# 1 Satellite Applications Handbook: The Complete Guide to Satellite Communications, Remote Sensing, Navigation, and Meteorology

Joseph N. Pelton, Scott Madry, and Sergio Camacho Lara

## Contents



**Abstract**

This chapter introduces what is meant by the term "applications satellite" and addresses why it makes sense to address the four main space applications in a consolidated reference work. This handbook also provides a multidisciplinary approach that includes technical, operational, economic, regulatory, and market perspectives. These are key areas whereby applications satellite share a great deal. This can be seen in terms of spacecraft systems engineering, in terms of launch services, in terms of systems economics, and even in terms of past, present, and future market development. This is not to suggest that there are not important

J.N. Pelton (✉)
Former Dean, International Space University, Arlington, Virginia, USA
e-mail: joepelton@verizon.net

S. Madry
International Space University, Chapel Hill, North Carolina, USA
e-mail: Scottmadry@mindspring.com

S. Camacho Lara
CRECTEALC, Luis Enrique Erro No. 1, Tonantzintla, San Andres, Cholula, Puebla, C.P. 72840, Mexico
e-mail: sergio.camacho@inaoep.mx

J.N. Pelton, S. Madry, S. Camacho-Lara (eds.), *Handbook of Satellite Applications*,
DOI 10.1007/978-1-4419-7671-0_91, 

technical and operational differences with regard to communications satellites, remote sensing satellites, global navigation satellites and meteorological satellites. Such differences are addressed in separate sections of the handbook.

Yet in many ways there are strong similarities. Technological advances that come from one type of applications satellite can and often are applied to other services as well. The evolution of three-axis body-stabilized spacecraft, the development of improved designs for solar arrays and battery power systems, improved launch capabilities, and the development of user terminal equipment that employs application-specific integrated circuits (ASIC) are just some of the ways the applications satellites involve common technology technologies and on a quite parallel basis.

These applications satellites provide key and ever important services to humankind. Around the world, people's lives, their livelihood, and sometimes their very well-being and survival are now closely ties to applications satellites. Clearly the design and engineering of the spacecraft busses for these various applications satellite services as well as the launch vehicles that boost these satellites into orbit are very closely akin. It is hoped that this integrated reference document can serve as an important reference work that addresses all aspects of application satellites from A to Z. This handbook thus seeks to address all aspects of the field. It thus covers spacecraft and payload design and engineering, satellite operations, the history of the various types of satellites, the markets, and their development – past, present, and future, as well as the economics and regulation of applications satellites, and key future trends.

**Key Words**

Applications satellite • Committee on the Peaceful Uses of Outer Space (COPUOS) • Earth observation • Global Navigation Satellite Systems • Launch services • Markets for satellite applications • Military satellite communications • Satellite broadcasting • Satellite communications • Satellite meteorology • Satellite navigation and positioning • Satellite remote sensing • Scientific satellites • United Nations

## Introduction

Artificial satellites have now been around for more than a half century. The launch of Sputnik in October 1957 ushered in the space age and confirmed Sir Isaac Newton's theoretical explanation of how an artificial satellite could be launched into Earth orbit. Today the world of satellites can be divided into two broad areas – scientific satellites and applications satellites. Scientific satellites explore and help humanity acquire new information about our world, our solar system, our galaxy, and the great cosmos within which we exist. The scientific satellites explore radiation from the Van Allen Belts to cosmic radiation. They engage in geodesy to measure our Earth and tectonic movements. They study the workings of the Sun and the characteristics of the our Solar System, including the planets, their moons, asteroids, comets, and the Oort cloud well beyond the orbit of Pluto. Astronomical observatory satellites explore the stars and galaxies and give us a view of the Universe near its beginning as well as of exo-planets in other star systems. This handbook, however, is about the applications satellites that provide practical services to people here on Earth. These are the communications satellites, the remote sensing satellites, the space navigation and positioning satellites, and the meteorological satellites that truly serve humankind.

Thousands of applications satellites have now been launched over the past half century. These practical satellites now represent a huge global industry. These satellites are a part of our everyday lives whether we know it or not. Every time you hear a weather report or every time you use a GPS or Glonass device to navigate your car you are relying on an applications satellite. Services such as worldwide news, satellite entertainment channels, coverage of sporting events, communications to ships at sea or aircraft in the skies, and many more frequently depend on satellites. Farmers now rely on satellites to irrigate their crops, add the right amount of fertilizer, or detect a crop disease. Fishing fleets use satellites to know where to fish. Energy and resource companies employ satellite imaging to know where to dig or drill. Efforts to combat global warming, preserve the Ozone layer that is essential to life on Earth, and other activities to sustain the biodiversity of plant and animal life on our planet all depend on applications satellites. Responding to major disasters routinely involves analysis of satellite imagery and mobile satellite communications. This then is a comprehensive reference work about the practical use of satellites to serve humanity and make our lives better.

