

NASA MOBILE SATELLITE PROGRAM

George Knouse
NASA Headquarters
Washington, DC

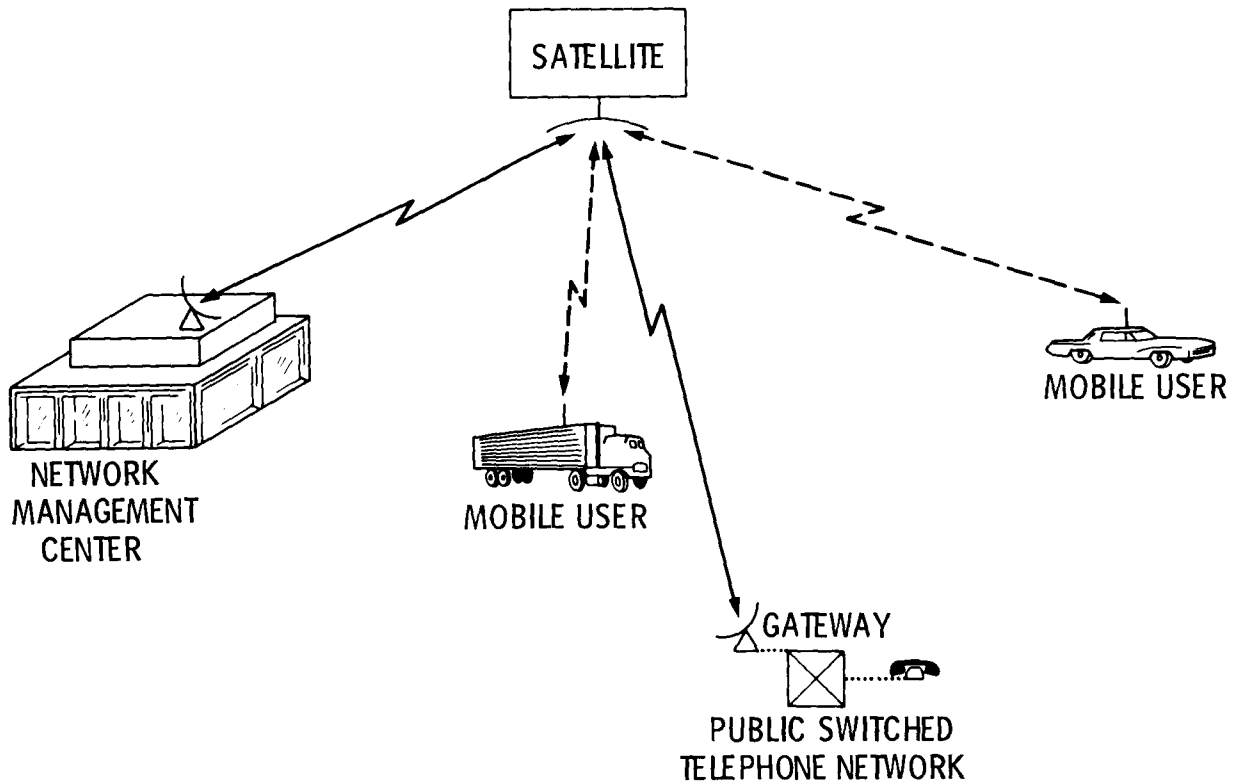
William Weber
Jet Propulsion Laboratory
Pasadena, CA

Large Space Antenna Systems Technology - 1984

December 4-6, 1984

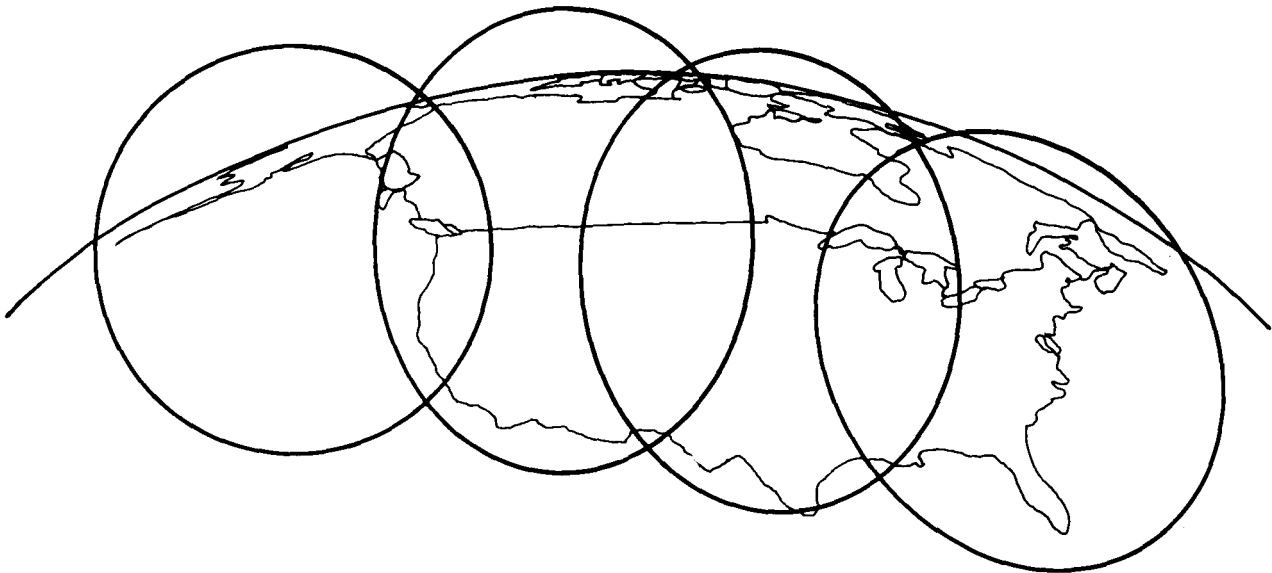
MOBILE SATELLITE CONCEPT
FUNCTIONAL DESCRIPTION

A Mobile Satellite System (MSS) provides communications over large geographic areas between mobile terminals (whether on land, sea, or in the air) and their associated base stations. Communications between the mobiles and the base stations or telephone gateway stations are relayed by a geostationary satellite. A network management center provides call setup and channel allocation and controls the operation of the network. A typical coverage area would include the 48 states, Alaska, and surrounding coastal waters, thus augmenting existing and planned terrestrial systems that are concentrated primarily in higher population areas. Representative services include telephony, two-way radio, dispatch, message and low-speed data, paging, and position location. Potential markets include both commercial and government applications such as interstate trucking, remote oil/gas drilling, business, and emergency response communications such as required for emergency medical service and wide-area law enforcement.



**A POSSIBLE FIRST-GENERATION MSS
BEAM COVERAGE PATTERN**

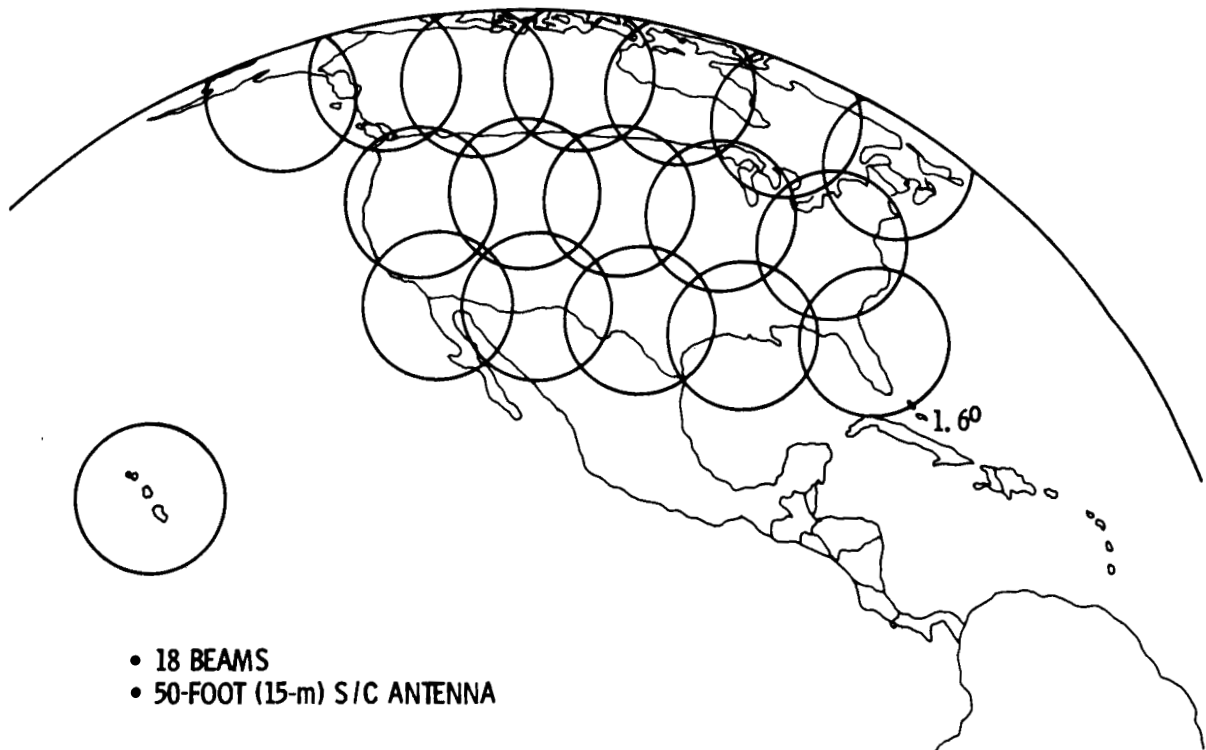
The MSS satellite will most likely be a conventional communications satellite bus with a relatively large deployable antenna, in the range of 10 to 30 feet in diameter. One possible design might include a 25 ft UHF antenna with a four beam pattern covering both the US and Canada. The first-generation system may be a joint venture between the US and Canada; however, it will be built and operated by the private sector. NASA and the Canadian Department of Communications (DOC) have worked cooperatively for the past five years toward accelerating the introduction of this new satellite service. Three companies in the US and one in Canada have expressed their intent to operate such systems. The FCC will soon issue a Notice of Proposed Rulemaking for frequencies in the 806-890 MHz band and will request applications for licenses for MSS. NASA is working with the FCC, US industry, DOC, and other government agencies to assure the launch of this new system by the end of the decade.



