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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION PLANS FOR SPACE COMMUNICATION TECHNOLOGY

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ABSTRACT

In January, 1973, a decision was made by the National Aeronautics and Space Administration (NASA) to de-emphasize space communications research and development. A re-examination of that decision and an assessment of its consequences has resulted in a decision by NASA to increase significantly its space communications activities.

A program plan is presented for a space communications application utilizing the 30/20 GHz frequency bands (30 GHz uplink and 20 GHz downlink). Results of market demand studies and spacecraft systems studies which significantly affect the supporting research and technology program are also presented, along with the scheduled activities of the program plan.

INTRODUCTION

In January, 1973, a decision was made by the National Aeronautics and Space Administration (NASA) to significantly reduce its space communications research and development effort. Since that time, a number of position papers have been published (refs. 1,2, and 3) which have addressed the impact of the reduced activity in space communications by the NASA and have recommended that the decision be re-evaluated. A re-examination of that decision and an assessment of its consequences has resulted in a new commitment to increase NASA's space communications activities.

A program plan for NASA's renewed space communications activities has been established. The goals of that plan are:

1. To enable growth in the capacity and effective utilization of the finite and valuable resource - the radiofrequency spectrum.
2. To develop technology focused on enabling overall reduction in communication service costs.
3. To serve as a catalyst to the creation of new and innovative services for the public good.

These goals provide a basis for a highly-focused five-year plan. A major element of that plan consists of the development and testing of enabling technology required for a space/ground system for trunking and direct-to-user applications using the 20 GHz and 30 GHz allocated frequency bands. The plan for the 30/20 GHz program (30 GHz uplink frequency, 20 GHz downlink frequency) is shown in figure 1 and includes systems and market studies of potential operational systems, a plan for a technology verification flight test and experimental operations, and a supporting research and technology development plan.

BACKGROUND STUDIES

Market Studies

Two market studies were conducted to develop demand forecasts for communications services in the 1980-2000 time period, to characterize the demand by user type, size, and demographics, to project costs of terrestrial and satellite systems, and to forecast the satellite share of the service demand. The studies were performed by the U.S. Telephone and Telegraph Corporation and Western Union, and are reported in references 4 and 5, respectively. Study results significant to the development of a supporting research and development program are included in the following discussion. Current on-orbit and planned satellites operating nominally in the 4-8 GHz and 12-18 GHz frequency bands (C and Ku bands, respectively) will occupy a significant fraction of the useable geosynchronous orbit by 1982, as shown in figure 2. Further, it is expected that these satellites will occupy all available orbit slots by 1990, even with closer satellite spaceing of 3^{o} (4.5^{o} is currently used) and increases in data-bandwidth efficiency (Bit/Hz) usage of available transponders. The probable satellite market capture is projected to exceed capacity by the 1990-1992 time period. The development of the 30/20 GHz bands for satellites can significantly increase communications capacity because these bands offer the opportunity for the use of low sidelobe, multi-narrow-beam antennas to achieve large-scale multiple reuse of each orbital position and frequency. To be competitive, however, the development of satellite systems in the 30/20 GHz frequency bands must achieve very high end-to-end access availability, from 0.9995 to 0.9999. To achieve this availability, the component and subsystem reliabilities must be high, and technology must be developed for dependable operation in a propagation media that is characterized by large signal attenuations due to rain (ref. 6).

Large costs are associated with central office facilities and terrestrial tails (access links) in large trunking systems. This tends to make direct-to-user applications appear attractive, although because of the high costs per unit bandwidth, a market has not yet been identified which would support such a service. The direct-to-user application is still being investigated.

Systems Studies

Studies of operational systems concepts for communication satellites operating in the 30/20 GHz frequency bands were performed by Ford Aerospace and Communications and Hughes Aircraft Company and are reported in references 7 and 8, respectively. The purpose of these studies is to define operational systems concepts for trunking and direct-to-user applications, to identify critical technology needs, and to estimate systems costs. The operational concepts defined for both applications are too numerous to permit detailed descriptions here, but all the concepts were designed for quadrature phase shift keyed (QPSK) digital transmission with a bit error rate (BER) of from 1×10^{-5} to 1×10^{-6}, and they all utilized multi-narrow-beam antenna systems.

The trunking concepts, shown in figure 3, are based on the use of multi-beam antenna systems with ten 30 GHz frequency uplink beams originating from ten major trunking sites and ten 20 GHz frequency downlink beams, one to each of the trunking sites. Spatially diversified earth terminals are used to minimize outage due to rain attenuation. Two connected ground terminals, separated by several kilometers, are unlikely to be simultaneously subjected to significant rain attenuation. The trunking configurations differ primarily in the methods of interconnect between the input low-noise amplifiers and the output high-power amplifiers. For frequency-division multiple access (FDMA) the method of interconnect is by means of hard-wired channel filters with various types of output high-power amplifiers used to amplify single or multiple channels. Complex multiplexing is used between the output amplifiers and the downlink feeds. The time-division multiple access (TDMA) trunking concepts which were developed improve satellite capacity utilization and provide flexibility in dynamically adapting to changing communication rates between trunking sites. The method of interconnect is by means of a switch matrix which provides a sequence of unequal time interconnect configurations. The switching may be done at an intermediate frequency or at baseband frequency. The baseband switching configurations require the additional complexity of demodulation and modulation in the spacecraft. This complication, however, is offset by advantages in bit stream regeneration and offers the potential advantage of limited storage.

