How it Works

The "How To" of Satellite Communications

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"Thanks to a few tons of electronic gear twenty thousand miles above the equator, ours will be the last century of the savage, and for all mankind, the Stone Age will be over."

Arthur C. Clarke

1.0 INTRODUCTION

Satellites are not magic. Strip away the costly and powerful launch vehicles and the little men in lab coasts who build these complex devices and you find that a communications satellite is really just a very tall microwave tower that relays telecommunications signals upon demand.

The power of communications satellite is their great height which allows coverage of vast areas.

Communications satellites can thus link together a nation, a continent, a world.

The communications satellite is a technology which is creating a global stock, bond, and money market; a host of international tele-education programs; universal television markets and ultimately the "global electronic village" (The so-called Global Information Infrastructure will not e accomplished by fiber optic cable alone).

Conventional ommunications satellites are positioned by rockets in space, 22,238 miles (35,786 kilometers) above the earth in order to achieve a constant "geosynchronous" orbit. (This is not reason, however, to consider satellites arcane, hard to understand or mystical). An accident of the earth's physics dictated that this special circular orbit in the equatorial plane should be at a distance almost one tenth of the way to the moon where gravitational attraction, orbital speed and a 24-hour orbit all coincide).

Today we are beginning to plan and implement new types of satellite systems which are closer to the earth's surface. These include satellites which are in so-called medium earth orbits, or MEOs (i.e. about 8000 miles or 13,000 kilometers) above the earth. We will also explore low earth orbit (LEO) satellites (i.e. 500 to 1000 miles or (800 to 1600 kilometers) over the surface of the globe. These systems produce lower transmission delays, less path loss, more frequency re-use and improved look angles for mobile satellite services in the higher latitude regions such as Europe, Canada, and Russia. In this book we will explore the ins and outs of GEO, MEO, LEO and other types of satellite systems.

In many ways it is best to forget about the "space" part of space communications". Just pretend the satellite is on a very long invisible pole that relays radio waves of very high frequencies and you begin to visualize the basic picture.

The purpose of this book is to avoid technical overkill and to still explain all the basics of communications satellites. It is in short a step-by-step road map to the world of satellites, how they work, and what services they provide. It will cover existing and future markets involving satellite applications in the areas of data, voice, video and other new areas like high definition TV. Past, present and future technology will be covered but only as useful and relevant.

Satellites represent a powerful technology that can do many things well. Terrestrial telecommunications, even fiber optic cables, cannot duplicate certain functions that satellites do superbly. Mobile services, global television broadcasting , and VSAT networks are unique satellite capabilities which fiber optics cables simply cannot equal. If you don't believe it try plugging a fiber optic cable into a jet plane or a truck, or try using cables to link together a regional network with 1000 computer nodes in it. Cables would be a hopelessly expensive way to make all the 499,500 pathways that could be created within a 1000 node system actively available. Satellites on the other hand are terribly good at creating large flexible, on-demand networks. But more about that later.

The purpose of this initial chapter is to let everyone get comfortable with satellite technology and its basic components. Let's begin with the "what", "where", "why", and "how" of satellite communications. The fundamental elements of satellite technology can be divided in two parts, the Space Segment and the Ground segment. Together these two components constitute a complete communications system which can easily interconnect with ground based communications systems.

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1.1 THE SPACE SEGMENT

The space segment is made up of an operational satellite plus usually a spare satellite for traffic restoration. This "spare" often carries traffic as well. Finally there is a system for keeping the satellite effectively in orbit called a Tracking, Telemetry, Command, and Monitoring (TTC&M) system.

The satellite which is the heart of the space segment has in fact only a few basic parts. There are the antennas that receive and transmit signals for communications purposes to earth stations or to relay TTC&M data and commands. There are solar cells and batteries to provide power. There are the electronic communications systems that filter, amplify, translate between uplink and downlink radio frequencies. Then there is a "platform" which provides a constant stable base from which communications can be provided to the earth below. Today the overwhelming percentage of satellites are maintained in geosynchronous orbit or as it is sometimes called the Clarke orbit. This is in honor of Arthur C. Clarke the man who first suggested in 1945 that an orbit 22,238 miles (35,786 kilometers) could be effectively used for space communications. Although Arthur C. Clarke is best known to us as the master of Science Fiction who created the HAL the mad computer in 2001 his true scientific contribution to radar, satellite communications and other fields like ocean thermal energy conversion (OTEC) are enormous.

