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# *Effect of argon plasma cleaning on GaAs FET passivation*

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## *Abstract*

Monolithic microwave integrated circuit (MMIC) chips are typically passivated with a dielectric film to improve their long-term environmental reliability. Improper passivation generally degrades chip performance, reducing wafer yield. Surface preparation of the field-effect transistor (FET) channel prior to dielectric passivation requires good control to reduce the native oxide and thus maintain the initial device performance. This paper describes a plasma process to etch the native oxide, coupled with silicon nitride passivation. Before nitride passivation, pulsed current/voltage measurement was used to study the effect of this etching process. It was found that argon plasma etching prior to passivation affects the channel surface differently, depending on the structure of the GaAs FET. For example, argon plasma etching using self-induced bias voltage in the plasma-enhanced chemical vapor deposition (PECVD) system is beneficial for GaAs metal-semiconductor FETs (MESFETs) that have a recess width approximately equal to the gate length. However, for delta-doped GaAs FETs with unrecessed gates, use of the plasma process before nitride passivation is likely to generate surface states and degrade FET performance.

## *Introduction*

The passivation of GaAs field-effect transistors (FETs) and monolithic microwave integrated circuits (MMICs) using dielectric films, with varying degrees of success, has been reported in the past few years [1]–[5]. The preferred

dielectric for passivation is silicon nitride, because devices passivated with this dielectric display significantly improved resistance to long-term burnout [4]. However, to maintain device performance after passivation, it is essential to control the interface states between the silicon nitride and the GaAs. For example, poor-quality passivation can degrade the breakdown voltage of power FETs and lead to a burnout problem, which has been attributed to the chemical instability of the GaAs native oxides [5].

This paper evaluates an *in situ* argon plasma etching process for removing the native oxide from the FET channel surface to control the interface prior to silicon nitride passivation. This technique was successfully applied to flat-profile power metal-semiconductor FET (MESFET) passivation, yielding FETs with excellent RF performance and device reliability. However, for delta-doped FETs with an unrecessed gate, use of the plasma process before nitride passivation was found to generate surface states and degrade FET performance. Thus it was determined that the usefulness of the plasma process during passivation depends on the device structure.

## Experimental procedures

### Device fabrication

Two types of device structures, one with a flat doping profile (regular MESFET) and the other delta-doped, were used for this study. Standard processing available at COMSAT Laboratories was used to fabricate both types of devices. The layers for the flat-doped MESFET were grown by vapor phase epitaxy (VPE), while molecular beam epitaxy (MBE) was used to grow the layers for the delta-doped FETs. Mesa etch was used for device isolation. The ohmic contacts to the device structure were formed by alloying Au/Ge/Ni/Ag/Au in a rapid thermal annealing system at 450°C. The COMSAT direct-write electron-beam (e-beam) lithography system was used to define the submicrometer gates, which were recessed using citric acid prior to Ti/Pt/Au metalization. The gate length of the MESFETs used in this study was 0.7 μm.

### Passivation process

Two distinct processes were used to passivate the two types of MESFETs. In the first process, the surface of the GaAs wafer was cleaned in a dilute etch mixture containing sulfuric acid, and the wafer was immediately loaded onto the grounded electrode of the plasma-enhanced chemical vapor deposition (PECVD) system. The wafer was then etched lightly in argon plasma using self-

induced bias voltage in the PECVD system. The parameters for the argon plasma etch were as follows:

- Pressure: 600 mTorr
- Argon Flow: 1,000 sccm
- Temperature: 250°C
- Time: 30 s

In the second process, the GaAs channel surface was etched in the sulfuric acid mixture and immediately loaded onto the grounded electrode; however, the sample was not subjected to argon plasma etch.

In both cases, the nitride film was deposited at 250°C in the PECVD system. The reactant gases were ammonia and silane, with nitrogen as the carrier gas. The deposition conditions were as follows:

- Gas Flow Rate
  - Ammonia: 3.8 sccm
  - Nitrogen: 800 sccm
  - Silane: 10 sccm
- Power: 25 W
- Pressure: 600 mTorr

This nitride film exhibited stress of $10^9$ dyne/cm$^2$ (tensile stress) as measured by a stress gauge; a refractive index of 2.0 as measured by an ellipsometer; and a silicon-nitrogen ratio of 0.75 as obtained by Auger analysis.

### Current transient measurement

Current transient measurement was used to evaluate the passivation characteristics of the FETs. In this technique, the drain current transient measurement samples and records the drain current ($I_{ds}$) of a FET at various times following an abrupt change in gate voltage (usually reverse-biased near pinchoff voltage, *e.g.*, at -4 to +1 V). The drain voltage is stepped in even increments from $V_{ds}$ (drain-to-source voltage) minimum (usually $V_{ds} = 0$) to $V_{ds}$ maximum ($>V_{ds}$ knee), and the $I_{ds}$ is measured and recorded for each $V_{ds}$ increment. These data are then plotted in the form of an I/V curve ($I_{ds}$ vs $V_{ds}$), with pulsed time as a parameter. If a drain current transient exists, the plotted data will be a family of curves showing the time-dependence of $I_{ds}$. Otherwise, the curves will overlay each other, providing a single trace (showing no time-dependence of $I_{ds}$).

Since GaAs FET performance is quantitatively related to the drain current, a large transient in the drain current usually indicates that significant surface states have been generated as a result of the plasma passivation process. A small transient, as indicated by the drain current curves being superimposed on each other, usually indicates low interface states in the passivated channel, unless the "access length" (the length from the recessed wall to the gate) is small [6].

## Experimental results and discussion

The $I_{ds}$ transient measurement was used to evaluate the passivation process. This measurement is performed both before and after nitride passivation, and the difference in the transient amplitude[*] before and after passivation is used to determine whether the surface states created by the PECVD process will adversely affect large-signal performance. In these experiments, small changes in the process chemistry were found to affect the amplitude of the transients. Before passivation, GaAs FETs usually show a certain amount of transient in the $I_{ds}$ pulse measurement. The amplitude of this transient increases relative to the amount of time the FET channel surface is exposed to the air prior to passivation. This increase in $I_{ds}$ transient amplitude before nitride passivation is believed to be due to oxidation of the GaAs surfaces.

Results on passivation for flat-profile MESFETs and delta-doped MESFETs are described below.

### Flat-profile MESFET passivation

Flat-profile MESFETs have a recess width of 1.8 μm. Figure 1 shows a cross section of the recessed gate configuration. To examine the effect of argon plasma cleaning, a flat-profile MESFET wafer was cleaved into halves. One half was treated with a wet chemical etch before passivation. A typical $I_{ds}$ transient measurement taken on this sample prior to nitride passivation is shown in Figure 2a. The MESFETs exhibited a transient amplitude of 0.8 ± 0.3 mA (the average of four measurements) in this piece. The sample was then etched in a sulfuric-acid-based solution and passivated with silicon nitride film. Figure 2b shows the $I_{ds}$ measurement of the same FET as in Figure 2a, after nitride passivation. The transient amplitude increases after passivation (4.2 ± 0.1 mA for four measurements on the same devices). The difference between $I_{dss}$ at $t = 0$ and $t \rightarrow \infty$ is about 3.4 mA in this case.

_____   _____
[*] Defined as the difference in saturation current curves between time $t = 0$ and $t = \infty$.
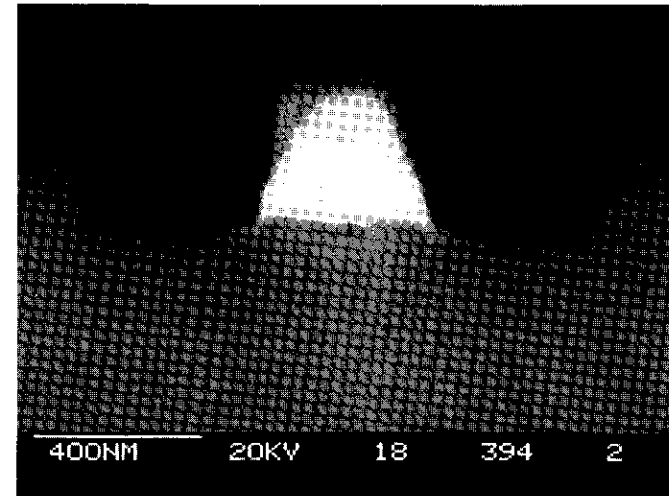
Figure 1. *SEM Micrograph of a Cross Section of the Flat-Profile MESFET*

The other half of the wafer was passivated using both a wet chemical etch and a plasma etching process. Figure 3a shows the $I_{ds}$ pulse measurement for the MESFET that was plasma etched before nitride passivation. A typical MESFET in this case shows a transient amplitude of about 0.8 ± 0.3 mA (four measurements) before nitride passivation. The same FET then is etched in a sulfuric-acid-based solution, loaded into the chamber, etched with argon plasma using a self-induced bias voltage in the PECVD system, and finally passivated with silicon nitride film. Figure 3b shows the transient measurement of this device after passivation. The amplitude of the transient in the $I_{ds}$ measurement decreased (0.2 ± 0.1 mA for four measurements on the same devices) after nitride passivation as a result of the plasma etching. This indicates that both the plasma etching and PECVD processes did not induce significant surface states or damage to the device.

To compare the surface composition differences between the plasma etching and non-plasma etching processes, samples of passivated devices from each process were subjected to SIMS analysis. A comparison of the interface regions of the two samples reveals that the oxygen peak at the interface of the plasma etched sample is a factor of 4 lower than that of the chemically etched sample, while the oxygen level in the bulk of the films is nearly the same. Figure 4 shows the surface oxygen composition for plasma etched and wet chemically etched surfaces as observed by SIMS. For a plasma etched surface,
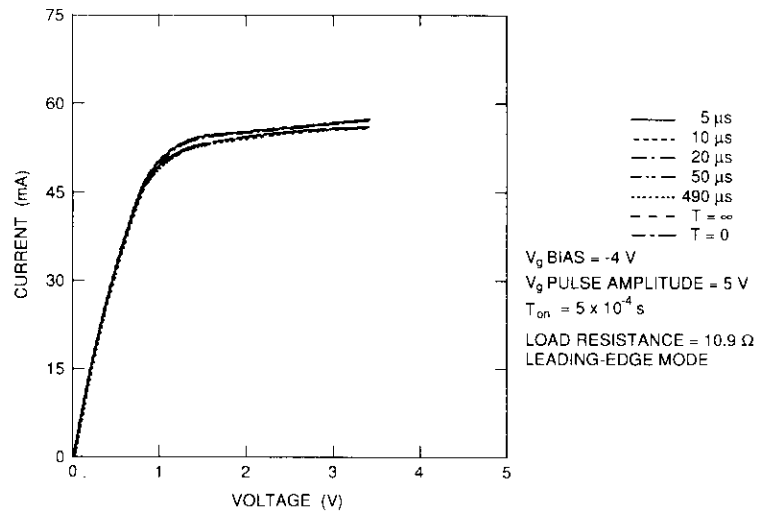
(a) Before Nitride Passivation
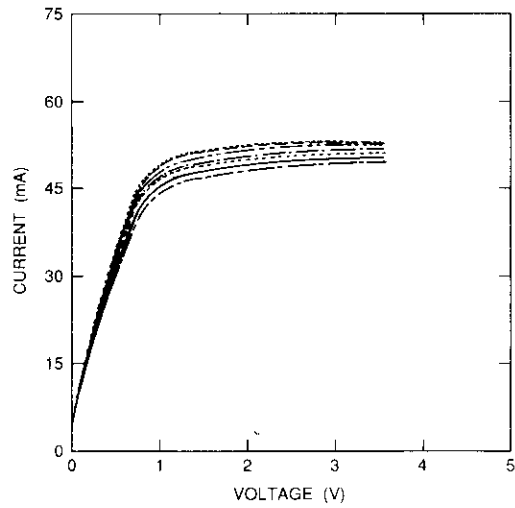


(b) After Nitride Passivation

Figure 2. $I_{ds}$ Transient Measurement Data for the Wet Chemically Etched Flat-Profile MESFET



(a) Before Nitride Passivation



(b) After Nitride Passivation

Figure 3. $I_{ds}$ Transient Measurement Data for the Plasma Etched Flat-Profile MESFET
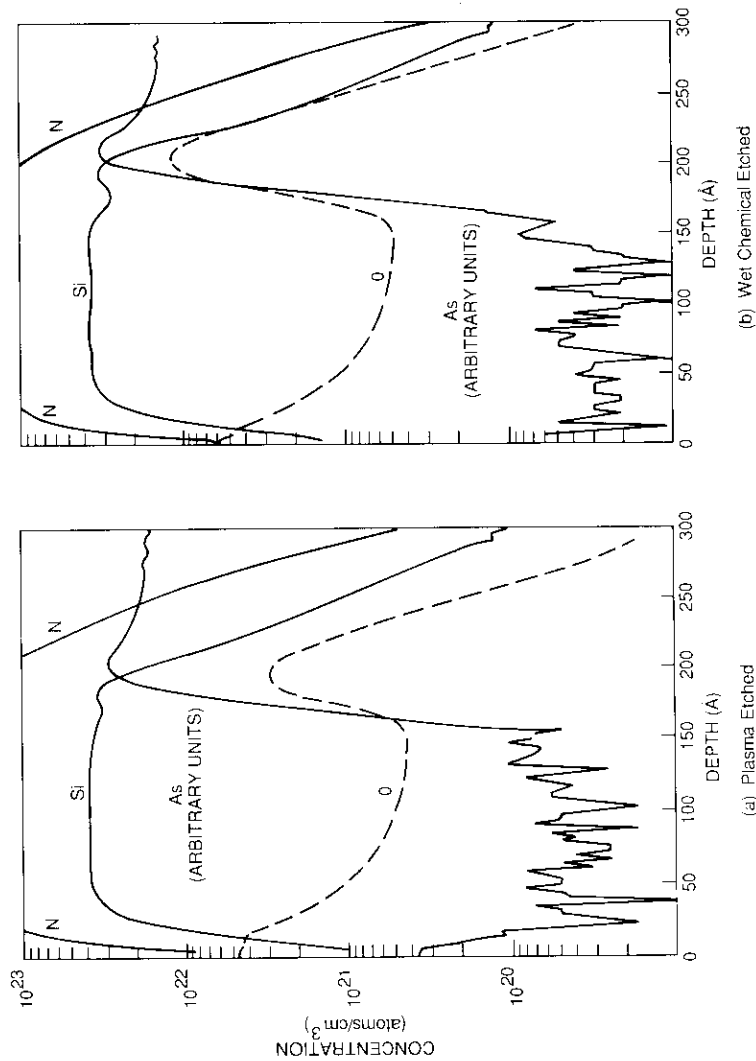
Figure 4. *SIMS Spectrum of the Etched Surfaces*

the oxygen concentration is around $2 \times 10^{21}$ atom/cm$^3$ at the interface region (where the arsenic concentration begins to increase). For a wet chemically etched surface, the oxygen concentration is around $10^{22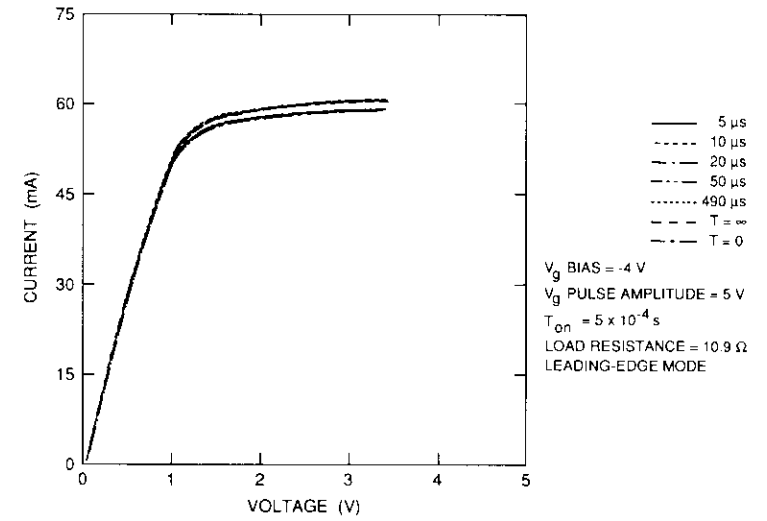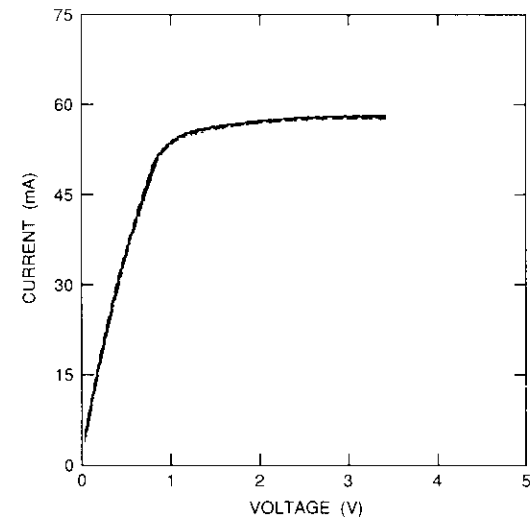}$ atom/cm$^3$ at the interface region. The light argon plasma etch reduces the surface oxide thickness and results in less transient in $I_{ds}$ measurement, as shown in Figure 3.

Table 1 compares the electrical parameters before and after nitride passivation for both argon plasma etched and wet chemically etched channels in MESFETs. The changes in drain-to-source saturation current, $I_{dss}$, transconductance, $G_m$, and pinchoff voltage, $V_p$, before and after nitride passivation are within 5 percent of each other. For plasma etched MESFETs, the shift in the breakdown voltage before and after nitride passivation is 0.8 V. For wet chemically etched MESFETs in the same wafer, the shift is around 1.5 V. Evidence of surface oxides reducing the breakdown voltage of GaAs devices has been reported previously [1]. The smaller voltage drop in the plasma etched MESFET is due to the removal of the surface oxides.

TABLE 1. ELECTRICAL PARAMETERS BEFORE AND AFTER NITRIDE PASSIVATION FOR FLAT-PROFILE MESFETs

| FET PARAMETERS | $V_p$ (V) | $I_{dss}$ (mA/mm) | $G_m$ (mS/mm) | $V_{br}$ (V) |
|---|---|---|---|---|
| *Argon Plasma Etch* | | | | |
| • Before Passivation | $2.8 \pm 0.3$ | $199 \pm 34$ | $177 \pm 15$ | $15.0 \pm 0.4$ |
| • After Passivation | $2.6 \pm 0.4$ | $214 \pm 28$ | $184 \pm 9$ | $14.2 \pm 0.7$ |
| *Wet Chemical Etch* | | | | |
| • Before Passivation | $2.6 \pm 0.5$ | $141 \pm 46$ | $158 \pm 12$ | $15.5 \pm 0.2$ |
| • After Passivation | $2.5 \pm 0.3$ | $145 \pm 33$ | $165 \pm 33$ | $14.0 \pm 0.4$ |

To test the reliability of the plasma etched wafer, the plasma etched sample was heated at 300°C for 72 hours. Figure 5 shows the $I_{ds}$ transient measurement for the device shown in Figure 3a, following 72-hr heating. The amplitude of the current transient does not change. Table 2 gives the parameter shift after heating. As can be seen, the pinchoff and breakdown voltages remain the same after a heating cycle, while the $I_{dss}$ and transconductance decrease (however, the change is within 5 percent). Meanwhile, for the wet chemically etched sample after the same thermal cycle, the parameter shifts are a little higher (around 10 percent) and there is a larger $I_{ds}$ transient amplitude change, indicating that the surface chemistry of the sample has changed due to thermal stress.
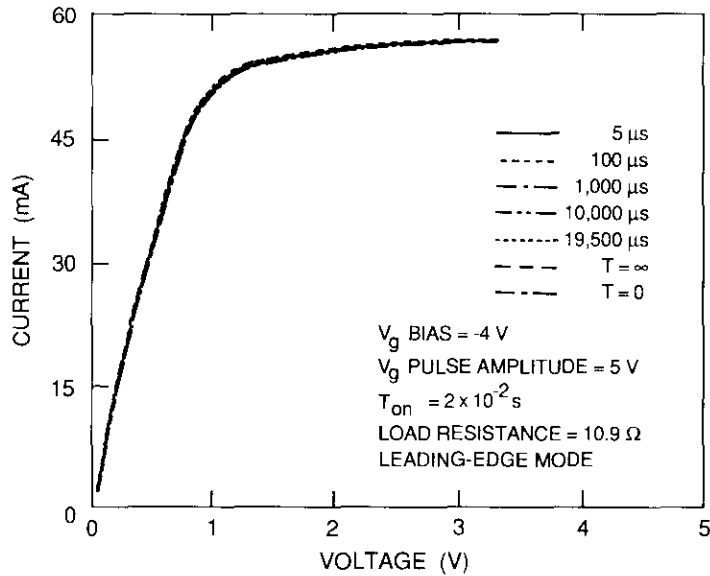
Figure 5. $I_{ds}$ Transient Measurement Data for the Plasma Etched
Flat-Profile MESFET Sample of Figure 3
After 300°C, 72-hr Heating

TABLE 2. ELECTRICAL PARAMETER SHIFT AFTER 300°C, 72-hr HEATING FOR
PLASMA ETCHED MESFET

| FET PARAMETERS | $V_p$ (V) | $I_{dss}$ (mA/mm) | $G_m$ (mS/mm) | $V_{br}$ (V) |
|---|---|---|---|---|
| After Passivation | 2.6 ± 0.4 | 214 ± 28 | 184 ± 9 | 14.2 ± 0.7 |
| After Heating (300°C, 72 hr) | 2.6 ± 0.5 | 197 ± 33 | 179 ± 11 | 14.1 ± 0.7 |

MESFETs passivated using the plasma etching process have demonstrated excellent RF performance. In the MMIC chips, 0.25-μm MESFETs of 400-μm gate width, passivated using the plasma etching process, have demonstrated an output power of 21.6 dBm at the 1-dB compression point, and 5.8-dB small-signal gain at 32 GHz, as shown in Figure 6. This is state-of-the-art performance for a power FET.
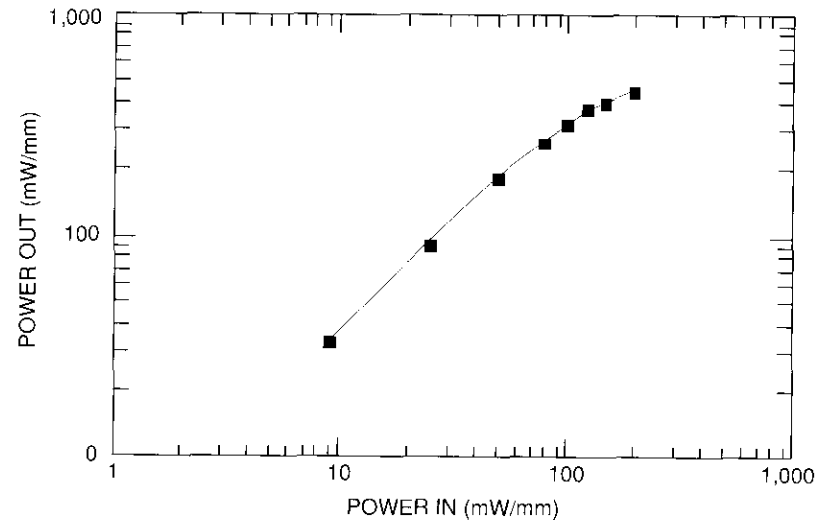


(a) 32-GHz Power Out vs Power In
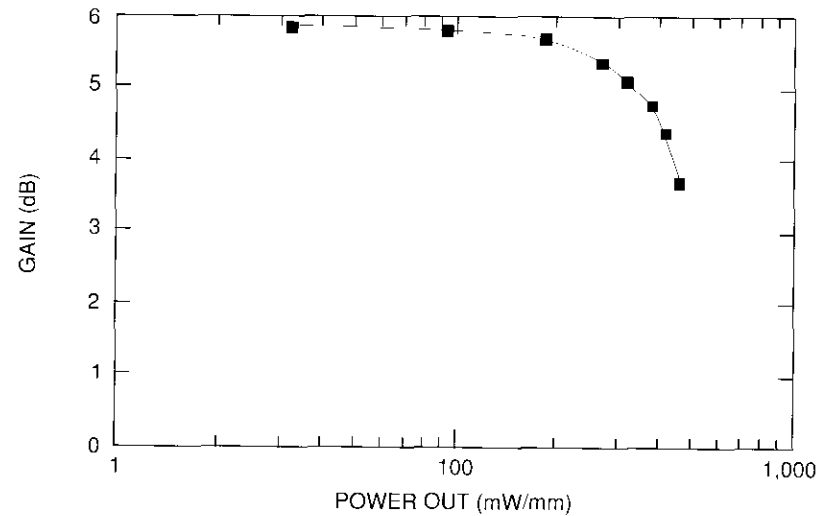


(b) 32-GHz Gain vs Output Power

Figure 6. RF Performance of a 0.25 x 400-μm Flat-Profile MESFET

## Delta-doped MESFET passivation

The structure of the delta-doped FETs is shown in Figure 7. These MESFETs have a gate length of 0.7 μm and source-to-drain spacing of 3 μm. The gate region of these devices is not recessed.

$3.0 \times 10^{17} \, cm^{-3}$

$3.4 \times 10^{12} \, cm^{-2}$

UNDOPED    100 Å
           400 Å
           DELTA-
           LAYER

UNDOPED    7,500 Å

SEMI-INSULATING SUBSTRATE
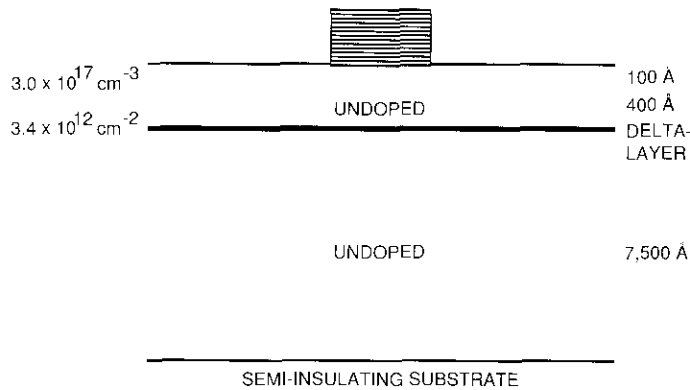
Figure 7. *Structure of the Delta-Doped FET*

To examine the effect of plasma etching, a delta-doped wafer was cleaved into halves. One half was passivated after plasma etching, and the other was passivated after wet chemical etching. Table 3 compares the DC parameters of the two pieces. Before passivation, the two halves exhibit similar DC characteristics; however, after passivation, the wet chemically etched sample demonstrates both higher breakdown voltage and higher transconductance.

TABLE 3. ELECTRICAL PARAMETERS BEFORE AND AFTER NITRIDE PASSIVATION FOR DELTA-DOPED MESFETs

| FET PARAMETERS | $V_p$ (V) | $I_{dss}$ (mA/mm) | $G_m$ (mS/mm) | $V_{br}$ (V) |
|---|---|---|---|---|
| Plasma Etch | $1.4 \pm 0.2$ | $214 \pm 14$ | $134 \pm 14$ | $16 \pm 1$ |
| Wet Chemical Etch | $1.2 \pm 0.1$ | $242 \pm 16$ | $145 \pm 10$ | $19 \pm 1$ |

Figures 8 and 9 compare the I-V characteristics and breakdown voltage before and after passivation for plasma etched and wet chemically etched delta-doped MESFETs. The plasma etched device (Figure 8) shows a kink in the breakdown voltage curve after passivation, which is not seen in the wet chemically etched MESFET (Figure 9). It appears that the plasma etching



(a) Before Passivation

(b) After Passivation
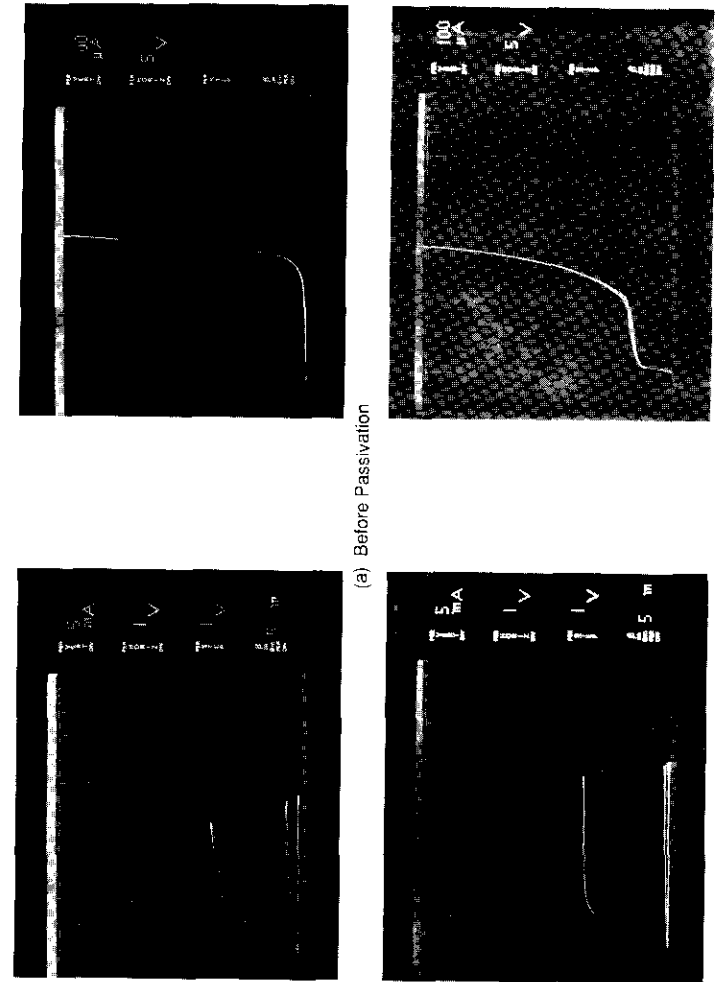
Figure 8. *I-V Characteristics and Breakdown Voltage for the Plasma Etched Delta-Doped MESFET*

(a) Before Passivation

(b) After Passivation
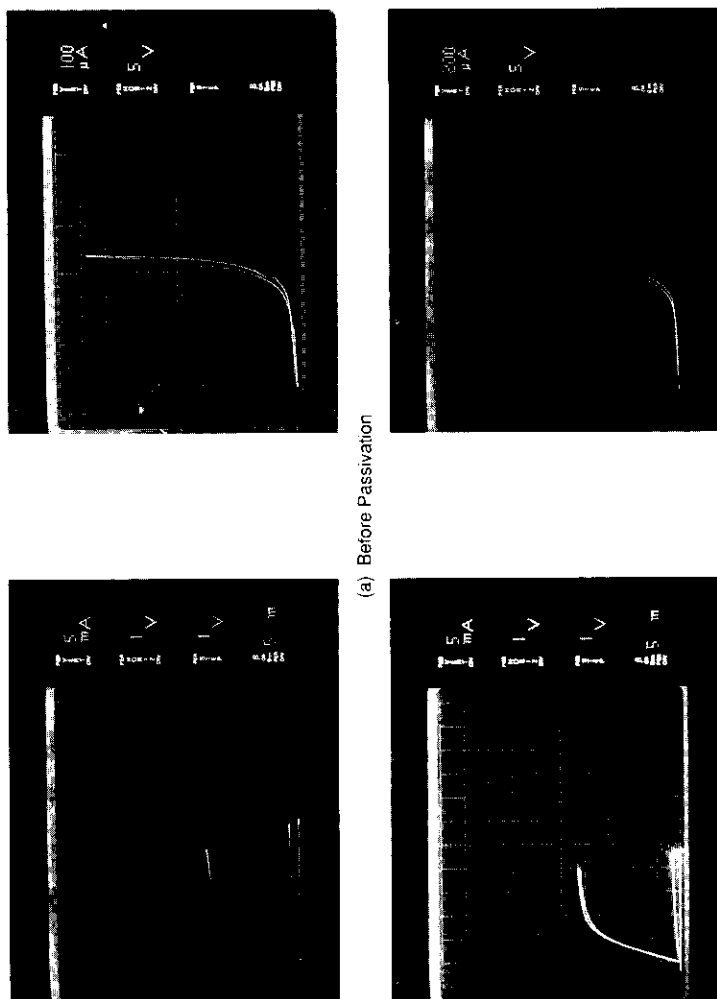
Figure 9. *I-V Characteristics and Breakdown Voltage for the Wet Chemically Etched Delta-Doped MESFET*

process generates surface states, which induce leakage current through the surface region.

The increase in surface states due to the plasma etching process is supported by data from $I_{ds}$ transient measurement. Figure 10 shows a comparison of the $I_{ds}$ current transient measurements for the two etching processes. For the wet chemical etching process (Figure 10a), the amplitude of the $I_{ds}$ transient is quite small, indicating that very few surface states are generated during the passivation process. However, for the plasma etching process (Figure 10b), the amplitude of the $I_{ds}$ transient is large, indicating that much damage has been done to the surface region of the delta-doped FET. Since the area of the channel region may determine the total number of the surface states, there are likely to be more surface states for the unrecessed sample with wider channel area than for the recessed flat-profile sample.

## Conclusions

It has been demonstrated that channel surface treatment prior to passivation is critical to achieving stable device passivation. Depending on the device structure selected and the geometry of the gate region, it is possible to use a light argon plasma to etch the GaAs native oxide prior to silicon nitride passivation. In a flat-profile MESFET with narrow recess width, this process results in devices with improved RF performance and excellent reliability under thermal stress. However, this dry etching process must be applied with care; otherwise, depending on the structure and geometry of the FET, it could have a detrimental effect on device performance, as was found to be the case with unrecessed delta-doped MESFETs.

## Acknowledgments

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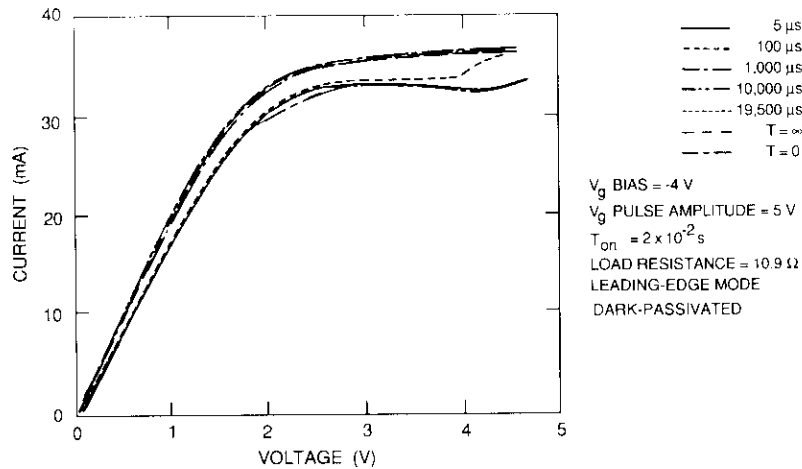
(a) Wet Chemical Etched
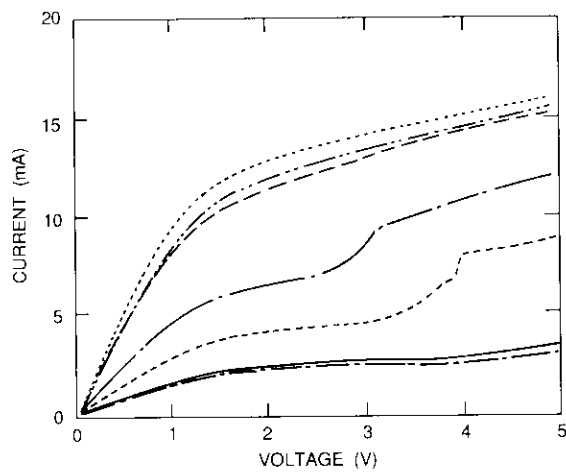


(b) Plasma Etched

Figure 10. *$I_{ds}$ Transient Measurement Data for the Delta-Doped MESFET*

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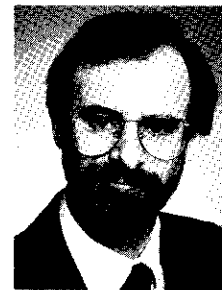
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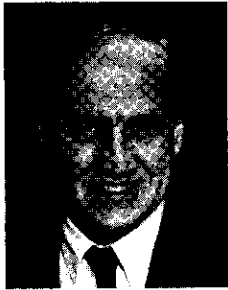
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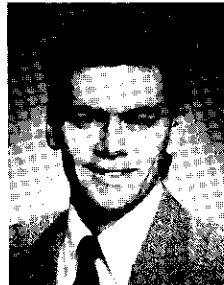




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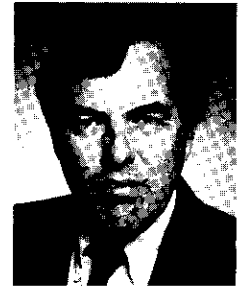




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*provided consulting services to the Air Force Wright Avionics Laboratory in the area of gallium arsenide device passivation.*

*Dr. Pande has authored more than 60 research papers and has secured two patents. He has won special recognition and inventors awards from Allied-Signal Corporation, and the Outstanding Contributions Award from Sperry (now Unisys) Semiconductor Operations. He is a Fellow of IEEE and a member of the American Physical Society, the New York Academy of Sciences, and the Electromagnetic Academy.*

# RF/optical interface design for optical intersatellite links

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(Manuscript received July 5, 1990)

## Abstract

Future data acquisition satellites will be required to multiplex a number of independent data streams of widely varying rates, and exhibiting Doppler variations between low and geosynchronous altitude satellites, into a single, continuous, high-rate data stream. Forward links in these systems will contain commands, and return links will handle data from low earth orbit satellites. This study addresses the flexibility of these links in handling varying missions and data rates to 1 Gbit/s, with a focus on requirements for the NASA Tracking and Data Acquisition System.

Five system components are described: the return link multiplexer, the return link transmultiplexer, the forward link multiplexer, the forward link demultiplexer, and operation of a frontside/backside switch. Ping-pong buffers provide rate buffering for each input data stream, and justification bits handle variations due to Doppler shift and local oscillator variation. The time-division multiplexed streams consist of a unique synchronization word for frame synchronization, and control words associated with each data burst to identify the presence or absence of a justification bit. Redundant data paths are described for both forward and return data streams.

## Introduction

Throughout its history, NASA has depended on a network of ground stations for telemetry, tracking, and command (TT&C) support of earth-orbiting satellites. While continuous contact is possible at synchronous altitude, direct communication between an earth station and low-orbit satellites is generally limited to a few minutes up to a 20-minute period. Gaps in coverage of several hours may occur. Even with the extensive NASA earth station network,

contact with an earth station is typically possible only about 15 percent of the time. On-board recording equipment is often required to store data during the gaps for later playback during an earth station contact. Due to the short contact time, these data must frequently be played back at a high rate, which further limits the amount of data that can be acquired by the satellite.

Satellites such as NASA's Tracking and Data Relay Satellite (TDRS) provide communications links between a single earth station and one or more low earth orbit (LEO) satellites. Their use has greatly improved worldwide connectivity between LEO satellites and the earth over what was previously possible with worldwide networks of earth stations alone. Two TDRSs in synchronous earth orbit provide forward and return links between LEO satellites and the earth station, increasing the direct contact time to 85 percent. The earth stations and LEO satellites both communicate with the data relay satellites. Figure 1a depicts communications with two TDRSs. Continuous communications are possible except for the period when a low-orbiting spacecraft is in a region where neither relay satellite is visible. This is shown as the zone of exclusion (ZOE).

The NASA Tracking and Data Acquisition System (TDAS) program was created to study future replacements for the TDRSs. The program added an intersatellite link (ISL) between the data relay satellites so that two of these satellites at proper orbital positions provide nearly continuous contact between the low-orbit satellites through a single earth station located at White Sands, New Mexico. Figure 1b illustrates communications for the TDAS. The ZOE for this system is considerably smaller, and earth stations can be located over a much larger area.

This paper discusses systems and implementational aspects of the digital RF/optical interface design, as well as multiplexing requirements for an optical ISL between the two relay satellites. Included is part of a report submitted to NASA for the proposed TDAS program [1]. The first part of the COMSAT Laboratories' study covers optical communications aspects. Marshalek [2] and Paul [3] have reported results on portions of the optical link design. Herein is addressed work on multiplexing and system engineering. The rates used in this design were specified by NASA; however, the techniques described here can be applied to other systems and missions as well. The interfaces in the data relay satellites that support digital communications with the LEO satellites and the earth stations are also described.

Communications between LEO satellites, data relay GEO (geosynchronous earth orbit) satellites, and an earth station are illustrated in Figure 1b. Two relay satellites are located in the geosynchronous equatorial plane orbit with a separation of 160°. One of these satellites, the "frontside" satellite, is visible from White Sands and has continuous communications with one or more earth

(a) TDRS



(b) TDAS
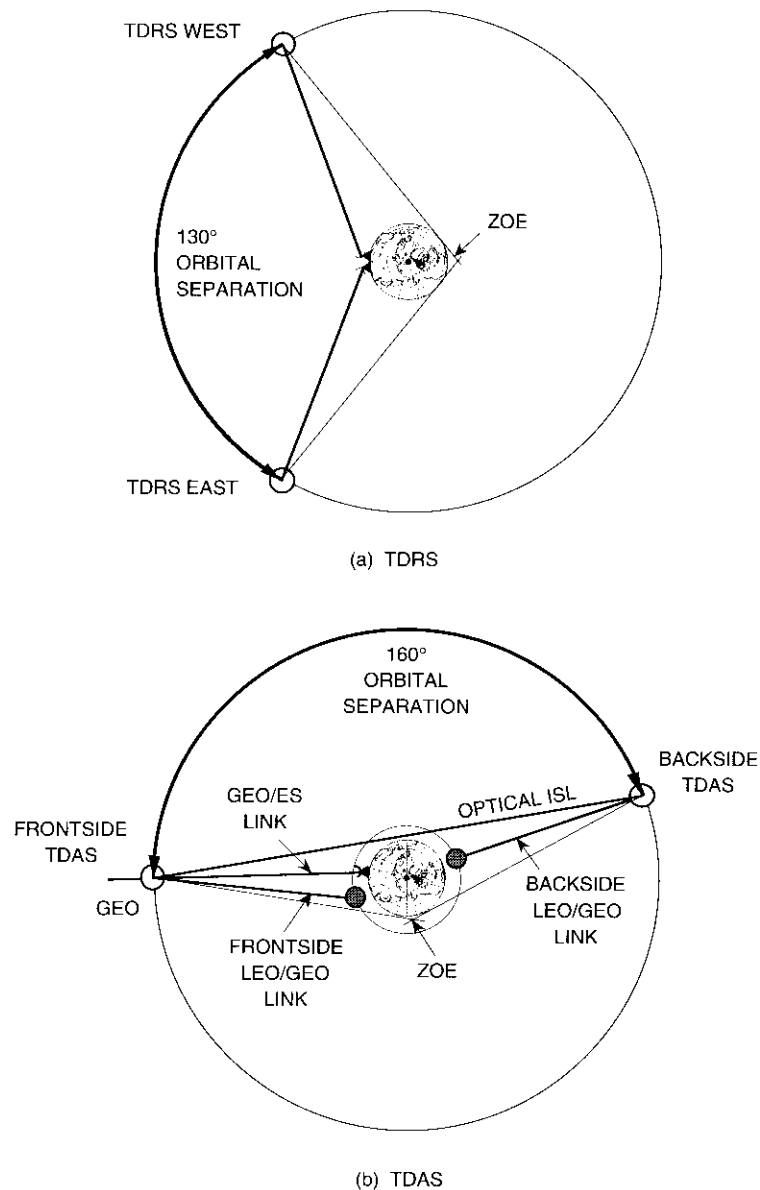
Figure 1. *Orbital Positions for TDRS and TDAS*

stations. An ISL provides continuous communications between the frontside and "backside" relay satellites. When the frontside relay satellite is visible from the LEO satellite, both the forward and return links between the earth station and the LEO satellite can function through the the frontside satellite. However, when only the backside relay satellite is visible from the LEO satellite, the forward and return links must be routed over the ISL. This combination permits nearly continuous communications between the earth station and the LEO satellite.

The channels and linkages supported by the system are illustrated in Figure 2. The table shown in the figure lists the forward and return channel types used for this study, the number of each type, and the symbol rate (high and low limits) per channel. The actual operating rate for a channel can be any value between the high and low limits. Each channel is given a three-letter name. The first letter indicates the frequency used between a LEO satellite and a TDAS satellite: L is a laser link, K and S are microwave frequencies, and W is undefined. The second and third letters indicate the access mode: SA is single access, while MA is multiple access. Each channel is demodulated to a baseband digital signal at the relay satellite. The cumulative rate in each direction is tallied in the bottom row. The maximum forward composite rate totals 103.63 Mbit/s, and the return rate totals 2,524.51 Mbit/s. Several LEO satellites can be served by this arrangement. It is unlikely that the maximum rates on all channels would combine simultaneously on the backside relay satellite; rather they would be distributed between the backside and frontside relay satellites. For this reason, the return intersatellite crosslink can be scaled to a lower number. For this study, the maximum capacity for the return crosslink is 2,000 Mbit/s, and the capacity for the forward link is 110 Mbit/s. The frontside satellite provides forward and return links for up to nine U.S. earth stations.

The principal objective of this study was to design the digital RF/optical interfaces needed on the frontside and backside relay satellites for switching and carrying the wide variety of digital channel rates to serve the needs of several orbiting LEO satellites. Another objective was to define a number of component building blocks that can be applied repetitively to the design. The communications techniques and design considerations for these building-block components are described, followed by a discussion of how they were used to design the major components for the return and forward links on the GEO relay satellites.

The design approach identifies a number of circuit elements that can be implemented using large-scale integration (LSI) or very large-scale integration (VLSI) techniques.

| LEO Ch | Return | | | Forward | | |
|---|---|---|---|---|---|---|
| | No. | Max Rate (MHz) | Min Rate (kHz) | No. | Max Rate (MHz) | Min Rate (kHz) |
| LSA | 1 | 1,000 | 10,000 | 1 | 50 | 1,000 |
| KSA | 2 | 300 | 1 | 2 | 25 | 1 |
| WSA | 3 | 300 | 1 | 3 | 1 | 1 |
| SSA | 10 | 12 | 0.1 | 2 | 0.3 | 0.1 |
| SMA | 2 | 0.05 | 0.1 | 2 | 0.01 | 0.1 |
| TT&C | 1 | 0.01 | 10 | 1 | 0.01 | 10 |
| Total | 19 | 2,524.51 | 10,016.2 | 11 | 103.63 | 1,015.4 |

Figure 2. *TDAS Overview*

## RF/optical digital interface design

The design of the RF/optical digital interface must take into consideration a number of factors. First, the fact that the links are between geostationary relay satellites and rapidly moving LEO satellites creates variations in the data rate on the links between the relay satellites and the LEO satellites which must be accommodated at the interface. The second factor concerns the impact of combining a number of streams from LEO satellites into a single high-rate stream in the relay satellite. The third consideration is the wide range of input rates necessary to accommodate the various channel rates, which must be changed as a function of LEO location and mission requirements. This requires a highly flexible time-division multiplexer (TDM) that can easily be reconfigured by ground command.

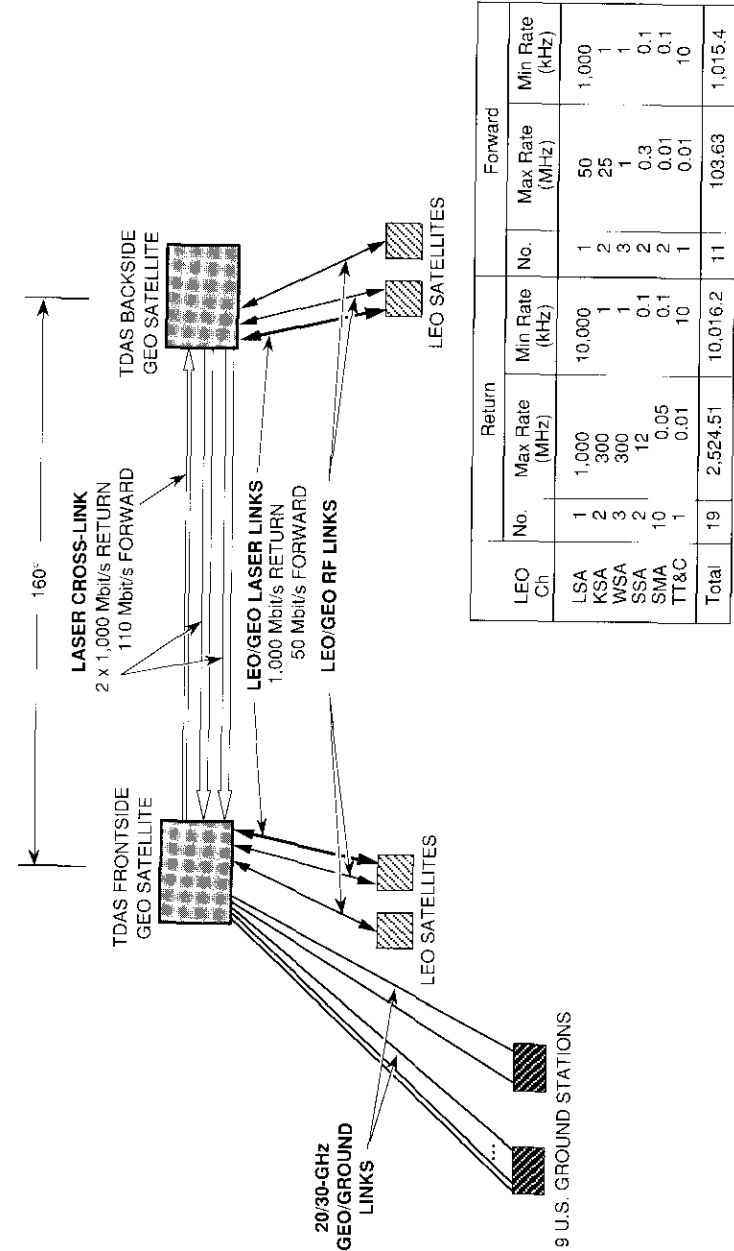This section discusses the general techniques needed to address some of these design challenges. These include multiplexing sources with rate variations caused by Doppler motion, combining channels that have different rates, and the factors to be considered in selecting frame periods. Techniques for frame synchronization and the detection of smoothing bits are then described. The operation of buffers that can perform the required multiplexer and demultiplexer functions is also discussed. In later sections, the techniques described here will be used to develop specific multiplexer designs for the forward and return links.

### Multiplexing data sources of varying Doppler effects

Transmissions arriving at a relay satellite from various LEO satellites are received on-board and multiplexed into a single high-rate data stream for transmission to the other relay satellite or to the earth. One requirement for an optical intersatellite data link is to multiplex a number of independent data streams (of widely differing rates and exhibiting Doppler variations typical of LEO/GEO paths) from arbitrarily located LEO platforms into a single, continuous, high-rate data stream. The maximum peak-to-peak rate variation caused by the effect of Doppler on the transmission from LEO to GEO satellites is $\pm 2.5 \times 10^{-5}$. A combination of data buffers and variable-rate TDMs provides the control and adjustment needed to handle these variations. These multiplexers permit the number of bits used per frame to be adjusted over a small number of justification bits in order to accommodate the rate variations of the individual channels when they are multiplexed on a constant-rate transmission path.

### Multiplexing variable-rate data channels

A second problem is posed by the range of operating data rates for each LEO/GEO channel. Each of these channels is described by maximum and minimum rates. Since the sum of the individual streams at maximum rates is larger than the available TDAS backside-to-frontside intersatellite data links, the TDM burst time format should be programmable to accommodate changes in the operational modes for the LEO/GEO links. A technique to provide highly efficient operation at the maximum rates is considered first, followed by a simple modification for operation at the minimum rates.

Figure 3 illustrates the basic method for interpolating data channels from differing sources onto a common-rate channel. In a frame of duration, $T_F$, and containing $N_F$ bits, the various channels to be accommodated are assigned a range of bits varying from a minimum, $m_i$, to a maximum, $n_i$, for the $i$th channel. The difference, $D_i$, between $n_i$ and $m_i$ must be selected to encompass the variations in channel data rate that result from the combined variations due to Doppler effect and source clock. $D_i$ is typically referred to as the number of justification bits and is determined by the procedure given below.
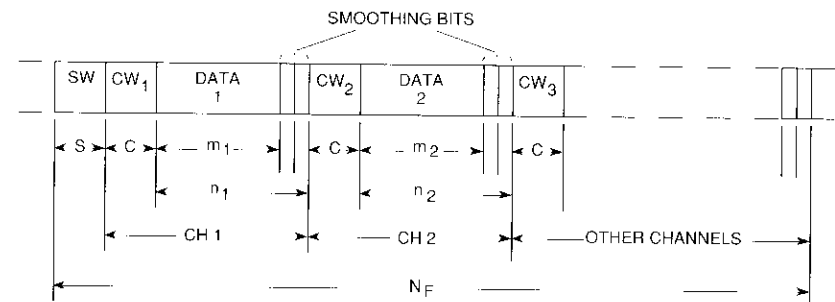


$N_F$ = Frame period
$m_i$ = Min bits used for channel i = $R_i T_F - 1$
$n_i$ = Max bits used for channel i = $R_i T_F + 1$
Nominal rate for channel i = $R_i$
Max rate for channel i = $R_i + \dfrac{1}{T_F}$
Min rate for channel i = $R_i - \dfrac{1}{T_F}$
Number of bits per frame = $N_F = S + kC + \sum\limits_{i=1}^{k} n_i$

Figure 3. *Optical Link Multiplex Frame*

If the Doppler rate variation coefficient is $d_i$ and the channel's nominal data rate is $R_i$, then the data rate can vary over the range

$$R_i(1 - d_i) < R_i < R_i(1 + d_i) \tag{1}$$

and the number of bits per frame can vary over the range

$$m_i < T_F R_i(1 - d_i) < T_F R_i < T_F R_i(1 + d_i) < n_i \tag{2}$$

The variables $m_i$ and $n_i$ must be selected so that they bound the range needed to accommodate the Doppler coefficient, $d_i$. Hence, the value of $D_i$ must be an integer (since there are no fractions of bits) that is greater than the peak-to-peak difference given by equation (2). Thus,

$$D_i = \lceil 2T_{Fmax} R_i d_i \rceil \tag{3}$$

where $\lceil \ldots \rceil$ indicates rounding up to the nearest integer. For the multiplexers recommended for TDAS, $D_i = 2$ has been selected, since it results in the simplest overall design.

As illustrated in Figure 3, the data channels from various sources are time-division multiplexed into a single stream. Each channel (identified by index $i$) is allocated a share of the frame capacity sufficient to accommodate a control word, $CW_i$, containing $C$ bits to carry interpolation control information, and a group of data bits to carry the actual data transmitted. For channel $i$, the number of data bits actually used during each frame varies from a minimum, $m_i$, to a maximum, $n_i$ (a range of $D_i = n_i - m_i = 2$ bits) to accommodate the rate variation; however, the maximum value ($n_i$) must always be provided. In a given frame, the actual number of bits used by the data must be signaled in $CW_i$ to the receiving demultiplexer in order to eliminate the non-data bits. A frame synchronization word, $SW$, of length $S$ is used to establish frame synchronization.