25-FOOT (7.6-m) SPACECRAFT ANTENNA

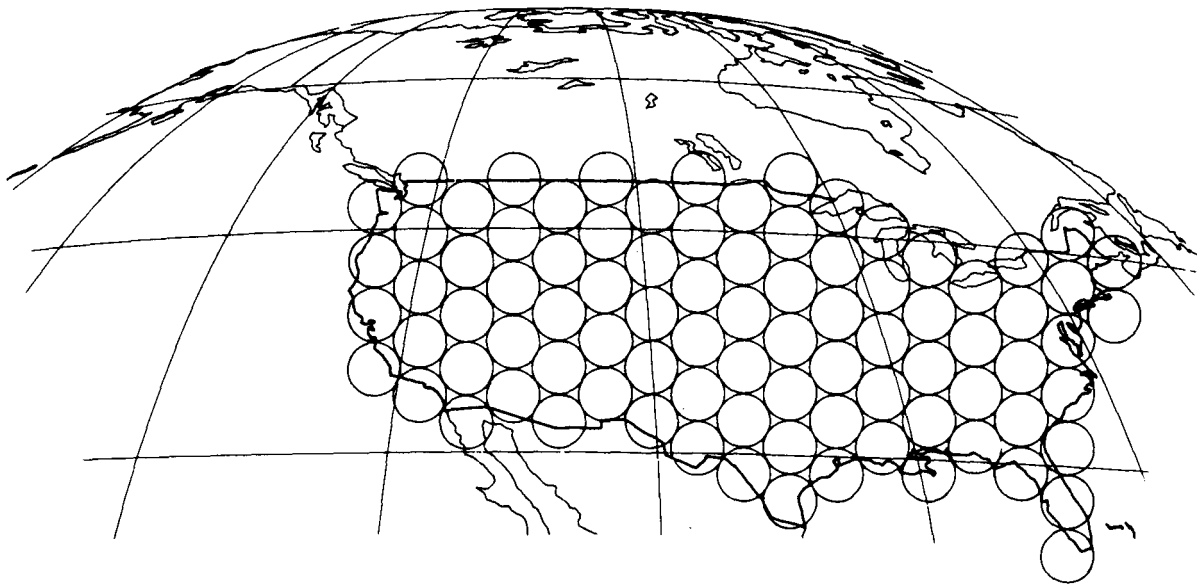
A POSSIBLE SECOND-GENERATION MSS BEAM PATTERN

The figure shows a possible second-generation MSS beam pattern resulting from a UHF 50-ft antenna. System studies by NASA, JPL, and their contractors have indicated that the second generation will be launched in the mid-1990s, have an antenna in the range of 15 to 25 meters, and use large communications satellite buses which are already in the planning stages. Frequency reuse among the antenna beams will provide greatly expanded channel capacity for the expected limited-frequency allocation.



A POSSIBLE THIRD-GENERATION MSS BEAM PATTERN

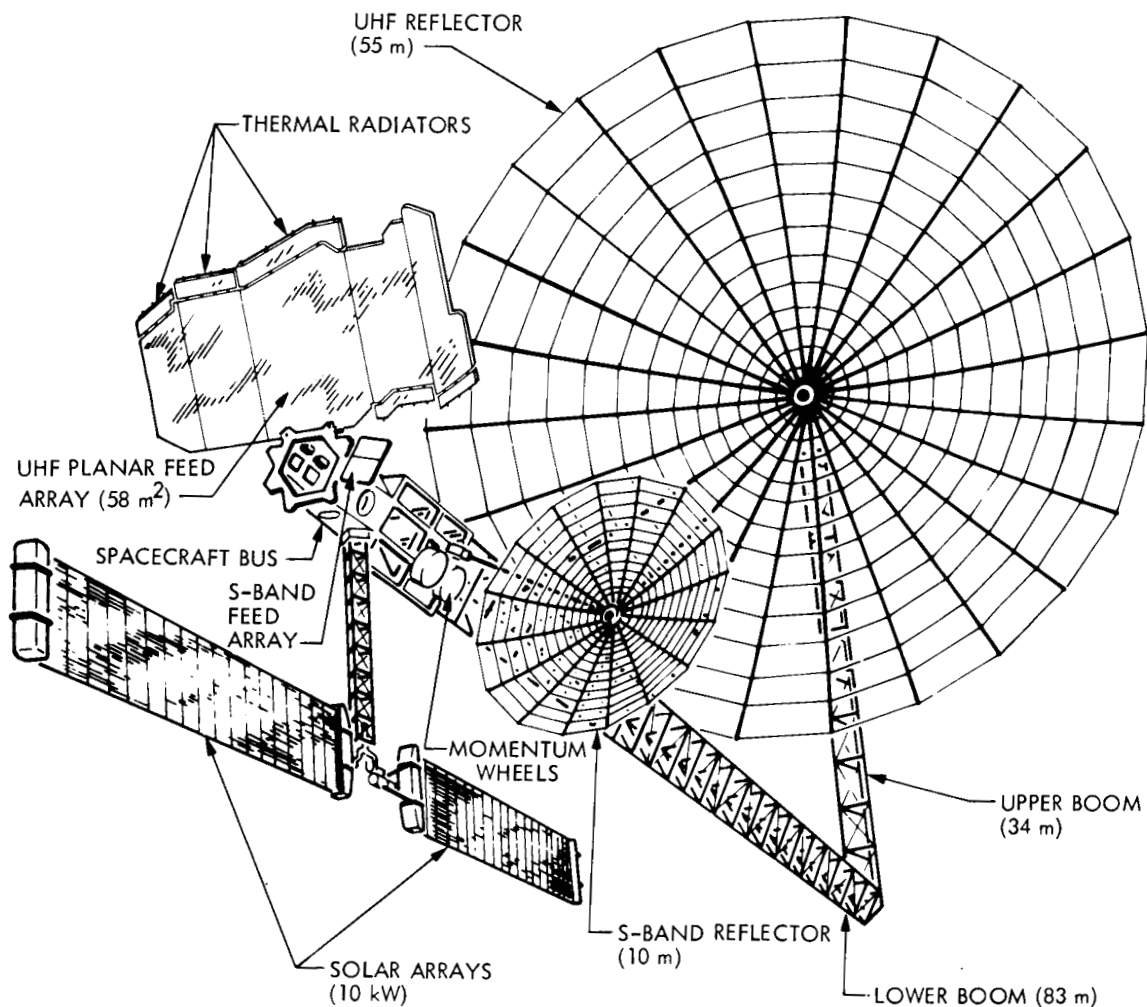
The figure shows a possible third-generation MSS beam pattern resulting from a UHF 180-ft antenna. System studies have indicated that the third generation will be launched near the turn of the century, have an antenna in the 40 to 55 meter range, and require totally new satellite design concepts. Such a system could provide affordable mobile services to hundreds of thousands, if not millions, of users.



