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Ka-Band (32-GHz) Downlink Capability for Deep Space Communications

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The first quarter century of U.S. solar system exploration using unmanned spacecraft has involved progressively higher operating frequencies for deep space telemetry: L-band (960 MHz) in 1962 to S-band (2.3 GHz) in 1964 to X-band (8.4 GHz) in 1977. The next logical frequency band to develop for deep space is Ka-band (32 GHz) for which a primary deep space allocation of 500 MHz between 31.8 GHz and 32.3 GHz was established in 1979. The telecommunications capability was improved by a factor of 77 (18.9 dB) through the frequency changes from L-band to X-band. Another improvement factor of 14.5 (11.6 dB) can be achieved by going to Ka-band.

Plans to develop and demonstrate Ka-band capability include the continued measurement of weather effects at DSN sites, development of a prototype DSN ground antenna and supporting subsystems, augmentation of planned spacecraft with Ka-band beacons, and development of spacecraft prototype modules for future Ka-band transmitters. Plans for augmenting the DSN with Ka-band capability by 1995 have also been developed.

A companion set of articles in this issue describes the Ka-band performance and technology in greater detail.

I. Introduction

The exploration of the solar system with spacecraft has expanded beyond the narrow confines of Earth from the early Pioneers and Mariners to the presently on-going odysseys of the Voyagers and later Pioneers well beyond two billion miles from Earth. With the exception of the Mariner '71, Mars Orbiter, Viking, and Pioneer Venus, these missions were flybys intended primarily for early reconnaissance. Missions planned for the near future include largely orbiters: Galileo in orbit around Jupiter; Mars Observer around Mars; and Magellan around Venus. Subsequent missions will be of increasing complexity: rendezvous, landing, roving, and return.

Spacecraft for these missions face stringent constraints: continued high performance on more complex missions with only a modest increase of mission investment. Fortunately, new spacecraft and ground capabilities continue to help ease these constraints. Within the domain of deep space communications, there has been a millionfold increase, for example, in the telemetry capability.

Figure 1 shows a profile of the DSN's capability to support the reception of increasingly greater data rates from increasingly greater distances. The abscissa shows the calendar years during which particular increases in capability first appeared. The ordinate shows the data rate that could have been supported in that year by the Deep Space Network (DSN) if the data had been sent from spacecraft at Mars or Neptune. The actual data rates that could have been supported by the DSN from a spacecraft at any particular distance scales inversely as the square of the relative distances.

Major jumps in the staircase function of Fig. 1 occurred as the frequency of operation increased from L-band (0.96 GHz) to S-band (2.3 GHz) to X-band (8.4 GHz). This occurs primarily because the capacity of a link established between two well-aimed high-gain antennas scales, to a first order, as the square of the operating frequency. Thus, moving from 0.96 GHz to 2.3 GHz offered a possible increase of 574% (or 7.6 dB), and from 2.3 GHz to 4 GHz another factor of 13.5 or 11.3 dB. Actual gains are reduced by propagating media effects and the limiting tolerances of the various components in the link, but may be increased by the reconfigurations possible at higher frequencies.

Command frequencies for uplink communication are also increased as telemetry frequencies increase, although usually later. This tendency to follow is because lower frequency uplinks multiplied up to the telemetry frequency in the spacecraft transponder introduce unwanted jitter in the downlink. The deep space telemetry frequency was shifted to X-band in 1977, but the command frequency is only now shifting to X-band. Figure 2 shows the trend to higher frequencies, including a projected increase to Ka-band (32 GHz for telemetry and 34 GHz for command).

The frequencies used for deep space communication tend to be those for which protection against interference exists. Figure 3 shows the present allocations available on a primary (protected) basis (Ref. 1). The next major frequency increase available for deep space is the move from X-band to Ka-band (32 GHz). The potential increase in link capability is 11.6 dB, although the actual increase is expected to be slightly less than that because of atmospheric effects and the performance of the antennas of the DSN that were designed for good performance at the lower X-band frequency. The use of quasi-optical techniques, and reduced spacecraft antenna diffraction losses, can offset these losses.

