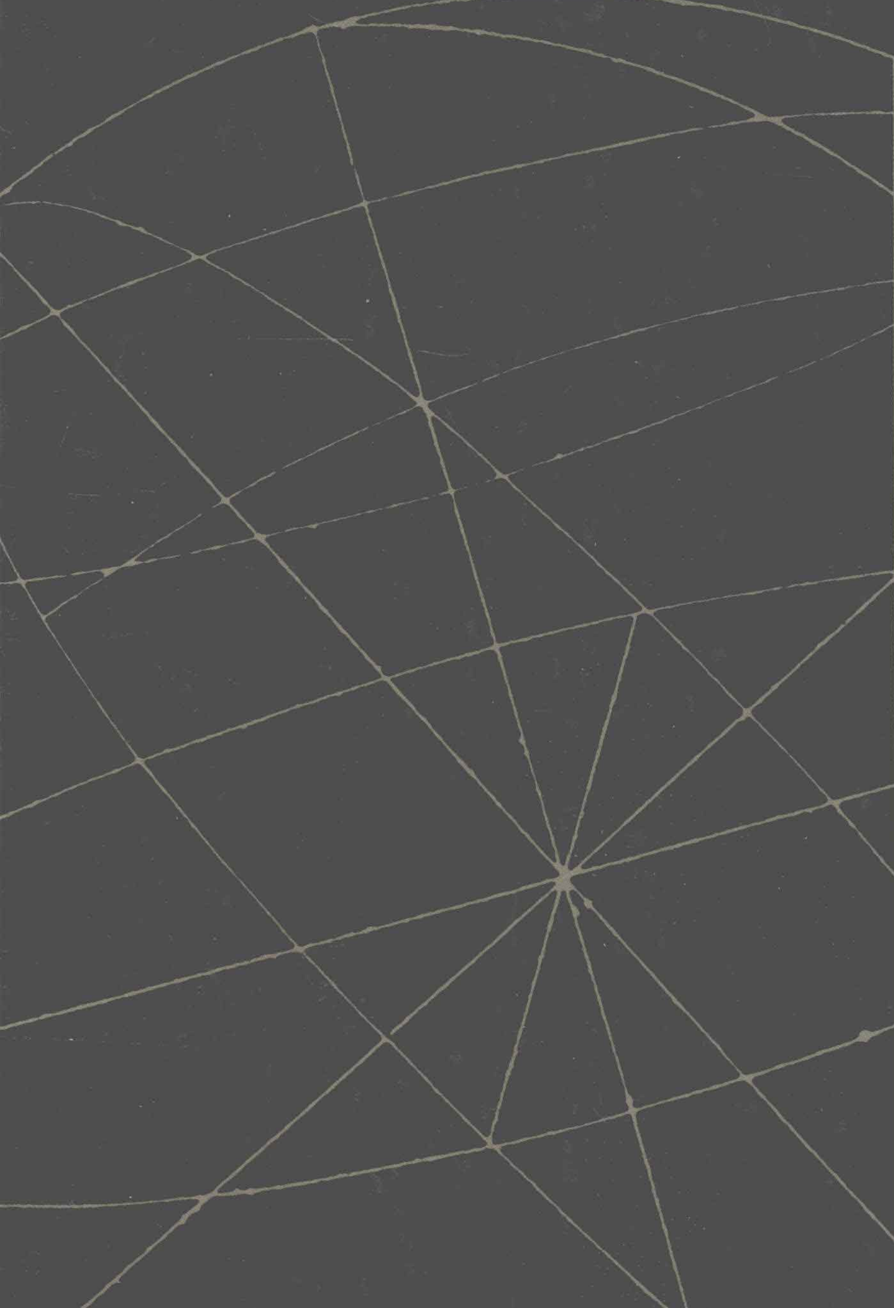
SATELLITE COMMUNICATIONS



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SATELLITE COMMUNICATIONS

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PREFACE

Although satellite communications would seem to be a straightforward extension of terrestrial radio systems, the use of satellites brings in new operational features not found in terrestrial systems. At the same time, new technology is required to exploit the unique features of satellite systems.

The inquiring student will also wish to understand something about the mechanics of orbital motion: why, for example, there is only one geostationary orbit, and how one might track nonstationary satellites.

