

Advanced Satellite System Architecture for VSATs with ISDN Compatibility[†]

Ronald E. Jorasch and Kent M. Price[‡]

Ford Aerospace Corporation
Space Systems Division
Palo Alto, CA 94303

A 88-27604

1 Abstract

This paper describes a future communications satellite system architecture concept which allows the use of Very Small Aperture Terminals (VSATs) of 1.2 m to 1.8 m diameter and which provides access according to the international Integrated Services Digital Network (ISDN) standard. This satellite system design could make dial-up integrated voice and data service available nationwide and perhaps worldwide. The paper gives a conceptual system design based on the year 1995 technology for the communications satellite, the earth terminal, and the ground-based master control station and interface to the terrestrial ISDN network.

streams at about 30 Mb/s, which can digitally switched on the satellite for routing to the appropriate downlink beam.

The proposed architecture uses a demand assignment access technique via an in-band order wire. Network control is achieved at a ground based master control station. Various channel capacities can be requested to one or several destinations with user charges allocated on the basis of time and data rate. Simultaneously with the use of the assigned ISDN "B" channels, low rate packet data may be communicated through the "D" channel.

2 Introduction

Significant current and projected improvements in satellite digital communications technology – including narrow spot beam antennas, coding, multi-channel demodulation, and high speed switching at baseband – now make it possible to accommodate over 15,000 simultaneous accesses via satellite from low cost VSAT terminals operating at data capacities ranging from 72 kb/s to 1.5 Mb/s. A satellite configuration consisting of 1,500 kg mass and 4 kW solar array power will accommodate a composite data throughput of over 2 Gb/s for a Ku-band system implementation and results in competitive costs per channel minute of utilization.

An interface with terrestrial fiber optic trunking networks is provided in order to take advantage of existing and planned low cost, broadband, digital connections to those destinations in the major city areas. Communications from the satellite to any terminal is achieved at a moderate TDM rate of about 30 Mb/s in order to facilitate feasible power amplification levels in the satellite and to allow low cost VSAT terminal configurations.

Recent key technology developments now permit use of a "bulk" or multi-channel demodulator to accommodate several hundred simultaneous FDMA uplinks in a light weight, power efficient unit suitable for use in space. In addition, the bulk demodulator can be reprogrammed in orbit in order to accept various mixes of data channel sizes in order to efficiently match the dynamically changing traffic demands. The outputs of each bulk demodulator are composite TDM data

The development of an efficient satellite system architecture for accommodating ISDN and low cost VSAT applications in the 1995–2000 time period will be subject to considerable modification over the intervening years before the final design review. The system will continually evolve as more information is obtained on customer requirements, traffic mix, and performance of key technology items being evaluated in the laboratories. However, it is essential to have a "strawman" baseline design in order to focus the development process and to verify the preliminary economic feasibility.

The described system is designed to accommodate any ISDN user location within CONUS by providing services directly to the customer's premises. The alternate terrestrial ISDN systems are subject to the bandwidth limitations of the copper wire tail circuits and restrict ISDN service to locations within several miles of the local office. This creates a unique marketing niche for a satellite-based ISDN system.

[†] This paper is based upon work sponsored by the National Aeronautics and Space Administration under contract NAS3-24683.

[‡] Member, AIAA

3 ISDN Interface

3.1 Overview

An Integrated Services Digital Network (ISDN) evolves from a telephony IDN (Integrated Digital Network) and provides end-to-end digital connectivity to support a wide range of services, including voice and non-voice services, to which users have access by a limited set of standard multi-purpose user-network interfaces.

The main feature of ISDN is the support of a wide range of voice and non-voice applications in the same network. A key element of service integration for ISDN is the provision for a range of services using a limited set of connection types and multipurpose user-network interface arrangements.

ISDNs support a variety of applications including both switched and non-switched connections. Switched connections in ISDN include both circuit switched and packet switched connections.

As far as practical, new services introduced into an ISDN should be arranged to be compatible with 64 kbit/s switched digital connections.

An ISDN contains intelligence for the purpose of providing service features, maintenance, and network management functions. This intelligence may not be sufficient for some new services and may have to be supplemented by either additional intelligence within the network, or possibly compatible intelligence in the user terminals.

A layered protocol structure is used for the specification of the access to an ISDN. Access from a user to ISDN resources may vary depending upon the service required and upon the status of implementation of national ISDNs.