Figures 4 and 5 show in two ways why Ka-band was selected—it is basically the last good location in the microwave "window" (Fig. 4) and offers, at least in clear, dry weather, an increase of 10 dB (Fig. 5). As the series of companion articles following shows, the strong potential exists for 8 dB to 10 dB improvement even with the limitations imposed by weather (Refs. 2, 3, 4, 5). The benefits of this potential to specific planned missions are also under study (Ref. 6).

The impact of only a 6 dB increase is reflected in Fig. 6. This shows, first, that a very large array of X-band antennas has the same reception capability (G/T) as one 70-meter antenna at Ka-band and, second, that a 70-meter X-band antenna has the same reception capability as one 34-meter antenna at Ka-band.

II. Historical Perspective

The consideration of Ka-band for deep space communication began more than a decade ago, in a variety of advanced mission planning studies. One of the first formal treatments occurred in Hunter's 1976 study "Orbiting Deep Space Relay Station" (Ref. 7). One of the outcomes of the 1979 World Administrative Radio Conference was the primary allocation for deep space communication only, in the three countries of interest, U.S.A., Australia, and Spain, with 31.8 to 32.3 GHz for space-to-ground and 34.2 to 34.7 GHz for ground-to-space (Ref. 1).

The argument for a ground-based Ka-band receiving station was strengthened by the realization in 1981 through measurement of the weather effects at 32 GHz (Ref. 8) that Ka-band reception was not as badly degraded by weather effects as previously anticipated.[1] Further, studies showed that DSN antennas could be upgraded to perform well at Ka-band.

The selection of Ka-band as the next choice to develop for deep space telemetry was not easy or simple. The belief still existed on the one hand that the combination of weather and DSN antenna limitations precluded meaningful increases in telemetry capability at higher frequencies, and that deep space communications should therefore remain indefinitely at X-band. On the other hand, it was argued that the shift to Ka-band would be too modest, and that a shift to an optical band for deep space communication would be more appropriate. The difficulty of resolving this issue with all involved elements at JPL and at NASA Headquarters delayed for a few years funding for the technology development necessary to enable Ka-band communications. References 9 and 10 show some of

[1] Letter from W. H. Bayley, Jet Propulsion Laboratory, Pasadena, California, to H. G. Kimball, NASA Headquarters, Code TN, "Applicability of the 32 GHz Frequency Region to Deep Space Communications," July 9, 1979 (internal document).

the trade-offs produced that finally enabled the decision to be resolved.

Thus, Ka-band has been accepted as the next logical frequency to develop capability for deep space communication, with optical as a reasonable follow-on. This decision became involved with a proposal for a new R&D antenna for the DSN (Ref. 11), a proposal for a Ka-band spacecraft beacon experiment (Ref. 12), and proposals for development of Ka-band components for future missions. Specifically, JPL concluded the following:

(1) Ka-band for deep space missions appears to be cost effective and to have an extended useful operational lifetime regardless of exactly when it is introduced.

(2) JPL should continue with serious Ka-band studies, making decisions as appropriate, but specifically should work toward including a Ka-band beacon on Mars Observer.

(3) A new R&D antenna should be included in the FY88 Construction of Facilities budget. (There is major potential synergism with Ka-band activities; the rationale and need for an R&D antenna at Goldstone are independent of the Ka-band decision.)

(4) A full-up operational optical communication system for the deep space network is not realistic before 2010.

(5) JPL should continue an appropriate level of activity, including monitoring the development of optical communications technology, doing deep space related specialized optical communication technology development, and considering the system implications of the use of optical communication for deep space missions.[2]

Subsequently, a Notice of Intent was signed, confirming agreement of both JPL and NASA Headquarters (Office of Aeronautics and Space Technology, Office of Space Tracking and Data Systems, and Office of Space Science and Applications) to proceed with the key ingredients to develop the Ka-band technology for subsequent deep space communications.