In addition to the well established geosynchronous satellites,there are some low and medium orbit systems that can provide mobile voice communications, low cost store and forward messaging services as well as navigational services. There are even a very new type mega-LEO satellite system such as the exciting new project called Teledesic. This system is backed up by the exciting entrepreneurial team of Bill Gates of Microsoft and Craig McCaw of McCaw Cellular fame. More about these exciting new developments later.

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1.2 THE GROUND SEGMENT

The ground segment portion of satellite communications just keeps getting smaller, simpler, cheaper and better. This is the result of these key factors: (a) the space segment is becoming more sophisticated and powerful which means the ground segment can be less sensitive and the antennas lower in cost. This also means the antenna surface area can be reduced; (b) the application of new solid state semiconductor technology has further led to production costs going down and reliability going up. It's much like new color TV sets versus older ones; (c) sophisticated mass production techniques for smaller antennas have allowed new economies of scale to be produced; and (d) key innovations related to digital transmission, digital signal processing, and digital compression techniques all of which let you do more for less.

There is often some confusion about several terms that are applied to the ground segment namely earth station, antennas, VSATs, TVRO terminals, and Teleport. Each term has a somewhat different meaning.

The earth station is the entire kit and caboodle. The earth station includes the antenna, the multiplex gear for the uplinks and downlinks, the power generator, the offices for the on-site staff, spare parts, supply roads, etc. It is often true that a single earth station facility will contain several earth station antennas. When such a multi-antenna earth station facility serves a large urban area, ties together terrestrial networks and accesses several satellite systems it is considered a Teleport. Such Teleports are usually for both national and international service. Unfortunately, everyone tends to have their own definition of Teleport so you may wish to check on some others.

The antenna is of course the major communications facility needed to work to the satellite. It is typically a direct feed parabolic antenna that combines a reflector and the associated electronics as will be described later. All earth station antennas can send and receive communications. There actually many types of antennas that can be used for satellite communications. These start with simple low-gain antennas such as di-pole and Yagi units. The progress upward to helix type systems and then move on to parabolic and torus shaped antennas. The torus and parabolic systems can look directly to the satellite (i.e. a direct feed antenna) or they can have reflective focus device as in an indirect feed system. Finally there are new phased-array antennas which use lots of small electronic components which then add up to an overall antenna system. These components can be flat or conformed to any shape such as the side of an airplance or the top of a car. The technical aspects of these various types of antennas will be described later.

A TVRO is a Television Receive Only terminal. It is designed exclusively to receive TV signals. These are relatively cheap ($750 to $2500) dishes typically 1.5 to 2.5 meters in size. Larger TVRO antennas (5-10 meters and $50,000 to $100,000) support the redistribution of television programming to cable TV systems which receive the signals and then sends them to subscribers by cable. Very small TVROs (40 centimeters to 1 meter) are now being used for direct-to-the-home television via Direct Broadcasting Satellites. The Hubbard and Hughes DirecTV systems are now offering these small dishes manufactured by RCA and Thomson Ltd. for about $700 but these prices will drop considerably as volume of sales increase. A TVRO whether it be very small or much larger is always a satellite "terminal" since it "terminates" a satellite signal and cannot originate a transmission. There are also operational DBS systems in Japan, Europe, France, Germany, and the United Kingdom.

Unfortunately, usage of the phrase "terminal" is not consistently used to refer only to antenna receivers. There is certainly an important and useful distinction between a transmit/receive earth station antenna and a receive only terminal. An interactive antenna costs about 10 times more than a terminal of about the same size which can only "receive". Sometimes the "terminal" is rather imprecisely used to describe two-way antennas as well. This is the case with the phrase Very Small Aperture Terminal (VSAT). This often refers to "private" or customer premise antennas which are typically 1.0 to 2.4 meters in size and support interactive networks. Reference to two-way antennas as terminals should usually be avoided. A clear understanding of the basic difference between interactive antennas and receive only terminals sorts out those in the know from those that don't. The shape, size and technical characteristics of the ground segment is always changing, but more about that later.

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1.3 SATELLITE COMMUNICATIONS SERVICES

The real purpose of satellite is of course to provide telecommunications service. Satellites are amazingly versatile because they provide such broadband frequencies, such broad coverage, and such easy interconnection among widely separated areas. Satellites are also highly cost effective particularly over very long distances or within networks. Satellites costs are insensitive to distance. Typical satellites ' for national, regional or even intercontinental coverage are provided in Table 1. This small but indicative list of key services is only a partial listing of the hundreds of services that now exist. Figures 1a and 1b, which follows Table 1 show in more detail which services are available in the narrow, medium and broadband ranges and the expanding areas of coverage with varying degrees of interactivity. Satellites tend to be most effective at the broad band services with the widest coverage. Terrestrial of course is best at local coverage. A totally new technology that fills the gap between satellite and terrestrial technology, known as High Altitude Long Endurance (HALE) platforms which can provide geosynchronous type coverage but from an altitude of about 65,0000 to 70,000 feet (i.e.18.5 to 20 kilometers). This technology which is based upon light weight, high altitude remotely piloted platfroms can fly above commercial airspace and provide telecommunicatons for areas equivalent to South Korea or Taiwan. This new technology which can provide cost effective service over wide areas to very low cost antennas will alsobeaddressed in subsequent chapters.