The direct-to-user concepts, depicted in figure 4, differ slightly from the trunking concepts. In these concepts, the space antenna system employs 25 overlapping beams to cover the contiguous states. Also, unlike the trunking concepts, in which one separated pair of ground terminals per beam is used, there are many terminals within the coverage pattern of each beam in the direct-to-user concepts. Beyond these differences, the FDMA and TDMA trunking and direct-to-user concepts are essentially similar. Link characteristics of these concepts are summarized in Tables I and II.

Critical technologies to support the operational concepts were identified by the systems studies as spacecraft data handling, low-noise amplifiers, high-power amplifiers, antennas, and earth terminals.

SUPPORTING RESEARCH AND TECHNOLOGY

The supporting research and technology development plan for the 30/20 GHz space communications program has the following objectives:

1. To provide technology advances for radio-frequency spectrum reuse and increased geosynchronous orbit utilization.
2. To decrease development risk for operational systems.

The philosophy of the supporting research and technology plan is to develop experimental hardware in each critical technology area and to conduct proof-of-concept tests of the hardware. It is intended that the experimental hardware will be suitably packaged to permit test operations in a representative space environment, and that the proof-of-concept tests will demonstrate satisfactory performance in that environment. This procedure is planned for all critical technology areas except for the antenna, in which case suitable environmental simulation does not appear to be practical.

The schedule for each development activity is planned to provide a technology data base to support the detailed design and development phase (fig. 1) of the 30/20 GHz space communications program. Therefore the schedule for each activity, including proof-of-concept testing, is to be completed by the end of Fiscal Year 1982. A schedule of deliverable experimental hardware has also been established to support a parallel in-house testing program at the NASA's Lewis Research Center. The in-house program will provide valuable added information about systems performance and implementation losses by testing the experimental hardware in combined configurations.

Spacecraft Data Handling

The supporting research and technology plan for spacecraft data handling provides for the development of elements which can be used to increase connectivity (system end-to-end access) and utilization of spacecraft communication capacity. Approaches are planned to support both direct-to-user and trunking applications, but the latter will be emphasized based on market study projections.

Development of experimental hardware and proof-of-concept tests, as shown in figure 5, are planned for an intermediate-frequency 10 by 10 switching matrix for trunking. The matrix will connect any set of 10 inputs to any set of 10 outputs. This activity is to be initiated in Fiscal Year 1979 with two parallel one-year study contracts. A follow-on contract for fabrication and testing of the switching matrix will be awarded to one of the first-year contractors. In addition, technology studies for bit stream processing and full-baseband processing will be started in Fiscal Year 1980. Demodulation and remodulation of the bit stream will be used with regeneration. In a more complex form, on-board processing will be performed using information contained in the bit stream formats. Approaches using full baseband processing (ref. 9) are currently being studied.

High-Power Amplifiers

The operational concepts developed by the systems studies identified 20 GHz amplifier radio-frequency (rf) output power requirements from six Watts to one kilowatt for downlink operation. As indicated in figure 6, the contractual program for this technology area calls for the development and testing of both traveling-wave tube (TWT) and solid state amplifiers. The TWT amplifier development to be initiated in Fiscal Year 1979 will provide a multi-mode TWT with a maximum saturated rf output power of 75 Watts. The TWT (ref. 10) will be optimized for linear operation to permit multi-channel amplification, and will incorporate a multi-stage depressed collector for high efficiency along with an impregnated "M"-type cathode designed for a 10-year life. Development of the supporting power processing system for the TWT amplifier will be started in Fiscal Year 1980.

The development goal for the solid state power amplifiers will be from one to 20 Watts of rf output power at 20 GHz frequency. The planned application will be for single channel operation with required bandwidths from 275 MHz to 2.5 GHz. Parallel developments of GaAs FET amplifiers for wider bandwidths and IMPATT amplifiers for the narrower bandwidths are planned. The solid state development will be divided into three phases - device, power combining circuits, and power amplifiers. The development will emphasize long life and high efficiency, with the design life objective being 10 years.

Antennas

The spacecraft antennas are key elements in the effort to achieve efficient frequency reuse and increased geosynchronous orbit utilization. These goals can be achieved by using narrow-beam-width, multi-beam antennas that confine rf illumination to small regions of the contiguous United States (CONUS) rather than full Earth or full CONUS coverage. This then permits increased use of the frequency band by other antenna beams. The satellite trunking antenna systems defined in the systems study concepts produce 10 spot beams for uplink reception and downlink transmission at 30 GHz and 20 GHz, respectively. The uplink and downlink functions may or may not be assigned to separate antennas. The required half-power beam width (HPBW) for these antennas as determined in the systems studies is 0.3 degrees. The satellite direct-to-user CONUS antenna systems defined in the systems studies use 25 beams of one degree HPBW. Sidelobe suppression of 30 dB is required to achieve high frequency reuse. For the trunking systems, all the major trunking sites cannot be discriminated without the use of polarization isolation. To limit co-channel interference to levels that achieve a bit error rate of 10^{-6} (ref. 6), polarization isolation greater than 25 dB is required.