This book, which covers these fundamental aspects, is intended for senior students in engineering-technology programs; it should also provide suitable material for an introductory course in undergraduate engineering-degree programs. It is assumed that the reader is familiar with, or is concurrently studying, basic communication circuits and systems, including modulation, noise, and microwave propagation, although these topics are briefly reviewed. Lengthy mathematical derivations are avoided, but references are given and mathematical results are used and explained as required.

Most of the calculations for satellite system performance are carried out in decibels or related units. These units and calculations are explained in detail, but as a prerequisite the student should have a good working knowledge of the decibel.

I would like to thank the many people and organizations who freely provided photographs, figures, and data. These have been acknowledged at the appropriate places in the text. Much of the material for the book was gathered while I was on sabbatical leave at the Communications Research Centre, Department of Communications, Ottawa, Canada. I am grateful for the generous assistance provided by the department, both financially and by way of access to resources. My thanks go to the staff at the Communications Research

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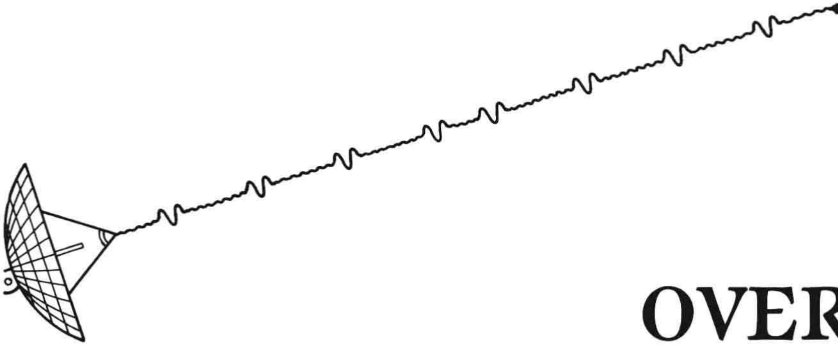


OVERVIEW OF SATELLITE SYSTEMS

1.1 INTRODUCTION

The use of satellites in communications systems is very much a fact of everyday life, as evidenced by the many homes that are equipped with antennas or "dishes" used for reception of satellite television. What may not be so well known is that satellites form an essential part of telecommunications systems worldwide, carrying large amounts of data and telephone traffic in addition to television signals.

Satellites offer a number of features not readily available with other means of communications. Because very large areas of the earth are visible from a satellite, the satellite can form the star point of a communications net linking together many users simultaneously, users who may be widely separated geographically. The same feature enables satellites to provide communication links to remote communities. This is especially valuable for communities in sparsely populated areas that are difficult of access by other means. Of course, satellite signals ignore political boundaries as well as geographical ones, which may or may not be a desirable feature.

The cost of setting up a satellite communications link is high, the 1984 estimated figure being $27 million, excluding launch and maintenance costs (Pritchard, 1984). The cost is *distance insensitive*, meaning that it costs about the same to provide a satellite communications link over a short distance as it does over a large distance. Thus a satellite communications system is economical only where the system is in continuous use and the costs can be reasonably spread over a large number of users.

Satellites are also used for remote sensing, examples being the detection of water pollution and the monitoring and reporting of weather conditions. Some of these remote-sensing satellites also form a vital link in search and rescue operations for downed aircraft and the like.

To provide a general overview of satellite systems, three different types of applications are described briefly in this chapter; (1) the largest international system, Intelsat; (2) the domestic satellite system in the United States, Domsat; and (3) the search and rescue system, Sarsat.