3.2 Channel Types and Uses

The ISDN may be described by a limited set of user-network interfaces and a limited set of ISDN connection types to support the telecommunications services. The following types of channels are available:

- **B Channel** (64 kbit/s)
 - Digital voice
 - High speed data
 - Other (e.g. facsimile and slow-scan video)
- **D Channel** (16 and 64 kbit/s)
 - Signalling
 - Low speed data
 - Telemetry such as emergency services
- **H Channel** (384, 1536, and 1920 kbit/s)
 - Higher speed user information

The B and H channels are circuit switched, which means they exist as an entity for the duration of the connection (i.e. many seconds) between two fixed locations. The D channel is packet switched on a packet-by-packet basis.

3.3 Network Interface

Possible ISDN user-network physical interfaces include the following:

- **Basic Service**
 - Rate: 192 kbit/s (full duplex)
 - Composition: 2 B (64 kbit/s) + 1 D (16 kbit/s) channels, plus synchronization and framing bits.
- **Primary Service**
 - Rate: 1,544 kbit/s (full duplex)
 - Composition: 23 B (64 kbit/s) + 1 D (64 kbit/s) channels.

The basic service is the maximum possible over a two wire subscriber local loop. The extra 48 kbit/s are used for synchronization and framing by the synchronous TDM protocol between the user and the network central office. The primary service rate is 1.544 Mbit/s (23B + D) for the United States, Canada, and Japan, and 2.048 Mbit/s (30B + D) for Europe.

3.4 Satellite System Applications

Considering the alternative of the local telephone company, the future satellite communications system may be able to compete in the following areas:

- Offer ISDN to regions without telephone service.
- Offer ISDN service to regions without ISDN.
- Offer communications independent of local telephone regulations.
- Offer “movable” and rapid deployment communications.

4 System Architecture

4.1 Traffic Mix

It is assumed that a potential system has about 100,000 users with VSATs in the 1995–2000 time period, not all of which operate simultaneously. It is also assumed that several classes of ISDN service are to be provided:

- Basic access (144 kbit/s) via 1.2 m VSAT
- Primary access (1.536 Mbit/s), 1.8 m VSAT

- Interface to terrestrial ISDN via 4.0 m terminals at nodes of fiber optic network.

The 1.2 m and 1.8 m VSATs each have a dual mode of operation in order to conserve satellite capacity and to allow the user to only pay for the capacity actually used. The 1.2 m VSAT can operate with full ISDN basic access capacity (2B+D, 144 kbit/s) or half capacity (B+1/2D, 72 kbit/s). Likewise the 1.8 m VSAT can provide full ISDN primary access capacity (23B+D, 1.536 Mbit/s) or half capacity (11B+D, 768 kbit/s).

The 4 m ground terminals are installed at several fiber optic node points on the terrestrial ISDN network to provide cross connection between the satellite system users and the terrestrial ISDN system users. Each terminal accommodates twenty primary access ISDN channels [20(23B+D)] with a total capacity of 30.72 Mbit/s.

Table 1 gives an estimate of user capacity and traffic mix on a single satellite. About 54% of the satellite throughput is used by 1.2 m VSATs, 23% by 1.8 m VSATs, and the remaining 23% by the 4 m node terminals. The satellite can accept up to 12,496 simultaneous FDM uplinks of which 12,000 are 1.2 m VSATs, 480 are 1.8 m VSATs, and 16 are node terminals. The equivalent number of half duplex 64 kbit/s channels is 30,560, giving a total satellite throughput of 1.956 Gbit/s.

The dual mode for the 1.2 m VSAT permits lower user charges when operating in a single B channel application rather than in the standard basic access 2B+D format. If no change is made to the VSAT transmitter power, an extra 3 dB signal power is available in the B+1/2D mode to improve signal quality and link availability. The dual mode for the 1.8 m VSAT acts in a similar manner.

4.2 Satellite Configuration

The design of the satellite configuration is significantly affected by projected user demands, the technology available in the 1995-2000 period, and the need to be cost competitive with alternative communication systems.

4.2.1 Uplink Coverage

Figure 1 shows the satellite antenna coverage for the uplink. It consists of four fixed elliptical beams roughly corresponding to the four CONUS time zones. The beams alternate in linear polarization with each using the full 500 MHz available bandwidth. The beam size permits a transmitter power levels of a few Watts for the 1.2 m VSATs with basic access ISDN service. The use of smaller beam sizes would lower ground transmitter power levels at the expense of loss in flexibility for efficient allocation of the bulk demodulators among beams.