The multibillion-dollar (US) world of commercial satellite applications and services continues to expand each year. This means that the technology is becoming more sophisticated and reliable and the practical applications ever broader. Commercial satellite applications and satellite technology are both becoming more sophisticated and efficient. This is particularly true in terms of finding more and more applications in different fields and in the expanded use of automation and the application of expert systems and artificial intelligence to allow more autonomous operation of satellites in outer space. The size of satellite applications markets are now measured in the hundreds of billions of dollars (US). Virtually every country and territory in the world relies on applications satellites for multiple space-based services. The diversity of the submarkets within the field we have defined as "satellite applications" continues to expand and becomes more complex. Indeed, in view of this growing dependency on space applications and the expanding number of satellites in near-, middle-, and geostationary Earth orbits, the international community, through the United Nations and other fora, is working to ensure the long-term sustainability of activities in outer space.

Today the field of "satellite applications" includes at least: (1) satellite communications, (2) satellite broadcasting, (3) satellite navigation and positioning, (4) geostationary satellite meteorology, (5) remote sensing and Earth observation, and (6) space-based information systems. And this is just the beginning. The above-cited satellite applications activities generate other major space-related activities and industries which are themselves of significant size. For instance, the field of commercial satellite applications creates a substantial part of a multibillion-dollar

(US) launch vehicle industry around the world. It also creates yet another multibillion-dollar market for earth station antennas, very small aperture antennas, micro-terminals, and hand-held satellite transceivers. Finally there are also important ancillary markets that also feed off of commercial "satellite applications." The supporting industries include:

1. *Space-related insurance and risk management industries* (such coverage requires expenditures equivalent to 10–20% of the value of the satellite and its launcher).
2. *Engineering, design, reliability testing, and regulatory support activities.* Key technical support is required to design new systems and carry out research related to new space and ground systems. (These engineering companies and research organizations prepare detailed technical specifications for satellite systems and work with specialized law firms to prepare requests for regulatory approvals and frequency assignments and allocations at the national, regional, and even global levels.)
3. *Financial institutions, investment banks, and underwriting corporations*. These institutions help to raise the billions of dollars in capital needed to build and launch the satellites and deploy hundreds of millions of earth station antennas, receive only terminals and two-way satellite telephones around the globe.
4. *Marketing and sales organizations*. These companies help with the sales of satellite applications services around the world to literally billions of people who depend on applications satellites for severe weather warnings, for radio and television services, for Internet connection, for navigational and routing information, and for vital information for farming, fishing, mining, or urban planning.

Today the overall field of "satellite applications" thus represents not only the primary sectors that build or operate commercial space satellite systems and launch them but a huge supporting work force as well. These include hundreds of service, engineering, manufacturing, specialized banking, and insurance companies. These supporting service industries represent an important set of commercial enterprises representing billions of dollars (US) in revenues (see Fig. 1.1).

Without all of these diverse satellite applications providing meteorological and weather information, communications, broadcasting, navigational, remote sensing, and supporting space-based information services, the world we live in would be greatly different. Without these systems, for instance, many more lives would be lost to hurricanes, tornadoes, tsunamis, earthquakes, volcanoes, and other violent acts of nature. Without these systems there would be less effective global communications systems. Satellite telecommunications systems support telephone, Internet, and other IP-based information services across virtually all of the world's 200 plus countries and territories. These satellite systems also provide communications to ships and offshore platforms and buoys in the seas as well as to the Polar region and to aircraft in the skies. Applications satellites are an important part of the world's search and rescue (SAR) infrastructure for downed pilots, stranded passengers and crews of shipwrecked vessels, or people lost in wilderness areas or subject to natural disasters. Other space navigational systems and geodetic satellite systems provide key real-time information to all parts of the world whether on land, the seas, or in the air, including tracking of goods in our global transportation network. These space systems, with increasing