As shown in figure 7, the spacecraft antenna supporting research and technology development plan is to be initiated in Fiscal Year 1980. The first phase of that effort consists of concept studies for the lens, reflector, and array approaches. Two approaches will be selected for the development of model prototype antennas and testing.

Low-Noise Amplifiers

Two approaches for the development of uplink low-noise amplifiers at 30 GHz frequency will be started in Fiscal Year 1980. As indicated in figure 8, both GaAs FET and parametric low-noise experimental amplifiers will be developed and tested. Deliverable units will be provided in Fiscal Year 1981 and proof-of-concept testing will be conducted in the Fiscal Year 1981-82 time period.

Minimum bandwidth requirements for the amplifiers are 2.5 GHz. The development goals for the GaAs FET amplifier are a 4.5 dB noise figure and gain of 8 to 10 dB, and the corresponding goals for the parametric amplifier are a 3 dB noise figure and 20 dB gain. A life requirement of 10 years will be emphasized.

Ground Terminals

High-speed modulator-demodulators (modems) will be required for TDMA operation. Carrier and bit stream lock will have to be maintained to achieve a maximum bit error rate of 10^{-6} at a bit rate of 2.5 gigabits per second. The modems will be required to operate with spatially-diversified ground terminals for both uplink transmission and downlink reception. In addition to the high-speed modems, the ground terminals will require high-power TWT's with rf output power levels of three to five kilowatts at 30 GHz frequency for uplink transmission.

The supporting research and technology effort for the high-speed modem development will begin in Fiscal Year 1981 with the delivery of experimental modems planned for late Fiscal Year 1982. High-power 30 GHz TWT development will be started in early Fiscal Year 1982 with the delivery of the first experimental TWT scheduled for mid-Fiscal Year 1983.

CONCLUDING REMARKS

NASA has resumed its space communications activities, and a highly focused five year plan has been prepared to implement that effort. A major element of that plan consists of the development and demonstration of enabling technology to provide a space communications capability in the 30/20 GHz frequency bands.

Market studies have been conducted which project that C and Ku frequency band satellites will fill all available geosynchronous orbital slots and that demand will exceed available communications capacity by the 1990-1992 time period. Achieving end-to-end availabilities of 0.999 and reliable operation in a propagation media that is characterized by large signal attenuations due to rain puts large demands on technology.

Systems studies have defined concepts for operational trunking and direct-to-user applications. The concepts presented approaches that achieve multiple reuse of each orbital position and frequency by the use of low sidelobe multi-narrow-beam antennas. Critical technology items to support the operational requirements are spacecraft data handling methods, low-noise amplifiers, high-power amplifiers, antennas, and earth terminals.

A supporting research and technology plan has been prepared to aid in the development of the technology to use the 30/20 GHz frequency bands for satellite operational systems and to minimize system development risk. A contractual program for the development of satellite switch matrices, solid state and traveling-wave tube amplifiers, multi-beam antennas, low-noise parametric and GaAs FET amplifiers, and ground terminal modems and high-power amplifiers has also been prepared. This plan provides for the development of experimental hardware in each critical technology area and also provides for proof-of-concept tests of the developed hardware. This activity, when completed by the end of Fiscal Year 1982, will provide a technology data base to support the detailed design and development phase of the 30/20 GHz communications satellite program.

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TABLE 1. LINK CHARACTERISTICS FOR TRUNKING SYSTEM
(With Ground Terminal Spacial Diversification)

Characteristic	Spacecraft Data Handling Method							
	Time-division multiple access (With remodulation)				Frequency-division multiple access			
End-to-end access availability	0.999		0.9999		0.999		0.9999	
Bandwidth, megahertz	1800	2500	1800	2500	165	274	165	274
Bit rate, megabits/second	2500	2500	2500	2500	274	274	274	274
Bit error rate	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}
Number of beams/antenna	10	5	10	5	10	5	10	5
Spacecraft receive antenna: half-power beam width, degrees	0.3	0.2	0.3	0.2	0.3	0.2	0.3	0.2
Spacecraft transmit antenna: half-power beam width, degrees	0.3	0.25	0.3	0.25	0.3	0.25	0.3	0.25
Ground terminal receive antenna: half-power beam width, degrees	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ground terminal transmit antenna: half-power beam width, degrees	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Spacecraft noise temperature, ^{o}K	700	450	700	450	700	450	700	450
Ground terminal noise temperature, ^{o}K	230	100	230	100	230	100	230	100
Downlink power, Watts/channel	11	6.3	26	15.1	10.6	1.2	25	2.8
Uplink power, Watts/channel	19.6	6.5	237	79	67	7.6	815	92.4
Rain margin, downlink, decibels	6.5	6.5	10	10	6.5	6.5	10	10
Rain margin, uplink, decibels	9	9	20	20	9	9	20	20