- APPROXIMATELY 90 BEAMS
- 180-FOOT (55-m) S/C ANTENNA

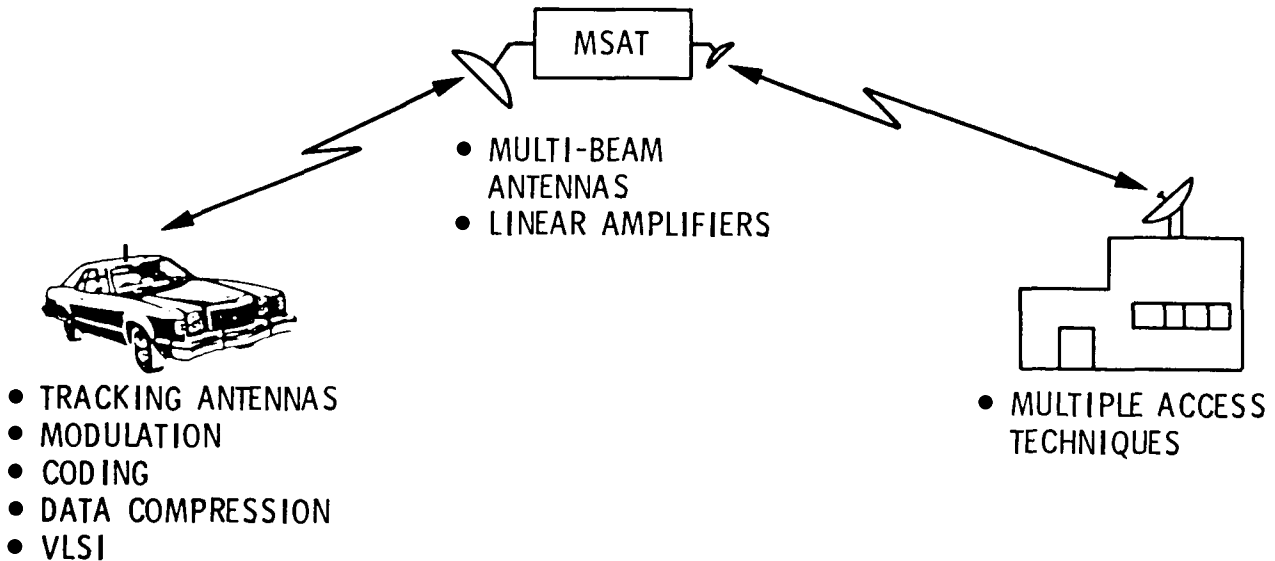
CONCEPTUAL DESIGN OF THIRD-GENERATION MSS

The figure shows the conceptual design of a third-generation system with a 55 meter, UHF, Lockheed wrap-rib deployable antenna. The 90 beams are generated by a planar feed array and beam-forming network. In this design, UHF frequencies are used for the satellite-to-mobile communications links while S-band is used for the satellite-to-base station links.



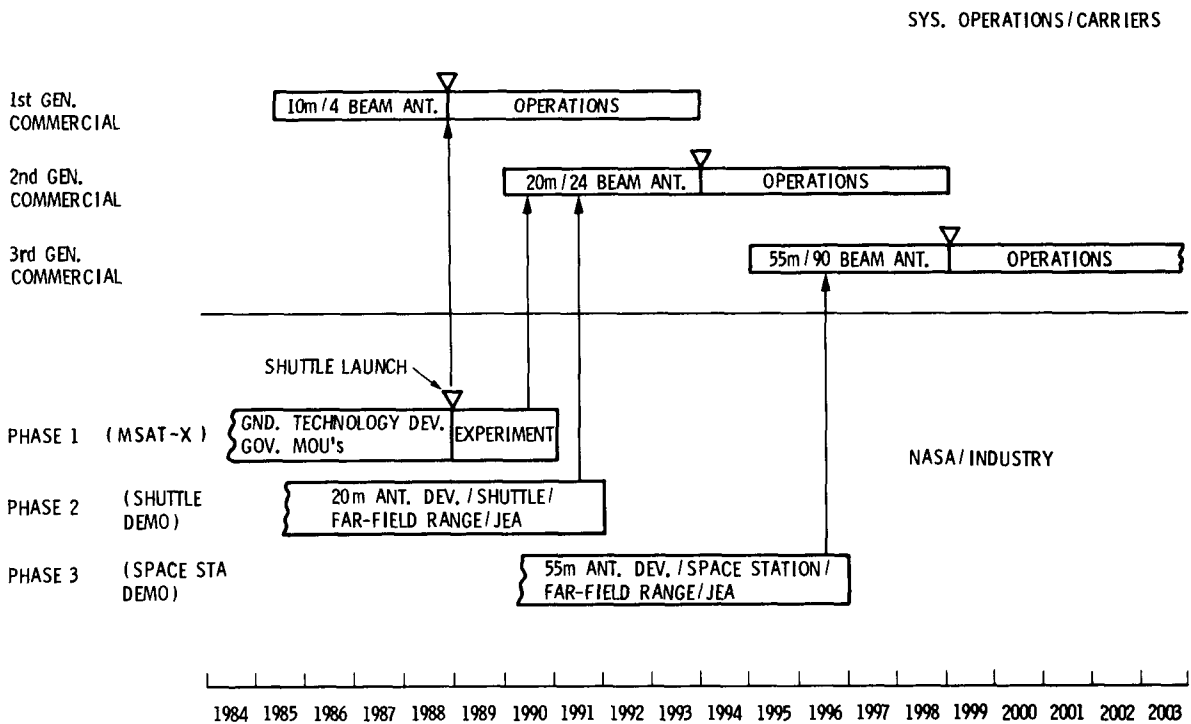
CONSTRAINTS THAT DRIVE TECHNOLOGY

Three key resources in the development, growth, and financial viability of a mobile satellite service are satellite power, RF spectrum, and orbital slots. The high-risk technologies in the NASA development program are directed toward conserving these critical resources. Space segment technologies to alleviate these constraints are multiple-beam antennas with frequency reuse, linear power amplifiers to reduce the intermodulation problems inherent in single-channel-per-carrier MSS operation, and possibly satellite switching and on-board signal processing. Ground segment technologies include: high gain, satellite tracking mobile vehicle antennas; narrow-bandwidth and power efficient modulation techniques; coding and error correction for the fading and noisy mobile channels; speech processing and data compression; VLSI to reduce size and cost; and multiple access and networking techniques for efficient utilization of the channels. The NASA Mobile Satellite Program includes the development of all of these technologies.



A PHASED MOBILE SATELLITE PROGRAM PLAN

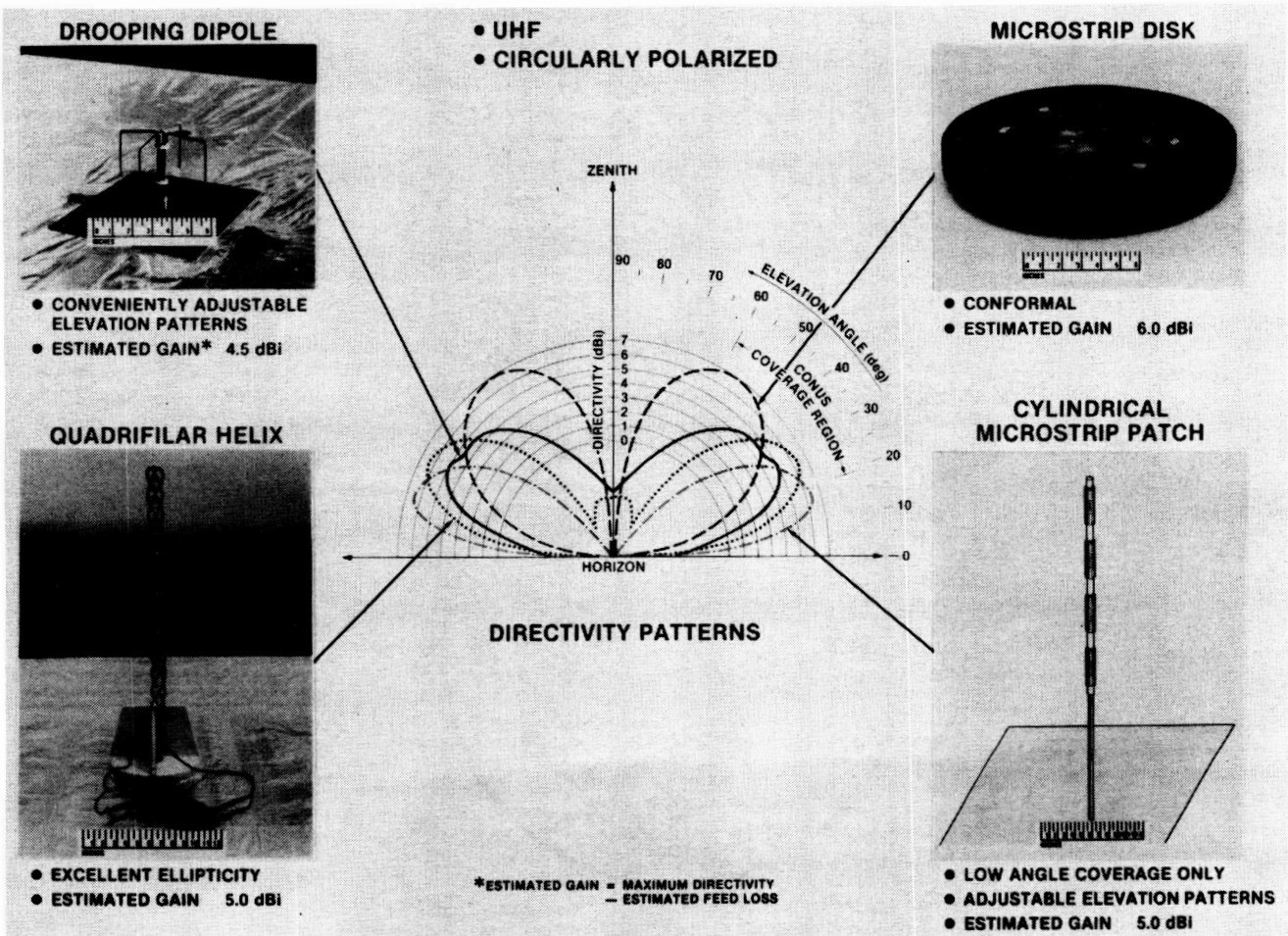
The NASA program is structured in three phases to support the planned commercial launch schedule. All phases employ the Joint Endeavor Agreement (JEA) mechanism for program implementation. This approach directly supports the President's Space Policy to make NASA incentives available to commercial entities that are willing to take significant investment risks to establish and market new space services and products. Phase 1, called the Mobile Satellite Experiment (MSAT-X), is directed toward the development of ground segment technology needed for future MSS generations. Technology validation and pre-operational experiments with other government agencies will be carried out during the two-year period following launch. The satellite channel capacity needed to carry out these experiments will be obtained from industry under a barter-type agreement in exchange for NASA-provided launch services. Phase 2 will develop and flight test the multibeam spacecraft antenna technology needed to obtain substantial frequency reuse for second-generation commercial systems. Industry will provide the antenna, and NASA will fly it on the Shuttle and test it on-orbit. Phase 3 is similar to Phase 2 but will develop an even larger multibeam antenna and test it on the Space Station.