III. Current Efforts

The beginning of the conversion of deep space communication to Ka-band will not occur until the Ka-band technology has been developed and demonstrated to provide the benefits anticipated and modeled. Several steps are involved:

(1) Continued measurement of weather effects at Ka-band at all three DSN complexes (U.S., Australia, and Spain), with water vapor radiometers to refine the weather model essential to projections of deep space link performance.

(2) Development of a DSN R&D ground antenna to verify the benefits of various approaches to be used to upgrade the existing 34-meter and 64/70-meter antennas to good efficiency at Ka-band. This is planned to be in operation by 1990.

(3) Development of a prototype low-noise Ka-band traveling wave maser of suitable gain-bandwidth product to ensure low system noise temperature performance at this higher frequency. Also, development of pointing capability consistent with Ka-band.

(4) Augmentation of planned deep space spacecraft with Ka-band beacons to enable simultaneous X-band and Ka-band reception in order to obtain accurate relative performance measurements. Use of X-band fourth harmonics is expected to permit the addition of experimental beacons at modest cost.

(5) Development of spacecraft modules to provide 2 to 50 Watts of Ka-band transmitted power at acceptable DC-to-RF efficiency. Also, provision for vernier pointing of the spacecraft beam over a few beamwidths. Figure 7 shows a possible progression of modules to be developed: the NASA X-band transponder (NXT) now under development by Cubic Corporation, X-band solid state power amplifiers (XSSPA) under development at JPL, a Ka-band exciter (KEX) to upconvert the X-band frequency of the NXT, a dual frequency X-band/Ka-band feed arrangement (XKFA) shown in the figure as a dichroic plate with separate feeds, and a phased array of Ka-band elements.

IV. A Plan for Operational Use by 1995

Once Ka-band has been demonstrated in the field through experiments with spacecraft and the DSN R&D station, conversion of new spacecraft and augmentation of the DSN to accommodate the new frequency will begin. Flight projects will rely on the developed prototypes and flight components to produce flight qualified elements for subsequent flights.

The augmentation of Ka-band to the DSN requires three distinct steps: modification of the 70-meter antennas, and the 34-meter high efficiency antennas (HEFs), and replacement of the 34-meter standard (STD) antennas. There is no plan to convert the 26-meter subnet. These steps will all be simplified if the DSN antennas are converted to beam waveguide operation as presently envisioned (Ref. 13, 14, 15).

[2] R. J. Parks, unpublished communication, April 16, 1986.

The 70-meter antennas after upgrade from 64 meters are expected to be usable at Ka-band with about 35% efficiency. This is based on data relative to current performance at 22 GHz and specifications established for the upgrade. Increased efficiency is expected to be possible through array feeds.

The 34-meter high efficiency (HEF) antennas are already expected to be 50% efficient at Ka-band according to calculations based on surface tolerances. Conversion to a beam waveguide configuration would again simplify addition of Ka-band telemetry capability because of added space for electronics.

A possible schedule for augmentation of the deep space communication channel to include Ka-band is shown in Fig. 8. This shows conversion of DSS 14 by the end of 1994 to be used for Cassini (Saturn Orbiter/Titan Probe) at encounter in 2001. The upgrade of the rest of the DSN would occur during the long Cassini cruise. Actual conversion would depend on other deep space missions of that era not yet well defined (e.g., Mars Sample Rover).

V. Conclusion

The augmentation of the deep space telemetry channel with Ka-band can be thought of as having started in 1979 when the deep space allocations were obtained. It will probably be completed in the mid-90s as all three DSN subnets are converted to provide a Ka-band capability and the deep space spacecraft all utilize Ka-band as their primary telemetry frequency in order to keep down mission costs or enhance mission performance.

The following articles on Ka-band provide details on the steps taken so far to provide deep space missions with the advantages of a Ka-band telemetry capability. They are not always consistent one with another, generally because they represent different stages of an evolving understanding of Ka-band and how it will eventually be implemented for deep space communication.

