KU BAND INTEGRATED RADAR/COMMUNICATIONS SUBSYSTEM FOR THE SHUTTLE

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ABSTRACT

The Ku Band Subsystem for the Space Shuttle Orbiter must operate as rendezvous radar and provide two way communications with the ground. A discussion of accomplishing these objectives while meeting the additional requirements of minimum weight, limited stowage volume, and adequate cooling is presented.

KU BAND SUBSYSTEM FOR THE SHUTTLE

The Ku Band Subsystem for NASAs Space Shuttle Orbiter operates as a radar during rendezvous with other space vehicles, and provides two way communications with the ground through the Tracking and Data Relay Satellite System (TDRSS). The subsystem must meet its requirements despite severe weight and stowage volume limitations.

In the communications mode, the subsystem searches for and acquires the TDRSS anywhere within 20 degrees of the designation given by the Orbiter. The subsystem then tracks the target anywhere within the unobscured volume. As shown in Table 1, the subsystem receives data at 216 kbps and transmits data at up to 50 Mbps. To achieve the required bit error rate (BER) of 10^{-6}, at the 0.2×10^{-12} W/m^2 provided by the TDRSS, the ratio of antenna gain to receiver noise temperature must be 4.8 dB/^{o}K. To provide the required 3×10^{-12} W/m^2 at TDRSS, the effective isotropic radiated power (EIRP), that is, the product of the effective antenna gain and the transmitter output must be greater than 48.8 dB above 1 W.

In the radar mode, the subsystem searches for, detects, and acquires targets within 30 degrees of the designation given by the Orbiter. The subsystem then tracks the target to provide the Orbiter with range, velocity, angle, and inertial angle rates. Table 2 details the requirements for this mode. The detection range and range accuracy requirements could be met by a simple, noncoherent pulsed radar, but the velocity accuracy requirement dictates the use of doppler measurement techniques. The specification of 0.14 deg/sec (3σ) angle rate accuracy is the most difficult requirement to meet.

TABLE 1. COMMUNICATIONS REQUIREMENTS

SEARCH AND ACQUISITION VOLUME	±20 DEGREES
TRACKING LIMITS	ORBITER OBSCURATION
FORWARD LINK	
DATA RATE	216 KBPS
SIGNAL POWER DENSITY FROM TDRSS	0.2×10^{-12} W/M^2
BIT ERROR RATE	ONE ERROR IN ONE MILLION BITS
GAIN/NOISE TEMPERATURE	4.8 DB/^{o}K
RETURN LINK	
DATA RATE	UP TO 50 MBPS
SIGNAL POWER DENSITY AT TDRSS	3×10^{-12} W/M^2
EFFECTIVE ISOTROPIC RADIATED POWER	>48.8 DB ABOVE 1 W

TABLE 2. RADAR REQUIREMENTS – NONCOOPERATING TARGET

SEARCH AND ACQUISITION VOLUME	±30 DEGREES, 100 FEET TO 12 MILES
TRACK LIMITS	ORBITER OBSCURATION, 100 FEET TO 12 MILES
RANGE ACCURACY (3σ)	80 FEET OR 1 PERCENT
VELOCITY ACCURACY (3σ)	1 FPS
ANGLE ACCURACY (3σ)	8 MR
ANGLE RATE ACCURACY (3σ)	0.14 MR/SEC

The subsystem performance requirements translate into the functional requirements shown in Table 3. The transmitter uses a traveling wave tube (TWT) with an average output power greater than 50 W. The receiver uses a microwave amplifier with a noise figure of less than 5 dB. Most important, it is possible to make use of a parabolic antenna with a 3 foot diameter.

In the communications mode, the Ku band equipment receives at 13.8 GHz and transmits at 15.0 GHz. To simplify the receiver, and because a wide band transmitter is feasible, the radar is operated near the communications receive frequency. Table 4 lists the characteristics to be demonstrated by the traveling wave tube employed. The helix TWT easily meets the bandwidth requirement, also providing a comfortable margin for the bandwidth required to handle 100 Mbps of convolutionally encoded data. The TWT is provided with a two stage collector. This characteristic means a higher tube efficiency resulting in a lower power consumption and a significantly minimized thermal management problem. More important, it means that low level RF drive modulation can be employed in the pulsed (radar) mode without suffering unmanageable increases in dissipation. The TWT is expected to weigh less than 6 pounds.

As shown in Table 5, the low noise microwave amplifier provides a $1550^{\circ}K$ system noise temperature, including the effects of antenna noise, waveguide losses, and the downconverter noise contribution. To accommodate the variation in signal strength with target size and range, the receiver provides a dynamic range of 110 dB. In the communications mode, a predetection bandwidth of 8 MHz is provided to pass 90 percent of the energy of the 3 MHz spread spectrum modulation on the forward link. In the radar mode, a 10 MHz bandwidth is required to pass the 122 ns pulse used at the shortest ranges. Because the radar uses frequency hopping, the receiver RF bandwidth is 300 MHz.