1.2 INTELSAT

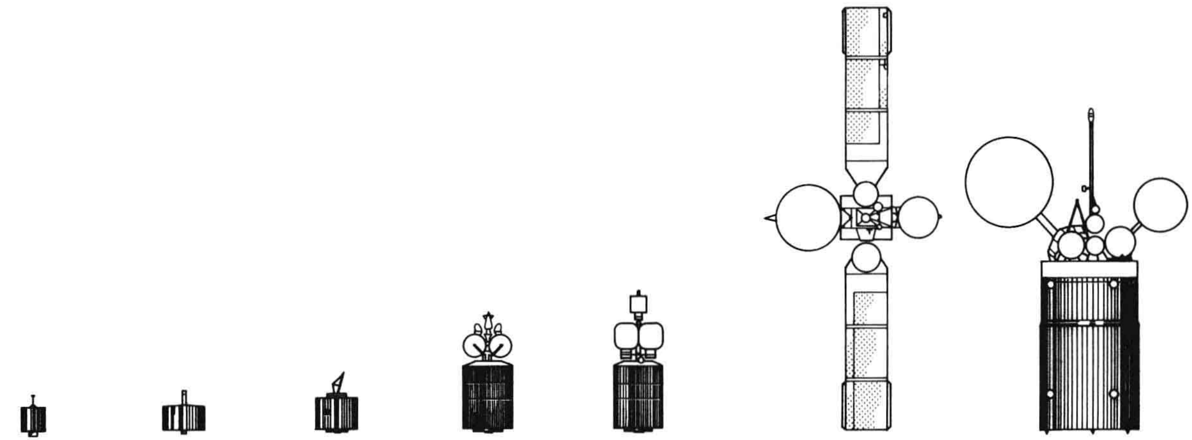
Intelsat is an acronym derived from *international telecommunications satellite*. The Intelsat Organization was established in 1964 to handle the myriad of technical and administrative problems associated with a worldwide telecommunications system. From an initial membership of 14, the membership has grown to 109 countries (Colino, 1985), and over 170 countries are served by this worldwide telecommunications network.

Starting with a single satellite, Early Bird (Intelsat 1), which was launched in 1965 and provided 480 voice channels, a series of satellites, designated Intelsat I, II, III, IV, V, and VI, have been launched or are in the planning stages. Figure 1.1 shows the evolution of the Intelsat satellites. It will be seen that there is a successive increase in the size and capacity of the satellites, the latest in the series, Intelsat VI, being capable of providing 80,000 voice channels.

The design lifetime for recently launched satellites ranges from 7 to 10 years, and thus the Intelsat satellites overlap in time, there being 23 in orbit in 1984 (Pritchard, 1984). A number of satellites of a given type are in service at any one time. For example, in planning for the next decade, the "initial buy" of the Intelsat VI series consisted of five Intelsat VI satellites, and it is envisaged that four of these will be launched successfully. This will leave one as a ground spare. For international service there are three operational satellites in the Atlantic Ocean Region, two in the Indian Ocean Region, and one in the Pacific Ocean Region, together with one spare orbiting satellite in each region. It is standard practice to have a spare satellite in orbit on high-reliability routes, and thus a system may include ground spares and orbiting spares.

As already mentioned, the international regions served by Intelsat are divided into the Atlantic Ocean Region (AOR), the Pacific Ocean Region (POR), and the Indian Ocean Region (IOR). For each region, satellites are positioned in geostationary orbit above the particular ocean, where they provide a transoceanic telecommunications route. The geostationary orbit is described in detail in Chapter 2. The coverage areas for Intelsat VI are shown in Fig. 1.2. Traffic in the AOR is about three times that in the IOR, and about twice that in the IOR and POR combined. Thus the system design is tailored mainly around AOR requirements (Thompson and Johnston, 1983).

In addition to providing transoceanic routes, the Intelsat satellites are used for domestic services within any given country and regional services between countries. Two such services are Vista for telephony and Intelnet for data exchange. Figure 1.3 shows typical Vista applications.



Designation: Intelsat	I	II	III	IV	IV A	V	V A/V B	VI
Year of first launch	1965	1966	1968	1971	1975	1980	1984/85	1986/87
Prime contractor	Hughes	Hughes	TRW	Hughes	Hughes	Ford Aerospace	Ford Aerospace	Hughes
Width (m)	0.7	1.4	1.4	2.4	2.4	2.0	2.0	3.6
Height (m)	0.6	0.7	1.0	5.3	6.8	6.4	6.4	6.4
Launch vehicles		Thor Delta		Atlas-Centaur		Atlas-Centaur and Ariane	Atlas-Centaur and Ariane	STS and Ariane
Spacecraft mass in transfer orbit (kg)	68	182	293	1385	1489	1946	2140	12,100/3720
Communications payload mass (kg)	13	36	56	185	190	235	280	800
End-of-life (EOL) power of equinox (W)	40	75	134	480	800	1270	1270	2200
Design lifetime (years)	1.5	3	5	7	7	7	7	10
Capacity (number of voice channels)	480	480	2400	8000	12,000	25,000	30,000	80,000
Bandwidth (MHz)	50	130	300	500	800	2137	2480	3520

Figure 1.1 Evolution of Intelsat Satellites. (From Colino, 1985. Courtesy ITU Telecommunication Journal.)

