Design Summary of the INTELSAT V Spacecraft

Christopher F. Hoeber* and Neil J. Barberis†
Ford Aerospace & Communications Corporation, Palo Alto, California

The second launch of INTELSAT V took place on May 23, 1981, and the switchover of traffic from INTELSAT IV-A occurred between July and October 1981. The complement of 15 spacecraft in the INTELSAT V series presently on order will actually consist of three distinct types of spacecraft whose capabilities have been gradually expanded. This growth has been made possible by increases in the launch vehicle capabilities, as well as the orderly introduction of advanced technology and the inherent design margins in the initial body-stabilized spacecraft design. Flights 1-4 offer the baseline INTELSAT V services. On flights 5-9, a totally independent payload, the maritime communications subsystem (MCS), will be made available to INMARSAT, who will then be able to offer maritime services. On flights 10-15, the available 6/4 GHz bandwidth has been increased 14.3%, from 1349 to 1542 MHz, and numerous reliability and operational improvements have been made to extend the expected lifetime from 7 to 9 yr. Flight 5, the first MCS spacecraft, was launched Sept. 28, 1982, and is now in operational service.

Nomenclature

APM	= antenna pointing mechanism
BECO	= booster engine cutoff
CM	= communications module
DOD	= depth of discharge
EIRP	= effective isotropic radiated power
EOL	= end of life
ETT	= electrothermal thruster
FET	= field effect transistor
FM	= frequency modulation
GFRP	= glass fiber reinforced plastic
G/T	= receive antenna gain to noise temperature ratio (receive figure of merit)
H/Z	= hemi/zone
IF	= intermediate frequency
INTELSAT	= International Telecommunications Satellite Organization
I_{sp}	= specific impulse
LHCP	= left-hand circularly polarized
MCS	= maritime communications system
MUX	= multiplexer
Ni-Cd	= nickel-cadmium
Ni-H_2	= nickel-hydrogen
rf	= radio frequency
RHCP	= right-hand circularly polarized
SADA	= solar array drive assembly
SSM	= support subsystem module
STS	= Space Transportation System
TDMA	= time division multiple access
TLM	= telemetry
TWTA	= traveling wave tube amplifier

Introduction

INTELSAT V (Fig. 1) is a high-capacity commercial communications satellite being built for the 106-member nation INTELSAT organization. Depending upon the operational configuration chosen by INTELSAT, the 1800+ kg, body-stabilized satellite will carry up to 12,000 two-way telephone circuits and two color television transmissions. The spacecraft communications subsystem operates at 6/4 GHz, expanding the available 500 MHz frequency band to 1.357 GHz through fourfold frequency reuse involving spatial isolation (shaped beams) and polarization diversity (orthogonal circular). In addition, INTELSAT V employs 14/11 GHz "spot" beams with an additional 780 MHz of bandwidth. A switching network interconnects the various coverage areas and allocates channels between the shaped beams in various combinations. This interconnectivity allows considerable flexibility in traffic allocation to specific areas of the Earth.

A more detailed discussion of the basic spacecraft design, including a description of all subsystems, is found in Refs. 1 and 2. Reference 3 shows in detail the communication subsystem characteristics and is an excellent presentation of how the requirements and technologies evolved and were ultimately realized in the highly successful launches of the first five spacecraft. Reference 4 describes the launches and results of in-orbit payload testing.

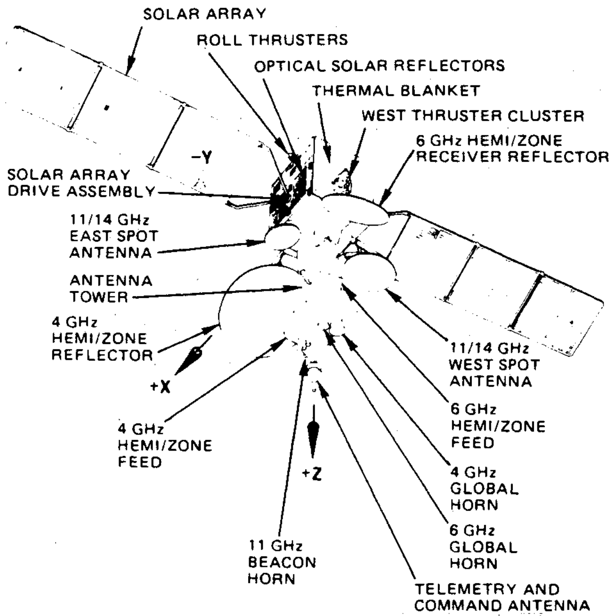

Fig. 1 Spacecraft configuration.

Presented as Paper 82-0537 at the AIAA 9th Communications Satellite Systems Conference, San Diego, Calif., March 7-11, 1982. Submitted April 1, 1982; revision received Jan. 31, 1983.

*Program Engineering Manager, Western Development Laboratories. Member AIAA.
†INTELSAT V-A Program Engineering Manager, Western Development Laboratories. Member AIAA.