TABLE II. LINK CHARACTERISTICS FOR DIRECT-TO-USER SYSTEM

Characteristic	Spacecraft Data Handling Method			
	Time-division multiple access (With remodulation)		Frequency-division multiple access	
End-to-end access availability	0.995	0.999	0.995	0.999
Bandwidth, megahertz	100	100	6.3	6.3
Bit rate, megabits/second	150	150	6.3	6.3
Bit error rate	10^{-5}	10^{-5}	10^{-5}	10^{-5}
Number of beams/antenna	25	25	25	25
Spacecraft receive antenna: half-power beam width, degrees	1.0	1.0	1.0	1.0
Spacecraft transmit antenna: half-power beam width, degrees	1.0	1.0	1.0	1.0
Ground terminal receive antenna: half-power beam width, degrees	0.24	0.24	0.24	0.24
Ground terminal transmit antenna: half-power beam width, degrees	0.16	0.16	0.16	0.16
Spacecraft noise temperature, ^{o}K	700	700	700	700
Ground terminal noise temperature, ^{o}K	230	230	230	230
Downlink power, Watts/channel	38	1000	2	54
Uplink power, Watts/channel	402	10000	13	342
Rain margin, downlink, decibels	6.5	20	6.5	20
Rain margin, uplink, decibels	13	27	13	27

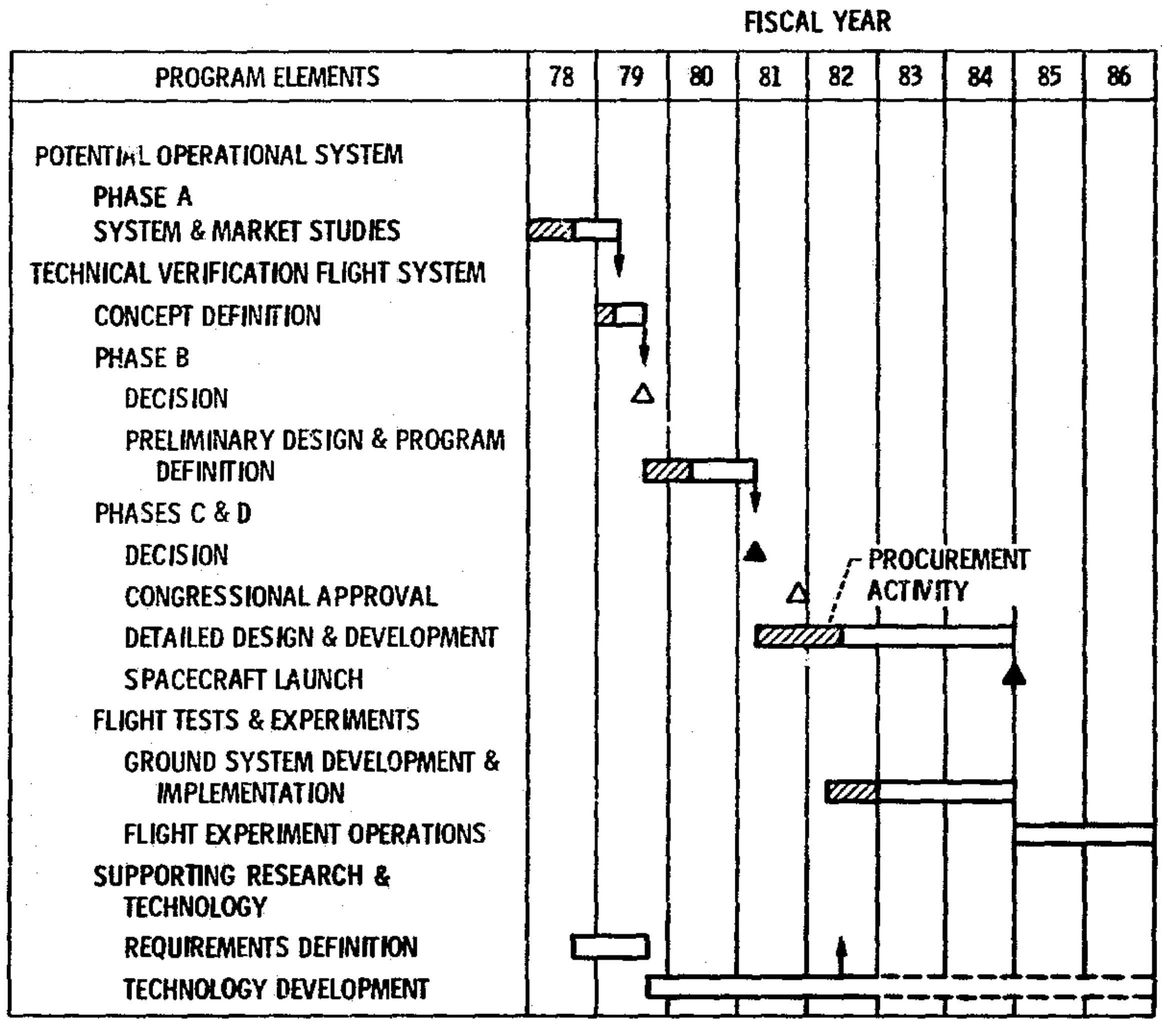

Figure 1. - 30/20 GHz frequency bands communication satellite program plan.