These articles are grouped into three categories: general, performance, and future activities. Within the general category, de Groot defines the Ka-band allocation (Ref. 1); Hansen and Kliore identify the benefits to specific deep space missions (Ref. 6); and Layland and Smith map out a possible scenario for evolving not only to Ka-band, but beyond to optical frequencies (Ref. 10). Next are articles on Ka-band performance of 70-meter antennas by Bhanji, et al. (Ref. 3); and weather effects at Ka-band by Slobin (Ref. 5). Future activities include a Ka-band beacon experiment by Riley (Ref. 12); measurements of Galileo harmonics for another Ka-band beacon experiment by Stanton and Manshadi (Ref. 16); a planned new DSN research and development antenna to receive the Ka-band beacon signals by Smith (Ref. 11); a plan by Riley to develop Ka-band spacecraft systems (Ref. 4); the benefits of beam waveguides in the DSN and their benefits to Ka-band operation of the DSN, by Clauss and Smith (Ref. 15); and some beam waveguide structural design considerations by Katow, et al. (Ref. 16).

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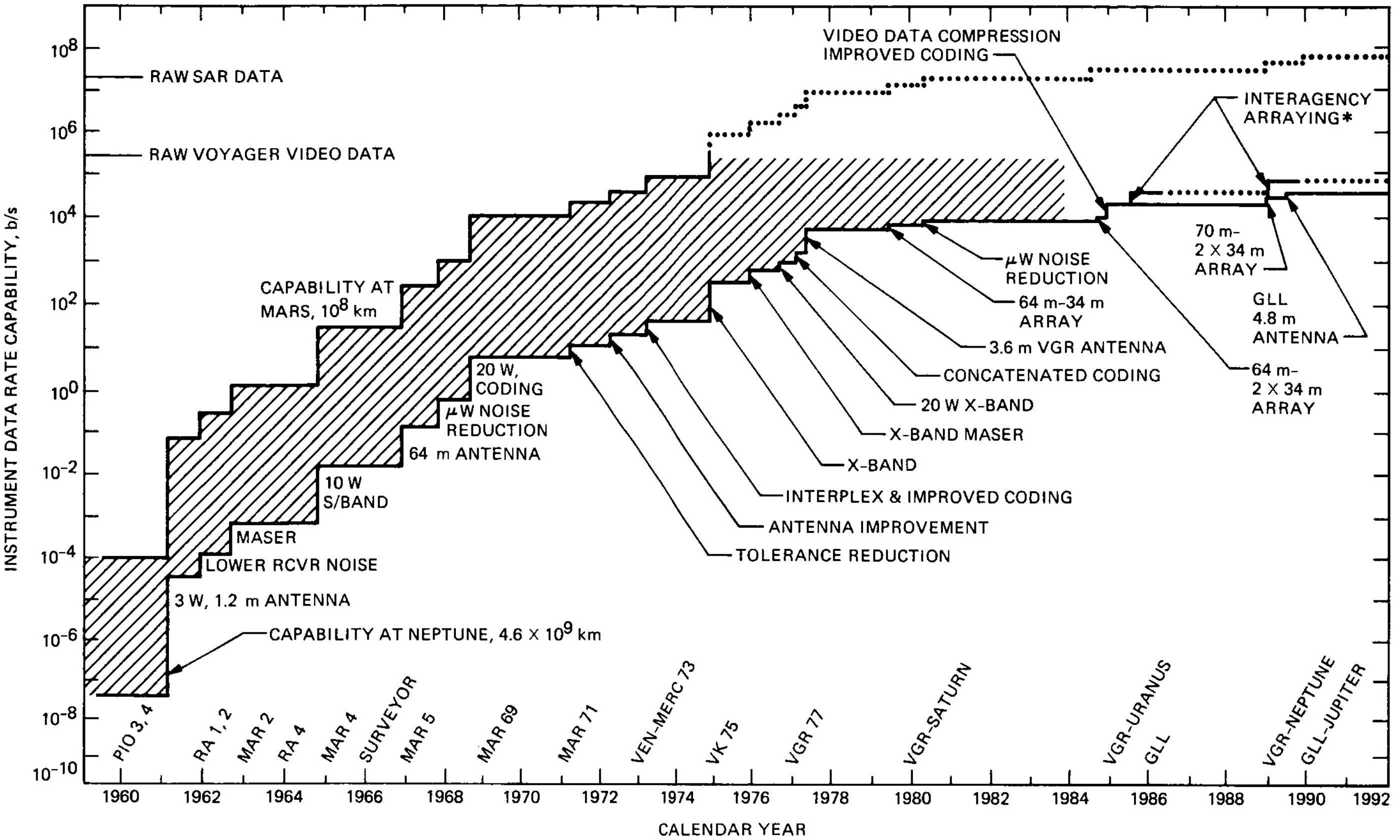