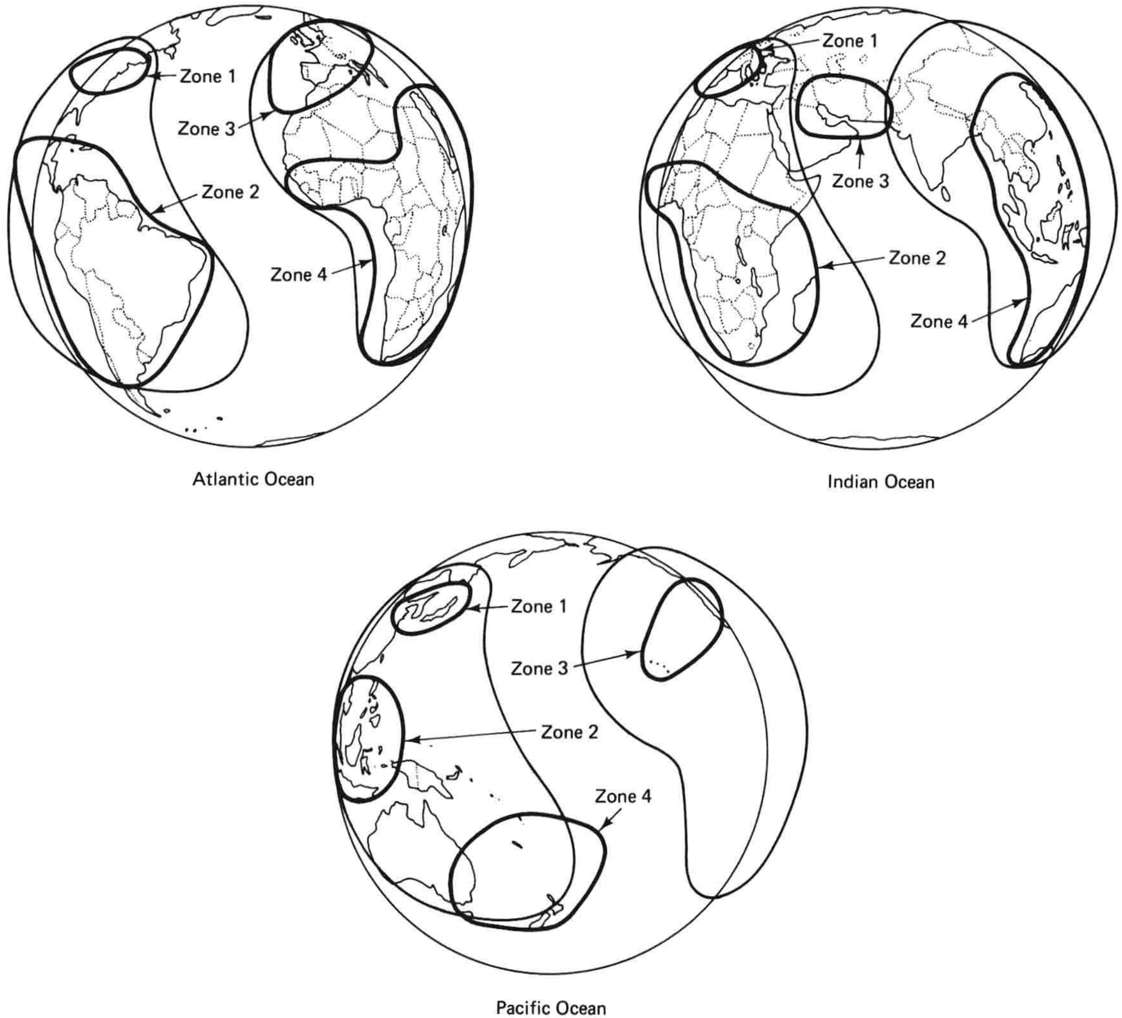


Figure 1.2 Intelsat VI coverage areas (From P. T. Thompson & E. C. Johnston. INTELSAT VI A New Satellite Generation for 1986–2000. International Journal of Satellite Communications vol. 1, 3–14 1983. © John Wiley & Sons Ltd. Reprinted by permission of John Wiley & Sons, Ltd.)