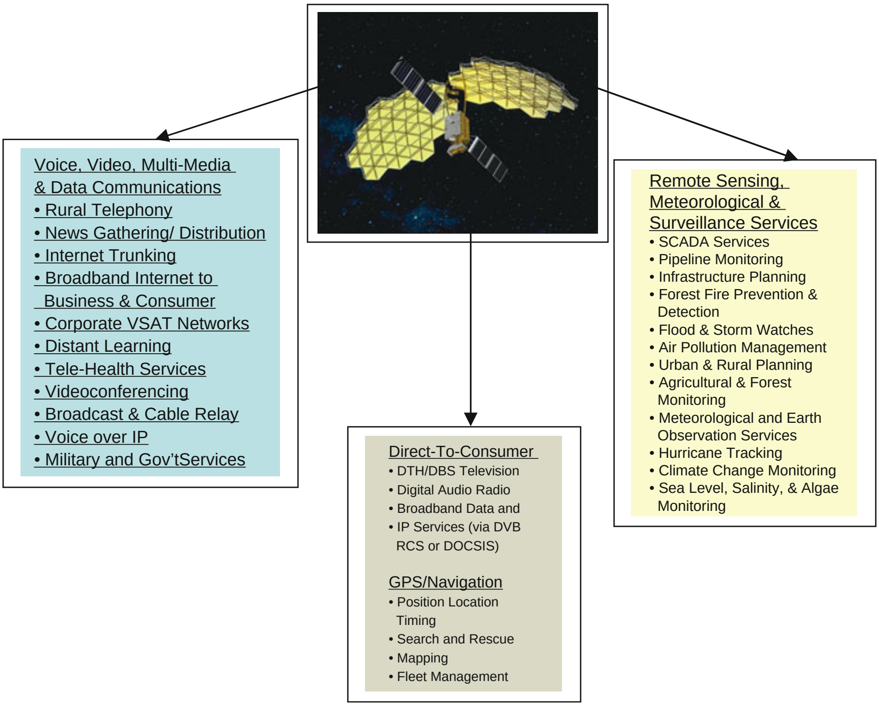


**Fig. 1.1** The wide range of satellite applications services provided from space today (Graphic courtesy of the author)

accuracy, can tell us where people or vehicles or buildings or a myriad of things are located for a wide range of applications. Without broadcasting satellites there would be limited television, radio, and other broadcasting services around the world.

Over a billion people receive television, radio, or communications live via satellite to their homes and offices. Satellite services have become so pervasive that they have almost disappeared from the public consciousness as something unique and special. The use of outer space has become almost commonplace in a span of a half century. Much like electric motors or batteries, the vast and extensive use of satellites in our everyday lives has thus often become "invisible." These key machines in the skies help us to predict the weather, receive an entertainment broadcast, connect to the Internet across the globe, know where we are in our cars and how to get to our destinations, protect us from fires, or help us to have access to a wide range of resources from apples to zirconium.

The growth of the satellite applications market will continue to be rapid and diverse – and for many years to come. The first graph below shows the evolutionary nature of the markets from a decade ago. Even then the satellite communications industry in terms of satellite and earth station manufacturing, launch services plus communications services when combined represented total annual revenues of nearly $90 billion. The global positioning system (GPS) to support satellite

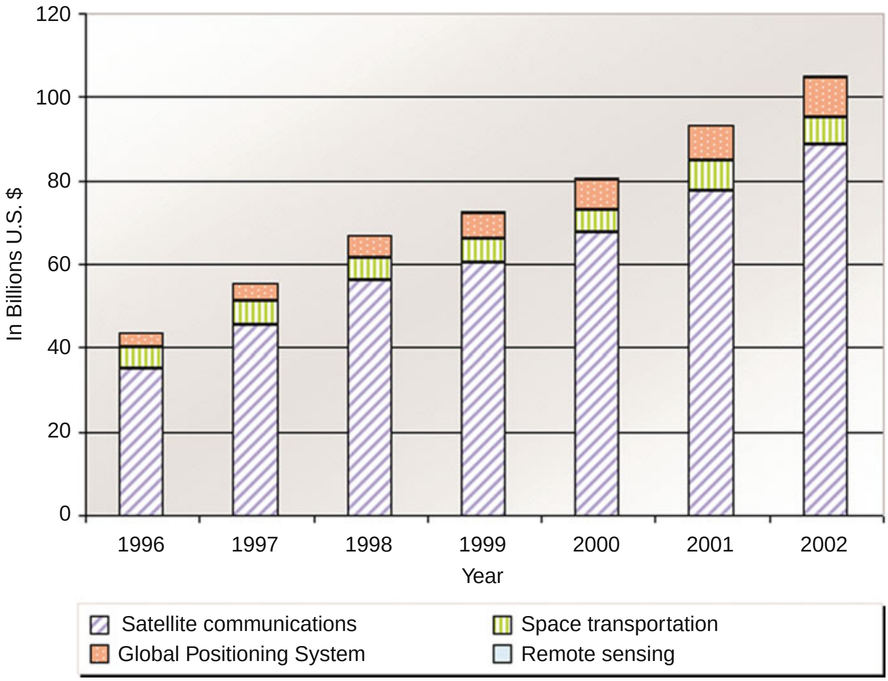


**Fig. 1.2** Early stages of growth of the commercial satellite applications market. (U.S. Department of Commerce, *Trends in Space Commerce, Office of Space Commercialization*. (U.S. Department of Commerce, Washington, D.C, 2002))

navigation applications was beginning to emerge as a key market when GPS receivers, and services related to GPS were combined. Commercial space transportation to support these industries was also a significant market, but space navigation and remote sensing was quite small (Fig. 1.2).