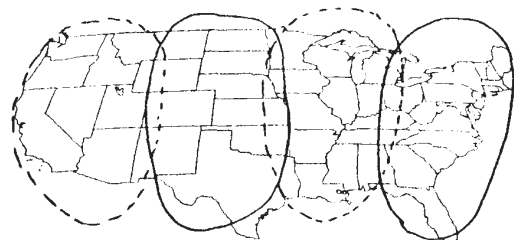


Figure 1: Uplink Antenna Coverage

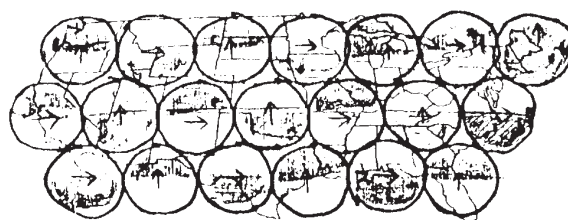


Figure 2: Downlink Antenna Coverage

4.2.2 Downlink Coverage

Figure 2 shows the downlink antenna coverage which consists of 21 fixed beams, each providing approximately 1° of coverage to the -3 dB power contour. There are 4 unique beam configurations, with beams alternating in polarization and each beam using no more than half of the available 500 MHz bandwidth.

The interbeam isolation could be reduced by using a 3.6 m satellite antenna with 0.5° composite beams. Each downlink beam is then comprised of four smaller composite beams, and has a sharper roll off in gain at the edge of the beam.

A scanning beam antenna system for the downlink is not used because the extra gain of a smaller beam is not needed to close the link with reasonable parameter values, and because of the added complexity to satellite signal routing and timing control.

4.2.3 Capacity

A 2 Gbit/s design goal for satellite data communications throughput is chosen. If the data throughput is reduced, the cost per channel becomes larger. However, if the satellite is too large, the accommodation of low initial capacity and on-orbit spare/replenishment plans become economically inefficient.

Class of User	ISDN Channel Structure	Total thruput (%)	Number of Uplinks	Equivalent Number of B channels
1.2 m VSAT	B + 1/2 D 2B + D	27.0 27.0	8,000 4,000	8,000 4,000
1.8 m VSAT	11B + D' 23B + D'	11.5 11.5	320 160	3,520 3,680
4.0 m node	20(23B + D')	23.0	16	7,360
Totals		100	12,496	30,560

Table 1: Estimate of User Capacity and Traffic Mix

4.2.4 Mass, Power, Lifetime

The design goals are a satellite beginning-of-life mass of 1,500 kg and an end-of-life power of 4,000 W. A ten year lifetime appears to be a reasonable objective for the 1995 era. Any of several launch vehicles may be utilized.

5 User Terminals

5.1 Classes of Terminals

In order to accommodate the diversity of user capacity requirements, several classes of terminal designs are allowed in the system. A small VSAT terminal with antenna diameter of 1.2 m is selected for accommodating the B+1/2D (72 kbit/s) to 2B+D (144 kbit/s) data links. This antenna size has an uplink half power beam width of 1.2° at 14 GHz. If satellites are to be spaced at 2° in the orbital arc, then any significant reduction in user terminal diameter will lead to uplink interference.

Another VSAT terminal class of 1.8 m diameter is proposed for accommodating the medium data rates of 11B+D (768 kbit/s) and 23B+D (1.536 Mbit/s) users. The greater size is a compromise to keep the terminal and satellite transmitter power levels to practical values.

A final class of 4.0 m diameter terminals is proposed for accommodating traffic to and from the fiber optic model switching centers. The size is required to accommodate the high data rates of up to 30.8 Mbit/s. Only a few 4.0 m terminals are required for the overall system and hence the cost per terminal is not significant in determining overall system costs.

5.1.1 Low Cost Implementation

In order to maximize the number of users and number of applications that are economically feasible, it is desired that the small VSAT terminal be available at low cost. A detailed determination of terminal costs is beyond the scope of this study. However, preliminary analysis indicates that a goal of \$15,000 per VSAT terminal may be feasible. This would be achieved through optimization of terminal performance parameters, maximum use of MMIC and VHSIC chips, and large scale production in lot sizes of 5,000 units.

Cost reduction for users is possible with time sharing of a terminal among several interconnected users. The interconnect could be achieved by use of microwave relay, excess cable TV system capacity, or other wideband links.

5.1.2 Design Parameters

The optimization of user terminal performance parameters is required in order to minimize overall system costs. It is desirable that the transmitter power level be within the capability of single devices. A minimum output power of 1.6 W is required for operation of the 1.2 m VSAT within the proposed system architecture, and this is expected to be readily available from solid state devices at Ku-band in the 1995 era.

