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Satellites Using the 30/20 GHz Band

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ABSTRACT

As we move forward in the decade, the need for added orbit capacity in bands other than C-band and Ku-band for communication satellite service has become apparent. Saturation of both these bands will occur in the next ten years, give or take a little, although debate continues as to exactly when. A review of the future options open to satellite system planners focuses attention on the use of the 30/20 GHz band. Very broad bandwidths available, coupled with a primary allocation for fixed satellite service, make the band very attractive. Exactly how the band should best be exploited will occupy planners for the next several years.

NASA, in concert with the system and service supplier industries, is planning a research and development program aimed at flight demonstration of 30/20 satellite systems which it is hoped will lead to operational system use in the early 1990's. This paper will discuss the communication system concepts and the spacecraft systems necessary to support these for operational use in 1990 and beyond.

INTRODUCTION

The recent evaluations of satellite communications demand for the coming decades indicate potential orbit capacity limits using C-band and Ku-band frequencies will be exceeded. Current filings before the FCC for C-band satellite positions exceed the available positions requiring the FCC to turn down requests for additional satellite systems necessary to meet the increasing demand. Increased interest in Ku-band positions have and will continue to present the FCC with the problem of dealing with requests for use of the same orbital positions by more than one potential carrier. Although there is still significant orbit capacity yet unused and unspoken for at Ku-band, it is not too early to plan for the time when the capacity limit of the band is reached. The course of action to be pursued in order to allow continued growth in satellite communications services after saturation of both C-band and Ku-band has occurred must be defined now.

Two approaches are possible - one would stress implementation of techniques and technologies that would increase the useful capacities of both the C- and Ku-bands, the second would focus on opening new frequency bands for commercial use. A proper plan, of course, would pursue a combination of the two approaches. This paper will focus attention on the next higher frequency band allocated for fixed satellite service at 30/20 GHz (Ka-band). The techniques and technologies to be developed are applicable at the lower frequency bands. Although this band has significant potential with a basic bandwidth allocated of 2.5 GHz, it does have a severe rain attenuation problem that must be accommodated before competitive service offerings can be made. If technology advances can be made to mitigate the rain fade problem, satellite systems having total capacities ten to twenty times greater than current systems are possible. This paper will discuss some of the factors that will influence the use of the 30/20 GHz band as well as the possible satellite configurations which promise to provide competitive service for both trunking applications as well as customer premise service applications.

BACKGROUND

NASA, as a result of both in-house and contracted studies, attempted to evaluate the expected demand for communication services over the next two decades. From these forecasts an attempt has been made to estimate the expected demand for satellite service as a subset of the total demand. Further estimates have been made as to the likely point at which saturation occurs for both C-band and Ku-band frequencies. The results of these forecasts are shown in figure 1. Total communications demand is shown in terms of equivalent 36 MHz transponders as a function of time. The majority of data used in this figure was generated in two contracted studies by Western Union and U. S. Telephone & Telegraph. The total demand is as indicated and shows a fourfold increase by the year 2000. Satellite traffic forecasts indicate a tenfold increase during the same time period. Two estimates of C-band plus Ku-band saturation limit are indicated for pre-1979 WARC allocations and post WARC. Although there is some difficulty in establishing a specific date when saturation will occur, it is no longer a matter of if it will occur, but a matter of exactly when. Regardless of the exact date, it is necessary now to plan for future expansion of services to the next higher frequency band, 30/20 GHz.

Moving to the 30/20 GHz band brings with it the necessity to effectively deal with the increased rain attenuation problem associated with the band. To illustrate the relative attenuation with Ku- and Ka-band, the expected outages due to rain at four locations within the U. S. are presented in figure 2. The effect of both 3 dB and 10 dB clear weather margins on the expected hours of yearly outages due to rain are shown. For a region such as Washington, D. C. where thunderstorms are prevalent, 17 hours of outage could be expected at 30 GHz even with 10 dB of margin compared to one hour at 12 GHz. Special consideration must be given in the design of 30/20 GHz satellite systems to compensate for rain outage. Power margin is useful in addressing the problem but power alone will not be sufficient.