PHASE 1/MSAT-X TECHNOLOGY DEVELOPMENT

LOW-GAIN VEHICLE ANTENNA TECHNOLOGY DEVELOPMENT

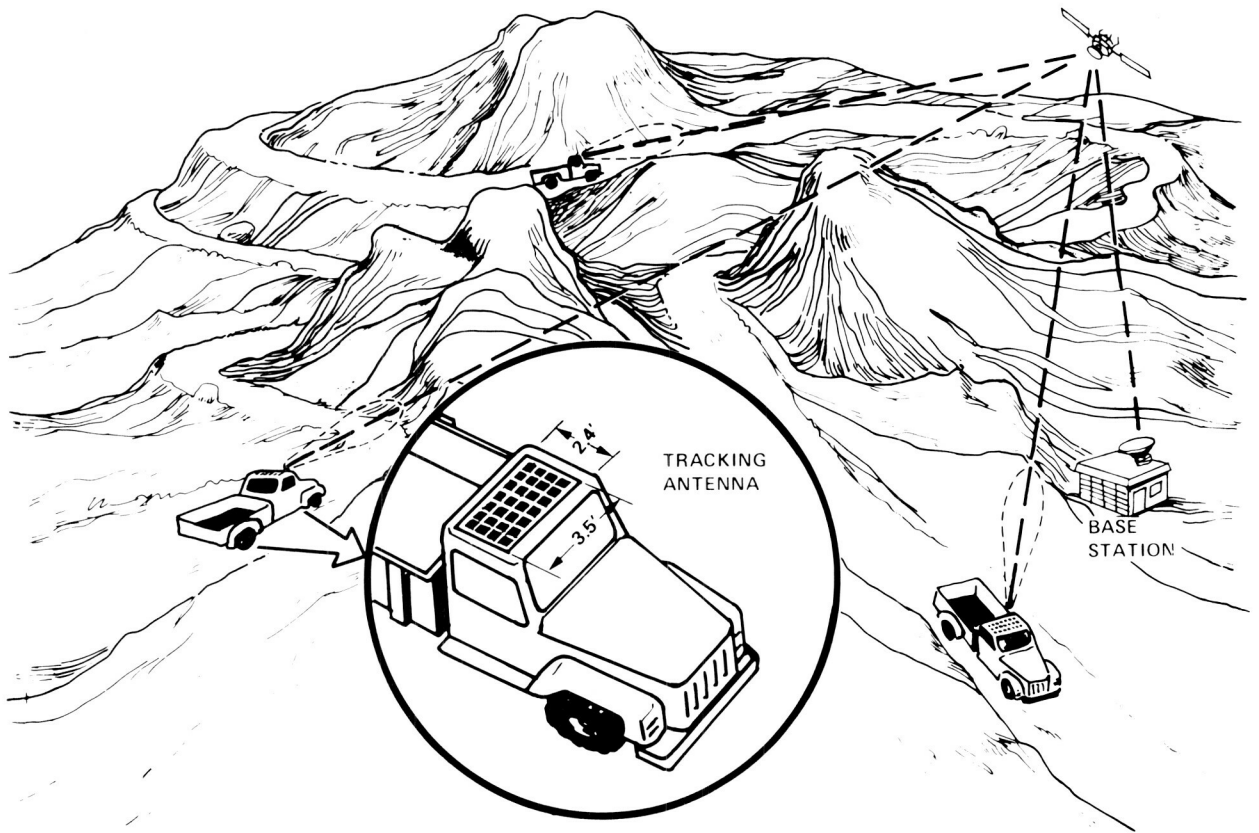
These are four low-gain vehicle antennas that have been developed in-house at JPL for MSS use. Each antenna type provides at least 4 dBi of peak gain and is omni-directional in azimuth. The individual designs differ in cost, gain, elevation angle coverage, size, and aesthetics. The first-generation MSS will employ antennas similar in design.



PHASE 1/MSAT-X TECHNOLOGY DEVELOPMENT

MEDIUM-GAIN TRACKING ANTENNA

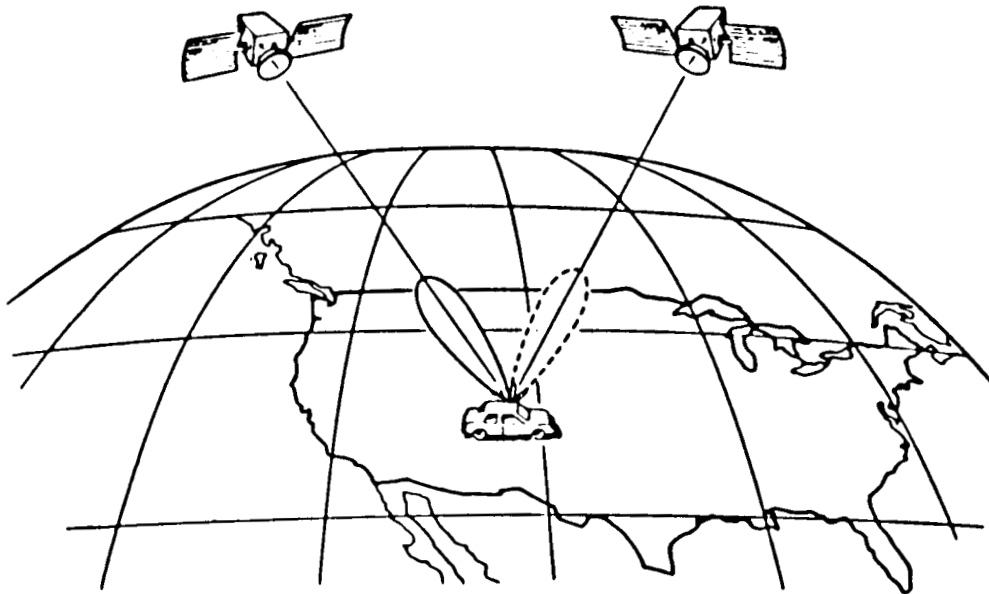
The medium-gain, satellite tracking vehicle antenna is a key technology development in the NASA program. Not only can it provide more gain, but it can also reduce the effects of multipath fading, thereby significantly reducing the power burden on the satellite. The goal of this development is an antenna with 10 dBi of gain, automatic satellite tracking in azimuth and elevation, and a low physical profile. As shown on the next page, another goal is to enable two satellite operation. Accomplishing all this at low cost will be a significant challenge.



PHASE 1/MSAT-X TECHNOLOGY DEVELOPMENT

MEDIUM-GAIN ANTENNA IN TWO-SATELLITE OPERATION

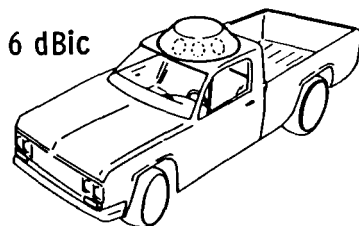
An additional goal of the medium-gain, tracking antenna is the ability to reject signals to/from a second satellite through the control of its sidelobes. Such antennas would enable a doubling of the MSS capacity through the use of two satellites operating at the same frequencies.