Another decision concerns the requirements for user terminal tunability. A trade-off determined that maximum operational flexibility is obtained at small increase in cost by incorporating the capability for tuning over selected segments of the 500 MHz bandwidth for both transmit and receive modes.

The stability of the uplink transmission is critical because each channel is separated from the adjacent channel by only 1.5 times the symbol rate. Rather

than incorporate highly accurate frequency references at each VSAT terminal, it is recommended that a downlink beacon signal be monitored in order to determine an offset frequency reference and also to provide a coherent timing reference. Coherence of uplink signals from users sharing a common bulk demodulator in the satellite leads to simplification of the satellite implementation.

Other tradeoff concerns the amount of processing of the D-channel information to be done at each VSAT terminal. For example the routing information could be separately extracted and transmitted as an auxiliary preamble and the need for transmitting full D-channel information at all times could be reduced. For the specific baseline system proposed, it is planned that no processing of the D-channel information is required at the VSAT terminal. The D-channel would be relayed intact via the satellite to a master communication control center which would perform the processing.

6 Network Control

A single ground-based network control facility with built-in redundancy may be located at a fiber optic network node in the Western United States. Based on the control information in the D channel, the network control establishes and maintains the communication links by controlling the satellite switch and the user terminal frequency assignments. In addition, authorization and billing functions are carried out via links to a nearby computer facility.

Due to the large expense of this facility (estimated \$100 M capital cost), an interface to the ground ISDN network ("node terminal") is co-located at this facility and shares some of its resources.

Note that all D channel bits transmitted by users must pass to this facility (via the satellite) for processing, and all D channel control bits received by users originate at this network control.

7 Case Example of System Implementation

As a reference for understanding a relatively complex complete system architecture, it is meaningful to trace a single user application. Figure 3 shows the link implementation for an ISDN basic access user (1.2 m VSAT, 2B+D channel). In this example an ISDN basic access format (2B+D) is transmitted from an originating point within CONUS and relayed via satellite to a destination point within CONUS. The 2B+D format consists of two 64 kbit/s channels and a 16 kbit/s signaling channel which are multiplexed into a single PCM data stream at 144 kbit/s.

The originating VSAT is 1.2 m in diameter and is located at the customer's premises. A separate random access channel is used initially for service request and to obtain channel assignments for transmit and receive. The system and ISDN protocols make this process invisible to the user, who simply picks up his telephone and dials a number. The communications information is digitized and transmitted on a Ku-band carrier (14.0 to 14.5 GHz) with differential coherent QPSK modulation to the satellite. Each uplink transmission utilizes an independent carrier frequency in a FDMA manner. Forward error correct coding at rate 3/4 is applied to the uplink transmission in order to reduce ground transmit power requirements by 4.3 dB. For the conditions of 99.5% availability and 10^{-7} bit error rate, a VSAT transmitter rf power of 1.6 W is required.

The satellite receives the uplink transmission in one of the four beams providing CONUS coverage. The 500 MHz bandwidth in each beam is received, divided into 28.8 MHz segments, and routed to a bulk demodulator. The demodulator digitizes the input and then does a fast fourier transform to separate the 200 channels of 144 kbit/s within this portion of the spectrum. An FEC decoder decodes and applies error correction to the individual channel. In the case example, the reference VSAT transmission is one of 200 channels processed by a particular bulk demodulator and decoder, and output as part of a TDM digital data stream.

After decoding, the data is directed to a switch/processor. The D-channel information (16 kbit/s) is stripped away and transmitted to the network control center located on the earth. A return path for D channel transmission is provided from the control center to the satellite, where it can be reconstituted with the downlink channels.

The switch/processor provides routing for selection of the proper downlink satellite beam (1 of 21) and the proper downlink transmitter servicing that beam (1 of 4). For the 2B+D class of service, there are an average of about 200 channels per downlink beam. These are multiplexed onto a single 30 Mbit/s TDM carrier, modulated using differential coherent BPSK with rate 5/8 coding, and transmitted on a downlink with 28.2 W rf power.

For this example, the destination terminal is a 1.2 m VSAT with 410 K system noise temperature. Alternate destinations could also include 1.8 m VSATs or a 4 m node terminal which is used to interconnect with the terrestrial system.

8 Satellite Design Features

8.1 Satellite Implementation

The baseline satellite configuration has a beginning-of-life mass of 1,500 kg, an end-of-life power of 4 kW, and a ten year on-orbit lifetime.