Table 1 INTELSAT V evolution

	Basic				V/MCS					V-A					
Component	F-1	F-2	F-3	F-4	F-5	F-6	F-7	F-8	F-9	F-10	F-11	F-12	F-13	F-14	F-15
Basic I-V payload	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MCS payload					X	X	X	X	X						
Ariane compatibility				X	X	X	X	X	X	X	X	X	X	X	X
NiH_2 batteries					X	X	X	X	X	X	X	X	X	X	X
Vortex heater controller	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Repressurization					X	X	X	X	X	X	X	X	X	X	X
GFRP E/W panels					X	X	X	X	X	X	X	X	X	X	X
6 GHz FET preamps					X	X	X	X	X	X	X	X	X	X	X
14 GHz FET preamps					X	X	X	X	X	X	X	X	X	X	X
Uprated apogee motor					X	X	X	X	X	X	X	X	X	X	X
Combined hemi channel 7-8					X	X	X	X	X	X	X	X	X	X	X
Delete 4 GHz APM					X	X	X	X	X	X	X	X	X	X	X
Delete TWTA equalizers					X	X	X	X	X	X	X	X	X	X	X
Dual polarized global										X	X	X	X	X	X
C-band spot beam										X	X	X	X	X	X
Channel 9 in zones										X	X	X	X	X	X
500 Hz TDMA										X	X	X	X	X	X
Upgraded ETTs					X	X	X	X	X	X	X	X	X	X	X
TWTA compensation heaters										X	X	X	X	X	X
Multiple simultaneous TLM										X	X	X	X	X	X
Converter redesign dc/dc										X	X	X	X	X	X
SADA slip ring redesign										X	X	X	X	X	X
Dual TLM carrier frequency										X	X	X	X	X	X
GFRP central cylinder										X	X	X	X	X	X
Lightweight harness						X	X	X	X	X	X	X	X	X	X
New TLM antenna										X	X	X	X	X	X
Modified gain step attenuator											X	X	X	X	X

The original INTELSAT V spacecraft was conservatively designed with growth in mind. Over the course of the 9 yr program (from program award to delivery of the 15th spacecraft) a number of evolutionary design modifications have been or will be made to the spacecraft to increase its capabilities, reliability, and lifetime. Table 1 shows the evolution of the program and Table 2 describes the modifications. Although some design changes have been phased in on other spacecraft, the major block changes were incorporated on flights 5-9, on which the MCS is incorporated, and on flights 10-15, which are designated INTELSAT V-A

The INTELSAT V/MCS spacecraft provides the basic INTELSAT V services, with an additional independent payload to be made available to INMARSAT. The MCS spacecraft also incorporates several design improvements that increase subsystem reliability and operational lifetime.

The INTELSAT V-A spacecraft represents a complete reconfiguration of the spacecraft layout and changes to the antenna farm support structure. The spacecraft is designed to forestall saturation of the Atlantic and Indian Ocean region primary spacecraft by matching the projected traffic increases in these areas. The INTELSAT V-A spacecraft incorporates all of the design improvements from the MCS configuration plus additional improvements to increase spacecraft reliability and lifetime. The INTELSAT V-A spacecraft provides the same service as the basic program, while effectively increasing the 6/4 GHz bandwidth by an additional 14% through frequency reuse techniques. This yields an increase in capacity from 12,000 duplex phone circuits plus 2 color television channels to 15,000 duplex phone circuits plus 2 color television channels. With the introduction of TDMA, the telephone capability can be increased to approximately 23,200 duplex circuits. INTELSAT spacecraft growth is illustrated in Fig. 2.

System Requirements

Payload Requirements

The MCS payload illustrated in Fig. 3 provides ship-to-shore and shore-to-ship services through an independent subsystem that shares some hardware with the INTELSAT V 6/4 GHz payload. The shore-to-ship link operates at 6417.5-6425.0 MHz uplink and 1575.0-1542.5 MHz downlink. The ship-to-shore link operates at 1636.5-1644.5 MHz uplink and 4192.5-4200.5 MHz downlink. The shore links operate through the orthogonally polarized port of the INTELSAT V global antenna, allowing any INTELSAT station with access to the spacecraft to also utilize the MCS payload.

To accommodate the large increase in dc power required by the MCS payload (principally the L-band power amplifier), the system requirement is that some, or all, of the 14/11 GHz (K-band) payload be turned off during MCS operation. This is compatible with the INTELSAT V operational scenario in that the K-band channels are not utilized on all deployed spacecraft. Including both payloads on flights 5-9, however, allows a single spacecraft in orbit to provide backup for both types of services. A low-power mode suitable for 15 voice circuits is provided, which allows 2 of the 6 K-band channels to remain operational. The high-power mode, which accommodates 30 voice circuits, requires turning off the entire K-band service.

The basic modification to INTELSAT V-A is to complete the INTELSAT V frequency plan by providing dual polarization frequency reuse on the global channels and adding channel 9 (36 MHz bandwidth) to the zone transponders. Any further bandwidth extensions would require drastic restructuring of the INTELSAT V frequency plan. The V-A payload is illustrated in Fig. 4.