To further illustrate the comparison of Ku- and Ka-band, the effect of spacecraft antenna gain on both transponder power and ground transmitter power is shown in figure 3. For a 99.5% link availability, comparing CONUS coverage type antennas for both frequencies requires 8 to 10 times as much power at Ka-band than at Ku-band. Comparable powers occur when the Ka-band system approaches coverages afforded by 0.3 degree spot beams. The need to use spot beams for Ka-band systems on the one hand increase the complexity of the satellite system while on the other hand facilitate increasing the total capacity of the satellite system through frequency reuse schemes for modest increases in satellite size. The discussion of satellite system configurations that attempt to reach a compromise in complexity and capacity to yield a cost competitive service offering is presented in the remainder of the paper.

SYSTEM CONFIGURATIONS

In order to evaluate potential satellite system configurations capable of providing cost competitive services, the service categories must be defined. For the purposes of this comparison two general types of area coverages will be considered. The first type provides trunking service to a limited number of locations within CONUS and is characterized by spot beam coverage of the served area. A sketch of a trunking system coverage is shown in figure 4. It is clear on the basis of geographical isolation between the spot beams used for the trunking service coverage that the same frequency could be assigned to each spot. This would permit levels of frequency reuse approaching the number of isolated spots used. The second type provides service in all areas of CONUS and allows interconnects without terrestrial tails to specific customers based on their individual needs. A sketch of the coverage of this customer premise system is shown in figure 5. Here spot beams are used to provide coverage throughout CONUS on a time-sharing basis. Techniques of beam hopping or beam scanning are contemplated. Since some form of contiguous spot beam coverage is contemplated, the degree of frequency reuse for this service will depend on the implementation scheme used. Adjacent beams cannot be at the same frequency, but the frequency might be reused in beam 1 to 3 beamwidths away with satisfactory isolation. This would allow, depending on spot size, frequency reuse rates of up to twenty times for spot sizes of 0.3 degrees.

Two basic multiple access schemes can and will be used with the multibeam system; Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA). Combinations of the two methods or hybrid access schemes are also possible. As we move into the late 1980's, the trend will be toward all digital system implementation. The use of spot beam coverage at Ka-band is considered mandatory to help compensate for the expected rain fades at these frequencies. The high gain multibeam antenna system becomes an integral part of any satellite system under consideration.

At 20 GHz a 14 foot diameter precision antenna will generate a 0.3 degree spot beam having a nominal earth coverage spot diameter of 120 miles. A sketch of a Cassegrain type antenna system for a scanning beam antenna is shown in figure 6. In this configuration two subreflectors are used coupled with frequency and polarization diplexers to allow room for transmit and receive scanning feed arrays as well as clusters of horns used in conjunction with fixed spot beams for trunking. Analysis of antenna system weights indicate that for 12 to 14 foot antennas total system weights of 400 to 500 pounds are expected. The majority of the weight is a result of the complex feed structures required to produce multiple spot beams with good sidelobe suppression characteristics. The size and weight of the antenna systems directly effect the minimum satellite system size of interest.

As a consequence of using a high gain (small coverage area) spot beam antenna system, interconnectivity between beams for point-to-point service increases the complexity of these systems compared to single beam CONUS coverage systems. Interconnectivity can be accomplished with ground-based switching and signal routing or with switching onboard the satellite itself. For the case of customer premise type service where small low cost terminals are necessary to maintain cost competitive service offerings, switching on the satellite appears to be the lowest cost alternative. Two techniques could be employed - one where simple switching is accomplished at an intermediate frequency (IF switching) without any signal processing to improve signal quality, and second where the signals are reduced to baseband and techniques of "Forward Error Correction" are used to improve the signal in the presence of rain fades either on the uplink or the downlink. A block diagram of a satellite transponder with both IF switching for trunking service and a baseband processor for Customer Premise Service (CPS) is shown in figure 7. In the illustration shown, an interconnect exists between the trunking and CPS systems. A detailed schematic of the baseband processor and its functions is shown in figure 8.

The satellite based communication system so far has a complex satellite and both large and small ground terminals. In addition a master control station is needed to permit efficient coordination and operation of the satellite and ground system network. The major functions of the Master Control Station are shown in figure 9. Each of the ground stations in the network has several processing functions as shown in figure 10. An artists rendition of a Master Control Station with a 12 meter antenna system is shown in figure 11. Two general spacecraft configurations are possible, one based on a spinner spacecraft bus with a despun communications platform (see figure 12). The large 4 meter antenna is shown with the complex feed system mounted on the base of the despun platform. This configuration results in a compact launch configuration with the antenna reflector folded down on the communications platform. Another configuration using a three axis stablized platform is shown in figure 13. A two antenna reflector system is illustrated to allow higher capacities and a flexible feed arrangement to provide CONUS coverage. Typical small ground terminal systems are shown in figures 14, 15 and 16 covering a range of applications from emergency services to permanent customer premises services with antenna sizes from 1 to 3 meters in diameter. An artists sketch of a 12 meter trunking terminal is shown in figure 17. For areas of the country where significant heavy rains occur, a diversity site located up to 10 km away would be coupled to this main site to allow use of either antenna system depending on the intensity of rain at each site. A similar ground terminal would be located at the Master Control Station site.

