The Solar Probe Antenna

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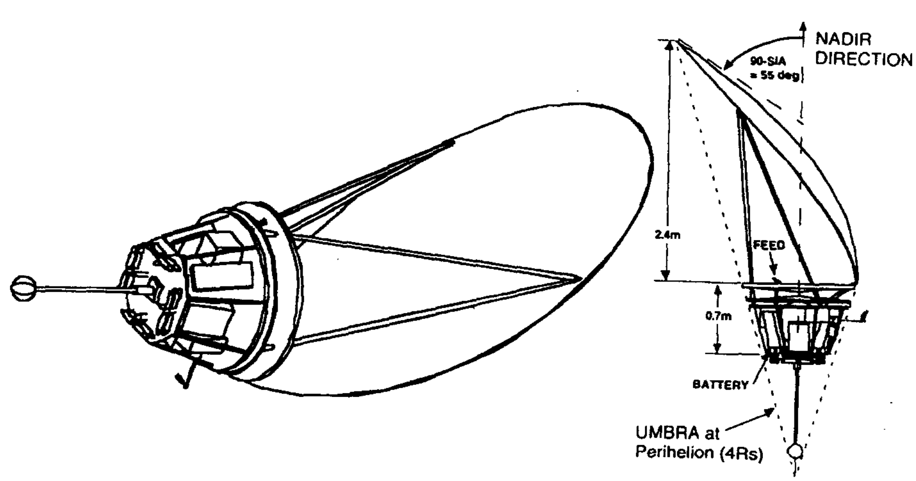
Abstract: This paper details the design of the antenna intended for use on the Solar Probe Mission. The antenna consists of a Carbon-carbon reflector jointly used as the antenna and thermal shield and a helical feed using tungsten wire and ceramic matrix composite (CMC) materials for the back plate, coaxial cable and waveguide. A complete prototype feed assembly was fabricated and tested.

Solar Probe Mission Description: The destination of the Solar Probe is the atmosphere of the Sun. It will approach the Sun within 2 million kilometers of the surface (a perihelion radius of 4 solar radii) while traversing its atmosphere or corona to make fundamental observations of the least understood environment in the solar system [1,2].

The most significant technology challenge is the thermal shield that would protect the spacecraft from the flux of 3000 suns (400W/cm^2) at perihelion while allowing the spacecraft subsystems to operate at near room temperature. The spacecraft configuration is shown in Figure 1 with the large thermal shield dominating the configuration. The shield is a section of a parabola of revolution (paraboloid) that has a dual function as a shield and as a high gain antenna [3,4].

Antenna Requirements: Measurements of the plasma environment including the birth and acceleration of the solar wind are the principle scientific objectives of this mission. To accomplish these measurements the spacecraft must not produce



a. Isometric View b. Side View

Figure 1. Solar Probe Spacecraft Configuration

excessive outgassing or sublimation that could ionize and contaminate the natural plasma environments that are to be measured. The scientific community has suggested the magnitude of contamination that is acceptable and has given a total mass loss specification of less than 2.5 milligrams per second at perihelion.

Traveling to a perihelion radius of four solar radii ($4R_s$) requires a very high-energy launch capability. In order to maximize the launch capability and minimize launch costs, the spacecraft must be small and lightweight as possible while satisfying the scientific payload accommodation requirements. Thus the shield must be made of lightweight materials such as composites. In addition, for a spacecraft traveling to $4R_s$ and maintaining its electronics at room temperature (approximately 300 K) a shield is required to shade the electronics while the shield itself will be operating at extremely high temperatures (greater than 2000 K). The combination of these requirements led to the selection of carbon-carbon as the ideal shield material because of its low density, high strength, and excellent high temperature characteristics.

The antenna geometry is detailed in Figure 2. It is an offset reflector with a focal length of 0.8 meters situated on top of the spacecraft. The feed is also shielded from the sun, but because the feed is outside the spacecraft thermal blankets, it still gets to a fairly high temperature (1400K) at perihelion.

Frequency and Feed specifications: Since X-band was chosen as the primary communications band, including both transmit and receive functions the frequency range of the feed is 7.145 to 8.5 GHz. To properly illuminate the reflector, a feed gain of about 10 dB is required. The feed is to be LHCP with an axial ratio of less than 2 dB and a return loss of less than –15 dB. The feed must operate at a peak temperature of 1400K. A number of low gain feed designs were considered including a horn, crossed-dipole in a cup and a helical antenna. A horn was ruled out because it would require a polarizer to generate the circular polarization and the combination of the horn and polarizer would be considerably larger than the other two designs and extend too far above the spacecraft platform. To cover both the transmit and receive bands with the crossed dipole requires a hybrid to combine the two arms of the crossed dipole 90 degrees out of phase to achieve circular polarization whereas the helix is inherently circular polarized. In addition the helix is inherently wider band and thus less sensitive to length changes due to thermal variations. The helix could also be constructed using a very high temperature capable metal. For these reasons the helix was chosen as the feed element.