In addition, 4 GHz (C-band) feeds are added to the existing K-band spot-beam reflectors to provide high EIRP coverage over a 5 deg field of view, steerable anywhere on the Earth's surface. Global polarization A (221 MHz bandwidth) can be switched to one spot beam, global polarization B (149 MHz bandwidth) to the other spot beam. These beams are intended to be leased for domestic services, a rapidly growing component of INTELSAT's traffic. There are no operational constraints on the use of the new services, except that the geometric relationship between the K-band coverages and the C-band coverages is fixed and it is unlikely that both would be used simultaneously. Again, this fits the anticipated growth in

Table 2 INTELSAT V program summary

Modification	Purpose
MCS payload	New communications service
6 GHz FET preamps	Improved communications performance
14 GHz FET preamps	Improved communications performance
Dual polarized global	New communications service
C-band spot beam	New communications service
Channel 9 in zones	New communications service
500 Hz TDMA	New communications service
Ni-H_2 batteries	Reliability and increased performance
Vortex heater controller	Improve ETT performance, lifetime
Repressurization	Improve ETT performance, lifetime
Upgraded ETTs	Increased spacecraft lifetime
Modified gain step attenuator	Improved performance
GFRP E/W panels	Weight savings
Combined hemi channel 7-8	Weight savings
Delete 4 GHz APM	Weight savings
Delete TWTA equalizers	Weight savings
GFRP central tube	Weight savings
Lightweight harness	Weight savings
TWTA compensation heaters	Reliability
Multiple simultaneous telemetry	Reliability
dc/dc Converter redesign	Reliability
SADA slip ring redesign	Reliability
Dual telemetry carrier frequency	Flexibility
Ariane compatibility	New launch vehicle
Uprated apogee motor	Increased launch capability

INTELSAT traffic, as K-band services will not be used on all spacecraft.

Payload Description

The MCS payload consists of separate L-C (ship-to-shore) and C-L (shore-to-ship) transponders that interface with the existing global transponders. Both transmit and receive L-band signals employ a quad helix Earth coverage antenna, which is deployable and steerable ± 2 deg in pitch to allow biasing the spacecraft for optimum coverage over a wide range of longitudes.

The L-band uplink is separated from the downlink in a diplexer, amplified and converted to 4 GHz for broadcast by a 4.5 W TWTA through the orthogonally polarized port of the existing global coverage transmit antenna.

The 6 GHz uplink is received by the orthogonally polarized port of the global coverage receive antenna and amplified by a global receiver, where it is downconverted to the 4 GHz IF frequency band. Here it is filtered to separate it from the communications traffic and further downconverted to the L-band. The L-band power amplifier is a linearized solid-state amplifier that produces 70 W in the high-power mode and 35 W in the low-power mode.

The INTELSAT V-A payload modifications consist of a straightforward addition of more INTELSAT V hardware. The primary modification to provide increased capacity is the addition of three transponders, with global coverage on both receive and transmit, operating on the opposite senses of circular polarization from the existing global transponders. The input multiplexing for the "A" polarization sense remains unchanged. For the "B" chain, a new input multiplexer has been added to separate the channels.

Amplification of the global signals is provided by 8.5 W TWTAs, in a three-for-two redundancy scheme, for each channel. The "A" and "B" polarization signals are assembled in their respective contiguous output multiplexers and then routed to their respective ports on the global transmit horn. Two two-for-one switches in the output waveguides allow the alternate routing of the global transponer signals to the new 4 GHz horns feeding the existing steerable 14/11 GHz reflectors.

Additional traffic-carrying flexibility is provided by the addition of 4 GHz high-polarization purity feed horns to the 14/11 GHz spot antennas. The horns are colocated with the existing 14/11 GHz corrugated horns, illuminating the same graphite-epoxy reflectors. The 4 GHz feeds are fed from the global transponder, described in the previous paragraph, with the west spot operating on the "A" sense of polarization (RHCP) and the east spot on the "B" sense of polarization (LHCP). Figures 5 and 6 depict the coverage region of each beam as seen from synchronous orbit. Antenna performances (predicted and required) are summarized in Tables 3 and 4.

In addition to the new hardware, several evolutionary modifications have been made. Effective on the MCS spacecraft, FET preamplifiers replaced the bipolar transistors