CONCLUSIONS

System communication circuit capacities of 10 to 20 times that of current satellite systems are possible at Ka as a result of the broad bandwidth of 2.5 GHz allocated at these frequencies coupled with frequency reuse made possible because of the multiple spot beam antennas. The high frequency and therefore small system component of this band does permit high capacity satellite systems to be developed within the capacity of current launch vehicle systems. For conventional satellite systems in the 1 to 2 kilogram weight class, system capacities of 3 to 10 gigabits per second are possible.

The key technologies to be demonstrated before the band can be used commercially include multibeam antennas and onboard switching and signal processing.

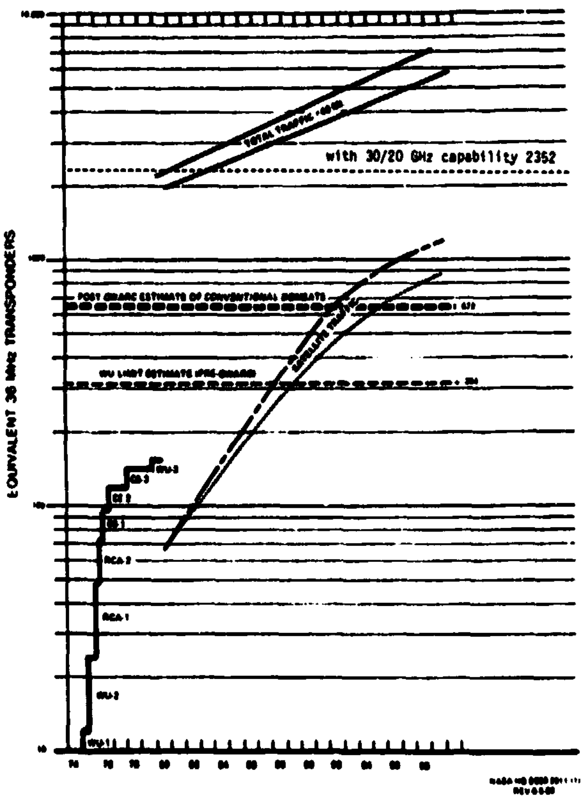

Figure 1. - U. S. Domsat communications traffic forecasts.

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LOCATION	FREQUENCY	3 dB MARGIN	10 dB MARGIN
AUSTIN, TEXAS	12 GHz	9 h	2 h
	20	23	6
	30	51	12
BLACKSBURG, VIRGINIA	12	18	1
	20	88	4
	30	175	8
HOLMDEL, NEW JERSEY	12	17	2
	20	40	5
	30	83	7
WASHINGTON, D.C.	12	5	1
	20	53	9
	30	106	17

*FROM SATELLITE BEACON MEASUREMENTS, ELEVATION ANGLES 30-50 DEGREES

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Figure 2. - Hours per year of expected outage on a satellite link due to rain*.

FREQ. BAND	COVERAGE	APPROX. ANT. GAIN	NET GAIN DELTA	TRANSPONDER POWER, WATTS	E/X HPA POWER, KW
14/12	CONUS	32	0	23	0.60
30/20	CONUS	32	0	209	4.80
30/20	1.5°	40	+5.0(1)	66	1.5
30/20	0.3°	53	+16.5(2)	4.7	0.11

99.5% AVAILABILITY, 10^{-4} BER

(1) INCLUDES 3 dB LOSS FOR BEAM EDGE

(2) INCLUDES 3 dB LOSS FOR BEAM EDGE AND 1.5 dB FOR OFF-AXIS SCAN

Figure 3. - Comparison of Ku CONUS system with various Ka systems (5 meter E/S, 43 MBPS burst channel).