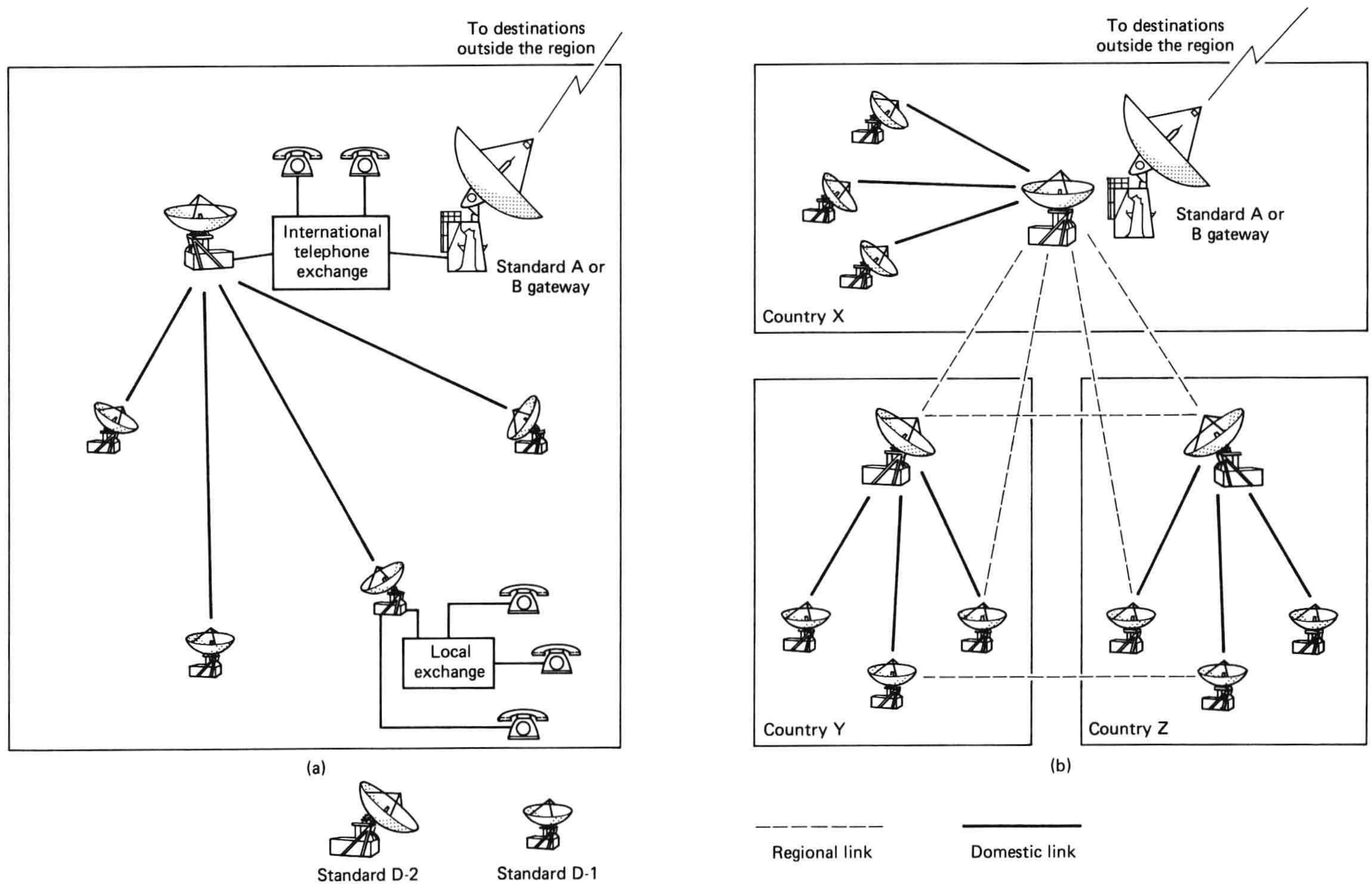


Figure 1.3 (a) Typical Vista application; (b) domestic/regional Vista network with standard A or B gateway. (From Colino, 1985. ITU Telecommunication Journal.)

