thumba Equatorial Rocket Launching Station (TERLS) in Thiruvananthapuram for upper atmospheric research. ISRO superseded the erstwhile INCOSPAR. ISRO then embarked on its mission to provide space-based services to the nation and develop technologies to achieve the same independently.

Throughout the years, ISRO has dedicated its service to the common man of India, and it stands as the sixth largest space agency in the world[1]. ISRO maintains one of the largest fleet of communication satellites – Indian National Satellite (INSAT) and remote sensing (IRS) satellites available for reliable communication and earth observation respectively. It develops and delivers application-specific satellite products and tools to the nation: broadcasts, communications, weather forecasts, disaster management tools, Geographic Information System (GIS), cartography, navigation, telemedicine, dedicated distance education satellites being some of them. A complete self-reliance in terms of these applications was achieved by developing a cost-effective and reliable launch system, which took form as the Polar Satellite Launch Vehicle (PSLV). Soon, PSLV went on to become the favoured carrier for satellites of various countries due to its reliability and cost-efficiency, promoting unprecedented international collaboration. The Geosynchronous Satellite Launch Vehicle (GSLV) was developed keeping in mind the heavier and more demanding geosynchronous communication satellites.

Apart from its activities in space science and technology, ISRO has also contributed to science and science education in the country. For this, various dedicated research centres and autonomous institutions for remote sensing, astronomy and astrophysics, atmospheric sciences and space sciences have been established under the aegis of the Department of Space. Besides providing various scientific data, ISRO's own lunar, Mars and other interplanetary missions along with scientific projects, encourage and promote scientific temper. ISRO has also contributed immensely towards igniting young minds throughout the country by successful accomplishment of its Mangalayan mission. With such accomplishments, ISRO has accounted for all the public investments made in its name.

The Mars Orbiter Mission (MOM) is the recent feat of ISRO; it is considered as one of the cheapest interplanetary missions which thrusted India into the elite space club. The Prime Minister Narendra Modi has compared this feat with the cost of travel by an auto in Ahmedabad (which is Rs 10/km). According to the Prime Minister, the expenditure incurred in the landmark MOM which India accomplished in the very first attempt is Rs 7/km as the cost of travel for 650 million km distance to Mars[2], and where the cost of the mission amounts close to US$ 74 million.

A comparative study conducted by the Japan Science and Technology Agency (JSTA) showed that India ranks

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sixth among all the countries in the world with space programmes[3]. The study involves parameters such as space transportation system, space applications, space science and manned space activities. This study has shown remarkable progress in space programmes for countries like Russia, India and China, especially in the field of Global Positioning System (GPS) technology. In the space transportation system, it has claimed that India has a launch success rate of 74.4% which is higher than the average of 71.4%. Russia has the maximum number of launches and is the only country to have launched from sea. As of now Europe, Japan and India do not have manned launch capability, which has already been mastered by USA, Russia and China.

Let us briefly have a look at the space budgets of various countries investing in their space programmes. According to an Organization for Economic Cooperation and Development (OECD) report[4] released in 2011, USA has the highest funding amounting to US$ 43,612 million, followed by China (US$ 6100 million), Japan (US$ 3349 million), France (US$ 2747 million) and Russian Federation (US$ 2511 million). The report mentions that India has a budget of US$ 861 million.

Spacecraft and launch vehicles

ISRO has had over 125 missions with 74 spacecraft missions and 45 launch missions, with Aryabhata being the first satellite to be launched by the United Soviet Union in 1975. In 1980, ISRO launched satellite Rohini into the orbit, with a self-made launcher Satellite Launch Vehicle-3 (SLV-3). The wheel has continued to spin ever since, with MOM being another feather to its hat. ISRO has various kinds of satellites under its spacecraft division, namely communication satellites, earth observation satellites, scientific spacecraft, navigational satellites, experimental satellites, small satellites and student satellites[5]. SLV-3 and Augmented Satellite Launch Vehicle (ASLV) were the first of their kind launchers developed by ISRO. Based on the above-mentioned experience, ISRO has developed PSLV (mid-earth orbit satellites; 2000–35,780 km from the surface of the earth) and GSLV (high-earth or geosynchronous orbit; height of about 35,780 km from the surface of the earth) to meet the needs of launching IRS and INSAT class of satellites[6]. PSLV and GSLV are operational satellites. Till now, PSLV has launched over 40 satellites for 19 countries.

Relevance of intellectual property in space science

In the present era, intellectual property has become an indispensable asset for any organization engaged in research and developmental activities. The European Space Agency (ESA) claims to have approximately 450 patent applications and patents for its inventions[7]. They cover subjects such as antennae, satellite attitude control mechanisms, communication equipment and systems, detectors, mechanical engineering, optical communication, power supplies and propulsion systems. The National Aeronautics and Space Administration (NASA), USA claims to have over 1600 patents in its technology transfer portal[8]. It has a comprehensive portfolio related to propulsion, robotics, materials and coatings, sensors, aeronautics, health, medicine and biotechnology, mechanics and fluid systems, electrical/electronics, instrumentation, power generation and storage, optics, manufacturing, communications and environment. Patent is an indicator of technical prowess of an organization, and is a valuable resource of technical information and conglomeration of technology. ISRO was selected for the present study since it is the leading public-funded organization with more than 23 laboratories and field stations extended across the country. This study is primarily about analysis, both quantitative and qualitative of the patents granted to ISRO. Considering the research activities of ISRO over the years and the amount of funds coming in, its patenting trend however seems average compared to other space agencies in the world. In addition, it has exclusively helped in promoting business and entrepreneurship. To the best of our knowledge, there have been no earlier studies covering all the patents granted to ISRO since its inception.

Methodology of the study

The search strategy adopted here is unlike the known ways of patent searching. Novelty search and patentability search normally require search strings and keywords to be formed before a search may be initiated. However, in this case, the patents along with their identification numbers have been published in the ISRO website itself[9]. There was a necessity to search patent office databases of foreign jurisdictions due to the unavailability of certain patents in the Indian Patent Office database. The search was carried out by mentioning the applicant name as Indian Space Research Organization and its various departments like Department of Space (DOS), Vikram Sarabhai Space Centre, etc. Several databases were used for the search, which primarily includes IPAIRS Version 2.0 of the Indian Patent Office, respective patent search engines of USPTO and EPO, PatentScope of WIPO and Google Patents.

A quantitative analysis normally uses bibliographic information contained in the patent documents, document number, patent classification, nationality and name of the applicant and inventor, and the filing and publication date of the patent. In this study the focus is basically on a particular Indian organization, i.e. ISRO and so we have eliminated nationality here. Also jurisdiction has not been

highlighted here since the study mainly focuses on retrieving the patents, analysing them and portrays the general filing trend over the years. The filing date, and data or qualitative assessment of the patent itself are used in this study. A total of 150 granted patents have been retrieved; however, information regarding patents published prior to 1995 could not be retrieved from the Indian Patent Office database. This limitation has been overcome using the INPAT database of CSIR-NISCAIR and LexisNexis patent search tool (trial access for research purpose).

Results and discussion

Quantitative analysis

The present study shows how ISRO has made inventions in various fields of space science and technology over the years, since its inception. The trend analysis has been done with patents available over the last 40 years. Since 1971, the trend has shown a climbing rate over four decades (Figure 1). Maximum number of patents was found to be granted between 1991 and 2000. A highest of 22 patents was filed in the year 1999 followed by 10 patents filed in 2000 and nine patents in 2006.

Patenting trends in various fields of technology: Another important aspect of the study is to find patenting trends in the respective departments of technology and engineering. We found six major areas of technology in which patents have been granted. These are chemical engineering and polymer technology, electronics and electromechanical applications, optics and antenna systems, materials science, communication systems, and sensors and transducers.

As mentioned before ISRO not only works with space-related inventions, but has also invested great deal in other areas that may or may not benefit space technology directly or indirectly. It has been found that 40% (60 patents) of the inventions are related to chemical engineering and polymer technology, which tops the list with the most number of patent applications. Next in line are applications from electronics and electromechanical area with 17% (26 patents) of the total patent applications and 16% (24 patents) from optics and antenna systems. Materials science, communication systems, and sensors and transducers constitute the rest with 13% (20 patents), 8% (12 patents) and 4% (6 patents) of the patent applications respectively (Figure 2).

ISRO has 23 centres all over India along with its subdivisions which were established at different points of time according to requirement; however, most of the patents are from three units, i.e. Bengaluru, Ahmedabad and Thiruvananthapuram. Figure 3 shows that most of the patented inventions are from the Satellite Centres at Ahmedabad and Bengaluru, Laboratory for Electro-Optical Systems, Liquid Propulsion Systems Centre, VSSC and Inertial Systems Unit.