The principal constraints on the subsystem are the size and weight limits of the antenna assembly. The antenna is stowed in the space between the payload outer contour and the payload bay door inner contour as shown in Figure 1. After the payload doors are opened, the antenna assembly is deployed by rotating the mounting boom with a deployment mechanism. To keep the mechanism within feasible limits, the weight of the deployed assembly must be kept to less than 160 pounds. The microwave assembly contains both the transmitter and the microwave receiver and is mounted on the deployed assembly to minimize the losses in waveguide runs. Figure 2 shows the assembly in its deployed configuration. The microwave

TABLE 3. FUNCTIONAL REQUIREMENTS

TRANSMITTER TUBE AVERAGE POWER	>50 WATTS
RECEIVER NOISE FIGURE	<5 DB
ANTENNA DIAMETER	3 FEET

TABLE 4. TRAVELING WAVE TUBE CHARACTERISTICS

BANDWIDTH	13.8 TO 15.1 GHZ
EFFICIENCY	43 PERCENT
COLLECTOR STAGES	2
WEIGHT	<6 POUNDS

TABLE 5. RECEIVER CHARACTERISTICS

EFFECTIVE SYSTEM NOISE	$1550\ ^{\circ}K$
DYNAMIC RANGE	120 DB
RF BANDWIDTH	300 MHZ
IF BANDWIDTH	
COMMUNICATIONS	8 MHZ
RADAR	10 MHZ

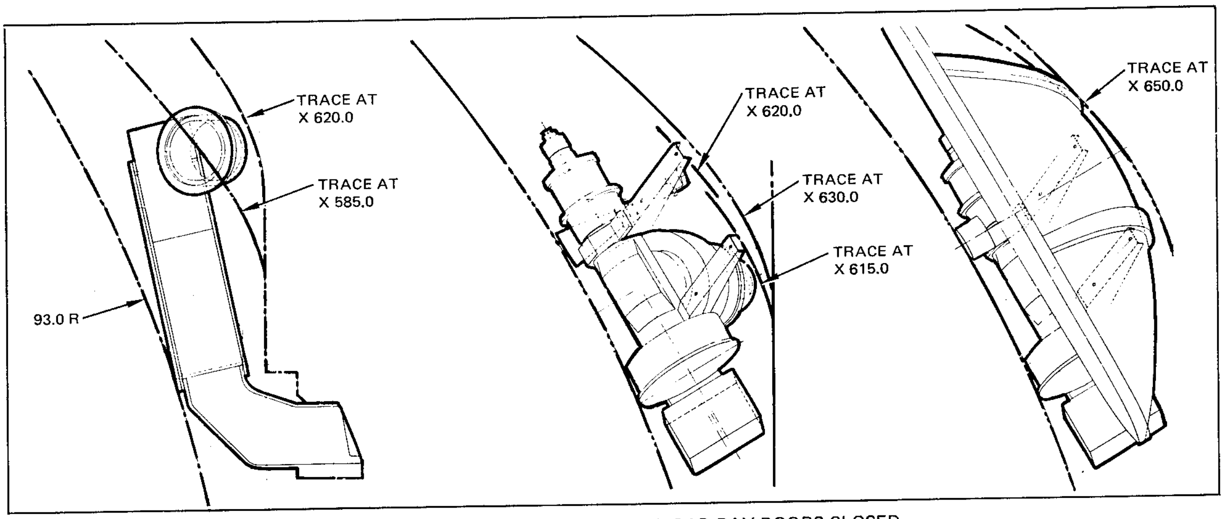

FIGURE 1. STOWED ANTENNA - PAYLOAD BAY DOORS CLOSED

assembly is sealed in a rectangular box supported at the forward end by a canted pedestal bolted to the deployment mechanism. The antenna is moved by the gimbals bolted to the top rear of the microwave assembly.

The antenna is edge mounted to save weight. Figure 3 shows that as the arms of a conventional yoke are shortened, the total weight of antenna and gimbals still remains the same. The weight saved by the lighter yoke is offset by the larger, heavier motors required to drive the increasing moment of inertia of the antenna. However, as the yoke arms approach their minimum length, the yoke weight drops sharply and also reduces the outer axis motor size and weight. The antenna drives are sized for a zero g field. Counterbalances are required for testing in a 1 g field.

The antenna characteristics are shown in Table 6. Circular polarization is required for compatibility with TDRSS, but linear polarization is preferred for radar. Several antenna configurations, such as Cassegrain feed and planar array, were considered, but the front feed parabola was selected because low sidelobe levels can be achieved and the antenna polarization can be switched with a simple waveguide phase shifter. The diameter, 36 inches, is the largest that will fit. The focal length, 0.292 D, is shortened to fit the stowage volume. The small f/D ratio reduces the gain slightly, but the communications transmit gain is still 39.4 dB and the communications receive gain is 38.9 dB. With the 50 W transmitter, an EIRP of 52.8 dBW provides a 4.0 dB margin over the required value shown in Table 1. Similarly, the receive G/T of 6.4 dB/°K provides a 1.8 dB margin over the requirement of Table 1. Finally, the front fed parabola provides low sidelobe levels because the aperture blockage is small and the distribution taper can be well controlled.