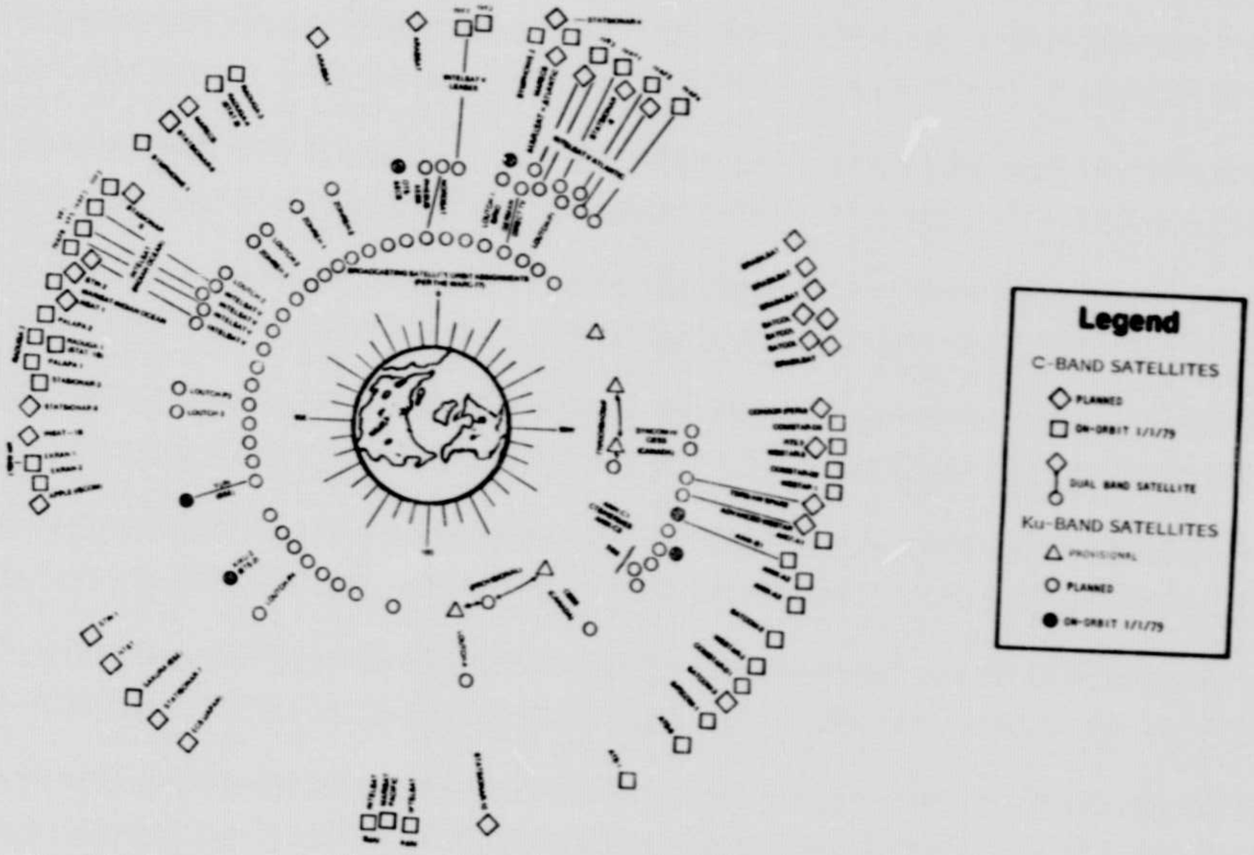

Figure 2. - On-orbit and planned C and Ku band satellites.