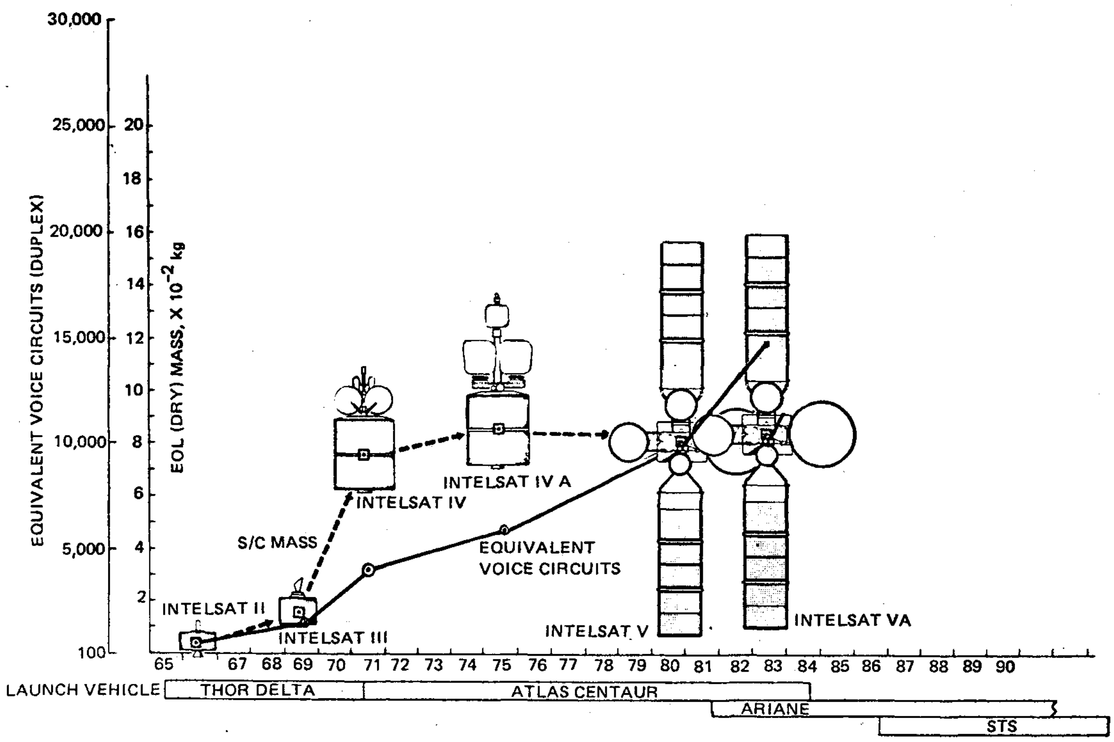

Fig. 2 INTELSAT spacecraft growth.

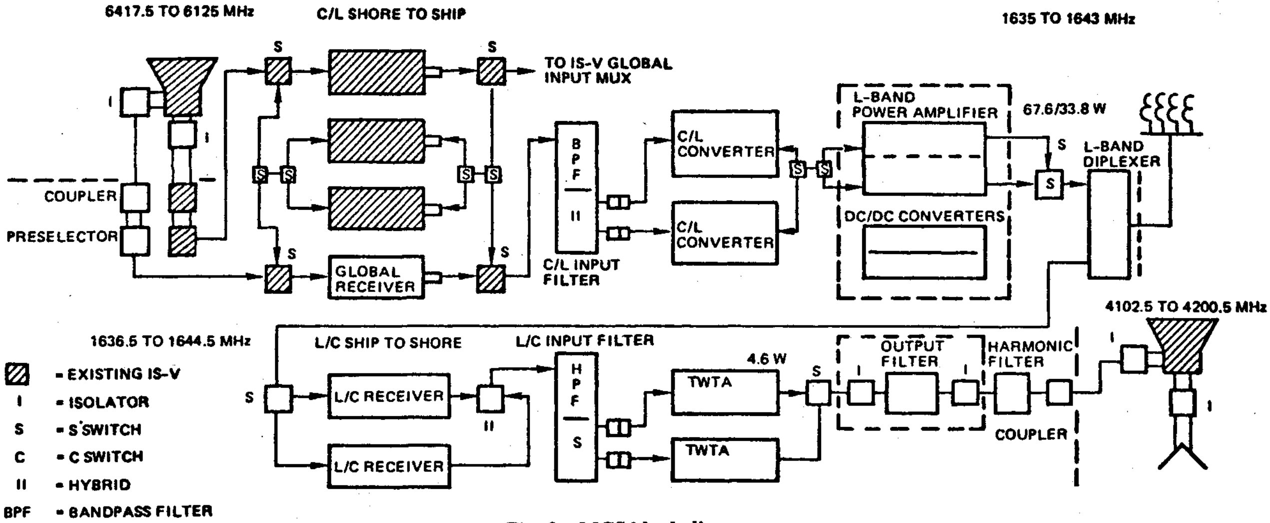

Fig. 3 MCS block diagram.

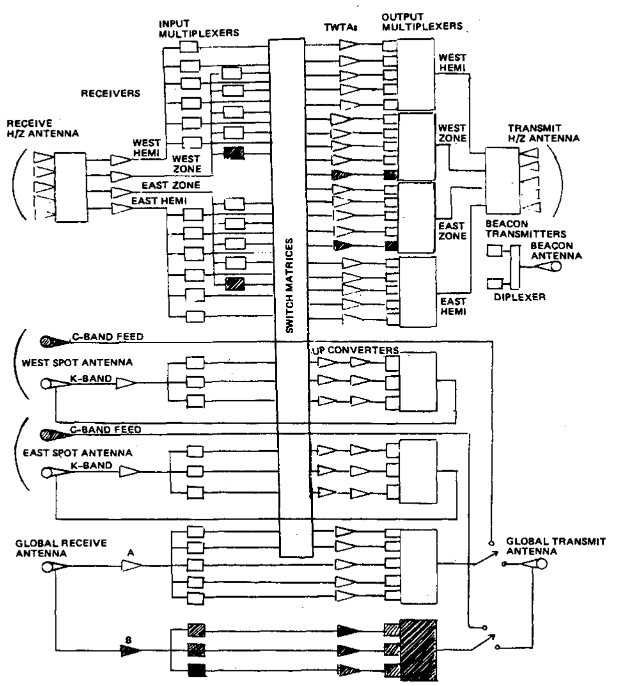

Fig. 4 INTELSAT V-A communications block diagram.