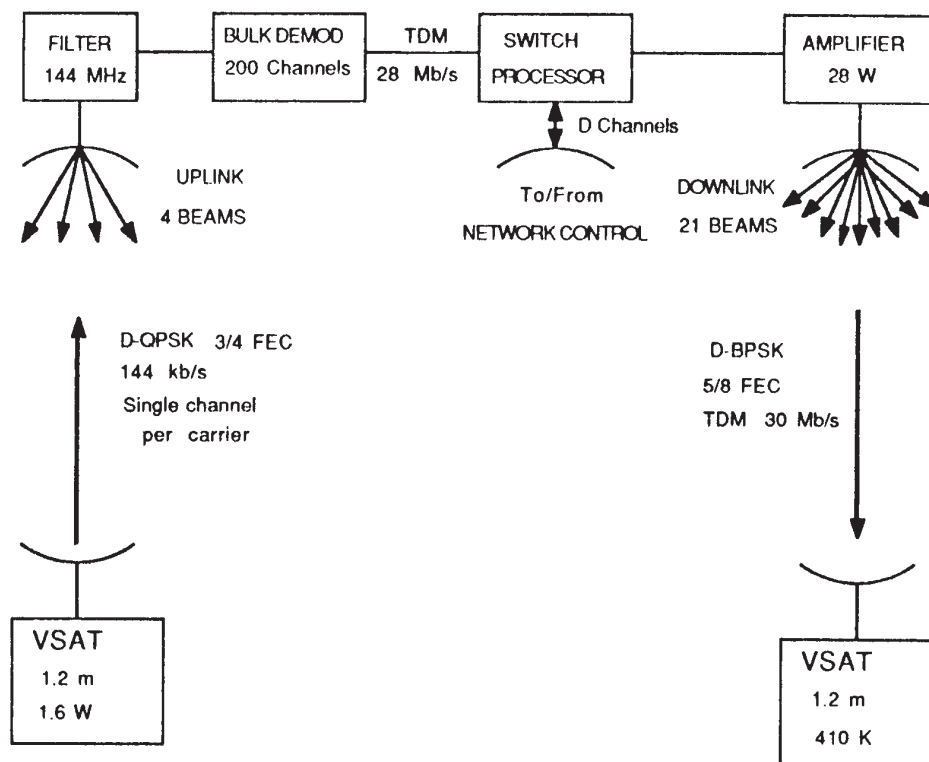


Figure 3: Case Example: Link Implementation for ISDN Basic Access (2B + D)

Figure 4 gives the block diagram of the communications subsystem. An originating VSAT signal is received by one of four uplink antenna beams, downconverted to an IF frequency, directed to one of 56 bulk demodulators, decoded, switched to the proper downlink beam, encoded, modulated, amplified in one of 84 power amplifiers, and radiated back to earth via one of 21 downlink antenna beams.

8.2 Bulk Demodulator

The bulk demodulator is the key new technology item. Its performance parameters need to be validated by computer simulation, prototype model development, and testing. The goal of the tests is to set the parameters of processing speed, filter bandwidth, and chip design. Preliminary analysis indicates that a channel separation of 1.5 times the symbol rate is adequate and provides adjacent channel rejection of 50 dB.

The baseline architecture incorporates separate bulk demodulator designs for each class of service. It would be desirable to have a single bulk demodulator design for low cost and on-orbit interchangeability. However, this must be traded-off against the efficiency in accommodating multiple uplink data rates for B+1/2D, 2B+D, 11B+D, and 23B+D services. Eventually the modulator design should have the capability of being reconfigured via software to accommodate different channel sizes.

A set of bulk demodulators is used to accept the multiple number of uplink FDM signals and convert them to demodulated TDM data streams.

Figure 5 shows a typical frequency plan and assignment of demodulators for an average uplink beam. In this example, 2,000 channels of (B+1/2D) service at 72 kbit/s each are contained within a bandwidth of 144 MHz which is divided among five bulk demodulators of 400 channels each. The output of each demodulator is a 38.4 Mbit/s TDM data stream which includes rate 3/4 coding.

In a similar manner, 1,000 channels of (2B+D) service at 144 kbit/s each are contained within a bandwidth of 144 MHz and divided among five bulk demodulators. The 80 channels of 11B + D service are contained within a bandwidth of 37 MHz which is divided among two bulk demodulators, each accepting 40 channels. The 40 channels of 23B + D service are also contained within a bandwidth of 37 MHz and divided among two bulk demodulators.