### Frame period selection

For each channel rate, $R_i$, to be accommodated, there exists a maximum frame period, $T_{Fmax}$, determined by equation (3) and the number of justification bits per frame, $D_i$. The maximum frame length is the minimum of the values calculated for each channel. If a longer frame is used, bit justification corresponding to $D_i = 2$ will not cover the desired range of Doppler variation

for all channels. However, shorter frames increase the Doppler variation range and reduce the size of the channel-forming buffers. The disadvantages of shortening the frame are reduced frame efficiency and increased symbol jitter in the recovered data stream. Thus, a tradeoff must be made between buffer size and frame efficiency, while maintaining low jitter in the recovered bit stream. At the high speeds used for the TDAS, it is clearly desirable that the buffer size be confined to a few hundred bits to stay within the expected bounds of GaAs technology.

For a given frame period, $T_F$, the range of transmission rates provided for channel $i$ is

$$\frac{m_i}{T_F} \le R_i \le \frac{n_i}{T_F} \tag{4}$$

Corresponding to the choice of $D_i = 2$, the values of $n_i$ and $m_i$ necessary to accommodate a nominal rate of $R_i$ are

$$n_i = R_i T_F + 1 \tag{5a}$$

$$m_i = R_i T_F - 1 \tag{5b}$$

and the maximum and minimum channel transmission rates are

$$R_i - \frac{1}{T_F} \le \text{Channel rate} \le R_i + \frac{1}{T_F} \tag{6}$$

For any value of $T_F$ up to the maximum, the number of bits per frame is determined by equation (5a). This choice results in the use of three values for the number of data bits per channel. The number of bits carried in each frame is indicated by the control word, $CW_i$, as given in Table 1.

TABLE 1. MULTIPLEX FRAME PARAMETERS

| DATA BURST LENGTH | NO. OF BITS | CONTROL WORD | RATE |
|---|---|---|---|
| Minimum | $R_i T_F - 1$ | 00 | $R_i - \dfrac{1}{T_F}$ |
| Nominal | $R_i T_F$ | 01 | $R_i$ |
| Maximum | $R_i T_F + 1$ | 11 | $R_i + \dfrac{1}{T_F}$ |

### Fraction of frames using other than nominal rate

By choosing $T_F$ to be equal to or less than the minimum $T_{Fmax}$, all the channel rates will be appropriately accommodated. Thus, in operation, the instantaneous minimum and maximum rates (provided by deleting or adding 1 bit) will be more than sufficient to accommodate the variation encountered on the channel. Most of the time the nominal rate will be used, and occasionally the maximum rate (add 1 bit) will be used to accommodate the effect of up-Doppler, or the minimum rate (delete 1 bit) to accommodate the effect of down-Doppler. It will be demonstrated below that the fraction of frames using the maximum and minimum rates, rather than the nominal rate, for a frequency variation coefficient, $d_i$, is

$$e_i = d_i R_i T_F \tag{7}$$

and consequently only one in $e_i^{\,l}$ frames will use other than the nominal rate $R_i$ (i.e., will carry other than $R_i T_F$ bits per frame).

To demonstrate the development of the above expression, consider the following. Over a time interval sufficient to contain a large number of frames, assume that $p$ frames occur at the nominal rate $R_i$, and $q$ at the maximum rate $R_i + 1/T_F$. The average rate during the time interval is the weighted average of the nominal and maximum-rate frames, which must equal the rate presented on the LEO/GEO link. Thus,

$$\frac{pR_i + q\left(R_i + \dfrac{1}{T_F}\right)}{p + q} = R_i\left(1 + d_i\right) \tag{8}$$

Solving for the fraction of frames that use the high rate,

$$e_i = \frac{q}{p + q} = d_i R_i T_F \tag{9}$$

This development pertains whether $d_i$ is positive or negative. Of course, when it is negative, the fraction of frames calculated is for the low rate.

### Synchronization and control words

The function of the frame synchronization word, $SW$, of $S$ bits in length, is to produce a synchronization pulse at the instant of correlation (corresponding to perfect alignment) between itself and a replica stored in a correlator, and to produce small deviations ($\pm 1$) around a mean value of $S/2$ when the alignment is not perfect. The operation of such a correlator is shown in Figure 4. Figure 4a shows that the output of the correlator as a stream containing the
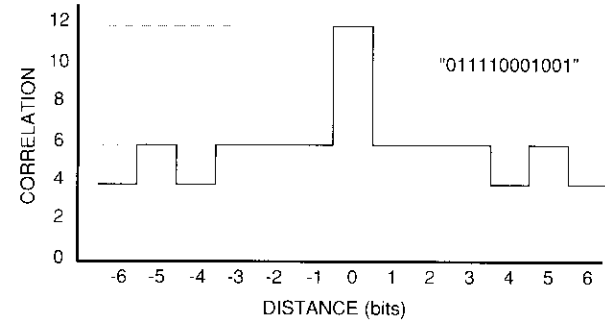


(a) Autocorrelation Output
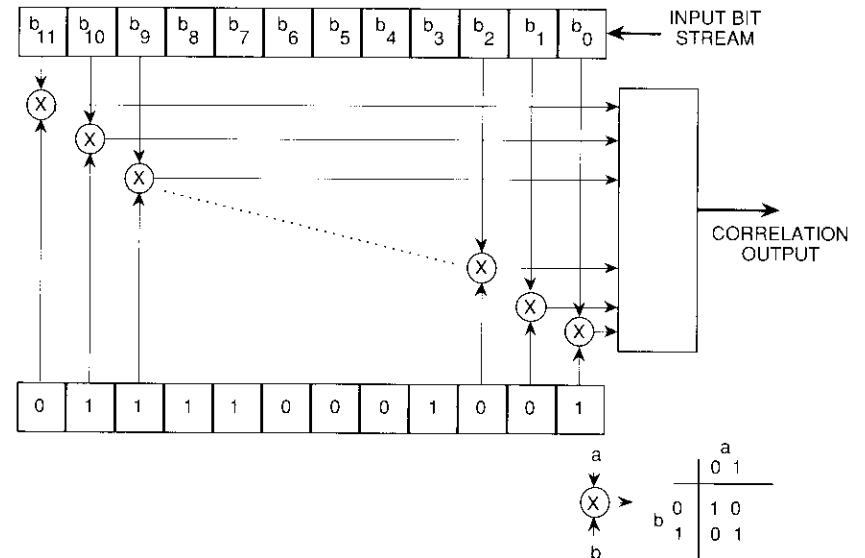
(b) Typical Synchronization Word Correlator

Figure 4. *Synchronization Word Correlation*

synchronization word is shifted 1 bit at a time through a register, and compared at each shift with a replica of the synchronization word. At each shift, the output is the number of bits that agree. At the instant of correlation, the output reaches a maximum value equal to the length of the synchronization word. The bit sequence of the synchronization word must be chosen to achieve these correlation properties.

A 12-bit word that has been used very successfully for time-division multiple access (TDMA) implementation, 011110001001, is used to implement the subject multiplexer. Figure 4b shows one implementation of the correlator. The false-alarm and miss probabilities of this word for gated and non-gated operation have been described by Campanella and Schaefer [4]. Non-gated operation is recommended during the search for the synchronization word, and gated operation during maintenance of synchronization.

The function of the control word is to signal when the group of bits in the frame is less than nominal, nominal, or greater than nominal. These three states require at least 2 bits to signal them. The control bits are extremely important for restoration at the receiver. An error in detecting the correct control word introduces both a clock and a data error. Therefore, error correction coding is mandatory. For this application, two different techniques were considered. One uses eightfold majority logic coding to yield 16 bits for the control channel. Up to three errors can occur in the 16-bit word without an error decision, or approximately one error in 5 bits.

A second option uses a control word only 8 bits long, but with similar properties. Use of this shorter control word will improve efficiency for low-rate channels by taking advantage of the fact that only three states are needed to represent the number of justification bits. The previous method allows four states to be decoded because 2 bits are used in each of the eight copies. If two errors are allowed to occur in the 8-bit control word, then the acceptable error rate is one error in 4 bits. To achieve this, at least five codes for the number of justification bits in the burst must be transmitted in the control word. With two bit errors, at least three of the codes must still agree so that the number of justification bits can be determined.

To determine the minimum number of bits in the control word, let $Q$ be the code representing the number of justification bits in the frame and let $Q = \{0, 1, 2\}$ represent the nominal, $n_l$, and $m_l$ lengths, respectively. The minimum-length control word can be constructed by forming a new word containing five instances of the code $Q$ raised to successive powers of 3, as

$$CW = p_0 + Q3^0 + Q3^1 + Q3^2 + Q3^3 + Q3^4 \qquad (10)$$

The control word values corresponding to $Q = 0, 1, 2$ and $p_0 = 0$ are $CW = 0$, 121, 242. This range requires an 8-bit control word. The next step is to evaluate the effects of all possible combinations of one and two errors. The corrupted control word is then decoded to determine if three valid codes can be obtained with two errors.

The value of $p_0$ can range from 0 to 13 without overflowing an 8-bit word. Each of these values for $p_0$ was evaluated with error patterns consisting of 0, 1, and 2 errors. The evaluation showed that two values for $p_0$ are acceptable: $p_0 = 2$ or 11. For the other values, there were one or more instances where two errors in the control word caused three of the coefficients to be corrupted. The two sets of 8-bit control words that meet the requirements for coding three buffer-length states in the presence of two errors in the 8-bit word are $CW = \{2, 123, 244\}$ and $\{11, 132, 253\}$. For either of these sequences, three distinct sets of numbers exist corresponding to the three values for $Q$ in the presence of 0, 1, or 2 errors. These sets can be stored in memory and used to quickly decode a control word.

### Composite transmission rate and frame efficiency

Referring again to the frame structure shown in Figure 3, the total number of bits carried in one frame containing $k$ channels of various sizes, $n_i$, is seen to be

$$N_F = S + kC + \sum_{i=1}^{k} n_i \qquad (11)$$

and hence the composite transmission rate is

$$R_c = \frac{N_F}{T_F} = \frac{S + kC}{T_F} + \sum_{i=1}^{k} R_i \qquad (12)$$

where $R_i$ is the rate of incoming channel $i$.

The frame efficiency is the ratio of channel data payload per frame to $N_F$, which is

$$\eta = \frac{1}{N_F} \sum_{i=1}^{k} n_i = \frac{N_F - (S + kC)}{N_F} \qquad (13)$$

It is obvious that, as the frame period is shortened, the number of bits contained in the synchronization word and the control words becomes an increasingly large fraction, thus reducing efficiency. Figure 5 shows the efficiency for various numbers of channels as a function of $N_F$. These curves are for a control word of length $C = 8$ bits and a synchronization word of $S = 12$ bits. A
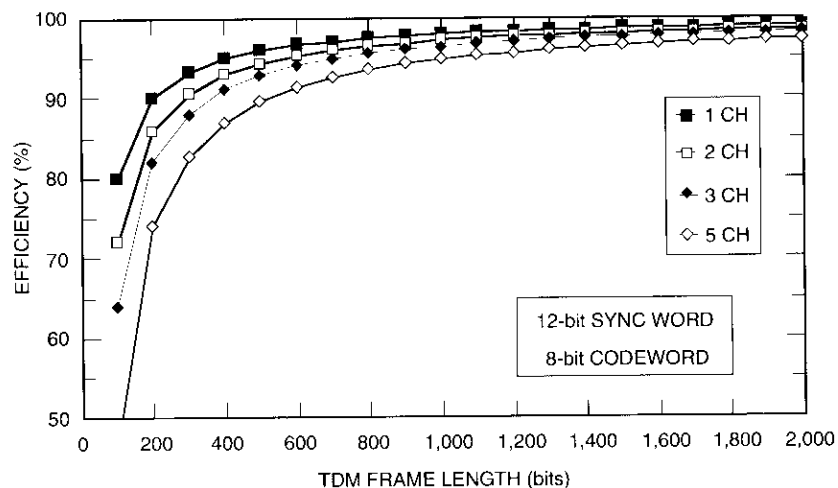
Figure 5. *Multiplexer Efficiency*

frame length of approximately 1,000 bits, yielding an efficiency of better than 90 percent assuming five channels, is a reasonable choice. Thus, for a 1-Gbit/s ISL transmission rate, the frame duration is approximately $T_F = 1$ μs.

## Multiplexer implementation

Figure 6 is a block diagram of an implementation of the TDAS optical data link multiplexer which illustrates the implementation details for two channels. Each channel's digital bit stream is presented to the multiplexing buffer, which performs the joint functions of formatting frame sub-bursts and compensating for rate variations in the data flow. Each buffer has a pair of buffer memories, designated $B_i$ and $\overline{B_i}$, respectively, that exchange function in a ping-pong fashion from frame to frame. Thus, if during one frame $B_i$ is read and $\overline{B_i}$ is written, in the next frame $\overline{B_i}$ is read and $B_i$ is written. The ping-pong action is implemented by exchanging the read and write clocks on alternating frames. By this means, data from the input channel are continuously formatted into data bursts transmitted at the proper frame location.

The data are written into each buffer using a clock derived directly from the channel data stream. They are read from each buffer by bursts of clock pulses generated by a master clock operating at the rate of the TDAS-multiplexed transmission link, namely $N_F/T_F$. A frame timing unit generates frame period pulses, $F$, which control the administration of the buffer read and
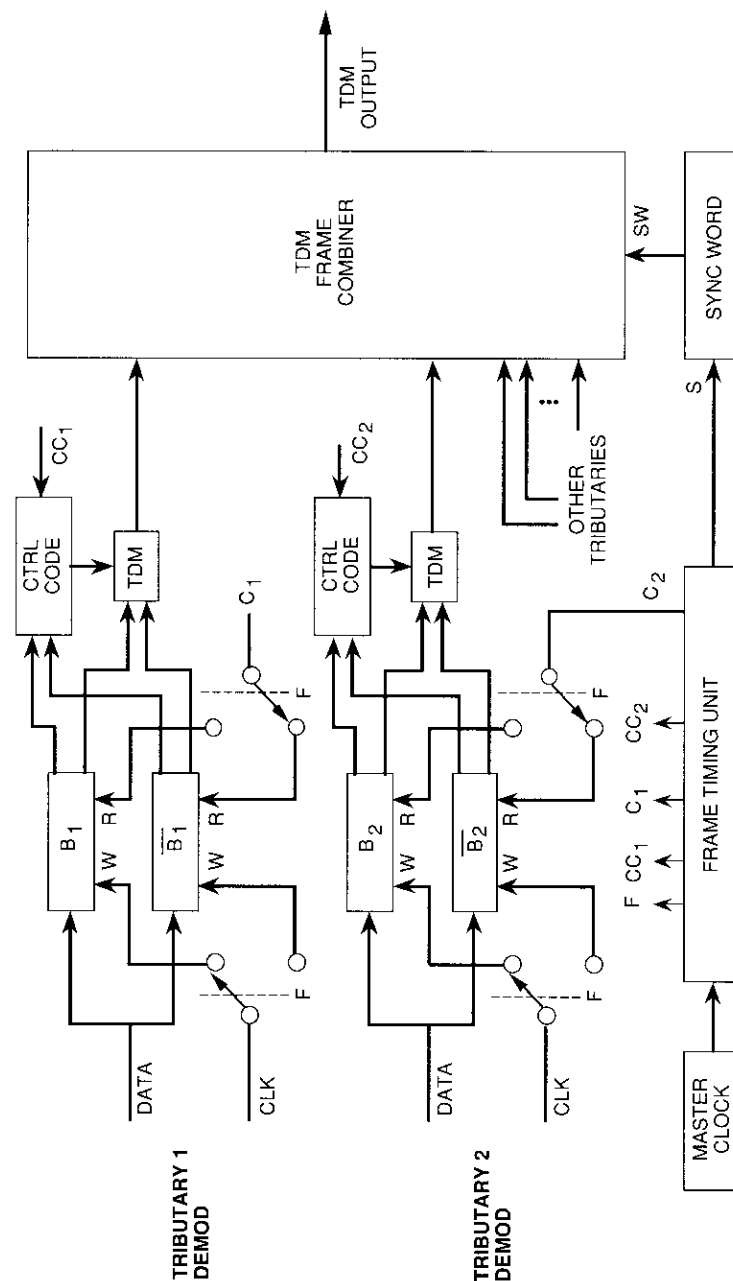
Figure 6. *Optical Link Multiplexer Circuit Elements*

write clocks, and bursts of clock pulses of the proper number and frame location to format the multiplexed stream. For buffer $B_i / \overline{B_i}$, the bursts of read clock pulses are designated as $C_i$. The variable $C_i$ comprises $n_i$ clock pulses (the maximum possible) which occur at a time in the frame that precisely locates the read $B_i / \overline{B_i}$ bits at their assigned location in the TDM frame. All $n_i$ bits are always read; however, the number actually written may be $n_i$, $n_i - 1$, or $n_i - 2$, depending on the accidents of alignment at the input to the buffer in filling the buffer. The burst thus formed is said to be "bit justified."

Figure 7 is a timing diagram that illustrates the buffer operation. The primary requirement is that the read and write periods for a buffer must never overlap. Writing $n_i$ bits causes the write period to shift to the right (delay), while writing $m_i$ bits causes the write period to shift to the left (advance). It is this action that accommodates the variable rates occurring on individual channels. This buffer fill condition is sensed at the end of each write cycle in a
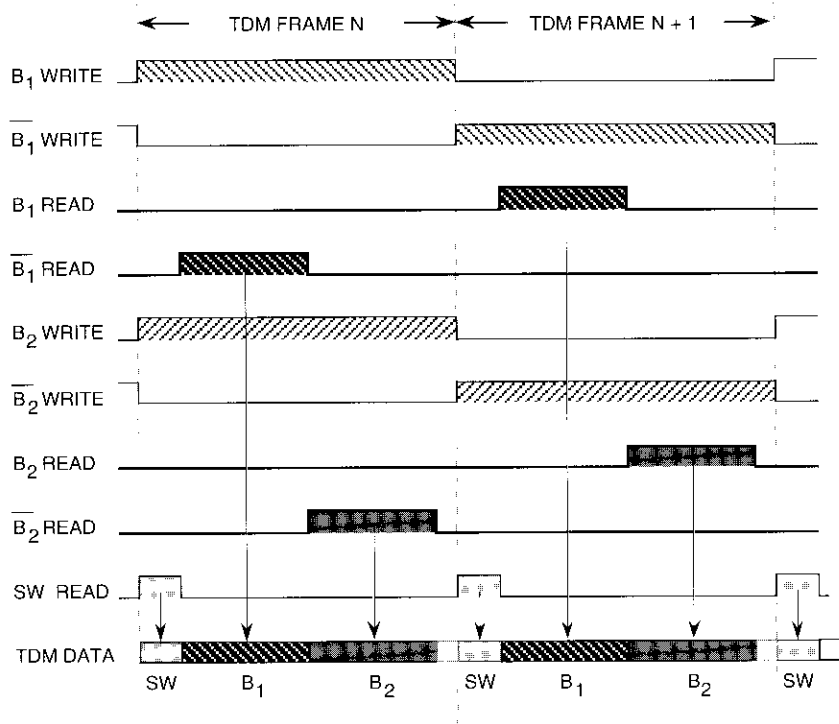


Figure 7. *Optical Link Multiplexer Timing*

buffer and sets the state of the control buffer to one of the three fill states. This state is read in $CW_i$, just before the data bits are read, by using the clock pulses designated as $CC_i$ generated by the frame timing unit. This process is repeated for each channel carried in the frame.

To generate the synchronization word bits that mark the beginning of each multiplex frame, the frame timing unit generates a set of clock pulses, $S$, that read the contents of the synchronization (sync) word buffer at the start of each frame. Other channel bursts are generated in the same manner using appropriately timed outputs from the frame timing unit.

## Demultiplexer implementation

Figure 8 depicts the implementation of the demultiplexer, while Figure 9 shows its timing. The multiplex stream comprises the sequence of bit-justified data sub-bursts (one for each origin channel generated by the multiplexer) and is supplied as input after demodulation from the optical receiver. To establish the timing of clock pulses necessary to accomplish the demultiplexing, the clock rate of the transmission link must be recovered and the instant of synchronization word correlation detected. Based on these signals, the frame timing unit generates the following timing symbols:

$F$    Frame timing signal that marks the start instant of each frame.

$C_i$    A sequence of $n_i$ clock pulses that occur at the received clock rate $N_F / T_F$ and at the proper time to write the $n_i$ bits of channel $i$'s sub-burst into the demultiplexing buffer, $B_i$ or $\overline{B_i}$.

$CC_i$    A sequence of clock pulses that occur at the time in the frame needed to write the control word for channel $i$ ($CW_i$) into the output smoothing buffer. The information is used during the frame following the frame in which it is received.

$CT_i$    A sequence of clock pulses that occur at the smoothed rate, $R_i$, used to read the contents of the demultiplexing buffer, $B_i$ or $\overline{B_i}$. The number of pulses is either $m_i$, $n_i - 1$, or $n_i$, as determined by the control word received from the previous block. The smoothed clock generator uses the control words and frame timing unit to generate the smoothed clock at rate $R_i$.

The demultiplexer restores the signal to the same rates and format found at the input to the multiplexer. Two functions are required: the additional justification bits inserted into the bit stream at the multiplexer input must be removed, and the average input clock rate, $R_i$, must be regenerated.
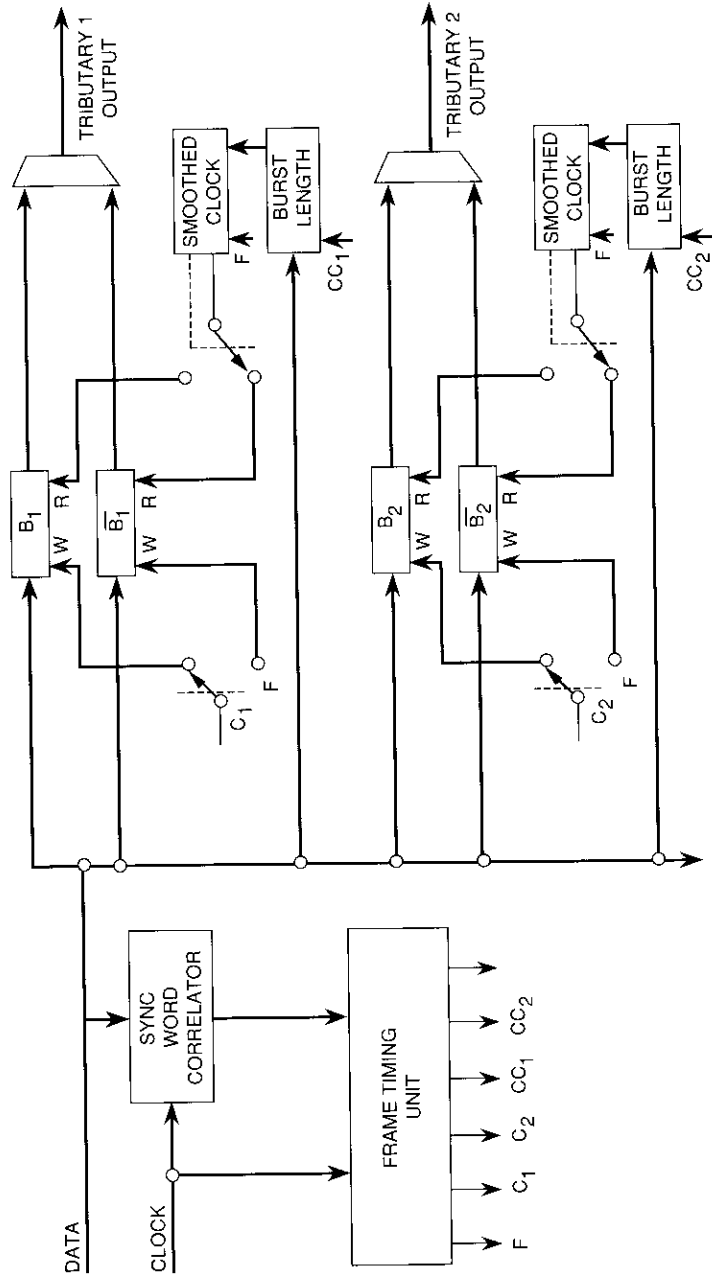
Figure 8. *Optical Link Demultiplexer Circuit Elements*
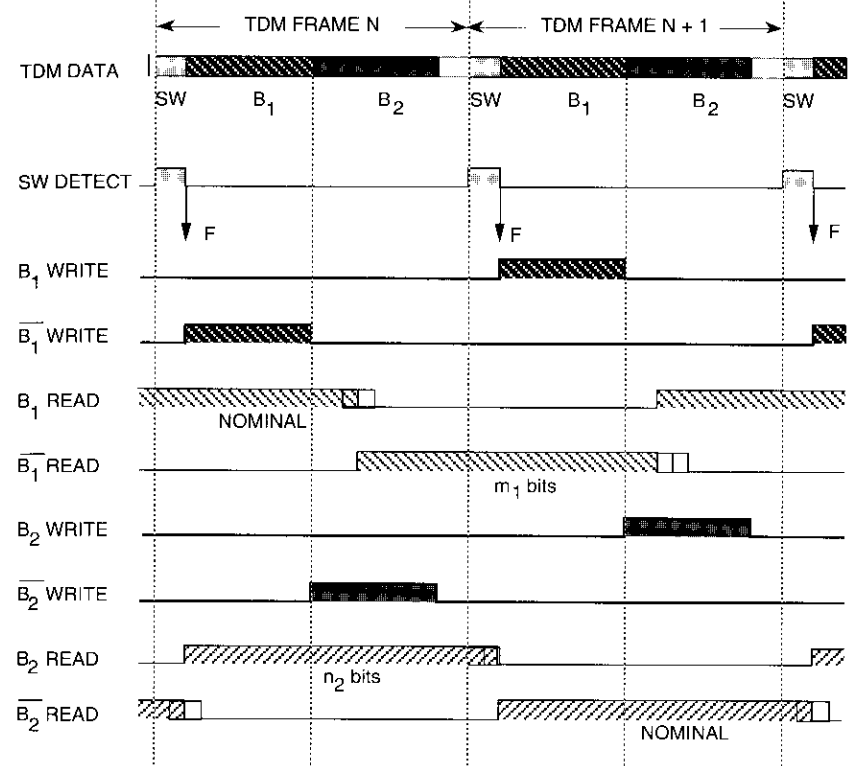


Figure 9. *Optical Link Demultiplexer Timing*

The clock signal corresponding to the multiplexed stream is used to write $n_i$ bits in each frame into the ping-pong buffers $B_i$ and $\overline{B_i}$. At this point, the stored signal still contains the justification bits. These bits must be eliminated and the rate adjusted to recover the channel stream. To accomplish this, the read clock rate is adjusted to recover the average rate, as follows. When the rate on the LEO/GEO link is high or low by a fraction $d_{im}$, the number of frames between frames that carry other than $n_i - 1$ bits is $e_{im}^{-1}$, which is obtained by substituting $d_{im}$ into equation (7). Thus, the number of bits over which the retiming clock is high or low is

$$L = \left( R_i \, T_F \, d_{im} \right)^{-1} = e_{im}^{-1} \qquad (14)$$

When the transmission rate over the link is at the nominal rate corresponding to $R_i$, each frame will contain $R_i T_F = n_i - 1$ bits ($T_F$ and $R_i$ referenced to the transmit end). When this is the case, the write and read clocks are the same. For this condition to be maintained, the read clock must operate at a rate $[(n_i - 1)/T_F]$ ($T_F$ referenced to the receive end). When the transmission rate is high, such that a frame carrying $n_i$ information bits occurs once every $L$ frames to accommodate the extra bit, the next read pointer is retarded by one address. The buffer must recover from this state by advancing the phase of the read clock by one bit period over a time interval, $LT_F$. This requires that the frequency of the read clock be increased to

$$\text{High read clock frequency} = \left(\frac{n_i - 1}{T_F}\right)\left(1 + \frac{L}{n_i - 1}\right) = R_i\left(1 + d_{im}\right) \quad (15)$$

This clock rate is maintained until the read clock phase advances by one bit period—a condition that is sensed by return of the alignment buffer to the normal state.

When the transmission rate is low, such that a frame carrying $n_i - 2$ bits occurs once every $L$ frames to accommodate the loss of 1 bit, the read vector is advanced by one address of the buffer. The buffer must recover from this state by retarding the phase of the read clock by one bit period over a time interval, $LT_F$. This requires that the frequency of the read clock be reduced to

$$\text{Low read clock frequency} = \left(\frac{n_i - 1}{T_F}\right)\left(1 - \frac{L}{n_i - 1}\right) = R_i\left(1 - d_{im}\right) \quad (16)$$

It is also necessary to accommodate corrections that can be caused by the drift of the smoothing clock itself. The smoothing clock always attempts to maintain the normal state in the read buffer. If, due to its own drift, it advances the clock rate to either the plus or minus state, the clock frequency will be decreased or increased in the same manner described above to correct for the drift, and the frequency correction will occur in the same way as for a rate change on the channel. Because these corrections are in addition to those needed to compensate for the bit justification corrections, both may occasionally occur simultaneously in the same direction, causing a shift of two addresses rather than one. Consequently, the buffer needs to accommodate either two leading or two lagging corrections. For such double address changes, the frequency must be increased or decreased by twice the amount used for a single address change. At the rates defined for this study, there is ample margin for this alignment.

## Return link design

The intersatellite return link must accommodate data from a large number of LEO/GEO digital up-links from different LEO platforms. The return link is the path from the LEO satellites to the GEO data relay satellite. The table in Figure 2 lists 19 separate channels to be handled by the two data relay satellites. These satellites function in either the backside or frontside role. The backside satellite functions are shown in Figure 10. The backside satellite collects data from the LEO satellites, forms these data into two 1-Gbit/s streams, and transmits the data to the frontside satellite using the optical ISLs. As shown in Figure 11, the frontside GEO satellite receives data directly from the LEO satellites, as well as from the backside GEO satellite. It then transmits a number of data streams to the earth stations.

One objective of this study was to develop a common design for the frontside and backside satellite roles. Since the functions of the two satellites differ, some of the equipment may not be used for both roles; however, a common design allows economies in terms of the number of spare satellites needed, and may be important for restoring service after partial failure in an orbiting spacecraft. Functions that must be performed by both the frontside and backside relay satellites include up-links and down-links to the LEO satellites. These are the Space/Space MW (microwave) link and the Space/Space Optical links shown on both figures. Functions that differ in the two spacecraft roles are those associated with the optical ISL and with the Space/Ground microwave links in the frontside satellite.

The table specifies maximum and minimum data rates for each return link channel, since each can vary over a wide range. Although the aggregate data rate for the 18 data streams can exceed the 2-Gbit/s capacity of the return optical ISL if all streams are at their maximum values, this would seldom occur in actual operation. During each LEO satellite orbit, communications alternate between the frontside and backside relay satellites. Therefore, only a portion of each of these links is active at any point in time. Three design considerations focus on a flexible multiplexer to maximize data collection, a design with redundancy to minimize the impact of component failure, and eventual implementation with space-qualified components capable of operation at gigabit-per-second rates. The number of building blocks used for each channel should be minimized.

These design considerations led to the following features in the return link design. First, each LEO data channel should be capable of transmission over either of the two optical ISLs. Second, as much flexibility in data rates as possible must be provided to accommodate changes in traffic demand over the
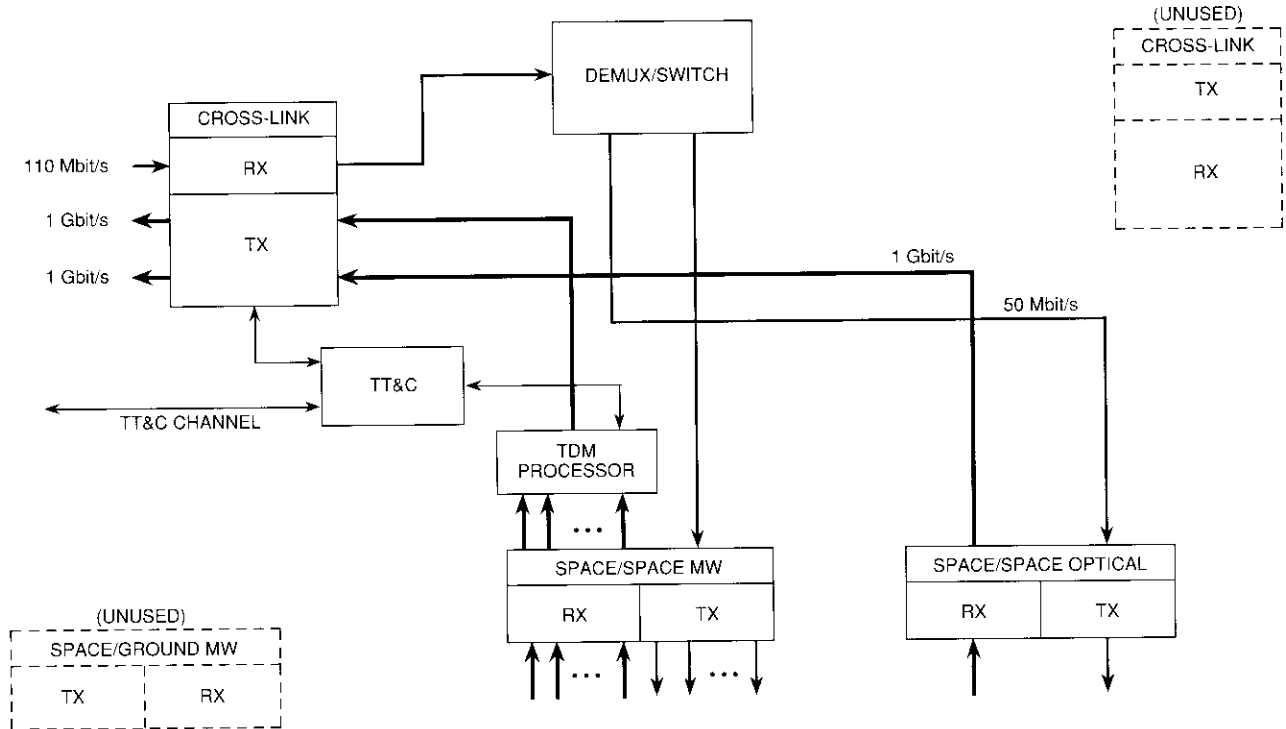
Figure 10. *Backside Operation*
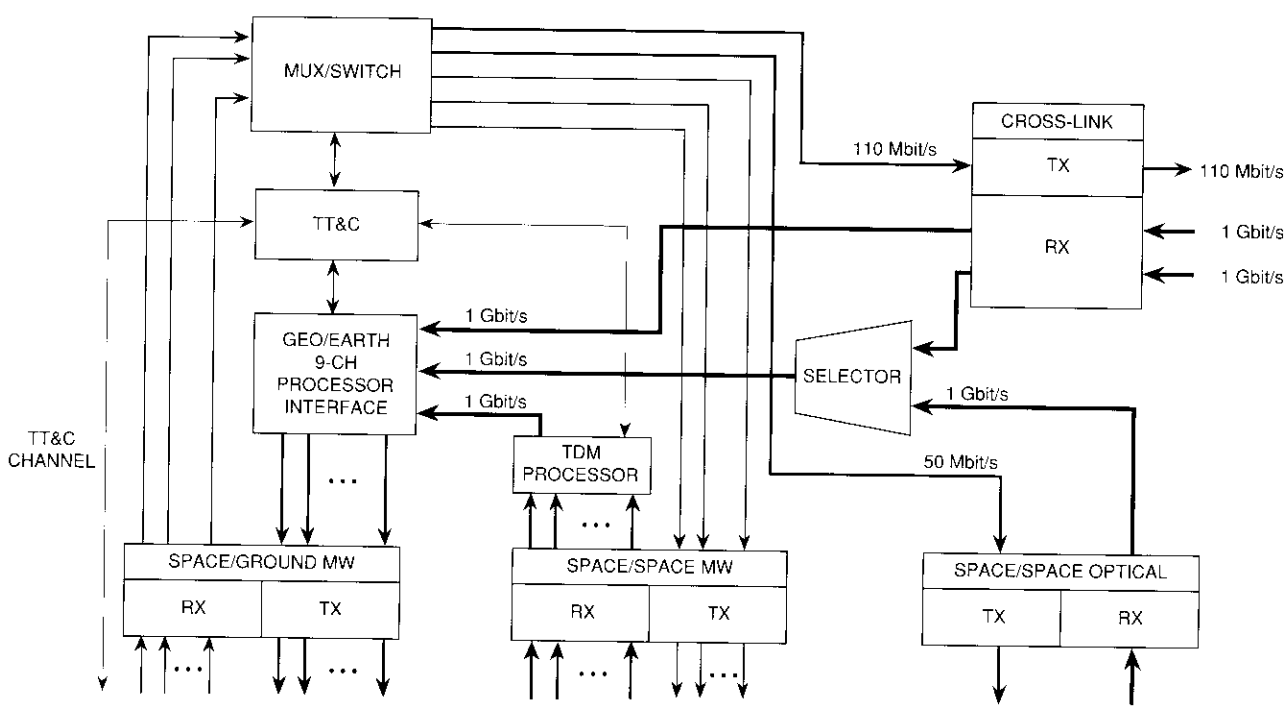
Figure 11. *Frontside Operation*

satellite's lifetime. Finally, the design should provide simple controls for on-orbit operation.

## Return link multiplexer design considerations

A return link multiplexer was designed which operates at 1 Gbit/s and also adapts to wide changes in the nominal rate for each channel without changing the topology of the data paths. The return link channels can be considered in three groups. First, most of the data are provided by six channels: the LSA channel operating at 1 Gbit/s, and the WSA and KSA channels operating at 300 Mbit/s each. Second, there are two channels with maximum operating rates of 12 Mbit/s. Third, there are 10 channels operating at 50 kbit/s, and the TT&C channel at 10 kbit/s. The approach was to design a multiplexer suitable for the maximum data rates for each channel, and then modify the clock signals to attain efficient operation at lower rates.

Suitable frame periods must first be determined for the first two groups. For the highest group, three 300-Mbit/s channels can be combined using a multiplexer similar to the one shown in Figure 6. Figure 5 shows the efficiency achieved when several streams of equal rate are combined, and suggests that the frame length should be at least 600 bits, with 1,000 bits being desirable. Three channels with a frame period, $T_F$, of 1 μs can be transmitted with an efficiency greater than 95 percent using an 8-bit control word. An alternative mode might combine five channels at 200 Mbit/s. A frame length of approximately 1,000 bits was selected as a reasonable choice for the primary multiplexer frame length. Therefore, the corresponding multiplexer primary frame period, $T_F$, is 1 μs. However, the 1-μs frame period will lead to very low efficiencies for the two 12-Mbit/s channels. A longer "superframe" is needed that is a multiple of the primary frame length. Superframes ranging from 10 to perhaps 30 frames in length provide efficiencies in the range of 85 to 95 percent for two channels, as shown in Figure 5.

The next decision involves the topology of the multiplexer design for the selected frame and superframe periods. One method often used to combine channels of widely differing rates is a hierarchical multiplexer structure. Lower-rate channels are first combined to form higher-rate channels, which are then combined with other high-rate channels. The high-rate frames repeat at a constant rate, and there are multiple frames in each superframe. If the data rates for each channel are constant, a hierarchical organization provides efficient data transmission and minimizes buffer size. One problem with a hierarchical multiplexer structure is the variation in tributary rates for this application. For example, the KSA and WSA channel rates can be as high as

300 Mbit/s or as low as 1 kbit/s. At the higher rates, the signal should be connected to a high-rate input, while at the lower rates it should be connected to a low-rate input. The need for alternative paths between high and low rates is a significant complication to the design of the multiplexer, and maintaining efficient operation over a range of rates becomes difficult.

An alternative to a hierarchical topology is to change the generation of clock signals to the ping-pong buffers. At high data rates, a ping-pong buffer is written and read during a frame period. At low rates, it is written and read during a superframe. Channels operating in the superframe mode are assigned one or more bits in each superframe. High-rate LEO channels operate in the frame mode at high data rates, and can be switched to the superframe mode at lower data rates. Moderate-rate LEO channels could operate in the superframe mode at all times, but the number of bits assigned in the primary frame is reduced as the data rate becomes lower. Burst slots in the TDM are dynamically assigned during orbital operation to accommodate the changing LEO missions. Figure 12 is a block diagram of this multiplexer. Each input labeled B is connected to a ping-pong buffer of the type shown in Figure 6.



NOTE: "B" DESIGNATES BUFFERED INPUTS
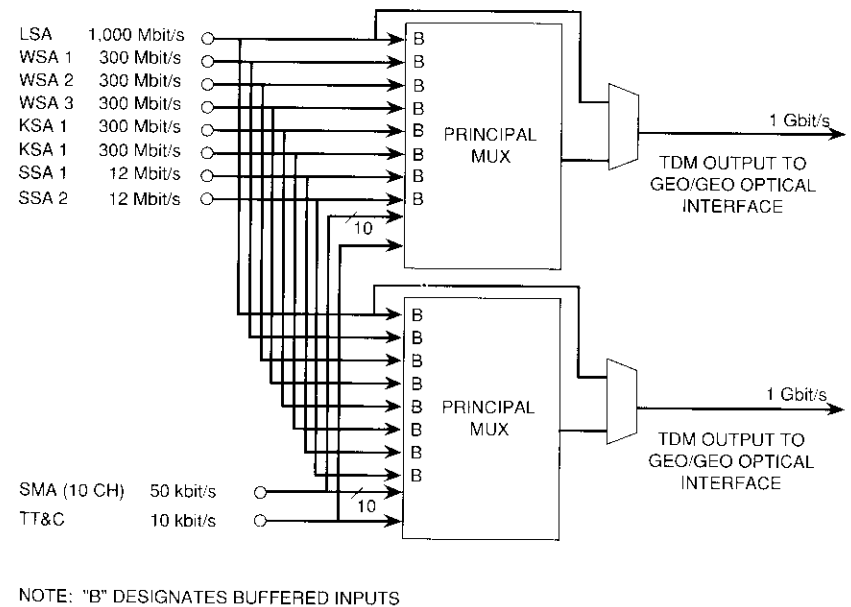
Figure 12. *Return Link Multiplexer*

The advantage of the above approach is that the design is modular and the circuit components are the same for all buffered channels. Only the control signals change. For each channel carried in a superframe, a codeword is sent once each superframe. A value of $D_i = 2$ is also used for justifying the bits carried in each superframe. The same control word is used to indicate the number of justification bits in the superframe burst.

Assuming that a superframe consists of $J_i$ TDM primary frames, a superframe channel will be assigned $k_i$ bits in each primary frame. The length of a superframe mode burst is simply $J_i \times k_i$. The number of bits required in the superframe, $N_s$, for these channels is

$$N_s = C + n_i = C + R_i J_i T_F + 1 \tag{17}$$

and the number of bits in each primary frame becomes

$$k_i = \left\lceil R_i T_F + \frac{1 + C}{J_i} \right\rceil \tag{18}$$

The remaining group of channels consists of the 10 SMA channels with maximum rates of 50 kHz, and the 10-kHz TT&C channel. These channels do not require much bandwidth, but represent a significant number of paths. If they are handled the same as the previous channels, then 11 additional buffers would be required and a third level of frame period would be needed. An alternative is to recognize that the superframe and frame rates are much higher than the bit rate from any of these channels; therefore, these channels can be transmitted by simply sampling the bit stream and sending 1 bit per sample. Although this is very inefficient in terms of transmission, the circuitry required in the multiplexer becomes trivial.

The above design now meets all of the design objectives. Efficient transmission of data at high rates has been achieved; the design is flexible and can be programmed after launch or in orbit; the design can be implemented using a few building blocks that are simply replicated for each channel; and redundant data paths have been provided in the optical ISL. The next section describes some on-orbit applications for this multiplexer design.

**Return link multiplexer operation**

Referring to the block diagram of Figure 12, it can be seen that two symmetric multiplexers are connected to the two ISLs. Each multiplexer can be programmed independently of the other. A 1-µs principal TDM frame

length is used for these examples. Since a very large number of rate combinations is possible, the examples of TDM frame time plans will be limited to the following:

- An LSA channel directly connected to an ISL channel.
- An LSA channel connected to an ISL channel using bit justification.
- Three WSA channels, two SSA channels, and the remaining low-rate channels.
- Two KSA channels and the remaining low-rate channels.
- Four WSA and KSA channels at reduced rates, plus all other low-rate channels.

Figure 13 shows frame structures for each of the above examples. The first is for a directly connected LSA channel operating at 1-Gbit/s. It simply comprises 1,000 bits of the LSA stream, where the bit rate is driven by the arrival rate on the LEO/GEO up-link, with no attempt to eliminate the Doppler effect. In this case, there is no need for either a frame synchronization burst or a codeword.

The second example is for the LSA connected to the 1-Gbit/s ISL channel. To carry precisely 1 Gbit/s, the actual link rate must exceed 1 Gbit/s by a small amount in order to accommodate the synchronization word and the codeword needed to control the demultiplexing clock. Thus, the frame must contain 1,022 bits and operate at 1,022 Gbit/s. Note that 1 bit in the frame is assigned to TT&C. This provides 1 Mbit/s, which exceeds the actual TT&C rate of 10 kbit/s by 100 times. Although this represents a minute inefficiency (0.1 percent), it is extremely simple to implement and provides an opportunity for higher rates and redundancy encoding.

Figures 13c and 13d show other frame configurations for carrying various mixes of 300-Mbit/s WSA and KSA, 12-Mbit/s SSA, and 50-kbit/s SMA channels. Each 300-Mbit/s WSA or KSA channel is bit-justified, using 301 data bits per channel plus an 8-bit codeword. Each 12-Mbit/s SSA is bit-justified using 13 data bits plus an 8-bit codeword, which represents a channel usage efficiency of 57 percent. Figure 13e shows four WSA or KSA channels operating at 230 Mbit/s, as well as all lower-rate channels.

The SMA channels are treated differently because of their relatively lower rate (50 kbit/s). Each SMA channel is assigned 1 bit in the frame, thus oversampling the channel by 20 times. Each of these channels can be sent using a self-clocking code such as RZ (return to zero), NRZ (nonreturn to zero), or biphase [5]. Doppler compensation can easily be accomplished by a Doppler buffer having a range of ±20 ms, which is sufficient to accommodate
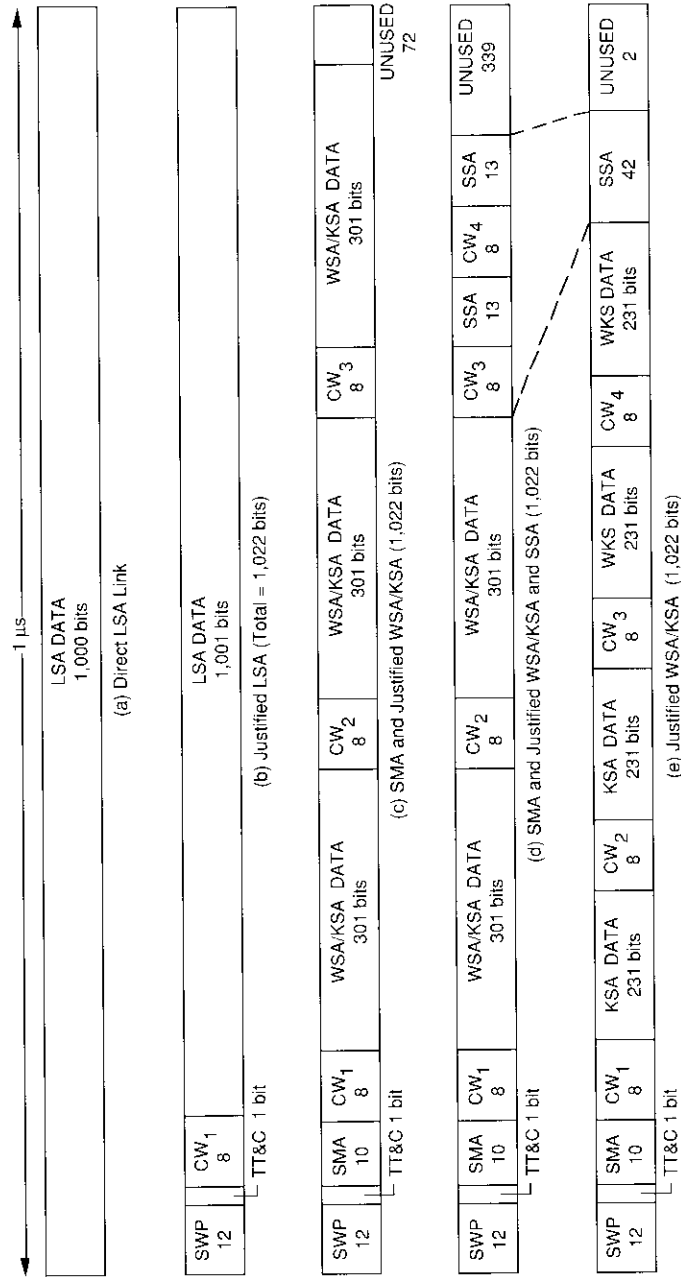
Figure 13. *Return Link Multiplex Frame Structure*

changes in the GEO/LEO range and can be implemented with a maximum memory size of 4 kbit/s.

The channel efficiency for the SSA channels (12 Mbit/s) can be improved by operation in a superframe. From equation (15), it is seen that for a codeword of size $C$, the superframe should have a length $J_i = C + 1$. A superframe length $J_i = 9$ allows 1 bit for the codeword plus the justification bit in each primary frame. This is a superframe period of 9 μs. For these values, equation (15) yields a $k_i$ value of 13 bits per primary frame to carry the entire SSA channel. This corresponds to a superframe length of $n_i = 217$ to carry 108 SSA channel bits, and hence improves the channel usage efficiency to 92 percent. The frame time plan for this case is shown in Table 2.

TABLE 2. EXAMPLE OF RETURN LINK MULTIPLEXER BURST ASSIGNMENT

| TDM CHANNEL | $k_i$ | $J_i$ | $R_i$ (Mbit/s) |
|---|---|---|---|
| Synchronization Word | 12 | 1 | |
| TT&C | 1 | 1 | 0.01 |
| WSA/KSA Ch 1 | 317 | 1 | 300 |
| WSA/KSA Ch 2 | 317 | 1 | 300 |
| WSA/KSA Ch 3 | 317 | 1 | 300 |
| SSA Ch 1 | 13 | 9 | 12 |
| SSA Ch 2 | 13 | 9 | 12 |
| Reserved for SMA Channels | 10 | – | 0.5 |
| Total | 1,000 | | 924.51 |

$k_i$ = number of bits from a superframe mode buffer transmitted in each frame.
$J_i$ = number of frames in a superframe.
$R_i$ = channel data rate.

**Return link demultiplexer**

The frontside relay satellite receives data from LEO satellites that are in a position to communicate with it, as well as multiplexed LEO data from the backside relay satellite. This unit, called the GEO/Earth Nine-Channel Processor in Figure 11, accepts data streams that may be received at either of the two relay satellites and provides nine output streams for transmission to the White Sands earth station. Each of the nine GEO/Earth streams is defined to have a 200-Mbit/s capacity. Therefore, the GEO/Earth processor must demultiplex signals from the optical ISL and then select the active stream, if any, from each

of the 18 data channels. If the data for a channel are being received from the backside relay satellite, they must be taken from the optical ISL. If the data are being received by the frontside satellite, they are taken from the appropriate LEO satellite receiver.

The number of active channels, the data rates for each channel, and the relay satellite receiving the data vary according to the orbits and mission programming of each LEO satellite. However, these factors are known at any moment in time and can be used to efficiently and dynamically program the GEO/Earth processor. Each input stream can be described by a form of burst time plan that changes according to a set of prescribed plans. The GEO/Earth processor can be programmed to select data from the correct relay satellite, to operate at the data rate currently in use, and to select of one of the GEO/Earth channels.

The 18 streams are processed for transmission to an earth station. Data streams with rates higher than 200 Mbit/s must be separated into two or more streams for transmission to the earth, while channels with lower data rates may be combined with other streams. The 12 low-rate streams can always be combined into a single stream. Both TT&C (telemetry) channels are sent to the earth station, and may be sent over more than one link to ensure reliable transmission of this important data. The GEO/Earth processor must combine 20 channels to form nine separate streams for transmission to the earth station.

Two different approaches to the design of the GEO/Earth processor have been considered. One is to demultiplex the streams received from the backside relay satellite, rate-buffer the data to remove the effects of LEO/GEO Doppler variation and restore the original transmission rate, separate the higher-rate streams, and combine these with the lower-rate streams. In the second approach, the blocks formed for multiplexing signals for the ISL are retained and the rate-smoothing buffers are implemented at the earth station.

In the first approach, two demultiplexers operate on the composite signals from the 1-Gbit/s ISLs, as shown in Figure 14. Since each link can handle a number of different signals, the rate buffers can receive signals from either of the two return ISLs. The smoothing buffers shown here are detailed in Figure 8. Seven rate buffers are needed for the WSA, KSA, and SSA channels. The 10 SMA channels and the TT&C channels are recovered by simply clocking the corresponding bits at the primary multiplex frame rate. Each smoothing buffer is connected to both ISL buffers. An input selector switch (not shown in Figure 8) connects the smoothing buffer to the link containing the data.

Each smoothing buffer consists of a ping-pong buffer and a clock regeneration circuit, operating in the manner described previously. As was determined for typical LEO orbiters, $d_{im} = 2.5 \times 10^{-5}$. To recover from a 1-bit correction in

Figure 14. Return Link Demultiplexer

the minimum time between corrections, the recovered clock rate for channel $i$ must run high at a rate $R_i(1 + 2.5 \times 10^{-5})$ or low at $R_i(1 - 2.5 \times 10^{-5})$ every time a high or low rate correction is signaled by the control word associated with the channel. Otherwise, the rate is $R_i$, which is the rate recovered from the received digital stream. The correction rate will last for an interval sufficient to contain $d_{im}^{-1}$ bits.
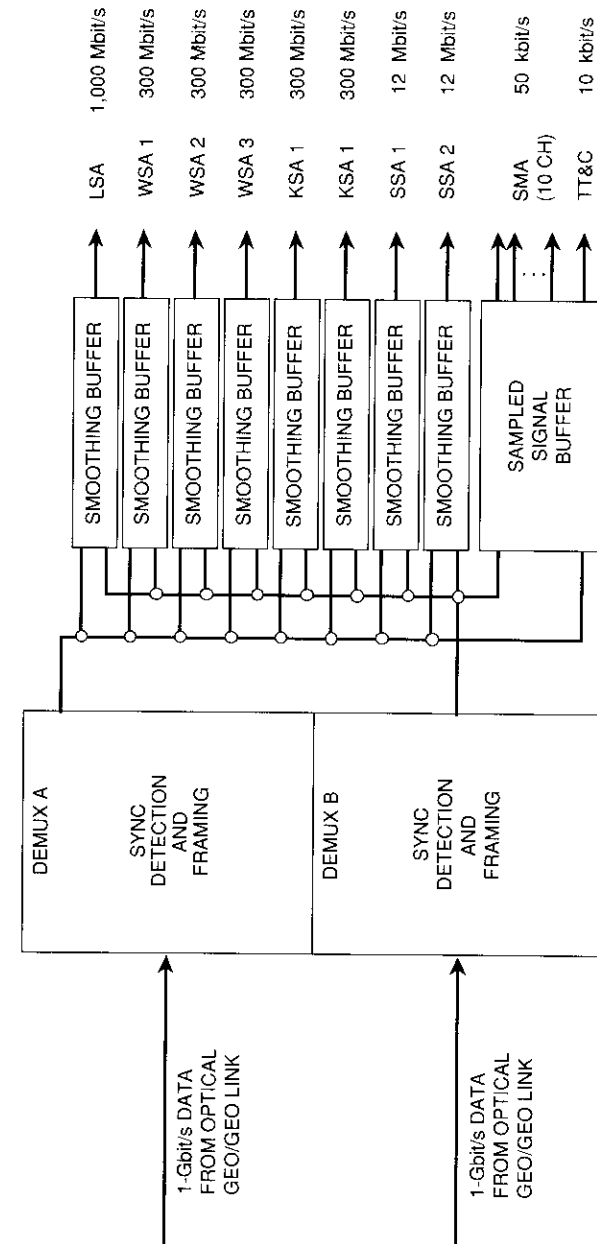
Each smoothing buffer must operate over the range of clock speeds given in the table in Figure 2. The demultiplexer's framing section is programmed to match the time-division plan used by the return link multiplexer. The outputs of the smoothing buffers must then be processed to form nine channels, each with rates under 200 Mbit/s. Two of the 300-Mbit/s channels can be separated into three 200-Mbit/s channels for transmission to the earth station. Similarly, a 1,000-Mbit/s data channel is separated into five 200-Mbit/s streams. These are the approaches required at the maximum rates for the six channels with the highest rates. Since these channels have a minimum rate of only 1 kbit/s, it is also possible that two or more of these signals could be multiplexed and sent in a single GEO/Earth link, instead of being separated into two or more GEO/Earth links. The remaining signals total less than 25 Mbit/s, even if all are at the maximum rates. These can be multiplexed into a single stream, with care being taken to accommodate the rate variation that may occur. The processing required is similar to that needed for the ISL. Since each of the 18 data streams has rate variations due to the GEO/LEO orbits, buffering is needed when signals are being combined.