Table 1

Narrow Band Services telex telegram facsimile (Group 3) 300 baud to 64 kilobit/second data services low resolution slow scan electronic images video text services e-mail

Medium Band Services analog voice digital voice facsimile(Group 4) voice plus data voice mail medium speed data services (64 kilobits/second to 2.0 megabits/second) limited-to-full motion videoconferencing stereo /high fidelity audio high resolution imaging high quality video phone services remote electronic printing integrated digital service-ISDN quality transmission from basic to primary rate interface (144 kilobits/second to 2.0 megabits/second)

Wide Band Services analog television digital television (6 megabits/second to 45 megabits/second

Advanced television services including enhanced definition TV and high definition TV. Remote Log-on and on-demand file transmission Scientific interactive networking (using advanced work stations with X-windows) Interactive CAD/CAM services Scientific Visualization (2D and 3D Displays) Super computer interconnect

As the number of services offered by satellites has increased, the quality, the reliability, the convenience, and cost performance have also generally improved. Only in the area of transmission delay have satellite services displayed a strategic disadvantage vis a vis terrestrial transmission technology. The three primary reasons why significant progress has been made in satellite communications services relate to digital communications techniques, low cost earth stations and high powered satellites with advanced antenna design and on-board switching and soon on-board processing.:

(a) Analog-to-digital conversion - Digital services, particularly with digital compression techniques, will tend to make communications services cheaper, more reliable, and high quality. By the year 2000, almost all urban based and business services will be digital in developed countries and a high percentage will be digital in developing countries as well. (The new Hughes DirecTV DBS satellite is able to deliver an amazing 150 channels of high quality TV simply due to new digital compression techniques.

(b) Low cost earth stations - Low cost earth stations will bring satellite services ever closer to the end user in terms of urban gateways, customer premise earth stations, desk top terminals, DBS receivers, and even hand held transceivers.. In Europe, Japan, Canada, Australia, the US. and in other countries, there will be Teleports in every major city and new satellite direct broadcast antennas will be on apartment buildings, condos and in a few years millions of single family homes. Alteady there are over 200,000 interactive VSAT installed worldwide with nearly 120,000 of these in the United States. In many multi-national companies there will be desktop data reception dishes no bigger than 75 centimeters in size (see figure 2). This is not an arcane prediction since there are several thousand new antennas of this type already in service. News and financial services organizations have moved strongly into this area, like Reuters, UPI and AP. There will also be thousands of very small antennas built into aircraft , ships, trains, trucks and cars. There will also be smart communication beepers that can send and receive very low level but highly effective digital signals. Again, this is not blue sky. Qualcomm a U.S. company is already offering this type of service today under the OMNITRACS trademark and under the EUTELTRACS name in cooperation with the European Telecommunications Satellite Organization (EUTELSAT).

(c) High power Ku-band satellites - Higher power and broad band satellites will be operating at the 14 / 12 Gigahertz (Ku band) and even the 30 / 20 Gigahertz (Ka band) in the 21st century as opposed to the basic (6/4 Ghz or C band) that gave birth to satellite communications in the 1960's and 1970's. This will provide certain advantages to sophisticated users who wish to deliver teleservices directly to urban environments but are deterred by the radio frequency environment which is very congested at the lower C band frequencies. Higher power and narrower antenna beams can mean higher throughput wider band services . It should also mean higher quality transmission or the use of lower cost, smaller antennas. It is important that all of these narrow and highly focussed beams be able to interconnect. This means that these advanced satellites will need on-board switching and in the next few years on-board processing to allow direct and efficient beam to beam linkages.

The bottom line is that the user community now has much greater say in the type and characteristics of the services that it can obtain via satellite. The early planners of satellite tended to be somewhat like Henry Ford in their thinking. They didn't say: "You can have any color you want just as long its black"; instead , they said if it isn't full time telephone, full time data, or occasional use television you have two options, go elsewhere or fit it into one of those three options. Earth station sizes in those days came in very limited options as well. Today flexibility for the user, service options , optimized antennas design , and high quality digital satellite services are all defining a whole different satellite environment.