The patenting trend shows that majority of the patent filings are from VSSC, DOS and Space Applications Centre (SAC). Figure 3 shows that after 1995, almost 34% (35 patents) of the 102 patents found are from VSSC. 13% (13 patents) from SAC and 9% (9 patents) from DOS. Other inventions have come from ISRO's Inertial Systems Unit, Antenna Systems Area and Satellite Centre. It should be noted that the patents are not related to space science and technology alone. For example, many inventions from VSSC may be directly or indirectly related to space applications. Further, this centre has several divisions like Propellant Engineering Division, Space Ordnance Group, Special Materials Division, Spectroscopy Division, and Polymer and Special Chemicals Division. VSSC is the major centre of ISRO where the design and development activities of satellite launch vehicles and sounding rockets are carried out and made ready for launch operations[9]. VSSC pursues research and development activities for associated technologies such as launch vehicle design, propellants, solid propulsion technology, aerodynamics, aero structural and aero thermal aspects, avionics, polymers and composites, guidance, control and simulation, computer and information, mechanical engineering, aerospace mechanisms, vehicle integration and testing, space ordnance, chemicals and materials. Systems reliability and quality assurance of all aspects of engineering and

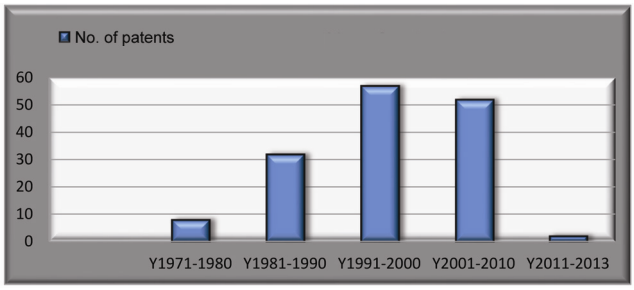

Figure 1. Patents granted over the past four decades.

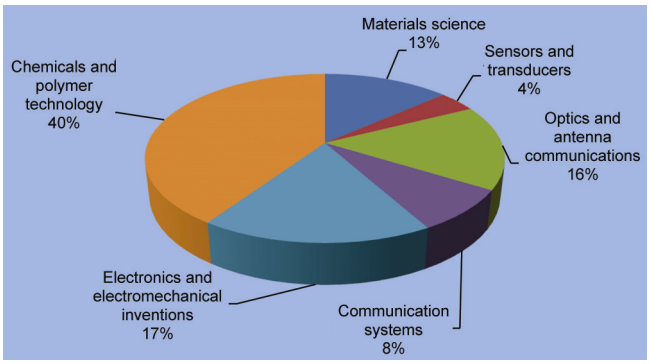

Figure 2. Patenting trends in various technologies.

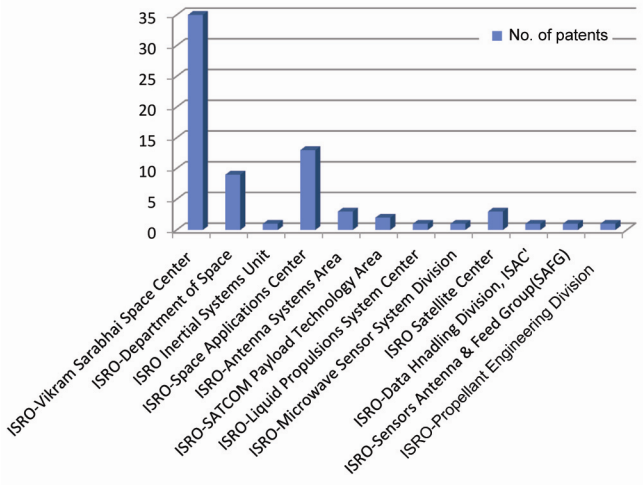

Figure 3. Total number of applicants versus number of patents, post 1995 only.

operations are studied and evaluated to the level of perfection required in each field.

SAC is one of the major centres of ISRO dealing with a wide variety of disciplines comprising design and development of payloads, capacity building and other areas of space sciences, thereby creating a synergy of technology, space science and its societal applications. SAC is responsible for the development, realization and qualification of communication, navigation, earth and planetary observation, meteorological payloads and related data-processing and ground systems. Several national-level application programmes in the area of natural resources, weather and environmental studies, disaster monitoring/mitigation, etc. are also carried out here. SAC plays an important role in harnessing space technology for a wide variety of applications for the benefit of society. Departments falling under SAC have several divisions which involve Antenna Systems Area, SATellite COMmunications (SATCOM) Payload Technology and Microwave Sensor Systems Division.

Qualitative (technology) analysis

The focus of this study is on the patents filed by ISRO in various areas of their research. This section throws light on the patent applications or the inventions themselves. In this study six major fields of engineering have been identified and the patents have been classified accordingly.

Chemical engineering and polymer technology: A total of 55 patents are found relevant to polymer technology, propellants, coatings on alloys and other areas related to chemical engineering. Since the net patent database of ISRO is not big, the classifications were not diversified but restricted to a particular field.

To begin with, Indian patent 137274 claims a process for preparing new phenolic resins. This invention is based on the discovery that when a mixture of bisphenol and cardanol is treated with formaldehyde solution in the presence of a catalyst such as liquor ammonia or sodium hydroxide, it gives a good yield of bisphenol–cardanol–formaldehyde resins. Patent 141877 is an improvement in the manufacture of silicon-based putties. It is a process of manufacturing a putty which consists of compounding a pigment and a filler with a silicone-based vehicle and mixing them together thoroughly to give a putty. The silicone-based vehicle is prepared by mixture thoroughly; natural elastosmers, plasticizers and silicone polymers have viscosities from 10,000 to 75,000 centistokes. Patent 143962 describes the production of hydrocarbons from vegetables oils. Patent 143864 has claimed a process for production of polyols. It is a process for producing polyols, comprising homopolymerizing 12-hydroxy stearic acid in an aromatic solvent to poly-(12 hydroxy stearic acid). The process happens in the presence of an acid catalyst, by monitoring the degree of polymerization, by measuring the drop in acid value of the homopolymer till the degree of polymerization. A range from 2 to 10 is achieved, treating poly-(12 hydroxy steric acid) with poly alcohols, so as to react completely with the residual carboxylic group of the said poly-(12 hydroxy stearic acid). The polyols can then be recovered from the reaction mixture.

(i) Fire extinguishing composition and powder: Patent 147483 has claimed a fire extinguishing composition and a method for preparing the same. It comprises of a homogenous dry powdery mixture of 50%–60% by weight of alkali metal chlorides, 40%–50% by weight of alkali earth metal chloride and at least 5% by weight of a suitable surface coating material. Patent 149900 is a process for the production of polyhydroxide resins. These comprise simultaneous esterification and hydroxylation, and subsequent polymerization of castor oil by roasting it with a dicarboxylic acid, a hydroxyl compound in an aromatic solvent and in the presence of a known acid catalyst, monitoring the process of polymerization by measuring the drop in acid value of the reaction mixture, and continuing the reaction till the acid value drops to less than 1. Thereafter the final product may be recovered.

(ii) Electro-deposition, metal and alloy coating, and alloy-producing chamber: Patent 164470 is a process for making an improved anode for electrochemical production of perchlorates, chlorates, bromates, iodates, periodates or the like. The process involves electrodepositing lead dioxide or mixed oxide-coated titanium mesh anode of titanium/titanium oxide or titanium/titanium oxide/ruthenium oxide/palladium oxide type in an electrolyte comprising a mixture of 250–300 g/l of lead nitrate and 25–30 g/l of copper nitrate at an acidic pH range (1.5–2) and current density of 3–4 Amp/dm^2 for at

least 10–12 h using a copper mesh cathode disposed on either side of the said anode. The electro-deposition is carried out keeping the anode stationary and agitating the electrolyte using oil-free compressed air to obtain a uniform lead dioxide coating on the mixed oxide-coated titanium mesh anode. Patent 165240 is an improvement in the process for preparing metal-coated dielectric substrates and metal-coated substrates. The substrates include quartz or glass comprising the following steps: clean the substrate in a conventional manner; deposit the desired metal film on the cleaned substrate to a thickness less than the desired final thickness; uniformly press a conventional adhesive tape over the surface of the film, thereafter stripping it off to remove the loosely adhered dust/metal particles; clean the coated substrate of step under ultrasonic agitation, followed by cleaning and drying; deposit the metal to the desired final thickness in a conventional manner, thereafter, if desired, deposit a protective layer of magnesium fluoride or silicon fluoride in a conventional manner.