The second approach to the design of the GEO/Earth nine-channel processor retains the blocks of data formed in the backside satellite. Two factors make this desirable. First, while the processing has removed most of the data stream variations due to Doppler effect, the smoothing buffers shown in Figure 8 tend to restore these variations. If the GEO/Earth links operate at the same rate as the data channels, this is of little concern. When two of the high-rate channels are separated and then combined into three GEO/Earth channels, the effects of Doppler variation in the data rates must again be considered. The second factor is the principle of minimizing the processing of data in a satellite. This is served by retaining the data blocks once they have been formed, and transferring functions to the earth station where possible.

To separate the high-rate data channels, it is necessary to form blocks of data in buffers. These blocks are then used to change the transmission rate to match the GEO/Earth channel rate of 200 Mbit/s. Since buffering of the signal in the backside satellite compensates for rate variations due to Doppler effect, it can also be used to simplify timing in the GEO/Earth processor. The data blocks (a codeword followed by a block of data) form the basis for a simple data

packet, needing only the addition of a sequence number to ensure that the streams can be properly reformed at the earth station.

If the frontside and backside satellites are identical in design, then one approach is to process incoming LEO data in the frontside satellite in the same manner as data are processed in the backside satellite. The burst time plans for the 1-Gbit/s streams in the frontside satellite can be identical to those used in the backside satellite. This reduces the effect of Doppler variations in the data rates for signals received directly by the frontside satellite from LEO satellites. In addition, the frontside satellite TDM processor shown in Figure 11 can be phase-locked to the signal received via the ISL from the backside satellite TDM processor shown in Figure 10. Corresponding streams from the frontside and backside relay satellites can then be presented to the GEO/Earth processor. Blocks of data are then selected from the appropriate stream according to a predetermined plan. Figure 15 is a block diagram of this approach.

The set of nine TDM streams is then formed from the 1-Gbit/s streams from the frontside and backside TDM processors. The functions required to implement these new streams can be identical to those shown in Figure 6 and used in the TDM processors. The primary additions are circuits to select blocks of data from the appropriate stream, and storage for the burst time plans for the input and output streams. The smoothing buffers shown in Figure 8 can be moved to the earth station if necessary. In some cases, signals received from the frontside relay satellite may be recorded for later processing, and could be recorded with the inserted codewords intact. The codewords could easily be removed during the processing steps, and the smoothing buffers would not be needed since the signal is not displayed in real time.

The optimum benefit of the second approach is attained if the frontside and backside satellites share a common design. In this case, the TDM multiplexer is available for LEO satellite channels received directly at the frontside satellite. In addition, the GEO/Earth TDM streams can be formed using the same types of circuits used for other functions. This approach becomes less attractive when the two relay satellites do not have a common design, or when the GEO/Earth channels have the same bandwidth as the LEO/GEO channels.

The first approach is desirable when the GEO/Earth channel bandwidths match the LEO channel bit rates, when a number of earth stations receive and process the data from a channel, and when a simple earth station design is desired. The second approach becomes desirable when the GEO/Earth channel bandwidths are different than the LEO channel bit rates, or when the spacecraft design should be as simple as possible. The smoothing buffers are relatively complex due to the wide range of operating rates that could be required, and should preferably be located at an earth station.
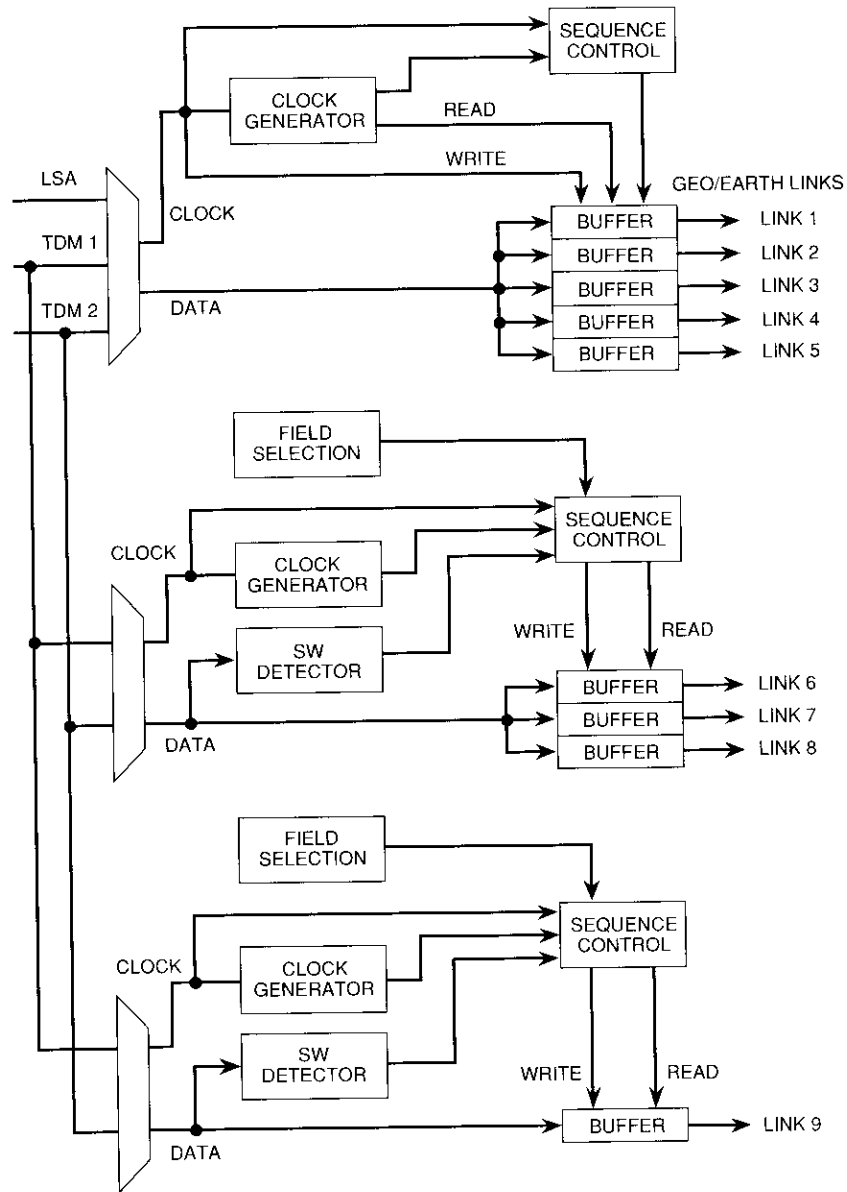
Figure 15. *GEO/Earth Nine-Channel Processor (220-Mbit/s links)*

## Forward link design

The forward link must accommodate a number of low-bit-rate carriers of various data rates arriving on up-links from the nine earth station locations. The table in Figure 2 lists the forward channels used for the TDAS program, totalling 103.63 Mbit/s. The carriers will have differing values of Doppler variation caused by orbital motion relative to the earth terminals.

Figure 11 showed some of the signal paths for forward link operations. Signals from the ground stations, received by the frontside satellite, are sent to the forward path switch/multiplexer. The 50-Mbit/s LSA link and the two 25-Mbit/s KSA links dominate the design.

The switch/multiplexer unit connects the nine earth-to-GEO up-link receivers, the 10 GEO/LEO links, and the forward link GEO/GEO optical ISL. Signals to be sent to LEO satellites in view of the frontside relay satellite are sent directly, without the need for multiplexing. Signals for LEO satellites in the view of the backside relay satellite are routed to an on-board forward link multiplexer, where they are combined onto a single TDM channel at a higher composite bit rate and transmitted to the backside satellite over an optical ISL. On-board the backside satellite, the composite TDM channel is demultiplexed to the original channel rates, and selected channels are sent to the LEO satellites in the view of the backside satellite.

Provision must be made on-board both relay satellites to serve either the frontside or backside role by switching the GEO/LEO down-links to either the output of the up-link interface for frontside operation, or to the optical link demultiplexer for backside operation. Also, to accommodate frontside operation, it is necessary to include a switch to connect the output of the up-link interface either directly to the GEO/LEO down-links for serving LEO satellites in the view of the frontside relay satellite, or to the input of the optical link multiplexer for serving LEO satellites in the view of the backside TDAS.

### Forward link multiplexer

The forward link multiplexer must combine earth-to-GEO up-link channels of differing bit rates, origins, and Doppler rates onto a common TDM channel for transmission over the frontside-to-backside ISL. A suitable multiplexer design is shown in Figure 16. This multiplexer employs a hierarchical organization. All of the up-link channels expected to be carried on the forward link are identified in the figure. The highest bit rate channels (one LSA at 50 Mbit/s and two KSA at 25 Mbit/s) determine the principal multiplexer frame period. Other channels operate in the superframe mode or in the sampling mode.
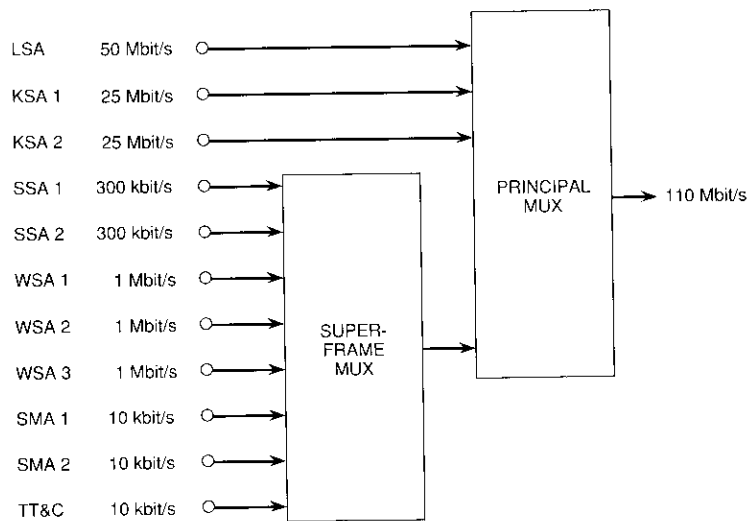
Figure 16. *Forward Link Multiplexer*

The principal multiplex frame plan is described in Table 3 and shown in Figure 16. It is assembled using the multiplexer design shown in Figure 8. The primary TDM frame is 10 μs and has a superframe length of 18 primary frames. Each primary frame contains 1,107 bits and has a length of 10 μs. The structure shown in Figure 16 accommodates one 50-Mbit/s channel using 517 bits ($n_i = 501$), and two 25-Mbit/s channels, each using 267 bits ($n_i = 251$). Each WSA channel uses 197 bits ($n_i = 181$) in the superframe mode, and each SSA channel uses 71 bits ($n_i = 55$) in the superframe mode. The TT&C and SMA channels are each assigned 1 bit in the primary frame and operate in the sampled signal mode. A synchronization word uses 12 bits. The length of the primary TDM frame is 1,107 bits and requires a 110.7-Mbit/s ISL. The efficiency of the link with all signals at the maximum rate is 94 percent.

This forward link design employs the same basic building blocks used by the return link. Flexibility is provided by using the same design for 8 of the 11 channels, which can operate over a wide variety of rates without changes to the basic structure. The three low-rate channels (the TT&C channel and the SMA channels) operate in the sampled signal mode. Although this represents a 10:1 oversampling at the maximum rate, these three channels contribute only 3 bits to the TDM frame. The advantages are that no adjustments to the multiplexer design on the relay satellites are needed for bit rate variations from maximum down to minimum, and the ping-pong buffers are eliminated. A processor will be needed at the ground to recover the signal from the set of samples.

TABLE 3. EXAMPLE OF RETURN LINK MULTIPLEXER BURST ASSIGNMENT

| TDM CHANNEL | $k_i$ | $J_i$ | $R_i$ (Mbit/s) |
|---|---|---|---|
| Synchronization Word | 12 | 1 | |
| TT&C | 1 | – | 0.01 |
| LSA Channel | 517 | 1 | 50 |
| KSA Ch 1 | 267 | 1 | 25 |
| KSA Ch 2 | 267 | 1 | 25 |
| WSA Ch 1 | 11 | 18 | 1 |
| WSA Ch 2 | 11 | 18 | 1 |
| WSA Ch 3 | 11 | 18 | 1 |
| SSA Ch 1 | 4 | 18 | 0.3 |
| SSA Ch 2 | 4 | 18 | 0.3 |
| SMA Ch 1 | 1 | – | 0.01 |
| SMA Ch 2 | 1 | – | 0.01 |
| Total | 1,107 | | 103.63 |

$k_i$ = number of bits from a superframe mode buffer transmitted in each frame.
$J_i$ = number of frames in a superframe.
$R_i$ = channel data rate.

**Forward link demultiplexer**

The demultiplexer for the forward link will operate on the composite channel rate of 110.7 Mbit/s. Each relay satellite will have the demultiplexer, but it will be used only when serving in the backside role. The demultiplexer design is shown in Figure 17. It must synchronize to the principal frame synchronization word every 10 μs and then distribute the TDM channels to expansion buffers, followed by retiming buffers operating in the manner described previously, in order to recover the original channel data streams.

The variations encountered on the earth-to-GEO up-link channels due to Doppler shift should be no worse than $\pm 10^{-8}$, and those due to originating clock variation no worse than $\pm 10^{-6}$; however, they could be less, depending on the clock specification. These values are much less than those encountered on the LEO/GEO links, which are $\pm 2.5 \times 10^{-5}$ due to much greater Doppler effect. In the design of the forward link demultiplexer, the clock variation will be assumed to be no worse than $\pm 10^{-6}$. To recover from addition or subtraction
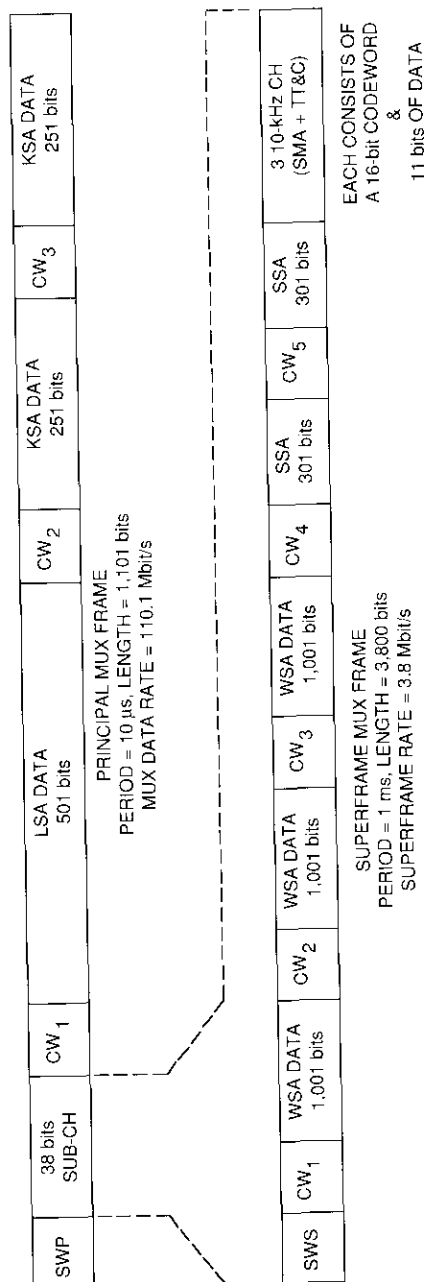
Figure 17. *Forward Link Multiplex Frame Structure*

of 1 bit in the minimum time between corrections, the retiming clock of the alignment buffer must run high, at a rate of $R_i(1 + 10^{-6})$, or low, at $R_i(1 - 10^{-6})$, respectively, and the rate will last for an interval sufficient for $10^{-6}$ bits to occur.

## Forward link switch

The forward link signals are received at the frontside relay satellite and transmitted to the backside relay satellite over a 110-Mbit/s optical link. Thus, both satellites have available the data to be sent to the LEO satellite. Since only one of the relay satellites should transmit this data, a frontside/backside switch is included in each satellite to control data routing. Each channel will have a different switching time for each LEO satellite. The switching can be activated by an on-board timer or by real-time command from the controlling earth station.

A "break before make" design is suggested. There should be no period when both relay satellites can forward data on the same channel. When control is to pass from the frontside to the backside relay satellite, the frontside switch will be disabled before the backside switch is enabled. The gap will include the time required for transmission between the frontside and backside satellites, as well as the time for operation of the switch. When control is to pass from the backside to the frontside relay satellite, the frontside satellite will forward the command to disable the backside switch, then wait an appropriate amount of time before enabling its corresponding switch. This switch should gate the demultiplexer output and switch components in the RF section. The interface to the RF components should be clock, data, and an enable signal.

## Conclusions

A design approach for the RF/optical link interface for a data relay satellite has been described. The two GEO data relay satellites are assumed to be connected by a pair of 1-Gbit/s optical links. This provides sufficient capacity to handle the number of TDAS return link data streams specified by NASA. Each GEO satellite has a number of links to LEO satellites. The frontside GEO role also includes links to nine earth stations.

The return link path may at times be from a LEO satellite to an earth station via the backside GEO satellite, and at other times via the frontside LEO satellite. A flexible multiplexer was described that can be programmed to support of a wide range of missions. The design includes techniques to deal with Doppler shifts caused by the varying high velocity of LEO satellites relative to GEO

satellites, and with local oscillator frequency variations. Design equations were provided which described the range of nominal and allowable variations in oscillator frequency. The forward link path is from an earth station to a LEO satellite through either the frontside GEO satellite, or through both the frontside and backside GEO satellites. For the forward link, provisions were included to ensure that signals from the earth station to the LEO spacecraft are relayed by only one of the spacecraft.

The design approach identified a number of circuit elements that can be implemented using LSI or VLSI techniques.

## Acknowledgments

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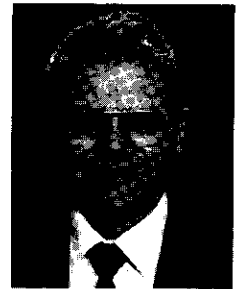
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# 140-Mbit/s COPSK modem laboratory tests and transatlantic field trials

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## Abstract

Results of laboratory and transatlantic field tests conducted using a 140-Mbit/s information rate, coded octal phase shift keying (COPSK) modem are presented. Laboratory testing included modem bit error rate (BER) performance as a function of receive IF level and frequency variations, as well as introduced IF linear slope, parabolic group delay, and linear amplitude distortion. These tests were performed in linear (back-to-back) and nonlinear (satellite simulator) channel environments. Under nominal conditions, the 140-Mbit/s COPSK system provided a BER of 1 x $10^{-6}$ at a lower $E_b/N_o$ than would be required of an uncoded 120-Mbit/s quadrature phase shift keying (QPSK) modem. Laboratory test results also showed that this system is more sensitive to channel distortion than uncoded 120-Mbit/s QPSK; however, performance is dramatically improved by using a transversal equalizer.

Field tests were conducted between INTELSAT Standard-A earth stations in France, the United States, and the United Kingdom, using zone beam transponders on an INTELSAT V-A satellite at 332.5°E longitude. The approach to conditioning the earth station and establishing the optimum operating points of its high-power amplifiers and satellite transponders is described, and the results of the conditioning are presented. The BER measurements are compared with the expected performance, and the results demonstrate performance consistent with current CCIR recommendations. These tests have particular historical significance, since they comprise the first transoceanic digital transmission at 140-Mbit/s information rate via any medium.

## Introduction

This paper presents results from laboratory and field testing of the 140-Mbit/s coded octal phase shift keying (COPSK) system (Figure 1) developed by COMSAT Laboratories to accommodate single-transponder global trunking, satellite restoration of transoceanic fiber optic cables, and other high-data-rate applications. Two units of the COPSK system have been built: one for the Intelsat Satellite Services (ISS) division of COMSAT, and the other for INTELSAT. Laboratory tests discussed include linear channel performance (back-to-back) as a function of IF input level and frequency offset. Further tests held the IF input level and frequency offset constant, while introducing added linear and parabolic delay and linear amplitude distortion. Dur-
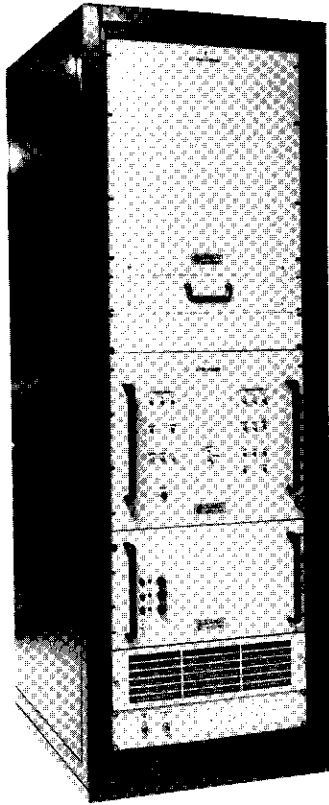


Figure 1. *COPSK System*

ing the portion of the laboratory tests involving added distortion, the effect of an IF transversal equalizer on improving performance was demonstrated. Also presented are nonlinear channel laboratory measurements made in conjunction with the INTELSAT V satellite simulator. Field test results demonstrate the performance of both units operated in back-to-back, earth station and satellite loopback, and satellite cross-connect configurations.

(COMSAT Laboratories has previously published the results of research activity in the area of bandwidth- and power-efficient coded modulation systems, in particular those utilizing COPSK. References 1 and 2 present information on the background and theory of this general class of system.)

Satellite testing of the COPSK unit was performed in a two-phase transatlantic field trial. These tests were carried out in cooperation with American Telephone and Telegraph (AT&T), British Telecom International (BTI), France Telecom (DTRE), and INTELSAT, and have historical significance in that they represent the first transatlantic transmission of data at a 140-Mbit/s information rate over any medium, including fiber optic cable. For each phase, similar test plans were followed which included earth station equalization, high-power amplifier (HPA) and satellite traveling wave tube amplifier (TWTA) calibration, earth station and satellite loopback bit error rate (BER) measurement, and one- and two-way (simultaneous) transatlantic BER measurements. Measurements were also made of the spectral spreading of the COPSK signal and the resulting out-of-band emissions (OBEs), and of BER with co-channel interference (CCI).

The COPSK system achieved a BER of better than $1 \times 10^{-7}$ through a 72-MHz transponder, with an energy-per-bit to noise-power density ratio $(E_b/N_o)$ comparable to or lower than that required for uncoded 120-Mbit/s quadrature phase shift keying (QPSK) [3]. A comparison with 120-Mbit/s QPSK is particularly appropriate for a number of reasons. Both systems use identical data-shaping filters [4], and consequently have identical spectral occupancy. Both systems were designed specifically for use in 72-MHz transponders with 80-MHz spacings and are subject to the same types of adjacent channel interference (ACI) and CCI. Also, because the INTELSAT procedures and specifications for link equalization of 120-Mbit/s QPSK [5] were followed in equalizing the links used during the COPSK tests, the link characteristics should be the same for either type of signal, and thus a valid comparison is possible.

Additional satellite tests of the COPSK system have been conducted [6] as part of digital high-definition television (HDTV) transmission experiments between the U.S. and Japan. During these tests, the BER performance of the COPSK system over a link employing small-aperture earth stations was demonstrated, as was its suitability for use in digital HDTV transmission.

## Laboratory testing

Laboratory tests of the two COPSK units were conducted to verify the functionality of each unit and to characterize the performance of the hardware. This testing was undertaken in two stages, with each stage including both linear channel (back-to-back) and nonlinear channel (satellite simulator) tests. In the first stage, system performance was measured *vs* variations in receive IF amplitude and frequency offset. In the second stage, nominal receive IF signal conditions were maintained, while linear slope and parabolic group delay distortions and linear slope amplitude distortions were introduced into the channel. A transversal equalizer was used during the second stage to determine its effect on performance in the distorted channel. The data and discussions which follow on laboratory measurements apply to the ISS unit; however, similar testing was done on the INTELSAT unit, with similar results.

## Measurements vs receive IF variations

Figure 2 shows the laboratory test setup for the COPSK unit. Linear channel testing, for the first stage of laboratory tests, was accomplished using the path indicated by the dashed line. BER was measured under combinations of receive IF amplitude and frequency offset extremes, with the amplitude varying from its nominal value to +2 and -10 dB, and the input frequency offset varying from zero to ±25 kHz (the allowable ranges specified for the COPSK unit, corresponding to the INTELSAT requirements in Reference 4). Since the modem is constrained to lock up in two (of eight possible) ambiguity states, the BER was measured in both of these states and then averaged, with the averaged data being presented. Figure 3a shows COPSK performance with no frequency offset over maximum input level variations. The worst-case performance occurs at an input level offset of -10 dB. Figure 3b depicts the effect of frequency offset at this worst-case level.

These measurements demonstrate that the COPSK system is capable of providing a BER of $1 \times 10^{-6}$ at an $E_b/N_o$ of 10.5 dB under nominal conditions of input level and frequency offset in a back-to-back configuration. This compares favorably with uncoded QPSK, which requires approximately 11.5 dB [3] to achieve the same error rate performance under the same operating conditions but is transmitting only 120 Mbit/s, as compared to the 140-Mbit/s COPSK rate.

Nonlinear channel testing of the system was performed next, using the laboratory setup shown in Figure 2, but this time employing the INTELSAT V satellite simulator. A 72-MHz Ku-band transponder was used. Data were taken for combinations of receive IF level and frequency offset extremes (as in
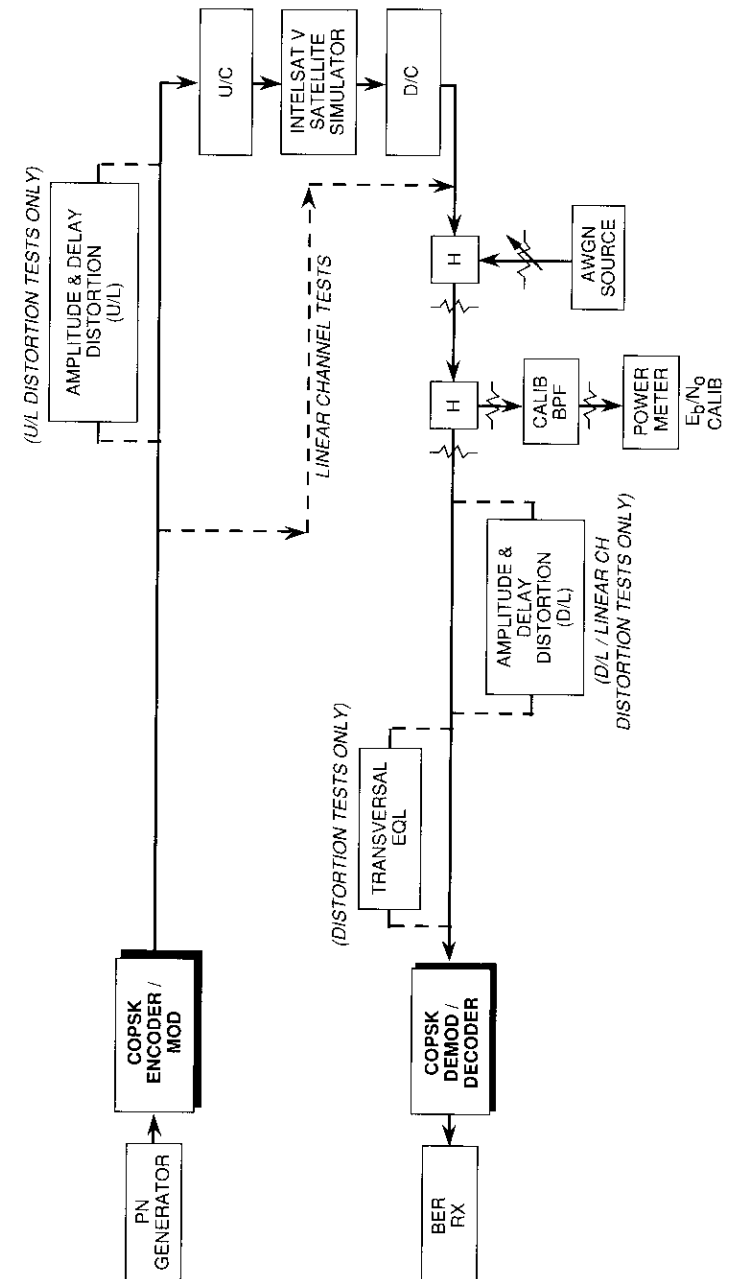
Figure 2. Laboratory Test Setup
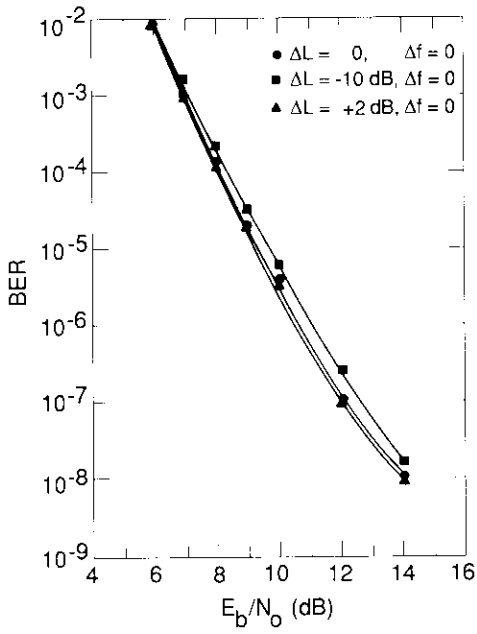
(a) With Input-Level Variation
(no frequency offset)
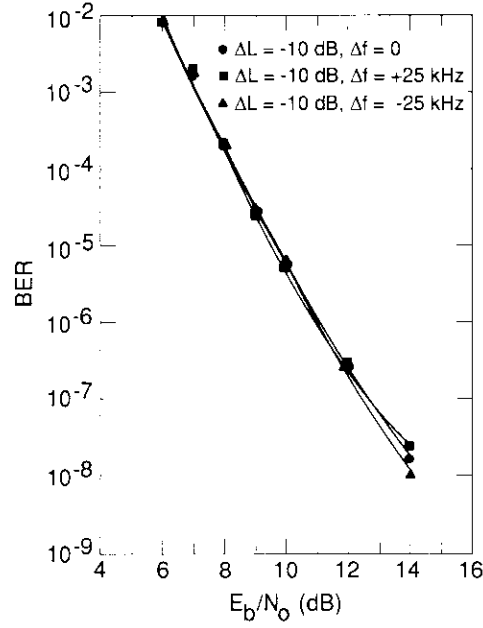
(b) With Frequency-Offset Variation
at Minimum Input Level

Figure 3. *Linear Channel BER Performance Parametric in Receive IF Signal Variations*
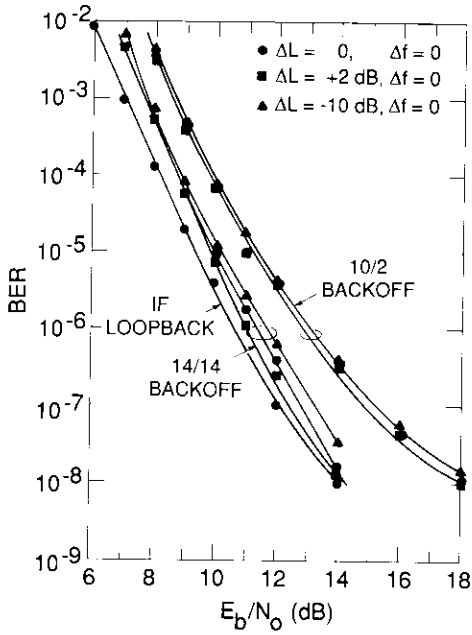


(a) With Input-Level Variation
(no frequency offset)
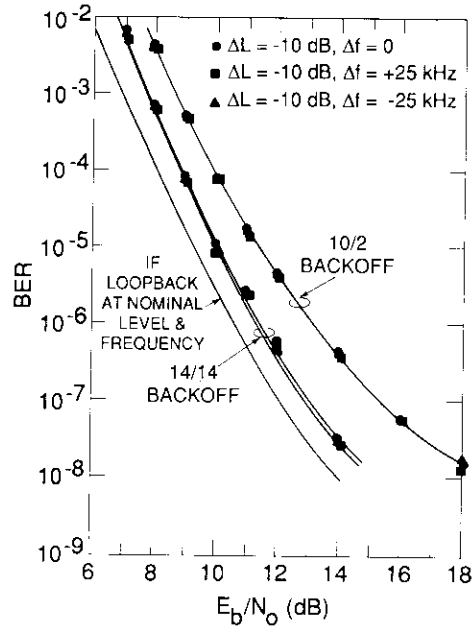
(b) With Frequency-Offset Variation
at Minimum Input Level

Figure 4. *Nonlinear Channel BER Performance Parametric in Receive IF Signal Variations
and Transponder IBOs*

the linear channel case), and for two values of HPA/TWTA input backoff (IBO) (14/14 and 10/2), in each case with the results from the two (allowed) ambiguity states being averaged. The two backoff combinations were selected to approximate a linear channel (14/14) for the purpose of test setup verification, and in the case of 10/2, to approximate the typical operating conditions of an actual satellite channel.

Figure 4a shows the COPSK performance with no frequency offset over maximum input level variations for the cases of IF loopback (*i.e.*, linear channel), 14/14 backoff, and 10/2 backoff. The performance in the 14/14 case is degraded by approximately 1 dB at a BER of 1 x $10^{-6}$ with respect to the IF loopback case (on the average), despite the fact that the TWTA and HPA are being operated in the linear region. This is due to the amplitude and group delay characteristics of the satellite simulator which, while they meet INTELSAT specifications, are more restrictive (*i.e.*, band-limiting) than those of the linear channel setup, and hence introduce a small amount of intersymbol interference. With the backoff set at 10/2, the effect of nonlinear operation of the TWTA becomes apparent, degrading the performance at 1 x $10^{-6}$ by an additional 1.5 to 2 dB. Figure 4b illustrates the effect of frequency offset at the worst-case input level of -10 dB from nominal for the 14/14- and 10/2-dB backoff cases.

These nonlinear channel results demonstrate that the COPSK system is capable of providing a BER of 1 x $10^{-6}$ at an $E_b/N_o$ of 13 dB under nominal operating conditions with the simulator configured for 10/2-dB HPA/TWTA IBO. As in the linear channel case, this performance compares favorably with uncoded 120-Mbit/s QPSK, which requires approximately 13.5 dB [7] to achieve the same error rate.

## Measurements vs introduced IF distortion

Performance of the COPSK system was characterized with IF group delay and amplitude distortions present, for both linear and nonlinear channels, under nominal receive IF level and frequency conditions. During these measurements, a three-tap transversal equalizer was placed in the channel and adjusted to cancel out as much of the introduced distortion as possible. This effort was motivated primarily by the improvement obtained through similar efforts with 120-Mbit/s QPSK operation [8].

The distortion types used for these measurements are listed in Table 1, with only one type of distortion being placed into the channel at a time. The procedure followed for each measurement was to add the distortion, measure the BER performance with no transversal equalizer, then measure the performance again after adjusting the transversal equalizer for best BER.

TABLE 1. DISTORTION TYPES USED IN LABORATORY TESTING OF COPSK SYSTEM

| DISTORTION | VALUE* |
|---|---|
| Linear Group Delay | (2, 4, 6) ns Positive Slope |
| | (4, 8, 10, 12) ns Negative Slope |
| Parabolic Group Delay | (5, 9) ns Concave Up |
| | (4, 8, 12, 14) ns Concave Down |
| Linear Amplitude | (2, 4, 6) dB Positive Slope |
| | (2, 4, 6) dB Negative Slope |

* Over a ±36-MHz frequency span.

Refer again to Figure 2 for a block diagram of the test setup used for linear channel distortion measurements. The measurement results for the linear channel case are summarized in Figure 5. In each graph, the upper and lower curves represent system performance without and with the transversal equalizer, respectively. It appears that the unequalized response of the system to linear group delay slope is not symmetrical about the 0-ns point, but is instead symmetrical about approximately -2 ns. This skewing of the response is the result of a +2-ns delay slope inherent in the equalizer used for these measurements. Symmetry is observed about the -2-ns point on the curve, since this amount of introduced distortion cancels out the residual distortion of the equalizer.

Compared to similar data obtained with 120-Mbit/s QPSK [8], and taking the residual skew of the equalizer into account, the COPSK system appears (on the average) to be about twice as sensitive (*i.e.*, experiences twice as much degradation, in dB, at a BER of 1 x $10^{-7}$) to all three types of distortion tested, with no transversal equalizer present. However, in spite of this increased sensitivity, the transversal equalizer is able to bring the system performance to within approximately 0.5 dB of that achieved with no added distortion, which represents a greater improvement than that experienced with QPSK.

For the nonlinear channel, two different cases were considered, namely introduced up-link and down-link distortion. In each case, the TWTA in the simulator was operated at 2-dB IBO, which approximates the operating point used in an actual link. Refer again to Figure 2 for a block diagram of the nonlinear channel test setup. The results of the down-link distortion tests are shown in Figure 6. The test results for this case, for all distortion types, were similar to those obtained in the linear channel case. The skew in the linear group delay slope distortion case previously discussed is again apparent.
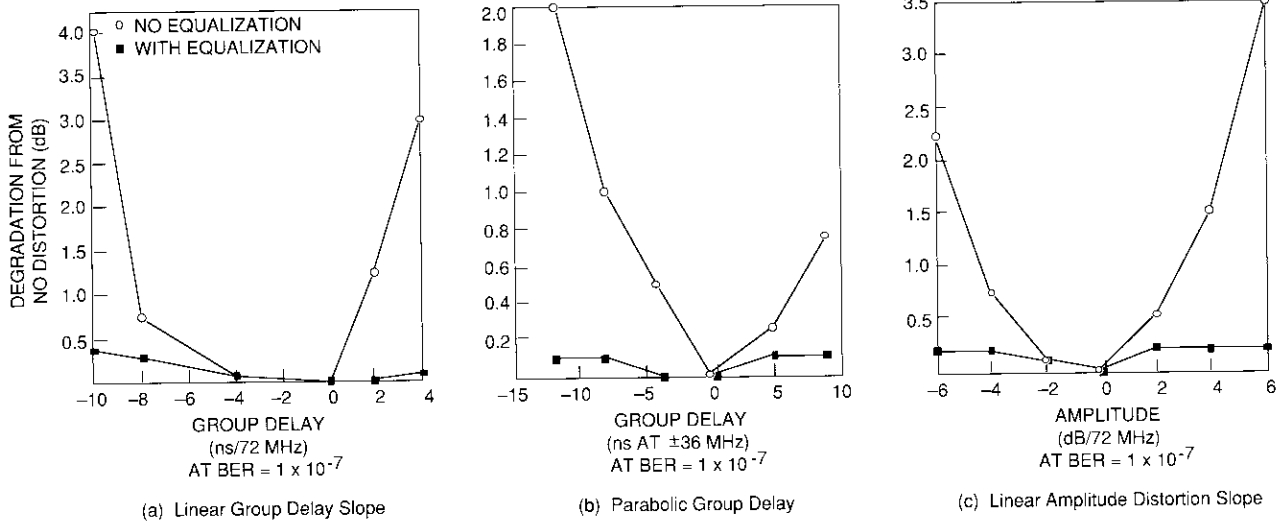
Figure 5. *Linear Channel Performance Degradation vs Group Delay and Amplitude Distortion*
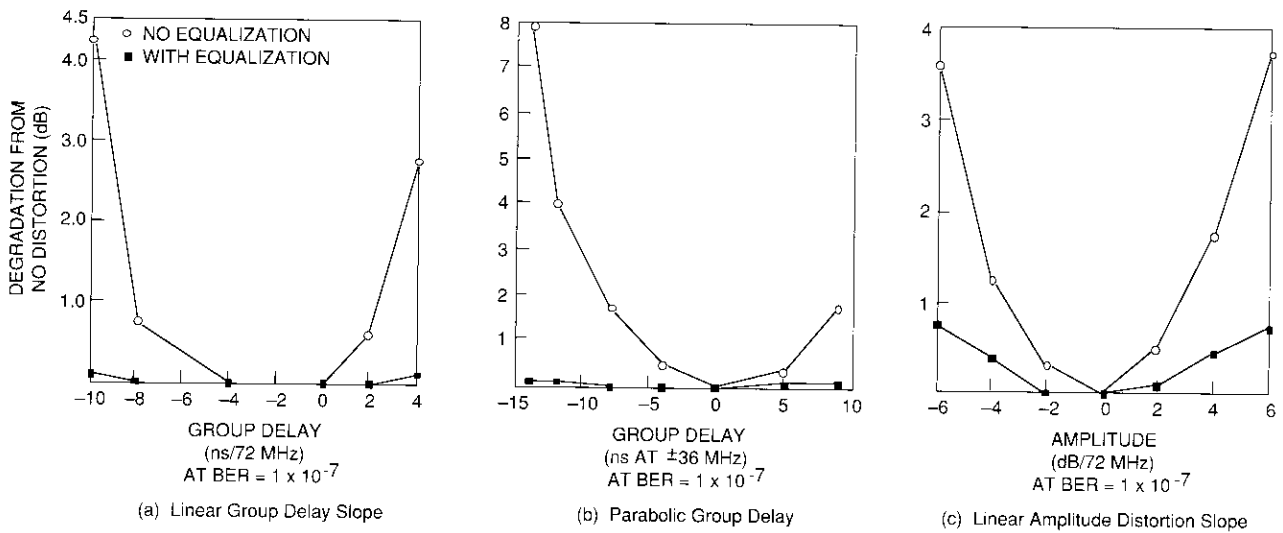
Figure 6. *Nonlinear Channel Performance Degradation vs Down-Link Group Delay and Amplitude Distortion*

Figure 7 shows the results of the up-link distortion tests. In this case, the transversal equalizer is not as effective in improving the performance as it was for the nonlinear channel down-link and linear channel setups. As discussed in Reference 8, this is to be expected due to the nonlinearity between the distortion element and the equalizer.

A comparison of the nonlinear channel results with those obtained for QPSK [8] reveals that, on the average, in the case of down-link distortion, the COPSK system is two to three times as sensitive to both types of group delay slope, and is equally sensitive to amplitude slope. Also, as was true for QPSK, the transversal equalizer provides significant improvement over the unequalized performance. For up-link distortion, COPSK is about five times more sensitive to linear group delay slope, three times more sensitive to parabolic delay slope, and one to two times as sensitive to linear amplitude distortion slope. However, the transversal equalizer appears to be more effective at improving this performance than it was for QPSK, particularly in the parabolic group delay and linear amplitude distortion cases.

## Transatlantic field trials

Field testing of the COPSK system through an INTELSAT V-A satellite across the Atlantic Ocean proceeded in two phases. The first involved transmission between the Roaring Creek (Bloomsburg, Pennsylvania, USA) and Goonhilly (Helston, Cornwall, UK) earth stations, and the second between the Roaring Creek and Pleumeur-Bodou (Pleumeur-Bodou, FR) earth stations. For phase I, the ISS unit was shipped to Roaring Creek and the INTELSAT unit to Goonhilly. For phase II, the INTELSAT unit was moved to Pleumeur-Bodou.

After appropriate station equalization, loopback testing was performed at all earth stations in back-to-back, station loopback, and satellite loopback configurations. This was followed by one-way and simultaneous transmission transatlantic testing. Equalization was performed according to INTELSAT TDMA earth station requirements for up- and down-links [5]. The OBE characteristics of the COPSK signals were checked at all three locations for compliance with INTELSAT specifications. The effects of CCl on BER were measured in the satellite loopback configuration at Roaring Creek and Pleumeur-Bodou, and in the transatlantic configuration from Goonhilly to Roaring Creek and Roaring Creek to Pleumeur-Bodou, by inserting a 120-Mbit/s QPSK interferer in the down-link.

The parameters of the three earth stations are listed in Table 2. The equivalent isotropically radiated power (e.i.r.p.) values given in this table are those actually measured during the transatlantic transmission, and correspond to the
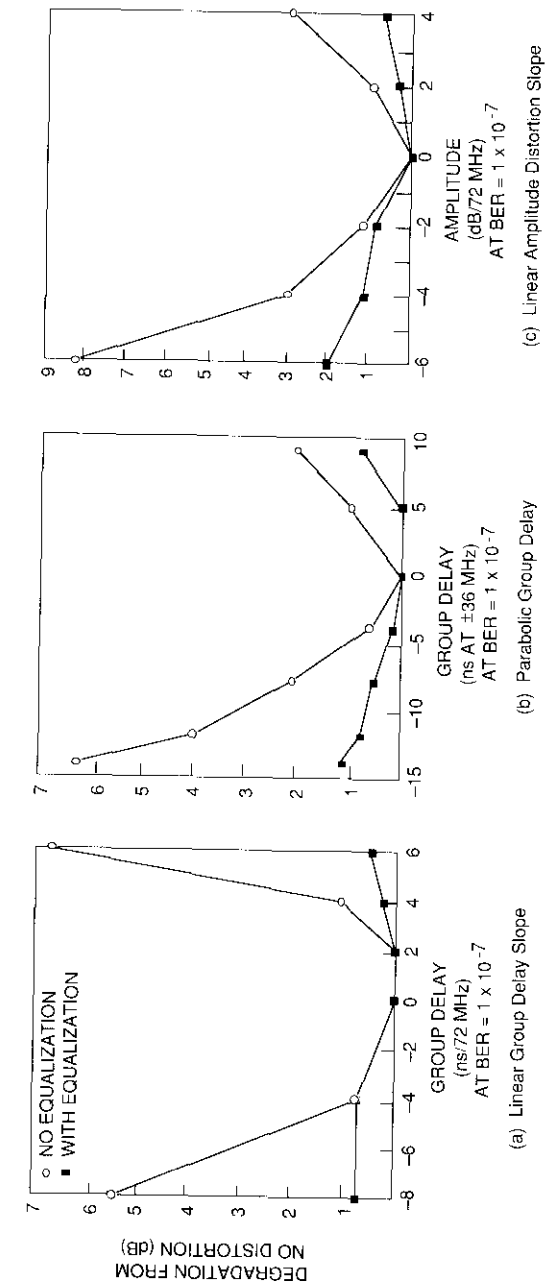
Figure 7. Nonlinear Channel Performance Degradation vs Up-Link Group Delay and Amplitude Distortion

TABLE 2. EARTH STATION PARAMETERS

| PARAMETER | ROARING CREEK | GOONHILLY | PLEUMEUR-BODOU |
|---|---|---|---|
| Location | Bloomsburg, PA (USA) | Helston, Cornwall (UK) | Pleumeur-Bodou (France) |
| INTELSAT Standard Class | A | A | A |
| INTELSAT Earth Station Code | RCK-1 | GHY-1 | PB-3 |
| Antenna Diameter (m) | 32 | 25.9 | 30 |
| Transmit Gain (dB) | 64.5 | 61.5 | 64.2 |
| Elevation Angle | 21.0° | 27.9° | 29.0° |
| e.i.r.p. (for TWTA 2-dB IBO) (dBW) | 83.9 | 82.8 | 80.2 |
| Earth Station $G/T$ (dB/K) | 41.4–41.6 | 40.7 | 40.7 |
| HPA Type | 3-kW Klystron | 3-kW TWTA | 3-kW TWTA |
| Output Backoff Used | 8 dB | 3 dB | (Linear)* |

*Saturation point of HPA not measured.

values required to achieve approximately 2-dB IBO at the satellite TWTA. The difference in e.i.r.p. values measured at Goonhilly and Pleumeur-Bodou was not resolved, but was most likely due to calibration errors. Time constraints did not permit recalibration of the net coupling loss. The elevation angles given are required for determining the OBE specification point. Satellite parameters are given in Table 3, and were the same for both phases of the field test.

## Link performance calculations

To estimate the performance expected during the field tests of the 140-Mbit/s COPSK system, as well as for general operation, link budgets were prepared. First, upper bounds on expected performance were calculated using pre-launch e.i.r.p. data. These data were about 1.5 dB better than the specified pre-launch e.i.r.p. data. These data were about 1.5 dB better than the specified performance for the transponders [42/52, West-Zone/East-Zone (WZ/EZ)] and the particular satellite involved (INTELSAT V-A, F-11). The upper performance bounds assume only thermal noise contributions. Performance in the direction of the participating earth stations was estimated from coverage patterns given in the *INTELSAT Earth Station Standards* (IESS) [9]. Perfect earth station an-

TABLE 3. SATELLITE PARAMETERS FOR THE TRANSATLANTIC FIELD TESTS

| PARAMETER | VALUE |
|---|---|
| Satellite | INTELSAT V-A, F-11, 332.5°E Longitude |
| Transponder | Ch. 3-4 Zone Beam (42 + 52) |
| Up-Link Frequency | 6050 MHz (RHCP) |
| Down-Link Frequency | 3825 MHz (LHCP) |

tenna pointing was assumed. These link budgets are contained in the "Upper Bound" column of Table 4.

Note that, at the desired operating point of the transponders, some considerable suppression of up-link thermal noise (and other up-link impairments) was expected. Because the transponders used TWTAs, approximately 8.0-dB small-signal suppression and 3.7-dB compression (based on actual TWTA measurements [10] of large and small unmodulated signals) were assumed at the operating point. Consequently the upper bound on one-way link performance was established as 24.2-dB $E_b/N_o$ from the United States to Europe and 24.5-dB $E_b/N_o$ from Europe to the United States.

Having established the upper bounds, interference and other impairments were introduced into the link budgets. For these budgets, satellite e.i.r.p. from the IESS [11] was assumed, with slightly less satellite pattern advantage to account for the locations of other earth stations relative to the satellite. An allowance of 0.5 dB was introduced for earth station antenna pointing tolerance.

The carrier-to-interference ratio (C/I) for ACI was taken as 30 dB, based on earlier work [12] for a similar COPSK carrier in one adjacent transponder bank. (A transponder bank consists of the two co-frequency hemi-beam transponders and the two co-frequency zonal-beam transponders.) An allowance of 0.7 dB was made for adjacent satellite interference, corresponding to 15 percent of the link noise (in accordance with CCIR Recommendation 523).

CCI was estimated by assuming three interference entries, each 30-dB down from the two geographically isolated and one oppositely polarized transponders in the bank. An earth station antenna axial ratio of 1.06 was also assumed. Therefore, the net C/I is 24.1 dB on both the up- and down-links. Assuming a 60-MHz noise bandwidth, this equates to a co-channel C/I noise density entry of 101.9 dB-Hz.

With the interference contributors given above, and using a more conservative value for satellite e.i.r.p. performance, the expected link performance is an $E_b/N_o$ of 16.5 to 16.7 dB, taking into account the small-signal suppression

TABLE 4. LINK BUDGETS FOR 140-Mbit/s COPSK OPERATION

| PARAMETER | UPPER BOUND | | NOMINAL EXPECTED | |
|---|---|---|---|---|
| | TO EUROPE | TO USA | TO EUROPE | TO USA |
| Earth Station e.i.r.p. (dBW) | 82.4 | 82.3 | 82.9 | 82.8 |
| Up-Link Path Loss (dB) | 200.1 | 200.0 | 200.1 | 200.0 |
| Pointing Error (dB) | – | | 0.5 | 0.5 |
| Satellite $G/T$ (dB/K) | -4.0 | -4.0 | -4.0 | -4.0 |
| Boltzmann's Constant (dBW/HzK) | -228.6 | -228.6 | -228.6 | -228.6 |
| Up-Link Thermal (dB-Hz) | 106.9 | 106.9 | 106.9 | 106.9 |
| Co-Channel Int. (dB-Hz) | – | – | 101.9 | 101.9 |
| Adjacent Channel Int. (dB-Hz) | – | | 107.8 | 107.8 |
| Up-Link $C/kT$ (dB-Hz) Transponder Input | 106.9 | 106.9 | 99.9 | 99.9 |
| G, 1 m² (dB) | 37.1 | 37.1 | 37.1 | 37.1 |
| Operating Flux Density (dBW/m²) | -80.6 | -80.6 | -80.6 | -80.6 |
| Satellite Flux Density (dBW/m²) | -78.6 | -78.6 | -78.6 | -78.6 |
| Input Backoff (dB) | 2.0 | 2.0 | 2.0 | 2.0 |
| Output Backoff (dB) | 0.3 | 0.3 | 0.3 | 0.3 |
| Sat. Saturation e.i.r.p. (dBW) | 34.2 | 33.9 | 32.0 | 32.0 |
| Operating e.i.r.p. (dBW) | 33.9 | 33.6 | 31.7 | 31.7 |
| Intermodulation (dB-Hz) | – | – | – | – |
| Down-Link Path Loss (dB) | 196.0 | 196.1 | 196.0 | 196.1 |
| Pointing Error (dB) | – | – | 0.5 | 0.5 |
| Earth Station $G/T$ (dB/K) | 40.7 | 41.5 | 40.7 | 41.5 |
| Down-Link Thermal (dB-Hz) | 107.2 | 107.6 | 104.5 | 105.2 |
| Co-Channel. Int. (dB-Hz) | – | – | 101.9 | 101.9 |
| Adjacent Channel Int. (dB-Hz) | – | – | 107.8 | 107.8 |
| Down-Link $C/kT$ (dB-Hz) | 107.2 | 107.6 | 99.3 | 99.5 |
| Up-Link $C/kT$ (dB-Hz) Transponder Output | 111.2 | 111.2 | 102.9 | 102.9 |
| Net Link $C/kT$ (dB-Hz) | 105.7 | 106.0 | 97.7 | 97.9 |
| Adj. Sat. and Terrestrial Int. (dB) | – | – | 0.7 | 0.7 |
| Available $C/kT$ (dB-Hz) | 105.7 | 106.0 | 97.0 | 97.2 |
| Available $E_b/N_o$ (dB) | 24.2 | 24.5 | 15.5 | 15.7 |

*For an INTELSAT V-A satellite at 332.5°E with zonal transponders.

and gain compression on the up-link, when signal noise and interference are referred to the output of the transponder. To be conservative, slightly less small-signal suppression (7.3 dB) and slightly more gain compression (4.3 dB) than had been measured on a different space TWTA were assumed. The link budgets for nominal expected operation are given in the "Nominal Expected" column of Table 4.

