SURFSAT - 1

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SURFSAT-1 is a satellite named after the California Institute of Technology's (Caltech's) Summer Undergraduate Research Fellowship (SURF) program. SURFSAT-1 was put into earth orbit as a secondary payload on the Delta II rocket that launched the Canadian RADARSAT into Polar orbit from Vandenberg Air Force Base on November 4, 1995. SURFSAT-1 consists of two aluminum boxes, each approximately 30 cm (12 in.) wide, 36 cm (14 in.) tall and 43 cm (17 in.) long, bolted to the Delta's second stage. The boxes are covered with solar panels that provide electrical power for radio systems at X-band (7.2 GHz earth-to-space and 8.48 GHz space-to-earth), Ku-band (15.33 GHz earth-to-space and 14.15 GHz space-to-earth) and Ka-band (32.0 GHz space-to-earth).

Figure 1 shows the Delta-2 second stage rocket and the SURFSAT-1 packages communicating with the Deep Space Network's (DSN's) 34-m research antenna and the 11-m Space Very Long Baseline Interferometry (SVLBI) antenna at Goldstone, near Death Valley, California.

Caltech's SURF Program students and DSN Advanced Systems Program sponsors began the design of SURFSAT-1 in July 1987, following a two-week course in small satellite technology at Utah State University.

SURFSAT-1 orbits the earth every 110 minutes in a Sun-synchronous orbit, inclined at 100.6322 degrees. SURFSAT's altitude varies from 937 km at perigee to 1495 km at apogee. The DSN's DSS-13 research station at Goldstone tracks SURFSAT on an average of six times per week. Two or three opportunities to track SURFSAT-1 occur every morning and evening, within two hours of sunrise or sunset. SURFSAT-1 tracks, from horizon to horizon, last up to 20 minutes, but are usually 12 to 15 minutes in duration.

SURFSAT-1's primary purpose is to enable an X- and Ka-band experiment by providing X- and Ka-band signals that can be compared for telecommunications link performance assessment at DSS-13. Precise evaluation of the Ka-band space-to-earth link at 32 GHz is needed to enable plans for future missions that maximize the potential factor of 14 advantage of Ka-band over X-band.

The 9.37 mm wavelength at 32 GHz enables antennas of fixed diameter to

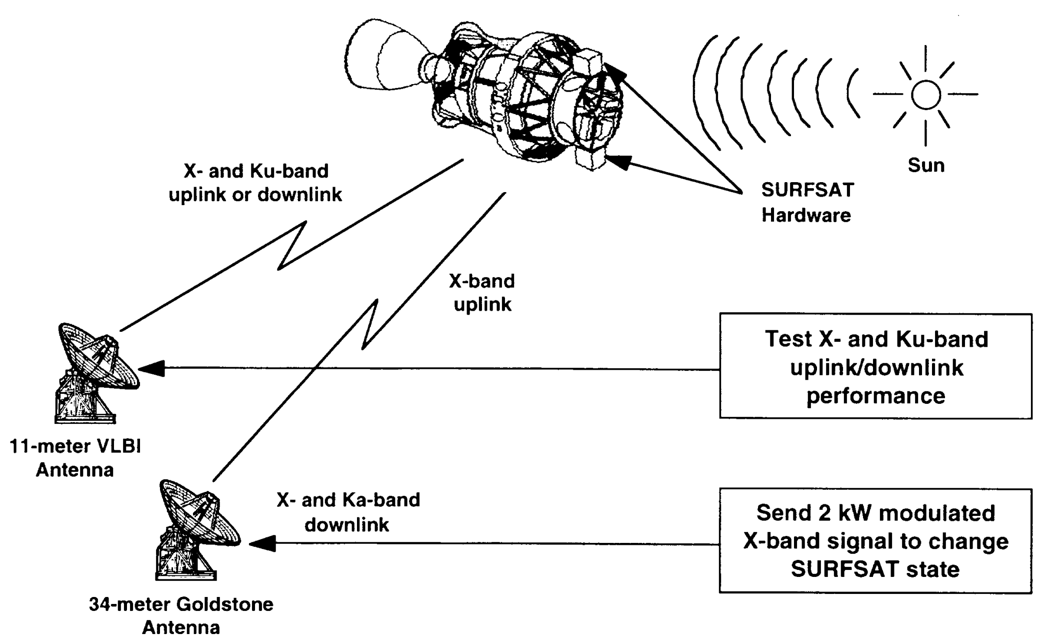

FIGURE 1. SURFSAT-1 AND THE DSN

have higher directivity (narrower half-power-beam-width (HPBW)) than can be achieved at the longer X-band wavelength of 3.56 cm at 8420 MHz. For example, a 32 GHz spacecraft transmitter is compared with an 8.42 GHz spacecraft transmitting system. If both transmitters provide the same RF power level and both antennas have the same diameter and efficiency, the power density delivered to a receiving system at far-field distances increases in proportion to the square of the frequency ratio. Therefore, 32 GHz divided by 8.42 GHz gives a frequency ratio of 3.8. The square of 3.8 is 14.44; the factor of 14.44 is an 11.6 dB advantage in the 32 GHz power delivered to a distant receiving system by a spacecraft transmitter, compared to a 8.42 GHz X-band transmitter system. The noise level (operating noise temperature) in receiving systems typically increases, primarily due to atmospheric effects, so the sensitivity of receiving systems decreases as the frequency is increased. This decrease in receiving system sensitivity causes the net link advantage of Ka-band over X-band to be decreased from the potential 11.6 dB value to a value expected to be between 5 dB and 8 dB. The SURFSAT-1 X-and Ka-band experiment will contribute to a better understanding of the Ka-band advantage over X-band. X- and Ka-band signal strength and frequency data are measured and reported in real time for track-by-track assessment of SURFSAT's and the DSN's performance. The X- and Ka-band signal strength and frequency data are also archived and transferred to analysts at the Jet Propulsion Laboratory (JPL) for future evaluation. Data from hundreds of passes collected throughout the year will be used to refine our knowledge of the performance advantages of using Ka-band for near-earth and deep space telecommunications.