The combined revenues for 2009 – just for global commercial satellite applications *services* – totaled around $105 billion (see Fig. 1.3). If one then adds in expenditures for satellite launches, the manufacturing of satellites, manufacturing of earth stations and various types of user terminal equipment, technical consulting support, licensing fees, and insurance and risk management, the total revenues associated with the commercial applications satellite industry – for satellite service revenues plus all other costs and expenditures – the net industry annual revenues climb to over $200 billion per annum.

If one were then to add in the additional costs associated with governmental and defense-related communications systems and the cost of governmentally operated geosynchronous meteorological satellite services, then the annual financial turnover for the satellite industry would exceed $250 billion or over a quarter trillion dollars. It is thus safe to say that overall the combined field of “commercial satellite

| REVENUES FOR IN APPLICATIONS SATELLITE SERVICES (2004-2009)[1] (Note: Figures Do Not Include Revenues for Satellite Manufacturing, Earth Station Manufacturing, Launch Services, Engineering, Licensing, Risk Management, etc.) (In billions of dollars (U.S.) per year) | | | | | | |
|---|---|---|---|---|---|---|
| **Type of Satellite Service** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** |
| **Total Direct to Consumer** | **$35.8 B** | **$41.3 B** | **$48.9 B** | **$57.9 B** | **$68.1 B** | **$75.3 B** |
| **DBS Televsion** | **$35.8 B** | **$40.2 B** | **$46.9 B** | **$55.4 B** | **$64.9 B** | **$71.8 B** |
| **DBS Radio** | **$0.3 B** | **$0.8 B** | **$1.6 B** | **$2.1 B** | **$2.5 B** | **$2.5 B** |
| **Direct Broadband Internet** | **$0.2 B** | **$0.3 B** | **$0.3 B** | **$0.4 B** | **$0.8 B** | **$1.0 B** |
| **Fixed Satellite Services** | **$8.9 B** | **$9.3 B** | **$10.7 B** | **$12.2 B** | **$13.0 B** | **$14.4 B** |
| **Transponder Lease** | **$7.0 B** | **$7.3 B** | **$8.5 B** | **$9.5 B** | **$10.2 B** | **$11.0 B** |
| **Managed Network Services** | **$1.9 B** | **$2.0 B** | **$2.2 B** | **$2.6 B** | **$2.8 B** | **$3.4 B** |
| **Mobile Services** | **$1.8 B** | **$1.7 B** | **$2.0 B** | **$2.1 B** | **$2.2 B** | **$2.2 B** |
| **Space Navigation Services** | **$5.8 B** | **$ 6.8 B** | **8.0 B** | **$9.4 B** | **$10.8 B** | **12.0 B** |
| **Remote Sensing** | **$ 0.4 B** | **$ 0.6 B** | **$0.4 B** | **$0.4 B** | **$0.8 B** | **$1.0 B** |
| **TOTAL** | **$52.7 B** | **$69.7 B** | **$70.0 B** | **$82.0 B** | **$94.8 B** | **$105.0 B** |

[1]Satellite Industry Association "Executive Summary, 2009 State of the Satellite Industry Report ", Prepared by the Futron Corporation, 2010 Washington, D. C.
www.sia.org/news_events/pressrelease/2010StateofSatelliteIndustryReport2010(Final).pdf

**Fig. 1.3** Annual revenues for applications satellite services

applications" represents quite a large global industry. Further this is an industry that has shown consistent growth for several decades and has continued to grow even in times of global recession.

## The Evolution of Commercial Satellite Applications

With the launch of the Sputnik satellite in October 1957 people began to think of outer space not as something in science fiction novels, but as a real and increasingly important activity. Everett Edward Hale as early as 1867, when he wrote *The Brick Moon*, speculated on the use of artificial satellites for communications, navigation, and remote sensing. But as of the late 1950s, scientists and engineers began to conceive of practical ways to utilize artificial satellites for needed services. The first application was satellite telecommunications. In the late 1950s and early 1960s, international communications capacity for overseas links was both very limited in scope and the per-minute rate of a telephone call was quite high. (Submarine cables for voice communications could only connect 36–72 voice circuits at a time and could not handle even low-quality black and white television transmissions on a live basis. One might have to pay $20–50 a minute for an overseas telephone connection.)