Using laboratory data obtained on the COPSK equipment (see Figure 4a), and with the $E_b/N_o$ expected for the link (including a quasi-linear TWTA representing an earth station HPA, and a second TWTA driven to 2.0-dB IBO), a BER of about $5 \times 10^{-8}$ to $8 \times 10^{-8}$ was the expected clear-sky performance for 140-Mbit/s COPSK with all four transponders in a bank handling the same type of $E_b/N_o$ signal. A margin of 0.5 to 1.0 dB to a BER of $1 \times 10^{-7}$ appeared to be available. Note that the link is primarily interference-limited, not thermal noise-limited.

The analysis also showed that a 21- to 22-dB $C/I$ is a good choice for investigating the effects of CCI on the overall link.

### Earth station equalization and loopback testing

Figure 8 is a simplified block diagram typical of the setups used at each earth station. Indicated on the diagram are the interconnections between the various pieces of earth terminal equipment, as well as the test equipment configurations and signal paths used for equalization and loopback testing. Path A was used for back-to-back testing of the COPSK system BER, which was performed upon arrival at the earth station to ensure proper equipment operation. The vane attenuator and power meter shown connected to the HPA input and output, respectively, were used to determine the HPA power transfer characteristic and saturation point at each site.* During this procedure, the vane attenuator was calibrated with respect to both HPA backoff and station e.i.r.p. so that it would then be possible to set or confirm the station operation point by simply reading the setting of the vane.

Up-link equalization was performed from the COPSK transmit output to the diplexer input. The frequency response of the up-link was measured using a microwave link analyzer (MLA) and a broadband down-converter, in accordance with INTELSAT TDMA equalization procedures [5]. During equalization, the HPA was operated well backed-off to ensure linear response. Fixed and/or adjustable equalizers were added, as shown, to flatten the up-link

*The saturation point was not measured at Pleumeur-Bodou, since linear operation during the test was ensured by virtue of the low loss between the HPA output and the antenna feed.

Figure 8. *Simplified Block Diagram of Earth Station Configuration for the Transatlantic Field Tests*

amplitude and group delay characteristics. At Roaring Creek, it was possible to bring this response within the masks specified in Reference 4; however, due in large part to the time constraints of the field tests, the responses at Goonhilly and Pleumeur-Bodou were left slightly out-of-spec. In a similar manner, the down-link was equalized from the diplexer output to the COPSK receive input. After equalization, the Roaring Creek and Pleumeur-Bodou responses were within the INTELSAT masks [4], while the Goonhilly response was left out-of-spec by a small amount, again because of scheduling considerations.

Station loopback BER testing was performed using path B* of Figure 8. For this test, two HPA operating points were used, one well within the linear region and the other corresponding to that required for 2-dB IBO of the satellite TWTA. This second operating point was established by measuring TWTA saturation while the satellite was configured in a loopback mode. Table 5 lists the HPA operating points measured. The lower backoff values (and thus higher HPA drive levels) at Goonhilly are a result of the lower antenna gain at that site (refer to Table 2). Nonlinear operation of the Goonhilly HPA is indicated by the fact that a 3.6-dB change in the HPA input drive was required in order to effect a 2-dB change in the TWTA drive level. At Roaring Creek and Pleumeur-Bodou, the corresponding changes in input drive were 2.2 and 2.0 dB, respectively.

TABLE 5. HPA OPERATING POINTS

| EARTH STATION | SATELLITE TWTA SATURATION | | SATELLITE TWTA 2-dB IBO | |
|---|---|---|---|---|
| | HPA IBO (dB) | e.i.r.p. (dBW) | HPA IBO (dB) | e.i.r.p. (dBW) |
| Roaring Creek | 9.5 | 85.9 | 11.7 | 83.9 |
| Goonhilly | 6.0 | 84.8 | 9.6 | 82.8 |
| Pleumeur-Bodou | – | 82.2 | – | 80.2 |

Figure 9 depicts the station loopback BER performance curves for Roaring Creek, Goonhilly, and Pleumeur-Bodou. The performance compares favorably with back-to-back measurements made on the COPSK system (Figure 3); and at Goonhilly, for the linear HPA case, the performance is actually better. This may be due to the difference in the amplitude and group delay characteristics of the two configurations. When operated for TWTA saturation,

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*At Goonhilly, it was not possible to connect the output of the test translator to the low-noise amplifier (LNA) input due to the equipment arrangement at the antenna site. Instead, a point accessible at the LNA output was used.

Figure 9. *Earth Station Loopback BER vs $E_b/N_o$*

however, the Goonhilly performance is degraded due to the nonlinear HPA operating point discussed earlier. This effect can also be seen in the Roaring Creek data, but to a lesser extent. The BER performance at Pleumeur-Bodou is nearly identical at the two HPA operating points, indicating basically linear HPA operation.

## HPA spectral spreading

Observations were made at the antenna feed couplers at each site (see Figure 8), with the HPA operating point set for satellite TWTA 2-dB IBO,* to establish the amount of spectral regrowth experienced by the COPSK signals and to verify that these signals were not violating INTELSAT requirements regarding OBEs [4]. The HPA output spectrum observed at Roaring Creek is shown in Figure 10 and is typical of that seen at all three sites. In addition to spectral regrowth, discrete frequency components are also visible due to the 1, 0 pattern used in the system preamble.

Based on the antenna elevation angle for each site (refer to Table 2), the allowable signal power at ±44 MHz from the center frequency of each signal was calculated with respect to the resolution bandwidth used to observe the output spectra (10 kHz for Roaring Creek and Pleumeur-Bodou; 1 MHz for Goonhilly) and is given in Table 6. From the known e.i.r.p. value corresponding to each site's spectrum, the spectral density of each signal was then calculated at the ±44-MHz specification point, assuming a signal bandwidth of 60 MHz, and again relative to the resolution bandwidth of the particular observation. The e.i.r.p. and calculated spectral density values are given in Table 6, along with the margins relative to the INTELSAT specification. In each case, the signal spectrum was within the specified limits.

## Satellite loopback equalization and testing

A satellite loopback configuration was established at each earth station to measure BER vs $E_b/N_o$. Prior to making this measurement, additional equalization was required in order to compensate for the output multiplex filter onboard the spacecraft, in accordance with INTELSAT procedures. The characteristics of this equalizer are specified by INTELSAT; no further adjustments were made to the earth station equalization.**

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*At Goonhilly, two observations were made at operating points corresponding to satellite TWTA IBO values of 1.2 and 5.8 dB.

**At Goonhilly, an additional equalizer was added to compensate for the LNA and associated waveguide, which were not part of the station loopback (as previously discussed).

(a) 100-MHz Sweep Width

(b) 200-MHz Sweep Width
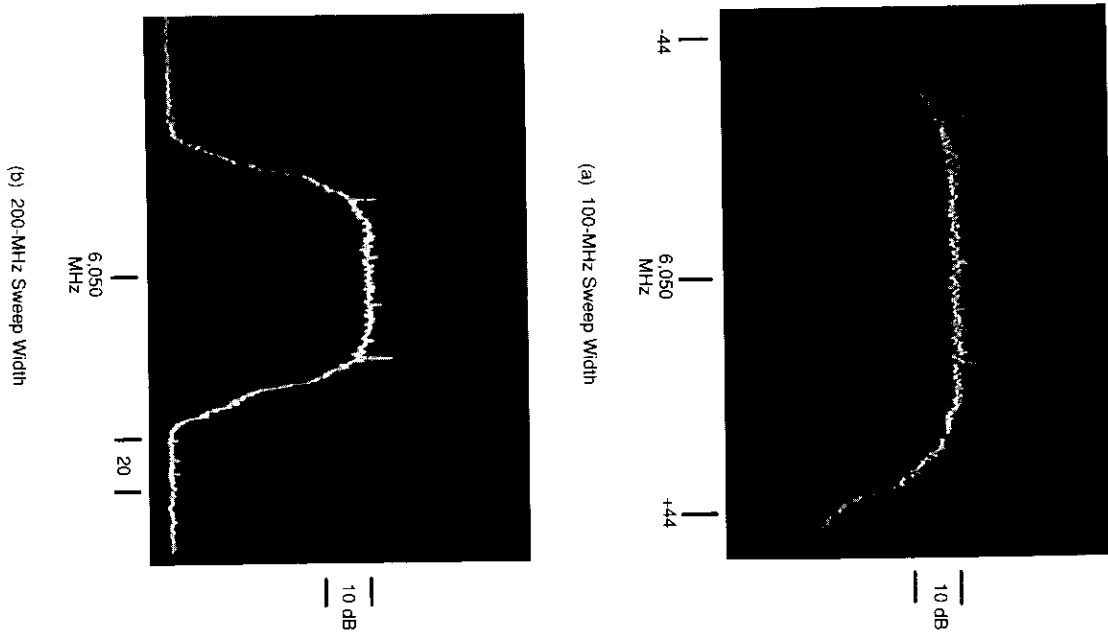
Figure 10. *HPA Output Spectrum for the Roaring Creek Earth Station*

TABLE 6. OUT-OF-BAND EMISSION PERFORMANCE

| EARTH STATION | OBE SPECIFICATION | OPERATING POINT | | SPECTRAL DENSITY AT ±44 MHz * | MARGIN (dB) |
| | | SATELLITE TWTA IBO (dB) | e.i.r.p. (dBW) | | |
|---|---|---|---|---|---|
| Roaring Creek | 26.8 dBW/10 kHz | 2.0 | 83.9 | 20 dBW/10 kHz | +6.8 |
| Goonhilly | 46.6 dBW/1 MHz | 1.2 | 83.6 | 46 dBW/1 MHz | +0.6 |
| | | 5.8 | 79.0 | 34 dBW/1 MHz | +12.6 |
| Pleumeur-Bodou | 26.6 dBW/10 kHz | 2.0 | 80.2 | 7.4 dBW/10 kHz | +19.2 |

* Assumes signal bandwidth $R_s$ = 60 MHz.

With the satellite equalizer in place, a frequency sweep of each satellite loopback link was performed using the MLA, and the results were compared with the INTELSAT satellite link response specifications [5]. In each case, the group delay responses did not meet the specifications at the band edges. The specification calls for less than 15 ns of group delay distortion at ±36 MHz. At Roaring Creek, this value was 27 ns at the low band edge and 21 ns at the high band edge. At Pleumeur-Bodou, only the low band edge did not meet specifications and was approximately 17 ns. However, the center portions of both group delay responses were quite flat over a large portion of the band. At Goonhilly, the differential group delay was approximately 20 ns across the band, and the responses indicated some type of interference, which was later identified as relatively low cross-polarization isolation in the antenna feed.

Next, the optimum satellite TWTA operating point was determined by injecting a fixed quantity of white noise into the receive signal at the down-converter output to establish an arbitrary value of BER (approximately 1 x 10⁻⁶ was used), and then varying the transmit e.i.r.p. with the vane attenuator so as to minimize the BER. Figure 11 shows a plot of the BER *vs* the satellite TWTA
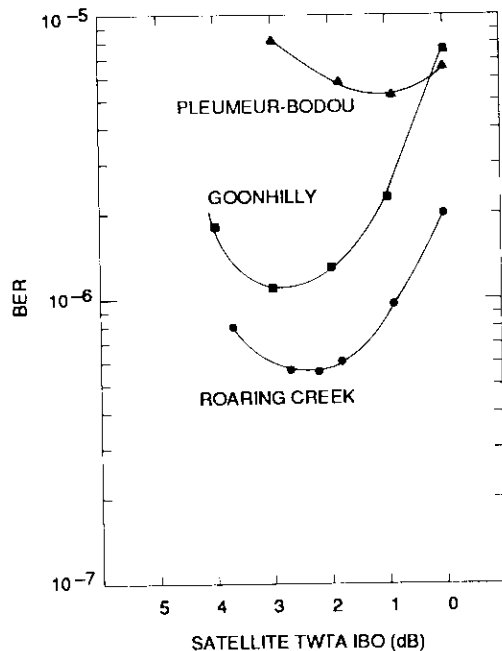


Figure 11. *BER vs Satellite TWTA Operating Point in Satellite Loopback*

operating point for each station. Since the noise added at each station was arbitrary and the $E_b/N_o$ was not measured, the absolute value of the different BER performance curves is not significant.

Based on these data, the satellite transponder operating point for each site was selected. For Roaring Creek and Pleumeur-Bodou, a 2-dB IBO was chosen, partly as a result of discussions held with the various participants during the test plan development. It was decided that 2 dB should be used if the data indicated that the optimum operating point was within 1 dB of the nominal 2-dB operating point of the INTELSAT TDMA system. At Goonhilly, the optimum operating point was found to be 3-dB IBO, and this value was used for satellite loopback measurements. This larger value of backoff is presumed to be due to the predominance of nonlinearity over thermal noise, since the HPA at Goonhilly is operating close to saturation.

With the optimum satellite operating points established, the BER *vs* $E_b/N_o$ was measured, and the results are presented in Figure 12. At Goonhilly and Pleumeur-Bodou, the performance was initially degraded. However, by placing a transversal equalizer in the down-link (in addition to the equalizers
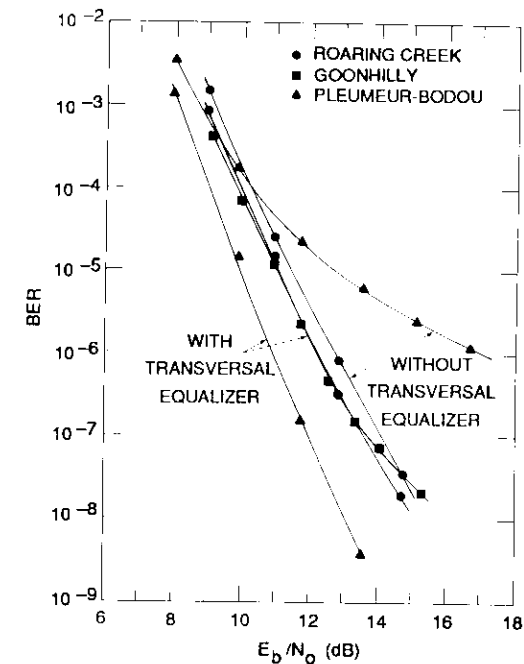


Figure 12. *Satellite Loopback Performance*

already present for station equalization), performance was significantly improved in both cases. A similar effort at Roaring Creek resulted in only about 0.5 dB of improvement at a BER of $1 \times 10^{-7}$.

It is unclear why the transversal equalizer had such a significant effect on BER performance at Goonhilly and Pleumeur-Bodou. One possibility is that the clock/data relationship within the COPSK demodulator/decoder is being affected by the satellite channel, and the transversal equalizer is compensating for this effect. Further measurements will be necessary to characterize this behavior. Note that the magnitude of improvement obtained with the transversal equalizer in these field measurements is consistent with that experienced in laboratory tests involving IF distortion, but in this case the source of the degradation is unknown.

It is likely that the link to Goonhilly experienced significant down-link interference because of relatively low polarization isolation in the feed. The $E_b/N_o$ performance did not approach the calculated upper bound nearly as closely as it did at Roaring Creek. For instance, the mean $E_b/N_o$ among the three loopback and two transatlantic measurements made at Goonhilly was 19.2 dB; whereas, the bounding link analysis had predicted an $E_b/N_o$ of up to 24.2 dB. In contrast, among the two loopback and two transatlantic measurements made at Roaring Creek, the mean $E_b/N_o$ obtained was 24.8 dB, compared to a predicted upper bound of 24.5 dB, and among the two loopback and two one-way transatlantic measurements made at Pleumeur-Bodou, the mean $E_b/N_o$ obtained was 24.4 dB compared to a predicted upper bound of 24.2 dB.

The values of $E_b/N_o$ used in the above analyses are given in Table 7. It was clearly possible to achieve $E_b/N_o$ values which would produce a BER much lower than $1 \times 10^{-7}$; however, a primary purpose of the field tests was to demonstrate that $1 \times 10^{-7}$ could be achieved. The time available for the tests was limited, and obtaining meaningful data at very low BERs (even at 140-Mbit/s) is difficult. Therefore, the $E_b/N_o$ range over which measurements were made was purposely limited by injecting noise on the receive side of the links.

## Transatlantic equalization and testing

After satellite loopback measurements were completed, the satellite was reconfigured for transatlantic operation. During each phase of the field trial, BER performance was measured with each earth station transmitting in turn, and then with simultaneous transmission from both stations. Additionally, BER performance was measured at Roaring Creek and Pleumeur-Bodou with CCI added on the down-link.

TABLE 7. VALUES OF LINK $E_b/N_o$ EXPERIENCED DURING THE COPSK FIELD TESTS

| DATE | DESCRIPTION | LINK $E_b/N_o$ (dB) |
|---|---|---|
| 3/14/88 | RCK–GHY | 17.7 |
| 3/15/88 | Satellite Loopback–GHY | 20.2 |
| 3/18/88 | Satellite Loopback–GHY | 19.5 |
| 3/20/88 | RCK–GHY | 19.2 |
| 3/22/88 | Satellite Loopback–GHY | 19.4 |
| 5/16/88 | Satellite Loopback–RCK | 21.1 |
| 5/17/88 | Satellite Loopback–RCK | 26.3 |
| 5/18/88 | PBD–RCK | 26.6 |
| 5/19/88 | PBD–RCK | 25.1 |
| 5/16/88 | Satellite Loopback–PBD | 25.3 |
| 5/17/88 | Satellite Loopback–PBD | 23.4 |
| 5/18/88 | RCK–PBD (single-carrier transmission) | 24.1 |
| 5/19/88 | RCK–PBD (with PBD carrier transmitting) | 22.6 |
| 5/19/88 | RCK–PBD (single-carrier transmission) | 24.7 |

First, the optimum operating point for each transatlantic link was determined in a manner similar to that used for satellite loopback. BER was then measured with a fixed amount of noise added on the down-link. The satellite TWTA operating point was varied by changing the earth station e.i.r.p. using the vane attenuator. The optimum point for the Roaring Creek-to-Goonhilly link was 2-dB IBO, while for the reverse link it was approximately 4-dB IBO. For the link between Roaring Creek and Pleumeur-Bodou, the optimum operating point was 2.5-dB IBO, and for the reverse link it was 3 dB. It appears from these data that the HPA backoff required at Goonhilly, because of the tradeoff regarding antenna size during the station design, was influencing the BER, and thus contributed to the selection of the optimum operating point. At Roaring Creek and Pleumeur-Bodou, the HPAs were nearly linear for the range of TWTA operating points tested.

As with satellite loopback testing, a satellite equalizer was added to the station down-link at all locations to compensate for the group delay distortion of the transponder output multiplex filter, in accordance with the INTELSAT *Satellite System Operating Guide* for TDMA/digital speech interpolation (DSI)

operations [5]. No further adjustments were made to the earth station at Roaring Creek. At Goonhilly and Pleumeur-Bodou, it was again necessary to use the transversal equalizer to obtain satisfactory BER performance.

The amplitude and group delay responses from Goonhilly to Roaring Creek are shown in Figure 13 at 14- and 2-dB IBO of the satellite TWTA, and are typical of those obtained from all sites. The responses are relatively flat over most of the band, but do not quite meet the INTELSAT requirements at the band edges. For the link response from Pleumeur-Bodou to Roaring Creek, the group delay again does not meet the specification at the band edges, but is quite flat over most of the band. The Roaring Creek-to-Pleumeur-Bodou link experienced less group delay distortion at the band edges, and consequently the response just met the INTELSAT requirements for 120-Mbit/s TDMA.

## Transatlantic BER measurement results

The BER vs $E_b/N_o$ performance curves for the Roaring Creek-Goonhilly transatlantic link are shown in Figure 14a. As can be seen, BER performance from Roaring Creek to Goonhilly was actually better than that observed over the reverse link, even though it was necessary to add a transversal equalizer on the Goonhilly down-link to achieve good performance. A transversal equalizer was also added at Roaring Creek; however, no significant improvement was observed and the equalizer was removed.

The value of interference introduced at Roaring Creek by the outgoing 140-Mbit/s COPSK transmission was measured to be a $C/I$ of 31 dB. This is in good agreement with the 30-dB figure used in the link analysis for one spatially isolated co-frequency transponder. The single simultaneous transmission had little effect on the Goonhilly-to-Roaring Creek BER, as can be seen in the figure.

The BER vs $E_b/N_o$ performance curves for the Roaring Creek-to-Pleumeur-Bodou transatlantic link with one-way and simultaneous transmission are shown in Figure 14b. Transversal equalizers were employed for these measurements at both locations. A BER of $4 \times 10^{-10}$ was achieved on the Roaring Creek-to-Pleumeur-Bodou link at an $E_b/N_o$ of approximately 17 dB. It is interesting to note that, as with the Goonhilly link, it was necessary to add the transversal equalizer to obtain reasonable performance; yet with the equalizer in use, the performance was actually better than that of the reverse link.

Although it appears from the curves of Figure 14b that the simultaneous transmission performance from Roaring Creek to Pleumeur-Bodou was superior to the one-way performance, the difference is actually the result of taking the data for these curves on different days. As mentioned above, this is one
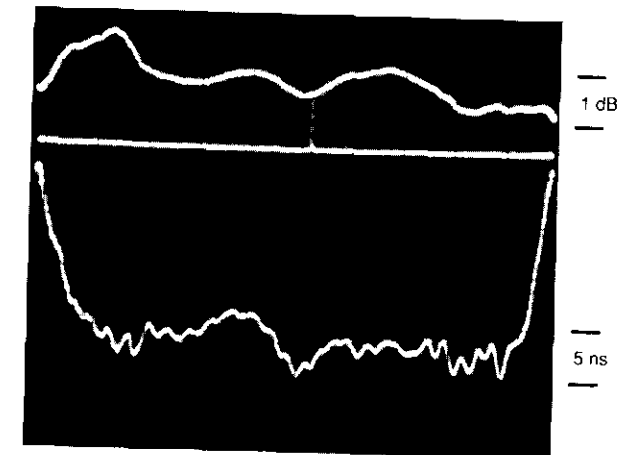
Center Frequency = 140 MHz
Markers at ±30 MHz

(a)  At 14-dB IBO

1 dB

5 ns
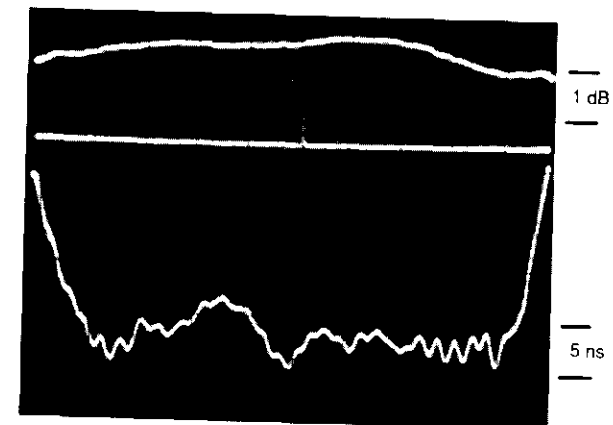
Center Frequency = 140 MHz
Markers at ±30 MHz

(b)  At 2-dB IBO

1 dB

5 ns

Figure 13. *Goonhilly-to-Roaring Creek Amplitude and Group Delay Swept Response*

indication of the repeatability of these measurements from one day to the next. To validate this, a single point was compared with one-way and simultaneous transmission, and there was approximately 0.1 dB of degradation for simultaneous transmission at $1 \times 10^{-7}$ BER.

The effects on BER performance of CCI added on the down-link at Pleumeur-Bodou were also measured. Figure 15 summarizes these data at $C/I$ values of 18, 21, and 24 dB.

## Summary

Extensive laboratory and field testing of the COPSK system have demonstrated the feasibility of 140-Mbit/s data rate transmission through a 72-MHz-wide satellite transponder, in a manner which compares very favorably with that of 120-Mbit/s QPSK. In the laboratory, undistorted linear and nonlinear

Figure 14. Transatlantic BER Performance
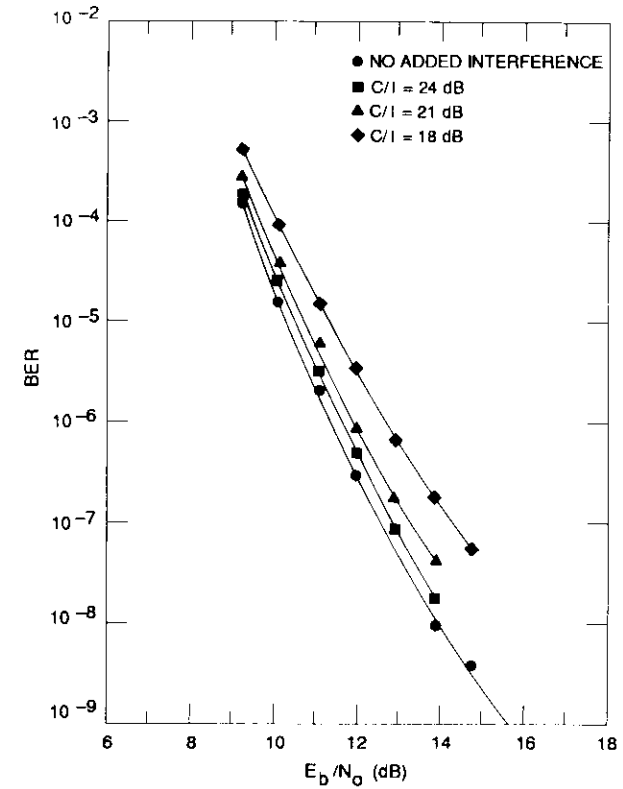
Figure 15. Roaring Creek-to-Pleumeur-Bodou BER Performance With CCI

channel performance was shown to be better than that obtained with uncoded 120-Mbit/s QPSK at comparable values of $E_b/N_o$. Greater sensitivity to linear slope, parabolic group delay distortion, and linear amplitude slope distortion than that experienced with QPSK was demonstrated, but was effectively canceled out when a transversal equalizer was placed in the receive signal path.

During the field trials, a BER of $1 \times 10^{-7}$ or better was achieved for transatlantic two-way operation in both phases of testing, at $E_b/N_o$ values ranging from 12.4 to 14.3 dB. Comparison with the expected nominal link performance shows that more than 1-dB margin should be available for the link to a BER of $1 \times 10^{-7}$. This is somewhat better than the performance of the (uncoded) 120-Mbit/s QPSK TDMA system currently in use. For the Roaring Creek-to-Pleumeur-Bodou link, BER was measured down to $4 \times 10^{-10}$. Compared to what was actually observed during these tests (Table 7), the $E_b/N_o$ from the expected nominal link performance budgets (Table 4) seems quite conservative. However, for the planning of service, a conservative approach is probably warranted. The OBE characteristics of the COPSK signal were shown to be well within INTELSAT specifications, even with an HPA operating in the nonlinear region.

A transversal equalizer was required at both the Goonhilly and Pleumeur-Bodou earth stations in order to obtain good performance; however, the reason for this is unclear. It is possible that some characteristic of the INTELSAT COPSK unit (as opposed to the ISS unit) requires a transversal equalizer when operated over a satellite link, since this same unit required the equalizer at two different earth stations.

Another important result of the field tests is the relatively stable performance demonstrated by the COPSK system. IF loopback data taken at various times during the field trials revealed almost identical performance. After initial alignment at the earth stations, no adjustments were made to the equipment at Roaring Creek and Goonhilly, and only one adjustment was made to the INTELSAT modem after it was shipped from Goonhilly to Pleumeur-Bodou.

## Acknowledgments

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# CTR Notes

# Results of a 12-GHz radiometric site diversity experiment at Atlanta, Georgia

D. V. ROGERS AND J. E. ALLNUTT

## Introduction

The increasing use of 14/11- and 14/12-GHz satellite communications systems has highlighted the need for accurate prediction methods for estimating the path attenuation caused by rainfall. At frequencies above 10 GHz, rain attenuation can cause unacceptable service outages on some paths. In regions where rain effects are severe, techniques for reducing the impact of rain impairments will be required for some links. One such technique is site diversity, wherein interconnected earth terminals are spaced sufficiently far apart to reduce the probability of joint occurrence of intense rain on the separate paths. Since many factors can affect the performance of such a system, INTELSAT has sponsored a series of site diversity measurements worldwide to study these effects. This note reports the results of a two-site site diversity experiment conducted near Atlanta, Georgia, USA.

## Experimental configuration

Passive Dicke-switched radiometers operating at 12 GHz, along with tipping-bucket rain gauges, were deployed at two sites (Atlanta and Cobb County, Georgia) separated by 37.5 km, as shown in Figure 1. The radiometers and rain gauges were identical to those used in earlier INTELSAT experiments, and the same automatic and manual calibration procedures were employed [1].

David V. Rogers, formerly Manager of the Propagation Studies Department at COMSAT Laboratories, is currently with the Communications Research Center, Department of Communications, Government of Canada.

Jeremy E. Allnutt is with the International Telecommunications Satellite Organization (INTELSAT).
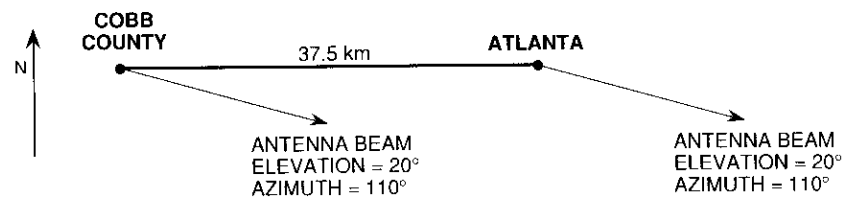
Figure 1. *Configuration of the 12-GHz Site Diversity Measurement Near Atlanta, Georgia*

The data were recorded locally on chart recorders, with time markers, and were later digitized and automatically transferred to magnetic tape for computer analysis.

The data collection period covered the interval from April 1979 through October 1980. However, for a variety of reasons (including occasional equipment malfunctions and a requirement to relocate some of the Cobb County equipment midway through the measurement to accommodate another experiment), joint operation of the two sites was not continuous (see Table 1). The resulting impact on the statistics is discussed later.

Atlanta is located in the southern foothills of the Appalachian mountains at a latitude of 33°39′ N and longitude of 84°26′ W. It is characterized by a moderately severe rain climate, with an average annual rainfall, M, of 1,236 mm and a convectivity ratio, ß, of 0.30, where ß is defined by Rice and Holmberg [2]. The ß factor is intended to correspond to the fraction of annual rainfall contributed by convective (thunderstorm) activity. That is, on average, 30 percent of the annual rainfall accumulation at Atlanta is presumed to arise from convective rain.

TABLE 1. DETAILS OF THE DATA COLLECTION PERIOD

| SITE | TOTAL EQUIPMENT UP-TIME | | | | MEASURED RAINFALL (NORMALIZED TO ANNUAL) |
| | RADIOMETER | | RAIN GAUGE | | |
| | (hr) | (%) | (hr) | (%) | (mm) |
|---|---|---|---|---|---|
| Atlanta | 10,525 | 76 | 11,770 | 85 | 1,427 |
| Cobb County | 7,564 | 55 | 6,875 | 50 | 1,055 |
| Joint Distribution | 6,232 | 45 | 6,232 | 45 | |

## Measurement results

RAIN RATE STATISTICS

The Rice-Holmberg rain rate model [2] is widely used to predict rain rate statistics. Using the derived ß value of 0.30 and the normalized annual rainfall for the two sites (computed from the measured accumulations of Table 1), rainfall rate statistics were predicted for each location. In Figure 2, these results are compared to the measured rain rate data. Within the accuracy limits of the rain gauge the agreement is quite good, which indicates that the several (presumably random) data gaps did not appreciably alter the cumulative statistics. A similar condition is assumed to prevail for the derived attenuation statistics.

DERIVED ATTENUATION STATISTICS

Attenuation statistics were derived in the standard way, from the measured sky noise data, by applying the well-known relation

$$A = 10 \log [T_m/(T_m - T_s)] \qquad (dB) \qquad (1)$$

where $T_m$ (K) is the equivalent temperature of the propagation medium (assumed to be 280 K) and $T_s$ (K) is the measured sky noise temperature increase caused by rain, which is obtained by normalizing to the nominal clear-sky noise level prior to rain events. Noise samples were digitized at approximately 1-minute intervals (a sampling rate which has been found sufficient for annual statistics). Due to logarithmic saturation, the accuracy of the attenuation values derived from equation (1) decreases as $T_s$ increases. The error in derived attenuation is estimated to be within ±0.5 dB for levels up to about 6 dB, increasing to about ±1.0 dB for computed rain fades of 10 dB.

Cumulative distributions of attenuation for the individual paths and for the diversity configuration (*i.e.*, the joint path statistics obtained by selecting the lesser of the two single-path attenuations for each sample in the time series) are displayed in Figure 3. These results are based on those periods when both radiometers were operating simultaneously (a total of 6,232 hours).

The curves of Figure 3 can be converted to a useful performance criterion called *diversity gain* [3], which is defined as the difference (in dB) between the average single-site and joint attenuation distributions for a specified time percentage. In Figure 4, the derived diversity gain is plotted *vs* the mean single-site attenuation, as well as *vs* the diversity gain predicted using an empirical model developed by Hodge [3], that predicted by the authors' model (for CCIR rain zone M) [4], and the "ideal" diversity gain representing
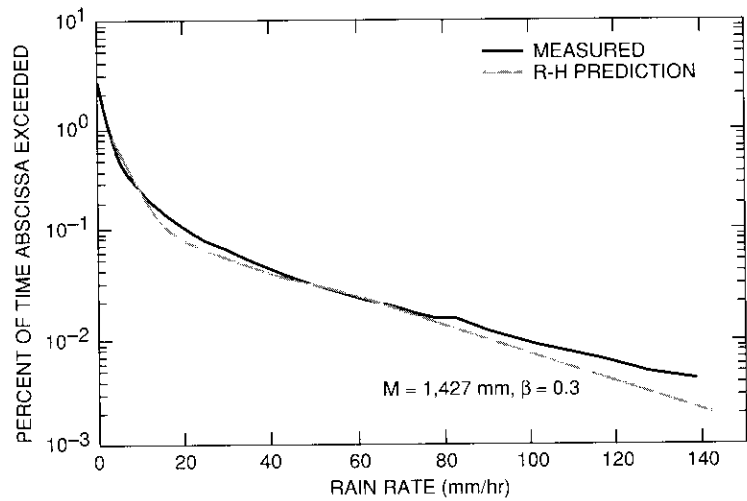
(a)  Atlanta
(4/79 – 10/80)
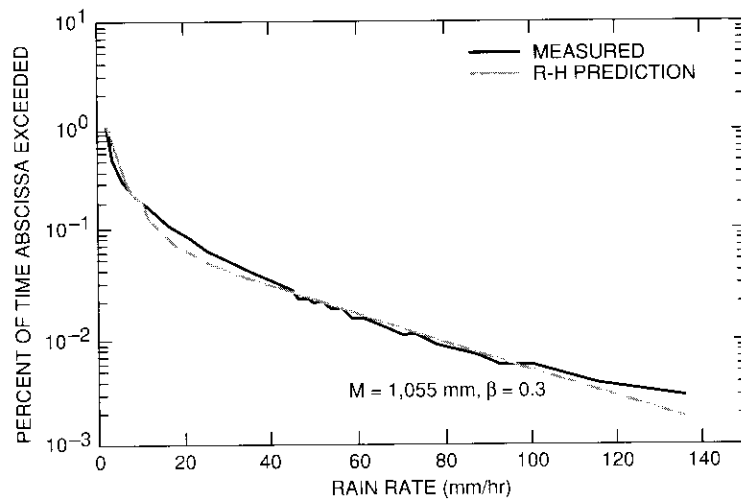


(b)  Cobb County
(11/78 – 10/80)

Figure  2. *Measured and Predicted Rain Rate Statistics*
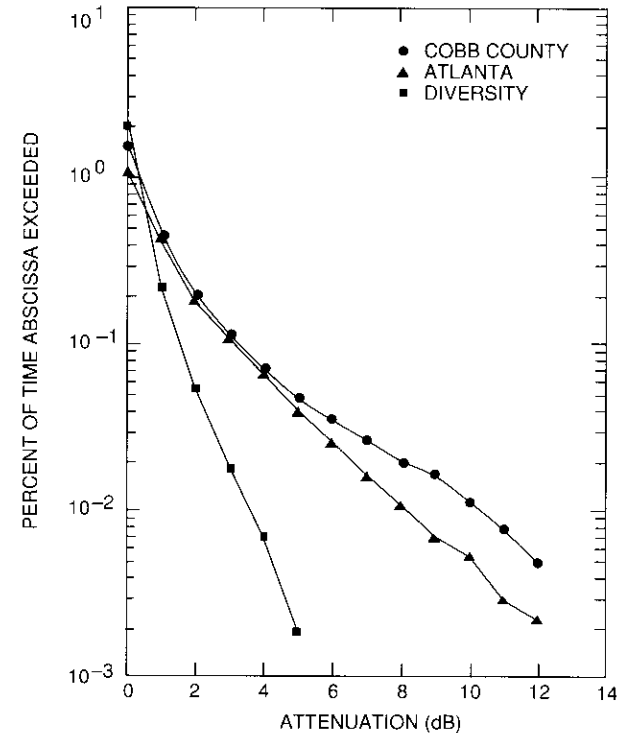


Figure  3. *Measured Cumulative 12-GHz Attenuation Statistics for Atlanta, Cobb County, and the Joint Distribution (4/79–10/80, based on joint experiment time only)*

decorrelated fading on the two paths. Hodge's model is based on rms curve fits to a sequence of diversity parameters, and should replicate average diversity gain behavior very well. Both predicted gains agree rather well with the measured gain; however, a comparison of the measured and predicted gains for many of the available data sets reveals that the performance of Hodge's model is superior overall [5].

Diversity gain for a given location has been demonstrated to be relatively insensitive to single-path fading characteristics, year-to-year variations in slant path impairments, and the length of the experimental period [6]. Figure 4 should therefore represent nominal site diversity performance for the Atlanta locale. The fact that the measured gain curve agrees well with Hodge's model, based on empirical fitting to data, supports this conclusion.
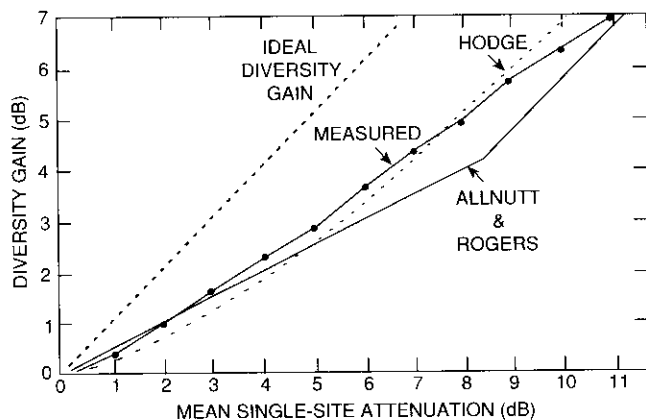
Figure 4. *Measured and Predicted Diversity Gain vs Mean Single-Site Attenuation*

It is instructive to compare the observed diversity gain with corresponding time percentages for the cumulative distributions of single-path attenuation of Figure 3. For example, it can be deduced that diversity gain exceeds 1 dB only for time percentages below about 0.2 percent (*i.e.*, for 99.8 percent of the year, the gain is expected to be less than 1 dB), although site diversity is not, of course, designed for such relatively unimpaired time percentages. At smaller time percentages, the gain is substantial (almost 3-dB gain for a single-site attenuation of 5 dB). Because the dynamic range of radiometers is limited to about 10 to 12 dB due to the saturation effect, it is not possible to deduce diversity gain for higher fades. This limitation is common to much of the available site diversity data, and presents a particular difficulty in the testing of site diversity models. The joint attenuation never exceeded 5 dB during the measurement period, and it would be reasonable to assume a fairly linear extension of the measured gain curve of Figure 4 to higher attenuations.

## Conclusions

Cumulative statistics for rain rate, single-site attenuation, and site diversity attenuation have been presented for a 12-GHz radiometric measurement conducted near Atlanta, Georgia. The diversity gain results are judged to be representative for the measurement location and configuration, and agree well with the predictions of an empirical site diversity model. Such results are needed for the design of site diversity systems and the development of predictive models.

## References

[1]    D. V. Rogers, "Diversity- and Single-Site Radiometric Measurements of 12-GHz Rain Attenuation in Different Climates," *IEE Conference Publication No. 195*, Pt. 2, 1981, pp. 118–123.

[2]    P. L. Rice and N. R. Holmberg, "Cumulative Time Statistics of Surface-Point Rainfall Rates," *IEEE Transactions on Communications*, Vol. COM-21, No. 10, October 1973, pp. 1131–1136.

[3]    D. B. Hodge, "An Improved Model for Diversity Gain on Earth-Space Propagation Paths," *Radio Science*, Vol. 17, No. 6 , November–December 1982, pp. 1393–1399.

[4]    D. V. Rogers and J. E. Allnutt, "Evaluation of a Site Diversity Model for Satellite Communications Systems," *Proc. IEE* , Vol. 131, Pt. F, 1984, pp. 501–506.

[5]    J. E. Allnutt, *Satellite-to-Ground Radiowave Propagation*, Ch. 4., London: Peter Peregrinus, 1989.

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# *Geostationary satellite log for year-end 1989*

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Since the last revision of the Geostationary Satellite Log in 1988, more than 40 new satellites have been launched into geosynchronous orbit. Hundreds more are in the planning stage, and industry analysts anticipate an upturn in the number of satellites launched over the next 5 years [1],[2].

This increased activity is taking place in a more complex world environment—one marked by the proliferation of both rival operators and advanced applications. Among the new satellites are the first separate systems authorized to compete with INTELSAT, as well as some of the first privately owned ventures to appear outside the United States. At the same time, markets ancillary to the traditional telecommunications offerings in the Fixed Satellite Service are developing as a result of additions such as direct broadcast satellites, remote sensing, and commercial mobile satellite services. Indeed, the trend toward hybridization of the Insat or Hispasat variety is blurring the customary divisions among categories of spacecraft. These realities are reflected in the updated Satellite Log, which covers all satellites in the geostationary arc. Alternative uses and prospective relocations are noted where known, as are details of system ownership.

Table 1 (see p. 108) lists in-orbit satellites through December 1989. Proposed satellites are listed in Table 2 (see p. 156) at their currently planned orbital positions. The primary source for both tables is the *List of Geostationary Space Stations* [3] compiled by the International Frequency Registration Board (IFRB). This has been supplemented with data from the IFRB's weekly circulars and other documents published by the Federal Communications Commission [4]. Wherever possible, actual subsatellite longitude is derived from NASA situation reports [5],[6], while a variety of secondary sources

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were consulted to verify technical parameters and other information pertaining to usage and operation [7]–[11].

Inevitably, reliance on the IFRB lists introduces distortions to the data. Delays associated with the registration procedure contribute to a situation in which satellites no longer operative—or in the case of planned systems, no longer under consideration—are still in the ITU process. For clarity, these systems have been retained, but with their current status indicated in the footnotes accompanying each table.

Table 3 (see p. 210) provides an index of the frequency codes used in Tables 1 and 2. Bands of operation are those defined in the Table of Frequency Allocations contained in the *ITU Radio Regulations*. Several common abbreviations are used to denote categories of service, as follows:

| | |
|---|---|
| FSS | Fixed Satellite Service |
| BSS | Broadcasting Satellite Service |
| MSS | Mobile Satellite Service |
| MMSS | Maritime Mobile Satellite Service |
| LMSS | Land Mobile Satellite Service |
| AMSS | Aeronautical Mobile Satellite Service |
| RNS | Radionavigation Satellite Service |
| SRS | Space Research Service |
| EES | Earth Exploration Service |
| MetSat | Meteorological Satellite Service |

The deployment and use of satellites in the geostationary orbit represents a continuous series of changes, punctuated by new launches, reassignments, and the passage of older satellites reaching the end of their stationkeeping lifetimes. The tables below are intended to offer only a snapshot of that process and may contain data that have already become outdated by the time of publication. The author invites both comments and corrections and would welcome additional information for future updates.

**References**

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[3] International Frequency Registration Board, *List of Geostationary Space Stations (List A/List B)*, International Telecommunication Union, Geneva, June 1989.

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[5] National Aeronautics and Space Administration, Goddard Space Flight Center, Project Operations Branch, "Satellite Situation Report," Vol. 29, No. 2, June 1989.

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[7] M. Long, *The 1990 World Satellite Annual*, MLE, Inc., Winter Beach, Florida, 1989.

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TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 5.1E | 11 May 78 1978-44-A 10855 | OTS[5] OTS-2 | ESA | FSS 14a/11,12a | $P$ 1436.3 $r_a$ 35805 $r_p$ 35776 $i$ 5.6 $n$ -0.0523 | IFRB: 5.0E SPA-AA/90/1194 |
| 5.6E | 2 Apr 89 1989-27-A 19919 | TELE-X NOTELSAT | Sweden, Norway | FSS,BSS 14a,17,20a/ 12c,12d,12e,12f | $P$ 1436.1 $r_a$ 35915 $r_p$ 35658 $i$ 0.1 $n$ -0.0009 | IFRB: 5.0E AR11/A/27/1535 AR11/C/733/1674 |
| 6.0E | 11 Dec 88 1988-109-A 19687 | SKYNET-4B | UK | FSS,MSS 0.2,0.3a,0.3b, 8a,44/ 0.3a,0.3b,7b | $P$ 1436.1 $r_a$ 35800 $r_p$ 35773 $i$ 2.6 $n$ -0.0009 | IFRB: 6.0E AR11/A/22/1531 AR11/C/183/1611 -ADD1/1652 |
| 7.0E | 4 Aug 84 1984-81-A 15158 | EUTELSAT 1-2 EUTELSAT I-F2 ECS 2 | Eutelsat | FSS 14a/11,12c,12d | $P$ 1436.1 $r_a$ 35815 $r_p$ 35758 $i$ 0.2 $n$ -0.0009 | IFRB: 13.0E SPA-AA/278/1426 SPA-AJ/328/1492 SPA-AJ/330/1492 SPA-AJ/433/1516 AR11/C/445/1644 |
| 10.0E | 21 Jul 88 1988-63-B 19331 | EUTELSAT 1-2 EUTELSAT I-F5 ECS 5[6] | Eutelsat | FSS 14a/11,12c | $P$ 1436.1 $r_a$ 35809 $r_p$ 35763 $i$ 0.2 $n$ +0.0055 | IFRB: 13.0E AR11/A/61/1578 -ADD1/1582 -ADD2/1589 -ADD3/1593 AR11/C/1078/1789 |
| 10.0E | 6 Mar 89 1989-20-B 19876 | METEOSAT S1 METEOSAT-4 MOP-1 | ESA | MetSat,SRS,EES 2/1.6f,1.6g,0.4g | $P$ 1436.3 $r_a$ 35798 $r_p$ 35783 $i$ 1.0 $n$ -0.0523 | IFRB: 10.0E AR11/A/414/1815 AR11/C/1606/1892 |
| 11.0E | 18 Jan 85 1985-7-A 15484 | STATSIONAR-27[7] GORIZONT 11 | USSR | FSS 6b,14a/4a,11 | $P$ 1436.2 $r_a$ 35794 $r_p$ 35781 $i$ 2.7 $n$ -0.0137 | IFRB: 12.0E AR11/A/392/1799 -CORR1/1822 AR11/C/1593/1888 |
| 13.0E | 16 Sep 87 1987-78-B 18351 | EUTELSAT 1-4 EUTELSAT I-F4 ECS 4[6] | Eutelsat | FSS 14a/11,12c | $P$ 1436.1 $r_a$ 35952 $r_p$ 35620 $i$ 0.0 $n$ +0.0055 | IFRB: 16.0E AR11/A/218/1685 AR11/C/874/1737 AR11/C/1080/1789 |
| 15.6E | 16 Jun 83 1983-58-A 14128 | EUTELSAT-1 EUTELSAT I-F1 ECS 1[6] | Eutelsat | FSS 14a/11 | $P$ 1436.1 $r_a$ 35802 $r_p$ 35769 $i$ 0.1 $n$ +0.0119 | IFRB: 10.0 SPA-AA/229/1370 SPA-AJ/327/1492 SPA-AJ/329/1492 SPA-AJ/432/1516 AR11/A/60/1578 -ADD1/1582 -ADD2/1589 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE Up/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|---|
| 19.2E | 8 Feb 85 1985-15-A 15560 | ARABSAT 1-A[8] ARABSAT F1 ARABSAT 1 | Arab League | FSS,BSS 6b/2.5a,4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35814 35758 0.1 +0.0055 | -ADD3/1593 AR11/C/230/1617 AR11/C/444/1644 IFRB: 19.0E SPA2-3-AA/7/1347 SPA-AA/210/1347 SPA-AJ/172/1388 RES33/C/1/1597 |
| 19.2E | 11 Dec 88 1988-109-B 19688 | GDL-6 ASTRA 1A | Luxembourg— Societe Europeene des Satellites | FSS,BSS 14a/11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35790 35783 0.1 -0.0009 | IFRB: 19.2E AR11/A/94/1594 -ADD1/1708 -ADD2/1747 AR11/C/614/1657 AR11/C/1283/1827 |
| 21.0E | 22 Jun 84 1984-63-A 15057 | STATSIONAR-19[9] RADUGA 15 | USSR | FSS 6a,6b,8a/4a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1437.3 35825 35794 3.4 -0.2962 | IFRB: 23.0E AR11/A/221/1686 AR11/A/239/1693 AR11/C/914/1750 -CORR1/1812 AR11/C/916/1752 -CORR1/1756 |
| 21.4E | 13 Dec 73 1973-100-B 06974 | USGCSS PH2[10] DSCS II F-4[11] DSCS 1-B OPS 9434 | US | FSS 8a/7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35794 35778 10.2 +0.0055 | |
| 24.0E | 5 Jun 89 1989-41-B 20041 | DFS-1 DFS KOPERNIKUS | West Germany | FSS 14a,30a/ 11,12c,12d,20b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35865 35708 0.1 -0.0009 | IFRB: 23.5E AR11/A/40/1556 -ADD1/1611 -ADD2/1828 AR11/C/695/1760 -ADD1/1877 |
| 26.8E | 18 Jun 85 1985-48-C 15825 | ARABSAT 1-B[8] ARABSAT F2 | Arab League | FSS,BSS 6b/2.5a,4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1[12] 35833 35740 0.1 -0.0009 | IFRB: 26.0E SPA2-3-AA/8/1347 SPA-AA/211/1347 SPA-AJ/173/1388 RES33/C/2/1597 |
| 34.7E | 20 Oct 88 1988-95-A 19596 | STATSIONAR-D3 RADUGA 22 | USSR | FSS 6a,6b,8a/4a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35833 35739 0.9 +0.0055 | IFRB: 35.0E SPA-AA/340/1480 AR11/C/29/1561 AR11/A/195/1675 AR11/C/1170/1796 -CORR1/1894 |
| 40.0E | 28 Dec 79 1979-105-A 11648 | STATSIONAR-12 GORIZONT 3 | USSR | FSS 6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.3 35799 35782 7.5 -0.0523 | IFRB: 40.0E SPA-AA/271/1425 SPA-AJ/304/1469 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|---|
| 44.4E | 25 Oct 86 1986-82-A 17046 | STATSIONAR-D4 RADUGA 19 | USSR | FSS 6a,6b,8a/4a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.0 35787 35783 1.2 +0.0184 | IFRB: 45.0E SPA-AA/154/1262 SPA-AJ/112/1335 AR11/A/196/1675 AR11/C/1171/1796 -CORR1/1894 |
| 45.4E | 15 Dec 89 1989-98-A 20367 | STATSIONAR-D4 RADUGA 24 | USSR | FSS 6a,6b,8a/4a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.0 35805 35763 1.3 +0.0312 | IFRB: 45.0E SPA-AA/154/1262 SPA-AJ/112/1335 AR11/A/196/1675 AR11/C/1171/1796 -CORR1/1894 |
| 48.9E | 21 Jun 89 1989-48-A 20083 | STATSIONAR-24 RADUGA 1-1 | USSR | FSS 6a,6b,8a/4a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.4 35815 35768 1.4 -0.0651 | IFRB: 49.0E AR11/A/314/1740 -ADD1/1798 -ADD2/1826 AR11/A/411/1806 -CORR1/1822 AR11/C/1497/1878 |
| 50.4E | 26 Dec 80 1980-104-A 12120 | STATSIONAR-T2[9] EKRAN 6[11] | USSR | FSS,BSS 6a,6b/4a | $P$ $r_a$ $r_p$ | 1436.5 35819 35769 | IFRB: 99.0E SPA2-3-AA/10/1426 SPA2-3-AJ/7/1469 |
| | | | | | $i$ $n$ | 7.1 -0.0972 | |
| 52.7E | 26 Jan 89 1989-4-A 19765 | STATSIONAR-5 GORIZONT 17 | Intersputnik | FSS 6b,14a/4a,11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35789 35786 1.1 -0.0137 | IFRB: 53.0E SPA-AA/93/1197 SPA-AA/150/1271 AR11/C/1114/1793 AR11/C/1200/1809 |
| 53.1E | 22 Apr 84 1984-41-A 14940 | STATSIONAR-5[13] GORIZONT 9 | Intersputnik | FSS 6b,14a/4a,11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1435.5 35783 35766 3.4 +0.1532 | IFRB: 53.0E SPA-AA/93/1197 SPA-AA/150/1271 AR11/C/769/1678 AR11/C/889/1743 -ADD1/1800 |
| 55.2E | 25 Oct 85 1985-102-A 16199 | CSDRN[14] COSMOS 1700 | USSR | FSS,SRS 14b,14f/11,13c | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.6 35811 35781 2.0 -0.1229 | IFRB: 95.0E SPA-AA/341/1484 SPA-AA/342/1484 AR11/C/69/1570 |
| 56.0E | 25 Aug 77 1977-80-A 10294 | SIRIO[15] SIRIO-1 | Italy | FSS 17/11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.6 35862 35728 5.9 -0.1100 | IFRB: 15.0W SPA-AA/73/1174 SPA-AA/102/1204 SPA-AJ/65/1282 |
| 57.4E | 23 Nov 74 1974-94-A 07547 | SKYNET-2B[10] | UK | FSS 8a/7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1437.7 35838 35798 9.0 -0.4054 | |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | Launch Date/ International Catalog Number[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Orbit Parameters[4] | | Registration Special Section Numbers |
|---|---|---|---|---|---|---|---|
| 59.5E | 30 Oct 82 1982-106-A 13636 | USGCSS PH2 INDOC DSCS II F-15 | US | FSS 8a/7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35793 35777 3.8 +0.0184 | IFRB: 60.0E SPA-AA/140/1253 |
| 60.0E | 27 Jan 89 1989-6-A 19772 | INTELSAT5A INDOC1[16] INTELSAT V-A IND 1 INTELSAT V-A F-15 | Intelsat | FSS 6b,14a/ 4a,11, 12a,12c,12d[17] | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35804 35769 0.0 -0.0009 | IFRB: 60.0E AR11/A/67/1580 AR11/C/462/1646 |
| 62.9E | 28 Sep 82 1982-97-A 13595 | INTELSAT5 INDOC1 INTELSAT V IND 1 INTELSAT MCS INDOC A INTELSAT V F-5 | Intelsat | FSS,MMSS 1.6b,6b,14a/ 1.5b,4a,11[18] | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.0 35807 35765 0.0 +0.0055 | IFRB: 63.0E SPA-AA/134/1250 SPA-AJ/58/1279 SPA-AA/214/1348 SPA-AJ/176/1389 AR11/C/1095/1791 |
| 66.0E | 19 Oct 83 1983-105-A 14421 | INTELSAT5 INDOC4 INTELSAT V IND 4 INTELSAT MCS INDOC D INTELSAT V F-7 | Intelsat | FSS,MMSS 1.6b,6b,14a/ 1.5b,4a,11[18] | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35803 35771 0.0 -0.0073 | IFRB: 66.0E SPA-AA/253/1419 SPA-AA/275/1425 SPA-AJ/353/1500 SPA-AJ/375/1511 AR11/C/857/1735 |
| 67.9E | 25 Jun 81 1981-61-A 12564 | STATSIONAR-T2[9] EKRAN 7[11] | USSR | FSS,BSS 6a,6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.9 35846 35757 6.8 -0.1935 | IFRB: 99.0E SPA2-3-AA/10/1426 SPA2-3-AJ/7/1469 |
| 68.6E | 8 Apr 83 1983-28-A 13974 | STATSIONAR-20[9] RADUGA 12 | USSR | FSS 6a,6b,8a/4a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35795 35778 4.5 -0.0009 | IFRB: 70.0E AR11/A/316/1740 -CORR1/1760 AR11/A/387/1798 -ADD1/1826 AR11/C/1193/1804 -CORR1/1822 AR11/C/1499/1878 |
| 69.1E | 15 Nov 85 1985-107-A 16250 | STATSIONAR-20[19] RADUGA 17 | USSR | FSS 6a,6b,8a/4a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35792 35786 2.0 -0.0330 | IFRB: 70.0E AR11/A/316/1740 -CORR1/1760 AR11/A/387/1798 -ADD1/1826 AR11/C/1193/1804 -CORR1/1822 AR11/C/1499/1878 |
| 70.0E | 30 Sep 83 1983-100-A 14377 | STATSIONAR-T2[9] EKRAN 11 | USSR | FSS,BSS 6a,6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.9 35807 35797 4.9 -0.1999 | IFRB: 99.0E SPA2-3-AA/10/1426 SPA2-3-AJ/7/1469 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|---|
| 72.3E | 4 May 79 1979-38-A 11353 | FLTSATCOM INDOC FLTSATCOM F-2 FLTSATCOM 2 OPS 6392 | US | FSS,MSS 0.3a,8a/0.3a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35848 35723 6.1 +0.0119 | IFRB: 72.0E SPA-AA/87/1186 SPA-AJ/169/1382 AR11/A/338/1762 |
| 72.4E | 10 Jun 76 1976-53-A 08882 | MARISAT-INDOC[20] MARISAT F-2 MARISAT 2 | US— Comsat General | FSS,MSS,MMSS 0.3a,1.6b,6b/ 0.3a,1.5b,4a[21] | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35806 35768 6.7 -0.0073 | IFRB: 72.5E SPA-AA/125/1237 SPA-AA/131/1243 SPA-AJ/56/1277 SPA-AJ/57/1277 |
| 72.7E | 31 Aug 84 1984-93-C 15236 | FLTSATCOM-A INDOC SYNCOM IV-2 LEASESAT F-2 LEASAT 2 | US— Hughes Communications | FSS,MSS 0.3a,8a/0.3a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35792 35781 1.1 -0.0009 | IFRB: 77.0E AR11/A/100/1605 -ADD1/1652 AR11/A/336/1762 -ADD1/1794 -ADD2/1802 |
| 74.2E | 31 Aug 83 1983-89-B 14318 | INSAT-1B | India | FSS,BSS, MetSat,EES 0.4b,6b/2.5a,4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35800 35774 0.0 -0.0073 | IFRB: 74.0E SPA-AA/208/1344 SPA-AJ/231/1429 |
| 79.5E | 2 Mar 84 1984-22-A 14783 | STATSIONAR-13 COSMOS 1540[22] | USSR | FSS 6b,14a/4a,11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.0 35797 35773 4.0 +0.0184 | IFRB: 80.0E SPA-AA/276/1426 AR11/C/598/1655 -ADD1/1737 AR11/A/271/1707 -CORR1/1728 AR11/C/1048/1779 |
| 80.3E | 18 Aug 88 1988-71-A 19397 | STATSIONAR-13 GORIZONT 16 | Intersputnik | FSS 6b,14a/4a,11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35808 35768 0.6 -0.0201 | IFRB: 80.0E SPA-AA/276/1426 AR11/A/271/1707 AR11/C/1048/1779 AR11/C/1124/1793 |
| 80.4E | 1 Oct 87 1987-84-A 18384 | STATSIONAR-13 COSMOS 1888[22] | Intersputnik | FSS 6b,14a/4a,11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.0 35805 35763 0.2 +0.0312 | IFRB: 80.0E SPA-AA/276/1426 AR11/A/271/1707 AR11/C/1048/1779 AR11/C/1124/1793 |
| 81.1E | 5 Jul 89 1979-62-A 11440 | STATSIONAR-13[9] GORIZONT 2[11] | USSR | FSS 6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1435.7 35788 35767 7.8 +0.1146 | IFRB: 80.0E SPA-AA/276/1426 SPA-AJ/305/1469 |
| 81.7E | 17 May 82 1982-44-A 13177 | STATSIONAR-13[9] COSMOS 1366[22] | USSR | FSS 6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35797 35774 5.7 +0.0119 | IFRB: 80.0E SPA-AA/276/1426 SPA-AJ/310/1469 AR11/C/598/1655 -ADD1/1737 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | Launch Date/ International Catalog Number[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Orbit Parameters[4] | Registration Special Section Numbers |
|---|---|---|---|---|---|---|
| 84.5E | 15 Feb 84 1984-16-A 14725 | STATSIONAR-3 RADUGA 14 | USSR | FSS 6a,6b,8a/4a,7b | $P$ 1436.1 $r_a$ 35810 $r_p$ 35761 $i$ 3.7 $n$ +0.0119 | IFRB: 85.0E SPA-AA/77/1179 SPA-AJ/27/1251 SPA-AA/155/1262 SPA-AJ/113/1335 |
| 85.3E | 19 Mar 87 1987-28-A 17611 | STATSIONAR-D5 RADUGA 20 | USSR | FSS 6a,6b,8a/4a,7b | $P$ 1436.1 $r_a$ 35793 $r_p$ 35779 $i$ 1.3 $n$ +0.0055 | IFRB: 85.0E SPA-AA/155/1262 SPA-AJ/113/1335 AR11/A/197/1675 AR11/C/1172/1796 -CORR1/1894 |
| 87.2E | 9 Oct 81 1981-102-A 12897 | STATSIONAR-3[9] RADUGA 10 | USSR | FSS 6a,6b,8a/4a,7b | $P$ 1435.9 $r_a$ 35792 $r_p$ 35771 $i$ 6.5 $n$ +0.0633 | IFRB: 85.0E SPA-AA/77/1179 SPA-AJ/27/1251 SPA-AA/155/1262 SPA-AJ/113/1335 |
| 87.6E | 7 Mar 88 1988-14-A 18922 | CHINASAT-1 DFH2-A1 PRC 22 | China | FSS 6b/4a | $P$ 1436.1 $r_a$ 35794 $r_p$ 35778 $i$ 0.1 $n$ +0.0055 | IFRB: 87.5E AR11/A/255/1702 -ADD1/1712 AR11/C/1027/1778 |
| 88.0E | 20 Sep 77 1977-92-A 10365 | STATSIONAR-T[9] EKRAN 2[11] | USSR | FSS,BSS 6a,6b/4a | $P$ 1436.6 $r_a$ 35967 $r_p$ 35624 $i$ 9.2 $n$ -0.1165 | IFRB: 99.0E SPA2-3-AA/2/1153 |
| 89.7E | 18 Nov 86 1986-90-A 17083 | STATSIONAR-6 GORIZONT 13 | USSR | FSS 6b,14a/4a,11 | $P$ 1436.3 $r_a$ 35795 $r_p$ 35784 $i$ 1.0 $n$ -0.0394 | IFRB: 90.0E SPA-AA/108/1210 SPA-AJ/30/1251 SPA-AA/151/1261 SPA-AJ/86/1318 AR11/C/1116/1793 |
| 93.4E | 21 Jul 88 1988-63-A 19330 | INSAT-1C | India | FSS,BSS, MetSat,EES 0.4b,6b/2.5a,4a | $P$ 1436.2 $r_a$ 35790 $r_p$ 35784 $i$ 0.1 $n$ -0.0073 | IFRB: 93.5E AR11/A/191/1673 -CORR1/1688 AR11/C/851/1708 |
| 95.1E | 26 Nov 87 1987-96-A 18575 | CSDRN[14] COSMOS 1897 | USSR | FSS,SRS 14b,14f/11,13c | $P$ 1436.1 $r_a$ 35812 $r_p$ 35761 $i$ 0.1 $n$ -0.0009 | IFRB: 95.0E SPA-AA/341/1484 SPA-AA/342/1484 AR11/C/69/1570 |
| 96.2E | 5 Jul 89 1989-52-A 20107 | STATSIONAR-14 GORIZONT 18 | USSR | FSS 6b,14a/4a,11 | $P$ 1436.1[12] $r_a$ 35807 $r_p$ 35774 $i$ 1.3 $n$ -0.0523 | IFRB: 96.5E SPA-AA/272/1425 SPA-AJ/306/1469 AR11/A/272/1707 -CORR1/1728 AR11/C/1050/1779 AR11/C/1181/1802 |