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1.4 HOW TO OBTAIN COMMUNICATION SATELLITE SERVICES - LEASE VS. BUY

Today, users can lease or buy satellite capacity and custom tailor it to their needs. They can buy or lease satellite capacity and with a government license they can own or lease their own earth stations. Especially in the United States almost very option is available, but things are also changing rapidly in Europe . Users can now decide a number of very key elements such as the following:

(a) Time Flexible Commitments: Contracts typically can be for a three month to two year term; for a part time/peak hour on a part time/off-peak hour occasional use commitment; or even partnership or piggy-back sharing of capacity with other users.

(b) Ownership Lease Vs. Buy - Options vary from country to country but the opportunity exists within several countries to buy satellite capacity outright for either domestic, regional or international service. In the US. you can resell parts of all of it, or broker it. One can also sub-lease it for long periods (e.g. 3-9 years), or resell it on demand by dividing the available capacity into ten or thirty minute blocks of time or more. Tax bracket, depreciation or insurance liability can be key in deciding the best strategy. Some have suggested that the US. market is "too wide open" and that the results has been to create too many unprofitable ventures , mergers and bankruptcies. What is clear today is that in the U.S. market there is a shortage of satellite capacity for television distribution and that of the 300 C-Band transponders available to broadcasters and other users as early 1995, the supply may be reduced by some 60 transponders over the next 3 years unless new capacity is launched.

(c) Flexibile Use of Capacity - In the early days of satellites you bought capacity for a specific purpose like voice or data services and that was that. Today one can buy bulk digital capacity and vary the use during the day from voice, to videoconference channel, to voice mail, to facsimile, to data. Usually voice is predominant during office hours and facsimile and data prevail at off-peak. The user now dictates how their capacity is used. As the new age of Integrated Services Digital Network (ISDN) standards arrives, the idea of having a single digital highway for all services will become increasingly common and the great flexibility of satellites to offer multiple services simultaneously will be more broadly accepted. This in many ways is what the talk about the National Information Highway and the

National Information Infrastructure is all about.

(d) Earth Station Antenna Characteristics - The INTELSAT system, the world's largest satellite system has well over a dozen different standards for earth stations. INTELSAT is the global communications satellite system that operates 20 satellites in the Atlantic, Pacific and Indian ocean regions. It has some 130 members and about 200 different countries and territories rely on INTELSAT for their satellite service. It also provides domestic services in some 40 countries. These antenna standard vary in size from 75 centimeters to 18 meters in cost from $2500 to $4 million. The old 30 meter stations used since the 1960s to support early, very low power satellite services are no longer being built. Domestic systems in the US., Europe and elsewhere do not have this much variation in the size and cost of their earth station antennas since the power levels and beam sizes for these more specialized satellites does not require a wide range of aperture sizes or multiplexing system.

Nevertheless there is still a wide arrange of choices available. These include: desk top antennas, TVROs, fly-away transportable, customer premise service VSATs, urban gateway antennas, large high volume earth station at international gateways, and ship to shore antennas. Today land mobile and aeronautical mobile satellite antennas are also coming into service. Some of these systems such as those of INMARSAT, Telesat Mobile Inc., and the American Mobile Satellite Consortium are using conventional approaches with very high powered geosynchronous satellites. Other innovators in the field, however, are planning to use unconventional low orbit satellite systems such as the Motorola Iridium cellular radio system, or the Aries Constellation System. or the Globalstar mobile satellite system of Loral and Qualcomm. Then there are the medium earth orbit systems such as TRW's Odyssey system and the INMARSAT Project 21 (now called INMARSAT P). Other proposed systems include the Starsys system, the Ellipso system and a number of store and forward "little LEO" systems of which the Orbital Sciences Corporation's mobile satellite system known as ORBCOM is the furtherest advanced. All of these low orbit satellites would use very small and cost effective ground transceivers. Indeed it is the improved look angle and the ability to work to very small and low cost transceivers that has largely stimulated the recent and strong interest in LEO and MEO satellites.