1.3 U.S. DOMSATS

Domsat is an abbreviation for *domestic satellite*. Domestic satellites are used to provide various telecommunications services, such as voice, data, and video transmissions, within a country. In the United States, all domsats are situated in geostationary orbit. As is well known, they make available a wide selection of TV channels for the home entertainment market, this being in addition to the large amount of commercial telecommunications traffic that is carried.

Table 1.1 shows the orbital assignments for geostationary satellites over the American continent, including Canada and Mexico. The geostationary orbit, which is discussed further in Sec. 2.10, is located directly above the equator, and the positions of the satellites are

TABLE 1.1 1983 ORBITAL ASSIGNMENTS

Orbital positions (west longitude) (deg)	User	Frequency bands (GHz)
143	Satcom V	4/6
141	Unassigned	4/6
139	Satcom I-R	4/6
137	Unassigned	4/6
134	Galaxy I	4/6
132	Rainbow	12/14
131	Satcom III-R	4/6
130	ABCI	12/14
128	American satellite	4/6 and 12/14
126	RCA	12/14
125	Telstar/Comstar	4/6
124	SBS	12/14
122	Spacenet	4/6 and 12/14
120	USSSI	12/14
119.5	Westar V	4/6
117.5	Canada	12/14
116.5	Mexico	4/6 and 12/14
113.5	Mexico	4/6 and 12/14
112.5	Canada	12/14
111.5	Canada	4/6
110	Canada	12/14
108	Canada	4/6
107.5	Canada	12/14
105	Gstar	12/14
104.5	Canada	4/6
103	Gstar	12/14
101	Unassigned	4/6 and 12/14
99	SBS	12/14
98.5	Westar IV	4/6
97	SBS	12/14
96	Telstar	4/6
95	SBS	12/14

TABLE 1.1 *(Continued)*

Orbital positions (west longitude) (deg)	User	Frequency bands (GHz)
93.5	Galaxy III	4/6
93	Unassigned	12/14
91	Spacenet	4/6 and 12/14
89	SBS	12/14
88.5	Telstar	4/6
87	RCA	12/14
86	Westar	4/6
85	USSSI	12/14
83.5	Satcom IV	4/6
83	ABCI	12/14
81	American satellite	4/6 and 12/14
79	Rainbow	12/14
78.5	Westar	4/6
77	RCA	12/14
76	Telstar	4/6
75	Unassigned	12/14
74	Galaxy	4/6
73	Unassigned	12/14
72	Satcom	4/6
71	Unassigned	12/14
69	Spacenet	4/6 and 12/14
67	Satcom	4/6

Source: FCC (1983a).

given in degrees of longitude as shown. Figure 1.4 gives a pictorial representation of the satellites in orbit for North America (Mexican satellites are not shown). In 1983, the FCC adopted a policy objective setting 2 degrees (deg) as the minimum orbital spacing for satellites operating in the 4/6-GHz band, and 1.5 deg for those operating in the 12/14-GHz band (FCC, 1983b). It is clear that interference between satellite circuits is likely to increase as satellites are positioned closer together. These spacings represent the minimum presently achievable in each band at acceptable interference levels. In fact, it seems likely that in some cases home satellite receivers in the 4/6-GHz band may be subject to excessive interference where 2-deg spacing is employed. As shown in Table 1.1, the two frequency bands currently in use are the 4/6-GHz or C-band, and the 12/14-GHz or Ku-band. Although direct broadcasting to the home may not be feasible in the 4/6-GHz band because of the interference problem mentioned, it is one of the services planned for the 12/14-GHz band, and Fig. 1.5 shows the components of a direct broadcasting satellite (DBS) system. The television signal may be relayed over a terrestrial link to the uplink station. This transmits a very narrow beam signal to the satellite in the 14-GHz band. The satellite retransmits the television signal in a wide beam in the 12-GHz frequency band. Individual receivers within the beam coverage area will receive the satellite signal.