SURFSAT-1 will contribute to a better understanding of the Ka-band advantage over X-band.

SURFSAT-1 transmitter and receiver systems include coherent transponders at X-band (7.2 GHz earth-to-space and 8.48 GHz space-to-earth) and Ku-band (15.33 GHz earth-to-space and 14.15 GHz space-to-earth). The X-band transponder has been used extensively to provide two-way Doppler data for SURFSAT-1 orbit determination. The Doppler data have enabled JPL's navigators to provide pointing predicts of SURFSAT-1 with millidegree level accuracy.

SURFSAT-1's transponders also provide a test capability for the DSN's new network of SVLBI antennas. The SVLBI project plans to use radio telescopes in orbit (Japan's VSOP and Russia's RadioAstron) together with earth-based antennas to observe and map distant radio sources. Correlation of the data from the orbiters with data received by earth-based DSN stations requires precise timing systems on the orbiters and at the earth-based receiving systems. Hydrogen masers with fractional frequency stability of better than one part in ten to the fourteenth are used at the earth-based station, and equivalent stability is needed on the orbiter. The plan to transfer a reference frequency with the required fractional frequency stability to the orbiter from the earth stations uses a precise two-way Doppler and media-compensated system. SURFSAT-1's early identification of SVLBI ground system failure modes enabled timely repairs, prior to the planned launch of the Japanese VSOP SVLBI spacecraft in January 1997.

More than 60 students from 14 colleges in the U.S. and U.K. have participated in the design and construction of SURFSAT-1.

A total of 303 SURFSAT tracks were performed at DSS-13 during the time period between the November 4, 1995 launch and the end of September 1996. Data were provided for the X- and Ka-band experiment, for orbit determination

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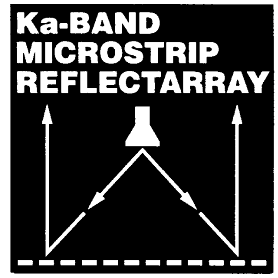
KA-BAND PRINTED MICROSTRIP REFLECTARRAY ANTENNA



JOHN HUANG AND RONALD POGORZELSKI

Innovative antenna designs are needed to meet future smaller spacecraft requirements. Typical high gain antennas used on spacecraft in the past have been parabolic dishes. These antennas are massive and their design has been largely constrained by the launch vehicle. One of the new concepts considered for small spacecraft application is the "reflectarray." These antennas can be conformally mounted on existing spacecraft structure with no additional support structure and they can be designed to radiate at wide angles to the reflector normal without incurring the aberration loss of a paraboloidal reflector. This article describes a recent program of design, fabrication, and evaluation of microstrip patch reflectarrays for microspacecraft application.

A printed reflectarray antenna consists of two basic elements; an illuminating feed and a thin reflecting surface. On the reflecting surface, there are many printed and isolated elements, but no power division network is required. The feed antenna illuminates these elements, which are designed to reradiate the incident field with proper phases to form a directive beam in the far field. This printed reflectarray combines some of the best features of microstrip array technology and the traditional parabolic reflector antenna. It has the low profile and beam scanning capabilities of the microstrip array and the large aperture with low insertion loss characteristic of a parabolic reflector.

There are many forms of printed reflectarrays, such as crossed-dipoles [1], circular rings [2], or microstrip patches [3]. There are also several variations [4,5] of the reflectarray that use microstrip patches. Two different microstrip patch reflectarrays were recently developed at the Jet Propulsion Laboratory (JPL). Both are circularly polarized at Ka-band, and each has a diameter of 0.5 m. One uses identical patches with different-length phase delay lines attached to compensate for the different spatial phase delays from the feed to the elements [3]. The second one, a new concept, uses identical patches with variable rotation angles [6,7] to achieve the phase compensation for circular polarization. This second unit achieved overall better performance and is reported here.

Antenna Description and Performance

The antenna, shown in Figure 1, has 6924 identical square microstrip patches

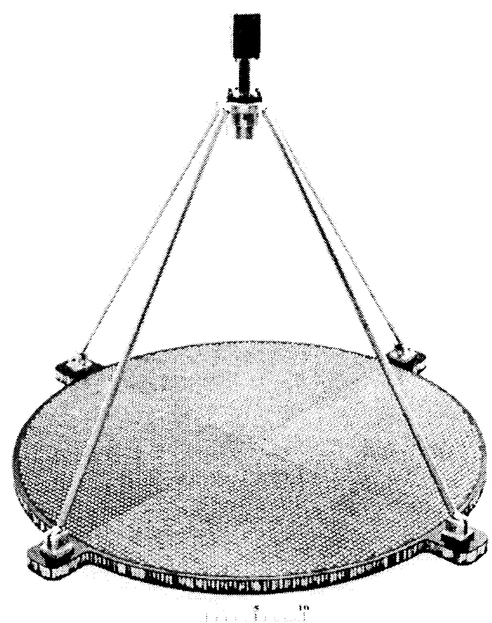


FIGURE 1. 0.5 M KA-BAND MICROSTRIP REFLECTARRAY USING ROTATED PATCH ELEMENTS.