A schematic of the feed is shown in Figure 3. It consists of a helical antenna, a coaxial cable, a coax to waveguide transition joint, and a short piece of high temperature capable waveguide with a short bend. Thermal shields on the top of the spacecraft bus separate the helix from the waveguide. The coax size was chosen to minimize the penetration hole in the thermal shields. A thermal block

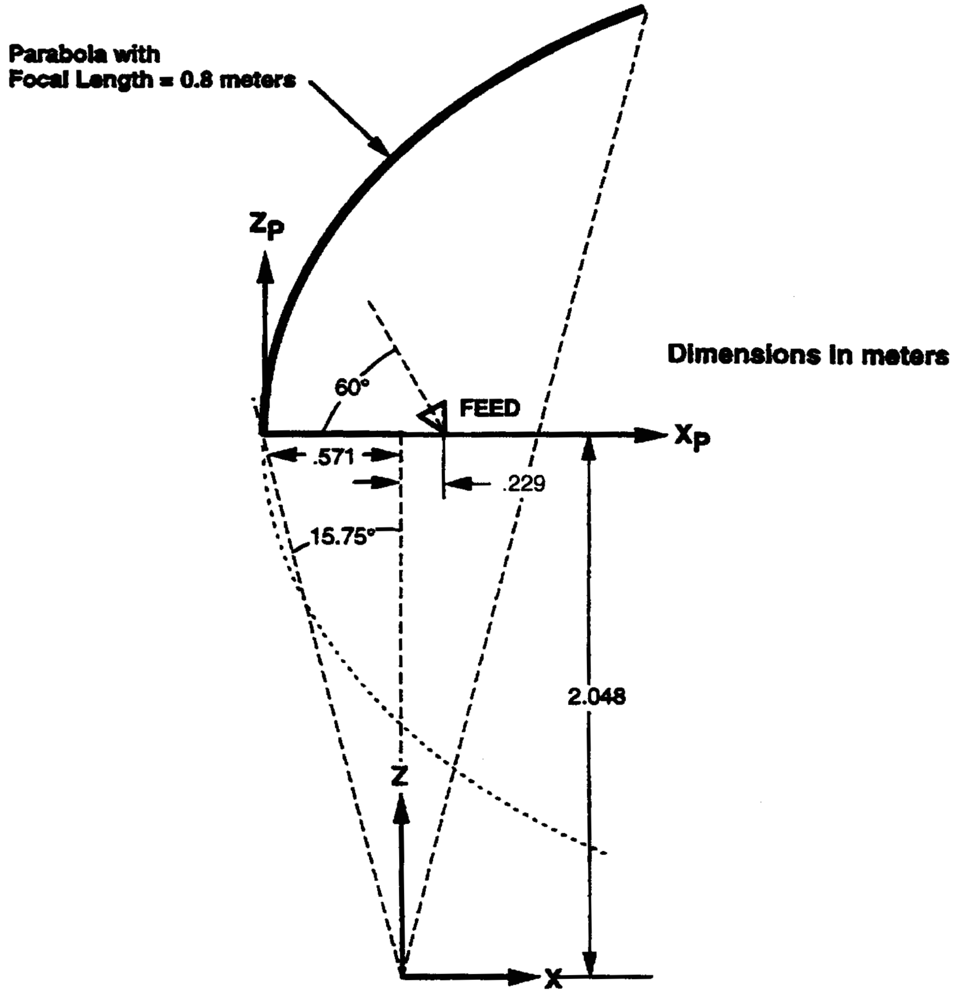


Figure 2. Solar Probe Antenna Geometry

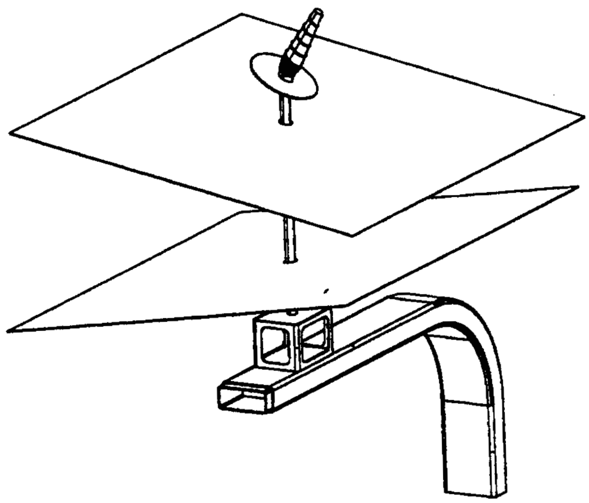


Figure 3. Waveguide and Feed Design

(choke air gap) separates the feed assembly from the room temperature waveguide in the spacecraft bus.

RF analysis was performed prior to fabricating the Solar Probe prototype. The purpose of this analysis was to establish a viable first cut solar probe design without having to fabricate numerous expensive prototypes.

Finite element models were constructed so that field propagation and S-parameters could be calculated in the transmit and receive frequency bands. The basic models were dimensioned for lab ambient temperature. S-parameters that were calculated for lab ambient temperature and with the probe depth dimension adjusted for the maximum specified temperature so that temperature induced changes in insertion loss and match could be evaluated. Worse case matching conditions were assumed in order to predict the performance of the fully integrated assembly. Based upon the results of the analysis, the final assembly was fabricated and tested.

Return loss and insertion loss measurements were performed on the completed Solar Probe Feed Assembly prototype. Return loss was nominally –12 dB across the band and insertion loss was approximately –1.0 dB.

The transmit and receive radiation patterns were measured. Utilizing these measured radiation patterns in a Physical Optics calculation and estimating a total additional loss of 2 dB from insertion loss, reflector reflectivity, etc. the estimated gains are 41.3 dB at the transmit frequency (8.425 GHz) and 39.6 dB at the receive frequency (7.145 GHz).

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