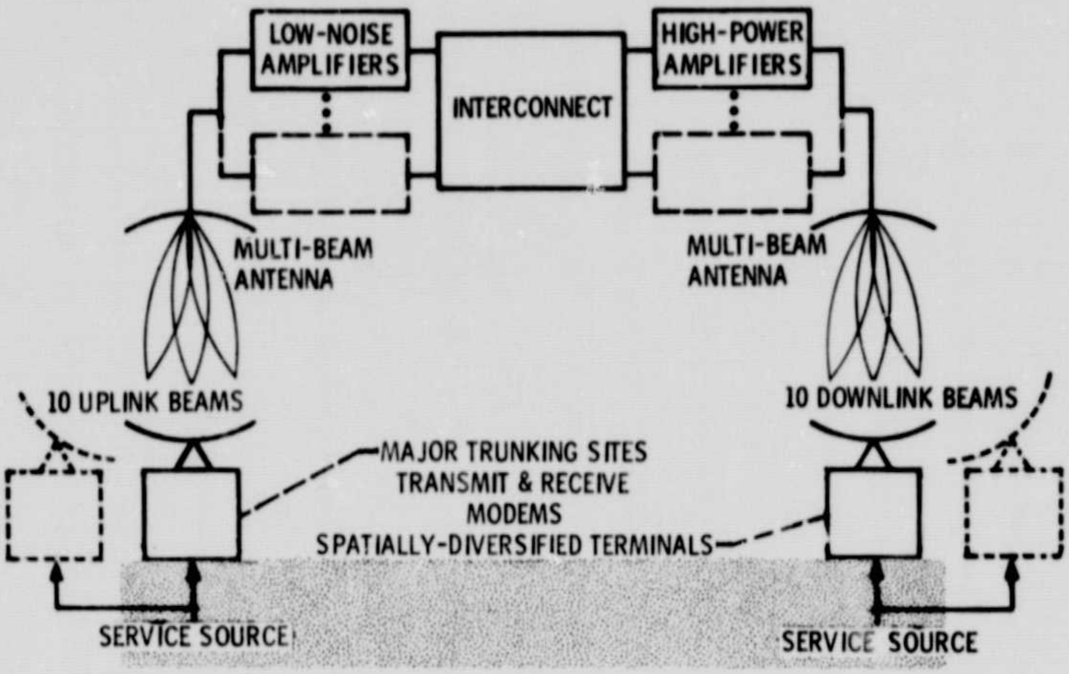

Figure 3. - Systems studies operational trunking concepts.

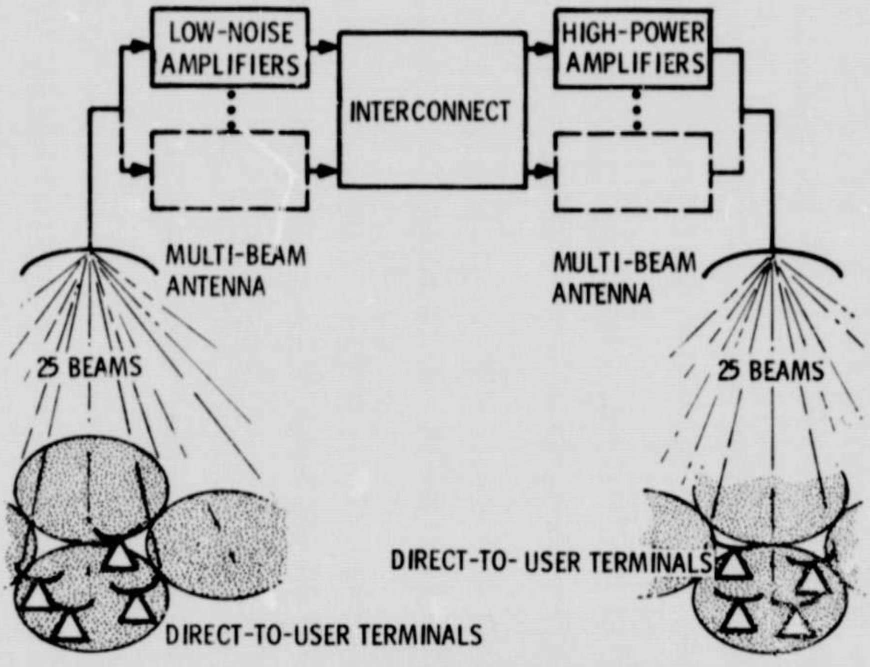

Figure 4. - Systems studies operational direct-to-user concepts.