Processing of the high data rate signal from a node terminal is accomplished by filtering and assignment to an appropriate number of conventional (non-bulk) demodulators.

The composite number of bulk demodulators per uplink beam is 14. Each has an output of approximately 37 Mbit/s including the FEC coding. The total number of bulk demodulators for the four uplink beams is

56. Some provision for switching of bulk demodulators among various beams is provided in order to accommodate variance in traffic throughput per beam. Additional units are also required for spares.

8.3 Error Correction Coding

The baseline architecture incorporates forward error correction (FEC) coding on the uplinks, demodulation and decoding on the satellite, and encoding and modulation of the downlinks. The advent of high speed digital circuits permits use of on-board decoding and encoding to improve link performance. The small additional weight and power requirements on the satellite are more than offset by the reduced transmit power to close the downlinks. The demodulation and decoding on the satellite also gives flexibility in routing for the ISDN applications with multiple destinations.

8.3.1 Decoder

The low rate VSAT terminals utilize rate 3/4 FEC coding and the medium rate terminals and node terminals utilize rate 5/6 coding. Each of the bulk demodulator outputs is demultiplexed and decoded with high speed circuitry accommodating about 37 Mbit/s throughput.

8.3.2 Coder

In the satellite, the various channels destined for low rate VSATs are assembled into two 30 Mbit/s data streams per downlink beam. The composite data stream is coded with rate 5/8 coding for improved signal power transmission efficiency. The channels destined for medium rate VSATs are assembled into one 30 Mbit/s data stream with 5/8 FEC coding. The channels destined for the high rate node terminals are also assembled into a 30 Mbit/s TDM format with rate 3/4 coding.

8.4 Switching

The demodulated, decoded, and demultiplexed circuit switched B channels are routed to the proper destination beam and output amplifier by means of the satellite switch. Control information is received by separately routing the associated D channel signals to a master control center located on the ground where it is processed and routed back to the satellite together with separate control information.

8.5 Modulators and Power Amplifiers

The three TDM formats destined for VSAT terminals are modulated with differential BPSK in order to maximize downlink power efficiency.

The efficiency of downlink transmitters is a key factor in permitting the system to accommodate 2 Gbit/s

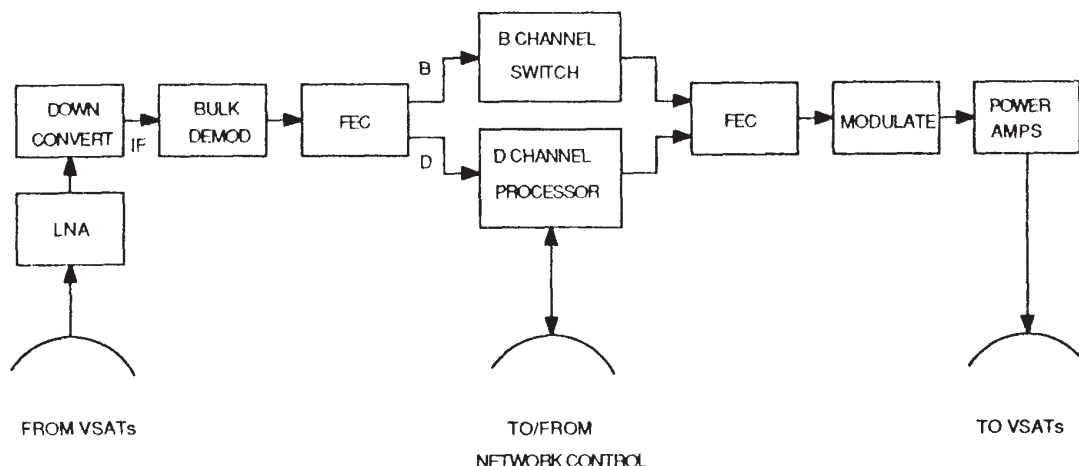


Figure 4: Functional Block Diagram of Satellite Communications Subsystem

throughput within the constraint of 4,000 W power. Each transmitter uses 6.2 W for communications to 4 m node terminals (4 each 20(23B+D) channels), 12.5 W to 1.8 m VSATs (40 each 23B+D channels), and 28.2 W to 1.2 m VSATs (1000 each 2B+D channels). Bulk modulators are not used for downlinks because of the need for linear amplifiers and greater satellite power and mass requirements.

9 Projected Economics

The results of an analysis of the satellite system economics and a comparison with terrestrial system costs are presented. A financial model is used which describes quantitatively the economics of the space segment of the U. S. domestic Fixed Satellite Service communication satellite systems, beginning with the design and continuing through construction, launch, and commercial operations.