at 6 GHz, allowing a 2.6 dB increase in G/T and spacecraft gain. FETs also replaced the 14 GHz tunnel diode amplifiers, with approximately 1 dB improvement in G/T. Combining channels 7 and 8 in the hemi transponder yielded a weight saving by deleting an input filter and its associated switches and equipment. Further weight savings were garnered by deleting the TWTA equalizers as a result of a slight relaxation of passband flatness requirements. On the INTELSAT V-A spacecraft, extensive TDMA operation at a 500 Hz frame rate requires additional line filtering in the 11 GHz TWTAs. The multicollector TWTA power consumption is proportional to rf drive. A partially loaded TDMA frame would drive the TWTA for only part of the 2 ms frame. If unfiltered, the resulting current surges drawn by the TWTA would produce an unacceptable voltage ripple on the primary power bus. Commandable heaters have been added to each TWTA group to allow spare satellites to remain aloft with their TWTAs off, thereby increasing mission lifetime. An additional commandable gain control has also been added for increased traffic flexibility.

Spacecraft Bus Requirements

The dual-bus, direct energy transfer system is designed to accommodate a continuous spacecraft primary load of approximately 1.3 kW. The increased power requirements of the MCS and V-A spacecraft are handled with a minor change in the basic INTELSAT V power subsystem. Table 5 presents the

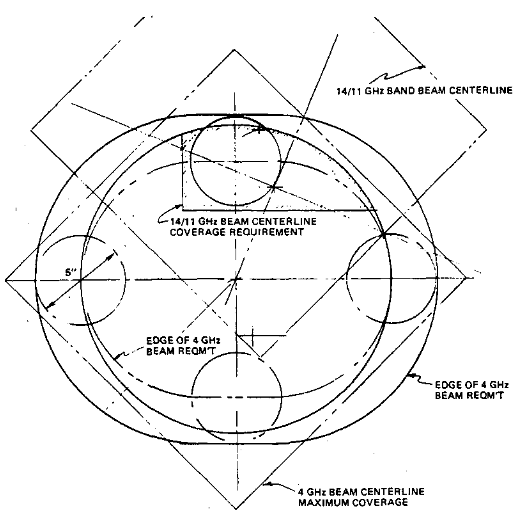

Fig. 5 East spot antenna coverage/steering zones.

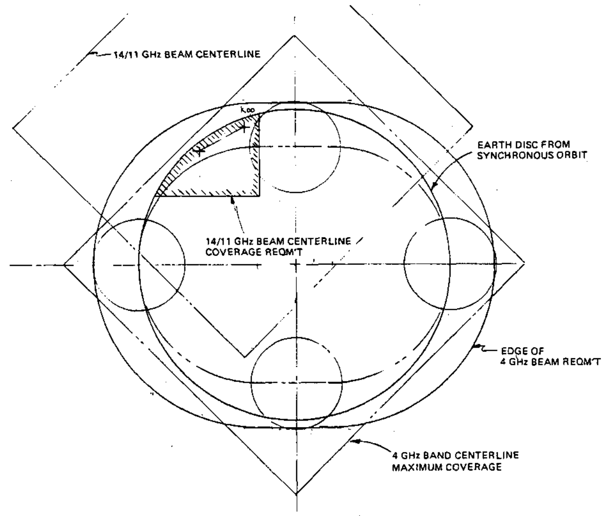

Fig. 6 West spot antenna coverage/steering zones.

Table 3 Performance of west spot beam antenna (INTELSAT V-A)

	C-band transmit		K-band transmit		K-band receive	
Parameter	Req't	Predicted performance	Req't	F-1 Performance	Req't	F-1 Performance
Gain/coverage						
at antenna, dBI	26.95	28.4	37.1	38.3	37.4	38.7
Loss, dB	–	0.75	–	0.7	–	0.7
At interface, dBI	26.2	27.6	36.2	37.6	36.7	38.0
Coverage, deg	5	5	1.6	1.6	1.6	1.6
Polarization	RHCP (AR = 0.4 dB max)	RHCP (AR = 0.29 dB max)	Linear (AR = 17 dB)	Linear (AR = 24 dB)	Linear (AR = 17 dB)	Linear (AR = 24 dB)
Gain slope	3 dB/0.8 deg chord	2.2	3 dB/0.4 deg chord	2.5	3 dB/0.4 deg chord	3
Isolation, dB	27	35				
5.7-7.2 deg	NA	NA	−27	< −27	−27	< −27
Beyond 7.2 deg	NA	NA	−33	< −33	−33	< −33