| Subsatellite Longitude[1] (deg) | Launch Date/ International Catalog Number[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Orbit Parameters[4] | | Registration Special Section Numbers |
|---|---|---|---|---|---|---|---|
| 96.5E | 15 Mar 82 1982-20-A 13092 | STATSIONAR-14 GORIZONT 5 | USSR | FSS 6b,14a/4a,11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.3 35933 35647 6.1 -0.0458 | IFRB: 96.5E SPA-AA/272/1425 SPA-AJ/306/1469 AR11/A/272/1707 -CORR1/1728 AR11/C/1050/1779 |
| 98.9E | 6 May 88 1988-36-A 19090 | STATSIONAR-T2 EKRAN 18 | USSR | FSS,BSS 6a,6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35793 35784 0.6 -0.0265 | IFRB: 99.0E SPA2-3-AA/10/1426 SPA2-3-AJ/7/1469 |
| 99.1E | 8 Dec 88 1988-108-A 19683 | STATSIONAR-T2 EKRAN 19 | USSR | FSS,BSS 6a,6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.0 35792 35776 0.9 +0.0312 | IFRB: 99.0E SPA2-3-AA/10/1426 SPA2-3-AJ/7/1469 |
| 99.4E | 27 Dec 87 1987-109-A 18715 | STATSIONAR-T2 EKRAN 17 | USSR | FSS,BSS 6a,6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35793 35777 0.2 +0.0184 | IFRB: 99.0E SPA2-3-AA/10/1426 SPA2-3-AJ/7/1469 |
| 99.7E | 4 Sep 87 1987-73-A 18328 | STATSIONAR-T2 EKRAN 16 | USSR | FSS,BSS 6a,6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35804 35767 1.3 +0.0119 | IFRB: 99.0E SPA2-3-AA/10/1426 SPA2-3-AJ/7/1469 |
| 101.5E | 1 Feb 86 1986-10-A 16526 | STW-2[23] PRC 18 | China | FSS 6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1435.8 35785 35776 0.8 +0.0761 | IFRB: 103.0E AR11/A/245/1695 -ADD1/1712 AR11/C/1023/1777 |
| 103.0E | 11 May 87 1987-40-A 17969 | STATSIONAR-21[24] GORIZONT 14 | USSR | FSS 6b,14a/4a,11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35792 35785 2.8 -0.0265 | IFRB: 103.0E AR11/A/243/1694 AR11/A/244/1694 AR11/C/905/1748 -ADD1/1752 -ADD2/1765 AR11/C/966/1766 |
| 108.1E | 18 Jun 83 1983-59-C 14134 | PALAPA-B1 PALAPA B-1 | Indonesia | FSS 6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.3 35792 35787 0.0 -0.0394 | IFRB: 108.0E SPA-AA/197/1319 SPA-AJ/185/1397 |
| 109.8E | 12 Feb 86 1986-16-A 16597 | BS-2 BS-2B YURI 2B[25] | Japan | FSS,BSS 14a/12e | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35805 35770 0.0 -0.0137 | IFRB: 110.0E SPA-AA/305/1459 SPA-AA/362/1512 AR11/C/10/1556 |

## Table 1. In-Orbit Geostationary Communications Satellites for Year-End 1989

| Subsatellite Longitude[1] (deg) | Launch Date/ International Catalog Number[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Orbit Parameters[4] | Registration Special Section Numbers |
|---|---|---|---|---|---|---|
| 110.0E | 23 Jan 84 1984-5-A 14659 | BS-2 BS-2A YURI 2A[26] | Japan | FSS,BSS 14a/12e | $P$ 1436.4 $r_a$ 35800 $r_p$ 35782 $i$ 0.6 $n$ -0.0586 | IFRB: 110.0E SPA-AA/305/1459 SPA-AA/362/1512 AR11/C/10/1556 |
| 110.4E | 22 Dec 88 1988-111-A 19710 | CHINASAT-2 DFH2-A2 PRC 25 | China | FSS 6b/4a | $P$ 1436.1 $r_a$ 35788 $r_p$ 35786 $i$ 0.1 $n$ -0.0073 | IFRB: 110.5E AR11/A/256/1702 AR11/C/1034/1778 |
| 113.1E | 20 Mar 87 1987-29-A 17706 | PALAPA-B2 PALAPA B-2P | Indonesia | FSS 6b/4a | $P$ 1436.2 $r_a$ 35791 $r_p$ 35786 $i$ 0.1 $n$ -0.0265 | IFRB: 113.0E SPA-AA/198/1319 SPA-AJ/187/1397 SPA-AJ/201/1407 |
| 124.7E | 8 May 85 1985-35-B 15678 | TELECOM-1B[27] | France | FSS 6b,8a,14a/ 4a,7b,12c,12d[28] | $P$ 1434.6 $r_a$ 35767 $r_p$ 35746 $i$ 1.3 $n$ +0.3843 | IFRB: 5.0W SPA-AA/269/1425 SPA-AJ/472/1612 AR11/C/128/1593 -ADD1/1619 AR11/C/186/1611 AR11/C/391/1628 |
| 127.6E | 10 Dec 87 1987-100-A 18631 | STATSIONAR-D6 RADUGA 21 | USSR | FSS 6a,6b,8a/4a,7b | $P$ 1436.3 $r_a$ 35793 $r_p$ 35788 $i$ 0.3 $n$ -0.0523 | IFRB: 128.0E AR11/A/198/1675 AR11/A/247/1695 AR11/C/919/1753 AR11/C/1173/1796 |
| 128.0E | 4 Feb 83 1983-6-A 13782 | CS-2A SAKURA 1 | Japan | FSS 6b,30a/ 4a,20a,20b | $P$ 1436.1 $r_a$ 35791 $r_p$ 35781 $i$ 1.8 $n$ +0.0055 | IFRB: 132.0E[29] SPA-AA/256/1421 SPA-AJ/323/1490 SPA-AJ/359/1505 |
| 128.0E | 5 Aug 83 1983-81-A 14248 | CS-2B SAKURA 2 | Japan | FSS 6b,30a/ 4a,20a,20b | $P$ 1436.1 $r_a$ 35791 $r_p$ 35783 $i$ 1.1 $n$ -0.0073 | IFRB: 136.0E[29] SPA-AA/257/1421 SPA-AJ/325/1490 SPA-AJ/368/1508 |
| 129.9E | 23 Feb 77 1977-14-A 09852 | ETS-2[30] KIKU 2 | Japan | MetSat,SRS 2/0.1c,1.7a | $P$ 1436.1 $r_a$ 35790 $r_p$ 35783 $i$ 8.0 $n$ -0.0009 | IFRB: 130.0E SPA-AA/91/1194 |
| 131.9E | 19 Feb 88 1988-12-A 18877 | CS-3A SAKURA 3A | Japan | FSS 6b,30a/ 4a,20a,20b | $P$ 1436.2 $r_a$ 35793 $r_p$ 35784 $i$ 0.1 $n$ -0.0265 | IFRB: 132.0E AR11/A/212/1680 AR11/C/1128/1794 -ADD1/1805 -CORR1/1810 -CORR2/1835 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|---|
| 135.8E | 27 Aug 87 1987-70-A 18316 | ETS-5[30] EMSS-C | Japan | FSS,MMSS,AMSS 1.6b,1.6d,6b/ 1.5b,1.5d,5a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 36010 35565 0.0 -0.0137 | IFRB: 150.0E AR11/A/217/1685 AR11/C/920/1754 AR11/C/923/1754 |
| 135.9E | 16 Sep 88 1988-86-A 19508 | CS-3B SAKURA 3B | Japan | FSS 6b,30a/ 4a,20a,20b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35791 35785 0.0 -0.0201 | IFRB: 136.0E AR11/A/213/1680 AR11/C/1145/1794 -ADD1/1805 -CORR1/1835 |
| 137.8E | 2 Aug 84 1984-80-A 15152 | GMS-3[31] HIMAWARI 3 | Japan | MetSat,SRS,EES 2/0.4g,1.6f,1.6g | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35789 35787 1.0 -0.0201 | IFRB: 140.0E AR11/A/54/1563 AR11/C/474/1648 -ADD1/1887 |
| 150.0E | 6 Mar 89 1989-20-A 19874 | JCSAT-1 JC-SAT 1 | Japan– Japan Communications Satellite | FSS 14a/12b,12c,12d | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35792 35784 0.0 -0.0201 | IFRB: 150.0E AR11/A/253/1700 AR11/C/946/1763 -CORR1/1813 -CORR2/1860 -ADD1/1860 |
| 154.0E | 31 Dec 89 1990-1-B 20402 | JCSAT-2 JC-SAT 2 | Japan– Japan Communications Satellite | FSS 14a/12b,12c,12d | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35794 35782 0.0 -0.0201 | IFRB: 154.0E AR11/A/254/1700 AR11/C/953/1763 -CORR1/1813 -CORR2/1860 -ADD1/1860 |
| 154.0E | 26 Nov 82 1982-113-A 13669 | STATSIONAR-2[9] RADUGA 11 | USSR | FSS 6a,6b,8a/4a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1473.8 36688 36355 4.7 -9.4398 | IFRB: 35.0E SPA-AA/76/1179 SPA-AJ/26/1251 SPA-AA/340/1480 AR11/C/29/1561 AR11/C/109/1578 |
| 156.0E | 27 Nov 85 1985-109-C 16275 | AUSSAT-2 AUSSAT A2 AUSSAT K-2 | Australia | FSS,BSS 14a/12b, 12c,12d,12g,12h | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35793 35783 0.0 -0.0201 | IFRB: 156.0E SPA-AA/300/1456 SPA-AA/373/1575 AR11/C/305/1624 |
| 157.9E | 5 Jun 89 1989-41-A 20040 | SUPERBIRD-A | Japan— Space Communications Corporation | FSS 14a,30a/ 12b,12c,20a,20b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35802 35768 0.1 +0.0184 | IFRB: 158.0E AR11/A/340/1762 AR11/C/1303/1836 -CORR1/1865 |
| 159.6E | 5 Sep 89 1989-70-A 20217 | GMS-160E[31] GMS-4 | Japan | MetSat,SRS,EES 2/0.4g,1.6f,1.6g | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2[12] 35854 35720 1.6 -0.0073 | IFRB: 160.0E SPA-AA/72/1173 AR11/C/8/1555 -ADD1/1887 AR11/A/423/1821 -ADD1/1833 AR11/C/1464/1875 -CORR1/1886 |

### TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 160.0E | 27 Aug 85<br>1985-76-B<br>15993 | AUSSAT-1<br>AUSSAT A1<br>AUSSAT K-1 | Australia | FSS,BSS<br>14a/12b,<br>12c,12d,12g,12h | $P$ 1436.2<br>$r_a$ 35795<br>$r_p$ 35780<br>$i$ 0.0<br>$n$ -0.0137 | IFRB: 160.0E<br>SPA-AA/299/1456<br>SPA-AA/372/1575<br>AR11/C/296/1624 |
| 164.0E | 16 Sep 87<br>1987-78-A<br>18350 | AUSSAT-3<br>AUSSAT A3<br>AUSSAT K-3 | Australia | FSS,BSS<br>14a/12b,<br>12c,12d,12g,12h | $P$ 1436.1<br>$r_a$ 35796<br>$r_p$ 35777<br>$i$ 0.1<br>$n$ -0.0009 | IFRB: 164.0E<br>SPA-AA/301/1456<br>SPA-AA/374/1575<br>AR11/C/314/1624 |
| 167.6E | 14 Jul 77<br>1977-65-A<br>10143 | GMS-140E[9,31]<br>GMS-1[11]<br>HIMAWARI 1 | Japan | MetSat,SRS,EES<br>2/0.4g,1.6f,1.6g | $P$ 1436.0<br>$r_a$ 36139<br>$r_p$ 35432<br>$i$ 7.1<br>$n$ +0.0119 | IFRB: 140.0E<br>SPA-AA/72/1173<br>SPA-AJ/95/1329 |
| 171.6E | 31 Oct 80<br>1980-87-A<br>12046 | FLTSATCOM W PAC<br>FLTSATCOM F-4<br>FLTSATCOM 4 | US | FSS,MSS<br>0.3a,8a/0.3a,7b | $P$ 1436.2<br>$r_a$ 35794<br>$r_p$ 35781<br>$i$ 5.4<br>$n$ -0.0137 | IFRB: 172.0E<br>SPA-AA/86/1186<br>SPA-AJ/167/1382 |
| 174.0E | 15 Dec 81<br>1981-119-A<br>12994 | INTELSAT5 PAC1[32]<br>INTELSAT V PAC 1<br>INTELSAT V F-3 | Intelsat | FSS<br>6b,14a/4a,11 | $P$ 1436.2<br>$r_a$ 35805<br>$r_p$ 35772<br>$i$ 0.2<br>$n$ -0.0265 | IFRB: 174.0E<br>SPA-AA/254/1419<br>SPA-AJ/376/1511 |
| 175.2E | 21 Nov 79<br>1979-98-A<br>11621 | USGCSS PH2 W PAC<br>DSCS II F-13<br>DSCS 2-D<br>OPS 9443 | US | FSS<br>8a/7b | $P$ 1436.2<br>$r_a$ 35790<br>$r_p$ 35785<br>$i$ 5.6<br>$n$ -0.0137 | IFRB: 175.0E<br>SPA-AJ/403/1514 |
| 176.1E | 14 Oct 76<br>1976-101-A<br>09478 | MARISAT-PAC[20]<br>MARISAT F-3<br>MARISAT 3 | US—<br>Comsat General | FSS,MSS,MMSS<br>0.3a,1.6b,6b/<br>0.3a,1.5b,4a[21] | $P$ 1436.1<br>$r_a$ 35791<br>$r_p$ 35782<br>$i$ 8.2<br>$n$ -0.0009 | IFRB: 176.5E<br>SPA-AA/3/1101<br>SPA-AA/6/1101<br>SPA-AJ/25/1244 |
| 177.0E | 23 May 81<br>1981-50-A<br>12474 | INTELSAT5 PAC2<br>INTELSAT V PAC 2<br>INTELSAT V F-1 | Intelsat | FSS<br>6b,14a/4a,11 | $P$ 1436.2<br>$r_a$ 35804<br>$r_p$ 35773<br>$i$ 1.2<br>$n$ -0.0265 | IFRB: 177.0E<br>SPA-AA/225/1419<br>SPA-AJ/377/1511<br>AR11/A/81/1588<br>AR11/C/590/1652<br>-ADD1/1660<br>AR11/C/681/1668<br>-ADD1/1802 |
| 177.5E | 14 Dec 78<br>1978-113-B<br>11145 | USGCSS PH2 W PAC-2<br>DSCS II F-12[33]<br>DSCS 2-C<br>OPS 9442 | US | FSS<br>8a/7b | $P$ 1436.1<br>$r_a$ 35792<br>$r_p$ 35779<br>$i$ 5.9<br>$n$ +0.0119 | IFRB: 180.0E<br>AR11/A/405/1805 |

| Subsatellite Longitude[1] (deg) | Launch Date/ International Catalog Number[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Orbit Parameters[4] | Registration Special Section Numbers |
|---|---|---|---|---|---|---|
| 177.9E | 20 Dec 81 1981-122-A 13010 | MARECS PAC1 MARECS PAC OC 1 MARECS A MAREC 1 | ESA | FSS,MMSS 1.6b,6b/1.5b,4a | $P$ 1436.1 $r_a$ 35803 $r_p$ 35773 $i$ 3.2 $n$ -0.0201 | IFRB: 178.0E SPA-AA/219/1353 SPA-AJ/241/1432 |
| 179.0E | 29 Aug 85 1985-76-D 15995 | FLTSATCOM-A[10] SYNCOM IV-4[34] LEASESAT F-4 LEASAT 4 | US— Hughes Communications | FSS,MSS 0.3a,8a/0.3a,7b | $P$ 1440.4 $r_a$ 36519 $r_p$ 35233 $i$ 0.3 $n$ -1.1502 | |
| 180.0E (180.0W) | 3 Mar 84 1984-23-A 14786 | INTELSAT5 PAC3 INTELSAT V PAC 3 INTELSAT MCS PAC A INTELSAT V F-8 | Intelsat | FSS,MMSS 1.6b,6b,14a/ 1.5b,4a,11[18] | $P$ 1436.1 $r_a$ 35800 $r_p$ 35774 $i$ 0.0 $n$ -0.0073 | IFRB: 180.0E SPA-AA/255/1419 SPA-AA/332/1476 SPA-AJ/455/1535 SPA-AJ/469/1599 AR11/C/682/1668 -ADD1/1805 AR11/C/692/1669 AR11/C/859/1735 |
| 183.9E (176.1W) | 9 Feb 78 1978-16-A | FLTSATCOM-A W PAC FLTSATCOM F-1 | US | FSS,MSS 0.3a,8a/0.3a,7b | $P$ 1436.0 $r_a$ 35793 | IFRB: 177.0W AR11/A/99/1605 |
| | 10669 | FLTSATCOM 1 OPS 6391 | | | $r_p$ 35775 $i$ 7.5 $n$ +0.0312 | -ADD1/1652 AR11/A/335/1762 -ADD1/1794 |
| 185.4E (174.6W) | 21 Nov 79 1979-98-B 11622 | USGCSS PH2 W PAC-2[9] DSCS II F-14[35] DSCS 2-E OPS 9444 | US | FSS 8a/7b | $P$ 1436.0 $r_a$ 35792 $r_p$ 35777 $i$ 5.6 $n$ +0.0247 | IFRB: 180.0E AR11/A/405/1805 |
| 188.8E (171.2W) | 29 Sep 88 1988-91-B 19548 | TDRS WEST TDRS-3 TDRS-C | US | FSS,SRS 2.1,6b,14f/ 2,2.2,4a,13c | $P$ 1436.3 $r_a$ 35798 $r_p$ 35781 $i$ 0.5 $n$ -0.0394 | IFRB: 171.0W SPA-AA/232/1381 AR11/C/47/1568 -ADD1/1595 |
| 190.5E (169.5W) | 17 Jan 86 1986-7-A 16497 | STATSIONAR-D2 RADUGA 18[36] | USSR | FSS 6a,6b,8a/4a,7b | $P$ 1426.1 $r_a$ 35752 $r_p$ 35427 $i$ 2.0 $n$ +2.5290 | IFRB: 170.0W SPA-AA/156/1262 SPA-AJ/114/1335 AR11/A/194/1672 AR11/C/1169/1796 -CORR1/1894 |
| 191.0E (169.0W) | 1 Aug 84 1984-78-A 15144 | STATSIONAR-10[37] GORIZONT 10 | USSR | FSS 6b,14a/4a,11 | $P$ 1436.3 $r_a$ 35808 $r_p$ 35772 $i$ 3.1 $n$ -0.0458 | IFRB: 170.0W SPA-AA/97/1197 SPA-AJ/52/1276 SPA-AJ/64/1280 |
| 212.9E (147.1W) | 20 Oct 82 1982-103-A 13624 | STATSIONAR-26 GORIZONT 6[9,38] | USSR | FSS 6b,14a/4a,11 | $P$ 1435.6 $r_a$ 35782 $r_p$ 35771 $i$ 5.3 $n$ +0.1275 | IFRB: 155.0W AR11/A/385/1797 -ADD1/1803 -CORR1/1813 AR11/C/1313/1836 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | Launch Date/ International Catalog Number[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Orbit Parameters[4] | Registration Special Section Numbers |
|---|---|---|---|---|---|---|
| 217.0E (143.0W) | 28 Oct 82 1982-105-A 13631 | US SATCOM-5 RCA SATCOM 5 SATCOM V AURORA 1 | US— Alascom | FSS 6b/4a | $P$ 1436.1 $r_a$ 35788 $r_p$ 35786 $i$ 0.0 $n$ -0.0073 | IFRB: 143.0W AR11/A/7/1524 AR11/C/414/1630 |
| 221.1E (138.9W) | 11 Apr 83 1983-30-A 13984 | US SATCOM 1-R GE SATCOM 1-R SATCOM F1R SATCOM IR | US— RCA Americom[39] | FSS 6b/4a | $P$ 1436.1 $r_a$ 35793 $r_p$ 35780 $i$ 0.0 $n$ -0.0009 | IFRB: 139.0W AR11/A/6/1524 -ADD1/1548 AR11/C/337/1625 |
| 223.9E (136.1W) | 28 Apr 83 1983-41-A 14050 | GOES WEST GOES-6[40] | US | MetSat,SRS,EES 0.4b,2/ 0.4g,1.6f,1.6g | $P$ 1436.0 $r_a$ 35793 $r_p$ 35779 $i$ 1.3 $n$ +0.0055 | IFRB: 135.0W SPA-AA/28/1147 SPA-AJ/367/1508 |
| 225.1E (134.9W) | 30 Oct 82 1982-106-B 13637 | USGCSS PH3 E PAC DSCS III F-1 DSCS III-A1 PSCS 16 | US | FSS,MSS 0.3a,8a/0.3a,7b[41] | $P$ 1436.1 $r_a$ 35802 $r_p$ 35772 $i$ 0.1 $n$ -0.0073 | IFRB: 135.0W SPA-AA/248/1413 SPA-AJ/344/1499 AR11/C/405/1629 |
| 225.9E (134.1W) | 28 Jun 83 1983-65-A 14158 | USASAT-11D HUGHES GALAXY 1 GALAXY 1 | US— Hughes Communications | FSS 6b/4a | $P$ 1436.2 $r_a$ 35789 $r_p$ 35786 $i$ 0.0 $n$ -0.0137 | IFRB: 134.0W AR11/A/120/1615 AR11/C/821/1696 |
| 228.9E (131.1W) | 14 Dec 78 1978-113-A 11144 | USGCSS PH2 E PAC-2 DSCS II F-11 DSCS 2-B OPS 9441 | US | FSS 8a/7b | $P$ 1436.4 $r_a$ 35801 $r_p$ 35784 $i$ 6.0 $n$ -0.0779 | IFRB: 130.0W AR11/A/404/1805 |
| 229.1E (130.9W) | 21 Nov 81 1981-114-A 12967 | US SATCOM 3-R GE SATCOM 3-R SATCOM F3R SATCOM IIIR | US— RCA Americom[39] | FSS 6b/4a | $P$ 1436.1 $r_a$ 35795 $r_p$ 35779 $i$ 0.1 $n$ -0.0073 | IFRB: 131.0W SPA-AA/329/1476 AR11/C/347/1625 AR11/C/348/1625 |
| 229.9E (130.1W) | 16 Jun 78 1978-62-A 10953 | GOES WEST[9] GOES-3[42] | US | MetSat,SRS,EES 0.4b,2/ 0.4g,1.6f,1.6g | $P$ 1436.2 $r_a$ 35820 $r_p$ 35756 $i$ 6.1 $n$ -0.0201 | IFRB: 135.0W SPA-AA/28/1147 SPA-AJ/367/1508 |
| 231.4E (128.6W) | 3 Nov 71 1971-95-B 05588 | USGCSS PH2[10] DSCS II F-2[11] | US | FSS 8a/7b | $P$ 1435.1 $r_a$ 35782 $r_p$ 35751 $i$ 10.7 $n$ +0.2559 | |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|---|
| 232.3E (127.7W) | 27 Aug 85 1985-76-C 15994 | ASC-1 CONTEL ASC-1 | US— American Satellite Co. | FSS 6b,14a/4a,12a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35796 35776 0.0 -0.0055 | IFRB: 128.0W AR11/A/202/1676 AR11/A/301/1723 -ADD1/1801 AR11/C/1066/1784 AR11/C/1106/1792 |
| 234.6E (125.4W) | 22 Apr 76 1976-35-A 08808 | SATCOM PHASE-3[9] NATO III-A NATO 3A | NATO | FSS 8a/7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35806 35770 7.4 -0.0201 | IFRB: 18.0W SPA-AA/144/1247 SPA-AJ/137/1355 |
| 234.9E (125.1W) | 19 Jun 85 1985-48-D 15826 | USASAT-20A TELSTAR 3D[43] TELSTAR 303 | US— AT&T | FSS 6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35794 35779 0.0 -0.0009 | IFRB: 126.0W AR11/A/304/1730 AR11/C/968/1769 |
| 237.0E (123.0W) | 8 Sep 88 1988-81-B 19484 | USASAT-10A STLC 2 SBS-5 | US— Satellite Transponder Leasing Corp.[44] | FSS 14a/12a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 36008 35566 0.1 -0.0073 | IFRB: 122.0W AR11/A/4/1567 AR11/A/10/1525 -ADD1/1548 AR11/A/105/1609 |
| 237.5E (122.5W) | 9 Jun 82 1982-58-A 13269 | WESTAR-5 WU WESTAR 5 WESTAR V | US— Western Union[45] | FSS 6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35793 35782 0.0 -0.0137 | AR11/C/616/1658 AR11/C/883/1741 IFRB: 123.0W AR11/A/5/1524 -ADD1/1548 AR11/C/284/1623 |
| 239.6E (120.4W) | 16 Oct 75 1975-100-A 08366 | GOES[9] GOES-1[42] | US | MetSat,SRS,EES 0.4b,2/ 0.4g,1.6f,1.6g | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.8 35802 35797 8.9 -0.1678 | IFRB: 140.0W SPA-AA/28/1147 |
| 240.0E (120.0W) | 23 May 84 1984-49-A 14985 | SPACENET-1 GTE SPACENET I | US— GTE Spacenet | FSS 6b,14a/4a,12a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35794 35781 0.0 -0.0137 | IFRB: 120.0W AR11/A/10/1525 -ADD1/1548 AR11/C/616/1658 -ADD1/1682 AR11/C/833/1699 |
| 241.7E (118.3W) | 8 Aug 85 1985-70-A 15946 | STATSIONAR-9[9] RADUGA 16[11] | USSR | FSS 6a,6b,8a/4a,7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1435.3 35777 35764 2.3 +0.2046 | IFRB: 45.0E SPA-AA/96/1197 SPA-AA/154/1262 SPA-AJ/51/1276 SPA-AJ/63/1280 SPA-AJ/112/1335 AR11/C/1472/1876 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|---|
| 243.2E (116.8W) | 27 Nov 85 1985-109-B 16274 | MORELOS 2 MORELOS II MORELOS-B | Mexico | FSS 6b,14a/4a,12a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35792 35782 0.0 -0.0073 | IFRB: 116.5W AR11/A/30/1540 -ADD1/1555 AR11/C/387/1628 |
| 245.1E (114.9W) | 12 Nov 82 1982-110-C 13652 | ANIK C-3 TELESAT 5 | Canada— Telesat Canada | FSS,BSS 14a/12a,12e | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.0 35790 35780 0.0 +0.0184 | IFRB: 117.5W SPA-AA/138/1252 SPA-AJ/69/1302 SPA-AA/357/1500 SPA-AJ/450/1533 AR11/C/42/1567 AR11/C/245/1620 AR11/C/447/1645 |
| 246.0E (114.0W) | 16 Jun 77 1977-48-A 10061 | GOES[9] GOES-2[11] | US | MetSat,SRS,EES 0.4b,2/ 0.4g,1.6f,1.6g | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.0 35813 35756 7.2 +0.0247 | IFRB: 140.0W SPA-AA/28/1147 |
| 246.6E (113.4W) | 17 Jun 85 1985-48-B 15824 | MORELOS 1 MORELOS I MORELOS-A | Mexico | FSS 6b,14a/4a,12a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35795 35779 0.0 -0.0073 | IFRB: 113.5W AR11/A/28/1539 -ADD1/1555 |
| 248.4E (111.6W) | 3 Nov 71 1971-95-A 05587 | USGCSS PH2[10] DSCS II F-1[11] OPS 9431 | US | FSS 8a/7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.3 35803 35776 10.8 -0.0394 | |
| 249.5E (110.5W) | 9 Nov 84 1984-113-B 15383 | ANIK D-2[46] ANIK D II | Canada— Telesat Canada | FSS 6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35792 35782 0.0 -0.0073 | IFRB: 110.5W SPA-AA/358/1500 AR11/C/716/1673 AR11/C/960/1764 -CORR1/1770 AR11/C/961/1764 -CORR1/1770 |
| 250.0E (110.0W) | 18 Jun 83 1983-59-B 14133 | ANIK C-2 TELESAT 7 | Canada— Telesat Canada | FSS,BSS 14a/12a,12e | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35792 35783 0.0 -0.0137 | IFRB: 110.0W SPA-AA/138/1252 SPA-AJ/347/1500 SPA-AJ/451/1533 SPA-AJ/466/1569 AR11/C/646/1666 -ADD1/1690 AR11/C/730/1674 -ADD1/1690 AR11/C/829/1698 |
| 250.7E (109.3W) | 21 Feb 85 1985-16-A 15574 | STATSIONAR-13[9] COSMOS 1629[22] | USSR | FSS 6b,14a/4a,11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1435.0 35779 35749 2.8 +0.2880 | IFRB: 80.0E SPA-AA/276/1426 AR11/C/598/1655 -ADD1/1737 AR11/A/271/1707 -CORR1/1728 AR11/C/1048/1779 |

## TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | Launch Date/ International Catalog Number[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Orbit Parameters[4] | Registration Special Section Numbers |
|---|---|---|---|---|---|---|
| 252.7E (107.3W) | 13 Apr 85 1985-28-B 15642 | ANIK C-1 | Canada— Telesat Canada | FSS,BSS 14a/12a,12e | $P$ 1436.0 $r_a$ 35862 $r_p$ 35779 $i$ 0.0 $n$ -0.4375 | IFRB: 107.5W SPA-AA/357/1500 SPA-AJ/434/1516 AR11/C/569/1649 -ADD1/1665 AR11/C/728/1674 AR11/C/832/1698 -ADD1/1709 |
| 255.0E (105.0W) | 28 Mar 86 1986-26-A 16649 | GSTAR-2 GTE GSTAR2 GSTAR-A2 | US— GTE Spacenet | FSS 14a/12a | $P$ 1436.2 $r_a$ 35794 $r_p$ 35781 $i$ 0.0 $n$ -0.0137 | IFRB: 105.0W AR11/A/15/1525 -ADD1/1548 AR11/C/1075/1784 |
| 255.5E (104.5W) | 26 Aug 82 1982-82-A 13431 | ANIK D-1 ANIK D I TELESAT 6 | Canada— Telesat Canada | FSS 6b/4a | $P$ 1436.1 $r_a$ 35797 $r_p$ 35776 $i$ 0.0 $n$ -0.0009 | IFRB: 104.5W SPA-AA/279/1426 SPA-AJ/427/1515 -ADD1/1664 SPA-AJ/465/1568 AR11/C/31/1565 AR11/C/43/1567 -ADD1/1612 AR11/C/105/1576 -ADD1/1600 AR11/C/151/1597 |
| | | | | | | AR11/C/587/1651 AR11/C/651/1666 |
| 255.6E (104.4W) | 12 Apr 85 1985-28-C 15643 | FLTSATCOM-A EAST PAC SYNCOM IV-3 LEASESAT F-3 LEASAT 3 | US— Hughes Communications | FSS,MSS 0.3a,8a/0.3a,7b | $P$ 1436.1 $r_a$ 35847 $r_p$ 35727 $i$ 0.7 $n$ -0.0073 | IFRB: 105.0W AR11/A/98/1605 -ADD1/1652 |
| 255.7E (104.3W) | 5 Dec 86 1986-96-A 17181 | FLTSATCOM-B EAST PAC[47] FLTSATCOM F-7 | US | FSS,MSS 0.3a,8a,44/ 0.3a,7b,20e,20f | $P$ 1436.1 $r_a$ 35863 $r_p$ 35709 $i$ 3.0 $n$ +0.0055 | IFRB: 100.0W AR11/A/50/1561 -ADD1/1587 |
| 257.0E (103.0W) | 29 Apr 85 1985-35-A 15677 | GSTAR-1 GTE GSTAR 1 GSTAR-A1 | US— GTE Spacenet | FSS 14a/12a | $P$ 1436.2 $r_a$ 35859 $r_p$ 35717 $i$ 0.0 $n$ -0.0201 | IFRB: 103.0W AR11/A/14/1525 -ADD1/1548 AR11/C/1073/1784 AR11/C/1074/1784 |
| 260.8E (99.2W) | 15 Nov 80 1980-91-A 12065 | USASAT-6A SBS F3 SBS-1[48] | US— Satellite Business Systems[49] | FSS 14a/12a | $P$ 1436.1 $r_a$ 35793 $r_p$ 35780 $i$ 1.3 $n$ -0.0009 | IFRB: 97.0W AR11/A/34/1553 AR11/C/325/1624 |
| 260.9E (99.1W) | 24 Sep 81 1981-96-A 12855 | USASAT-6C SBS F1 SBS-2[48] | US— Satellite Business Systems[49] | FSS 14a/12a | $P$ 1436.1 $r_a$ 35792 $r_p$ 35783 $i$ 1.3 $n$ -0.0137 | IFRB: 95.0W AR11/A/35/1553 AR11/C/331/1624 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 261.1E (98.9W) | 26 Feb 82 1982-14-A 13069 | WESTAR-4 WU WESTAR 4 WESTAR IV | US— Western Union[45] | FSS 6b/4a | $P$ 1436.2 $r_a$ 35798 $r_p$ 35777 $i$ 0.1 $n$ -0.0137 | IFRB: 99.0W AR11/A/4/1524 -ADD1/1548 AR11/C/272/1623 |
| 262.5E (97.5W) | 26 Feb 87 1987-22-A 17561 | GOES EAST GOES-7[50] | US | MetSat,SRS,EES 0.1a,0.2,0.4b,2/ 0.4g,1.6f,1.6g | $P$ 1436.1 $r_a$ 35815 $r_p$ 35756 $i$ 0.0 $n$ +0.0119 | IFRB: 75.0W SPA-AA/28/1147 SPA-AJ/366/1508 |
| 264.0E (96.0W) | 28 Jul 83 1983-77-A 14234 | TELSTAR-3A TELSTAR 3A TELSTAR 301 | US— AT&T | FSS 6b/4a | $P$ 1436.2 $r_a$ 35796 $r_p$ 35779 $i$ 0.0 $n$ -0.0137 | IFRB: 97.0W AR11/A/8/1524 -ADD1/1548 AR11/C/879/1738 |
| 265.0E (95.0W) | 11 Nov 82 1982-110-B 13651 | USASAT-6B SBS F2 SBS-3 | US— Satellite Business Systems[49] | FSS 14a/12a | $P$ 1436.1 $r_a$ 35795 $r_p$ 35779 $i$ 2.0 $n$ -0.0073 | IFRB: 99.0W SPA-AA/124/1235 SPA-AJ/61/1280 |
| 266.5E (93.5W) | 21 Sep 84 1984-101-A 15308 | USASAT-12B HUGHES GALAXY 3 GALAXY III | US— Hughes Communications | FSS 6b/4a | $P$ 1436.1 $r_a$ 35793 $r_p$ 35780 $i$ 0.0 $n$ -0.0009 | IFRB: 93.5W AR11/A/122/1615 AR11/C/824/1697 |
| 267.0E (93.0W) | 8 Sep 88 1988-81-A 19483 | USASAT-16A GSTAR-3 GTE GSTAR 3 GSTAR-A3 | US— GTE Spacenet | FSS,AMSS 1.6a,14a/12a[52] | $P$ 1186.3[51] $r_a$ 36073 $r_p$ 25414 $i$ 1.9 | IFRB: 93.0W AR11/A/222/1687 AR11/C/998/1772 |
| 268.9E (91.1W) | 30 Aug 84 1984-93-B 15235 | USASAT-9A STLC 1 SBS-4 | US— Satellite Business Systems[49] | FSS 14a/12a | $P$ 1436.1 $r_a$ 35791 $r_p$ 35782 $i$ 0.0 $n$ -0.0009 | IFRB: 91.0W AR11/A/101/1609 AR11/C/818/1696 |
| 269.0E (91.0W) | 10 Aug 79 1979-72-A 11484 | WESTAR-3 WU WESTAR 3 WESTAR III | US— Western Union[45] | FSS 6b/4a | $P$ 1436.2 $r_a$ 35792 $r_p$ 35783 $i$ 1.5 $n$ -0.0137 | IFRB: 91.0W SPA-AA/37/1152 SPA-AJ/197/1406 SPA-AJ/198/1406 |
| 272.9E (87.1W) | 11 Mar 88 1988-18-A 18951 | SPACENET-3 GTE SPACENET III SPACENET 3R | US— GTE Spacenet | FSS,AMSS 1.6a,6b,14a/ 4a,12a[52] | $P$ 1436.2 $r_a$ 35790 $r_p$ 35784 $i$ 0.0 $n$ -0.0073 | IFRB: 88.5W AR11/A/13/1525 AR11/C/834/1699 |
| 274.9E (85.1W) | 1 Sep 84 1984-93-D 15237 | USASAT-3C TELSTAR 3C TELSTAR 302 | US— AT&T | FSS 6b/4a | $P$ 1436.0 $r_a$ 35795 $r_p$ 35778 $i$ 0.0 $n$ -0.0009 | IFRB: 86.0W AR11/A/9/1524 AR11/C/246/1620 AR11/C/1084/1790 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 275.0E (85.0W) | 12 Jan 86 1986-3-B 16482 | USASAT-9C GE SATCOM K-1 SATCOM KU1 | US— RCA Americom[39] | FSS 14a/12a | $P$ 1436.2 $r_a$ 35794 $r_p$ 35783 $i$ 0.0 $n$ -0.0265 | IFRB: 85.0W AR11/A/103/1609 AR11/C/1052/1780 -CORR1/1922 |
| 277.9E (82.1W) | 16 Jan 82 1982-4-A 13035 | USASAT-7B GE SATCOM 4 SATCOM F4 SATCOM IV | US— RCA Americom[39] | FSS 6b/4a | $P$ 1436.1 $r_a$ 35798 $r_p$ 35776 $i$ 0.0 $n$ -0.0073 | IFRB: 83.0W SPA-AA/327/1474 AR11/C/188/1612 -ADD1/1626 |
| 279.0E (81.0W) | 28 Nov 85 1985-109-D 16276 | USASAT-9D GE SATCOM K-2 SATCOM KU2 | US— RCA Americom[39] | FSS 14a/12a | $P$ 1436.2 $r_a$ 35794 $r_p$ 35782 $i$ 0.0 $n$ -0.0201 | IFRB: 81.0W AR11/A/104/1609 AR11/C/1053/1780 -CORR1/1922 |
| 280.7E (79.3W) | 5 Apr 83 1983-26-B 13969 | TDRS CENTRAL TDRS-1[53] TDRS-A | US | FSS,SRS 2.1,6b,14f/ 2,2.2,4a,13c[54] | $P$ 1440.6 $r_a$ 35882 $r_p$ 35867 $i$ 3.6 $n$ -1.1310 | IFRB: 79.0W SPA-AA/233/1381 AR11/C/48/1568 AR11/C/773/1679 |
| 284.0E (76.0W) | 22 Jul 76 1976-73-A | COMSTAR D-2[55] COMSTAR 2 | US— Comsat General | FSS 6b/4a | $P$ 1436.1 $r_a$ 35789 | IFRB: 95.0W SPA-AA/32/1152 |

| | 09047 | | | | $r_p$ 35786 $i$ 4.8 $n$ -0.0137 | SPA-AJ/40/1268 |
|---|---|---|---|---|---|---|
| 284.0E (76.0W) | 21 Feb 81 1981-18-A 12309 | USASAT-12C COMSTAR D-4[55] COMSTAR 4 | US— Comsat General | FSS 6b/4a | $P$ 1436.1 $r_a$ 35790 $r_p$ 35786 $i$ 3.2 $n$ -0.0201 | IFRB: 76.0W AR11/A/123/1615 AR11/C/907/1748 -CORR1/1785 |
| 286.0E (74.0W) | 22 Sep 83 1983-98-A 14365 | USASAT-7A HUGHES GALAXY 2 GALAXY II | US— Hughes Communications | FSS 6b/4a | $P$ 1436.2 $r_a$ 35795 $r_p$ 35780 $i$ 0.0 $n$ -0.0137 | IFRB: 74.0W SPA-AA/312/1465 AR11/C/812/1689 -ADD1/1710 |
| 286.5E (73.5W) | 5 Oct 80 1980-81-A 12003 | STATSIONAR-8[9] RADUGA 7[11] | USSR | FSS 6a,6b,8a/4a,7b | $P$ 1436.5 $r_a$ 35765 $r_p$ 35747 $i$ 7.3 $n$ +0.3907 | IFRB: 25.0W SPA-AA/95/1197 SPA-AJ/50/1276 SPA-AJ/62/1280 AR11/A/246/1695 AR11/C/918/1752 |
| 287.8E (72.2W) | 17 Jan 76 1976-4-A 08585 | CTS[10,56] CAS-C | Canada | FSS 14a/12a | $P$ 1436.2 $r_a$ 35830 $r_p$ 35746 $i$ 9.4 $n$ -0.0201 | |
| 287.9E (72.1W) | 8 Sep 83 1983-94-A 14328 | USASAT-8B GE SATCOM 2-R SATCOM F2R SATCOM IIR | US— RCA Americom[39] | FSS 6b/4a | $P$ 1436.2 $r_a$ 35800 $r_p$ 35774 $i$ 0.0 $n$ -0.0073 | IFRB: 72.0W AR11/A/37/1553 AR11/C/221/1617 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|---|
| 290.2E (69.8W) | 28 Mar 86 1986-26-B 16650 | SBTS A2[57] BRAZILSAT A2 SBTS 2 | Brazil | FSS 6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35819 35758 0.1 -0.0265 | IFRB: 70.0W AR11/A/16/1526 -ADD1/1558 AR11/C/94/1576 -ADD1/1609 |
| 291.0E (69.0W) | 10 Nov 84 1984-114-A 15385 | USASAT-7C SPACENET-2 GTE SPACENET II SPACENET 2 | US— GTE Spacenet | FSS 6b,14a/4a,12a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35827 35748 0.0 -0.0137 | IFRB: 69.0W AR11/A/11/1525 -ADD1/1548 AR11/C/835/1699 -ADD1/1710 |
| 295.0E (65.0W) | 8 Feb 85 1985-15-B 15561 | SBTS A1[57] BRAZILSAT A1 SBTS 1 | Brazil | FSS 6b/4a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35852 35724 0.0 -0.0201 | IFRB: 65.0W AR11/A/17/1526 -ADD1/1558 AR11/C/99/1576 -ADD1/1609 |
| 296.0E (64.0W) | 22 May 81 1981-49-A 12472 | GOES EAST[9] GOES-5[42] | US | MetSat,SRS,EES 0.4b,2/ 0.4g,1.6f,1.6g | $P$ $r_a$ $r_p$ $i$ $n$ | 1435.9 35790 35780 2.5 +0.0184 | IFRB: 75.0W SPA-AA/28/1147 SPA-AJ/366/1508 |
| 300.0E (60.0W) | 28 Jan 77 1977-5-A 09785 | SATCOM PHASE-3B NATO III-B NATO 3B | NATO | FSS 8a/7b | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.2 35808 35770 7.0 -0.0330 | IFRB: 60.0W AR11/A/358/1773 -ADD1/1878 |
| 307.0E (53.0W) | 17 May 88 1988-40-A 19121 | INTELSAT 5A CONT1 INTELSAT VA CONT 1 INTELSAT IBS 307E INTELSAT V-A F-13 | Intelsat | FSS 6b,14a/ 4a,11, 12a,12c,12d[17] | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35793 35782 0.0 -0.0137 | IFRB: 53.0W AR11/A/115/1609 -ADD1/1628 -ADD2/1638 AR11/A/128/1617 AR11/C/674/1667 AR11/C/704/1673 -ADD1/1731 |
| 314.8E (45.2W) | 15 Jun 88 1988-51-C 19217 | USASAT-13I PANAMSAT I PAS 1 | US— Pan American Satellite | FSS 6b,14a/4a,11,12a | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35798 35775 0.0 -0.0009 | IFRB: 45.0W AR11/A/199/1675 AR11/C/866/1736 |
| 319.2E (40.8W) | 13 Mar 89 1989-21-B 19883 | TDRS EAST TDRS-4 TDRS-D | US | FSS,SRS 2.1,6b,14f/ 2,2.2,4a,13c | $P$ $r_a$ $r_p$ $i$ $n$ | 1432.2 35737 35682 0.3 +0.9879 | IFRB: 41.0W SPA-AA/231/1381 AR11/C/46/1568 AR11/C/1183/1802 |
| 319.9E (40.1W) | 10 Jun 86 1986-44-A 16769 | STATSIONAR-25[9] GORIZONT 12 | USSR | FSS 6b,14a/4a,11 | $P$ $r_a$ $r_p$ $i$ $n$ | 1436.1 35817 35758 1.5 -0.0137 | IFRB: 37.5W AR11/A/384/1797 -ADD1/1803 -CORR1/1813 AR11/C/1311/1836 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 322.6E (37.4W) | 27 Oct 89 1989-87-A 20315 | INTELSAT6 335.5 INTELSAT VI ATL 1 INTELSAT VI F-2[58] | Intelsat | FSS 6b,14a/4a,11 | $P$ 1436.1 $r_a$ 35833 $r_p$ 35740 $i$ 0.1 $n$ -0.0009 | IFRB: 24.5W AR11/A/69/1584 AR11/C/627/1658 |
| 325.5E (34.5W) | 5 Mar 82 1982-17-A 13083 | INTELSAT5 ATL4 INTELSAT V ATL 4 INTELSAT V F-4 | Intelsat | FSS 6b,14a/4a,11 | $P$ 1436.2 $r_a$ 35802 $r_p$ 35777 $i$ 0.2 $n$ -0.0394 | IFRB: 34.5W SPA-AA/121/1232 SPA-AJ/220/1418 |
| 328.9E (31.1W) | 27 Aug 89 1989-67-A 20193 | BSB-1 BSB-R1 MARCO POLO 1 | UK— British Satellite Broadcasting | FSS,BSS 14a,17/ 12c,12d,12e | $P$ 1436.2[12] $r_a$ 35798 $r_p$ 35777 $i$ 0.1 $n$ -0.0137 | IFRB: 31.0W AR11/A/23/1532 -CORR1/1888 AR11/A/26/1534 AR11/C/173/1605 -ADD1/1655 -ADD2/1801 AR11/C/181/1611 -ADD1/1655 -ADD2/1801 AR11/C/731/1674 -CORR1/1731 -ADD1/1801 |
| | | | | | | AR11/C/1209/1815 -ADD1/1893 |
| 331.4E (28.6W) | 12 May 77 1977-34-B 10001 | USGCSS PH2 ATL[9] DSCS II F-8 DSCS 2-A | US | FSS 8a/7b | $P$ 1437.0 $r_a$ 35817 $r_p$ 35792 $i$ 8.1 $n$ -0.2320 | IFRB: 12.0W SPA-AA/128/1242 SPA-AJ/153/1373 |
| 332.5E (27.5W) | 29 Jun 85 1985-55-A 15873 | INTELSAT5A ATL2 INTELSAT VA ATL 2 INTELSAT V-A F-11 | Intelsat | FSS 6b,14a/4a,11 | $P$ 1436.2 $r_a$ 35799 $r_p$ 35778 $i$ 0.0 $n$ -0.0265 | IFRB: 27.5W SPA-AA/335/1478 AR11/C/13/1556 AR11/C/123/1592 AR11/C/815/1694 |
| 333.9E (26.1W) | 10 Nov 84 1984-114-B 15386 | MARECS ATL1 MARECS ATL 1 MARECS B2[59] | ESA | FSS,MMSS 1.6b,6b/1.5b,4a | $P$ 1436.1 $r_a$ 35779 $r_p$ 35779 $i$ 2.8 $n$ +0.0954 | IFRB: 26.0W SPA-AA/222/1353 SPA-AJ/244/1432 |
| 334.7E (25.3W) | 14 Apr 89 1989-30-A 19928 | STATSIONAR-8 RADUGA 23 | USSR | FSS 6a,6b,8a/4a,7b | $P$ 1436.3 $r_a$ 35794 $r_p$ 35786 $i$ 1.2 $n$ -0.0458 | IFRB: 25.0W SPA-AA/95/1197 SPA-AJ/50/1276 SPA-AJ/62/1280 AR11/A/246/1695 AR11/C/918/1752 |
| 335.5E (24.5W) | 22 Mar 85 1985-25-A 15629 | INTELSAT5A ATL1 INTELSAT VA ATL 1 INTELSAT V-A F-10[58] | Intelsat | FSS 6b,14a/4a,11 | $P$ 1436.2 $r_a$ 35798 $r_p$ 35778 $i$ 0.0 $n$ -0.0201 | IFRB: 24.5W SPA-AA/334/1478 AR11/C/12/1556 AR11/C/122/1592 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | Launch Date/ International Catalog Number[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Orbit Parameters[4] | Registration Special Section Numbers |
|---|---|---|---|---|---|---|
| 335.5E (24.5W) | 27 Oct 89 | INTELSAT6 335.5E INTELSAT VI ATL 1 INTELSAT VI F-2[58] | Intelsat | FSS 6b,14a/4a,11 | $P$ 1436.1 $r_a$ 35833 $r_p$ 35740 $i$ 0.1 $n$ -0.0009 | IFRB: 24.5W AR11/A/69/1584 AR11/C/627/1658 |
| 335.6E (24.4W) | 28 Oct 87 1987-91-A 18443 | STATSIONAR-8 COSMOS 1894[22] | USSR | FSS 6b/4a | $P$ 1436.2 $r_a$ 35794 $r_p$ 35784 $i$ 0.3 $n$ -0.0330 | IFRB: 25.0W SPA-AA/95/1197 SPA-AJ/50/1276 SPA-AJ/62/1280 |
| 338.4E (21.6W) | 18 Jan 80 1980-4-A 11669 | FLTSATCOM ATL FLTSATCOM F-3 FLTSATCOM 3 OPS 6393 | US | FSS,MSS 0.3a,8a/0.3a,7b | $P$ 1436.1 $r_a$ 35803 $r_p$ 35767 $i$ 5.6 $n$ +0.0184 | IFRB: 23.0W SPA-AA/84/1186 SPA-AJ/163/1382 SPA-AJ/164/1382 |
| 338.6E (21.4W) | 6 Dec 80 1980-98-A 12089 | INTELSAT5 CONT4[9,16] INTELSAT V CONT 4 INTELSAT V F-2 | Intelsat | FSS 6b,14a/4a,11 | $P$ 1437.3 $r_a$ 35819 $r_p$ 35802 $i$ 0.6 $n$ -0.3091 | IFRB: 1.0W AR11/A/83/1588 AR11/C/593/1652 |
| 339.8E (20.2W) | 14 Nov 84 1984-115-A 15391 | SATCOM PHASE-3[9] NATO III-D NATO 3D | NATO | FSS 8a/7b | $P$ 1436.6 $r_a$ 35952 $r_p$ 35642 $i$ 2.2 $n$ -0.1357 | IFRB: 18.0W SPA-AA/144/1247 SPA-AJ/137/1355 |
| 340.8E (19.2W) | 28 Oct 88 1988-98-A 19621 | TDF-1 | France | FSS,BSS 17/12e | $P$ 1436.2 $r_a$ 35800 $r_p$ 35775 $i$ 0.0 $n$ -0.0137 | IFRB: 19.0W AR11/A/57/1570 AR11/C/107/1578 AR11/C/124/1592 AR11/C/142/1597 AR11/C/703/1670 AR11/C/741/1674 |
| 340.8E (19.2W) | 8 Aug 89 1989-62-A 20168 | TV-SAT 2 | West Germany | FSS,BSS,SRS 20a/2.2,12e | $P$ 1436.2[12] $r_a$ 35806 $r_p$ 35769 $i$ 0.0 $n$ -0.0137 | IFRB: 19.0W AR11/A/350/1767 -ADD1/1815 -CORR1/1881 AR11/C/1500/1885 |
| 340.9E (19.1W) | 12 Jul 89 1989-53-A 20122 | L-SAT OLYMPUS 1[60] | ESA | FSS,BSS 13a,14a, 17,20a,30a/ 12c,12e,12f,20b | $P$ 1436.2[12] $r_a$ 35799 $r_p$ 35776 $i$ 0.0 $n$ -0.0137 | IFRB: 19.0W SPA-AA/308/1463 SPA-AA/337/1479 AR11/A/32/1544 AR11/A/88/1590 AR11/C/6/1554 AR11/C/124/1592 AR11/C/174/1605 AR11/C/232/1619 AR11/C/782/1682 |