Collectively this explosion in the types of satellite antennas available to the user community can be summed up as the "Satellite Communications User Revolution". The rules of the game concerning the use of satellite communications have changed enormously over the last 20 years. Almost all changes have made services more affordable, more flexible, higher quality, more accessible, more controllable, and easier to own or lease for expanded periods. In short, satellites have become more user friendly . In fact, in some ways they have become user selective. Technology has helped a lot, but regulatory and institutional changes have made much of the difference. This is not suggest that all problems and challenges have been overcome. In fact, there are several key issues involving the relative performance of satellite versus fiber optics that are critical concerns. One issue is that of broad band, high quality service and the other is that of transmission latency or delay. Fiber optic cable have tremendous capacity measured in multi-gigabits/ second and extremely high quality (i.e. bit error rates of better than 10-10) Satellites can, in theory, achieve high throughput rates as well and the highest capacity INTELSAT satelites can achieve a very respectable 2 to 3 gigabits/ second in an all digital mode. The practical problem is that satellites need new wide band allocations to achieve very high throughput. Even more to the point, the new alloations with the necessary broadband widths are in the very difficult to deal with millimeter wave bands. The precipitation attenuation of bands of 30 GHz is extremely difficult to address so as to keep high quality service comparable to fiber. Neverthess new antenna and processing designs such as those represented by the Hughes Spaceway design and the Teledesic satellite designs suggest that there are solutions. In short truly high powered pencil beams with on -board connectivity could be both broad band and high quality as well. Finally the low earth orbit systems and the new HALE technology give promise of systems that are faster end to end than fiber optic systems. If these two issues can be effectively overcome, it would seem that satellites can expect to make a very strong showing into the next century.

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1.5 THE CONTINUING REVOLUTION IN COMMUNICATIONS SATELLITES

After Sputnik in 1957 came a rush of experimental communications satellites as shown in Figure 3. It was only in 1965, that operational communications satellites first appeared on the scene . There was the low to medium altitude Initial Defense Satellite Communications System (ISCS), the Soviet twelve hour orbit Molniya system; and the INTELSAT geosynchronous satellite system beginning with Early Bird in April 1965. The only global commercial satellite service that was available was thus provided by INTELSAT. This initial service was only international and it was provided through Post and Telecommunications (PTT) organizations or designated organizations. These included the following: United States (COMSAT), United Kingdom (General Post Office now British Telecom), Italy (Telespazio), Japan (KDD), Australia (OTC), France (Directorate General Telecommunications, now France Telecom) and Canada (COTC, now Teleglobe). Commercial entities provided the service in some instances but always under monopoly arrangements. In the years that followed Canada created a monopoly commercial organization to provide domestic services . They called the new enterprise Telesat.

During the years of Presidents Kennedy and Johnson, from 1960-68, the policy leadership in the US. was focused primarily on major technological and space related innovation. In this post-Sputnik and Vietnam War era, there was considerable initiative to create a national satellite entity for domestic satellite service and to demonstrate global leadership in space systems . During the Nixon years opinion shifted toward competitive satellite systems. Despite the shift in the US. favoring competition and multiple satellite systems, most other countries proceed to implement national or regional satellite systems on the basis of traditional monopolies of the Post and Telecommunications Ministries, crown corporations or national commercial organizations with monopoly rights and privileges.

The US. open skies policy was clearly at odds with the unitary approach to satellite systems of most other governments. By the mid 1980's, however, US. policy makers concluded that their open competition policy was producing benefits. They thus began to move toward deregulation, privatization and pro-competitive policies and proceeded with the divestiture of AT&T. In the UK. and Japan governments began to take a strong interest in competition and deregulation. They began to imitate US initiatives in spirit if not exactly in actual fact. Today there are major new polices on space communications in not only the US., but also Japan, Netherlands, the United Kingdom Singapore , Australia and Germany. Perhaps the biggest backer of competition is the European Commission in Brussels, Belgium. There is one major difference between the US. and most of the rest of the world. While the US. encourages all comers, other countries have tended to limit competition to only two or three selected players. Instead of monopoly, there is "duopoly" or "triopoly"; except for the American "free for all-opoly." Recently, this too has changed and the United Kingdom's regulatory group OFTEL has decided to abandon it duopoly policy with regard to British Telecom and the Mercury Cable and Wireless and to welcome in all new, qualified competitors.

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1.6 CONCLUSION

The remainder of the book will return to the themes of satellite technology, earth stations technology, new services and markets, satellite cost-competitiveness versus other options , and future trends and government deregulation and pro competitive policies. The constant objective will be to make the issues, the "players" and even the technical explanations as clear as a high quality satellite transmission. The first step is to understand something about satellites and how they work. This is the acid test. If you can get past Chapters 2 and 3 which are somewhat of a technical challenge, the rest of the book should be as easy as an evening breeze. Alternatively if you find Chapters 2 and 3 rough going, skip them and come back later after you have digested the less demanding parts of the book.

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