Patent 210179 is a process and a device for producing magnesium lithium alloy. Here solid lithium metal is added under alloying conditions to molten magnesium in the absence of conventional fluxes. The resulting alloy is free from alkali metal contamination. The alloy yield is very high. The invention also includes a device for preparing this alloy. It consists of an encasement chamber, an alloying chamber, a casting chamber, and a means for electrically heating the alloying chamber. Patent 240393 is regarding a cathode for an aqueous secondary cell and a method for manufacturing the same. It consists of a nickel plaque with a coating of polyaniline having oligomeric phthalocyanine incorporated therein. The invention also includes a cell having a cathode and a zinc anode separated by a sheet or film impregnated with aqueous zinc sulphate solution. A method of making the cathode is also included in the invention.

Patent 166955 is an improvement relating to vacuum and electrolytic coating of metals on metallic or dielectric substrate. Patent 177292 relates to a process of gold plating on titanium alloys. The inherent lightness, high strength-to-weight ratio and ability of titanium to withstand fairly higher temperatures has focused attention for its increasing use in aerospace and allied fields. Full utilization of titanium is, however, prevented by its tendency to gall and seize, and by the lack of corrosion resistance at elevated temperatures. To overcome these limitations and also to meet some functional requirements, suitable treatment of titanium is of at most importance. Patent 177292 is a process of integral black anodizing on magnesium alloys. The inherent lightness and good strength-to-weight ratio of magnesium alloys have focused attention on their increasing applications in aerospace and allied fields. Magnesium is a reactive metal. It forms oxide carbonate film when exposed to the atmosphere. Many protective treatments are applied to magnesium components. Most of them do not possess adequate corrosion resistance to excessive exposure and, therefore, require the application of a secondary coating like paint to achieve the requisite corrosion resistance. Black coatings with high solar absorption and infrared emittance are important for passive thermal control systems, and also in optical devices to avoid reflections. The present invention describes a process of galvanic integral black anodizing on magnesium alloys, where an anodic thickness of 1–25 pms (pulsed magnetron sputtering) can be obtained with a micro hardness better than 100 VHN (Vickers Hardness Number). These coatings provide solar absorption and infrared emittance of 0.92 and 0.90 respectively. They can be utilized as excellent thermal control surfaces to improve heat radiation characteristics.

The following is a series of inventions relating to electrodeposition on alloys. Patent 170666 discloses a process for chromate coatings on magnesium–lithium alloys. Patent 171172 is a process for producing a coated substrate made of materials such as metals, dielectric or semi-conductor, coated with diamond-like carbon having improved optical and durability properties. Patent 171053 is a process for producing a rear surface black chrome-coated dielectric substrate having improved optical and durability properties. Patent 171728 is a process which describes gold plating on aluminum alloys. Patent 170548 involves the following steps: ultrasonic cleaning in ispropyl alchol; alkaline cleaning in a bath containing potassium hydroxide 40–65 g/1, trisodium phosphate 9–12 g/1, potassium fluoride 1–2 g/1, at temperature 70–95°C for 5–10 min; rinsing in water; acid cleaning in 40–60% cro3 (chromium trioxide) for 4–7 min; rinsing in water; direct nickel plating for 12–20 min at a current density of 45–65 Amp/ft^2 in a bath having pH of 2.5–3.5 and kept at 50°C to 65°C, the said bath containing 100–140 g/l of basic nickel carbonate, 100–115 ml/l of 40% hydrofluoric acid, 35–45 g/l of citric acid and 1–2 g/l of sodium lauryl sulphate; electroless nickel plating for 75–130 min in a bath having pH of 4.8–6.8 and kept at 75–90°C, the said bath containing 8–12 g/l of basic nickel carbonate, 9–12 ml/l of 40% hydrofluoric acid, 5–6 g/l citric acid, 12–18 g/l ammonium hydrogen fluoride, 18–22 g/l sodium hypophosphite and 25–35 ml/l of 30% ammonium hydroxide; rinsing and drying in air; gold striking at a current density of 1–2 Amp/ft^2 for 2–5 min, in a bath having pH of 3–5 and kept at 60–65°C, said bath containing 2–3 g/l of gold potassium cyanide, 45–65 g/l of citric acid and 45–65 g/l of sodium citrate; electroplating gold at a current density of 2–4 Amp/ft^2 for 10–60 min in a bath having pH of 3–5 kept at 65–73°C, the said bath containing 8–14 g/l of gold potassium cyanide, 45–65 g/l of citric acid and 45–65 g/l of sodium citrate followed by rinsing in water; heating at 100°C for 1–2 h; dipping in boiling water; dipping in hot alcohol and drying in air.

Patent 172692 explains a process for preparing a novel fire-extinguishing powder. It involves drying urea and

potassium bicarbonate separately at a temperature between 85°C and 125°C to obtain moisture content below 0.05%; grinding the dried urea and potassium bicarbonate in the ratio 0.6 : 8.1 and sieving through 800 μm sieve. It further involves mixing the resultant powders and heating for 2–6 h at a temperature between 120°C and 160°C, grinding the cooled reaction product to particle size of 20–80 μm, coating the ground product with chemicals such as wax, magnesium stearic, stearic acid and silicons resins in combination or sequentially; sieving the dried, coated material through 100–200 μm sieve; blending the sieved, coated product with special-purpose additives such as tricalcium phosphate, calcium silicate, and sieving through 800 μm sieve.

(iii) Propellants: Patent 172236 is a process for preparing a propellant grain. It involves preparing a hydroxyl-terminated polybutadiane (HTPB) propellant slurry in a known manner, casting the slurry into blocks, curing the blocks at a temperature of about 70°C followed by room temperature curing, assembling the blocks in the desired shape using the said slurry as the bonding material and then pouring the assembly at room temperature for a few days to obtain the finished grain. Patent 170640 describes a thin foil heat flux sensor and its method of manufacture. It comprises a foil of predetermined thickness and diameter attached to a copper body having on axial hole to accommodate the foil serving as the best sink. There may be two copper load wires; one of them attached to the centre of the foil and the other attached to the copper body, forms a differential thermocouple system whose output may be directly proportional to the absorbed heat flux.

Patent 207452 is a method and an apparatus for manufacturing thin-webbed solid propellant grains for propellant motors. Patent 207299 is a process for synthesizing a hydroxyl-terminated glycidyl azide polymer. This compound is used as a binder in solid propellants. Patent 206778 is a process for the synthesis of polyarylene ether ketone resins. Here, dihalobenzophenones are condensed with dihydroxy aromatic compounds such as resorcinol and hydroquinone. The reaction is carried out in the presence of anhydrous alkaline carbonate, benzophenone and an aromatic hydrocarbon solvent. The mixture is preferably heated up to 240°C and the polymer is then recovered from the reaction mixture. Patent 213926 is a process for the synthesis of 4,4′-dihalobenzophenones. Halobenzene is made to react with carbon tetrachloride in the presence of anhydrous aluminum chloride as a catalyst. The reaction is then steam-distilled and the product separated and crystallized from the aqueous layer. Patent 206762 describes a process for the synthesis of cross-linked polysilahydrocarbon.

(iv) Rubber-to-metal/or alloy interface composite structure: Patent 240333 is a method for producing an improved balloon for assessing wind profile in the upper atmosphere. This is not connected with complex space technology and applications, but contributes towards climate and environment assessment. The method comprises fabricating a spherical balloon of reduced weight and constant volume at low cost from mixed polypropylene and polyethylene film by joining the edges of tailored petals, each containing cones with metal-coated adhesive tape which reflects radar tracking signals of increased strength, and providing a ballast weight and feeding nozzle in the bottom part and two super-pressure vent valves disposed in diametrically opposite positions, one being near the top and the other near the bottom part of the balloon. An adhesive composition is described in patent 256945 to bond rubber to metals and alloys. The two-component adhesive composition consists of a primer to be applied on the metal/alloy surface and an overcoat adhesive to be applied on the primed metal alloy surface and rubber. The primer is based on a nitrile–phenolic adhesive composition, whereas the overcoat adhesive is based on a neoprene–phenolic adhesive composition. Curing of the adhesive can be effected at room temperature to provide a strong joint at the rubber-to-metal/alloy interface resulting in the required composite structure. Patent 228944 is a process for the synthesis of siloxane–imide–epoxy resins. It comprises a reaction between a siloxane containing diimide-diacid and epichlorohydrin under epoxidation conditions in the presence of a quaternary ammonium halide catalyst; the resin is recovered thereafter.