*INTER-AGENCY ARRAYING IS USED ONLY FOR SPECIAL EVENTS (e.g., VGR AT URANUS - NEPTUNE)

Fig. 1. Profile of deep space telemetry capability

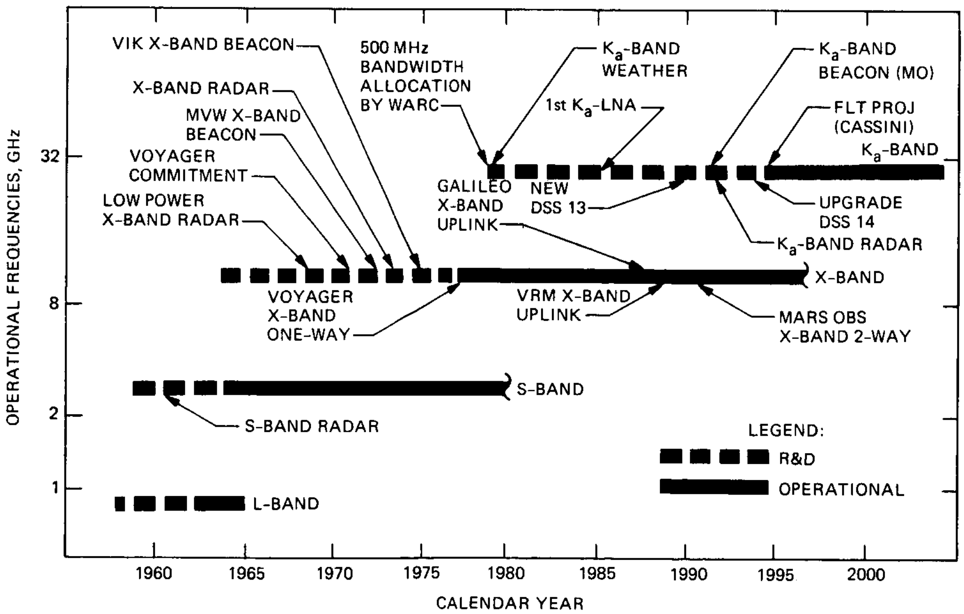


Fig. 2. Progression of deep space frequency bands

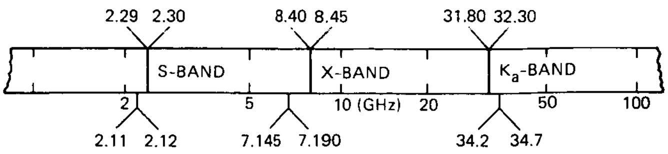