Table 4 Performance of east spot beam antenna (INTELSAT V-A)

	C-band transmit		K-band transmit		K-band receive	
Parameter	Req't	Predicted performance	Req't	F-1 Performance	Req't	F-1 Performance
Gain/coverage						
at antenna, dBI	26.95	28.5	33.3	34.0	33.9	34.6
Loss, dB	–	0.75	–	0.7	–	0.6
At interface, dBI	26.2	27.7	32.8	33.3	33.2	34.0
Coverage, deg	5	5	3.2×1.8	3.2×1.8	3.2×1.8	3.2×1.8
Polarization	LHCP (AR = 0.4 dB max)	LHCP (AR = 0.17 dB max)	Linear (AR = 17 dB)	Linear (AR = 20 dB)	Linear (AR = 17 dB)	Linear (AR = 21 dB)
Gain slope	3 dB/0.8 deg	1.8	3 dB/0.4 deg	2.4	3 dB/0.4 deg	2.7
Isolation, dB	27	39				
5.7-7.2 deg	NA	NA	−27	< −27	−27	< −27
Beyond 7.2 deg	NA	NA	−33	< −33	−33	< −33

Table 5 INTELSAT V power summary

	Synchronous average power, W								
	Basic INTELSAT V			MCS[a]			INTELSAT V-A		
Parameter	Autumn equinox	Summer solstice	Eclipse	Autumn equinox	Summer solstice	Eclipse	Autumn equinox	Summer solstice	Eclipse
Total load	1011	986	901	1037	1012	927	1116	1092	1004
Battery changing at 7 yr	101	30	–	101	30	–	101	30	–
Total solar array load	1112	1016	–	1148	1042	–	1217	1122	–
Contract 10% load contingency	111	102	–	115	104	–	122	112	–
Solar array capability at 7 yr	1400	1288	–	1400	1288	–	1400	1288	–
System power margin at 7 yr	177	170	76	135	142	149	61	54	72
Battery depth of discharge for maximum eclipse, %[b]	–	–	50.75	–	–	52.2	–	–	65.3

[a]MCS high-power mode. [b]Maximum 55% for F1-4 (NiCd) worst case with one battery cell failed; maximum 70% for F5-12 (NiH_2) worst case with one battery cell failed.

spacecraft power requirements, showing significant margins for all spacecraft configurations. Note that the power budgets show a 10% contingency, required by contract with INTELSAT, to allow for uncertainties in solar array degradation. The Ni-Cd batteries employed on the basic program are limited to 55% DOD at the end of the longest eclipse (1.2 h). The increased power requirements of the MCS and INTELSAT V-A spacecraft are accommodated by Ni-H_2 batteries, with an allowable DOD of 70%.

The increased dry spacecraft mass associated with both the MCS and INTELSAT V-A spacecraft, coupled with the requirement for launch on the Ariane, have led to a re-evaluation of the spacecraft structural margins and frequencies. STS liftoff and Atlas-Centaur BECO load cases remain the worst-case load conditions, while the second-stage cutoff "pogo" condition of the Ariane imposes structural constraints in the frequency range of 28-35 Hz.

Table 6 presents a mass summary for the three spacecraft types. The Atlas/Centaur launch vehicle capability has been increased for the launch of both the MCS and INTELSAT V-A spacecraft, resulting in longer spacecraft lifetime. This increased launch vehicle capability is used to on-load 13 kg more fuel on INTELSAT V-A. This increased fuel load is made possible by the repressurization system incorporated on flight 5. Note that the basic INTELSAT V was designed for less than 200 kg of fuel load; the tanks are filled to the maximum allowed by the launch vehicle liftoff capability to maximize spacecraft lifetime beyond the contractually required 7 yr.

The lifetimes stated in the table are conservatively calculated, with a significant amount of fuel reserved to correct for launch vehicle errors. The expected lifetimes of the first two spacecraft to be launched are over 9 yr (flight 2) and 8 yr (flight 1), well in excess of the required 7 yr.

Table 6 INTELSAT V mass summary (Atlas/Centaur launch)

Parameter	Basic INTELSAT V	MCS	INTELSAT V-A
Dry spacecraft mass, kg	826	865	848
Fuel, kg	227	227	240
Apogee motor consumables, kg	870	892	892
Adapter mass, kg	21	21	21
Launch mass, kg	1944	2005	2001
Mission lifetime, yr	7.64	8.45	9.95

Table 7 End-of-life thermal dissipations, W

	FM1-4	FM5-9	FM10-15	Bus capability
North CM	299	291	443	490
South CM	346	345	296	426
SSM[a]	104	142	98	–
Total	854	899	955	

[a] Without batteries.