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE Up/Down-Link (GHz) | ORBIT PARAMETERS[4] | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 341.5E (18.5W) | 19 May 83 1983-47-A 14077 | INTELSAT5 ATL2 INTELSAT V ATL 2 INTELSAT MCS ATL A INTELSAT V F-6 | Intelsat | FSS,MMSS 1.6b,6b,14a/ 1.5b,4a,11[18] | $P$ 1436.1 $r_a$ 35802 $r_p$ 35773 $i$ 0.0 $n$ -0.0137 | IFRB: 18.5W SPA-AA/119/1232 SPA-AA/236/1388 SPA-AJ/175/1389 SPA-AA/240/1390 SPA-AJ/218/1418 AR11/C/1094/1791 |
| 342.0E (18.0W) | 19 Nov 78 1978-106-A 11115 | SATCOM PHASE-3 NATO III-C NATO 3C | NATO | FSS 8a/7b | $P$ 1436.2 $r_a$ 35792 $r_p$ 35783 $i$ 4.1 $n$ -0.0137 | IFRB: 18.0W SPA-AA/144/1247 SPA-AJ/137/1355 |
| 344.4E (15.6W) | 4 Apr 86 1986-27-A 16667 | WSDRN[61] COSMOS 1738 | USSR | FSS,SRS 14b,14f/11,13c | $P$ 1436.2 $r_a$ 35826 $r_p$ 35750 $i$ 1.8 $n$ -0.0201 | IFRB: 16.0W SPA-AA/341/1484 AR11/C/67/1570 |
| 344.5E (15.0W) | 10 Nov 84 1984-113-C 15384 | FLTSATCOM-A ATL SYNCOM IV-1 LEASESAT F-1 LEASAT 1 | US— Hughes Communications | FSS,MSS 0.3a,8a/0.3a,7b | $P$ 1436.2 $r_a$ 35873 $r_p$ 35702 $i$ 0.9 $n$ -0.0137 | IFRB: 15.0W AR11/A/97/1605 -ADD1/1652 AR11/C/1009/1775 |
| 345.1E (14.9W) | 19 Feb 76 1976-17-A 08697 | MARISAT-ATL[20] MARISAT F-1 MARISAT 1 | US— Comsat General | FSS,MSS,MMSS 0.3a,1.6b,6b/ 0.3a,1.5b,4a[21] | $P$ 1436.2 $r_a$ 35794 $r_p$ 35782 $i$ 7.8 $n$ -0.0201 | IFRB: 15.0W SPA-AA/4/1101 SPA-AA/7/1101 SPA-AJ/33/1254 |
| 345.5E (14.5W) | 31 Mar 88 1988-28-A 19017 | STATSIONAR-4 GORIZONT 15 | Intersputnik | FSS 6b,14a/4a,11 | $P$ 1436.2 $r_a$ 35790 $r_p$ 35784 $i$ 0.3 $n$ -0.0073 | IFRB: 14.0W SPA-AA/92/1197 AR11/C/765/1677 AR11/C/875/1737 AR11/C/1112/1793 AR11/C/1203/1809 |
| 346.3E (13.7W) | 1 Aug 88 1988-66-A 19344 | STATSIONAR-4 COSMOS 1961[22] | Intersputnik | FSS 6b/4a | $P$ 1436.2 $r_a$ 35793 $r_p$ 35782 $i$ 0.6 $n$ -0.0137 | IFRB: 14.0W SPA-AA/92/1197 AR11/C/765/1677 AR11/C/875/1737 AR11/C/1113/1793 AR11/C/1204/1809 |
| 348.2E (11.8W) | 30 Jun 83 1983-66-A 14160 | STATSIONAR-11 GORIZONT 7 | USSR | FSS 6b,14a/4a,11 | $P$ 1436.1 $r_a$ 35808 $r_p$ 35766 $i$ 4.1 $n$ -0.0073 | IFRB: 11.0W SPA-AA/270/1425 SPA-AJ/303/1469 AR11/A/269/1707 -CORR1/1728 AR11/C/877/1737 -CORR1/1743 AR11/C/964/1766 AR11/C/1120/1793 AR11/C/1201/1809 |

TABLE 1. IN-ORBIT GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | LAUNCH DATE/ INTERNATIONAL CATALOG NUMBER[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | ORBIT PARAMETERS[4] | REGISTRATION SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 349.0E (11.0W) | 14 Jun 80 1980-49-A 11841 | STATSIONAR-11 GORIZONT 4[11] | USSR | FSS 6b/4a | $P$ 1460.1 $r_a$ 36273 $r_p$ 36236 $i$ 7.2 $n$ -6.0110 | IFRB: 11.0W SPA-AA/270/1425 SPA-AJ/303/1469 AR11/C/877/1737 -CORR1/1743 AR11/C/1120/1793 |
| 349.2E (10.8W) | 19 Jun 81 1981-57-A 12544 | METEOSAT S2 METEOSAT-2[62] | ESA | MetSat,SRS,EES 2/1.6f,1.6g,0.4g | $P$ 1436.2 $r_a$ 35794 $r_p$ 35783 $i$ 2.4 $n$ -0.0265 | IFRB: 10.0W AR11/A/415/1815 AR11/C/1607/1892 |
| 352.0E (8.0W) | 4 Aug 84 1984-81-B 15159 | TELECOM-1A | France | FSS 6b,8a,14a/ 4a,7b,12c,12d[28] | $P$ 1436.2 $r_a$ 35793 $r_p$ 35781 $i$ 0.0 $n$ -0.0073 | IFRB: 8.0W SPA-AA/268/1425 SPA-AJ/299/1461 SPA-AJ/361/1508 SPA-AJ/387/1512 AR11/C/125/1593 -ADD1/1610 AR11/C/184/1611 AR11/C/390/1628 |
| 354.9E (5.1W) | 15 Jun 88 1988-51-A 19215 | METEOSAT[9] METEOSAT-3 METEOSAT-P2 | ESA | MetSat,SRS,EES 2/1.6f,1.6g,0.4g | $P$ 1436.3 $r_a$ 35793 $r_p$ 35787 $i$ 0.4 $n$ -0.0458 | IFRB: 0.0E AR11/A/413/1815 |
| 357.2E (2.8W) | 11 Mar 88 1988-18-B 18952 | TELECOM-1C | France | FSS 6b,8a,14a/ 4a,7b,12c,12d[28] | $P$ 1436.2 $r_a$ 35794 $r_p$ 35781 $i$ 0.0 $n$ -0.0137 | IFRB: 3.0E AR11/A/29/1539 -ADD1/1713 -CORR1/1730 AR11/C/115/1589 -ADD1/1643 AR11/C/131/1594 -ADD1/1643 AR11/C/157/1598 -ADD1/1643 |
| 359.0E (1.0W) | 31 Dec 89 1990-1-A 20401 | SKYNET-4A | UK | FSS,MSS 0.2,0.3a,0.3b, 8a,44/ 0.3a,0.3b,7b | $P$ 1436.2 $r_a$ 35794 $r_p$ 35783 $i$ 3.3 $n$ -0.0265 | AR11/A/21/1531 AR11/C/182/1611 -ADD1/1652 -ADD2/1711 AR11/C/588/1652 |
| 359.0E (1.0W) | 28 Sep 85 1985-87-A 16101 | INTELSAT5A CONT4[16] INTELSAT VA CONT 4 INTELSAT V-A F-12 | Intelsat | FSS 6b,14a/4a,11 | $P$ 1436.2 $r_a$ 35799 $r_p$ 35775 $i$ 0.0 $n$ -0.0073 | IFRB: 1.0W AR11/A/117/1609 -ADD1/1628 -ADD2/1638 AR11/C/677/1668 |

[1] Satellite longitudes are those recorded in the current release of NASA's *Geosynchronous Satellite Report.* For satellites not covered in that report, locations were compiled from the most recent secondary sources available.

[2] International designations are assigned at the time of launch. Object catalog numbers are those used by NORAD, the U.S. Space Command, and NASA.

[3] IFRB satellite network names appear first, followed by common or alternate names.

[4] $P$ = period (min); $r_a$ = apogee (km); $r_p$ = perigee (km); $i$ = inclination (deg); $n$ = drift (deg/day). Negative $n$ indicates westward and positive $n$ indicates eastward drift. Unless otherwise noted, basic elements are compiled from NASA's *Satellite Situation Report* for June 30, 1989.

[5] Orbital Test Satellite. An experimental precursor to the Eutelsat ECS series, OTS-2 is currently maintained in geostationary orbit by means of solar sailing to test subsystem performance.

[6] Shortly after its deployment in the late summer of 1988, ECS 5 was positioned at 10°E. This freed ECS 4, which had been at that location, to move to 13°E where it assumed traffic from ECS 1. The latter was then moved to a new orbital location at 16°E.

[7] Gorizont 11 was initially deployed at Statsionar-5 (53°E), but is currently at Statsionar-27. It is believed to be carrying Ku-band transponders, although no Loutch payload has been registered at this location.

[8] In October 1989, Arabsat agreed to lease 12 transponders on its 1-B satellite to the Indian government. As a result, the system's existing traffic is being transferred to Arabsat 1-A, which had functioned previously as an in-orbit spare. In November it was announced that both satellites would be put into inclined orbit for extended use with the COMSAT Maneuver.

[9] Satellite not currently on-station.

[10] Registration information unavailable.

[11] Believed to be inoperative.

[12] Basic elements compiled from NASA's *Satellite Situation Report* for September 30, 1989.

[13] Gorizont 9 was initially deployed at Statsionar-14 (96.5°E) and subsequently relocated to Statsionar-5 (53°E).

[14] The orbital location 95°E has been established as the central station in the Soviet Satellite Data Relay Network. Cosmos 1700, now at 55.2°E, was previously at that position and was reported to be transmitting messages from ground control center to the Mir Space Station in 1986. At this time, it is thought to be inoperative.

[15] Experimental Ku-band communications satellite.

[16] At 60°E, INTELSAT V-A F-15 replaces INTELSAT V-A F-12, which was previously at that position and which has been relocated to 1°W. At the latter location, F-12 has in turn replaced INTELSAT V F-2, which came to the end of its normal stationkeeping lifetime in September 1989.

[17] INTELSAT V-A F-13 and F-15 each carry Ku-band spot beams designed to enhance their provision of IBS.

[18] INTELSAT V F-5, F-6, F-7, and F-8 each carry a maritime communications subsystem (MCS) for lease by Inmarsat. L-band signals from shipboard terminals are converted to C-band frequencies for relay to coast earth stations.

[19] Raduga 17 was initially deployed at Statsionar-D3 (35°E) and subsequently relocated to Statsionar-20 (70°E). It appears to have been replaced at its previous position by Raduga 22, launched in 1988.

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[20] Serves as an in-orbit spare for the Inmarsat system.

[21] The Marisat satellites' UHF channels were leased to the U.S. Navy under the Gapsat program from 1973 until the successful deployment of the first FLTSATCOM satellites, and intermittently thereafter. More recently, the American Mobile Satellite Company in the U.S. and Telesat Mobile in Canada have proposed to purchase the unused capacity on Marisat F-1 on a temporary basis to provide commercial mobile satellite services on the North American continent.

[22] Designation uncertain, but believed to be functionally equivalent to a Gorizont. In the past, emissions have also been detected in Ku-band, indicating the presence of a Loutch transponder on board Cosmos 1540, 1629, and 1888. Currently, only Cosmos 1888, 1894, and 1961 appear to be in operation.

[23] Shiyan Tongxin Weixing. Experimental version of the DFH2 series domsats.

[24] Gorizont 14 was initially deployed at Statsionar-7 (140°E) and subsequently relocated to Statsionar-21 (103°E).

[25] In early 1989, NHK purchased a spare DBS satellite from GE Astro-Space for $130 million, including in-orbit delivery. Originally built for COMSAT's Satellite Television Corporation, the spacecraft was renamed BS-2X and was intended to serve as a backup for BS-2B, which will be nearing the end of its operational lifetime in 1991. BS-2X was subsequently destroyed in an abortive Ariane launch as this log was being compiled, on February 22, 1990. NHK is reportedly seeking a replacement.

[26] Experimental satellite with only one active transponder.

[27] Telecom 1B, previously positioned at 5°W, suffered a malfunction of its on-board attitude control system in January 1988. Although now partially stabilized, it is still not operational.

[28] The X-band transponder is operated by the French Ministry of Defense for the Syracuse network of military communications.

[29] CS-2A and CS-2B were removed from their original orbital positions in 1988 and replaced by second-generation CS-3 satellites.

[30] Engineering Test Satellite. An experimental satellite constructed by NASDA, ETS-5 incorporates a separate maritime mobile satellite project developed by the Japanese Ministry of Transportation. In addition, it carries an aeronautical mobile satellite payload (AMEX) operating at both C- and L-band frequencies.

[31] Geostationary Meteorological Satellite System.

[32] INTELSAT V F-3 served as Intelsat's Atlantic Ocean Region contingency spare at 53°W until May 1988, when it was replaced at that location by INTELSAT V-A F-13.

[33] DSCS II F-12 was originally deployed at approximately 60°E and was until recently operated at that position.

[34] Leasesat F-4 may have been intended to assume the orbital position registered for FLTSATCOM-A W PAC (177°W). However, it was rendered inoperative by a failure of its communications payload which occurred shortly after it reached geosynchronous orbit.

[35] DSCS II F-14 was identified at the time of launch as an in-orbit spare.

[36] Raduga 18 was initially deployed at Statsionar-8 (25°W) and subsequently relocated to Statsionar-D2 (170°W).

[37] Gorizont 10 was initially deployed at Statsionar-13 (80°E) and subsequently relocated to Statsionar-10 (170°W).

[38] Gorizont 6 was initially deployed at Statsionar-7 (140°E). Its closest current station is Statsionar-6.

[39] Acquired by General Electric and renamed GE American Communications.

[40] Disabled by failure of on-board imaging system in early 1989. Not operational.

[41] The DSCS III series of satellites carries an AFSATCOM single-channel UHF transponder in addition to the normal X-band package.

[42] Partially operational.

[43] The FCC has authorized AT&T to relocate Telstar 3D to 123°W.

[44] Acquired by Hughes Communications in July 1989.

[45] All Westar satellites were acquired by Hughes Communications in 1988.

[46] Telesat Canada plans to relocate Anik-D2 to 111°W by year-end 1990.

[47] This satellite is believed to be FLTSATCOM F-7, the first of a series of advanced payloads carrying an experimental EHF channel in addition to the UHF and X-band channels carried on previous FLTSATCOM satellites. Two other satellites in the series—F-6 and F-8—were scheduled to be brought into service in 1987 but were either destroyed or damaged on the launch pad.

[48] SBS-1 and SBS-2 are currently collocated at approximately 99°W. COMSAT has received temporary authority from the FCC to operate these satellites in an inclined orbit by means of the COMSAT Maneuver. It has also been granted permission to move SBS-1 to 97°W, pending a ruling on its request to permanently relocate both satellites to 76°W.

[49] When Satellite Business Systems was dissolved in 1985, three of its in-orbit satellites—SBS-1, SBS-2, and SBS-3—were acquired by MCI. A fourth, SBS-4, was purchased by IBM's subsidiary Satellite Transponder Leasing Corp. Subsequently, in 1987 and 1988, MCI transferred both SBS-1 and SBS-2 to Comsat General, and in July 1989 control of SBS-4 went to Hughes Communications when the latter acquired STLC from IBM.

[50] GOES-7 was originally deployed at the position reserved for GOES EAST (75°W). However, since the failure of GOES-6 it has become the only fully operational weather satellite available to NOAA and is occasionally relocated in order to maximize its coverage.

[51] GSTAR-3 experienced an apogee kick motor failure following launch and was not raised into geostationary orbit until November 1989. Its expected lifetime has been reduced to 5 years.

[52] GSTAR-3 (Geostar R02) and GTE Spacenet 3R (Geostar R01) each carry L-band antennas with receive-only capability for interim reception of signals from Geostar mobile transmitters. These RDSS signals are converted to Ku-band for down-link.

[53] TDRS-1 was originally deployed in the position reserved for TDRS EAST, but was replaced by TDRS-4 in early 1989. It has since been relocated and will be maintained in operation as an in-orbit spare.

[54] S-band antenna believed to be inoperative.

[55] Originally deployed at 95°W, Comstar D-2 has been collocated with Comstar D-4 at 76°W. Beyond their nominal mission lifetimes, both satellites have been placed in inclined orbit and are being maintained in operation by means of the COMSAT Maneuver.

[56] Communications Technology Satellite or Cooperative Applications Satellite. An experimental Ku-band satellite, CTS was a joint project of the Canadian Department of Communications and NASA. Not operational.

[57] Sistema Braziliana de Telecomunicacoes por Satellite.

[58] By April 1990, after initial tests have been completed, INTELSAT VI F-2 will be relocated from its temporary slot at 322°E to replace INTELSAT V-A F-10 at 335.5°E.

[59] Inmarsat has announced plans to establish a fourth "operation region." As a result, it will relocate Marecs B2 from 26°W to 55°W beginning in late September 1990.

[60] Experimental satellite carrying payloads for DBS, Ku- and Ka-band communications, and propagation testing.

[61] Western station in the Soviet Satellite Data Relay Network.

[62] Meteosat-2 ceased routine operations in August 1988 when it was replaced by Meteosat-3. The latter will in turn be replaced by MOP-1 as primary satellite in the Meteosat Operational System, although it will remain in use as an in-orbit spare and its laser-based clock synchronization retroreflector will continue to operate.

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 1.0E | 31 Aug 87 | GDL-5 ASTRA[5] | Luxembourg– Societe Europeene des Satellites | FSS,BSS 13a,14a/11 | 25 | AR11/A/93/1594 -ADD1/1730 -ADD2/1747 -ADD3/1841 AR11/C/612/1657 |
| 1.0E | 31 Dec 92 | STATSIONAR-22[6] | USSR | FSS 6b/4a | 20 | AR11/A/410/1806 -CORR1/1822 |
| 1.0E | 1 Jun 92 | TOR-15 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/372/1790 AR11/C/1418/1862 |
| 1.0E | 1 Jun 92 | VOLNA-21 | USSR | MSS 0.3a,0.3b/0.3a | 20 | AR11/A/375/1793 AR11/C/1581/1887 |
| 3.0E | 30 Sep 91 | TELECOM-2C | France | FSS,SRS 2,6b,8a,14a/ 2.2,4a,7b,12c,12d | 10 | AR11/A/326/1745 -ADD1/1772 -ADD2/1798 AR11/C/1103/1792 AR11/C/1166/1795 AR11/C/1331/1839 |
| 4.0E | 1 Jun 91 | MILSTAR 13[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/454/1837 AR11/C/1549/1885 |
| 5.0E | 1 Jun 92 | TOR-19 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/390/1798 AR11/C/1492/1878 |
| 7.0E | 31 Dec 87 | F-SAT 1[8] | France | FSS,SRS 2,6b,30a/ 2.2,4a,20b | 10 | AR11/A/79/1587 AR11/C/564/1649 AR11/C/568/1649 |
| 7.0E | 28 Feb 94 | EUTELSAT 2-7E EUTELSAT II-F4 | Eutelsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,14a/ 1.5b,1.5c,1.5d, 11,12c,12d[9] | 20 | AR11/A/305/1732 -ADD1/1766 -ADD2/1782 -ADD3/1894 AR11/C/1205/1809 -ADD1/1882 |
| 8.0E | 30 Aug 90 | STATSIONAR-18[6] | USSR | FSS 6b/4a | 20 | AR11/A/220/1686 AR11/C/911/1749 -ADD1/1756 -ADD2/1877 |
| 8.0E | 10 Aug 90 | TOR-8 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/285/1710 AR11/C/1361/1851 |
| 8.0E | 15 Oct 90 | VOLNA-15 | USSR | MSS,AMSS 0.3a,0.3b,1.6d/ 0.3a,1.5d | 20 | AR11/A/241/1693 AR11/C/983/1769 -CORR1/1812 |
| 10.0E | 31 Dec 88 | APEX[10] | France | FSS,SRS 2,6b,30a/ 2.2,4a,20b,39,82a | 10 | AR11/A/62/1578 -ADD1/1611 -ADD2/1716 -ADD3/1730 AR11/C/388/1628 AR11/C/479/1648 AR11/C/582/1651 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | In-Use Date[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Period of Validity[4] (yr) | Special Section Numbers |
|---|---|---|---|---|---|---|
| 10.0E | 28 Feb 94 | EUTELSAT 2-10E EUTELSAT II-F2 | Eutelsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,14a/ 1.5b,1.5c,1.5d, 11,12c,12d[9] | 20 | AR11/A/349/1766 -ADD1/1766 -ADD2/1782 -ADD3/1894 AR11/C/1206/1809 -ADD1/1882 |
| 12.0E | 31 Dec 84 | PROGNOZ-2[11] | USSR | SRS,EES 3/2.2 | 20 | SPA-AA/317/1471 SPA-AJ/411/1515 AR11/C/1562/1886 |
| 12.0E | 1 Jun 92 | STATSIONAR-27[6] | USSR | FSS 6b/4a | 20 | AR11/A/392/1799 -CORR1/1822 AR11/C/1593/1888 |
| 12.0E | 1 Jun 92 | TOR-18 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/389/1798 AR11/C/1479/1877 |
| 12.0E | 1 Jun 92 | VOLNA-27 | USSR | MSS 0.3a,0.3b/0.3a | 20 | AR11/A/378/1793 AR11/C/1590/1887 |
| 13.0E | 28 Feb 94 | EUTELSAT 2-13E EUTELSAT II-F1 | Eutelsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,14a/ 1.5b,1.5c,1.5d, 11,12c,12d[9] | 20 | AR11/A/306/1732 -ADD1/1766 -ADD2/1782 -ADD3/1894 AR11/C/1207/1809 -ADD1/1882 |
| 13.0E | 31 Dec 87 | ITALSAT | Italy | FSS,SRS 2,30a,48/20b,39[12] | 7 | AR11/A/157/1633 AR11/C/772/1679 AR11/C/827/1697 |
| 15.0E | 30 Apr 92 | ZENON-B | France | FSS,AMSS,SRS 1.6d,2,6b/ 1.5d,2.2,4a | 10 | AR11/A/364/1781 |
| 15.0E | 31 Jul 87 | AMS-1 | Israel | FSS 6b,14a/4a,11 | 10 | AR11/A/39/1554 -ADD1/1563 AR11/C/816/1695 -ADD1/1708 -ADD2/1803 |
| 15.0E | 31 Jul 87 | AMS-2 | Israel | FSS 6b,14a/4a,11 | 10 | AR11/A/39/1554 -ADD1/1563 AR11/C/817/1695 -ADD1/1708 -ADD2/1803 |
| 15.0E | 31 Dec 90 | STATSIONAR-23[6] | USSR | FSS 6b/4a | 20 | AR11/A/318/1740 -CORR1/1760 AR11/C/1195/1804 |
| 15.0E | 31 Dec 90 | TOR-12 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/309/1736 AR11/C/1444/1872 |
| 15.0E | 1 Jun 92 | VOLNA-23 | USSR | MSS 0.3a,0.3b/0.3a | 20 | AR11/A/376/1793 AR11/C/1584/1887 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 16.0E | 28 Feb 94 | EUTELSAT 2-16E EUTELSAT II-F3 | Eutelsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,14a/ 1.5b,1.5c,1.5d, 11,12c,12d[9] | 20 | AR11/A/478/1861 -ADD1/1894 AR11/A/479/1861 |
| 16.0E | 1987[13] | SICRAL-1A[14] | Italy | FSS,MSS 0.3b,8a,14a,44/ 0.3a,7b,12c,12d,20f | 8 | AR11/A/44/1557 -ADD1/1588 -ADD2/1652 |
| 17.0E | 30 Apr 92 | SABS[15] | Saudi Arabia | FSS,BSS 14a,14b/11,12e,12f | 20 | AR11/A/353/1768 -ADD1/1801 |
| 17.0E | 17 Apr 93 | SABS 1-2[15] | Saudi Arabia | FSS,BSS 14a,14b/11,12e,12f | 20 | AR11/A/125/1616 AR11/C/1212/1815 -CORR1/1830 -CORR2/1862 |
| 19.0E | 30 Apr 92 | ZENON-C | France | FSS,AMSS,SRS 1.6d,2,14a/ 1.5d,2.2,11 | 10 | AR11/A/365/1781 |
| 19.0E | 1 Mar 93 | TOR-26 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/459/1839 |
| 19.0E | 1 Feb 91 | MILSTAR 9[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/450/1837 AR11/C/1533/1885 |
| 19.2E | 3 Mar 90 | GDL-7 ASTRA 1B[16] | Luxembourg– Societe Europeene des Satellites | FSS,BSS 14a/11 | 20 | AR11/A/472/1860 |
| 21.0E | 30 Apr 93 | BABYLONSAT-3 | Iraq | FSS 14a/11 | 20 | AR11/A/441/1832 -ADD1/1875 |
| 22.0E | 1987[13] | SICRAL-1B[14] | Italy | FSS,MSS 0.3b,8a,14a,44/ 0.3a,7b,12c,12d,20f | 8 | AR11/A/45/1557 -ADD1/1588 -ADD2/1652 |
| 23.0E | 1 Aug 90 | STATSIONAR-19 | USSR | FSS 6a,6b/4a[17] | 20 | AR11/A/221/1686 AR11/C/916/1752 -CORR1/1756 |
| 23.0E | 1 Aug 90 | TOR-7 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/284/1710 AR11/C/1356/1851 |
| 23.0E | 15 Oct 90 | VOLNA-17 | USSR | MSS,AMSS 0.3a,0.3b,1.6d/ 0.3a,1.5d | 20 | AR11/A/242/1693 AR11/C/986/1769 -CORR1/1812 |
| 26.0E | 30 Apr 91 | ZOHREH-2 | Iran | FSS 14a/11 | 20 | AR11/A/297/1719 -ADD1/1728 -ADD2/1776 AR11/C/1235/1818 |
| 27.0E | 1 Jun 92 | TOR-20 | USSR | FSS,MSS 43,44,20b,20f | 20 | AR11/A/391/1798 AR11/C/1484/1877 |

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 28.5E | 30 Nov 89 | DFS-2 DFS KOPERNIKUS | West Germany | FSS,SRS 2,13a,14a,30a/ 2.2,11,12c,12d,20b | 10 | AR11/A/41/1556 -ADD1/1611 -ADD2/1828 AR11/C/698/1670 -ADD1/1877 |
| 30.0E | 30 Apr 93 | BABYLONSAT-1 | Iraq | FSS 14a/11 | 20 | AR11/A/439/1832 -ADD1/1875 |
| 30.0E | 1 Mar 91 | MILSTAR 10[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/451/1837 AR11/C/1537/1885 |
| 31.0E | 1 Jan 91 | ARABSAT 1-C ARABSAT F3 | Arab League | FSS,BSS 6b/4a | 10 | AR11/A/345/1764 AR11/C/1366/1854 -CORR1/1875 |
| 32.0E | 31 Dec 87 | VIDEOSAT-1[8] | France | FSS,SRS 2,14a/2.2,12c,12d | 10 | AR11/A/80/1588 AR11/C/574/1650 AR11/C/580/1650 |
| 32.0E | 31 Jul 92 | TOR-21 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/416/1815 AR11/C/1568/1886 |
| 33.5E | 31 Dec 90 | DFS-5 DFS KOPERNIKUS | West Germany | FSS,SRS 2,13a,14a,30a/ 2.2,11,12c,12d,20b | 10 | AR11/A/465/1840 -ADD1/1871 |
| 34.0E | 30 Apr 91 | ZOHREH-1 | Iran | FSS 14a/11 | 20 | AR11/A/296/1719 -ADD1/1728 -ADD2/1776 AR11/C/1224/1818 |
| 35.0E | 31 Dec 84 | PROGNOZ-3[11] | USSR | SRS,EES 3/2.2 | 20 | SPA-AA/318/1471 SPA-AJ/412/1515 |
| 35.0E | 1 Aug 90 | TOR-2 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/279/1710 AR11/C/1299/1832 |
| 35.0E | 31 Oct 91 | VOLNA-11 | USSR | MSS,AMSS 0.3a,0.3b,1.6d/ 0.3a,1.5d | 20 | AR11/A/150/1631 -ADD1/1677 AR11/C/977/1769 |
| 36.0E | 28 Feb 94 | EUTELSAT 2-36E EUTELSAT II-F5 | Eutelsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,14a/ 1.5b,1.5c,1.5d, 11,12c,12d[9] | 20 | AR11/A/307/1732 -ADD1/1766 -ADD2/1782 AR11/C/1208/1809 -ADD1/1882 |
| 38.0E | 31 Dec 91 | PAKSAT-1 | Pakistan | FSS,BSS,MetSat 0.4b,14a,14b/ 11,12b,12c,12d, 12g,12h[18] | 15 | AR11/A/90/1592 -ADD1/1649 -ADD2/1715 AR11/C/1367/1858 -CORR1/1870 |
| 40.0E | 10 May 84 | STATSIONAR-12 | USSR | FSS 6b/4a | 20 | SPA-AA/271/1425 AR11/C/878/1737 AR11/C/1122/1793 |

## TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE Up/Down-Link (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 40.0E | 31 Jul 92 | TOR-22 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/417/1815 AR11/C/1563/1886 |
| 41.0E | 30 Jul 92 | ZOHREH-4 | Iran | FSS 14a/11 | 20 | AR11/A/394/1800 |
| 41.0E | 31 Dec 92 | PAKSAT-2 | Pakistan | FSS,BSS,MetSat 0.4b,14a,14b/ 11,12b,12c,12d, 12g,12h[18] | 15 | AR11/A/91/1692 -ADD1/1649 -ADD2/1715 |
| 45.0E | 31 Jul 92 | STATSIONAR-9A | USSR | FSS 6b/4a | 20 | AR11/A/402/1803 |
| 45.0E | 1 Aug 90 | TOR-3 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/280/1710 AR11/C/1336/1839 |
| 45.0E | 1980[13] | VOLNA-3 | USSR | MSS,MMSS,AMSS 0.3b,1.6b,1.6c,1.6d/ 0.3a,1.5b,1.5c,1.5d | 20 | SPA-AA/171/1286 SPA-AJ/98/1329 |
| 45.0E | 1 Dec 90 | VOLNA-3M | USSR | MMSS 1.6b/1.5b | 20 | AR11/A/249/1697 -CORR1/1715 AR11/C/1398/1861 |
| 47.0E | 30 Apr 91 | ZOHREH-3 | Iran | FSS 14a/11 | 20 | AR11/A/298/1719 -ADD1/1728 -ADD2/1776 AR11/C/1246/1818 |
| 49.0E | 1 Jun 92 | TOR-16 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/373/1790 AR11/C/1454/1872 |
| 51.0E | 30 Apr 93 | BABYLONSAT-2 | Iraq | FSS 14a/11 | 20 | AR11/A/440/1832 -ADD1/1875 |
| 53.0E | 31 Jul 90 | SKYNET-4C[19] | UK | FSS,MSS 0.3a,8a,44/0.3a,7b | 10 | AR11/A/84/1588 -ADD1/1597 AR11/C/867/1737 |
| 53.0E | 1 Sep 90 | MORE-53 | USSR | FSS,MMSS 1.6b,6b/1.5b,4a | 15 | AR11/A/185/1662 AR11/C/1088/1791 -CORR1/1883 |
| 53.0E | 31 Jul 92 | TOR-23 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/418/1815 AR11/C/1573/1886 |
| 53.0E | 1980[13] | VOLNA-4 | USSR | MSS,MMSS,AMSS 1.6b,1.6c,1.6d/ 1.5b,1.5c,1.5d | NA | SPA-AA/172/1286 SPA-AJ/99/1329 |
| 55.0E | 1 Sep 90 | MILSTAR 4[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/445/1837 AR11/C/1513/1885 |
| 57.0E | 30 Jun 93 | USGCSS PH3 INDOC2 DSCS III | US | FSS,SRS 1.7b,8a/2.2,7b | 10 | AR11/A/490/1875 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | In-Use Date[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Period of Validity[4] (yr) | Special Section Numbers |
|---|---|---|---|---|---|---|
| 58.0E | 31 Dec 90 | TOR-13 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/310/1736 AR11/C/1413/1862 |
| 60.0E | 31 Dec 89 | USGCSS PH3 INDOC DSCS III | US | FSS,SRS 1.7b,8a/2.2,7b | 10 | AR11/A/267/1706 -ADD1/1730 AR11/C/413/1629 AR11/C/1219/1816 -CORR1/1842 |
| 60.0E | 1 Oct 90 | INTELSAT6 60E INTELSAT VI IND 1 INTELSAT VI F-5 | Intelsat | FSS 6b,14a/4a,11 | 15 | AR11/A/71/1584 AR11/C/626/1658 -ADD1/1713 AR11/C/1624/1905 |
| 61.5E | 1 Nov 92 | ACS-7[20] | US | MSS,AMSS 1.6c,1.6d/1.5c,1.5d | 15 | AR11/A/398/1800 |
| 62.0E | 31 Jul 92 | TOR-24 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/419/1815 AR11/C/1595/1890 |
| 63.0E | 1 Nov 90 | INTELSAT6 63E INTELSAT VI F-4 | Intelsat | FSS 6b,14a/4a,11 | 15 | AR11/A/366/1782 AR11/C/1269/1819 -CORR1/1841 -CORR2/1853 |
| 64.5E | 1 Jul 89 | INMARSAT IOR INMARSAT II[21] | Inmarsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,6b/ 1.5b,1.5c,1.5d,4a | 15 | AR11/A/178/1644 -ADD1/1760 AR11/C/846/1706 -ADD1/1784 |
| 65.0E | 31 Jul 92 | TOR-25 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/420/1815 AR11/C/1600/1890 |
| 66.5E | 31 Jan 90 | INMARSAT IOR-2 INMARSAT II[21] | Inmarsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,6b/ 1.5b,1.5c,1.5d,4a | 15 | AR11/A/293/1713 -ADD1/1760 |
| 69.0E | 31 Dec 90 | TOR-14 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/311/1736 AR11/C/1449/1872 |
| 70.0E | 1 Jun 92 | TOR-17 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/37/1790 AR11/C/1474/1877 |
| 70.0E | 1 Jun 92 | VOLNA-19 | USSR | MSS 0.3a,0.3b/0.3a | 20 | AR11/A/374/1793 AR11/C/1578/1887 |
| 70.0E | 1 Nov 91 | USASAT-13N CELESTAR 2 | US– McCaw Space Technologies[22] | FSS 14a/11,12c,12d | 10 | AR11/A/344/1763 AR11/C/1438/1871 -ADD1/1900 |
| 72.0E | 1 Jan 88 | FLTSATCOM-B INDOC[23] | US | MSS 44/20f | 10 | AR11/A/337/1762 -ADD1/1794 -ADD2/1802 |
| 74.0E | 31 Jul 90 | INSAT-2C | India | FSS,BSS, MetSat,EES 0.4b,6b/4a,4b | 20 | AR11/A/262/1702 AR11/C/1083/1789 -CORR1/1804 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | In-Use Date[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Period of Validity[4] (yr) | Special Section Numbers |
|---|---|---|---|---|---|---|
| 76.0E | 2 Jul 94 | GOMS[24] | USSR | FSS,MetSat 0.4b,8d,30a/7b,20b | 20 | AR11/A/205/1678 -ADD1/1712 AR11/C/1277/1825 |
| 76.0E | 31 Dec 90 | GOMS-M[24] | USSR | FSS,MetSat,SRS,EES 0.4b,2,2.1,8d,30a/ 0.4g,1.6f,1.6g,7b,20b | 15 | AR11/A/425/1822 |
| 77.0E | 17 Oct 89 | CSSRD-2[25] | USSR | FSS,SRS 14b,14f/11,12c,13c | 20 | AR11/A/188/1672 -CORR1/1711 |
| 80.0E | 30 Dec 82 | POTOK-2[26] | USSR | FSS 4b/4a | 15 | SPA-AA/345/1485 AR11/C/22/1558 |
| 80.0E | 31 Oct 88 | PROGNOZ-4[11] | USSR | SRS,EES 3/2.2 | 20 | SPA-AA/319/1471 SPA-AJ/413/1515 AR11/C/742/1675 |
| 81.5E | 1 Mar 94 | FOTON-2 | USSR | FSS 6b/4b | 10 | AR11/A/236/1692 AR11/C/1015/1776 -CORR1/1790 -CORR2/1881 |
| 83.0E | 31 Jan 89 | INSAT-1D[27] | India | FSS,BSS, MetSat,EES | 15 | AR11/A/126/1617 -ADD1/1636 |
| | | | | 0.4b,6b/2.5a,4a | | -ADD2/1671 AR11/C/860/1735 |
| 83.0E | 31 Jan 90 | INSAT-2A | India | FSS,BSS, MetSat,EES 0.4b,6b/4a,4b | 20 | AR11/A/260/1702 AR11/C/1081/1789 -CORR1/1804 |
| 85.0E | 1 Aug 90 | TOR-4 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/281/1710 AR11/C/1341/1839 |
| 85.0E | 1980[13] | VOLNA-5 | USSR | MSS,MMSS,AMSS 0.3b,1.6b,1.6c,1.6d/ 0.3a,1.5b,1.5c,1.5d | 20 | SPA-AA/173/1286 SPA-AJ/100/1329 |
| 85.0E | 1 Dec 90 | VOLNA-5M | USSR | MMSS 1.6b/1.5b | 20 | AR11/A/250/1697 -CORR1/1715 AR11/C/1400/1861 |
| 87.5E | 15 Dec 92 | DFH-3-0C | China | FSS 6b/4a | 10 | AR11/A/470/1850 -ADD1/1875 |
| 90.0E | 1 Sep 90 | MORE-90 | USSR | FSS,MMSS 1.6b,6b/1.5b,4a | 15 | AR11/A/184/1662 AR11/C/1090/1791 -CORR1/1883 |
| 90.0E | 1 Oct 90 | MILSTAR 5[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/446/1837 AR11/C/1517/1885 |
| 93.5E | 31 Mar 90 | INSAT-2B | India | FSS,BSS, MetSat,EES 0.4b,6b/4a,4b | 20 | AR11/A/261/1702 AR11/C/1082/1789 -CORR1/1804 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 98.0E | 15 Mar 89 | CHINASAT-3 DFH2-A3 | China | FSS 6b/4a | 10 | AR11/A/257/1703 -ADD1/1712 AR11/C/1039/1778 |
| 103.0E | 15 Jun 92 | DFH-3-0B | China | FSS 6b/4a | 10 | AR11/A/469/1850 -ADD1/1875 |
| 105.0E | 31 Aug 92 | FY-2A FENG YUN-2A | China | FSS,SRS, MetSat,EES 0.4b,2,6b/0.4g, 1.6f,1.6g,1.7a,4a | 15 | AR11/A/492/1877 |
| 105.5E | 1 Apr 90 | ASIASAT-C ASIASAT 1 | UK– Asia Satellite Telecommunications[28] | FSS 6b/4a | 12 | AR11/A/493/1877 AR11/C/1614/1899 |
| 105.5E | 1 Nov 90 | TONGASAT C-5 | Tonga– Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/460/1840 -CORR1/1892 AR11/C/1627/1908 |
| 110.0E | 1 Aug 90 | BS-3 YURI 3 | Japan | FSS,BSS,SRS 2,14a/ 2.2,12e,12g,12h | 20 | AR11/A/334/1750 -ADD1/1762 AR11/C/1424/1864 |

| 115.5E | 1 Nov 90 | TONGASAT C-6 | Tonga– Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/461/1840 -CORR1/1892 AR11/C/1628/1908 |
| 116.0E | 30 Sep 90 | ASIASAT-B | UK– Asia Satellite Telecommunications[28] | FSS 6b/4a | 12 | AR11/A/481/1861 AR11/C/1611/1899 |
| 118.0E | 30 Jun 89 | PALAPA-B3[30] PALAPA B-3 | Indonesia | FSS 6b/4a | 10 | AR11/A/157/1637 AR11/C/654/1666 |
| 121.5E | 1 Nov 90 | TONGASAT C-7 | Tonga– Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/462/1840 -CORR1/1892 AR11/C/1629/1908 |
| 122.0E | 1 Sep 90 | ASIASAT-A | UK– Asia Satellite Telecommunications[28] | FSS 6b/4a | 12 | AR11/A/480/1861 AR11/C/1608/1899 |
| 125.0E | 15 Dec 91 | DFH-3-0A | China | FSS 6b/4a | 10 | AR11/A/468/1850 -ADD1/1875 |
| 128.0E | 1 Aug 90 | TOR-6 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/283/1710 AR11/C/1315/1838 |
| 128.0E | 31 Oct 90 | VOLNA-9 | USSR | MSS,AMSS 0.3a,0.3b,1.6d/ 0.3a,1.5d | 20 | AR11/A/149/1631 -ADD1/1677 AR11/C/974/1769 -CORR1/1892 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | In-Use Date[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Period of Validity[4] (yr) | Special Section Numbers |
|---|---|---|---|---|---|---|
| 128.0E | 1 Dec 90 | VOLNA-9M | USSR | MMSS 1.6b/1.5b | 20 | AR11/A/251/1697 AR11/C/1402/1861 |
| 130.0E | 1 Jul 90 | PROGNOZ-5[11] | USSR | SRS,EES 3/2.2 | 20 | AR11/A/275/1709 AR11/C/938/1763 |
| 130.0E | 1 Nov 92 | TONGASAT AP-1 | Tonga– Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/512/1893 AR11/C/1720/1941 |
| 130.0E | 1 Aug 90 | TOR-10 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/290/1711 AR11/C/1320/1838 |
| 131.0E | 1 Nov 90 | TONGASAT C-8 | Tonga– Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/463/1840 -CORR1/1892 |
| 133.0E | 1 Dec 90 | MILSTAR 7[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/448/1837 AR11/C/1525/1885 |
| 134.0E | 1 Nov 92 | TONGASAT AP-2 | Tonga– Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/513/1893 AR11/C/1721/1941 |
| 134.0E | 1 Sep 92 | ACS-6[20] | US | MSS,AMSS 1.6c,1.6d/1.5c,1.5d | 15 | AR11/A/397/1800 |
| 140.0E | 1 Sep 90 | MORE-140 | USSR | FSS,MMSS 1.6b,6b/1.5b,4a | 15 | AR11/A/186/1662 AR11/C/1092/1791 -CORR1/1883 |
| 138.0E | 1 Nov 92 | TONGASAT AP-3 | Tonga– Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/514/1893 AR11/C/1722/1941 |
| 142.5E | 1 Nov 92 | TONGASAT AP-4 | Tonga– Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/515/1893 AR11/C/1723/1941 |
| 145.0E | 31 Dec 87 | STATSIONAR-16 | USSR | FSS 6b/4a | 20 | AR11/A/76/1586 -ADD1/1593 AR11/C/849/1707 AR11/C/1126/1793 |
| 148.0E | 1 Nov 93 | TONGASAT AP-5 | Tonga– Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/516/1893 AR11/C/1724/1941 |
| 150.0E | 1 Aug 91 | MILSTAR 15[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/456/1837 AR11/C/1557/1885 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | In-Use Date[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Period of Validity[4] (yr) | Special Section Numbers |
|---|---|---|---|---|---|---|
| 151.0E | 1 Nov 94 | TONGASAT AP-8 | Tonga–Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/519/1893 AR11/C/1727/1941 |
| 152.0E | 1 Apr 91 | MILSTAR 11[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/452/1837 AR11/C/1541/1885 |
| 154.0E | 1 Nov 94 | TONGASAT AP-7 | Tonga–Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/518/1893 AR11/C/1726/1941 |
| 156.0E | 29 Feb 92 | AUSSAT B2 | Australia | FSS,BSS,AMSS,SRS 1.6a,1.6d,14a/ 1.5d,12b,12c, 12d,12g,12h,31[31] | 15 | AR11/A/361/1779 -ADD1/1790 AR11/A/356/1772 -ADD1/1880 -ADD2/1894 AR11/A/380/1796 AR11/A/435/1828 -ADD1/1894 AR11/A/437/1830 AR11/A/495/1878 -CORR1/1900 |
| 157.0E | 1 Nov 93 | TONGASAT AP-6 | Tonga–Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/517/1893 AR11/C/1725/1941 |
| 160.0E | 1 May 92 | ACSAT-1[32] | Australia | FSS 8a/7b | 15 | AR11/A/393/1799 |
| 160.0E | 29 Feb 92 | AUSSAT B1 | Australia | FSS,BSS,AMSS,SRS 1.6a,1.6d,14a/ 1.5d,12b,12c, 12d,12g,12h,31[31] | 15 | AR11/A/360/1779 -ADD1/1790 AR11/A/355/1772 -ADD1/1880 -ADD2/1894 AR11/A/379/1796 AR11/A/434/1828 -ADD1/1894 AR11/A/436/1830 AR11/A/494/1878 -CORR1/1900 |
| 160.0E | 1 Dec 92 | TONGASAT C-3 | Tonga–Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/432/1828 AR11/C/1719/1940 -CORR1/1950 |
| 162.0E | 1 Jun 89 | SUPERBIRD-B[33] | Japan–Space Communications Corporation | FSS 14a,30a/ 12b,12c,20a,20b | 13 | AR11/A/341/1762 AR11/C/1307/1836 -CORR1/1865 |
| 164.0E | 31 Dec 92 | TONGASAT C-2 | Tonga–Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/431/1828 AR11/C/1718/1940 -CORR1/1950 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | In-Use Date[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Period of Validity[4] (yr) | Special Section Numbers |
|---|---|---|---|---|---|---|
| 166.0E | 1 Jun 94 | GOMS-2[24] | USSR | FSS,MetSat,SRS,EES 0.4b,2,2.1,8d,30a/ 0.4g,1.6f,1.6g,7b,20b | 20 | AR11/A/207/1578 -ADD1/1712 AR11/C/1281/1825 -CORR1/1894 |
| 166.0E | 31 Dec 89 | GOMS-2M[24] | USSR | FSS,MetSat,SRS,EES 0.4b,2,2.1,8d,30a/ 0.4g,1.6f,1.6g,7b,20b | 15 | AR11/A/427/1822 |
| 166.0E | 1 Jul 90 | PROGNOZ-6[11] | USSR | SRS,EES 3/2.2 | 20 | AR11/A/276/1709 AR11/C/940/1763 |
| 167.0E | 17 Oct 89 | VSSRD-2[25] | USSR | FSS,SRS 14b,14f/11,12c,13c | 20 | AR11/A/187/1672 |
| 167.45E | 30 Jun 91 | PACSTAR-1 PACSTAR A-1 | Papua New Guinea– Pacific Satellite[34] | FSS,AMSS 1.6d,6b,14a/ 1.5d,4a,5a,12a,12b,12c | 20 | AR11/A/200/1676 AR11/A/331/1749 -ADD1/1783 AR11/C/1179/1801 -CORR1/1828 -CORR2/1850 AR11/C/1432/1866 |
| 170.0E | 1 Oct 91 | USASAT-13M CELESTAR 1 | US– McCaw Space Technologies[22] | FSS 14a/12a,12c,12d | 10 | AR11/A/343/1763 AR11/C/1436/1871 -ADD1/1900 |
| 170.75E | 1 Nov 91 | TONGASAT C-1 | Tonga– Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/430/1828 AR11/C/1717/1940 -CORR1/1950 |
| 171.0E | 1 Jul 92 | ACS-5[20] | US | MSS,AMSS 1.6c,1.6d/1.5c,1.5d | 15 | AR11/A/396/1800 |
| 172.0E | 31 Dec 86 | FLTSATCOM-B WEST PAC[23] | US | MSS 44/20f | 10 | AR11/A/51/1561 -ADD1/1587 |
| 175.0E | 31 Dec 89 | USGCSS PH3 W PAC DSCS III | US | FSS,SRS 1.7b,8a/2.2,7b | 10 | AR11/A/266/1706 -ADD1/1730 AR11/C/409/1629 AR11/C/1216/1816 -CORR1/1842 AR11/C/1222/1817 -CORR1/1842 |
| 177.5E | 1 Jul 91 | MILSTAR 14[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/455/1837 AR11/C/1553/1885 |
| 179.5E | 31 Oct 89 | INMARSAT POR-1 INMARSAT II[21] | Inmarsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,6b/ 1.5b,1.5c,1.5d,4a | 15 | AR11/A/329/1747 |
| 180.0E | 31 Dec 92 | USGCSS PH3 W PAC-2 DSCS III | US | FSS,SRS 1.7b,8a/2.2,7b | 10 | AR11/A/408/1806 |
| 182.0E (178.0W) | 1 Jul 90 | USASAT-13K FINANSAT-2 | US– Financial Satellite[35] | FSS 6b/4a | 10 | AR11/A/264/1703 AR11/C/945/1763 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 185.0E (175.0W) | 30 Jun 91 | PACSTAR-2 PACSTAR A-2 | Papua New Guinea–Pacific Satellite[34] | FSS,AMSS 1.6d,6b,14a/ 1.5d,4a,5a,12a,12b,12c | 20 | AR11/A/201/1676 AR11/C/1180/1801 -CORR1/1804 -CORR2/1828 |
| 187.5E (172.5W) | 31 Dec 92 | TONGASAT C-4 | Tonga–Friendly Islands Satellite Communications[29] | FSS 6b/4a | 20 | AR11/A/433/1828 AR11/C/1697/1928 -CORR1/1952 |
| 189.0E (171.0W) | 4 Aug 88 | TDRS 171W | US | SRS 2,14f/2.2,13c | 15 | AR11/A/474/1860 -CORR1/1903[36] |
| 189.0E (171.0W) | 1 Apr 89 | USASAT-14E[37] | US | FSS 6b/4a | 10 | AR11/A/421/1815 AR11/C/1710/1936 |
| 190.0E (170.0W) | 31 Jul 92 | STATSIONAR-10A[6] | USSR | FSS 6b/4a | 20 | AR11/A/403/1803 |
| 190.0E (170.0W) | 1 Aug 90 | TOR-5 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/282/1710 AR11/C/1351/1851 |
| 190.0E (170.0W) | 1980[13] | VOLNA-7 | USSR | MSS,MMSS,AMSS 0.3b,1.6b,1.6c,1.6d/ 0.3a,1.5b,1.5c,1.5d | 20 | SPA-AA/175/1286 SPA-AJ/102/1329 |
| 190.5E (169.5W) | 1 Jun 90 | FOTON-3 | USSR | FSS 6b/4b | 10 | AR11/A/237/1692 |
| 192.0E (168.0W) | Dec 1983[13] | POTOK-3[26] | USSR | FSS 4b/4a | 10 | SPA-AA/346/1485 |
| 195.0E (165.0W) | 1 Sep 91 | USASAT-13L CCC-1 | US–Columbia Communications[38] | FSS 14a/11,12a | 10 | AR11/A/354/1770 |
| 201.0E (159.0W) | 1 Jul 90 | PROGNOZ-7[11] | USSR | SRS,EES 3/2.2 | 20 | AR11/A/277/1709 AR11/C/942/1763 |
| 205.0E (155.0W) | 31 Dec 89 | STATSIONAR-26 | USSR | FSS 6b/4a | 20 | AR11/A/385/1797 -ADD1/1803 -CORR1/1813 AR11/C/1313/1836 |
| 212.0E (148.0W) | 1 May 91 | MILSTAR 12[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/453/1837 AR11/C/1545/1885 |
| 214.0E (146.0W) | Jun 1985[13] | AMIGO-2[39] | Mexico | FSS,BSS 17,20a/12f,12g | 10 | RES33/A/2/1560 |
| 214.0E (146.0W) | 15 Nov 90 | USASAT-20C[40] | US | FSS 6b/4a | 10 | AR11/A/259/1702 AR11/C/970/1769 |
| 215.0E (145.0W) | 30 Jun 92 | MORELOS 4 MORELOS IV | Mexico | FSS 6b,14a/4a,12a | 10 | AR11/A/467/1840 |
| 215.0E (145.0W) | 1 Dec 90 | VOLNA-21M | USSR | MMSS,AMSS 1.6b,1.6d/1.5b,1.5d | 20 | AR11/A/252/1697 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 215.0E (145.0W) | 31 Dec 84 | FLTSATCOM-A PAC SYNCOM IV-5[41] LEASESAT F-5 LEASAT 5 | US– Hughes Communications | FSS,MSS 0.3a,8a/0.3a,7b | 10 | AR11/A/181/1652 |
| 219.0E (141.0W) | 30 Jun 92 | MORELOS 3 MORELOS III | Mexico | FSS 6b,14a/4a,12a | 10 | AR11/A/466/1840 |
| 220.0E (140.0W) | 31 Dec 89 | USASAT-17C[42] | US | FSS 6b/4a | 10 | AR11/A/228/1687 AR11/C/933/1761 |
| 221.0E (139.0W) | 1993[13] | ACS-3A[43] AMSC-3 | US– American Mobile Satellite[44] | MSS,AMSS 1.6c,1.6d/1.5c,1.5d | 15 | |
| 221.0E (139.0W) | May 1991[13] | USASAT[43] GE SATCOM C-5 AURORA II[46] | US– Alascom[45] | FSS 6b/4a | 10 | |
| 223.0E (137.0W) | 31 Dec 89 | USASAT-17B[47] GE SATCOM C-1[48] | US– GE Americom | FSS 6b/4a | 10 | AR11/A/227/1687 |
| 224.0E (136.0W) | Jun 1985[13] | AMIGO-1[39] | Mexico | FSS,BSS 17,20a/12f,12g | 10 | RES32/A/1/1560 |
| 224.0E (136.0W) | 31 Jan 90 | USASAT-16D[49] | US | FSS 14a/12a | 10 | AR11/A/225/1687 AR11/C/1000/1772 |
| 225.0E (135.0W) | 31 Aug 93 | USASAT-21A GE SATCOM C-4 | US– GE Americom | FSS 6b/4a | 10 | AR11/A/483/1864 -ADD1/1883 -CORR1/1935 |
| 225.0E (135.0W) | 1 Jun 83 | USGCSS PH3 E PAC DSCS III | US | FSS,SRS 1.7b,8a/2.2,7b | 10 | SPA-AA/349/1493 SPA-AJ/344/1499 AR11/C/405/1629 |
| 226.0E (134.0W) | 31 Jan 90 | USASAT-16C COMSTAR K-2[50] COMGEN-B | US– Comsat General | FSS 14a/12a | 10 | AR11/A/224/1687 AR11/C/1064/1783 |
| 227.0E (133.0W) | 19 Apr 94 | USASAT-22A GALAXY IR | US– Hughes Communications | FSS 6b/4a | 12 | AR11/A/536/1903 AR11/C/1777 AR11/C/1778–1779 |
| 228.0E (132.0W) | 15 Mar 87 | USASAT-11C WESTAR-B[51] | US– Western Union | FSS 14a/12a | 10 | AR11/A/111/1609 AR11/C/1063/1782 |
| 229.0E (131.0W) | 1 Apr 96 | USASAT-23B GALAXY B-R[52] | US– Hughes Communications | FSS 14a/12a | 12 | AR11/A/640/1946 |
| 229.0E (131.0W) | 31 Dec 94 | USASAT-22H[37] | US | FSS 6b/4a | 12 | AR11/A/600/1920 -CORR1/1945 |
| 230.0E (130.0W) | 15 Jun 87 | USASAT-10D GALAXY-B[52] GALAXY K-2 | US– Hughes Communications | FSS 14a/12a | 20 | AR11/A/108/1609 AR11/C/1057/1781 |