Fig. 3. The 1979 allocation at Ka-band to augment existing bands

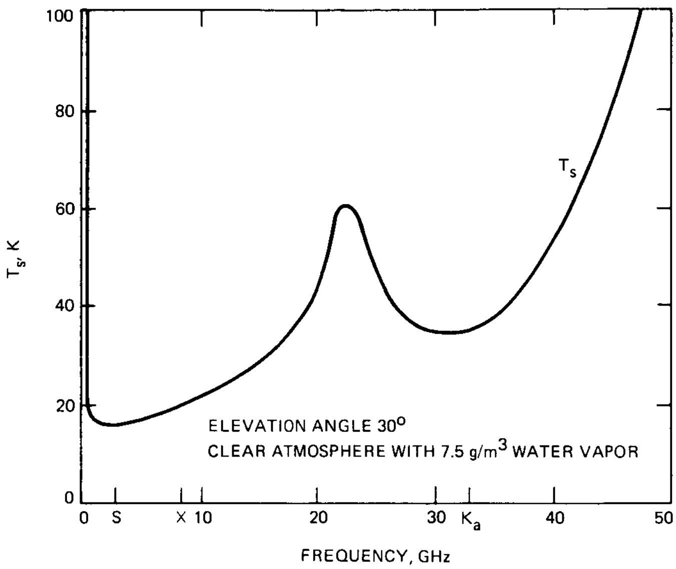


Fig. 4. Projected DSN 70-meter antenna system temperature

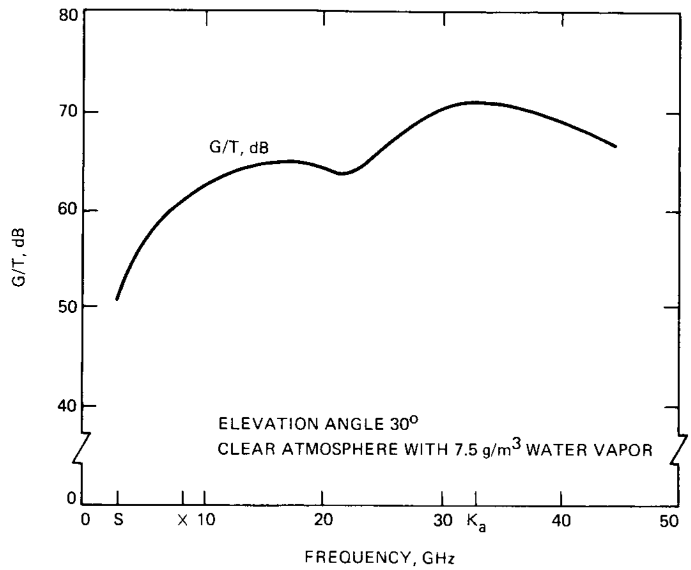


Fig. 5. Projected DSN 70-meter antenna system *G/T*

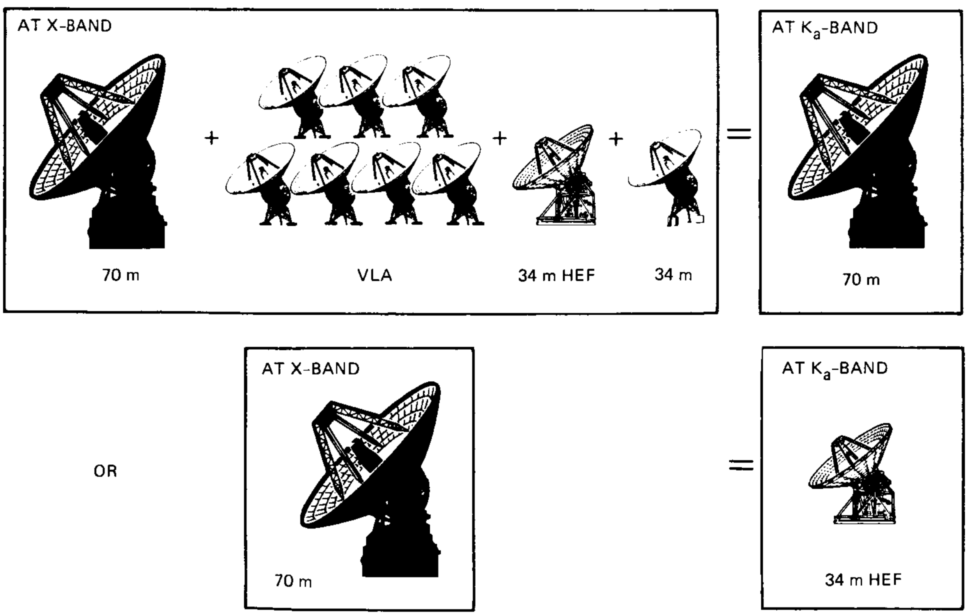