In the various sections that follow, the history of satellite applications is provided in detail, but the following provides a brief overview. The first practical application of satellites was in the field of telecommunications. A series of experimental satellites were launched in the early 1960s to test the feasibility of communications satellites for commercial purposes. These satellites, known variously as SCORE, Courier 1B, Echo, Telstar, Relay, and Syncom, proved vital to the design of the operational systems that were to follow. These early experimental satellites helped space system designers to discard the idea of using passive satellites for telecommunications. Echo was a metallic coated balloon launched for meteorological experiments, but bounced electronic signals off its reflective surface without amplification. These experiments confirmed that this type of "passive satellite" represented much too low of a capacity for commercial needs. These experiments and many others – particularly the Syncom satellites – showed that deploying satellites into geosynchronous orbit and providing telecommunications services from orbiting spacecraft was technically feasible (Pelton 1974).

This special Geo orbit (sometimes call the Clarke orbit in honor of Sir Arthur Clarke who first suggested this orbit for communications satellites) allowed virtually complete global coverage with only three satellites and eliminated the need for Earth Station antennas to track rapidly across the sky. This is because the Geo orbit allows the satellite to "seem to hover constantly" above the same location over the equator. (Note: A more formal definition of the geostationary orbit is an Earth orbit having zero inclination and zero eccentricity, whose orbital period is equal to the Earth's sidereal period. The altitude of this unique circular orbit is very close to 35,786 km.)

These various experiments led to the deployment of operational telecommunications in 1965. The three initial satellite telecommunications systems, all launched in 1965, were the Intelsat system that deployed the "Early Bird," the low-orbit Initial Defense Communications Satellite System deployed by the US defense department, and the Molniya satellite system for the USSR. There were three Molniya satellites deployed into highly elliptical orbits that were suited to northern latitude coverage over Russia and to the satellite countries known as Soviet Socialist Republics.

The rest is history. The Intelsat satellite system grew into a truly global network that ultimately served nearly 200 countries and territories around the world. A number of national satellite systems were launched to meet domestic communications needs (particularly to meet television and radio broadcasting needs and service to rural and remote areas). In time regional satellite systems evolved and yet other systems were deployed to meet maritime, aeronautical, and land mobile communications. Military-, security-, and defense-related satellite systems were also launched to meet the specialized needs of military agencies. Today there are many hundreds of communications satellites in orbit and well over a thousand have been launched since the late 1950s. Some of these telecommunication satellites are in geosynchronous orbit, others are in medium earth orbit, and yet others are deployed as constellations in low earth orbit. Some of these are multipurpose and support various types of telecommunications services for telephone, radio, and television broadcasting or distribution or data networking and Internet-related services. Other satellites are designed and optimized for mobile communications for land, sea, or aircraft communications.

Close on the heels of the telecommunications satellites came other types of applications satellites. Military reconnaissance satellite systems were a very high early priority for both the Soviet Union and the USA in the cold war. Fully half of the first 20 Soviet Cosmos series space launches were for military Zenith imaging systems, and the US Corona satellite system was developed in secret starting in 1959. The Corona program was started under the camouflage of public statements that these satellites were scientific payloads. The Corona program was not publicly acknowledged for many years and not until well after being out of service. These "spy" satellites set the stage for remote sensing and weather satellites.

First came the weather or meteorological satellites, which were initially developed in order to provide weather and cloud cover information for the military imaging systems. The US President's Science Advisory Committee reported in 1958 that "The satellite that will turn its attention downward holds great promise for meteorology and the eventual improvement of weather forecasting." But the potential benefit of weather satellites was evident and the first civil weather satellite launched was the TIROS (Television and Infra-red Observation Satellite), which started as a defense department program and was transferred to the new NASA in April of 1959. Its first images in 1960 provided a synoptic view of weather patterns, sea ice, and other features that were immediately analyzed on the ground to great effect, and were the first in an unbroken series of weather satellites that operate to this day. TIROS was in a low Earth (435 miles or approximately 700 km) orbit, but the potential for a permanent geostationary orbital view was clear. The first geo weather satellite was the US GEOS-1, launched on October 16, 1975, demonstrating the benefit of the geostationary orbit for weather observation. Over the past 30 years, additional weather satellites have been launched by Europe, Japan, India, Russia, and China. These now provide a constant global view of our world and have revolutionized our understanding of global weather patterns and our ability to accurately forecast the weather.

This was followed by remote satellite sensing systems and specialized Earth observation satellites, with the launch of the Earth Resources Technology Satellite in July 1972 (later renamed Landsat 1). The Landsat series led the way in the development of dedicated Earth resources satellites that were specifically designed for a wide range of applications such as agriculture, forestry, and water resources. These systems have continued to develop and have improved their capabilities, with spatial resolution improving from 80 m with Landsat 1 to under 0.5 m with the current ultrahigh resolution systems.