The thermal control of the INTELSAT V spacecraft is achieved by a reliable passive thermal design, augmented by commandable and thermostatically controlled heaters where necessary. The passive design entails controlling heat-transfer paths by the appropriate use of thermal control coatings, insulation, and heat sinks. The MCS and INTELSAT V-A thermal control subsystems must satisfy all of the requirements of the basic program while incorporating the increased payload electronics. The primary impact of the enhanced payloads has been a redefinition of the worst-case thermal design case in terms of rf power loads in the TWTAs at EOL. The thermal subsystem is configured to provide flexibility for variation in the spacecraft heat load, including payload growth, through easily accomplished modification of insulation blankets and radiators. Maximum EOL power dissipations for each block of spacecraft are listed in Table 7, along with the maximum power dissipation capability of the spacecraft constrained by the bus configuration. Power dissipation for the MCS spacecraft is within the rejection capability per panel and incorporation of the MCS payload required some heat sink redesign. This was not the case for the V-A spacecraft, however, where the addition of the global "B" polarization sense transponder yielded a power dissipation in excess of the south panel rejection capability. Equipment located on the north and south communication module panels were interchanged to take advantage of the higher dissipative capability of the north panel caused by the reduced solar constant at the summer solstice and the absence of radiative coupling with deployed antennas.

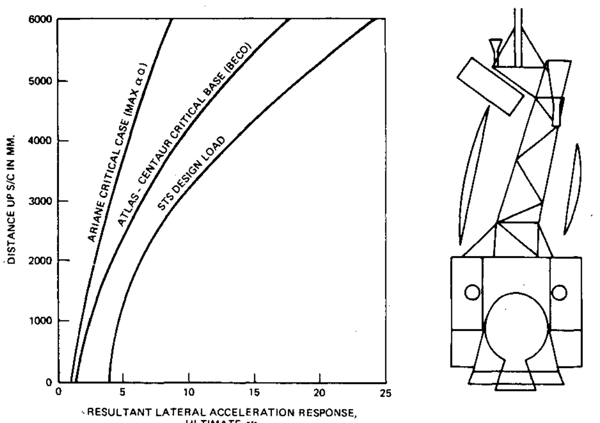

Fig. 7 Resultant lateral acceleration response, ultimate *g*.

Thermal control of the L-band antenna and deployment mechanism is accomplished with use of multilayer insulation blankets puls thermal control paint. The heat path between the main body and antenna is attenuated by multilayer insulation blankets at the antenna deck surface interface and by minimizing the conductive heat paths at the deployment mechanism mounting points.

Both the MCS and V-A spacecraft are required to be Ariane compatible. A review of the Ariane coupled loads analysis results shows the Ariane loads to be well below those of the Atlas/Centaur and STS. Comparative maximum accelerations for the various launch vehicles are shown in Fig. 7. Assuming no change in response acceleration due to increased spacecraft mass, the main body structure can accommodate the more severe STS loads based on a 1.5 safety factor from limit to ultimate. Propellant tank resonant frequencies are of particular concern because INTELSAT V analyses and tests indicate that tank frequencies impinge on the lower range of the 28-35 Hz Ariane "pogo" frequency regime.

The INTELSAT V-A spacecraft incorporates a graphite-epoxy face skin honeycomb panel central thrust tube, replacing the aluminum, stringer-stiffened cylinder. A graphite cylinder has been fabricated and subjected to static load testing to STS design loads from the basic INTELSAT program. Vibration testing of a prototype spacecraft with the graphite-epoxy central tube has been completed. The results indicate a slight shift in propellant tank frequencies. The structural design-limiting case for the cylinder is during apogee motor soakback. Extensive thermal and structural analyses have been performed in the apogee motor support ring graphite tube interface.

The INTELSAT V-A redundant telemetry transmitters have been modified to provide a flexible modulation capability of selecting any combination of up to four signals (PCM telemetry, real-time FM, nutation signal, and ranging) to be summed and used as the drive signal to the telemetry phase modulator. Adjustable modulation indices (either 1.0 or 0.6 rad per selected modulation) are provided to insure a uniform carrier power as a function of simultaneous data streams. The modified telemetry transmitters also allow selecting, by ground command, the operating frequency of each transmitter (TLM-1 and TLM-2 operating frequencies are offset by 0.5 MHz). This feature facilitates colocation operations between INTELSAT IV-A, V, and V-A type spacecraft. The spacecraft are colocated during the period when traffic is switched from one spacecraft to another. When colocated within 0.1 deg, the two spacecraft are simultaneously in the Earth station's flow of view. By judiciously turning the transponder on and off, the ground sees "one" spacecraft, although each is carrying the same traffic during the switchover.

Configuration

The configuration for the INTELSAT V spacecraft with the MCS package is relatively unchanged except for the addition of the 1.5 GHz transponder in the main body and the 1.5 GHz deployable antenna on the antenna deck. The deployment mechanism material is fabricated from aluminum to minimize thermal distortions between the stowed antenna and the aluminum mainbody. A linear actuator is used to provide the ± 2 deg pitch motion of the antenna.