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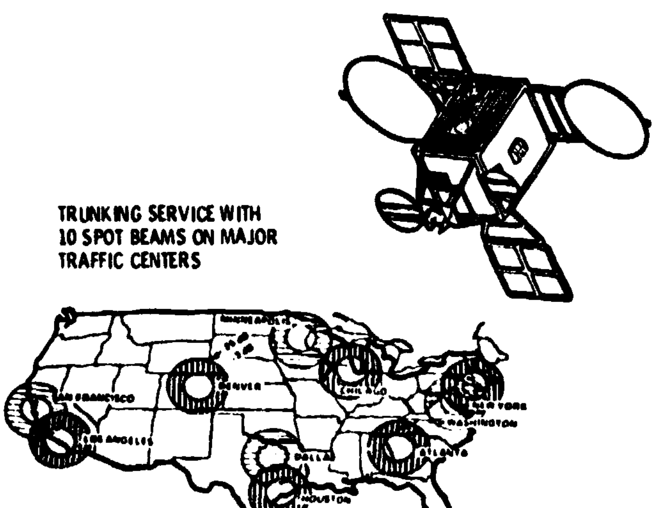

Figure 4. - NASA 30/20 GHz Wideband program operational system.

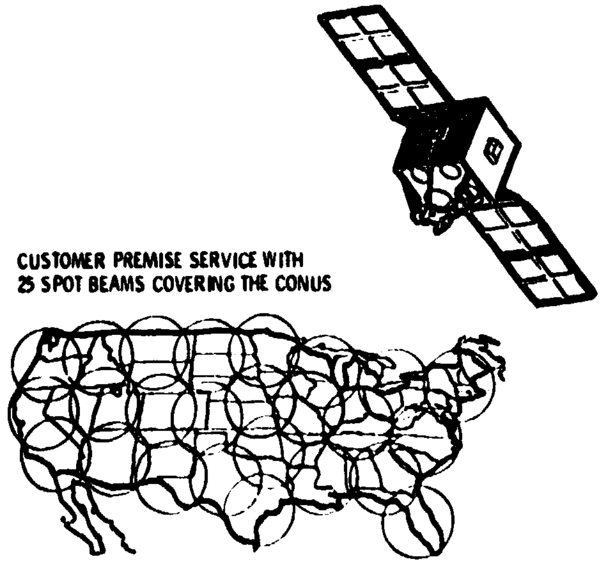

Figure 5. - NASA 30/20 GHz Wideband program operational system.

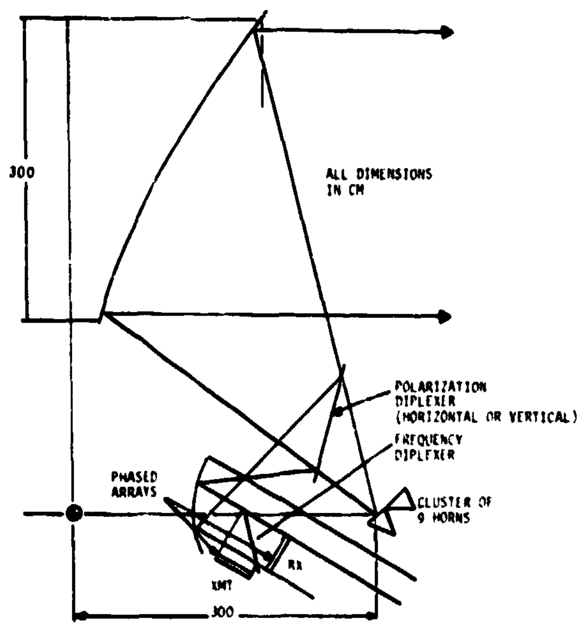

Figure 6. - Combined fixed- and scanned-beam reflector assembly.