The most recent class of satellite applications to evolve are those associated with satellite navigation, also referred to as precision timing and navigation systems (PNT) or Global Navigation Satellite Systems (GNSS). These systems were first devised to assist with military- and defense-related purposes such as targeting and mapping, such as the early US TRANSIT and Soviet Tsikada Doppler-based systems, which were first fielded in 1959 (Transit) and 1974 (Tsikada). Today, however, there are a wide range of commercial uses for space navigation satellite systems and these satellites actually represent a multibillion-dollar industry worldwide. This market has grown rapidly and continues to develop new uses. Next-generation system development started with the US Navstar GPS system, first developed in 1973 and fully deployed in 1994. Europe, Russia, India, Japan, and China are all developing and launching their own advanced systems, and the future of this class of satellites is bright.

Later in this handbook the more detailed histories of these various types of applications satellites are provided for those that would like to know how these various types of satellite systems evolved over time.

More than a thousand applications satellites are now in low, medium, or geosynchronous orbits and these are being used to provide one or more types of commercial satellite services. Indeed there have been a number of instances where a satellite built for one type of application such as telecommunications had another "package" added to the satellite to provide meteorological imaging such as was the case with an Indian "Insat" satellite. Sometimes an operational satellite will have an experimental package attached to test out a new technology. One example of this was the Orion international communications satellite that had an experimental inter-satellite link (ISL) package added to it for performance testing. Today most satellites are designed for a particular application because the frequency bands (or radio frequency spectrum) allocated for space applications through the International Telecommunication Union are (ITU) are typically different for different types of applications.

Later in this handbook specifics of these allocations are provided. Nevertheless satellites can have a primary payload for one application and then have one or more secondary payload(s) for other applications or to experiment with a new technology or new frequency band. An example of this is the US NOAA polar orbiting POES satellites which also carry the Cospas_SARSAT search and rescue and ARGOS telemetry systems. For 50 years now there have been applications satellites in the Earth orbit. Thousands of these various types of satellites have been launched and some of them have come back from their orbit and burned up in the atmosphere or crashed backed into Earth. Others have been pushed out into space above a geosynchronous orbit where they will stay for millions of years. There are, however, many thousands of defunct and derelict satellites or parts of satellites or launchers still in orbit known as orbital debris. Currently on the order of 20,000 bits of "orbital debris," about the size of a tennis ball or larger, are known to be in orbit and millions of microscopic elements are present – especially in low earth and polar orbits. By December of 2010, 4,765 launches and 251 on-orbit breakups had led to an orbital debris tracking condition where at least 16,200 objects had been entered into the US Space Surveillance Network (SSN) catalog.

The problem of orbital debris crashing into a satellite, space station, or other active space object is thus a growing concern. The crash between a defunct Russian Kosmos satellite and an active Iridium communications satellite in 2009 has served to highlight these concerns. The United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) that has been addressing this issue for some time has now agreed as of June 2007 to voluntary procedures to reduce the threat of orbital debris creation in future years.[1]

## What Does the Term "Satellite Applications" Mean and Why Consider It in a Unified Way?

Why a Handbook of Satellite Applications? One can find handbooks and reference sources in many areas that include the various "fields" of satellite applications. There are reference handbooks on satellite telecommunications, satellite broadcasting, satellite-based remote sensing, or Earth observation. There are also some reference materials on satellite-based meteorology and space navigation. The key to "satellite applications" is to recognize that while these space-based services all tend to have a different range of users – and require different specialists to use the information, the underlying technology with regard to designing, manufacturing, launching, insuring, financing, and getting regulatory approval for "applications satellites" are in many ways quite similar. As noted above an applications satellite designed for one type of service or application can also have a secondary or even tertiary package (i.e., payload) to perform operations in an entirely different field. The platform used for telecommunications, broadcasting, remote sensing, Earth observation, meteorological purposes, or space navigation start out to be remarkably similar in their design, manufacture, testing, launch requirements, and, in many cases, even their deployment.

## Common Elements of Applications Satellites

An applications satellite's mission is defined by its payload, which carries out its specialized function, but the platform on which the payload resides is quite often similar in terms of structure, power systems, tracking, telemetry, command and monitoring systems, stabilization, positioning, pointing and orientation systems, thermal control systems, and so on. Many manufacturers of applications satellites have evolved toward the design of various size platforms that meet various customer needs. At the smaller end of the spectrum the Surrey Space Center's microsatellite "bus" or platform has been used for communications, IT related, remote sensing, and other scientific purposes. For progressive larger satellites with more ambitious objectives to support larger payloads, commercial aerospace manufacturers have progressive larger platforms that support larger and more sophisticated missions.