(v) Resins and copolymers: Patent 206786 is a process for preparing addition curable phenolic resin having ethynyl phenyl azo groups comprising the steps of coupling ethynyl phenyl diazonium salt with a phenol formaldehyde resin, separating, purifying and drying the precipitated phenolic resin having ethynyl phenyl azo groups. Patent 210232 relates to film-forming acrylic copolymers with pendant phenol group, which are useful as adhesives. The copolymers are prepared by copolymerizing an alkenyl cyanide monomer, an acrylic acid ester monomer and a monomer containing an unsaturated phenol group in the presence of a free radical initiator. The copolymer is separated and may be cast into films for forming adhesives. Patent 196377 relates to a process for hard anodizing aluminium and its alloys containing impurities of iron-bearing inter-metallics. It is particularly useful in hard anodizing aluminium which contains iron bearing inter-metallic impurities. The article to be anodized is first subjected to known steps of degreasing, descaling and desmutting. Anodization is effected in an electrolytic bath containing 80–125 ml/l of sulphuric acid and 1–6 ml/l of hydrochloric acid at temperature ranging from –10°C to +5°C and current density of 15–40 Amp/ft^2. For obtaining an anodic coating of 40–100 μm, anodizing is carried out for 60–180 min. The process also involves washing, drying and sealing after each stage. Patent

226107 is a process for preparing composite propellant containing active copper oxide. Patent 189927 relates to an improved colour reversal process for producing colour prints.

(vi) Piezoelectric ceramic material and composites: Patent 254253 relates to a method of passive vibration damping composite materials such as Kevlar and graphite composites with embedded Kevlar flexcore at ambient and varying temperatures using surface activation technique of plasma etching along with thin hybrid layers (on one side only) of high-sensitivity ferro-electrically soft and hard piezo-electric ceramic material layers. The surface activation is done using plasma etching technique to obtain better adhesion of piezo-ceramic material, with composites. Hydrophilic polymers such as Kevlar fibre-reinforced plastic and hydrophobic graphite composites are treated with radio frequency (RF) plasma to modify the surface properties, such that they get reflected in the adhesion enhancement between plasma-treated polymer surfaces and the thin piezo-ceramic material coating at elevated temperatures. It has been found that there is significant passive damping contribution at resonant frequencies from the thin hybrid piezo-electric coatings on one side of the substrate composite materials like graphite and Kevlar fibre with embedded Kevlar flexcore at elevated space domain temperatures.

(vii) Detonator and its assembly: Patent 205207 is a method for process-safe detonator. The invention provides a process-safe detonator with cylindrical housing with an open and a closed end. An initiator unit disposed at the open end of the hollow housing to provide a hot-wire sensitive pyrotechnic charge, a diaphragm member disposed by pasting on the initiator unit. A stem channel extends from the initiator unit member to the closed end of the hollow housing disposed in housing, nickel hydrazine nitrate (NHN). This acts as a low friction sensitive primary explosive disposed in said stem channel in proximity to the initiator unit to receive flame from the pyrotechnic charge of the initiator unit, a secondary high-explosive disposed in functional contact with the NHN, to receive the explosive force for detonation. A sealing member disposed on the open end of the hollow housing for effective sealing of the detonator. Patent 206764 is regarding a room-temperature curable flame-retardant composition. It comprises a linear organo polysiloxane, a silane compound, a metallic salt of a carboxylic acid, inorganic filler such as silicon carbide, an organo phosphate and traces of platinum or platinum containing complex. This invention also includes a curable poly-siloxane containing composition which includes poly-siloxane and inorganic filler such silicon carbide, an organo phosphate and traces of platinum or platinum-containing complex. It is used for curing the above composition containing an alkyl oximo silane, aminoalkyl tri alkoxy silane and a metallic salt of a carboxylic acid. Patent 216622 is a process for producing siloxane polymers having atomic oxygen resistance and a method of producing articles coated therewith. Patent 210250 is a method of manufacturing a substrate of aluminum or its alloy with an anodized electrically conducting surface.

Patent 224638 describes a detonator assembly. It consists of a housing provided with a hollow cup-shaped body and a spacer member separating the cup from a hollow cylindrical body. The cup-shaped body has terminals connected thereto and houses initiator charges and a secondary explosive in close contact with each other. The cylindrical body has two columns of charge. The transition charge column located near the spacer has a smaller diameter than the output charge next to it. The transition charge also has lower density than the output charge.

(viii) Ceramic precursor: Patent 210164 is a process for preparing alpha crystalline ferric oxide. Here an aqueous solution of an alkali is slowly added to an aqueous solution of a ferric salt. The yellowish-brown precipitate is washed, dried, powdered and then further dried and ground to obtain ferric oxide having crystalline structure. Patent 213967 is a process for producing polycarbosilane, a ceramic precursor from poly-hydrocarbon. Patent 214017 is a film-casting machine and process for producing polyimide films. A film-casting machine is provided with a roller having a smooth surface mounted on a housing with a removable top cover. The roller is provided with a variable speed drive. A heater is located inside the housing below the roller. An inlet in the housing provides inert gas. A feeder plate is located close to the blade assembly for feeding the material to be cast and at least one temperature sensor is provided for sensing the temperature inside the housing. Patent 208583 relates to a novel process for synthesizing boron- and silicon-containing oligomers which are ceramic precursors. Boric acid and substituted alkoxysilanes are condensed in the presence of an inorganic acid catalyst at a temperature ranging from 100°C and above. The oligomer is separated from the reaction mixture and stored in an inert atmosphere. These oligomers yield a high percentage of ceramic residue on pyrolysis and are used in the preparation of ceramic bodies and ceramic coatings. Patent 217063 is regarding vulcanizable rubber-based insulator composition. The insulator composition consists of masticated rubber hydroxyl-terminated polybutadiene resin, dibenzo thiazole disulphide, tetra methyl thiruam disulphide and known fillers and extradients.

Patent 210132 is regarding a curable silicone rubber composition for making vibration isolators. Patent 210136 relates to a thermosetting adhesive from acrylic copolymers having pendant phenolic groups. An alkenyl cyanide monomer, an acrylic acid ester monomer and a monomer containing both an unsaturated and a phenol group are copolymerized in the presence of a free-radical initiator.

The copolymer is isolated and converted to thermosetting adhesive by adding stoichiometric quantity of a polyelectrophile to form a thermosetting adhesive. Patent 217041 relates to composite solid propellant composition based on hydroxyl-terminated polybutadiene and a process for making the same. Patent 204527 relates to low-density curable coating composition useful in providing thermal protection for aerospace vehicles. It consists of a two component system of a premix dispersion and a curing component. The premix consists of a mixture of hydroxyl-terminated polymethlsiloxane silica, ferric oxide and zinc oxide blended with phenolic microballoons. This is dispersed in an organic solvent. The curing component consists of alkyloximinosilane, amino-alkyl-tri-alkoxy-silane and an organotin compound. This invention also includes a process for preparing the above composition. Patent 206804 relates to a curable coating composition comprising a blend of premix dispersion and a curing component. The premix consists of a mixture of hydroxyl-terminated polydimethylsiloxane, silica, ferric oxide and zinc oxide dispersed in an organic solvent and the curing component consists of a mixture of alkoxy-tris-alkyl-alkoxy-silane, amino-alkyl-trialkoxy-silane and an organotin compound.

Communication systems: Twelve patents have been found in this area where the inventions are related to radar technology, noise reduction in communication channels, signal-strength measurement, secured data communications, GPS-based searches and others.

Patent 230737 is about a single aperture multimode tracking-cum-communication feed system. Patent application 1190/CHE/2006 provides a system for higher-level security to data communication in computer networks, comprising an organizational network, a third party network, a phantom server with an intermediate data storage, a toggling means disposed to isolate the organizational network from the third party network and toggling means further disposed to permit secured data communication between the organizational network and the third party network through the phantom server. This method explains higher-level security to data communication in computer networks by effecting the transmission of data between organizational network and the third party network. This is achieved by toggling through a phantom server. Patent 217004 is a method for pulsed signal strength measurement in RF signals. Patent 204289 relates to a method for eliminating noise in data acquisition systems. The signal to be acquired is sampled and digitized at a rate that is several times the required sampling rate. Thereafter, the sample values are averaged to derive a single representative value that is free from the influence of high-frequency random noise. To eliminate the effect of low-frequency systematic noise, the number of samples to be averaged must be an integral multiple of f_s/f_n (where f_s is the sampling frequency and f_n is the noise frequency). Over-sampling of the input signal simplifies the anti-alias filter requirements. System calibration techniques may be employed to further reduce the effect of component nonlinearity, offsets, reference errors, and a digital multiplier to enhance the measurement range. Patent 201926 is a method for processing space-borne sliding spotlight synthetic aperture radar signal for extended azimuth coverage.