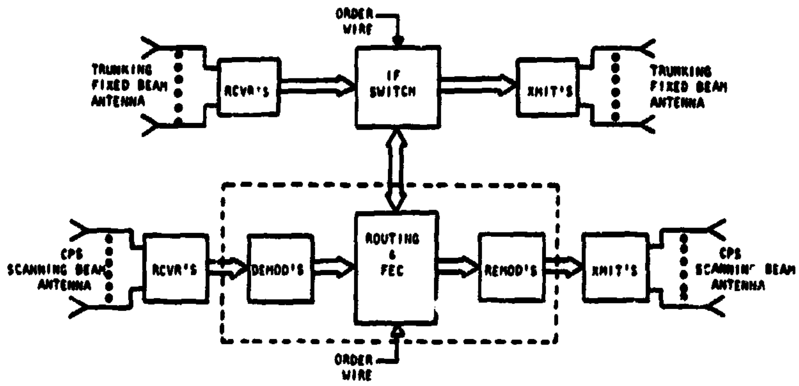

Figure 7. - Satellite transponder with baseband processor. CS-80-3740

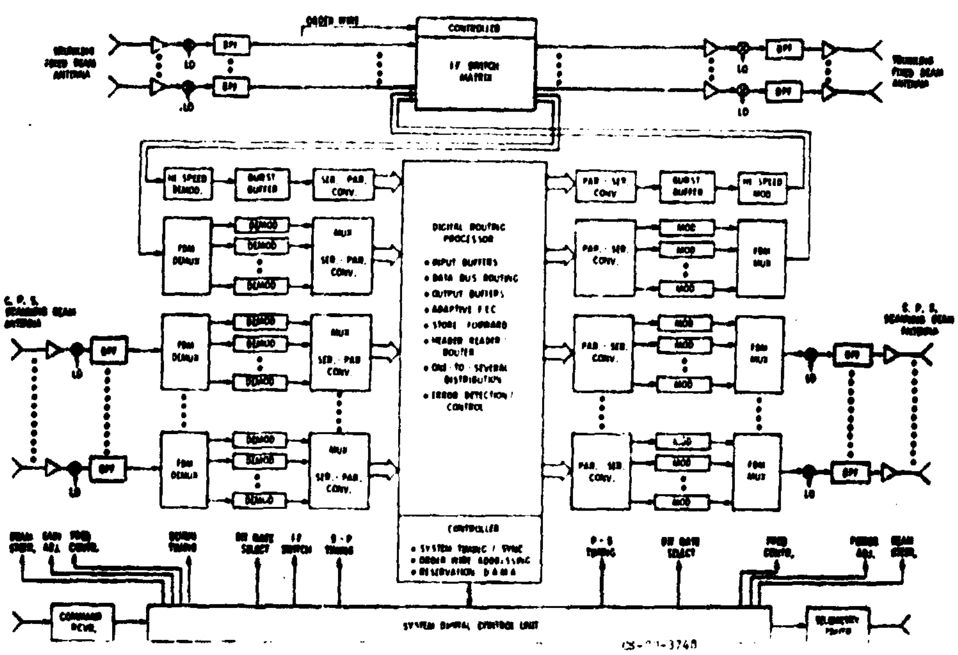

Figure 8. - Baseband processor - generalized concept for Hybrid FDAM/TDM uplink - TDM downlink; scanning beam antenna.

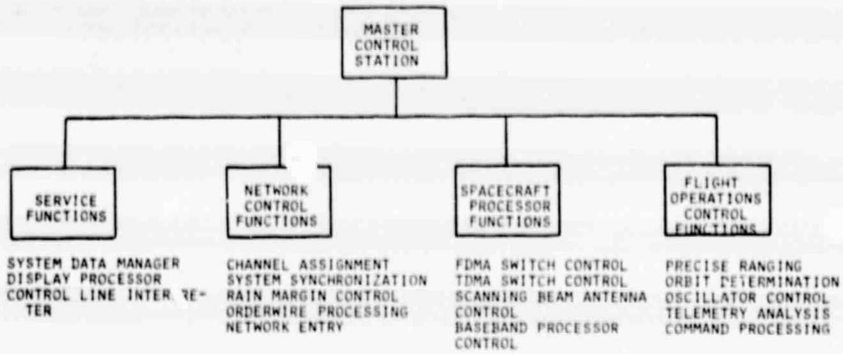

Figure 9.

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DEMAND ASSIGNMENT

- FORMAT AND TRANSMIT REQUEST DESTINATION AND VOLUME TO MASTER CONTROL STATION
- TRANSMIT AND RECEIVE TIME DELAY TO BURST CONTROLLERS
- UPDATE TRANSMIT AND RECEIVE TIME ESTIMATES

SIGNAL CONTROL

- TRANSMIT SIGNAL QUALITY DATA TO MASTER CONTROL STATION
- RELAY SWITCH STATE COMMANDS TO ENCODERS/DECODERS AND POWER CONTROL UNIT