Two case examples are analyzed:

- Small user with 1.2 m VSAT and 144 kbit/s capacity.
- Large user with 1.8 m VSAT and 1.536 Mbit/s capacity.

For each case, two system operation scenarios are evaluated:

A. Immature System Scenario:

- System consists of two operational satellites and one in-orbit spare.
- 30,000 users (VSATs)
- System utilization is 20% of the total available channel minutes.

- System development (non-recurring) costs equal the cost of an in-orbit spare.
- 20% rate of return on investment required for the space segment costs.

B. Mature System Scenario:

- There is one ground spare for every two operational satellites.
- 100,000 users (VSATs)
- System utilization is 30% of the total available channel minutes.
- There are no non-recurring costs.
- 18% rate of return on investment required for the space segment costs.

Each operational satellite is assumed to have a capital cost of \$184 M and a capacity of 15,000 duplex channels of 64 kbit/s. User costs are broken down into VSAT lease costs, network master control station costs, communication costs, and operations/billing costs.

9.1 Small User Subscriber Charges

Table 2 gives a summary of small user costs for scenarios A and B. Cost is given in \$/yr for a 64 kbit/s channel being utilized 30 hours per week. The figures are based on satellite costs of \$24,500/channel for Scenario A and \$15,300/channel for Scenario B. Costs per channel minute are 11 cents for Scenario A and 4 cents for Scenario B, and correspond to costs per channel year of \$10,300 for Scenario A and \$3,770 for Scenario B.

The total cost per year in Table 2 for Scenario A, the immature system, are \$15,960, which is equivalent to 17 cents per channel minute for the hypothesized