Patent US5572227 is a multiband antennae system for operating at L-band, S-band and Ultra High Frequency (UHF) band. The antenna includes L-band antenna elements and S-band antenna elements provided in the form of quadrifilar helices spaced from each other on the surface of a hollow cylindrical insulator. UHF band antenna elements are provided in the form of a cage dipole on the surface of the hollow cylindrical insulator. The L-band antenna input is connected to a first connector through an L-band feed network card. The S-band antenna input is connected to a second connector through an S-band feed network card. The UHF-band antenna input is connected to a third connector through a split sheath balloon provided along the axis of the hollow cylindrical insulator. Patent EP20100782053 relates to a method for communicating signal data in Global Navigational Satellite System (GNSS) system using low density parity check (LDPC) convolution codes. The method involves, at the transmitting end, formatting signal data into a set of sub-frames. Each sub-frame of the signal data can be encoded in accordance with a parity check matrix defining Tanner graph representation of LDPC convolution codes. The encoded signal data can be interleaved and added with a synchronized word field to transmit an interleaved block of encoded signal data through a communication channel. At the receiving end, the interleaved block of encoded signal data can be de-interleaved after it is received from the communication channel. The Tanner graph provides the connectivity in time-invariant parity check matrix. A message-passing technique is used to decode the LDPC encoded message. The encoded signal data can be decoded through the message-passing technique to obtain the signal data primitively transmitted at the transmitting end. Such a method is capable of achieving error-free performance over the GNSS communication channel for effective navigation data communication, and also provides good bit error rate performance over a wide range of signal-to-noise ratio.

Electronics and electro-mechanical inventions: A total of 25 patents have been found relevant to this section. Inventions are connected to microelectronics, circuits, electro-mechanical devices, valves, shock protector, thermodynamics and others.

Patent 167460 is regarding electric shock protector which may be useful for the common man. The ‘domestic electric shock protector’ comprises a balanced current transformer having live and natural wires wound in opposite directions with equal number of turns to form the

primary; the secondary is wound on the same core, the output of which is fed to the gate of the silicon controlled rectifier (SCR). The cathode of the SCR is connected to the live wire through an electromagnetic relay having two changes over contacts for tripping the power supply to the load. Further details may be found in the invention itself. Patent 216641 relates to a system for experimental mechanics applications such as static, dynamic and non-destructive testing at an affordable cost. The system according to the invention comprises a processor with an interface connected to conditioners and controllers. Transducers provide signals corresponding to the measured values to the conditioners. The processor provides control signal, to the controller for controlling the motors and relays attached to the testing instruments. The processor is also provided with a multimedia system with audio and video features. Patent 247506 is related to the digital imaging of holograms and real-time generation of holographic interferograms and shearograms based on the principle of digital holography for non-destructive testing (NDT) related applications. The system is of modular design, consisting of an optical recording head and an image processor with real-time digital hologram processing software. The recording head includes a device to generate two coherent waves, devices to control the intensity of the reference beam and to adjust the object illumination, a mechanism to combine the object and reference waves forming an interference pattern at the recording plane and CMOS (complementary metal oxide transistor) sensor. The detection device transfers data to a processor, which performs real-time digital reconstruction of the holograms, holographic interferograms and shearograms, which are displayed in the monitor. These data are used for non-destructive evaluation.

Patent 235617 is regarding a device for compensating the effect of temperature variation on brightness of light-emitting diodes. Patent 229296 describes a control circuit for diode-based RF circuits. Patent 220157 describes a method for multi-channel current monitoring.

Patent 207522 describes a high-speed differential encoder. Patent 210266 relates to an electro-mechanical safe-arm device useful for providing safety to the pyrotechnically actuatable systems in rockets and missiles. It consists of a limited-rotation bi-directional torque motor, the stator of which is housed in the safe-arm body and the rotating part, which carries the magnet and a pair of detonators. Rotation of the motor shaft aligns and de-aligns the detonators with respect to the receptor ordnance in the 'arm' and 'safe' positions respectively. The unit also features shorting/grounding of detonators in 'safe' position for connecting the detonator leads to the power source in the arm, as well as electrical indication of status by means of a two-position rotary switch. 'Bidirectional torque' is what a motor can provide and not by which a motor is not disclosing about the invention. Patent 213933 describes a low-shock ball-lock separation mechanism for separating upper stage and satellite of a space launch vehicle. The said mechanism comprises locking the interface rings by means of balls and keeping them under locked condition by a rotatable retainer ring provided with radial holes for the release of balls during separation. The retainer ring is actuated by a pair of thrusters, preferably pyrotechnic thrusters. The entire separation technique is dependent only on the actuation of any one of the thrusters, thus improving reliability. This separation mechanism will facilitate an extremely low shock. Patent 207705 describes a deployable solar sail assembly for satellites and a method of making the same. Patent 206763 is regarding a shape memory alloy step drive mechanism. Patent 210246 is on a precision slip-ring for tracking radars and instruments. The slip-ring comprises plurality of co-planner concentric conductor rings supported by an inner support member and embedded in at least one side of an insulator disc made of moulded epoxy resin with only part of the conductor rings being covered by the epoxy resin, two movable electrical contacts from opposite sides of each conductor ring and lead wires being taken from each conductor ring and each movable contact for external connection. Patent 204476 describes a flexible electrical heater suitable for flat surface mounting and a method of making the same. It comprises a nichrome foil element with a cladding of kapton polyamide film. It has acrylic adhesive to insulate the nichrome foil element and insulated lead wires welded at both ends of the nichrome foil filament. Patent 207442 relates to a high-density hybrid integrated circuit package. Patent describes a 191409 pressure-controlled water evaporative refrigeration system having a vacuum vessel with a water inlet, a base plate disposed horizontal to the base of the vessel having a plurality of downwardly extending metallic fins immersed at least partly in the water, and a means for evacuating the vessel. Patent 191228 describes a multi-channel load-testing machine with the master unit connected to a hydraulic power pack and pressure distributing manifold. Patent 189912 is on a spin bean for spinning a plurality of synthetic filament yarns and its manufacture.

Patent 237839 describes a plasma generator of high thermal energy for evaluating heat insulation materials at high temperature. European patent EP2422204 (filed by ISRO) is a system and method for detecting and isolating faults in pressure sensing of flush air data system (FADS). Patent application 1591/CHE/2006 is a circuit for compensating gain variation over operating frequency and/or temperature range.

Optics and antenna systems: This category has 24 patents which are related to electro-optical instruments, image analysis, novel and unique reflectors, and antenna reflectors.

Patent 156709 describes a light pointer. It comprises a barrel engaged with a handle; the barrel and handle

respectively, house a lens and an electric light source, and means for fixing the light source in a predetermined position. Whenever the barrel is moved inward or outward with respect to the handle, the lens is focused to form an external real image of the light source to serve as a pointer. Patent 156712 describes a microfiche camera. It incorporates a lens and shutter, comprising a film cassette carrier mounted against a plurality of apertures of slits, as a means for moving the cassette carrier in right angular directions, and then index the means for controlling the movement of the cassette carrier in the directions in steps of predetermined magnitude. The cassette carrier is movable into a plurality of uniformly spaced positions to obtain a corresponding number of images on the film after exposure thereof in the said position.

Patent 156711 is regarding a dual densitometer. This is a device used for measuring transmission and reflection densities of an object. It consists of a light transmission measuring section and a light reflection measuring section. The former comprises a first source of light and means for transmitting it through the object on the cathode of a first photomultiplier. The latter comprises a second source of light and means for transmitting it, reflected from the object, on the cathode of a second photomultiplier, feedback means for adjusting the dynode voltage of the photomultipliers to maintain the anode current constant for different input signals to the cathode. The change in the dynode voltage being proportional to the optical density of the object is a method for calibrating a portion of the said voltage in terms of optical density units for display on a digital read-out. Patent 160232 describes drum scanner imager device comprises a light source disposed adjacent to a scanning drum for mounting the hard copy/transparency input picture. An imaging drum is provided with a light trap cover for mounting the unexposed photo-paper/film. This drum is coupled to the scanning drum; an optical system for sensing the reflected/transmitted light signal from the input picture and separating the same into red, blue, green, black and white channels, photomultipliers for receiving the colour-separated output of the optical system and feeding the same into an electronic processing system for carrying out operations such as colour and density correction and contrast enhancement. A glow modulator helps in reconverting the processed output of the electric processing system into light signals for exposing the photo-paper/film on the imaging drum. Patent 167910 is a process for preparing a dual-surface, electrically conducting silver reflector which has improved optical and durability properties, comprising the following steps cleaning the substrate (such as glass and quartz) in a conventional manner, depositing tantalum pentoxide or any other transparent oxide such as yttrium oxide and cerium oxide as a binding layer on one side of the cleaned substrate, depositing silver on the binding layer to a thickness around 800–1000 Å in a conventional manner; depositing at least one protective layer, the first protective layer deposited being that of tantalum pentoxide or any other transparent dielectric material such as yttrium oxide, cerium oxide, strontium fluoride and magnesium fluoride in a thickness range from 500 to 800 Å on the silver layer.