STATION STATUS

- FORMAT AND TRANSMIT STATION STATUS DATA TO MASTER CONTROL STATION

Figure 10. - Ground station processing functions. CS-80-3739

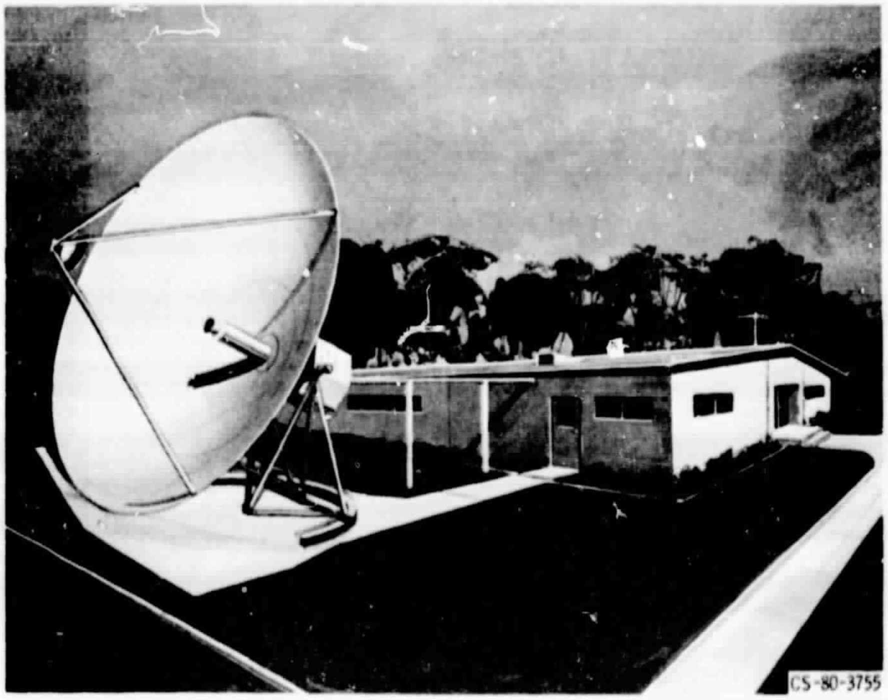

Figure 11.

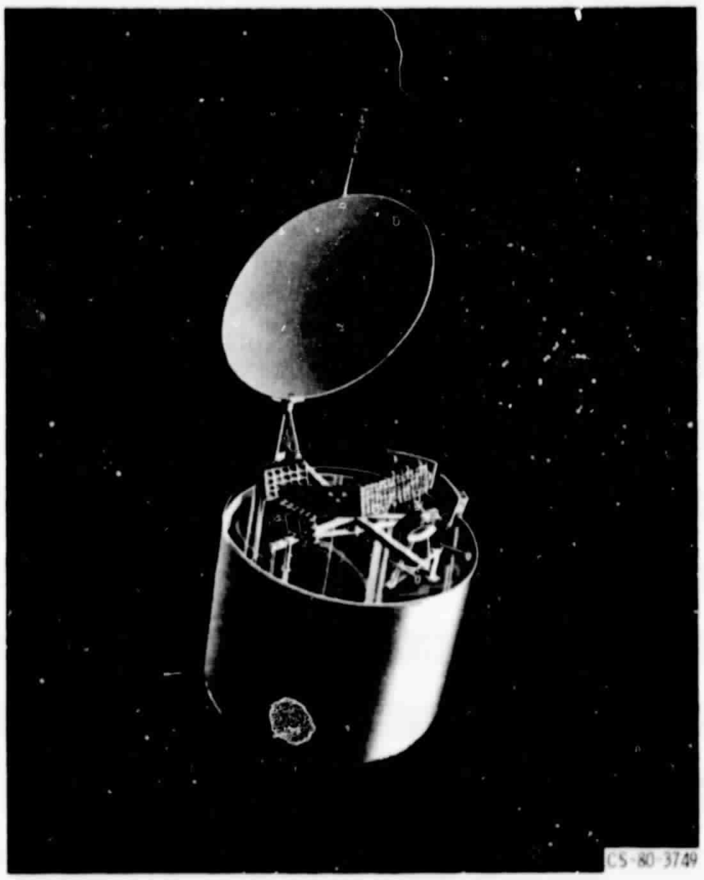

Figure 12.