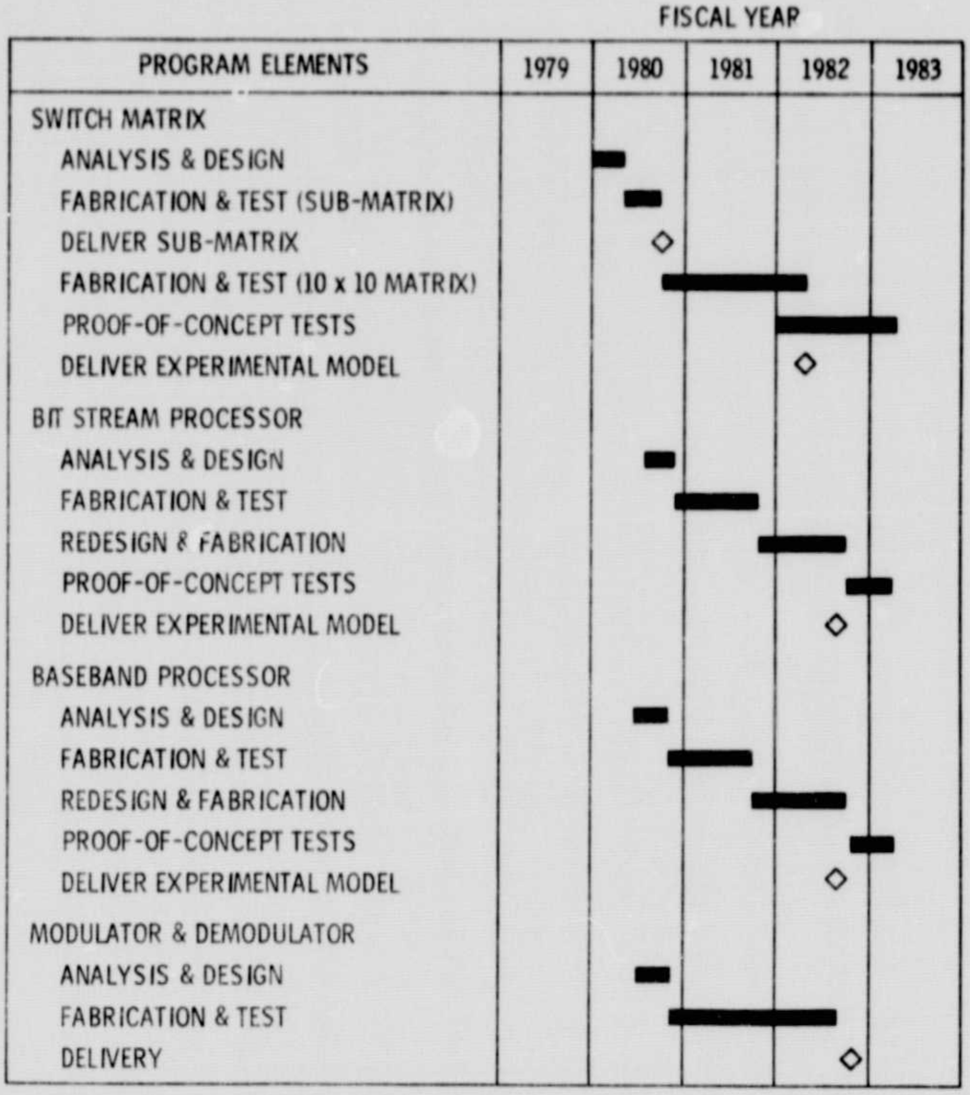

Figure 5. - 30/20 GHz frequency bands supporting research and technology spacecraft data handling schedule.