Patent 167632 describes an optical reflecting projector. This comprises a table, the surface of which incorporates first and second spaced transparent panes. It must have at least one light source, which is disposed under the table for illuminating an object placed on the first pane; at least two mirrors and a convex lens are disposed under the table. The lens and at least one of the mirrors are mounted in predetermined positions, whereby light rays from the illuminated object are reflected and refracted at the mirrors and lens, to form a real image of the object on a translucent sheet placed on the second pane for being viewed or copied, the size of the image being determined by the said positions. Patent 167535 claims a three-coordinate viewer for use in the study of photographs. It comprises a table, the table-top incorporating a transparent sheet; a light source as placed below the table-top for transmitting light outward through the sheet; a platform for receiving optical apparatus and instruments, as described, the platform being mounted above the table-top; and means comprising guide bars and screw rods engaged with the platform. The screw rods can be rotated by the handles for moving the platform over predetermined distances in the X and Y coordinate directions, and a rack and pinion with a knob for turning the pinion for moving the platform over predetermined distances in the Z coordinate directions. The location of the platform is definable to train the apparatus and instruments on an object placed on the sheet, for the purpose of viewing the same.

Patent 167194 is regarding an additive colour viewer for analysis and interpretation of remote sensing data. It comprises a plurality of channels of an optical projecting system, each channel having a projection lamp with a heat-absorbing glass plate beneath it, a colour filter selection wheel disposed below the glass plate, a condenser lens located below the filter wheel, and a projection lens placed below the condenser lens. The colour viewer further comprises an input film plane for receiving the film to be viewed, the film plane may be disposed between the condenser and projection lenses of all the channels, a plurality of folding mirrors located below the projection lenses of all the channels for reflecting the projected light rays onto a viewing screen.

Patent ES2424457 describes a hollow prism for detecting liquid level in the presence of an optical beam, including a hollow member; dielectric members sealed to the hollow member with one of the dielectric members arranged at an inclined angle to the other; a sealed hollow space disposed between the dielectric members, wherein an incident optical beam enters through the first dielectric member at normal incidence and exits as an emergent

beam through the second dielectric member, and wherein the emergent optical beam remains undeviated when the hollow member is not immersed in a liquid medium and the emergent beam suffer deviation when immersed in the liquid medium. The invention also provides a fibre optic liquid-level detector with the hollow prism for detecting liquid levels. Patent application 310/MAS/2001 discloses a waveguide rotary joint for uninterrupted transmission of electromagnetic energy during rotation of one of the wave guide sections of the rotary joint. The wave guide rotary joint comprises a rotatable circular wave guide section in close electrical contact with a symmetrical and matching stationary circular wave guide section to form a choke joint, opposite to the end of the choke joint of the rotatable circular wave guide section. The stationary circular wave guide section is provided with a shorting section and a rectangular wave guide section with a door-knob transition element.

Patent 207455 relates to an optoelectronic apparatus for static and dynamic measurements. It consists of a laser source on a rigid base with optical elements such as mirrors, beam splitters, beam expanders, image capturing means and a computer for measuring displacement and slope by interferometry. Patent 241032 relates to a method of making mechanically active parabolic microwave antennae having polycarbonate reflector skins. It consists of metal beams that have actuatable piezoelectric bimorphs disposed thereon and the means for holding flat antenna body when the flat body is mounted and the piezoelectric body is actuated, parabolic bending of the body results. Patent 247886 describes a microwave antenna reflectors made of flexible composite membranes such as carbon fibre-reinforced plastic and glass fibre-reinforced plastic composite body having a parabolic structure, the convex side being coated with at least one layer of piezoelectric material. The microwave antenna provides passive vibration damping effect.

Patent 251718 describes a segmented shaped multibeam reflector antenna, and Patent 257011 describes a method for simultaneously generating pencil beam and shaped beam from a single shaped reflector.

Sensors and transducers: Six patents related to this area have been found. In includes liquid depletion sensor, ultrasonic liquid level sensor and moisture sensor.

Patent application 1659/CHE/2009 is about a symmetrical branching ortho mode transducer with enhanced bandwidth. Patent 252111 relates to a method of providing two squinted beam feeds to a microwave sensor and a composite elliptical feed. Patent 248462 describes a liquid depletion centre. The invention senses the depleting levels of a liquid in a storage tank. The sensor comprises a housing, a base member and a plurality of supporting members fixed to the base member. The sensor has a plurality of metallic discs, fixed to the supporting members by allowing them to pass through the circular passages on the discs. The supporting members extend from the peripheral disc to the base member. The pack of discs forms a set of parallel-plate capacitors with insulating members disposed to form intervening gaps. A plurality of electrically conducting lugs is disposed on the discs to provide capacitance from the discs to an external electronic means using lead wires. The sensor uses the capacitance during depletion levels of the liquid, which is converted into voltage to determine the depleting levels of the liquid.

Patent 213968 describes an ultrasonic liquid-level sensor. It comprises a sensor head having a sealed top at one end and a sensing gap along part of the length of the sensor head; a piezoelectric disc transmitter and piezoelectric disc receivers provided on each side of the sensing gap with connecting leads from the piezoelectric disc transmitter and the piezoelectric disc receiver. The other end of the sensor head is connected to a hollow stem provided with a sensor cap and an electrical connector for taking out the connections from the piezoelectric disc transmitter and piezoelectric disc receiver to an external circuit. Patent 216467 describes a non-destructive moisture sensor. It comprises a microwave generator, a microwave detector and a microstrip resonator connected between the microwave generator and detector. The output from the microstrip resonator is connected to a microprocessor through an interfacing circuit which employs an amplifier to obtain an output corresponding to the normalized percentage of moisture in the material to be tested. Patent 198098 relates to a waveguide transducer assembly. It consists of a circular waveguide section connected to a rectangular waveguide section through a coaxial waveguide section. An aperture housing a probe is provided for the circular waveguide section. The coaxial waveguide section houses a multistep ridged waveguide. The circular waveguide section has a tapered circular section. This assembly enables effective transmission of power. Patent 204437 describes an integral diaphragm absolute pressure transducer. It comprises a diaphragm fixed to a pressure port having an inlet tube for exposing the diaphragm to the pressure to be measured. One or more strain gauges are attached to the diaphragm, the side opposite to the said pressure inlet. This may be enclosed in an evacuated hermetically sealed chamber. The strain gauge may be taken out through an insulated sealing to an upper cover.

Materials science: Twenty patents have been classified under this field. The following inventions pertain to enhancement of tensile strength of metals or alloys, extensive work on alloys and alloy-making, production of fibre-reinforced plastics and others.

Patent 167571 is about film drier. It comprises a closed chamber provided with a door; a heater and blower unit disposed below the chamber and a passage through perforations on the inner surface of the chamber. The air

heated from the unit enters the chamber before leaving the same through an exit. There is a mounting for receiving a film-spool and a second mounting, driven by a motor, for receiving a take-up spool. The film form the film-spool may be passed around a plurality of spaced rollers housed within the chamber before being wound on the take-up spool. This is to expose the surface of the film to the hot air within the chamber. There may be means for controlling the speed of the motor and the temperature within the chamber. The film is dried as it runs from the film-spool to the take-up spool at a predetermined speed while being subjected to heated air at a predetermined temperature. Patent 170292 describes a process for preparing a durable anti-reflector for improved transmission of infrared rays. It comprises cleaning a substrate of germanium, silicon or gallium arsenide; depositing a binder layer of germanium of thickness 1000–1500 Å on the cleaned substrate; and depositing on the substrate with the binder layer. An antireflection layer of a substance is selected from the group consisting of zinc sulphide, zinc selenide, cadmium telluride, cadmium selenide, arsenic trisulphide and arsenic triselenide to a desired thickness.