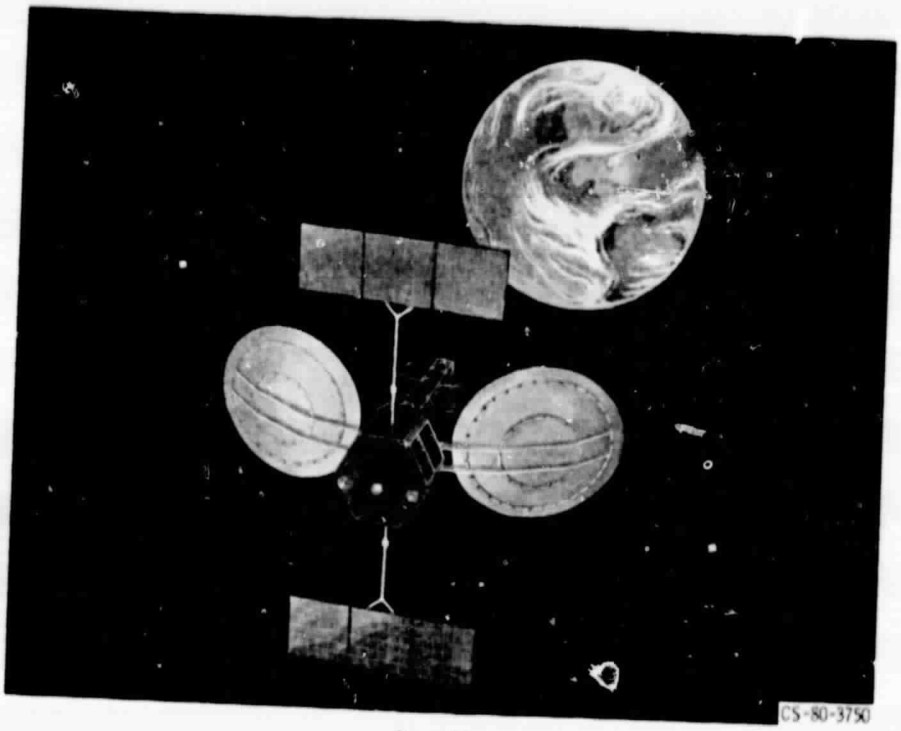

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Figure 13.

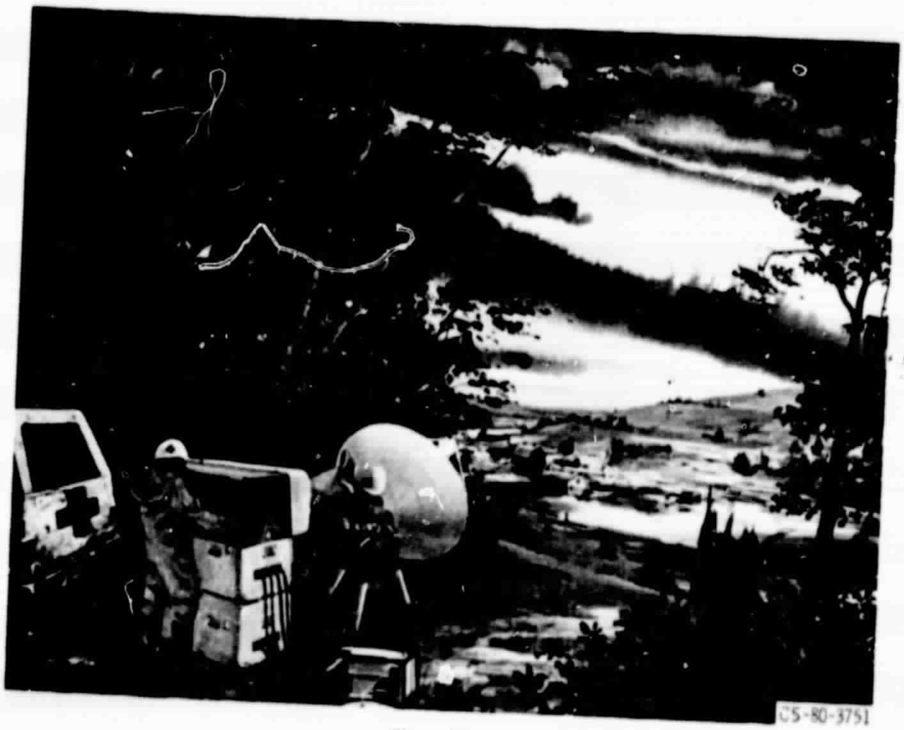

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Figure 14.

Figure 15.

Figure 16.

Figure 17.