Over the last 40 years there have been more telecommunications and broadcasting satellites designed, manufactured, and launched than other types of applications satellites. These "communications satellites" have been deployed for commercial, governmental, and military purposes. Just because of their sheer volume, the platforms developed for communications satellites have generally tended to characterize the range of platforms available for other purposes in terms of size, structural integrity, maneuverability, lifetime, power systems, and pointing accuracy. At the very beginning a new platform was designed for each satellite. This custom design process was often driven by the fact that satellites were becoming more capable in size and performance. This constant upgrading of performance and the need for larger satellite antennas required greater pointing accuracy.

In another context, the satellites were also being designed for longer life. Several prime characteristics defined the design of these increasingly complicated and larger platforms. These characteristics were: (1) increased capability for the payload; (2) prime or peak power requirements over the satellites' lifetime; (3) the pointing accuracy and orientation requirements for the satellite platform and the size and shape of the antennas or functional elements that must be supported by this platform; and (4) the lifetime desired for the satellites operation and the need to remove satellites from their operational orbit at end of life – factors that required more fuel and larger fuel tanks. These four characteristics were the main drivers that led to a wide range of platform designs. Over time the manufacturers realized, just like manufacturers of automobiles, that one did not have to design a new "bus" or "platform" every time there was a new order for a communications or other type of applications satellite. Thus manufacturers began to standardize classes of platforms from nano- or microsatellites up through giant 10,000–12,000-kg platforms that are built for the largest type of direct broadcast or mobile satellites that can be launched by currently available launch systems such as the Atlas 5 or the Ariane 5.

Although the platforms might be quite different in volume and mass, varying from about 200–12,000 kg, they usually contain many of the same features. These are: batteries (for emergencies and when the satellite might be in eclipse); solar cell arrays (as a prime source of electrical power); a strong but lightweight structure to hold the satellite and its components together; a thermal control system to keep the components and its payload from becoming too cold or too hot; an electrical system for controlling components; a tracking, telemetry, command, and monitoring system so that people on the ground can actively know how the satellite platform and its payload is operating and send commands to maintain effective operations; a source of fuel and a thruster maneuvering system to aid in keeping a proper orbit; and a finely tuned pointing and orientation system, particularly to help position and point the satellite antennas or onboard sensing system for best performance. Finally there is a star, sun, and/or Earth sensing system to allow people on the ground to know exactly how the satellite is pointing on an X, Y, and Z axis or there is something like an RF alignment system to allow very precise pointing.

This platform or bus will also contain a payload (or in some cases multiple payloads) to perform a particular function such as communications, broadcasting, meteorological sensing, Earth sensing, Earth observation, space navigation, or perhaps a scientific experimental mission. Regardless of the payload and its mission, these elements will largely be common to the "bus" that delivers payload to where it needs to go and to support the payload's operation 24 h a day, 7 days a week, until the mission is complete. When the mission is complete the payload is then employed to help with the final disposition of the satellite, such as bringing the satellite from low earth orbit back into the atmosphere where it will burn up or crash harmlessly into an ocean. If the satellite should happen to be in geosynchronous orbit (i.e., a distance that is equivalent to one tenth of the way to the Moon), then the usual maneuver to remove this type of spacecraft from orbit is to raise it above Geo orbit where it will stay for many thousands of years.

Although there are many common elements to an applications satellite “bus” there still remain quite a large diversity of design elements that are described in the later chapters of this handbook. Some satellites need to be very accurately oriented to perform their mission and others much less so. Thus they range from very simple and low-pointing orientation systems to much more sophisticated ones. The simplest orienting system that is still in use is a gravity gradient system. With this type of platform design there are long booms that can be deployed to extend out into space away from the satellite. Once the booms are extended perhaps 5 m or more away from the satellite in different directions, the pull of gravity from the Earth can more or less orient the satellite toward the Earth. Other designs include satellites that spin around at speeds like 50–60 rpm, while their payloads inside spin in the opposite direction to achieve constant pointing toward the Earth with a stable orientation. These “spinners” were quite common in the early days of satellite communications. Today the most common “bus” is a three-axis-oriented platform that has one to three momentum or inertial wheels inside of the core of the satellite that spin at very high speeds, such as 4,000–5,000 rpm; this serves much like a spinning top to provide very accurate pointing orientation toward the Earth or wherever the platform needs to be oriented.

Just as there are options with the pointing and orienting system there are also options with regard to the thermal control system. Different types of reflective surfaces can be used to control solar heating. There are devices called heat pipes that can transfer heat from the interior of the satellite to the exterior. Despite the diversity of design options, most commercial manufacturers of satellites have a series of four or so basic platforms from which to build desired application satellites again, just as automobile manufactures have four or so chasses from which they build new automobiles. These various elements of the satellite platforms are discussed in great detail in the special section devoted to this subject.