Patent 173110 is an improvement in the process of anodizing titanium alloys. It involves the following steps: solvent degreasing in methyl ethyl ketone with ultrasonic vibrations for 5–10 min; cathodic alkaline cleaning in a bath containing 15–40 g/l of sodium hydroxide, 10–25% g/l of sodium meta-silicate, 10–25 g/l of sodium carbonate, 5–15 g/l of disodium hydrogen orthophosphate and 0.5 g/l of sodium dodecyl sulphate at a temperature of 50–100°C, potential difference of 5–8 V for 5–10 min; followed by rinsing with water, acid pickling in a solution containing 100–200 ml/l of nitric acid (70%) and 5–15 ml/l of hydrofluoric acid (40%) for 1–3 min, followed by rinsing with water; anodizing in an electrolyte containing 75–300 g/l of sulphuric acid, 10–25 g/l of oxalic acid and 10–30 g/l of ethylene glycol at a temperature of 15–40°C, potential difference of 5–90 V for 5–30 min, followed by rinsing with water dipping in hot distilled or de-ionized water at 80–85°C for 30–40 s and drying in air. Patent 174078 is a novel process for the production of high purity precipitated silica from rice husk ash. It comprises mixing rice husk ash with 0.25–0.5 times by weight of caustic soda and 3–6 times by weight of water; heating the mixture with steam to a temperature of 90°–120°C to obtain a solution of sodium silicate; filtering the sodium silicate solution to separate the sediments from the solution; adjusting the concentration of the solution to obtain a sodium silicate solution with 10%–15% by weight of sodium silicate; neutralizing the solution with dilute mineral acids such sulphuric acid or hydrochloric acid, maintaining a temperature of 30–60°C; optionally adding 29–40 g of ethylene diamine tetraacetic acid per kilogram of silica content; heating the neutralized solution in the temperature range 80–98°C to precipitate silica; separation of silica in a known manner followed by washing and drying to obtain purified silica. Patent 178085 is an improvement in the process of electroslag refining or casting with inoculation. It involves producing refined ingot or castings with improved properties comprising refining and casting with insulation, characterized by pre-casting the steel or steel alloy in the form of electrode, distributing the alloying element uniformly along the length of the electrode, re-melting under the slag by passing current to obtain the required size and shape of the refined ingot. Patent 253851 describes a high-purity porous silica fibre-silica matrix composite and its method of manufacture.

Patent application 768/CHE/2004 describes a linear–electromechanical actuator. Patent application 197/MAS/2003 is a solution to bird-hit cases of aeroplanes. The invention relates to a breach mechanism for conducting simulating tests for bird-hit on aircraft comprising a mild detonating cord (MDC), a diaphragm and a triggering device held between a holder with a groove on its inner face and a lid, a highly explosive material in a linear explosive cord with an initiator for triggering and detonating with its propagation velocity, thereby causing the diaphragm to cut-off by guillotine action.

Patent 206295 describes a retractable-cum-variable height container for transportation and storing spacecraft precarious environmental and climatic condition suitable for carrying out various tests. Patent 210655 describes silver-graphite brush block and a method of producing the same. Graphite is subjected to surface coating with solver prior to mixing it with silver. This improves the physical and mechanical properties of the block brush. Patent 214419 is a process for producing novel alloy steel of improved tensile strength. Patent 212359 describes portable device for automatic NDT of panels. Patent US8640428 describes strength-enhancing insert assemblies. Insert assemblies of high specific strengths to reduce stress concentration at locations where multidirectional stresses act on sandwich structures have been designed based on mapping stress distribution and failure initiation.

(i) Surgically implantable joint prosthesis: Patent application 240/CHE/2004 is a technology concerned with instrumentation use in medical science. A surgically implantable distal humerus and elbow joint prosthesis with oscillating mechanism consists of a distal humeral component, a sleeve bearing, condylar component, oscillating guide ring, two collared bushes, pivot pin-locating screw and a proximal ulnar stem. When assembled together, the upper end of the distal humeral component forms the bone-anchoring component. The lower end accommodates the sleeve bearing, and this assembly along with the oscillating guide ring fits into the condylar component, which is connected to the proximal ulnar component by the pivot pin with two collared bushes and pivot pin

fixing screw. The lower end of the proximal ulnar stem forms the intramedullary-anchoring component. This prosthesis permits a flexion movement and an oscillatory movement.

Open innovation, the road ahead

Open innovation is a relatively new concept that emerged about 10 years ago[10]. It has received significant amount of attention and so far a number of leading companies in the US, Europe and other countries have reported success with it[11,12]. The intention of highlighting the concept of open innovation is that the same may strongly be considered by ISRO to widen its avenues, welcome more technologies and make better use of its patent portfolio in commercial terms. In the past R&D or in-house R&D was considered as valuable strategic assets. It was only restricted to top companies like IBM, DuPont, Bell Laboratories, AT&T, etc. However, this notion of in-house generation of ideas and then to reach the market was considered as a good practice in the 20th century.

Now, companies/public-funded organizations have relooked at the fundamental ways of working. The current trend is treading the new path to the market, i.e. by going outside the comfortable domain of in-house operations. This involves looking outside for more ideas that might fuel more innovative inventions[13]. By the end of the 20th century, a number of factors came into play which uprooted the underpinnings of closed innovation as the only way to reach the market. This may be due to a dramatic rise in skilled workers and immigrants, who may do the same work with a lesser pay. For example, when an organization funded and invented a discovery, but did not pursue further on its development, the people involved pursued it on their own in a start-up financed venture capital. Such firms then flourished by raising their capital by stocks or by other means. Most of the companies/organizations which went by the old-school-thought of in-house production to market could not reach beyond a certain point. So, an organization like ISRO can look to open its avenues, regarding open innovation. An organization which focuses only on in-house ideas may be prone to miss out on many technologies, which may have the potential to tie with their existing businesses to uncover further potential. This may prove as a loss to those organizations that have made huge investments in their R&D, only to discover them abandoned or in the hands of other people, which probably if it had been tapped could yield tremendous commercial value. In this section, we will take few examples from terrestrial and space sectors to see how successful innovator companies adopted to gain revenue, reduce cost and continue disruptive innovation.

For instance, CISCO which initially lacked deep internal R&D capabilities, competed with the companies that invested heavily on its own research and state-of-the-art components, performed better than them, competing in the same field of technology. CISCO deployed a completely different strategy in the battle for innovation. Whatever technology was required, it acquired from outside by partnering or investing in start-ups and outsourcing its other needs. By this way, it kept pace with other R&D giants, all without deploying much time, funds and energy of its own in research activities.

So in the case of open innovation, firms and companies may commercialize external and internal ideas by deploying outside its own laboratories and leverage ideas from the open market. One of the ways is by financing start-ups and putting their own men into it. The inventions generated out of its labs can be well commercialized. So the open model innovation has a porous boundary between a firm and its surrounding, so as to enable free flow of innovation and then take the same to the market for commercialization.

Looking at the pharmaceutical industry, it may face a threat of patent expiration in the near future. This may be due to diminishing new drug breakthroughs, adverse regulatory laws, increasing competition, and a harsh economic climate. Merck & Company may have felt these mounting pressures and had become increasingly reliant on blockbuster drugs and with its new drug pipeline running dry, it accepted that the biotech industry is too complicated for it to navigate alone. Thousands of new ideas were emerging around the world, both inside and outside of the company. In 2009, it changed the classical model of innovation behind closed doors and opened up to the open innovation strategy that allowed the company to source new ideas externally and at a faster rate.

Procter and Gamble (P&G) is an example of successful implementation of the outside-in method. A large number of technology entrepreneurs were assembled to search for promising new technologies and products. This strategy called 'connect and develop' sought to outsource to suppliers, competitors, research centres, universities, and government entities to bring innovation to the company. The collaboration catches external ideas with the aim to increase innovation and reduce R&D expenses. Though in 2000 P&G did not reach its intended goals, it gained increased revenue, cost reduction, and experience from the outside-in method.

Another example is the case of Tesla Motors Inc., whose Chief Executive Officer (CEO), Elon Musk announced in 2014 that the company will not initiate patent lawsuits against anyone who in good faith wants to use their technology. This announcement was a surprise to the automobile giants. He justified it by stating that the company and its rivals making electric cars may contribute to the world, a common rapidly evolving technology platform. He has said that Tesla's biggest competitor is the Behemoth Gasoline Car Industry, and not other electric car companies. The goal of this inside-out strategy is

to stimulate the creation of electric car companies, grow the market, and spur the industry to develop infrastructure that will answer to new requirements.