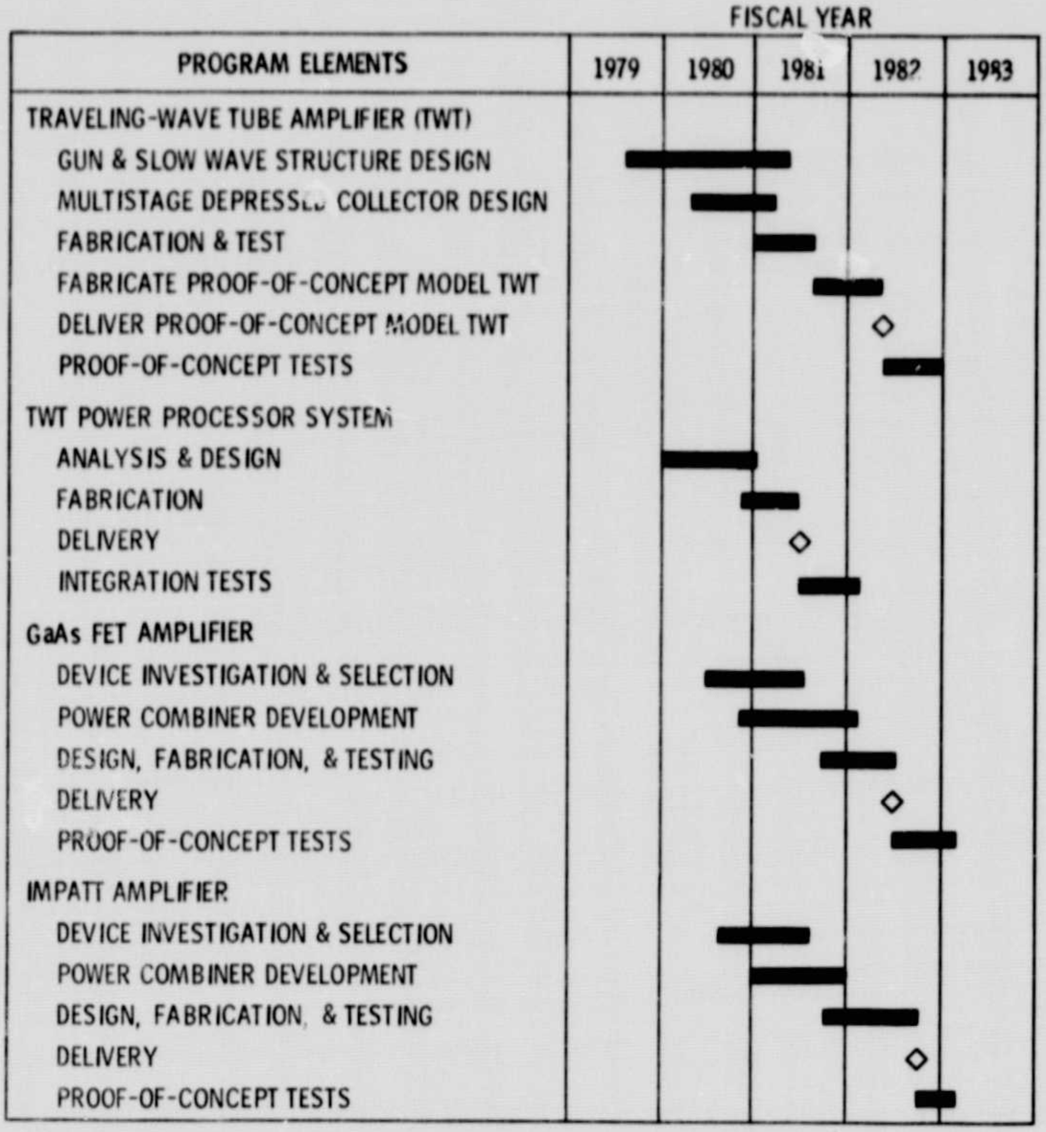

Figure 6. - 30/20 GHz frequency bands supporting research and technology high-power amplifier schedule.

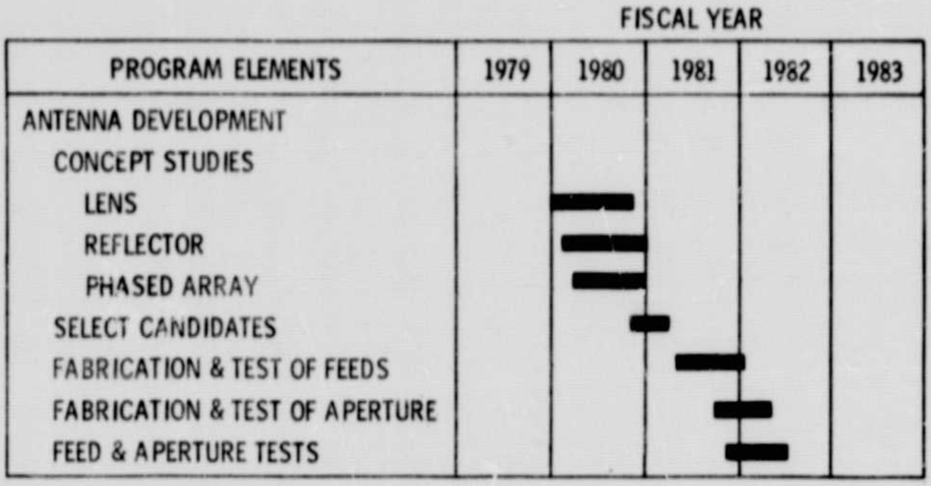

Figure 7. - 30/20 GHz frequency bands supporting research and technology antenna schedule.

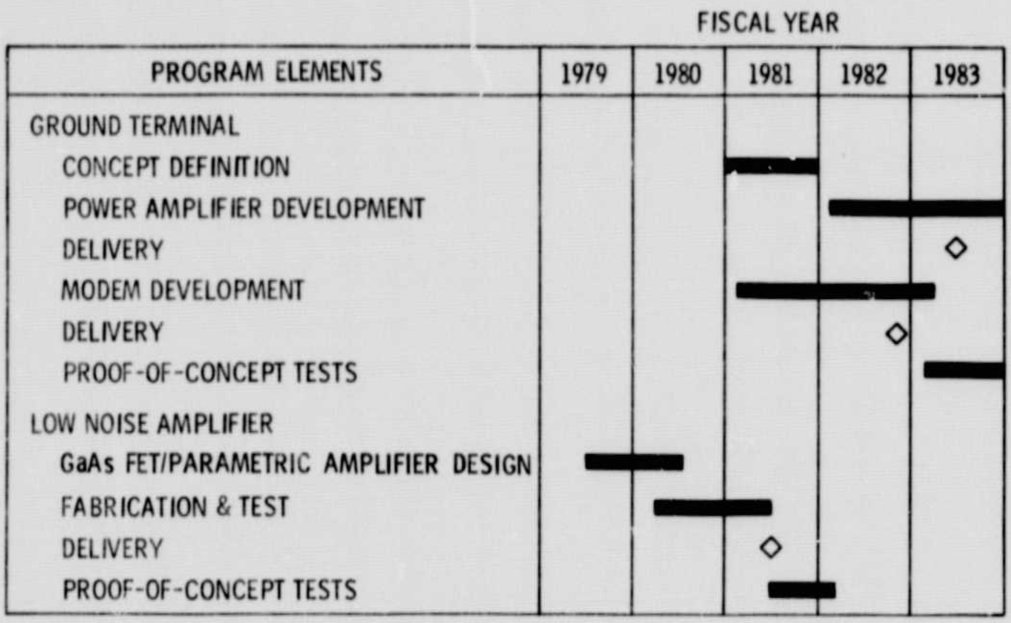

Figure 8. - 30/20 GHz frequency bands supporting research and technology ground terminal and low-noise amplifier schedule.