The repressurization package includes a separate 400 in.^{3}, 3500 psia helium gas bottle separated from the hydrazine propellant tanks by a normally closed multifunction pyrotechnic valve. The system permits hydrazine onloading by decoupling the blowdown of the thrusters. Repressurization also allows operation of the ETTs in a better

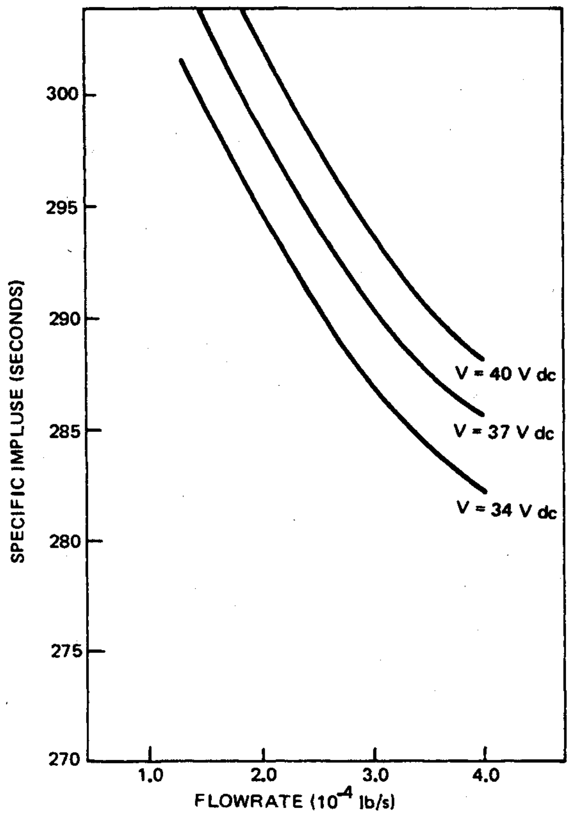

Fig. 8a ETT I_{sp} vs flow rate.

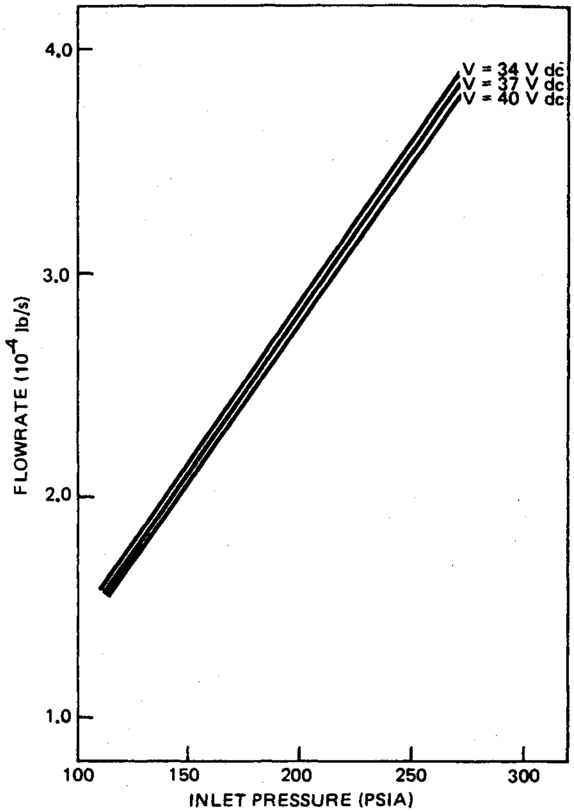

Fig. 8b ETT flow rates vs inlet pressure.

operating pressure regime. The relationship between I_{sp} and system pressure for the ETTs is shown in Fig 8.

Other product improvement design changes implemented on the MCS spacecraft include the addition of vortex heater control electronics and increased feed tube inner diameter to both improve performance and increase the lifetime for the ETTs. An upgraded apogee kick motor utilizing a lightweight carbon-carbon nozzle, increased propellant load and specific impulse, and a remote safe and arm was incorporated for improved performance. Graphite-epoxy face skin honeycomb panels were substituted for the east/west main body panels and shielding removed from specific harnesses for weight savings. In addition to incorporating the MCS design improvements, the INTELSAT V-A spacecraft incorporates a product improvement in the solar array drive assembly, where the positive and negative power rings have been completely isolated from each other and the power-to-signal ring gap increased to eliminate any shorting possibility.

Acknowledgments

Ford Aerospace & Communications Corporation is the prime contractor for the INTELSAT V spacecraft. International team members are Aerospatiale (France), MBB (Germany), Thomson-CSF (France), Selenia (Italy), Mitsubishi Electric Co. (Japan), and Marconi (U.K.). This paper is based in part upon work performed under the sponsorship of INTELSAT. Views expressed herein are not necessarily those of INTELSAT.

References

[1]Rusch, R.J., Johnson, J.J., and Baer, W., "INTELSAT V Spacecraft Design Summary, 1978," Paper presented at the 7th Communication Satellite Systems Conference, San Diego, Calif., April 1978, pp. 8-20.

[2]Hoeber, C.F., "INTELSAT V System Design," *WESCON Conference Records*, San Francisco, Calif., 1977.

[3]Quaglione, G., "Evolution of the INTELSAT System from INTELSAT IV to INTELSAT V," AIAA Paper 80-4024, 1980.

[4]Neer, J.T. and Hoeber, C.F., "INTELSAT V System Summary and Initial Launch Operations," *Proceedings of the XXXII Congress of the International Astronautical Federation*, Rome, Italy, Sept. 1981, pp. 133-149.