Recently, Tesla Motors and SpaceX have collaborated to work on a dream project called the Hyperloop. This project is about a capsule for transporting people which can reach speeds of 1200 km/h. This ambitious project is being built by Hyperloop Transportation Technologies Ltd, where its CEO has gathered a team of professionals from NASA, Yahoo, Boeing, Airbus, Salesforce and Stanford. The project involves technologies from varied fields like space technology, aeronautics and computer science. The project welcomes ideas from students, universities and other enthusiasts, where their contributions shall be duly rewarded. This is a good example of open source project, where the makers intend to complete the project with the best ideas available by welcoming them from the outside.

If space technology is seen closely, there are a good number of actors employing Open Innovation (OI) methods[14]. Neptec Design Group Ltd is an example of a successful implementation of the inside-out and outside-in practices. They have developed the TriDAR 3D laser vision system allowing autonomous spacecraft or astronauts to rendezvous with equipment which were till now not been marked with visual docking markers.

Building on these innovations, Neptec Technologies Corp was founded to commercialize technologies developed by Neptec Design Group. One of the resulting products is the OPAL (Obscurant Penetrating) commercial light detection and ranging (LIDAR) system. The sensor is specifically designed for commercial markets, but incorporates many functionalities and technologies developed for space applications. The information transfer between these two companies has allowed them to use the knowledge gained in space to applications on earth. Neptec is also incorporating lessons learned from its commercial business that it can spin-back into its space activities. This twofold innovation system allows both companies to contribute ideas to each other while sharing development risk and benefits across several industries and markets.

The example of the inside-out method of OI is the Canadian company MacDonal, Dettwiler and Associates (MDA). Using knowledge and expertise gained from the construction and operation of Canadarms, MDA partnered with University of Calgary to create NeuroArm, a robot system designed for neurosurgery. The control system designed for Canadarm was adapted to allow a surgeon's hand to be steadier when performing surgery. The MDA engineering team was embedded in the surgical room during the development process to understand the environment and surgical rhythm to ensure that the switch to virtual controls is as seamless as possible. Since its introduction in 2008, NeuroArm has gone on to perform more than 70 successful surgeries.

In India, ISRO developed an artificial foot based on space technology in partnership with Bhagwan Mahavir Viklang Sahayta Samithi (BMVSS) as part of an inside–out process[15]. The polyurethane (PU) technology developed by ISRO is borne out of its pioneering R&D on various polymeric materials. The materials ensure reliability and quality of launch vehicles and satellites. PU is a versatile polymer that can be produced in various forms like adhesives, coating materials and in flexible or rigid forms. ISRO has developed PU polymer and its advanced derivatives, which are being extensively used in propellants, cryogenic insulation, thermal insulation pads, structural damping, acoustic insulation and other lightweight structural materials for vibration control, shock absorption liners and adhesives.

There are further improvements in the R&D of PU done by BASF, Covestro, Dow, Huntsman, Mitsui, Arkema, DIC Corporation, Henkel, Lubrizol and SIKA[16]. In 2005, Dow Chemical International Pvt Ltd (Dow India) joined hands with BMVSS for development and value addition on the PU foot. ISRO has made flexible and accommodative technology transfer agreement with BMVSS that resulted joining others like Dow India for further value addition of PU. From 2005 to 2007, Dow India's PU team, BMVSS, and other manufacturing partners spearheaded the project, which involved changing from polymer material to PU and modifying the mould design. In 2008, Dow India took this relationship to the next level when it committed to becoming the organization's largest corporate sponsor and contributed fund as a part of its corporate social responsibility programme.

The technical collaboration between Dow India and BMVVS expertise led to improvement in the design and development of the PU Jaipur foot, a prosthetic artificial limb that has functionality and is cosmetically close to a natural human limb. The change of polymer material to PU produced tangible results: reducing the manufacturing cost of the foot by approximately 25%, increasing longevity of the foot and increasing manufacturing productivity from one limb per hour to eight limbs per hour with enhanced consistency of quality through the use of computer controlled injection moulding process. For the recipients, the foot weight was reduced by around 20% that allows greater flexibility, enabling them to not only walk comfortably, but also to squat, kneel, crouch and sit cross-legged an all functional, all terrain limb. The PU foot that has been acknowledged by leading orthopedic experts as having greater flexibility, comfort and high durability. Development work continues today with Dow India's PU team looking at coating the foot with an elastomer layer to increase longevity and developing a rigid PU keel to give additional strength and increase the product life. Lately, Massachusetts Institute of Technology, USA, the world's leading technology institute, along with the American Society of Mechanical Engineers has joined Dow India, Pinnacle Industries and BMVSS in this

project. PU is expected to revolutionize artificial limb manufacturing, benefitting millions of amputees all over the world, if it adopts 3D printing at the earliest.

ISRO has also contributed in other fields apart from space science and technology which have directly and indirectly reached the society[17,18]. It had always laid emphasis on the development of indigenous technology. The space programme had built synergy in industrial development in the country and also built a strong partnership with Indian industries[19–21]. More than 500 small-, medium- and large-scale industries participate in the space programme in the form of engineering hardware development, supply of materials, mechanical fabrication, development of electronics components and software, testing and other services. Almost 60% of the money spent on a launch vehicle flows to Indian industries. Tele-education and tele-medicine are examples of recently deployed space-based applications where almost 100% of the ground segment equipment and services have been developed by Indian Industries.

ISRO has also contributed to capacity building and nurturing the Indian industries through technology transfer, consultancy, funding and infrastructure development. So far, ISRO has transferred about 300 technologies to industries in the fields of electronics and computer-based systems, specialty polymer chemicals and materials, electro-optical instruments, mechanical equipments and ground systems. Many of the industries have been able to supply products developed using these technologies to users other than the space programme. Thus a large sector of general engineering users have benefitted from the space programme.

In addition, there are projects related to disaster management, land and water management, micro-level planning of forest resources, quantifying the methane flux from cattle manure dumps in rural areas, study of soil conditions and soil technology, impact assessment of slope stability and sedimentation on land-degradation processes, groundwater scoping and analysis, etc.

Further, research proposals are supported by ISRO in any area of relevance to the space programme, e.g. physics of the ionosphere and magnetosphere; meteorology, dynamics of the atmosphere; geophysics, geology; astronomy; cosmology; astrophysics; planetary and interplanetary space physics and climatology. Space technology: rocket and satellite technology; propulsion systems design and optimization; aerodynamics and heat transfer problems related to space vehicles; guidance and control systems for launch vehicles and spacecraft; polymer chemistry, propellant technology; ultra-light weight structure; satellite energy systems; space electronics, space communication systems; orbital mechanics, and new material development. Space application: remote sensing of the earth's resources; space communication; satellite geodesy image processing, satellite meteorology including weather forecasting, space education and ecology. ISRO has also completed 500 projects from 2000 to 2014 (ref. 22). These projects range from geo-sensing, satellite data analysis to study prospects related to environment and ecology.

Despite tremendous technical progress, ISRO should not be complacent. In 2012, SpaceX made history as it became the first commercial vehicle to visit the International Space Station. The launch also signalled an era of private entrepreneurship entering in the space arena. NASA's biggest bet in recent times is entrusting small private companies with big public responsibilities, ISRO should not lose this opportunity of open innovation (outside-in/inside-out) methods aggressively to enrich its IP portfolio and knowledge base, since its patents are less compared to other space agencies in the globe.

Conclusion

From humble beginnings in the 1960s, ISRO has made noteworthy progress in the field of space science and technology. It has always drawn constant flak from the West, whenever it had inched a little ahead. From launch vehicles and satellites to inventions which help the common man. ISRO has contributed tremendously towards nation-building. The present study though only focuses on a smaller aspect of the feats achieved by ISRO; in this era, the patent portfolio of an organization is a required asset. The study has analysed both quantitatively and qualitatively, the patents granted to ISRO. These patents have been granted on diverse subject matters like communication systems, instrumentation, optics and antenna systems, electric and electro-mechanical inventions, sensors and transducers, polymer chemistry, alloys, coatings and materials science. Even though ISRO ranks among the top seven leading space agencies in the world, it has less number of patents. ISRO should give importance for protecting its intellectual property. Further, patents available since its inception are already in public domain and people may use the technology disclosed in the patent documents without paying incentives if it is not in-force. The organization has made great progress in science and technology and one of the foremost intentions of this study has been to highlight the technical prowess of ISRO.

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