PHASE 1/MSAT-X TECHNOLOGY DEVELOPMENT

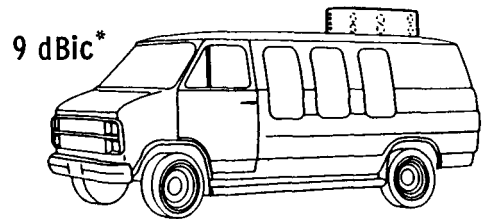
MEDIUM-GAIN ANTENNA CONCEPTS

JPL currently has contracts with Ball Aerospace and Cubic Corporation to study concepts suitable for the medium-gain, tracking antenna. These studies seek to quantify the expected cost of these antennas as a function of antenna gain and profile. All designs have used microstrip patches. The tracking mechanisms have included mechanical steering, electronic switching, or electronic phase shifting in decreasing order of profile height, but in increasing order of cost. Future contracts will develop promising concepts to the prototype stage. These antennas will eventually be tested with the first-generation mobile satellite system as a part of the MSAT-X experiment phase.



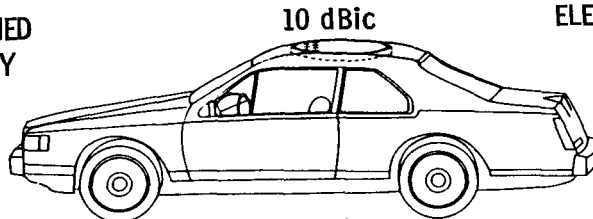
6 dBic

ELECTRONICALLY SWITCHED TRUNCATED CORE ARRAY



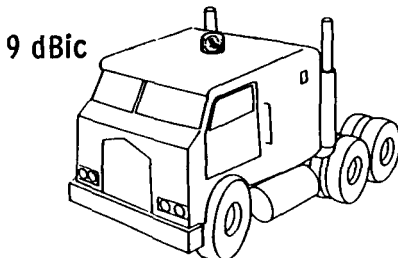
9 dBic*

ELECTRONICALLY SWITCHED CYLINDRICAL ARRAY



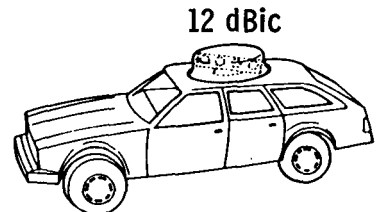
10 dBic

CONFORMAL ELECTRICALLY STEERED PHASED ARRAY



9 dBic

MECHANICALLY STEERED HELIX



12 dBic

MECHANICALLY STEERED TILTED ARRAY

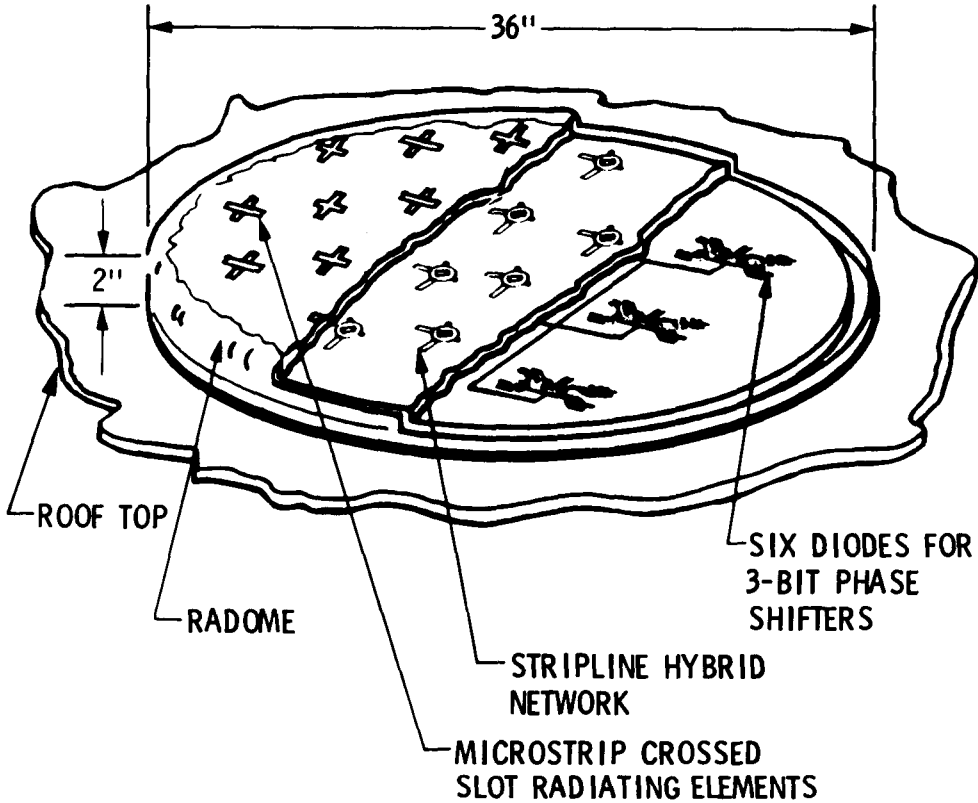
PRODUCED BY BALL AEROSPACE

*DECIBEL ISOTROPIC CIRCULAR (dBic)

PHASE 1/MSAT-X TECHNOLOGY DEVELOPMENT

PHASED-ARRAY VEHICLE ANTENNA

The center concept from the previous page is further depicted in this drawing. This concept has the promise of very low profile and fully electronic operation. The expected cost at this time is, however, prohibitive. The technology challenges will be to reduce the component costs in this concept or to develop other concepts more suited to low-cost implementation.



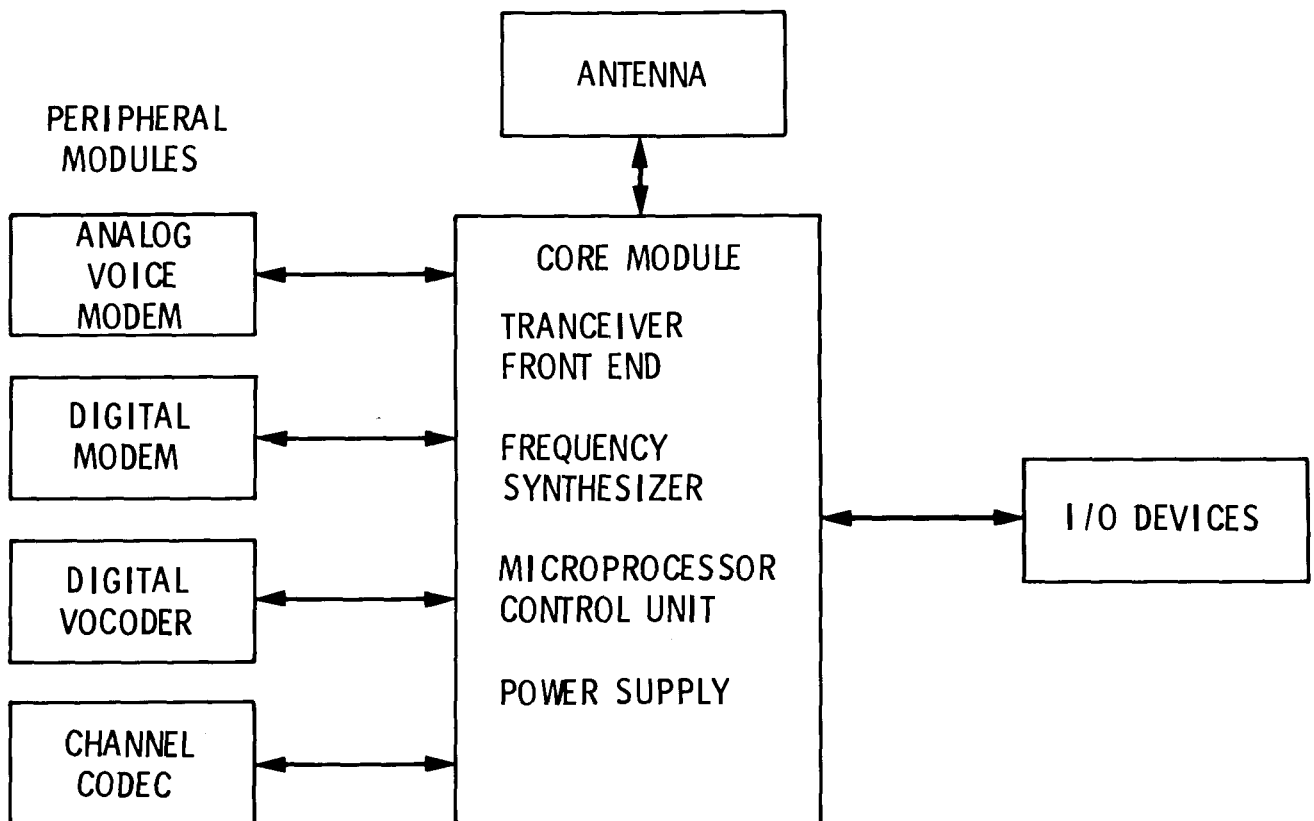
PROPOSED BY BALL AEROSPACE

PHASE 1/MSAT-X TECHNOLOGY DEVELOPMENT

MODULAR MOBILE RADIO TERMINALS

The MSAT-X program also includes the development of mobile radio components and technologies which will alleviate the bandwidth and power constraints for future MSS generations. Key developments will include a modular mobile radio for testing new modulation and transmission techniques with the first-generation system; narrow bandwidth analog and digital modulation techniques for voice and data transmission; coding and error correction techniques to overcome the effects of noise and fading; and digital speech processing and data compression techniques for narrow bandwidth digital voice transmission. The goal is to reduce the required channel bandwidth from the current mobile standard of 30 kHz (analog FM) to 5 kHz for both digital voice and data, while at the same time reducing the required transmitted power. In addition to the mobile terminal technologies, MSAT-X will develop networking techniques for the efficient control and management of the MSS network. Techniques addressed will include multiple-access techniques and adaptive channel assignment techniques for combined voice and variable bandwidth data. The goal is to maximize the utilization of the available channels. The experiment phase of MSAT-X will include tests with the first commercial MSS of all the MSAT-X technology developments in mobile terminals, mobile antennas, base stations, and network management techniques.