In general, however, smaller and lower cost satellites will have shorter lifetimes with smaller capacities if they are communications satellites. If they are sensing satellites they will have lower resolution or lesser sensing capabilities. In short, smaller applications satellites will have lesser capabilities than the larger spacecraft. Further, there are often economies of scale that are achieved in the design of larger and longer-lived satellites and they also tend to be most cost efficient to launch on a “per kilogram to orbit” basis.

## Organization and Effective Utilization of the Satellite Applications Handbook

This handbook is organized to be useful to a wide range of potential users from design engineers, faculty members and teachers, to reference librarians and students. It is organized into major sections. These sections are each self-contained and provide the history, demand for the service, and technology – past, present, and future. Thus there are sections on: (a) *Space Telecommunications* (this section includes the main categories of Fixed Satellite Services, Mobile Satellite Services, Broadcast Satellite Services, plus store and forward data services, etc.); (b) *Satellite Precision Timing and Navigation* (this type of satellite application has now become the second largest commercial satellite service in terms of market size); (c) *Space Remote Sensing* (this section not only covers remote sensing and Earth Observation, but it also addresses the *Global Information System* (*GIS*) and related software); and (d) *Space Systems for Geosynchronous Meteorology*. This is the remaining key civilian practical use of outer space. It is different in that the provision of this service is largely by governmental agencies rather than commercial companies. The practical value of this service is more difficult to quantify but each and every year this type of satellite applications serves to save many, many lives and greatly minimizes property damage.

**Conclusion**

This handbook thus addresses the above-described four areas of commercial satellite applications and seeks to do so in considerable depth. It does not, however, specifically address classified military and defense-related satellite applications.

What is presented is specific and detailed information about all forms of telecommunications satellites, remote sensing and Earth Observations, satellite navigation, and satellite meteorological satellites. Coverage is provided for the commercial use by defense organizations of applications satellites in a so-called dual use mode. This term applies to civilian or commercial satellites that are also used to meet certain largely "non-tactical" military applications. In this regard it is important to note that military usage of satellites is in many ways quite parallel to civilian space applications, and often presages the development of commercial systems. This is to indicate, for instance, that the basic engineering and design characteristics of telecommunications and remote sensing satellites are often quite similar, although military systems may add special features such as radiation hardening, antijamming capabilities, and encryption capabilities.

The aforementioned four satellite applications are today the prime commercial and practical civilian uses of outer space. To be comprehensive the handbook also presents current and detailed information regarding global launching capability around the world and also addresses the design, manufacture, test, and deployment of the application satellite spacecraft platforms or "buses" that are launched to support these various types of commercial satellite services. As noted above, the platforms for these various applications satellites are quite similar even though the payloads may be quite different.

Finally the last part of the handbook addresses the key economic, regulatory, social business, and trade issues that are associated with applications satellites. Again, although the payloads that are contained on various types of applications satellites are different, the economics, trade, and regulatory aspects in these various commercial systems are similar. This is to say that applications satellites of various types need to use radio frequencies (RF) to send information to and from earth and that accordingly there is a need for RF allocations by the International Telecommunication Union for these various operations. There are national processes for the approval of specific frequency assignments to particular spacecraft in a way to prevent undue frequency interference. There are also a host of technical, economic, regulatory, trade, and even social and religious issues that arise from the use of applications satellites since by their very nature these satellites are international in their operation. Thus commercial applications satellites and their operation, for instance, come under some degree of regulatory control by the World Trade Organization (WTO) with regard to how these services are distributed or sold and the nature of international and national regulation and control. Orbital debris is an increasing threat to the safe operation of applications satellites. This final section thus addresses all of these types of issues and especially regulatory, trade, business, and social issues.

There are several other elements of the reference handbook that should be particularly noted in terms of convenience of use. First of all, the various parts of this handbook are divided into major sections and chapters with highly descriptive titles. Secondly, each chapter contains a list of key words so that if one is interested in "orbital debris," "photo voltaic solar cells," "lithium batteries," "frequency allocations," "precision timing," or the "United Nations Committee on the Peaceful Uses of Outer Space (COPUOS)" these terms should be easily identified. The organization of the handbook is typically structured to put information about any one subject in a concentrated location. This means that power systems are discussed together rather than in four different sections for each type of applications satellite. Finally the appendices are a key source of information about actual applications satellite systems and other types of technical information.

## Notes

1. United Nations Committee on the Peaceful uses of Outer Space Voluntary Guidelines on Orbital Debris, http://www.orbitaldebris.jsc.nasa.gov/mitigate/mitigation.html

## References

J.N. Pelton, *Global Satellite Communications Policy: Intelsat, Politics and Functionalism* (Lomond Systems, Mt. Airy, MD, 1974), pp. 47–50