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 230.0E (130.0W) | 10 Sep 90 | ACS-3[20] | US | AMSS 1.6d/1.5d | 15 | AR11/A/303/1723 AR11/C/1110/1792 |
| 230.0E (130.0W) | 31 Dec 92 | USGCSS PH3 E PAC-2 DSCS III | US | FSS,SRS 1.7b,8a/2.2,7b | 10 | AR11/A/407/1806 |
| 230.0E (130.0W) | 15 Jun 92 | USRDSS WEST[53] GEOSTAR S3 | US– Geostar | FSS,AMSS,Radiolocation 1.6a,6b/2.4,5a | 10 | AR11/A/176/1641 -ADD1/1673 -ADD2/1780 |
| 231.0E (129.0W) | 18 Jul 94 | USASAT-24A CONTELSAT-2 | US– Contel ASC | FSS 6b,14a/4a,12a | 10 | AR11/A/577/1912 |
| 233.0E (127.0W) | 1993[13] | USASAT-24G[43] SPOTNET-2 NEXSAT-2 | US– National Exchange Satellite[54] | FSS 6b,14a/4a,12a | 10 | |
| 234.0E (126.0W) | 15 Sep 87 | USASAT-10C MMC-2 | US– Martin Marietta[55] | FSS 14a/12a | 20 | AR11/A/107/1609 AR11/C/989/1769 |
| 235.0E (125.0W) | 19 Apr 94 | USASAT-22B GALAXY V-W | US– Hughes Communications | FSS 6b/4a | 12 | AR11/A/537/1903 AR11/C/1780 AR11/C/1781–1782 |
| 235.0E (125.0W) | 18 Jul 94 | USASAT-23E GTE GSTAR 4 | US– GTE Spacenet | FSS 14a/12a | 10 | AR11/A/576/1912 AR11/C/1772 AR11/C/1773 |
| 236.0E (124.0W) | 1 Nov 88 | USASAT-10B EXPRESSTAR B | US– Federal Express[56] | FSS 14a/12a | 10 | AR11/A/106/1609 AR11/C/1054/1781 -CORR1/1811 |
| 239.0E (121.0W) | 18 Jul 94 | USASAT-23C GTE GSTAR 1R | US– GTE Spacenet | FSS 14a/12a | 10 | AR11/A/575/1912 AR11/C/1759 AR11/C/1760 |
| 240.0E (120.0W) | 1 Nov 90 | MILSTAR 6[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/447/1837 AR11/C/1522/1885 |
| 249.5E (110.5W) | 1 Dec 90 | ANIK E-B[57] TELESAT E-B | Canada– Telesat Canada | FSS 6b,14a/4a,12a | 12 | AR11/A/323/1744 -ADD1/1765 AR11/C/1293/1832 -CORR1/1861 |
| 252.7E (107.3W) | 1 May 90 | ANIK E-A[57] TELESAT E-A | Canada– Telesat Canada | FSS 6b,14a/4a,12a | 12 | AR11/A/322/1744 -ADD1/1765 AR11/C/1291/1832 -CORR1/1861 |
| 253.5E (106.5W) | 5 Oct 89 | MSAT[58] | Canada– Telesat Mobile[59] | MSS,LMSS,MMSS, AMSS,SRS 0.8,1.6b,1.6c,1.6d,2/ 0.8,1.5b,1.5c,1.5d,2.2 | 10 | AR11/A/55/1563 -ADD1/1572 -ADD2/1611 -ADD3/1721 AR11/A/300/1723 -CORR1/1731 AR11/C/936/1761 -CORR1/1821 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | In-Use Date[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Period of Validity[4] (yr) | Special Section Numbers |
|---|---|---|---|---|---|---|
| 254.0E (106.0W) | 31 Jul 92 | SIMON BOLIVAR 1 CONDOR 1[61] | ASETA[60] | FSS 6b/4a | 10 | AR11/A/422/1817 -CORR1/1861 |
| 257.0E (103.0W) | 18 Jul 94 | USASAT-24B SPACENET-1R GTE SPACENET IR | US– GTE Spacenet | FSS 6b,14a/4a,12a | 10 | AR11/A/578/1912 AR11/C/1761 AR11/C/1762–1763 |
| 259.0E (101.0W) | 1 Jul 90 | USASAT-16B USASAT-17A FORDSTAR 1 FORDSAT I | US– Ford Aerospace Satellite Services[62] | FSS 6b,14a/4a,12a | 10 | AR11/A/223/1687 AR11/A/226/1687 AR11/C/999/1772 AR11/C/931/1755 |
| 259.0E (101.0W) | 18 Jul 94 | USASAT-24C CONTELSAT-1 | US– Contel ASC | FSS 6b,14a/4a,12a | 10 | AR11/A/579/1912 |
| 259.0E (101.0W) | 1993[13] | ACS-1A[43] AMSC-2 | US– American Mobile Satellite[44] | MSS,AMSS 1.6c,1.6d/1.5c,1.5d | 15 | |
| 260.0E (100.0W) | 10 Sep 90 | ACS-1[20] | US | AMSS 1.6d/1.5d | 15 | AR11/A/301/1723 -ADD1/1801 AR11/C/1106/1792 |
| 260.0E (100.0W) | 15 Jul 90 | USRDSS CENTRAL[53] GEOSTAR S2 | US– Geostar | FSS,AMSS,Radiolocation 1.6a,6b/2.4,5a | 10 | AR11/A/175/1641 -ADD1/1663 -ADD2/1780 |
| 260.0E (100.0W) | 10 Aug 89 | ACTS[63] | US | FSS 30a/20b | 10 | AR11/A/321/1744 -ADD1/1753 |
| 261.0E (99.0W) | 19 Apr 94 | USASAT-22C GALAXY IV-R | US– Hughes Communications | FSS 6b/4a | 12 | AR11/A/538/1903 AR11/C/1783 AR11/C/1784–1785 |
| 261.0E (99.0W) | 19 Apr 94 | USASAT-23D[43] GALAXY A-R[52] | US– Hughes Communications | FSS 14a/12a | 12 | AR11/A/605/1921 |
| 263.0E (97.0W) | 30 Apr 89 | STSC-2 | Cuba | FSS 6b/4a | 10 | AR11/A/268/1706 -ADD1/1723 |
| 263.0E (97.0W) | 19 Apr 94 | USASAT-24D TELSTAR 401 | US– AT&T | FSS 6b,14a/4a,12a | 10 | AR11/A/542/1903 |
| 265.0E (95.0W) | 19 Apr 94 | USASAT-22D GALAXY III-R | US– Hughes Communications | FSS 6b/4a | 12 | AR11/A/539/1903 |
| 267.0E (93.0W) | 1 Jul 90 | USASAT-12D USASAT-16A FORDSTAR 1 FORDSAT I | US– Ford Aerospace Satellite Services[62] | FSS 6b,14a/4a,12a | 10 | AR11/A/124/1615 AR11/A/221/1687 AR11/C/998/1772 |
| 267.0E (93.0W) | 1993[13] | USASAT-24I[43] SPOTNET-1 NEXSAT-1 | US– National Exchange Satellite[54] | FSS 6b,14a/4a,12a | 10 | |
| 269.0E (91.0W) | 15 Apr 88 | WESTAR 6-S[64] WESTAR VIS GALAXY VI | US– Hughes Communications | FSS 6b/4a | 10 | AR11/A/299/1722 AR11/C/962/1765 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 270.0E (90.0W) | 1 Jun 90 | MILSTAR 1[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/442/1837 AR11/C/1501/1885 |
| 271.0E (89.0W) | 19 Apr 94 | USASAT-24E TELSTAR 402 | US– AT&T | FSS 6b,14a/4a,12a | 10 | AR11/A/543/1903 |
| 271.0E (89.0W) | 30 Jun 90 | SIMON BOLIVAR-B CONDOR-B[61] | ASETA[60] | FSS 6b/4a | 10 | AR11/A/209/1679 -CORR1/1861 |
| 275.0E (85.0W) | 25 Jun 94 | NAHUEL-2[65] | Argentina | FSS 6b,14a/4a,12a | 10 | AR11/A/204/1677 -CORR1/1881 |
| 277.0E (83.0W) | Mar 1988[13] | STSC-1 | Cuba | FSS 6b/4a | 10 | AR11/A/58/1578 |
| 277.0E (83.0W) | 31 Dec 86 | USASAT-7D ASC-2[66] CONTEL ASC-2 | US– Contel ASC | FSS 6b,14a/4a,12a | 10 | AR11/A/12/1525 -ADD1/1548 AR11/C/257/1623 |
| 279.0E (81.0W) | 19 Apr 94 | USASAT-22F[43] GALAXY V-E | US– Hughes Communications | FSS 6b/4a | 12 | AR11/A/541/1903 -CORR1/1935 |
| 280.0E (80.0W) | 25 Jun 94 | NAHUEL-1[65] | Argentina | FSS 6b,14a/4a,12a | 10 | AR11/A/203/1677 -CORR1/1881 |
| 281.0E (79.0W) | 31 Jan 87 | TDRS-C2 | US | SRS 2,14f/2.2,13c | 15 | AR11/A/265/1704 -ADD1/1713 |
| 281.0E (79.0W) | 15 Mar 87 | USASAT-11A MMC-1 | US– Martin Marietta[55] | FSS 14a/12a | 10 | AR11/A/109/1609 AR11/C/991/1769 |
| 281.0E (79.0W) | 19 Apr 94 | USASAT-24F GE SATCOM H-1 SATCOM HYBRID-1 | US– GE Americom | FSS 6b,14a/4a,12a | 12 | AR11/A/544/1903 AR11/C/1704/1929 |
| 282.5E (77.5W) | 30 Jun 90 | SIMON BOLIVAR-A CONDOR-A[61] | ASETA[60] | FSS 6b/4a | 10 | AR11/A/208/1679 -CORR1/1861 |
| 283.0E (77.0W) | 1 Feb 89 | USASAT-11B EXPRESSTAR A | US– Federal Express[56] | FSS 14a/12a | 10 | AR11/A/110/1609 AR11/C/1060/1782 |
| 284.6E (75.4W) | 1 Mar 93 | COLOMBIA 1A[67] | Colombia | FSS 6b/4a | 10 | AR11/A/428/1825 |
| 284.6E (75.4W) | 31 Jul 86 | SATCOL-1A[67] | Colombia | FSS 6b/4a | 10 | SPA-AA/338/1479 AR11/C/79/1573 -ADD1/1587 |
| 284.6E (75.4W) | 31 Jul 86 | SATCOL-1B[67] | Colombia | FSS 6b/4a | 10 | SPA-AA/338/1479 AR11/C/80/1573 -ADD1/1587 |
| 285.0E (75.0W) | 1 Mar 93 | COLOMBIA 2[67] | Colombia | FSS 6b/4a | 10 | AR11/A/429/1825 |
| 285.0E (75.0W) | 31 Jul 86 | SATCOL-2[67] | Colombia | FSS 6b/4a | 10 | SPA-AA/338/1479 SPA-AJ/128/1343 AR11/C/81/1573 |

## TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 285.0E (75.0W) | 31 Jan 90 | USASAT-18A COMSTAR K-1[50] COMGEN-A | US– Comsat General | FSS 14a/12a | 10 | AR11/A/230/1687 AR11/C/1002/1773 |
| 286.0E (74.0W) | 19 Apr 94 | USASAT-22E GALAXY II-R | US– Hughes Communications | FSS 6b/4a | 12 | AR11/A/540/1903 |
| 287.0E (73.0W) | 1 Jan 90 | USASAT-18B WESTAR-A[51] | US– Western Union | FSS 14a/12a | 10 | AR11/A/231/1687 AR11/C/1004/1773 |
| 288.0E (72.0W) | 9 Sep 89 | USASAT-15B STLC 3 SBS-6 | US– Satellite Transponder Leasing Corp.[68] | FSS 14a/12a | 10 | AR11/A/163/1637 -ADD1/1673 AR11/C/993/1770 |
| 288.0E (72.0W) | 30 Jun 90 | SIMON BOLIVAR-C CONDOR-C[61] | ASETA[60] | FSS 6b/4a | 10 | AR11/A/210/1679 -CORR1/1861 |
| 288.0E (72.0W) | 10 Sep 90 | ACS-2[20] | US | AMSS 1.6d/1.5d | 15 | AR11/A/302/1723 AR11/C/1108/1792 |
| 289.0E (71.0W) | 31 Jan 90 | USASAT-18C GALAXY-A[52] GALAXY K-1 | US– Hughes Communications | FSS 14a/12a | 20 | AR11/A/232/1687 AR11/C/1005/1773 |
| 290.0E (70.0W) | 31 Dec 89 | SATS-1 | Brazil | FSS 6b/4a | 7 | AR11/A/399/1802 AR11/C/1461/1874 |
| 290.0E (70.0W) | 31 Dec 86 | FLTSATCOM-B W ATL[23] | US | MSS 44/20f | 10 | AR11/A/49/1561 -ADD1/1587 |
| 290.0E (70.0W) | 15 Jul 91 | USRDSS EAST[53] GEOSTAR S1 | US– Geostar | FSS,AMSS,Radiolocation 1.6a,6b/2.4,5a | 10 | AR11/A/174/1641 -ADD1/1673 -ADD2/1780 |
| 291.0E (69.0W) | 1 Apr 96 | USASAT-24H[37] | US | FSS 6b,14a/4a,12a | 10 | AR11/A/643/1947 |
| 292.0E (68.0W) | 1 Jan 91 | MILSTAR 8[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/449/1837 AR11/C/1529/1885 |
| 293.0E (67.0W) | 3 Apr 87 | USASAT-15D[69] GE SATCOM K-3 SATCOM KU3 | US– GE Americom | FSS 14a/12a | 10 | AR11/A/165/1637 -ADD1/1673 AR11/C/997/1770 |
| 293.0E (67.0W) | 1 Jan 86 | USASAT-8A[70] GE SATCOM C-6 | US– GE Americom | FSS 6b/4a | 10 | AR11/A/36/1553 AR11/C/394/1629 |
| 295.0E (65.0W) | 31 Dec 89 | SATS-2 | Brazil | FSS 6b/4a | 7 | AR11/A/400/1802 AR11/C/1462/1874 |
| 295.0E (65.0W) | 30 Jun 92 | SBTS B2 BRAZILSAT B2 | Brazil | FSS 6b/4a | 15 | AR11/A/367/1785 -ADD1/1796 |
| 295.0E (65.0W) | 30 Jun 92 | SBTS C2 BRAZILSAT C2 | Brazil | FSS 14a/12a | 15 | AR11/A/369/1785 -CORR1/1796 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 296.0E (64.0W) | 30 Nov 90 | USASAT-14D[71] USASAT-15C ASC-3 CONTEL ASC-3 | US– Contel ASC | FSS 6b,14a/4a,12a | 10 | AR11/A/161/1637 AR11/A/164/1637 -ADD1/1673 AR11/C/930/1755 AR11/C/996/1770 |
| 298.0E (62.0W) | 30 Jun 89 | USASAT-14C[70] GE SATCOM C-7 | US– GE Americom | FSS 6b/4a | 10 | AR11/A/160/1637 AR11/C/929/1755 |
| 298.0E (62.0W) | 11 Aug 90 | TDRS 62W | US | SRS 2,14f/2.2,13c | 15 | AR11/A/473/1860 |
| 298.0E (62.0W) | 1 Nov 94 | ACS-2A AMSC-1 | US– American Mobile Satellite[44] | MSS,AMSS 1.6c,1.6d/ 1.5c,1.5d | 15 | AR11/A/603/1920 |
| 299.0E (61.0W) | 30 Jun 92 | SBTS B3 BRAZILSAT B3 | Brazil | FSS 6b/4a | 15 | AR11/A/368/1785 -ADD1/1796 |
| 299.0E (61.0W) | 30 Jun 92 | SBTS C3 BRAZILSAT C3 | Brazil | FSS 14a/12a | 15 | AR11/A/370/1785 -CORR1/1796 |
| 300.0E (60.0W) | 31 Dec 88 | USASAT-15A[37] | US | FSS 14a/12a | 10 | AR11/A/162/1637 -ADD1/1673 |
| 300.0E (60.0W) | 25 Jun 94 | USASAT-26H[37] | US | FSS 14a/11,12a,12c,12d | 15 | AR11/A/570/1911 |
| 300.0E (60.0W) | 25 Jun 94 | USASAT-25H[37] | US | FSS 6b/4a | 15 | AR11/A/562/1911 |
| 302.0E (58.0W) | 15 May 93 | USASAT-13E ISI-2 | US– International Satellite, Inc.[72] | FSS 14a/11,12a,12c,12d | 10 | AR11/A/136/1620 AR11/C/702/1670 -CORR1/1945 |
| 302.0E (58.0W) | 20 Jun 94 | USASAT-26G[37] | US | FSS 14a/11,12a,12c,12d | 15 | AR11/A/569/1911 |
| 302.0E (58.0W) | 20 Jun 94 | USASAT-25G[37] | US | FSS 6b/4a | 15 | AR11/A/561/1911 |
| 303.0E (57.0W) | 30 Sep 87 | USASAT-13H[73] | US | FSS 6b/4a,11 | 10 | AR11/A/177/1643 |
| 304.0E (56.0W) | 15 May 93 | USASAT-13D ISI-1 | US– International Satellite, Inc.[72] | FSS 14a/11,12a,12c,12d | 10 | AR11/A/135/1620 AR11/C/701/1670 -CORR1/1945 |
| 304.0E (56.0W) | 15 Jun 94 | USASAT-26F[37] | US | FSS 14a/11,12a,12c,12d | 15 | AR11/A/568/1911 |
| 304.0E (56.0W) | 15 Jun 94 | USASAT-25F[37] | US | FSS 6b/4a | 15 | AR11/A/560/1911 |
| 305.0E (55.0W) | 31 Mar 89 | INMARSAT AOR -WEST INMARSAT II[21] | Inmarsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,6b/ 1.5b,1.5c,1.5d,4a | 15 | AR11/A/328/1747 |

| Subsatellite Longitude[1] (deg) | In-Use Date[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Period of Validity[4] (yr) | Special Section Numbers |
|---|---|---|---|---|---|---|
| 305.0E (55.0W) | 31 Dec 88 | USASAT-14B[37] | US | FSS 6b/4a | 10 | AR11/A/159/1637 |
| 305.5E (54.5W) | 31 Jul 89 | MARECS ATL4 | ESA | FSS,MMSS 1.6b,6b/1.5b,4a | 10 | AR11/A/477/1860 -ADD1/1889 |
| 307.0E (53.0W) | 1 Jan 93 | INTELSAT6 307E | Intelsat | FSS 6b,14a/4a,11 | 15 | AR11/A/286/1711 -ADD1/1724 AR11/C/1270/1821 -CORR1/1841 |
| 307.5E (52.5W) | 31 Dec 86 | USGCSS PH3 W ATL DSCS III | US | FSS,SRS 1.7b,8a/2.2,7b | 10 | AR11/A/173/1639 -ADD1/1730 AR11/C/904/1746 -CORR1/1835 AR11/C/1018/1777 |
| 310.0E (50.0W) | 1 May 93 | USASAT-13C | US– Orion Satellite[74] | FSS 14a/11 | 10 | AR11/A/134/1618 AR11/C/748/1675 -CORR1/1945 |
| 310.0E (50.0W) | 1 Feb 93 | INTELSAT6 310E | Intelsat | FSS 6b,14a/4a,11 | 15 | AR11/A/287/1711 -ADD1/1724 AR11/C/1271/1821 -CORR1/1841 |
| 313.0E (47.0W) | 1 May 93 | USASAT-13B ORION-2 | US– Orion Satellite[74] | FSS 14a/11,12a,12c,12d | 10 | AR11/A/133/1618 -ADD1/1716 AP30/A/36/1722 -ADD1/1940 AR11/C/747/1675 AR11/C/1712/1939 |
| 313.0E (47.0W) | 1 Aug 90 | USASAT-13J FINANSAT-1 | US– Financial Satellite[35] | FSS 6b/4a | 10 | AR11/A/263/1703 AR11/C/944/1763 |
| 313.0E (47.0W) | 10 Jun 94 | USASAT-26E[37] | US | FSS 14a/11,12a,12c,12d | 15 | AR11/A/567/1911 |
| 313.0E (47.0W) | 10 Jun 94 | USASAT-25E[37] | US | FSS 6b/4a | 15 | AR11/A/559/1911 |
| 315.0E (45.0W) | 1 Jan 89 | USASAT-13F[75] | US | FSS 14a/11,12a,12c,12d | 10 | AR11/A/154/1635 -ADD1/1714 AR11/C/755/1676 AR11/C/1423/1864 |
| 315.0E (45.0W) | 5 Jun 94 | USASAT-26D[37] | US | FSS 14a/11,12a,12c,12d | 15 | AR11/A/566/1911 |
| 315.0E (45.0W) | 5 Jun 94 | USASAT-25D[37] | US | FSS 6b/4a | 15 | AR11/A/558/1911 |
| 316.5E (43.5W) | 1 Jan 88 | VIDEOSAT-3[8] | France | FSS,SRS 2,14a/ 2.2,12a,12b,12c,12d | 10 | AR11/A/148/1631 -ADD1/1638 AR11/C/766/1678 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | In-Use Date[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Period of Validity[4] (yr) | Special Section Numbers |
|---|---|---|---|---|---|---|
| 317.0E (43.0W) | 1 Jun 88 | USASAT-13G PANAMSAT II PAS 2 | US– Pan American Satellite | FSS 14a/11,12a,12c,12d | 10 | AR11/A/155/1635 AR11/C/756/1676 |
| 317.0E (43.0W) | 30 May 94 | USASAT-26C[37] | US | FSS 14a/11,12a,12c,12d | 15 | AR11/A/565/1911 |
| 317.0E (43.0W) | 30 May 94 | USASAT-25C[37] | US | FSS 6b/4a | 15 | AR11/A/557/1911 |
| 317.5E (42.5W) | 31 Dec 86 | USGCSS PH3 MID-ATL DSCS III | US | FSS,SRS 1.7b,8a/2.2,7b | 10 | AR11/A/140/1622 -ADD1/1638 -ADD2/1730 |
| 319.0E (41.0W) | 1 Dec 89 | USASAT-14A[37] | US | FSS 6b/4a | 10 | AR11/A/158/1637 -ADD1/1815 AR11/C/891/1743 -ADD1/1936 |
| 319.0E (41.0W) | 25 May 94 | USASAT-26B[37] | US | FSS 14a/11,12a,12c,12d | 15 | AR11/A/564/1911 |
| 319.0E (41.0W) | 25 May 94 | USASAT-25B[37] | US | FSS 6b/4a | 15 | AR11/A/556/1911 |
| 322.5E (37.5W) | 31 Dec 87 | VIDEOSAT-2[8] | France | FSS,SRS 2,14a/ 2.2,12a,12b,12c,12d | 10 | AR11/A/86/1598 -ADD1/1630 AR11/C/575/1650 AR11/C/727/1673 -CORR1/1678 |
| 322.5E (37.5W) | 20 May 94 | USASAT-26A[37] | US | FSS 14a/11,12a,12c,12d | 15 | AR11/A/563/1911 |
| 322.5E (37.5W) | 20 May 94 | USASAT-25A[37] | US | FSS 6b/4a | 15 | AR11/A/555/1911 |
| 322.5E (37.5W) | 31 Dec 89 | STATSIONAR-25 | USSR | FSS 6b/4a | 20 | AR11/A/384/1797 -ADD1/1803 AR11/C/1311/1836 |
| 322.5E (37.5W) | 1 May 93 | USASAT-13A ORION-1 | US– Orion Satellite[74] | FSS 14a/11,12a,12c,12d | 10 | AR11/A/132/1618 -ADD1/1716 AP30/A/35/1722 -ADD1/1940 AR11/C/746/1675 AR11/C/1711/1939 |
| 325.5E (34.5W) | 15 Oct 91 | INTELSAT6 325.5E INTELSAT VI F-1 | Intelsat | FSS 6b,14a/4a,11 | 15 | AR11/A/288/1711 -ADD1/1724 AR11/C/1272/1821 -CORR1/1841 |
| 326.0E (34.0W) | 30 Nov 88 | INMARSAT AOR -CENT 1A INMARSAT II[21] | Inmarsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,6b/ 1.5b,1.5c,1.5d,4a | 15 | AR11/A/351/1767 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| Subsatellite Longitude[1] (deg) | In-Use Date[2] | Satellite Designation[3] | Country or Organization | Service Frequency Code Up/Down-Link (GHz) | Period of Validity[4] (yr) | Special Section Numbers |
|---|---|---|---|---|---|---|
| 327.0E (33.0W) | 30 Nov 91 | SKYNET-4D | UK | FSS,MSS 0.3a,8a,44/0.3a,7b | 10 | AR11/A/333/1749 |
| 327.5E (32.5W) | 31 Jul 89 | MARECS ATL3 | ESA | FSS,MMSS 1.6b,6b/1.5b,4a | 10 | AR11/A/476/1860 -ADD1/1889 |
| 328.0E (32.0W) | 30 Nov 88 | INMARSAT AOR -CENT 2A INMARSAT II[21] | Inmarsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,6b/ 1.5b,1.5c,1.5d,4a | 15 | AR11/A/352/1767 |
| 329.0E (31.0W) | 1 Dec 91 | HISPASAT-1[76] | Spain | FSS,BSS 8a,13a,14a/ 7b,11,12a,12c,12d 12e,12f,12g | 20 | AR11/A/487/1871 -ADD1/1929 AR11/C/1707/1936 |
| 329.0E (31.0W) | 31 Mar 90 | EIRESAT-1 | Ireland– Atlantic Satellites[77] | FSS,BSS 13a,17/11 | 15 | AR11/A/182/1656 -ADD1/1794 -ADD2/1803 AR11/C/1349/1850 |
| 332.5E (27.5W) | 1 Jul 90 | INTELSAT6 332.5E[78] INTELSAT VI F-3 | Intelsat | FSS 6b,14a/4a,11 | 15 | AR11/A/70/1584 AR11/C/628/1658 -ADD1/1713 |
| 333.5E (26.5W) | 30 Jun 88 | STATSIONAR-D1[6] | USSR | FSS 6b/4a | 20 | AR11/A/193/1675 AR11/C/1168/1796 |
| 333.5E (26.5W) | 1 Aug 90 | TOR-1 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/278/1710 AR11/C/1295/1832 |
| 334.0E (26.0W) | 31 Aug 88 | INMARSAT AOR -CENT INMARSAT II[21] | Inmarsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,6b/ 1.5b,1.5c,1.5d,4a | 15 | AR11/A/152/1634 -ADD1/1760 AR11/C/843/1706 -ADD1/1784 |
| 335.0E (25.0W) | 1 Aug 90 | TOR-9 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/289/1711 AR11/C/1440/1872 |
| 335.0E (25.0W) | 1 Mar 91 | VOLNA-1A | USSR | MSS,AMSS 0.3a,0.3b,1.6d/ 0.3a,1.5d | 20 | AR11/A/291/1712 -CORR1/1812 |
| 335.0E (25.0W) | 1 Dec 90 | VOLNA-1M | USSR | MMSS 1.6b/1.5b | 20 | AR11/A/248/1697 -CORR1/1715 AR11/C/1396/1861 -CORR1/1872 |
| 336.0E (24.0W) | 31 Dec 88 | INMARSAT AOR -CENT2 INMARSAT II[21] | Inmarsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,6b/ 1.5b,1.5c,1.5d,4a | 15 | AR11/A/292/1713 -ADD1/1760 |
| 336.0E (24.0W) | 31 Dec 84 | PROGNOZ-1[11] | USSR | SRS,EES 3/2.2 | 20 | SPA-AA/316/1471 SPA-AJ/410/1515 AR11/C/1561/1886 |
| 337.0E (23.0W) | 31 Dec 86 | FLTSATCOM-B EAST ATL[23] | US | MSS 44/20f | 10 | AR11/A/48/1561 -ADD1/1587 |

TABLE 2. PLANNED GEOSTATIONARY COMMUNICATIONS SATELLITES FOR YEAR-END 1989

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE Up/Down-Link (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 338.5E (21.5W) | 1 Jan 92 | INTELSAT K[79] | Intelsat | FSS,BSS 14a/11,12a,12c,12d, 12e,12f,12g | 15 | AR11/A/614/1923 |
| 340.0E (20.0W) | 31 Jan 89 | GDL-4 ASTRA[5] | Luxembourg– Societe Europeene des Satellites | FSS,BSS 6b,14a/11 | 25 | AR11/A/92/1594 -ADD1/1747 -ADD2/1802 -ADD3/1841 AR11/C/610/1657 -CORR1/1744 |
| 340.0E (20.0W) | 1 May 92 | ACS-4[20] | US | MSS,AMSS 1.6c,1.6d/1.5c,1.5d | 15 | AR11/A/395/1800 |
| 341.0E (19.0W) | 31 Dec 88 | TDF-2 | France | FSS,BSS,SRS 2,11,17/2.2,12f | 10 | AR11/A/216/1684 AR11/C/1346/1839 |
| 341.0E (19.0W) | 31 Mar 91 | SARIT[80] | Italy | FSS,BSS,SRS 2,13a,30a/2.2,20b | 7 | SPA-AA/371/1457 AR11/A/294/1716 AR11/C/1334/1839 |
| 341.0E (19.0W) | 1986[13] | LUX-SAT[81] | Luxembourg | FSS,BSS 17,20a/12e,12f | 10 | AR11/A/20/1529 |
| 341.0E (19.0W) | 1986[13] | SUI-19W/1[82] HELVESAT 1 | Switzerland | FSS,BSS,SRS 2,20a/12e,12f | 10 | SPA-AA/356/1500 |
| 342.0E (18.0W) | 1 Jul 90 | GOMS-1M[24] | USSR | FSS,MetSat,SRS,EES 0.4b,2,2.1,8d,30a/ 0.4g,1.6f,1.6g,7b,20b | 15 | AR11/A/426/1822 |
| 342.2E (17.8W) | 1 Sep 90 | SATCOM-4 | NATO | FSS,MSS 0.3a,8a,44/0.3a,7b | 20 | AR11/A/342/1762 AR11/C/1288/1832 -CORR1/1852 |
| 344.0E (16.0W) | 1 Aug 92 | ZSSRD-2[25] | USSR | FSS,SRS 14b,14f/11,12c,13c | 20 | AR11/A/189/1672 -CORR1/1711 AR11/C/880/1740 -CORR1/1881 |
| 344.0E (16.0W) | 1 Aug 90 | MILSTAR 3[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/444/1837 AR11/C/1509/1885 |
| 345.0E (15.0W) | 1 Aug 88 | INMARSAT AOR-EAST INMARSAT II[21] | Inmarsat | FSS,MSS,MMSS,AMSS 1.6b,1.6c,1.6d,6b/ 1.5b,1.5c,1.5d,4a | 15 | AR11/A/153/1634 -ADD1/1760 AR11/C/840/1706 -ADD1/1784 -CORR1/1883 |
| 345.0E (15.0W) | 1 Jun 90 | FOTON-1 | USSR | FSS 6b/4b | 10 | AR11/A/235/1692 |
| 346.0E (14.0W) | 2 Jul 94 | GOMS-1[24] | USSR | FSS,MetSat,SRS,EES 0.4b,2,2.1,8d,30a/ 0.4g,1.6f,1.6g,7b,20b | 20 | AR11/A/206/1578 -ADD1/1712 AR11/C/1273/1825 -CORR1/1894 |
| 346.0E (14.0W) | 1 Sep 90 | MORE-14 | USSR | FSS,MMSS 1.6b,6b/1.5b,4a | 15 | AR11/A/183/1662 AR11/C/1086/1791 -CORR1/1883 |

| SUBSATELLITE LONGITUDE[1] (deg) | IN-USE DATE[2] | SATELLITE DESIGNATION[3] | COUNTRY OR ORGANIZATION | SERVICE FREQUENCY CODE UP/DOWN-LINK (GHz) | PERIOD OF VALIDITY[4] (yr) | SPECIAL SECTION NUMBERS |
|---|---|---|---|---|---|---|
| 346.0E (14.0W) | 1980[13] | VOLNA-2 | USSR | MSS,MMSS,AMSS 1.6b,1.6c,1.6d/ 1.5b,1.5c,1.5d | 10 | SPA-AA/170/1286 SPA-AJ/97/1329 |
| 346.5E (13.5W) | 30 Dec 82 | POTOK-1[26] | USSR | FSS 4b/4a | 15 | SPA-AA/344/1485 AR11/C/18/1557 |
| 348.0E (12.0W) | 31 Jul 84 | USGCSS PH3 ATL DSCS III | US | FSS,SRS 1.7b,8a/2.2,7b | 10 | SPA-AA/250/1413 SPA-AA/351/1493 SPA-AJ/287/1451 AR11/C/403/1629 |
| 349.0E (11.0W) | 31 Dec 87 | F-SAT 2[8] | France | FSS,SRS 2,14a,30a/ 2.2,12c,12d,20b | 10 | AR11/A/73/1586 AR11/C/466/1647 |
| 351.0E (9.0W) | 1 Jul 90 | MILSTAR 2[7] | US | MSS,SRS 0.3a,1.7b,44/ 0.3a,2.2,20f | 20 | AR11/A/443/1837 AR11/C/1505/1885 |
| 352.0E (8.0W) | 30 Sep 91 | TELECOM-2A | France | FSS,SRS 2,6b,8a,14a/ 2.2,4a,7b,12c,12d | 10 | AR11/A/324/1745 -ADD1/1772 AR11/C/1097/1792 AR11/C/1162/1795 AR11/C/1325/1839 |
| 352.0E (8.0W) | 30 Apr 92 | ZENON-A | France | FSS,AMSS,SRS 1.6d,2,14a/ 1.5d,2.2,11 | 10 | AR11/A/363/1781 |
| 355.0E (5.0W) | 30 Sep 91 | TELECOM-2B | France | FSS,SRS 2,6b,8a,14a/ 2.2,4a,7b,12c,12d | 10 | AR11/A/325/1745 -ADD1/1772 AR11/C/1100/1792 AR11/C/1164/1795 AR11/C/1328/1839 |
| 357.0E (3.0W) | 31 Dec 90 | TOR-11 | USSR | FSS,MSS 43,44/20b,20f | 20 | AR11/A/308/1736 AR11/C/1408/1862 |

[1] Satellite longitudes are those recorded in the July 1989 release of the IFRB's *List of Geostationary Space Stations.*

[2] In-use dates are taken from the notifying administration's most recent IFRB filing and do not necessarily indicate the date of launch.

[3] IFRB satellite network names appear first, followed by common or alternate names.

[4] Period of validity refers to the number of years for which frequency assignments are to be in use.

[5] SES officials announced in January 1990 that procurement of a third Astra satellite is a "strong possibility." It would be located at either 1°E or 20°W.

[6] An X-band (Gals) payload has also been registered at this location, suggesting that the station is intended for a Raduga satellite.

[7] The Milstar satellites, originally intended for deployment in both geosynchronous and highly inclined polar orbits, are designed to combine the functions of proposed follow-on satellites for the FLTSATCOM and AFSATCOM programs. Lockheed Corporation is the prime contractor for the series.

[8] First announced in 1983, F-Sat and Videosat are each designed to provide for fixed satellite traffic between France and its overseas departments. Neither project has received much publicity in recent years and some sources suggest that they have since been superseded by the Telecom II series.

[9] Eutelsat announced in 1989 that it is considering modifying some of its second-generation satellites to operate a pan-European land mobile satellite service in the L-band.

[10] Apex is intended to transmit television and telephony signals between France and its overseas departments, as well as part of the African continent. In addition to its C- and Ka-band transponder, it will carry three beacons in the 20-, 40-, and 80-GHz frequency ranges for conducting propagation experiments.

[11] Prognoz, or "Forecast," is a remote-sensing satellite designed to study atmospheric processes and monitor the depletion of natural resources. Earlier satellites in this series collected data on solar radiation and were launched into highly eccentric orbits.

[12] In addition to its Ka-band payload for domestic telecommunications, Italsat will be equipped to carry out propagation experiments in the 40/50-GHz range. It is currently scheduled for launch in September 1990.

[13] No other date given.

[14] The Sicral network is designed to offer coverage of all Italian territories, including Italian flag ships in the Mediterranean and the North Atlantic.

[15] Saudi Arabian Broadcasting Satellite System. Intended to provide DBS and to facilitate networking among medium-wave broadcasting stations.

[16] In June 1989, SES acquired a GE 5000 satellite that was originally built for Crimson Satellite Associates, GE's failed joint venture with HBO. Renamed Astra 1B, it will be collocated with the in-orbit Astra 1A.

[17] Transmits in the earth-to-space direction in the 5.725- to 6.275-GHz frequency band.

[18] In addition to telephony and television broadcasting services, Paksat-1 and Paksat-2 will be used to collect meteorological and hydrological data.

[19] According to the British Ministry of Defense, Skynet 4C is to serve as an in-orbit spare for the system's operational satellites at 6°E and 1°W. In the event of a failure of either Skynet 4A or 4B, it would be relocated to one of the latter positions.

[20] Orbital positions at 61.5°E, 134°E, 171°E, 130°W, 100°W, 72°W, and 20°W have been designated for a U.S.-based mobile satellite system. A global AMSS network, composed of six operational satellites and an in-orbit spare, was proposed by Aeronautical Radio, Inc. (Arinc) in 1987. The so-called AvSat system would have occupied similar locations but would have utilized both C- and L-band frequencies. The FCC subsequently rejected Arinc's application, in part because it conflicted with the commission's previously announced frequency allocation plan, and in part because Arinc failed to demonstrate adequate financial backing. Some of the ACS slots have since been assigned to American Mobile Satellite Corporation (see Footnote 44).

[21] The INMARSAT II launch schedule has been revised several times, with the result that launch options originally secured with Arianespace for 1989 were never used. Current plans call for the first INMARSAT II satellite to be launched in June 1990, and the second in February 1991. Flight numbers had not been assigned at the time of publication.

[22] McCaw Space Technologies filed an application with the FCC in 1986 for an international separate satellite system consisting of two in-orbit satellite serving India, China, Southeast Asia, and the Pacific Rim. The Celestar network would provide Ku-band capacity for transpacific communications and would offer connections to the TPC-3 fiber optic cable.

[23] Possibly reserved for FLTSATCOM F-6 or F-8, which were destroyed in launch pad accidents (see Table 1, Footnote 46). These satellites were each equipped with an experimental EHF transponder and were thought to be precursors to the Milstar series.

[24] Intended to join the U.S. GOES and Japanese GMS satellites as part of the World Meteorological Organization's World Weather Watch Program, the first of the GOMS satellites was originally scheduled for deployment in the early 1980s. Introduction of the series has since been delayed several times.

[25] The Soviet SSRD system is designed to retransmit space research data by means of low earth orbit satellites known as subscribers. The latter are to be arranged in three regional networks, each served by a geostationary repeater satellite located at central (CSSRD), western (ZSSRD), and eastern (VSSRD) orbital stations.

[26] Designed to facilitate the transmission of digital data between central and peripheral earth stations, the Potok system has been registered for nearly a decade. It has yet to be officially implemented, although observers speculate that several of the recent geostationary Cosmos satellites may have functioned as experimental Potok prototypes.

[27] Insat-1D was to have been launched in July 1989, but was damaged by a crane while still on the launch pad. It has been returned to its manufacturer, Ford Aerospace, for repairs and will be rescheduled for launch in 1990.

[28] Asia Satellite Telecommunications is a joint venture company owned by Cable & Wireless, Hutchison Whampoa, and the China International Trust (CITIC). It is intended to provide domestic telecommunications, television programming distribution, and private network services for the countries of Southeast Asia, South Korea, Taiwan, and China. Current plans envision the use of one in-orbit satellite, the refurbished Westar VI, which is scheduled for launch in April 1990. AsiaSat has applied for three orbital positions—105.5°E, 116°E, and 122°E—although company officials have indicated a preference for 105.5°E.

[29] A private company formed at the behest of the Tongan government, Friendly Islands Satellite Communications has reserved 16 orbital slots over the Pacific. A company spokesman has predicted that four of these will be occupied by Tongan domestic satellites by 1993, while the remaining slots may be leased to operators of separate satellite systems such as Finansat or Pacstar.

[30] Palapa B-3 will be preceded at this location by Palapa B-2R, which was successfully launched into orbit as this table was being compiled, on April 13, 1990. Palapa B-2R was originally launched in 1984 as B-2, but failed to achieve geosynchronous orbit. It was subsequently recovered by the Space Shuttle, refurbished, and repurchased by the Indonesian government.

[31] The second-generation Aussat B satellites will carry several specialized payloads in addition to their standard Ku-band package. These include an L-band transponder for mobile satellite services, an experimental Ka-band beacon, and a retroreflector mirror for ranging experiments. Additionally, as many as eight transponders on each satellite can be reconfigured to provide coverage of New Zealand.

[32] ACSAT is intended to provide government communications services.

[33] Superbird-B, launched February 22, 1990, as this table was being compiled, was destroyed when the Ariane rocket carrying it exploded shortly after lift-off. A replacement is under construction and is tentatively scheduled for launch in late 1991.

[34] Pacific Satellite, Inc., is owned principally by PacifiCorp subsidiary TRT Telecommunications. Its proposed Pacstar system, composed of two hybrid satellites operating in the C- and Ku-bands, is intended to provide domestic services to Papua New Guinea and other island nations in the Pacific Basin. By incorporating high-power spot beams into its satellite design, PSI hopes to facilitate the use of smaller earth stations, including VSATs. In addition, the Pacstar payload will carry an L-band transponder for AMSS.

[35] Originally conceived as a global network linking banks and other financial institutions in the U.S., Europe, and Asia, the Finansat system would consist of two C-band satellites. Each would utilize spread-spectrum technology and would be accessible via VSAT. Granted a conditional authorization by the FCC, Financial Satellite Corporation has received two 1-year extensions of the time limit set for demonstrating permanent financial qualifications. In January 1990 it requested a third extension.

[36] Cancels information contained in preceding advance publication.

[37] Unassigned.

[38] Columbia Communications Corporation has received conditional authorization from the FCC to establish a separate system providing Ku-band capacity and transpacific private line services. It has yet to place a contract for a satellite at this location. In a related development in 1989, Columbia became the highest bidder for the right to lease excess C-band transponders on NASA's TDRS satellites.

[39] The Amigo satellites are intended to provide domestic DBS in the 14/12-GHz band.

[40] Originally assigned to Alascom for use by its Aurora II satellite, this location was relinquished by that operator in 1988 when Aurora II was reassigned to 139°W.

[41] The fifth and final satellite in the Leasat series, Syncom IV-5, was launched as this table was being compiled in January 1990. It is intended to serve the Pacific Ocean Region and may be earmarked to replace the aging FLTSATCOM F-1 at 177°W.

[42] Originally assigned to Hughes Communications for use by its Galaxy IV satellite, this location was relinquished by that operator in 1988 when Galaxy IV was reassigned to 99°W.

[43] This network is newly registered with the IFRB. As of year-end 1989, advance publication information was still not available.

[44] A consortium of eight U.S. companies, the American Mobile Satellite Corporation was made necessary by the FCC's decision in 1986 to license only one mobile satellite system. This decision was based on the commission's concerns that the existing spectrum allocated to MSS was insufficient and could not be equitably divided among what were then a total of 12 individual applicants.

Eight of these original applicants—Hughes Communications, McCaw Space Technologies, MTel, Mobile Satellite Corporation, North American Mobile Satellite, Satellite Mobile Telephone Company, Skylink, and Transit Communications—contributed $5 million each to finance the corporation's startup costs. AMSC's network will consist of three in-orbit satellites, the first of which is scheduled for launch in late 1993. The consortium plans to offer a variety of thin-route and mobile communications services, and the system will be operated in conjunction with Telesat Canada's MSAT program to ensure continental coverage.

[45] Alascom's follow-on satellite will be operated by GE Americom, with the latter marketing 10 of 24 transponders.

[46] In its November 1988 Domsat Order, the FCC assigned Aurora II to 137°W and GE's Satcom C-1 to 139°W. Both operators subsequently requested to exchange orbital locations and this was authorized in January 1990.

[47] The network name USASAT-17B was previously associated with the proposed GTE Spacenet 4, which has since been withdrawn. This orbital slot is now assigned to GE Americom, and a new designation is expected from the IFRB.

[48] Designated as an in-orbit spare for GE's Satcom fleet.

[49] This location was originally assigned to GTE Spacenet for use by its GStar III satellite (launched September 8, 1988), but was subsequently relinquished by that operator when GStar III was reassigned to 93°W.

[50] A proposed domestic satellite system for the provision of Ku-band services, the Comstar K program was authorized by the FCC in 1985 to occupy orbital positions at 75°W and 134°W. The operator has since relinquished these assignments.

[51] Western Union's planned Ku-band system, consisting of two in-orbit satellites, has been cancelled. The existing Westar fleet was purchased by Hughes Communications in 1988.

[52] Hughes Communications was authorized by the FCC in 1985 to construct and launch two Ku-band satellites, to be launched at 71°W and 130°W. Hughes allowed these authorizations to lapse and instead sought permission to place its satellites at 99°W and 131°W. The changes were approved by the FCC in its 1988 Domsat Order.

[53] The orbital locations 70°W, 100°W, and 130°W have been designated by the FCC for the United States Radiodetermination Satellite System. Geostar Corporation, which is currently offering its radiolocation and navigational services through the use of leased transponders on-board the in-orbit GStar III and GTE Spacenet 3R satellites, has applied for use of these slots for its proposed RDSS network. Geostar's System 3.0 dedicated satellites will broadcast a continuous timing and interrogation signal from the operator's central earth station. These signals will in turn be encoded and retransmitted by individual mobile transceivers for relay back to the earth station via each of the three operational satellites, thus allowing for an accurate position fix.

[54] National Exchange, Inc., owned primarily by the Burlington Northern Railroad, has been authorized by the FCC to operate two hybrid satellites. The Spotnet communications package incorporates multiple spot beam coverage patterns, reuse of orbital frequencies, and high e.i.r.p. ratings to maximize its compatibility with small customer-premise earth stations.

[55] One of several prospective domsat operators to apply for FCC approval in 1983, Martin Marietta Communications Systems had intended to operate a network of high-power satellites in the Ku-band for the provision of specialized business communications and private networks. It later abandoned the venture.

[56] The Expresstar system was devised in the early 1980s to provide a variety of electronic mail, facsimile, and other high-speed data communications—marketed collectively under the trade name Zapmail. The new courier services suffered from a lack of consumer interest, and in 1987 Federal Express cancelled the project.

[57] The Anik E series comprises two hybrid satellites operating in both C- and Ku-bands. It is intended to replace the in-orbit Anik C and Anik D spacecraft.

[58] The MSAT system, operating at UHF and EHF frequencies, was first proposed in 1983. It was originally designed to provide rural telephone links and land and maritime mobile communications via transportable earth stations. Later, in 1986, an L-band payload was added to incorporate AMSS. The program is being developed in cooperation with AMSC, and both companies have issued Requests for Proposals for their respective satellites. In the interim, they plan to offer initial services using space segment leased from Inmarsat, including transponders on Marisat F-1 (14.0°W), Marecs B2 (26.1°W), and INTELSAT MCS Pacific-A (180.0°E).

[59] Fifty percent of Telesat Mobile's stock is owned by its parent company, Telesat Canada. The remainder has been purchased by Canadian Pacific Ltd., Cable & Wireless, and a bloc of Japanese investors led by C. Itoh.

[60] The Association of State Telecommunication Undertakings of the Andean Sub-Regional Agreement (ASETA) is a joint body created by the nations of Bolivia, Colombia, Ecuador, Peru, and Venezuela. It is entrusted with building and operating a regional satellite system for the provision of domestic and transborder telecommunications services.

[61] The designation Condor was officially changed in 1988 to Simon Bolivar.

[62] Ford Aerospace Satellite Services Corporation (FASSC), a subsidiary of Ford Motor Company, was created in 1983 and received authorization from the FCC 2 years later to build and launch a pair of hybrid satellites. The Fordstar satellites, based on the design used for the INTELSAT V series, were to have been launched in 1987 and were intended to provide capacity for satellite newsgathering, video distribution, VSAT networks, and other specialized applications. But although Ford began construction in 1986, the project lagged behind schedule. Following speculation that FASSC had failed to generate much interest among potential end users, the division was sold to AT&T, which had expressed a desire to obtain its orbital slots.

[63] Advanced Communications Technology Satellite. Sponsored by NASA, the ACTS program is intended to develop a satellite compatible with the demands of an intelligent network. Its principal innovations will consist of on-board switching capabilities and the use of multiple spot beams in flexible "scanning" configurations.

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[64] Westar VI was acquired by Hughes Communications in 1988, together with the rest of the Westar fleet. It will be added to the Hughes Galaxy network and has been renamed. Launch is tentatively scheduled for June 1990.

[65] Argentina's Nahuel network, consisting of two in-orbit satellites, is intended to provide domestic services, including DBS and low-speed data transmissions.

[66] Contel ASC-2 was constructed by RCA between 1983 and 1984 under Contel's initial order for two satellites. It had been slated to be brought into service shortly after the deployment of ASC-1, but the launch date was indefinitely postponed as a result of the Challenger disaster. In 1988, the satellite's initial assignment of 81°W was changed to 83°W. Contel appealed the decision, requesting reassignment to 99°W, but the FCC denied that petition. In 1989, Contel again requested reassignment, this time to 101°W—a slot assigned to its proposed follow-on, Contelsat-1.