MODULE DIAGRAM



PHASE 1 NASA/INDUSTRY JOINT ENDEAVOR

In order to validate the advanced ground segment technology, NASA, contingent on FCC's rulemaking and regulatory process, intends to enter into a Joint Endeavor Agreement with private industry. The joint endeavor between NASA and the owner/operator of the first commercial mobile satellite system will be based on a barter-type agreement under which the US entity or system operator would supply a percentage of the satellite channel capacity to NASA for the advanced technology validation and other government agency pre-operational experiments in exchange for NASA-provided launch services. (NASA has already signed Memoranda of Understanding with six other government agencies in anticipation of their participating with NASA in these technology validation and pre-operational experiments.) The US system operator, possibly in conjunction with its Canadian counterpart, i.e. Telesat, would specify, procure, own, and operate the space segment. This approach has precedent and is supported by US industry.

- NASA PROVIDES STANDARD LAUNCH SERVICES

- U. S. SYSTEM OPERATOR SUPPLIES CHANNEL CAPACITY

- NASA USES CHANNELS FOR
 - GROUND TERMINAL TECHNOLOGY VALIDATION FOR 2nd-GENERATION SYSTEMS

 - SUPPORT OTHER GOVERNMENT EXPERIMENTERS

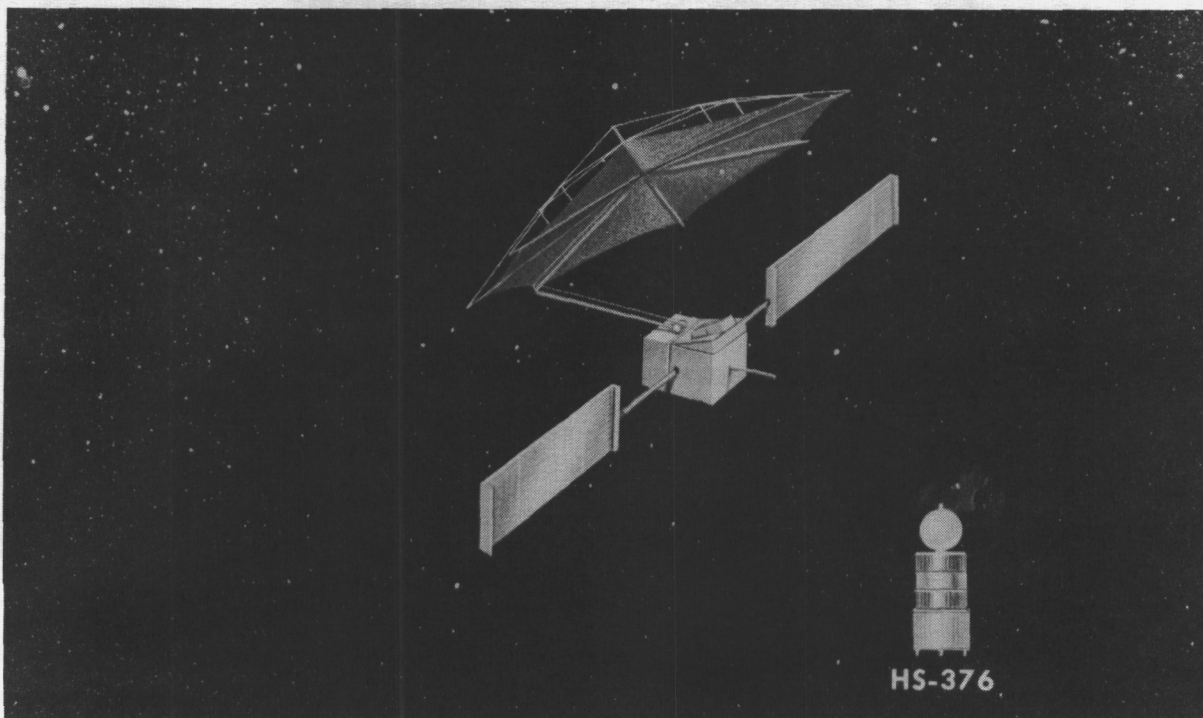
PHASE 2/3 PROGRAM GOAL

The second and third phases of NASA's program are to provide the critical enabling technology of spacecraft multibeam antennas required for second- and third-generation MSS. Antennas of this type are able to reuse the limited frequency resource four to twenty times and reduce RF power per channel requirements by factors of 10 to 100 or more over that of a first-generation system. This magnitude of increased performance will allow satellite capacity to grow in accordance with expected market demands and will decrease user costs. Further, it will make possible adding a higher proportion of high resource services such as mobile telephones. Phase 2 will emphasize the development and flight test on the Shuttle of the antenna system for the second-generation MSS, while Phase 3 will emphasize the development of the third-generation antenna with a flight test on the Space Station.

PROVIDE THE CRITICAL ENABLING
SPACECRAFT MULTI-BEAM ANTENNA
TECHNOLOGY REQUIRED FOR THE SECOND- AND
THIRD-GENERATION MOBILE SATELLITE
SYSTEMS

A SECOND-GENERATION MOBILE SATELLITE

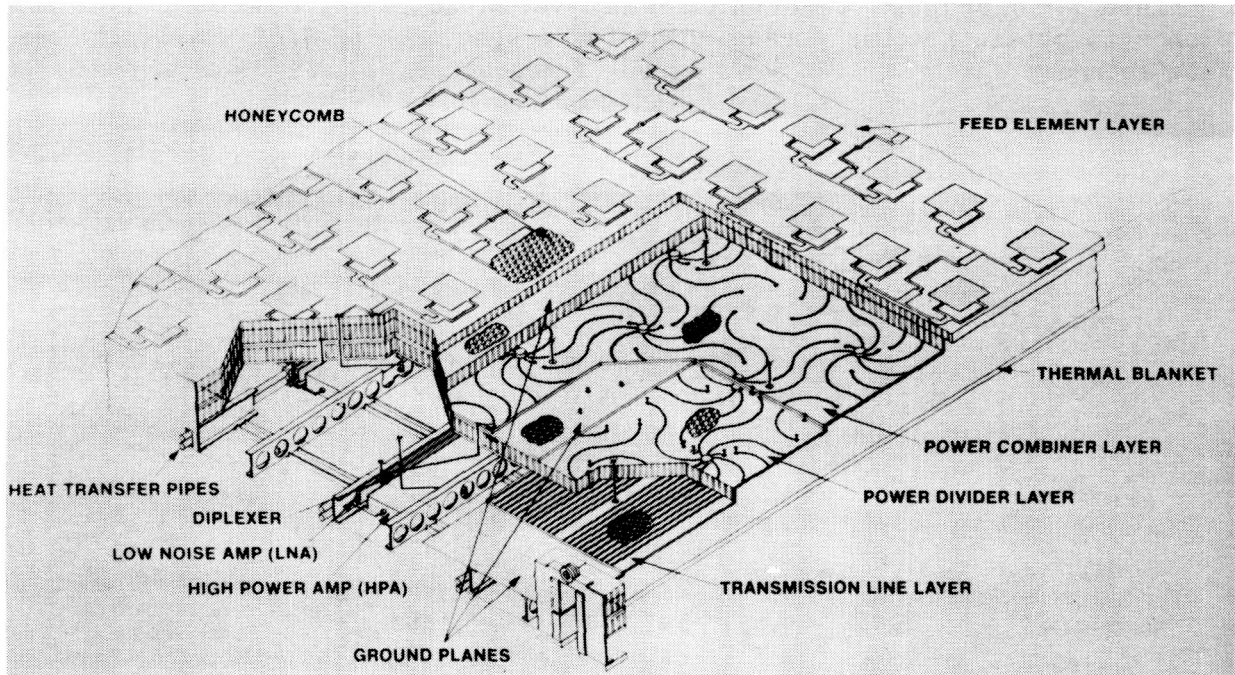
A candidate second-generation antenna system might include a 20-meter reflector and a multiple-beam feed array producing 24 beams for the US and Canada. This beam pattern allows the available band of frequencies to be reused about six times. A spacecraft with this type of antenna might weigh 2500 pounds on-orbit with a prime power capability of about 3.5 to 4.5 kW. The Hughes HS-376 spacecraft is shown for size comparison. Clearly the antenna system dominates the satellite and is the key technology to enable the second-generation satellite. In the RF area, the key aspect of the antenna development is the multiple-beam feed array and the beam-forming network (BFN) which distributes the signals to the feed array elements. The feed array and BFN must: be lightweight; transmit and receive simultaneously with a 5% frequency separation; provide multiple beams with sufficiently low sidelobes to enable frequency reuse; and maintain its performance through the thermal and dynamic distortions in the space environment. The challenges in the mechanical and structural areas of the antenna include the reflector, the booms and masts between the spacecraft bus and the reflector and feeds, and the feed array assembly itself. Each of these components must deploy properly, achieve reflector/feed alignment and surface accuracy, be lightweight yet be rigid during control system maneuvers, and maintain tolerances through thermal variations. The demand for low sidelobes to obtain frequency reuse dictates a precision of 1/60 wavelength rms surface accuracy which implies 6 mm at UHF frequencies.