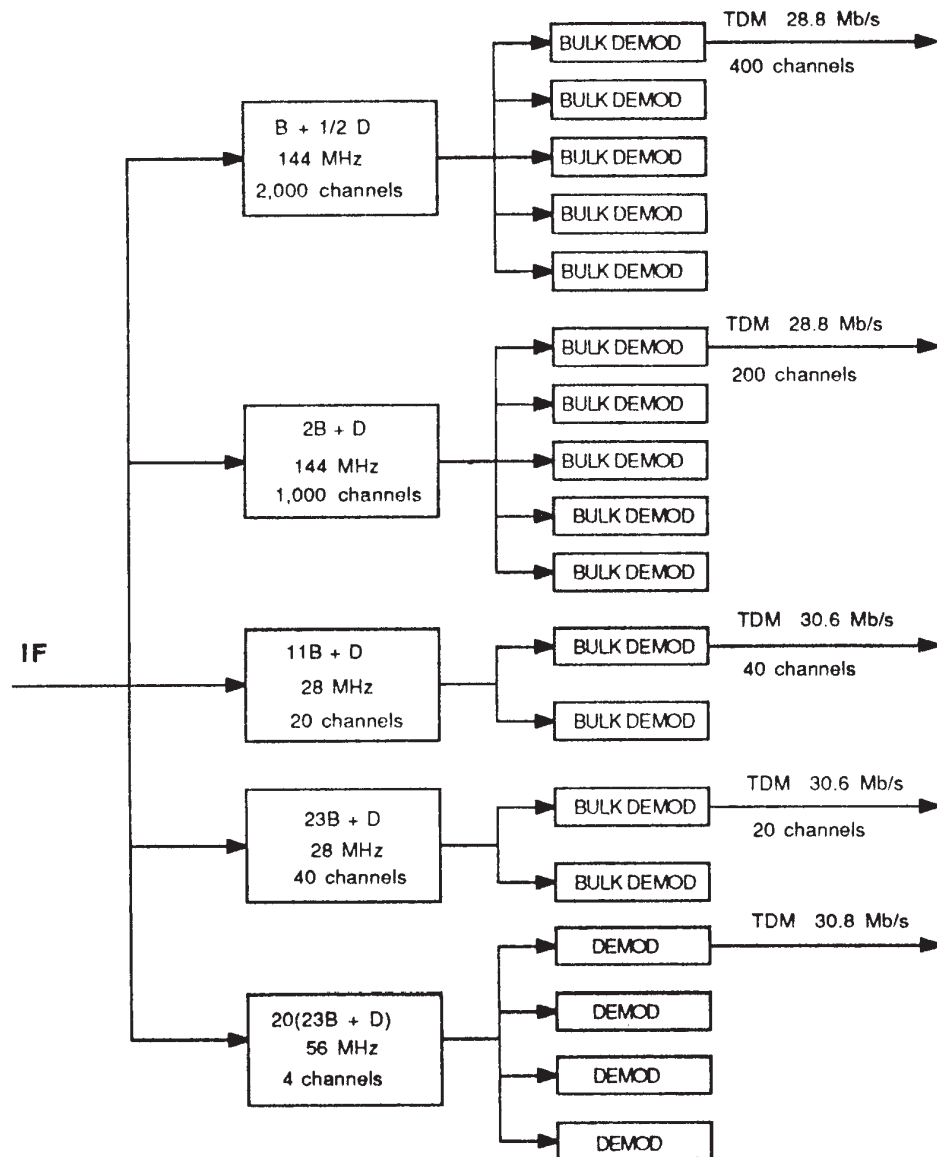


Figure 5: Assignment of Bulk Demodulators per Beam

Cost Category	Scenario	
	A	B
VSAT lease	4,400	4,400
Master control	900	270
Communications	10,300	3,770
Operations/billing	360	360
Totals (\$/yr)	15,960	8,800

Table 2: Small User Costs, \$/yr

Cost Category	Scenario	
	A	B
VSAT lease	6,600	6,600
Master control	7,200	2,160
Communications	82,400	29,960
Operations/billing	2,880	2,880
Totals (\$/yr)	99,080	41,600

Table 3: Large User Costs, \$/yr

30 hr/week usage. However, the mature system (Scenario B) cost is equivalent to 9 cents per channel minute for the same usage.

9.2 Large User Subscriber Charge

Table 3 gives a summary of large user costs for scenarios A and B. Cost is given in \$/yr for a 1.536 kbit/s channel being utilized 10 hours per week. Costs per channel minute are \$2.64 for Scenario A and \$0.96 for Scenario B, and correspond to costs per channel year of \$82,400 for Scenario A and \$29,960 for Scenario B.

The total costs per year in Table VIII-4 for Scenario A, the immature system, are \$99,080, which is equivalent to \$3.18 per channel minute for the hypothesized 10 hr/week usage. However, the mature system (Scenario B) cost is equivalent to \$1.33 per channel minute for the same usage.

9.3 Comparison with Terrestrial Systems

Current (1/87) costs for interstate leased lines are around \$3,000 per month for a 64 kbit/s duplex circuit of 1,000 miles length. Assuming a usage of 30 hours per week, per minute cost equals 38 cents (compare with the mature satellite system cost of 9 cents). Assuming continuous usage, per minute cost equals 7 cents. These costs do not include local access charges.

The cost for a 1.536 Mbit/s duplex circuit (T1) is \$18,000 per month. Assuming a usage of 10 hours per week, per minute cost equals \$6.92 (compare with

the mature satellite system cost of 96 cents). Assuming continuous usage, per minute cost equals 42 cents. These costs do not include local access charges.

This comparison is faulted in that current terrestrial circuit costs are being compared with projected 1995 satellite circuit costs. However, the point to be made is that the satellite circuit costs appear to be in the "ballpark" of terrestrial circuit costs.

10 Conclusions

The following conclusions are made from this work:

- Using 1995 technology, an on-board processing satellite with 2 Gb/s throughput providing 30,000 simultaneous half duplex 64 kb/s circuits via VSATs is possible. Such a satellite would have a beginning-of-life mass of 1,500 kg and end-of-life power of 4,000 W.
- Demodulation/re-modulation on the satellite allows use of forward error correction coding on the individual uplinks and downlinks, with improvements of 3.5 dB and 5.3 dB respectively.
- In-band signaling via the ISDN "D" channels allows demand assigned use of the system which subsequent cost savings to users. Users only pay for the communications capacity they use.
- Use of FDMA uplinks minimizes the cost of the user terminal. The user transmitter and receiver are tunable according to instructions from the network control in order to allow full use of system capacity.
- Use of moderate-rate TDM downlinks (continuous 30 Mb/s) does not increase ground terminal costs, and reduces satellite costs.
- The critical technology to allow 30,000 simultaneous accesses is the bulk demodulator. Use of GaAs technology is projected to reduce size and power requirements such that this device is practical for satellite applications in the 1995 time frame.
- An extensive ground-based master control facility, similar to a telephone company local office, is required to handle authorization, billing, and network control.
- Projected user costs per channel minute compare favorably with current terrestrial circuit costs.
- The required 30,000 by 30,000 digital switch required by the satellite is feasible using custom switching chips.