[67] Since 1982, the Colombian government has intermittently discussed the possibility of establishing a domestic satellite system. Under the original Satcol proposal, it went so far as to solicit bids for three spacecraft, but never placed a contract. That project, like the more recent "Colombia" satellites which have been registered at the same orbital locations, has been postponed indefinitely. Colombia is instead cooperating with other Andean governments in the establishment of ASETA's proposed regional satellite network.

[68] Pending FCC approval, ownership of all STLC satellites, including SBS VI (tentatively scheduled for launch in 1991), will pass to Hughes Communications as a result of the latter's offer to acquire the IBM subsidiary in 1989.

[69] GE Americom, which was authorized to deploy its Satcom K-3 satellite at 67°W, relinquished this assignment in 1989. This action followed an unsuccessful attempt to secure FCC approval for modifications to both K-3 and the ground spare, K-4, so as to offer high-power services (including domestic DBS) through Crimson Associates, GE's joint venture with HBO. In denying GE Americom's petition, which was opposed by neighboring domsat operators, the FCC created a special bifurcated high-power-density arc with eastern (75°W–79°W) and western (132°W–136°W) segments.

[70] GE Americom has not pursued its predecessor RCA's plans for a Satcom C-6 and Satcom C-7. It has relinquished its assignments for these satellites.

[71] Contel has relinquished its assignment at 64°W. Its proposed ASC-3 satellite has been superseded by the follow-on Contelsat-1 and Contelsat-2.

[72] International Satellite, Inc., received conditional authorization from the FCC in 1985 to begin work on its proposed separate satellite system. It has since been granted two extensions and is seeking a third. ISI's original plans envisioned a network of two in-orbit satellites, each with spot beams covering CONUS and the major western European countries. The design is intended to facilitate the use of customer-premise earth stations for the transmission of video programming and high-speed data communica-

tions and would ensure single-hop capability between any point in the U.S. and terminals in Europe. The company is a partnership between TRT Telecommunications and other smaller investors, including Satellite Syndicated Systems and Kansas City Southern Industries.

[73] Originally assigned to PanAmSat, the orbital position 56°W has been abandoned by that operator in favor of 43°W.

[74] Orion Satellite, a subsidiary of Orion Network Systems and the first of several start-up ventures to apply for FCC authorization as a separate system, completed the Intelsat coordination process in July 1989. It has since finalized a contract for two satellites with British Aerospace, a minority shareholder. The operator intends to offer private line services, including teleconferencing, facsimile, and high-speed data communications, beginning in 1992. It has also discussed the possibility of offering leased domestic services to several West African countries. Although at one time Orion was considering a network of three satellites at 37.5°W, 47°W, and 50°W, it does not currently intend to deploy a satellite at the latter location.

[75] Originally assigned to Cygnus Satellite Corporation, an early U.S. applicant for separate system licensing, the orbital location 45°W was relinquished by that operator when it was acquired by PanAmSat in 1987. Also in the course of that acquisition, PanAmSat gained the rights to Cygnus' assignment at 43°W—the position currently proposed for its second satellite, PAS-2.

[76] The Hispasat network is based on a design incorporating multiple payloads. It will offer DBS capabilities in addition to providing long-distance telephony and television distribution services. The presence of an X-band transponder indicates future military applications as well. Although only advance publication data were available for Hispasat-1 at the time of compilation, the Hispasat system will ultimately consist of two in-orbit satellites.

[77] Atlantic Satellites Ltd., owned principally by Hughes Communications, is licensed by the Irish government to build and operate a system capable of providing DBS services to the U.K. and Western Europe. It is also considering transatlantic private line services in the fixed satellite service.

[78] INTELSAT VI F-3 was launched on March 14, 1990, as this table was being compiled, but was stranded in low earth orbit after the Martin Marietta booster rocket on which it was mounted failed to properly disengage. The satellite was not damaged, although some of its stationkeeping fuel was expended in subsequent maneuvers intended to free it from its booster and raise it to a higher orbit. Plans are being considered to retrieve it using the Space Shuttle.

[79] INTELSAT K, the organization's first all-Ku-band satellite and the first Intelsat satellite to be purchased off the shelf without design competition, was acquired from GE Astro-Space in June 1989. It was originally built as Satcom K4 and was intended for use by the now-defunct Crimson Associates. After modifications, it will be collocated at 338.5°E with INTELSAT V F-6, currently located at 341.5°E. INTELSAT K will primarily handle video and business communications and is considered a precursor to the planned INTELSAT VII series. ITU registration information was not available at the time of publication.

[80] Satellite di Radiodiffusione Italiano. A proposed DBS system for Italian programming, Sarit is expected to be modeled after Olympus 1 and will carry additional transponders for data communications.

[81] Luxembourg's first foray into the DBS market, the Luxsat project was centered around a high-power satellite capable of broadcasting into neighboring countries. It was intended to compete with France's TDF and West Germany's TV-Sat networks, but it was abandoned in 1983 in favor of the medium-power GDL system now being pursued by SES.

[82] Helvesat is the project devised by Switzerland for its own DBS system. Few details are known about the program, although it would probably be used to develop transborder broadcasting capabilities for the Swiss Broadcasting Corporation. The Swiss government solicited proposals from satellite manufacturers in 1986 for the purpose of conducting a feasibility study.

TABLE 3. FREQUENCY CODES FOR ALLOCATED BANDS, SERVICES, AND ITU REGIONS

| CODE | SERVICE | LINK DIRECTION ITU REGION[1] | | ALLOCATED FREQUENCY BAND (GHz) | |
|---|---|---|---|---|---|
| 0.1a | MSS[2] | Up[3]1, 2, 3 | | 0.12145 | – 0.12155 |
| 0.1b | AMSS (sec[4]) | Up 1, 2, 3 | Down 1, 2, 3 | 0.117975 | – 0.137 |
| 0.1c | MetSat[5], SRS[6] | | Down[7]1, 2, 3 | 0.136 | – 0.138 |
| 0.1d | SRS (sec) | | Down 1[8], 2, 3 | 0.138 | – 0.1436 |
| 0.1e | SRS | | Down 1, 2, 3 | 0.1436 | – 0.14365 |
| 0.1f | SRS (sec) | | Down 1[8], 2, 3 | 0.14365 | – 0.144 |
| 0.1g | RNS[9] | | Down 1, 2, 3 | 0.1499 | – 0.15005 |
| 0.1h | SRS | | Down 3[10] | 0.174 | – 0.184 |
| 0.2 | MSS | Up[3]1, 2, 3 | | 0.24295 | – 0.24305 |
| 0.3a | MSS | Up 1, 2, 3 | Down 1, 2, 3 | 0.235 | – 0.322 |
| 0.3b | MSS | Up 1, 2, 3 | Down 1, 2, 3 | 0.3354 | – 0.3999 |
| 0.3c | RNS | | Down 1, 2, 3 | 0.3999 | – 0.40005 |
| 0.4a | MetSat, SRS | | Down 1, 2, 3 | 0.40015 | – 0.401 |
| 0.4b | MetSat (sec) EES[11] (sec) | Up 1, 2, 3 | | 0.401 | – 0.403 |
| 0.4c | LMSS, MMSS | Up 2[12] | | 0.4055 | – 0.406 |
| 0.4d | MSS | Up[3]1, 2, 3 | | 0.406 | – 0.4061 |
| 0.4e | LMSS, MMSS | Up 2[12] | | 0.4061 | – 0.410 |
| 0.4f | SRS | Up 1, 2, 3 | | 0.450 | – 0.460 |
| 0.4g | MetSat (sec)[13] EES (sec) | | Down 1, 2, 3 | 0.460 | – 0.470 |
| 0.4h | SRS | | Down 3[10] | 0.470 | – 0.485 |
| 0.6 | LMSS (sec) MMSS (sec) | Up 2 | | 0.608 | – 0.614 |
| 0.7 | BSS (CR[14]) | | Down 1, 2, 3 | 0.620 | – 0.790 |
| 0.8 | LMSS[15], MMSS[15] | Up 1[16], 2, 3 | Down 1[16], 2, 3 | 0.806 | – 0.890 |
| 0.9 | LMSS[15], MMSS[15] | Up 1[16], 3 | Down 1[16], 3 | 0.942 | – 0.960 |
| 1.2a | RNS | | Down 1, 2, 3 | 1.215 | – 1.260 |
| 1.2b | SRS (sec) EES (sec) | Passive 1, 2, 3 | | 1.215 | – 1.300 |
| 1.3 | SRS (sec) EES (sec) | Passive 1, 2, 3 | | 1.370 | – 1.400 |
| 1.5a | EES (sec) | Passive 1, 2, 3 | | 1.525 | – 1.530 |
| 1.5b | MMSS | | Down[17]1, 2, 3 | 1.530 | – 1.544 |
| 1.5c | MSS | | Down[18]1, 2, 3 | 1.544 | – 1.545 |
| 1.5d | AMSS | | Down[19]1, 2, 3 | 1.545 | – 1.559 |

TABLE 3. FREQUENCY CODES FOR ALLOCATED BANDS, SERVICES, AND ITU REGIONS (CONT'D)

| CODE | SERVICE | LINK DIRECTION ITU REGION[1] | | ALLOCATED FREQUENCY BAND (GHz) | |
|---|---|---|---|---|---|
| 1.5e | RNS | | Down 1, 2, 3 | 1.559 | – 1.610 |
| 1.6a | AMSS | Up 1, 2, 3 | Down 1, 2, 3 | 1.610 | – 1.6265 |
| 1.6b | MMSS | Up 1, 2, 3 | | 1.6265 | – 1.6455 |
| 1.6c | MSS | Up[18]1, 2, 3 | | 1.6455 | – 1.6465 |
| 1.6d | AMSS | Up[19]1, 2, 3 | | 1.6465 | – 1.6605 |
| 1.6e | SRS | Passive 1, 2, 3 | | 1.6605 | – 1.6684 |
| 1.6f | MetSat | | Down 1, 2, 3 | 1.670 | – 1.690 |
| 1.6g | MetSat, EES | | Down 1, 2, 3 | 1.690 | – 1.710 |
| 1.7a | SRS | | Down 3[20] | 1.700 | – 1.710 |
| 1.7b | SRS | Up 2, 3[21] | | 1.750 | – 1.850 |
| 1.7c | MetSat | Up[22]1, 2, 3 | Down[22]1, 2, 3 | 1.770 | – 1.790 |
| 2 | SRS, EES | Up 1, 2, 3 | Down 1, 2, 3 | 2.025 | – 2.110 |
| 2.1 | SRS | Up 1, 2, 3 | | 2.110 | – 2.120 |
| 2.2 | SRS | | Down 1, 2, 3 | 2.200 | – 2.300 |
| 2.4 | Radiolocation | Passive 1, 2, 3 | | 2.450 | – 2.500 |
| 2.5a | BSS (CR) | | Down 1, 2, 3 | 2.500 | – 2.690 |
| 2.5b | FSS | | Down[23] 2, 3 | 2.500 | – 2.535 |
| 2.5c | FSS | | Down[23] 2 | 2.535 | – 2.655 |
| 2.6a | SRS (sec) EES (sec) | Passive 1, 2, 3 | | 2.640 | – 2.655 |
| 2.6b | SRS (sec) | Passive 1, 2, 3 | | 2.655 | – 2.690 |
| 2.6c | FSS | Up[23] 2, 3 | Down[23] 2 | 2.655 | – 2.690 |
| 2.6d | SRS, EES | Passive 1, 2, 3 | | 2.690 | – 2.700 |
| 3 | SRS (sec) EES (sec) | Passive 1, 2, 3 | | 3.100 | – 3.400 |
| 4a | FSS | | Down 1, 2, 3 | 3.400 | – 4.200 |
| 4b | FSS | | Down[24]1, 2, 3 | 4.500 | – 4.800 |
| 4c | SRS (sec) EES (sec) | Passive 1, 2, 3 | | 4.950 | – 4.990 |
| 4d | SRS (sec) | Passive 1, 2, 3 | | 4.990 | – 5.000 |
| 5a | AMSS | Up 1, 2, 3 | Down 1, 2, 3 | 5.000 | – 5.250 |
| 5b | SRS (sec) EES (sec) | Passive 1, 2, 3 | | 5.250 | – 5.350 |
| 6a | FSS | Up 1 | | 5.725 | – 5.850 |
| 6b | FSS | Up[24]1, 2, 3 | | 5.850 | – 7.075 |
| 7a | SRS | Up 1, 2, 3 | | 7.145 | – 7.235 |

TABLE 3. FREQUENCY CODES FOR ALLOCATED BANDS, SERVICES, AND ITU REGIONS (CONT'D)

| CODE | SERVICE | LINK DIRECTION ITU REGION[1] | | ALLOCATED FREQUENCY BAND (GHz) | | |
|------|---------|------|------|------|---|------|
| 7b | FSS | | Down 1, 2, 3 | 7.250 | – | 7.750 |
| 7c | MSS | | Down 1, 2, 3 | 7.250 | – | 7.375 |
| 8a | FSS | Up 1, 2, 3 | | 7.900 | – | 8.400 |
| 8b | MSS | Up 1, 2, 3 | | 7.900 | – | 8.025 |
| 8c | EES (sec)[25] | | Down 1, 2, 3 | 8.025 | – | 8.400 |
| 8d | MetSat | Up 1, 2, 3 | | 8.175 | – | 8.215 |
| 8e | SRS[26] | | Down 1, 2, 3 | 8.400 | – | 8.500 |
| 8f | SRS (sec) | Passive 1, 2, 3 | | 8.550 | – | 8.650 |
| | EES (sec) | | | | | |
| 9a | SRS (sec) | Passive 1, 2, 3 | | 9.500 | – | 9.800 |
| | EES (sec) | | | | | |
| 9b | MetSat (sec) | | Down 1, 2, 3 | 9.975 | – | 10.025 |
| 10 | SRS, EES | Passive 1, 2, 3 | | 10.600 | – | 10.700 |
| 11 | FSS | Up[24] 1[27] | Down[24] 1[27], 2, 3 | 10.700 | – | 11.700 |
| 12a | FSS | | Down 2[28] | 11.700 | – | 12.300 |
| 12b | FSS | | Down 3[29] | 12.200 | – | 12.500 |
| 12c | FSS | Up 1 | Down 1, 3 | 12.500 | – | 12.700 |
| 12d | FSS | Up 1, 2 | Down 1, 3 | 12.700 | – | 12.750 |
| 12e | BSS | | Down 1, 2[28,30] 3 | 11.700 | – | 12.200 |
| 12f | BSS | | Down 1, 2[28] | 12.200 | – | 12.500 |
| 12g | BSS | | Down 2[28], 3[31] | 12.500 | – | 12.700 |
| 12h | BSS | | Down 3[31] | 12.700 | – | 12.750 |
| 13a | FSS | Up[24] 1, 2, 3 | | 12.750 | – | 13.250 |
| 13b | SRS (sec) | Up 1, 2, 3 | | 13.250 | – | 13.400 |
| 13c | SRS (sec) | Passive 1, 2, 3 | | 13.400 | – | 14.000 |
| | EES (sec) | | | | | |
| 14a | FSS | Up[32] 1, 2, 3 | | 14.000 | – | 14.500 |
| 14b | FSS | Up[32] 1, 2, 3 | | 14.500 | – | 14.800 |
| 14c | LMSS (sec) | Up 1, 2, 3 | | 14.000 | – | 14.500 |
| 14d | RNS (sec) | | Down 1, 2, 3 | 14.300 | – | 14.400 |
| 14e | SRS (sec) | | Down 1, 2, 3 | 14.400 | – | 14.470 |
| 14f | SRS (sec) | Passive 1, 2, 3 | | 14.800 | – | 15.350 |
| 15a | EES (sec) | Passive 1, 2, 3 | | 15.200 | – | 15.350 |
| 15b | SRS, EES | Passive 1, 2, 3 | | 15.350 | – | 15.400 |
| 15c | AMSS | Up 1, 2, 3 | Down 1, 2, 3 | 15.400 | – | 15.700 |
| 17 | FSS | Up[33] 1, 2, 3 | | 17.300 | – | 17.700 |

TABLE 3. FREQUENCY CODES FOR ALLOCATED BANDS, SERVICES, AND ITU REGIONS (CONT'D)

| CODE | SERVICE | LINK DIRECTION ITU REGION[1] | | ALLOCATED FREQUENCY BAND (GHz) | | |
|------|---------|------|------|------|---|------|
| 20a | FSS | Up[33] 1, 2, 3 | Down 1, 2, 3 | 17.700 | – | 18.100 |
| 20b | FSS | | Down 1, 2, 3 | 18.100 | – | 21.200 |
| 20c | MetSat | | Down 1, 2, 3 | 18.100 | – | 18.300 |
| 20d | SRS (sec)[34] | Passive 1, 2, 3 | | 18.600 | – | 18.800 |
| | EES (sec)[34] | | | | | |
| 20e | MSS (sec) | | Down 1, 2, 3 | 19.700 | – | 20.200 |
| 20f | MSS | | Down 1, 2, 3 | 20.200 | – | 21.200 |
| 21 | SRS, EES | Passive 1, 2, 3 | | 21.200 | – | 21.400 |
| 22 | SRS, EES | Passive 1, 2, 3 | | 22.210 | – | 22.500 |
| 23 | BSS | | Down 2, 3 | 22.500 | – | 23.000 |
| 24 | SRS, EES | Passive 1, 2, 3 | | 23.600 | – | 24.000 |
| 27 | FSS | Up 2, 3 | | 27.000 | – | 27.500 |
| 30a | FSS | Up 1, 2, 3 | | 27.500 | – | 31.000 |
| 30b | MSS (sec) | Up 1, 2, 3 | | 29.500 | – | 30.000 |
| 30c | MSS | Up 1, 2, 3 | | 30.000 | – | 31.000 |
| 31 | SRS, EES | Passive 1, 2, 3 | | 31.300 | – | 31.800 |
| 33 | FSS | | Down 3[35] | 31.800 | – | 33.800 |
| 36 | SRS, EES | Passive 1, 2, 3 | | 36.000 | – | 37.000 |
| 37 | FSS | Up 3[35] | | 37.000 | – | 39.000 |
| 39 | FSS | | Down 1, 2, 3 | 37.500 | – | 40.500 |
| 40 | MSS | | Down 1, 2, 3 | 39.500 | – | 40.500 |
| 42 | BSS | | Down 1, 2, 3 | 40.500 | – | 42.500 |
| 43 | FSS | Up 1, 2, 3 | | 42.500 | – | 43.500 |
| 44 | MSS, RNS | Up 1, 2, 3 | Down 1, 2, 3 | 43.500 | – | 47.000 |
| 48 | FSS | Up 1, 2, 3 | | 47.200 | – | 50.200 |
| 50a | SRS, EES | Passive 1, 2, 3 | | 50.200 | – | 50.400 |
| 50b | FSS | Up 1, 2, 3 | | 50.400 | – | 51.400 |
| 50c | MSS (sec) | Up 1, 2, 3 | | 50.400 | – | 51.400 |
| 58 | SRS, EES | Passive 1, 2, 3 | | 51.400 | – | 59.000 |
| 65 | SRS, EES | Passive 1, 2, 3 | | 64.000 | – | 66.000 |
| 66 | MSS, RNS | Up 1, 2, 3 | Down 1, 2, 3 | 66.000 | – | 71.000 |
| 72a | MSS | Up 1, 2, 3 | | 71.000 | – | 74.000 |
| 72b | FSS | Up 1, 2, 3 | | 71.000 | – | 75.500 |
| 82a | FSS | | Down 1, 2, 3 | 81.000 | – | 84.000 |
| 82b | MSS | | Down 1, 2, 3 | 81.000 | – | 84.000 |
| 84 | BSS | | Down 1, 2, 3 | 84.000 | – | 86.000 |

[1] Numbers placed after the link direction refer to the ITU Regions for which the allocation applies.

[2] In all cases, MSS includes LMSS, MMSS, and AMSS.

[3] For emissions of emergency position—indicating radiobeacons only. See footnote 592 in the ITU *Table of Frequency Allocations*. (All footnotes cited hereafter refer to this publication.)

[4] sec = secondary allocation.

[5] Meteorological Satellite Service.

[6] Space Research Service.

[7] The band 0.136–0.137 was allocated to the Meteorological Satellite Service and the Space Research Service on a primary basis only until January 1, 1990. After that date it is allocated to those services on a secondary basis (fn. 595).

[8] In Region 1, the bands 0.138–0.1436 and 0.14365–0.144 are allocated to the Space Research Service on a secondary basis only in the following countries: West Germany, Austria, Belgium, France, Israel, Italy,Liechtenstein, Luxembourg, the U.K., Sweden, Switzerland, and Czechoslovakia (fn. 600).

[9] Radionavigation Satellite Service.

[10] China only (fns. 619 and 673).

[11] Earth Exploration Satellite Service.

[12] Canada only (fn. 648).

[13] Allocation to the Meteorological Satellite Service is on a primary basis in the following countries: Afghanistan, Bulgaria, China, Cuba, Hungary, Japan, Mongolia, Poland, Czechoslovakia, and the USSR (fn. 672).

[14] CR = community reception, TV only (fns. 693 and 757).

[15] Use of these services in the designated bands is limited to operation within national boundaries (fns. 699, 700, and 701).

[16] Norway and Sweden only (fn. 699).

[17] The allocation to the Maritime Mobile Satellite Service in the band 1.530–1.535 became effective January 1, 1990 (fn. 726).

[18] Use of this service in the designated band is limited to distress and safety operations (fn. 728).

[19] Transmissions in the bands 1.545–1.559 and 1.6465–1.6605 from terrestrial aeronautical stations directly to aircraft stations are also authorized when such transmissions are used to extend or supplement the satellite-to-aircraft links (fn. 729).

[20] India, Indonesia, Japan, and Thailand only (fn. 743).

[21] Afghanistan, Australia, India, Indonesia, Japan, and Thailand only (fn. 745).

[22] Bulgaria, Cuba, Hungary, Mali, Mongolia, Poland, East Germany, Roumania, Czechoslovakia, and the USSR only (fn. 746).

[23] Use of this service in the designated bands is limited to national and regional systems (fn. 761).

[24] Use of this band is subject, in whole or in part, to the provisions and associated plan of national allotments as adopted by the Second Session of the World Administrative Radio Conference on the "Use of the Geostationary Satellite Orbit and the Planning of Space Services Utilizing It."

[25] Allocation to the Earth Exploration Satellite Service is on a primary basis in Region 2 and in the following countries: Bangladesh, Benin, Cameroon, China, the Central African Republic, the Ivory Coast, Egypt, France, Guinea, Upper Volta, India, Iran, Israel, Italy, Japan, Kenya, Libya, Mali, Niger, Pakistan, Senegal, Somalia, Sudan, Sweden, Tanzania, Zaire, and Zambia (fn. 815).

[26] Allocation to the Space Research Service is on a secondary basis in the following countries: Belgium, Israel, Luxembourg, Malaysia, Singapore, and Sri Lanka (fn. 817).

[27] Use of this service in Region 1 is limited to feeder links for the Broadcasting Satellite Service (fn. 835).

[28] Use of this service in the designated bands in Region 2 is limited to national and sub-regional systems (fn. 839).

[29] Use of this service in the designated bands in Region 3 is limited to national and sub-regional systems (fn. 845).

[30] In Region 2, transponders on satellites in the Fixed Satellite Service in the band 11.7–12.1 may also be used for transmissions in the Broadcasting Satellite Service. Such transmissions are limited to a maximum e.i.r.p. of 53 dBW per television channel (fn. 836).

[31] Use of this service in the designated bands in Region 3 is limited to community reception (fn. 847).

[32] For countries outside of Europe and for Malta, the band 14.5–14.8 is reserved solely for feeder links for the Broadcasting Satellite Service. Similarly, the band 14–14.5 may also be used for this purpose, subject to coordination with other networks in the Fixed Satellite Service (fns. 858 and 863).

[33] Use of the band 17.3–18.1 is limited to feeder links for the Broadcasting Satellite Service (fn. 869).

[34] Allocation to the Space Research Service and the Earth Exploration Satellite Service is on a primary basis in Region 2.

[35] Japan only (fns. 892 and 899).

operación de un conmutador delantero/trasero. Las memorias intermedias basculantes proporcionan la separación de las distintas velocidades para cada corriente de datos entrantes, y los bitios de justificación compensan las variaciones debidas al corrimiento Doppler y la variación del oscilador local. Las corrientes del multiplejador por distribución en el tiempo (TDM) consisten en una palabra única de sincronización para sincronizar las tramas, y las palabras de control asociadas a cada ráfaga de datos para identificar la presencia o ausencia de un bitio de justificación. Se describen trayectos de datos redundantes para las corrientes de datos de ida y de retorno.

## *Pruebas de laboratorio y ensayos de campo transatlánticos con un modem COPSK de 140 Mbitios/s*

D. H. LAYER, J. M. KAPPES Y C. B. COTNER

**Abstracto**

Se presentan los resultados de las pruebas de laboratorio y los ensayos de campo transatlánticos realizados con un módem de modulación por desplazamiento de fase octal (COPSK) codificada a una velocidad de información de 140 Mbitios/s. Las pruebas en el laboratorio incluyeron el rendimiento de la tasa de errores en los bitios (BER) del módem como una función del nivel de la frecuencia intermedia (IF) de recepción y de las variaciones en la frecuencia, introduciéndose una pendiente lineal de IF, retardo de grupo parabólico y distorsión de amplitud lineal. Estas pruebas se hicieron por medio de canales adosados y no lineales (simulador de satélite). Bajo condiciones nominales, el sistema COPSK de 140 Mbitios/s proporcionó una BER de 1 x $10^{-6}$ a una relación $E_b/N_0$ más baja de lo que se requeriría de un módem con modulación por desplazamiento de fase cuadrivalente (QPSK) no codificada de 120 Mbitios/s. Los resultados de las pruebas de laboratorio también demostraron que este sistema es más sensible a las distorsiones del canal que la QPSK no codificada de 120 Mbitios/s; sin embargo, el funcionamiento mejora considerablemente cuando se utiliza un igualador transversal.

Los ensayos de campo se realizaron entre estaciones terrenas tipo A de INTELSAT situadas en Francia, los Estados Unidos y el Reino Unido, utilizando transpondedores de haz de zona de un satélite INTELSAT V-A ubicado a 332,5° de longitud este. Se describe el método empleado para acondicionar las estaciones terrenas y establecer los puntos de funcionamiento óptimo de sus amplificadores de alta potencia y los transpondedores del satélite, y se presentan los resultados de esa labor. Se comparan las mediciones de la BER con el rendimiento previsto, y los resultados demuestran un funcionamiento acorde con las actuales recomendaciones del CCIR. Estas pruebas son de notable importancia histórica, pues representan la primera transmisión digital transoceánica jamás realizada a una velocidad de información de 140 Mbitios/s por cualquier medio.

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*Non-COMSAT author.

COMSAT HISTORY PROJECT

Interview with Lewis Meyer

Interview conducted by Thomas Maxwell Safely

TMS: When and in what capacity did you join COMSAT? Let's go
back to the very beginning.

LM: I joined COMSAT June of 1963 as the Finance Coordinator,
which at the time was the Financial Officer of the newly-formed
COMSAT organization. Dr. Charyk, whom I worked with and for,
in the Pentagon (although I was never assigned to his office, I
was detailed to work on various projects) asked me if I would
like to come over and do somewhat the same work for COMSAT that
I had been doing in the Pentagon. At that point in time I had
not fully achieved the most I could get out of Civil Service.
After discussions with Bob McNamara and Gene Zukert and Joe
Charyk, I finally decided to come with COMSAT. COMSAT was just
newly organized. It had an organization Board of Directors,
had a Chairman/Chief Executive Officer, Leo Welch, and
[President of the Company] Joe Charyk. At the same time that I
came on board, Sig Reiger and Sid Metzger came on board. Bill
Calloway was on board handling the small[1]/ financial details
and the basic accounting that COMSAT required in those days.

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1/    delete:   small

We were housed in a stately mansion called, "Tregaron." It had beautiful grounds, which although didn't provide the optimum office space, was adequate for the many meetings and discussions and close cooperation required at that time in COMSAT's development.

TMS: What was your first concern? You came on as, I guess this isn't your title, but as Chief Financial Officer for the company -- a company that was just in the process of building its staff, had, well, I'm tempted to say, no real assets. You were really building from the ground up. Everything had to be acquired in one sense or another, since the initial legislation didn't appropriate any funds for the start-up of COMSAT. What was it like, what were your chief concerns at that point?

LM: My chief concerns were two-fold: One, the financial well-being of COMSAT and this was fulfilled through an agreement with ten various and sundry banks which either had affiliations through the Board of Directors, or through people in Washington who were interested in COMSAT, or through various banking houses who were interested in the development of space. The secondary, but more major concern was developing a program with which COMSAT could go forward. At the same time, we were

negotiating with foreign entities based on the interim arrangements which had been signed. We were developing programs and mapping a schedule of achievement for these programs. Also, we were discussing spacecraft and launch vehicles with the aerospace industry and with NASA.

TMS: What was your particular role in what you call the secondary, but more major concern -- of developing the program. For instance, John Johnson has talked in some detail with other people about the initial negotiations with European counterparts who would be the members of INTELSAT. How was the program developed here at COMSAT on a domestic level?

LM: Well, both Sig Reiger and I had known each other. He worked for Rand and I worked for the Air Force. Rand did various studies and Sig did various studies for Rand and for the Air Force. I was familiar with his costing analysis of certain programs and he was familiar with my financial analysis of certain programs. We were trying to develop programs by which the corporation, looking ahead for a progression of programs, and these iterations of programs resulted in our selection of a program to base our financing upon [sic]. This was a medium altitude system and all of the program aspects --

the dates and the financial details of the program -- were

outlined to present to the Board, various interested carriers,

and ultimately, the underwriters. [This effort was] for the

provision of a program [to be considered] when the organization

of COMSAT took place, and the organizing Board (if that's their

name now) would be replaced by a Board that had carrier

Directors, Presidential Appointees and other Directors. The

program was the program which Dr. Charyk, Mr. Welch, Sig Reiger

and I, and at times Allen Throop, presented to the carrier

hierarchies and to the underwriters and became the program

[for] which three hundred million dollar financing was

obtained.

TMS: You are saying that initially, especially from the

financial point of view, it was a medium altitude satellite

system that was thought to be the best for COMSAT. On the

basis of what, led you to decide on a medium altitude satellite

system?

LM: On the basis I think, and this is a technical question

that Mr. Metzger or Jim Potts or somebody like that can answer,

on the basis at the time, don't forget 1964 was awful early --

1963/1964 was awful early -- to be thinking of commercial use

of space. At the time it looked like, in order to get the

coverage of the country, that a multitude of earth stations and

satellites moving in orbits was the answer. Coverage was

important and being able to stay in an orbital region that was

free of interference was important.[2/] This program based on

studies, technical studies, that Sig Reiger had made as a first

step toward a communications system by satellite.

TMS: Was it your feeling, at the time, that underwriters,

banks, the financial community would more readily support a

medium altitude system?

LM: Oh, I don't think that I had the feeling one way or the

other. The banks, the underwriters, our Board, our company, we

were all enthusiastic. We were all, while maybe not convinced,

were set on a course that had a number of medium altitude

satellites [and] as I said, another number of earth stations

which could track these satellites and provide communications.

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[2/]    change to:  Coverage was important and being able to stay
        in an orbital region was important.

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TMS: Do you recall then, why the decision was made to not go with medium altitude but to try a geosynchronous satellite? Where there financial considerations involved apart from technical aspects?

LM: No. I think that the switch from the medium altitude system came about as a result of discussions with the Europeans, and the reticence of the Europeans to enter into [satellite communication], although they had signed a treaty, they were not of a mind to jump in with both feet, so to speak. I think Dr. Charyk was searching for an initial way to get started and to get the Europeans to come into INTELSAT and to participate with United States carriers in landing their communications, so to speak. For every United States carrier which transmits, there has to be a non-U.S. overseas carrier to receive. So, I guess there were discussions between Dr. Charyk, [and] Allen Puckett of Hughes. Hughes was working with NASA and had launched a geosynchronous satellite. The marketing person of Hughes, a Gordon Murphy, was selling a synchronous satellite. Sig Reiger, in discussions with the Hughes engineers, and Dr. Charyk came to the conclusion that an initial capability could be gotten through the use of a

synchronous satellite.  In fact, my memory is a little hazy on this, but I think that we made arrangements (I made arrangements)3/ with the Japanese to carry the Japanese Olympics to the United States.  I think that was in late '63 or late '64, I'm not sure which.  I'm not sure that that wasn't carried through a NASA satellite at a geosynchronous altitude. However, we negotiated with Hughes for what we were to call "Early Bird" and completed a contract.  We were then looking at a satellite system that in no way, shape, or form approached the cost of the program that we contemplated with the medium altitude system.

TMS:  Were there complications as a result of the fact that a prospectus and a first stock offering had really been developed with this medium altitude system in mind.  A particular kind of technology, a particular amount of money required to do that, and then a decision made to go with a different kind of technology; in some ways a different set of risks, and a different amount of money required.  I know that the initial capitalization of the company created some controversy, after the fact, for COMSAT and some people accused it of being over

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3/    delete:  I made arrangements

capitalized and so on and so forth. Were there any initial concerns on your part or on the part, of other officers, in that direction when it was decided that a geosynchronous satellite was the way to go?

TMS: Well, I didn't have any problems. I'm sure Allen Throop, our General Counsel, who, along with I think David Melamed, our first Secretary, probably had problems that wouldn't stop. There was no doubt in my running of a programs that a program consisting of three geosynchronous satellites and four or five earth stations was much more reasonable; but that was not my area of concern. I supported the General Counsel's Office with financial information or financial discussions with whoever in the SEC or the FCC they were dealing with. But that was not on my list of problems. Of course, I participated in meetings and voiced my opinion freely.

TMS: What was on your list of problems?

LM: Well, my list of problems consisted of people, housing, how would you structure an RFP for satellites, how would the program of Early Bird with carriers not using it fully -- but

on a part time basis affect the program.

TMS: We were talking about the concerns that you had -- your
list of problems -- and I'm glad we re-round for a moment
because I was going to ask about the carriers: their support
for COMSAT and COMSAT's concern for their reaction to the
satellite system -- their willingness to go with it. It kinds
of take us into question three a bit. The buyers, the carriers
who would buy COMSAT's satellite capacity.

LM: Well, the carriers initially, as I said, were on our Board
and owned fifty percent of COMSAT. They were possibly
reluctant to buy fifty percent of COMSAT -- a new venture,
truly a competitive venture, to theirs. AT&T had its cables,
or a cable, over the Atlantic and several small cables
elsewhere. It [AT&T] was planning larger and a multiplicity of
cables over the Atlantic and other routes -- the Pacific
primarily. So that they were reluctant dragons.[4/] Yet,
AT&T, in my estimation in the early days of our struggles, were

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4/    change: "dragons" to "to enter".

very cooperative and were[5/] help.  They sold us an earth

station at Andover.  People might think we paid too much for

it, but it was a book value plus transaction -- which the FCC

reviewed.  We needed an earth station and they had an earth

station.  We got into certain arrangements in another area

which other people handle -- pricing and tariffing of the

services.  I don't think that they were ever in a strong or a

weak bargaining position with respect to COMSAT.  They were

very cooperative.  They were very responsible Board members.

They participated in our Board deliberations.  I would say that

their advice and help and their key people's participation was

a key to COMSAT's success.  You could open many doors in many

countries because you were affiliated with AT&T.  AT&T was

world renowned and Harold Bodkin was a marketing man of many

skills who was internationally famous as an AT&T

representative.  It's amazing to me how I remember these names

like Harold Bodkin I haven't even thought of Harold Bodkin for

twenty years.

TMS:  Can you think of one particular instance in which you

_____

5/    add: a big

-10-

were involved that would really highlight the way in which
AT&T, or any of the carriers, (AT&T, of course, took a leading
role at that point in the early days) in which AT&T promoted
COMSAT's interests; it really helped the business along?

LM: I think, from the outset, I was most impressed by, I think
it was Chairman of the Board at that time, Kappell of AT&T, and
his support of COMSAT and his, whether it was his, or making
available to COMSAT the expertise of Jim Dingman who was a
significant person in the AT&T hierarchy and who gave COMSAT
some guidance that you couldn't buy from AT&T. AT&T felt for
COMSAT in COMSAT's attempt to get into the international
marketplace. Just by the acceptance of AT&T, I think COMSAT
was able to succeed.

TMS: Sympathy is not a real common motivation in business, at
least not from the outside looking in.

LM: I don't think AT&T ever sympathized with anybody.

TMS: Why would they do this for a potential competitor? Why
the interest in COMSAT? Sure, they had a big chunk of COMSAT

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stock, but compared to their company's value, it was fairly
small stuff.

LM:  You can start with that.  They [AT&T] had a big chunk of
COMSAT stock.  You can surmise, which I'm doing now, that the
international activities of AT&T -- a multi-billion dollar
annual revenue company -- looking into international business,
it was very small -- three to five percent -- of their
business.  COMSAT, not in the true sense, but was "politically"
supported in the '63/'65 time period.  AT&T, I think, coldly
calculated that this was no time to beat on an upstart.  It
wasn't enough of a business threat to AT&T to want not giving
Washington, so to speak, the fullest cooperation and COMSAT
their full cooperation.  There was also an incentive:  if the
stock went up and they got out -- as they did -- they would
make money on it and it would prove to be a good investment --
which it did.  I think AT&T's position was that, as long as
this small company didn't get into the domestic business, that
they were perfectly willing to help it and go along with it and
let it into the international business, so to speak.
TMS: So, you think that they [AT&T] saw COMSAT as having a
nitch in the marketplace within which they were really willing

to support and very forthcoming with their support. The forthcomingness of AT&T has been, I think, has been fairly well acknowledged.

LM: I think they realized that Congress and some powerful communications persons on the Hill wanted COMSAT to have a monopoly nitch and I think they acceeded to it in order not to incur the disfavor of these Congressional giants. They participated and very willingly and very openly and they were very helpful.

TMS: Okay. Let's shift gears a little bit and talk about how COMSAT has grown over time from fairly modest beginnings at Tregaron; we now sit on the eighth floor of L'Enfant Plaza. Looking back, what would you say have been the great achievements of COMSAT; the milestones, again, with your particular perspective, your particular interest in corporate finance? What have the milestones, the turning points, been?

LM: Well, my particular expertise was to diverted from finance to procurement. Dr. Charyk, I think, at the insistence of a particular Board member who was financially-oriented and who

-13-

didn't think a government background in finance was adequate

for COMSAT (by the way, this person failed horribly as

Secretary of Treasury),6/ decided that one of the important

things to COMSAT would be how it spent its money rather than

keeping track of where it was going and what it was doing.  So,

he decided that I should establish and administer a centralized

procurement function.  So, at that time, I, based on some

recommendations of some officers at the Pentagon, I, while I

was still responsible for the financial functions, hired Carl

Reber.  Meanwhile, the Board people hired Bruce Matthews, who

was very big in the mid-West at the time.  I went on to do the

contracting and all of the procurement for COMSAT and

ultimately for INTELSAT.  The most important things were to get

a place to live, as they say, and get an RFP out for a follow-

on at that point, to Early Bird.  By that time, the interim

arrangements were in effect and the competition aspects of the

arrangements precluded just going to Hughes for another Early

Bird or advanced Early Bird or an Early Bird Two or whatever

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6/  delete:  I think, at the insistence of a particular Board
     member who was financially-oriented and who didn't think
     a government background in finance was adequate for
     COMSAT (by the way, this person failed horribly as
     Secretary of Treasury)

you want to call it.  Meanwhile, we had gone to Hughes again

for a DCA service, the famous "thirty circuit" case, and so I

was a pretty busy person in buildings and space and dealing

with NASA for launch capability, dealing with contractors for

spacecraft and still handling a lot of the housekeeping

functions; but that was after we were out of the stock phase

that all this happened.  I spent the rest of my time in the

procurement function -- various aspects -- and I gravitiated to

mostly the INTELSAT function.  But in the early days, it was a

busy place and not a lot of people.

TMS:  In some ways, it makes me think that as you set up

procurement you became involved in a great many more things and

perhaps saw a great deal more of what was going on than you

might have been if you were involved with portfolio management,

strictly, or the initial financing.  You might have been put in

a better position to acknowledge the milestones as they passed;

the things that really shaped COMSAT to the point that it's

arrived at today.  That's not a question is it?  Whether you

agree with that or not, let's go back and have another crack at

the milestones.  Which were the ones you thought were most

important?

LM:  I think there is no doubt in my mind that Early Bird
turned everything around for COMSAT.  The coming into effect of
the interim arrangements was a milestone -- a very large one.
I think the next milestone with respect to INTELSAT was the
definitive arrangements negotiations which I participated in,
with respect to the procurement aspects at that time, and they
were most meaningful.  Of course, the stock offering was a
large milestone after or before Early Bird.  I think that's
about it.

TMS:  It calls to mind another question that I have raised with
other people.  Procurement and the satellites, in particular,
COMSAT has had very good fortune with its satellites -- a high
degree of dependability -- for the most part they've functioned
at a level exceeding what people thought they would function.
They either lasted longer or provided a greater number of
circuits or whatever.  To what extent do you see the actual
procurement policies that COMSAT adopted with regard to
satellites as playing a role in their dependability over the
long haul?

LM:  Well, I don't think that procurement policies provided

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dependability. In the procurement policies that I affected, and I personally handled all of the major spacecraft contracts and launch vehicles, I was guarding against the things that happened during my tenure at the Pentagon: the ballistic missile overruns,[7/] the B-52 overruns, the failure of management to know when programs were not going well until after they were in a deep overrun position; and in the Air Force, in the early days, the failure of the contractors and accounting system to point out anything. I think Dr. Charyk was very sensitive to these issues because as Undersecretary of the Air Force, he had responsibility to Congress to explain why programs overrun [sic] billions of dollars. So our contracts were written very carefully and [with] very detailed specifications. Our contracts were written with very careful and detailed test specifications.[8/] Our procurement office then maintained the contracts and did not allow any exceptions to the contract or deviations from the contract. If a contractor overran the contract, his recourse was to his

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7/    change to:  cost plus contracting the ballistic missile
      overruns

8/    change to:  So our contracts were written very carefully
      on a fixed price, incentive basis with performance
      specifications as well as detailed test specifications.

-17-

comptroller not to me or my procurement office. That was a
secondary effect. The major effect was the cooperation and the
surveillance of our engineering staff -- Marty Votaw and his
people primarily living with the contractor and knowing what he
was doing and knowing the specification and assisting him to
make sure that the specification was met. Hughes had Hal Rosen
who could solve a problem overnight and know what to do about
it and know how to fix it and do it within the scope of the
contract. TRW had some of the same type of people, but they
needed help · because they had problems with their
subcontractors and it did not for an optimum program. I think
Votaw's crew of on-site maintenance, if you will, or
surveillance, if you want, was meaningful to acquire the very
low cost of changes to all of the spacecraft contracts. In
fact, the only cost changes were those which were initiated by
INTELSAT wanting something more than was contemplated or
wanting additional options. Outside of that, there was a very
close financial surveillance. We knew what they were doing, we
knew what they were spending.

TMS: It strikes me as kind of, well, an unusual thing to have
done at the time -- on-site -- really having your engineers

on-site at Hughes all the time; not just an occasional inspections, and very, very tight control of contracts. How were these procedures cooked-up; I mean who came with the ideas?

LM: Well, I think that the Dr. Charyk led the parade, I acknowledged it. As I said, from my Pentagon experience, we knew you couldn't take a company through that kind of a financial experience. I think it was an acknowledgment of Reiger and Charyk... remember Charyk guided the technical portion of the company as well as everything else; but he was considered a technical man and I feel that it was a proper choice -- a technical man to be President of COMSAT. I think that we all knew [about cost overruns]. Sig Reiger, knew because working for Rand he had to know the details of every cost overrun the Air Force ever had. I knew, because I was the Secretary's [of Air Force] financial man and I was on budget staff for so many years. Dr. Charyk knew [as Undersecretary of the Air Force] because he was on the thin end of the funnel trying to explain to Congress why the overruns came about and what they would do to stop them or somewhat abate them. So, I think, by and large, the people concerned with strict contract

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compliance all were knowledgeable through prior experience.

They just felt that COMSAT couldn't afford this experience.

So, I think it was a big technical labor of love. If Marty

Votaw saw them running a test [and they did not comply with the

test specifications, they ran it again].

If they wanted to change the specifications he [Votaw] made

sure that it was changed in such away so it would be [of] no

cost change to the [contract]. So, the contractors got used to

the idea that if there was a change and they caused it that

they had better be prepared to pay for it, or take it out of

their hides, or take out of their.... The contracts were good

contracts in that if the contractor succeeded, he made a lot

more profit than he was making at the Pentagon or any place

else.

TMS: How was that?

LM: Well, we had incentive contracts, which I devised, where

the contractor could get up to between thirty and thirty-five

percent profit on the job -- over cost. We never really knew

what the real cost was, but that's something that you have to

accept[9]/ the integrity and the honesty of the contractors.
But, it was possible for them to either lose ten percent on a
bad bird or make thirty to thirty-five percent on a good
bird[10]/ -- over the lifetime of the bird. Those kind of
numbers, I don't think were ever occasioned in the aerospace
industry. It made for an incentive, on both sides, to have a
great satellite; and we had some good satellites, we had some
bad ones, but that's another story.

TMS: That's very interesting. In some ways, it sounds almost
as if the Pentagon experience of a number of the top officers
at COMSAT early on was, you might call it, one of the strengths
of the company because it pointed out the pitfalls that needed
to be avoided. Would you agree with that?

LM: In this area yes. But, I would say that I think the
general knowledge of Dr. Charyk, in the reconnaissance area and
the knowledge of what happens to satellites, and Sig Reiger's
knowledge of satellites, the Hughes team, the TRW team, the

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9/     change:  "accept" to "rely on"
10/    change:  "bird" to "operating satellite"

Ford team, all that comes out of the United States space program. All of the associations came out of the space program, the ballistic missile program, and a combination of NASA and Department of Defense programs [which] provided communications satellites. NASA in those years, had a very strong communications satellite effort going, spending millions of dollars.[11] The Air Force had, of necessity, a delivery of warhead problem which lead them to missiles, ballistic missiles; first, air-breathing missiles: then ballistic missiles. So, I would say, if you get out of the Pentagon alive, you can pretty much survive wherever you go.[12] But yes, I think all of our associated aerospace industry contacts and knowledge of programs helped COMSAT, it had to. That's why, I assume Phillip Graham went to Dr. Charyk -- he knew where he was working.

TMS: Can you think of anything else that COMSAT did differently from other firms involved in aerospace development? The procurement procedures are one thing that you point to.

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[11] delete: spending millions of dollars

[12] delete: So, I would say, if you get out of the Pentagon alive, you can pretty much survive wherever you go.

Were there any other things that you thought COMSAT really pioneered?

LM:   I think the Laboratories pioneered many earth station and spacecraft innovations which had been used on succeeding spacecraft, [and] new earth stations.  COMSAT Labs has been responsible in the past for echo cancellers, they are coming down the line now to the end of the TDMA innovation -- that's another story.  I guess your reference on those stories should be Dr. Harrington, the former director of the Labs, Burt Edelson maybe, Bill Pritchard; all successive Lab directors.

TMS:   When the Labs were first started-up, there was some discussion, especially among the various members of INTELSAT, some criticism let's say, of the expense involved and some question as to whether or not this was really a necessary facility for COMSAT to have.

LM:   Initially, I never heard any bitching about the Labs. INTELSAT couldn't possibly do any complaining until the advent

of the Secretary General which was probably 1976 - 1977[13]/ (you tell me).  The Labs was [sic] no different than any other laboratory working for any other government agency; AT&T, Lincoln, IT&T, Federal Laboratories, RCA's Sarnoff Labs.  They all work cost-plus and the Labs was working cost-plus; and it was cost-plus something like ten percent, if I remember.  The government was paying cost-plus someplace between six and twelve percent.  Anyway, the Labs was totally dedicated to INTELSAT.  There was nothing going on there that wasn't devoted to communications satellites.  And by charter, by edict, the Board didn't want the Labs to participate in anything except communications satellites oriented projects.  So, the bitching starts when the Secretary General and one of its procurement offices decides that one of the ways of being a hero and cutting the budget is to cut back the Labs because the Labs have accumulated high salary people and cost-plus now is very expensive.[14]/  So they, during the Secretary General's or the

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13/  change to:  1975 - 1977

14/  change to:  So, the complaints start when the Secretary General and one of its procurement offices decides that one of the ways of cutting the budget is to cut back the Labs because the Labs have accumulated high salary people and cost-plus now is more expensive.

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Director General's reign, they, instead of cutting back the program as a good company that thought they were paying too much should do, they tried to change the program by having their own R&D done on a fixed- price basis; and you just can't do R&D on a fixed-price basis unless you know what kind of a specification there is. In defense of the Labs, several big projects were overrun; notably the TT&C and the CSM, both of which were taken on contract on a cost-plus basis without an appropriate work statement. In fact, in the CSM, I think the work statement came out of INTELSAT about eighteen months after the program started. So, if you are looking for overruns on a cost-plus program, that's were you get them.

TMS: You mean for eighteen months the Labs were working on a project without any specification?

LM: Without a specification that was good enough to do, to complete the job. INTELSAT was watching what was happening in the development and little by little they developed a good work statement and responsive spec. So, you know, I have never heard except for what I just said, that so they changed....they got budget conscience and changed to a fixed-price basis. They

still, though, do their surveillance of contractors[15/] which

has grown measurably since the Director General and the

Secretary General.  COMSAT had a small group of kind of top

flight.... they have a large group of....[16/]  I haven't been

in touch with them so I can't quantify them or qualitatively

rate them.  But most of what you hear is what people want to

say to defend their own position.  I think the Labs' problems

with  some of the contracts with INTELSAT have been, I would

say on some large programs, seventy-five percent the

responsibility of INTELSAT, twenty-five percent responsibility

of the way the Labs did things and fifty-fifty on others.  But,

the Labs in their other contracts for NASA and other government

agencies don't have the same history as they have with

INTELSAT; so that might tell you something.  One of the

problems, in my estimation, I discussed this with Dr.

Harrington, it's evident that Dr. Evans knows it, is their use

of the higher paid engineers on projects.  Some laboratories

can get away with proposing at a lot less than Labs.  They do

it by proposing their second or third tier engineering talent

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15/    add:   through COMSAT

16/    change to:   COMSAT had a small group of top flight
       engineers who became the nucleus of their capability.

-26-

and letting their high-price talent merely contribute as a function of overhead. The Labs, in addition to their high salary people who work on things hands on -- people that do good engineering work on their contracts -- they just have been old hands and they are pretty well up the salary level, deservedly so, but they are not the kind of people you [can be cost] competitive with. Our friends at NAC in Japan did these jobs at maybe the third or fourth tier engineering level and they use their top tier as supervisors level. You have to keep your overhead down as you are doing this, but that's life.17/

TMS: It's kind of interesting, in the midst of what complaining there has been on the part of INTELSAT, have they made any major move to contract R&D away from the Labs, say to Lincoln Labs up at MIT?

LM: No, but if you look at a list of INTELSAT's procurements other than contracts that are sole-source to COMSAT, COMSAT has

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17/ delete: Our friends at NEC in Japan did these jobs at maybe the third or fourth tier engineering level and they use their top tier as supervisors level. You have to keep your overhead down as you are doing this, but that's life.

supported the operational side of INTELSAT and, at the present

time, about a million and a half of INTELSAT R&D is done at the

Labs on a sole-source basis.  It used to be five or six

million.  So, it's gone downhill.[18]  What they have done is

taken more of the R&D out of the sole-source and put it into

the competitive area.  In the competitive area in Europe and

other countries, in countries other than Europe, government

subsidizes research and development contractors.  Our

government doesn't subsidize.[19]


TMS:  Making it difficult for COMSAT Labs to beat bids.


LM:  It means that COMSAT Labs has to... somebody has to

subsidize COMSAT Labs; the shareholders have been, to a certain

extent.  Again, very strictly in the area of satellite

communications only, COMSAT has been able to cost-share with

the United States Government and with INTELSAT on certain

projects [in] which cost-sharing is appropriate.  You are going

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[18]  delete:  So, it's gone downhill.

[19]  delete:  In the competitive area in Europe and other
      countries, in countries other than Europe, government
      subsidizes research and development  contractors.  Our
      government doesn't subsidize.

to work on that type of project out of your corporation's funds and you now get a contract, and if you get a contract the corporation' funds takes it so far, and the customer's funds takes it to another point, or another plateau, or another whatever they are after. But, this is prevalent all over the world and they're doing business that way. COMSAT's Labs' combination of high salaries[20] and high overhead has probably precluded them from getting a larger share of the INTELSAT pie and it probably precluded them from getting a larger share of the government pie.

TMS: This suggests another question that I offered you and that was the challenges that COMSAT has had to face. Looking back, what do you think are the major ones?

LM: I would rather, after a lot of this detail is put down on paper, have someone look at this manuscript and pick out, from what we have all said, the major things. I would suggest that when that is done, all of us could more meaningfully speak to what we feel. Right now, I couldn't, without a lot of thought

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20/   delete:  combination of high salaries and

and maybe some discussion with a lot of people...[21]  Oh, I

think a major milestone, I could say, is the loans to the ten

banks.  First thing, that's initial financing.  Next thing is

the stock offering.  There comes public ownership and

independence.  Next thing is the carriers selling their share

-- that's complete independence.[22]  That's only the SEC and

the FCC they are worried about.  Getting into the domestic

business, which is not my business, I have never been in it,

but I've been here.  I couldn't, I don't think, fairly answer

that question.[23]


TMS:  Okay.  Fair enough.

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[21]  delete:  I would rather, after a lot of this detail is
      put down on paper, have someone look at this manuscript
      and pick out, from what we have all said, the major
      things.  I would suggest that when that is done, all of
      us could more meaningfully speak to what we feel.  Right
      now, I couldn't, without a lot of thought and maybe some
      discussion with a lot of people...

[22]  add:  The formation and completion of the corporate
      charter (to have a worldwide international
      telecommunications system).

[23]  delete:  That's only the SEC  and the FCC they are
      worried about.  Getting into the domestic business, which
      is not my business, I have never been in it, but I've
      been here.  I couldn't think, fairly answer that question.

LM:  I would like to see Dr. Charyk's answer to that question.

TMS:  Yes, so would I, very much so.  At this point, is there anything else you thought about saying as you looked over these questions; that you want to put down on the record or anything that you want to add that we have not covered here?  Sometimes in looking the questions over in advance, you think of something you want to say and then we go off in a completely different direction.

LM:  I think, from my standpoint, there is probably a lot that is unsaid.  If you pick up anything from other people that is specific and want my opinion of that specific, feel free.

TMS:  Okay.  Very good.

LM:  I just think that we've gotten through about a full of hour.  No, more than that.  My phone call [in the middle of the interview] was only about five minutes.  Well, close to an hour and a half and I think you really... I'm surprised at my memory for some of the things.  But, I would be glad if you pick up anything.  Are you going to talk to Allen Throop?

TMS:   I already have.

LM:   Oh, alright.  Well, when you start getting this down on paper, if you.... I talked to John McLucas and he's going to be the ultimate review.

TMS:   I believe that's true.

LM:   Alright.  When you are getting manuscripts, if you circulate them to people who contributed, I will review it. I'll also be glad if you come on other questions when you talk to other people.

TMS:   Great.  I think you very much.

LM:   Fine and dandy.