PHASE 2 TECHNOLOGY DEVELOPMENT

MSS INTEGRATED PLANAR FEED ARRAY

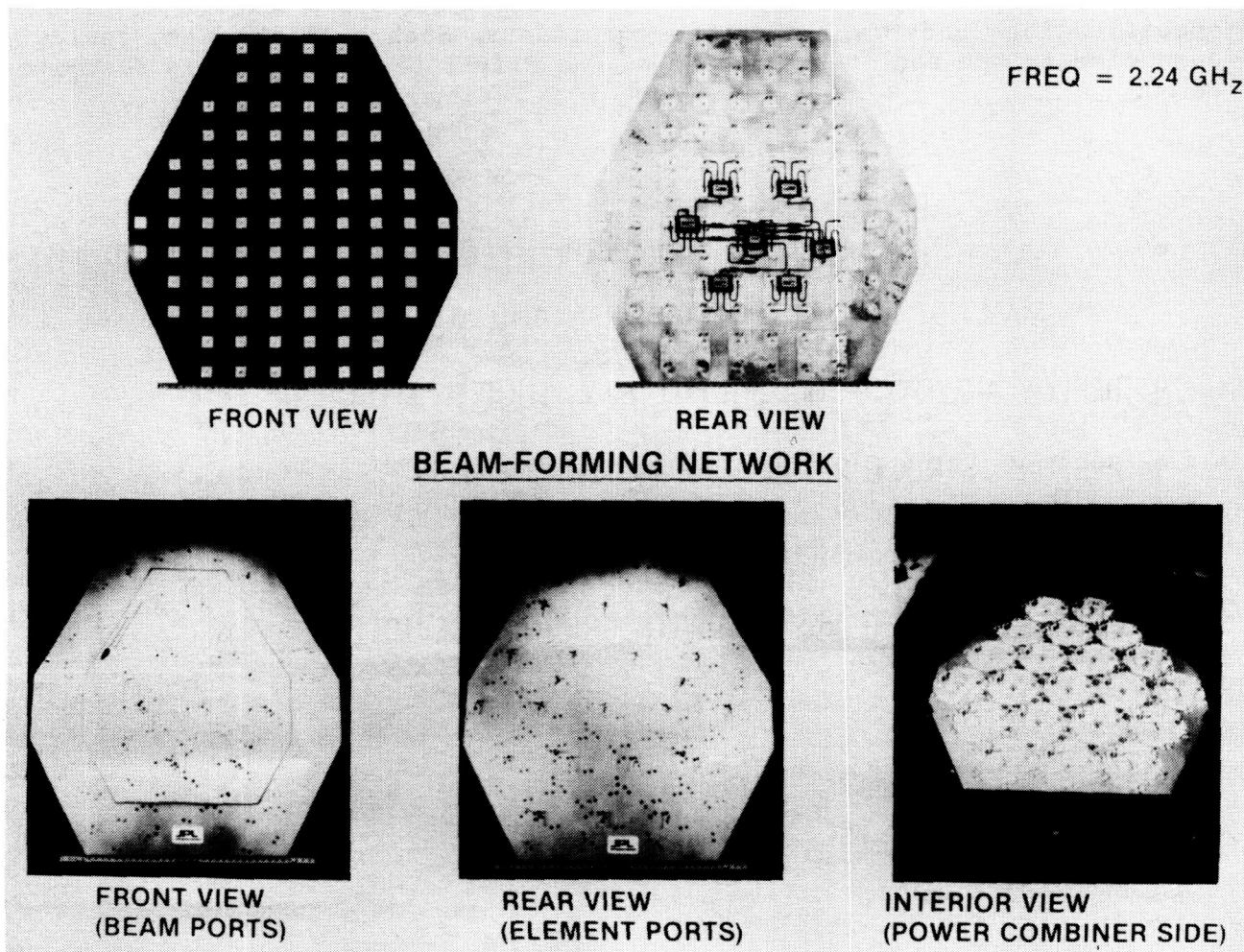
A key element in the antenna system is the multibeam feed array. The accompanying chart shows a cutaway drawing of the assembly. The top layer contains the microstrip feed elements. Four patches form a sub-element and seven sub-elements form a cluster which produces a single beam. The design uses over-lapping cluster feeds where adjacent beams may share 4 sub-elements. Using this concept, one can synthesize feeds with large, effective apertures, resulting in low sidelobes, yet solving the feed packing problem in the tight space available in the focal plane. The beam-forming network is formed from an intricate network of microstrip layers. The electronics, i.e., HPA's, LNA's, and diplexers, are also housed in the feed-array assembly as can be seen in the chart.



PHASE 2 TECHNOLOGY DEVELOPMENT

EIGHT-BEAM OVERLAPPING CLUSTER FEED

Currently, JPL is implementing an eight-beam breadboard based on the conceptual design on the previous page. The breadboard will consist of the microstrip feed array and the matching beam-forming network. The beam-forming network has been fabricated by Ford Aerospace. To reduce the physical size of the breadboard the feed was designed to operate at S-band. When completed and tested, this breadboard feed will be further tested with the 15-meter deployable reflector developed by NASA/Langley and the Harris Corporation.



PHASE 2 TECHNOLOGY DEVELOPMENT

ANTENNA FLIGHT TEST

Ground testing of an entire 20-meter, second-generation MSS antenna system to predict system performance on-orbit is possible but would be extremely difficult and expensive, and the results may be of dubious value. A flight test of the entire antenna system would greatly reduce the risk and uncertainty of launching such an antenna and would at the same time validate ground test procedures for future antenna systems. The NASA Shuttle is ideally suited for performing the majority of 0-g, dynamic, and thermal tests required to space qualify this antenna system. The broad objectives of this second-generation MSS antenna flight test are: demonstrate the reliable deployment of the antenna system structure; measure the aperture precision and feed alignment; measure the thermal and dynamic structural characteristics of the entire antenna system; and verify through RF measurements that the antenna meets all predicted performance specifications under all expected conditions. Such a flight test could be conducted by the end of the decade. One flight test scenario is described below.

- FLY FULL ANTENNA SYSTEM (REFLECTOR, FEEDS, BOOMS, ETC.) ON SHUTTLE
 - MAY NOT NEED FULL FEED ARRAY AND ALL BOOMS
- DEPLOY ANTENNA FROM SHUTTLE BAY (SHUTTLE ATTACHED)
- PERFORM STRUCTURAL AND RF MEASUREMENTS
- REFURL ANTENNA - RETURN WITH SHUTTLE
- CORRELATE FLIGHT RESULTS WITH GROUND PREDICTIONS

PHASE 2 TECHNOLOGY DEVELOPMENT

FLIGHT TEST ANTENNA SPECIFICATIONS

The flight test antenna, to be of value for the second-generation MSS, must have the minimal specifications listed below. L-band is included as a candidate growth frequency for MSS. Ideally the test feed should have at least two beams at both UHF and L-band, one boresight feed and one off-axis feed at each frequency.