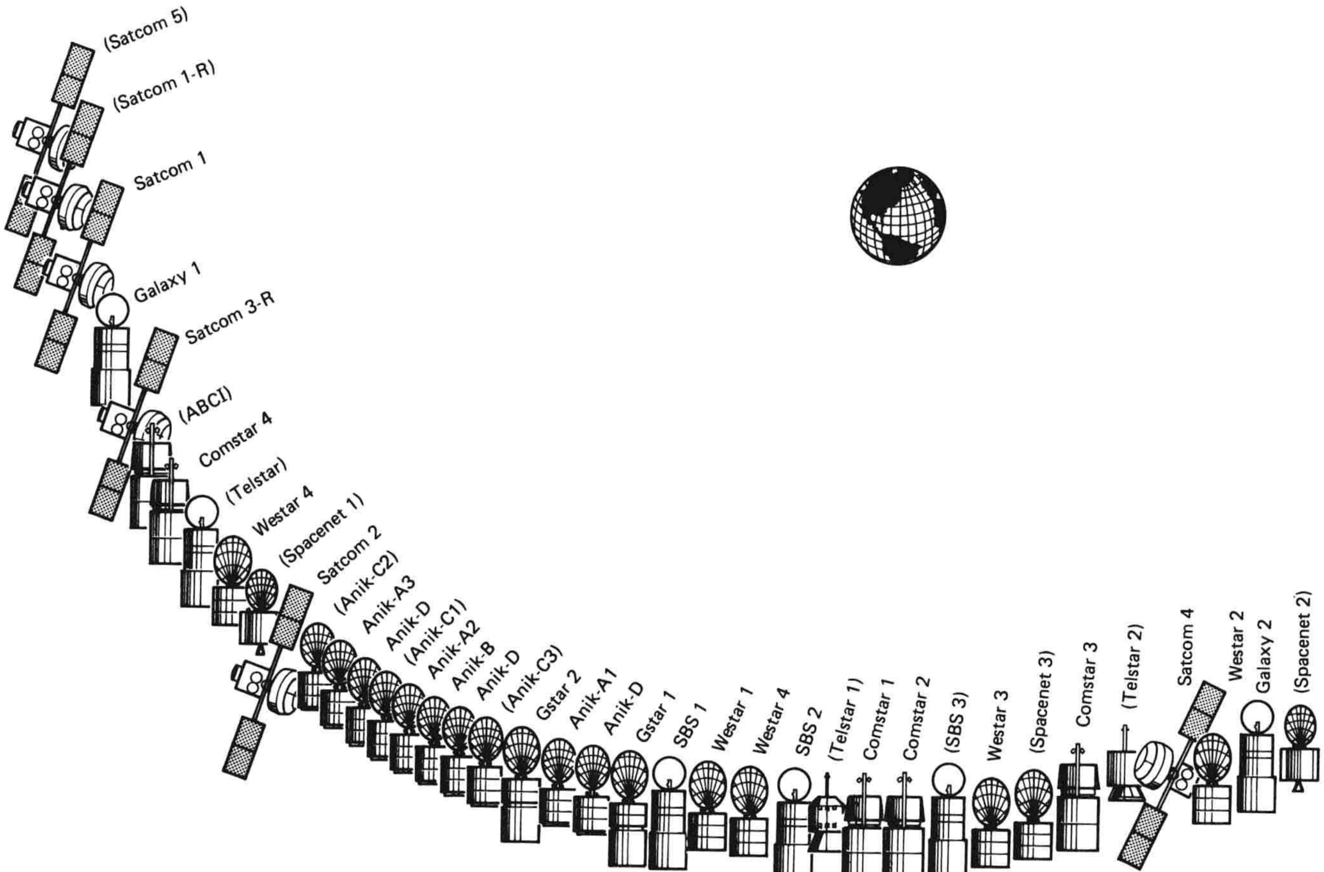


Figure 1.4 Satellite Orbital Positions for North America, operating and (authorized for launch). (From Scientific Atlanta, 1985/6. With permission.)