Fig. 6. The X- and Ka-band *G/T* equivalences

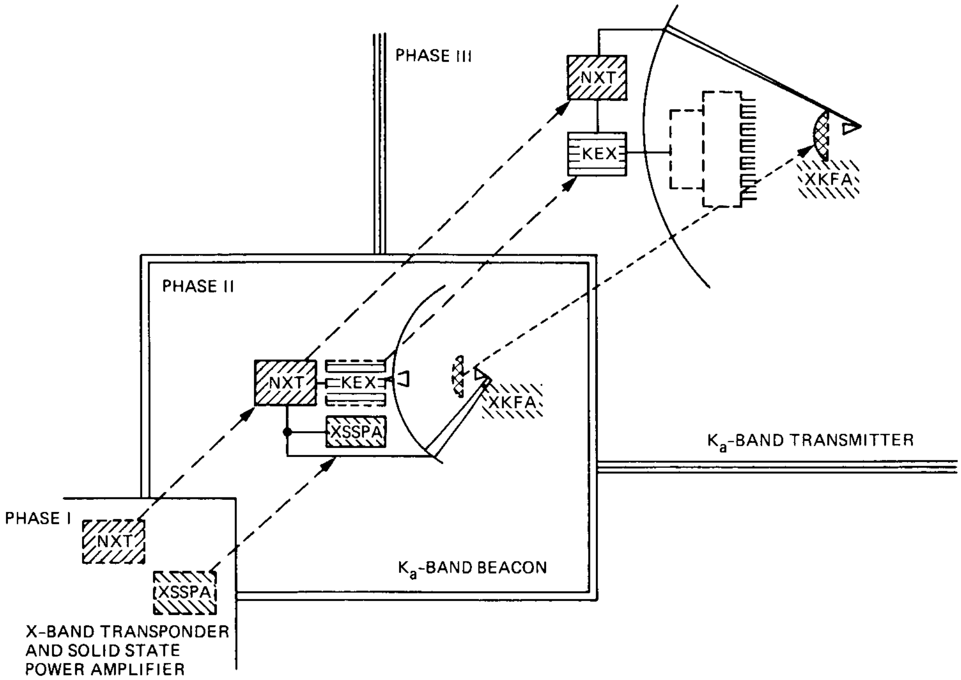
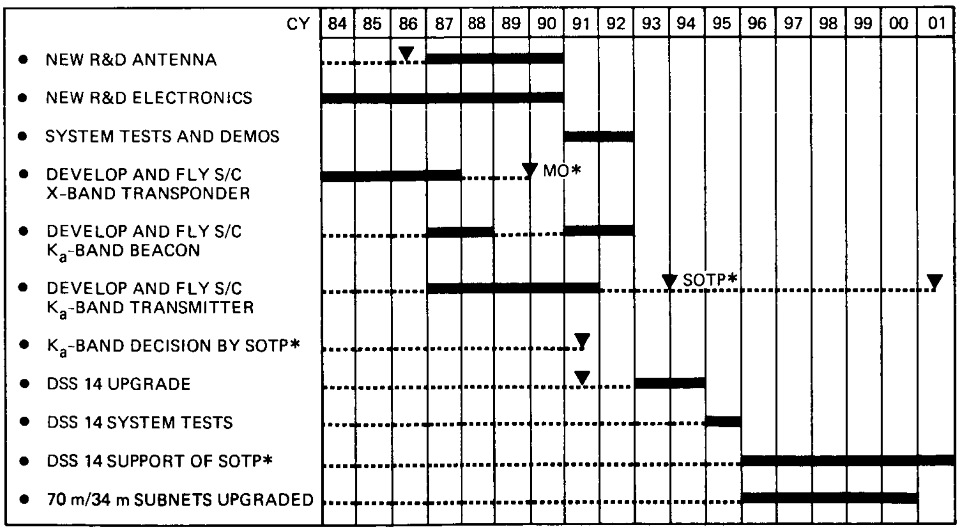


Fig. 7. Modular additions of spacecraft hardware



*MO - MARS OBSERVER
SOTP - SATURN ORBITER/TITAN PROBE

Fig. 8. Plan for Ka-band upgrade