- 20-m OFFSET-FED DEPLOYABLE ANTENNA

- $F/D = 1.0 - 1.5$

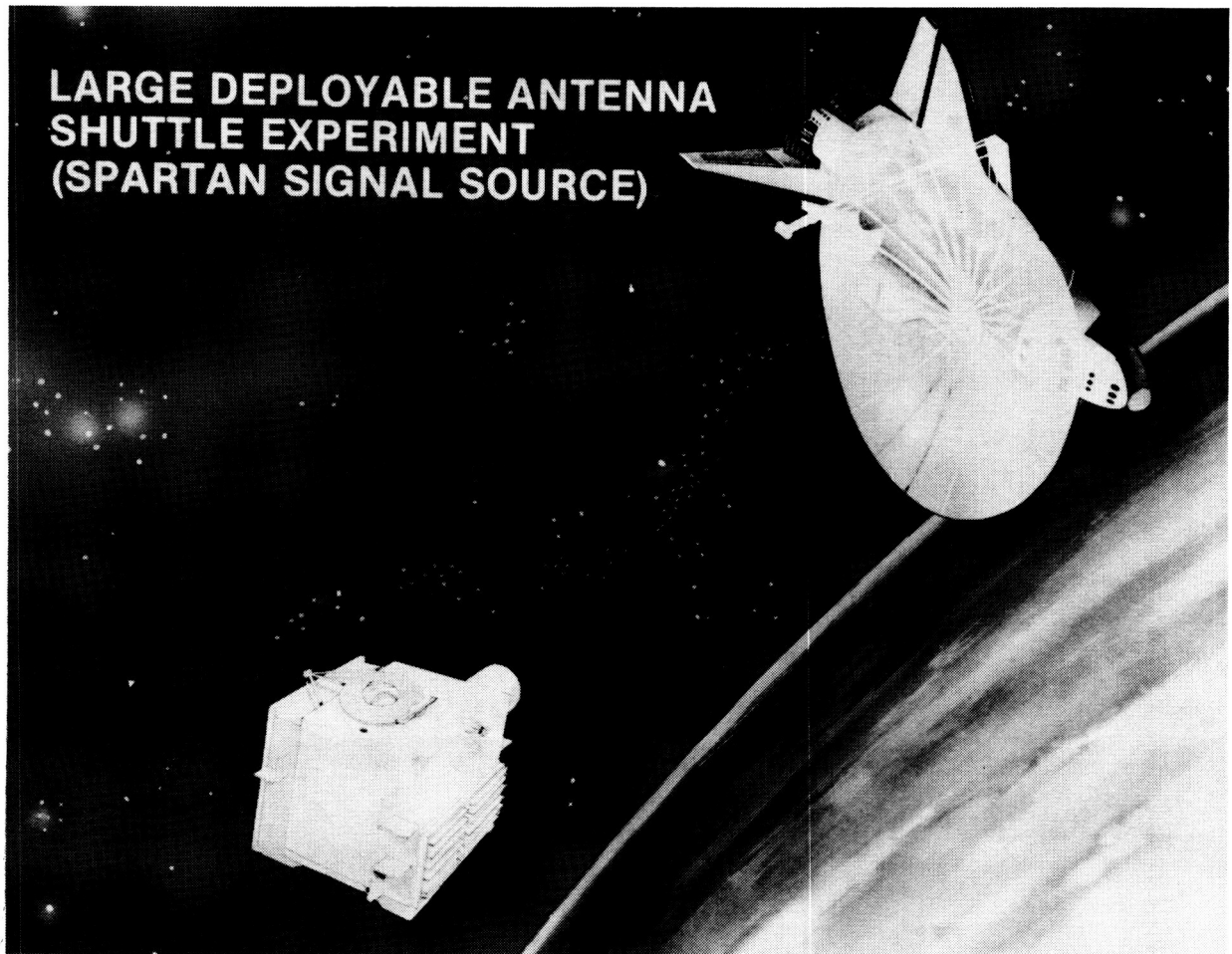
- RMS SURFACE ERROR
 - 3 mm FOR L-BAND
 - 6 mm FOR UHF

- BEAM ARRANGEMENTS
 - MULTIPLE BEAMS
 - AT LEAST 2 BEAMS

PHASE 2 TECHNOLOGY DEVELOPMENT

FLIGHT TEST WITH SPARTAN SPACECRAFT

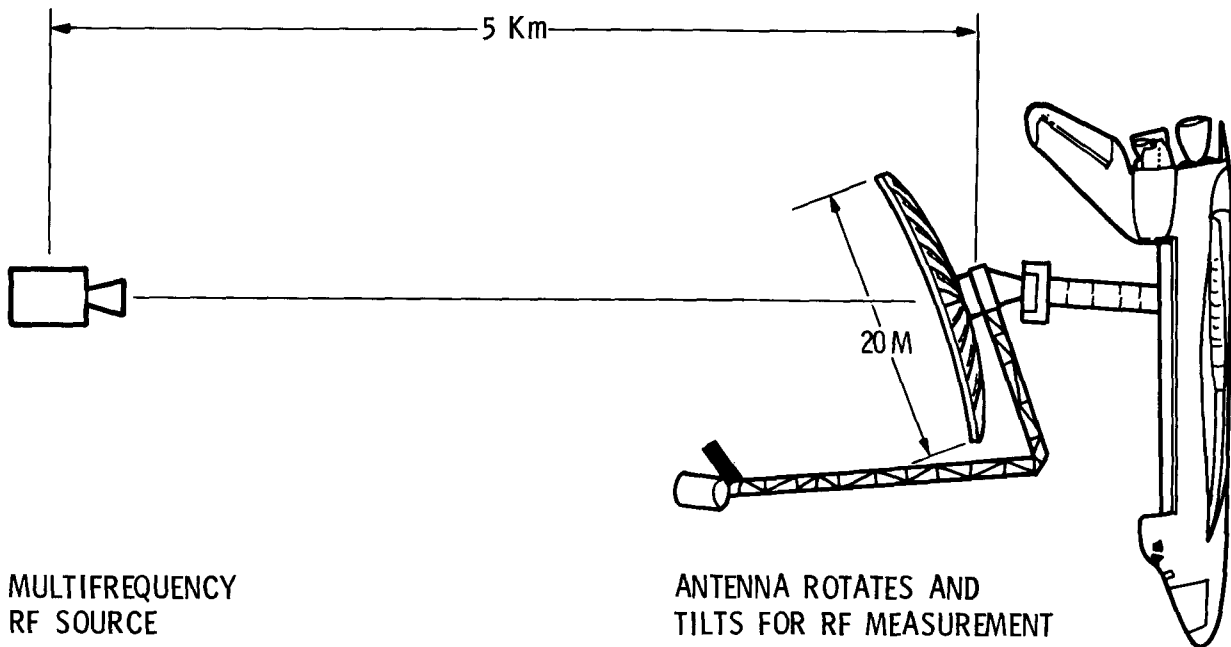
One possible configuration for the flight RF far-field performance tests is depicted below. The Spartan is a reusable and retrievable spacecraft under development at NASA Goddard. For the antenna flight tests the Spartan payload could include an RF beacon and be positioned at 5 km from the Shuttle. Following RF tests the Shuttle would retrieve the Spartan and return it and the refurled antenna.



PHASE 2 TECHNOLOGY DEVELOPMENT

RF FAR-FIELD MEASUREMENTS

The Spartan could be positioned at 5 km from the Shuttle for the far-field measurements at both UHF and L-band. The antenna would require articulation in azimuth and elevation about its attachment point, or some other movement mechanism, to obtain the beam patterns.



PHASE 2 TECHNOLOGY DEVELOPMENT

NASA/INDUSTRY JOINT ENDEAVOR ON FLIGHT TEST

The second-generation antenna is technology intended for use by the private sector. NASA's new space commercialization program was formed to assist industry develop this type of technology through cooperative development programs when such development is of benefit to both NASA and industry. A suggested split of responsibilities in this endeavor is as follows. Industry would be responsible for the design, development, and implementation of the flight test antenna. NASA would be responsible for: the design, development, and implementation of an on-orbit test facility including the possible use of the Spartan spacecraft; Shuttle integration and launch of the test article; on-orbit tests of the test antenna including all instrumentation and data reduction; and, as appropriate, other technology tests and experiments, including alternative feeds. If possible, the antenna will be refurled on-orbit and returned to the manufacturer.

- INDUSTRY (ANTENNA MANUFACTURER)
 - DESIGN, DEVELOP AND FABRICATE ANTENNA SYSTEM FLIGHT PROTOTYPE

- NASA
 - DESIGN, DEVELOP AND FABRICATE ON-ORBIT TEST FACILITY
 - LAUNCH ANTENNA ON SHUTTLE
 - PERFORM ON-ORBIT TESTS, REDUCE DATA AND TRANSFER TO INDUSTRY

SUMMARY

NASA, industry, the FCC, and Canada have increased their efforts to enable the commercialization of the mobile satellite service by the end of the decade. NASA has served as the focal point in the many areas of this development process. NASA has defined a three-phase program of development of ground and space segment technologies which will enhance and enable the second and third generation mobile satellite systems. NASA is prepared to enter into a joint endeavor with industry to acquire channel capacity on the first commercial system for the purpose of conducting advanced technology experiments and for the use of other government agencies. NASA is also prepared to enter into a joint endeavor with industry to build and flight test on the Shuttle a second generation MSS antenna system.