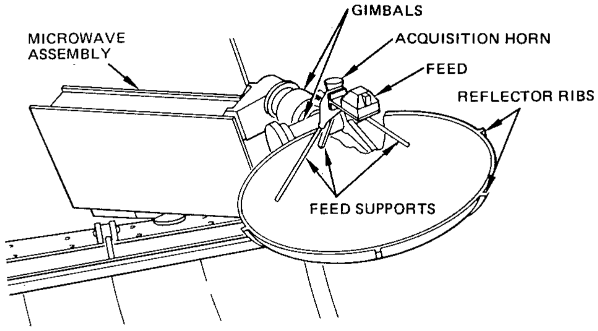

FIGURE 2. DEPLOYED ASSEMBLY

TABLE 6. ANTENNA CHARACTERISTICS

POLARIZATION (COMMUNICATIONS/ RADAR)	CIRCULAR/LINEAR
DIAMETER (D)	36 INCHES
FOCAL LENGTH	0.292 D
GAIN (TRANSMIT/RECEIVE)	39.4 DB/38.9 DB
FIRST SIDELOBE	-22 DB

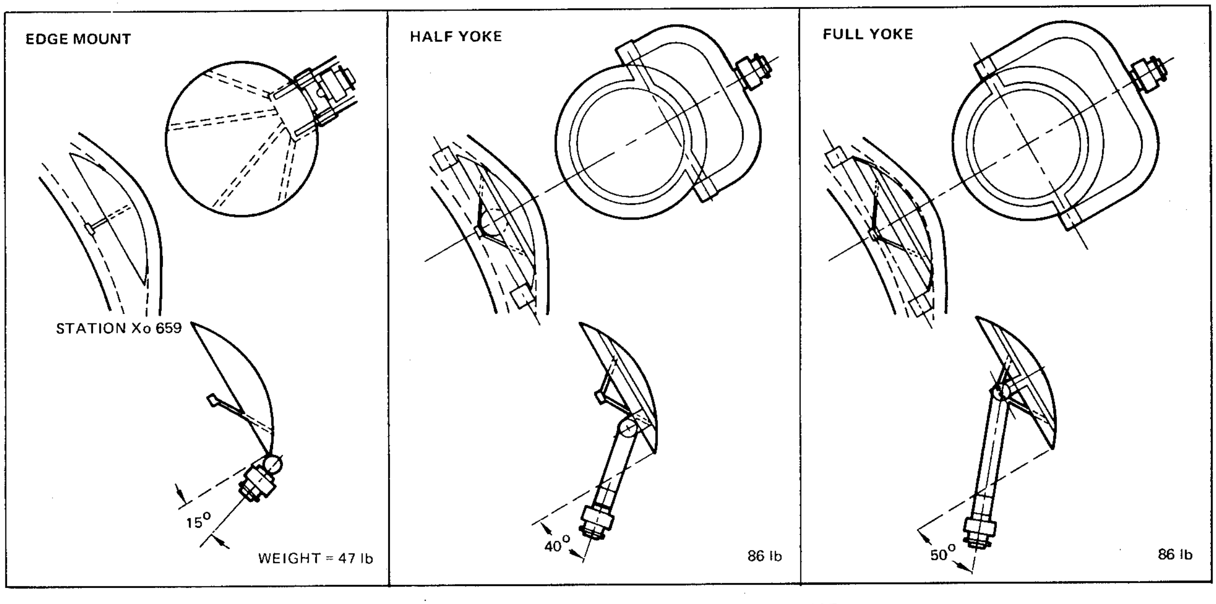

FIGURE 3. WEIGHT VERSUS ANTENNA UNBALANCE

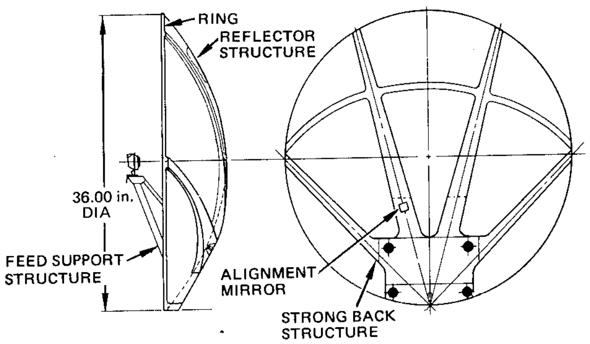

FIGURE 4. ANTENNA REFLECTOR

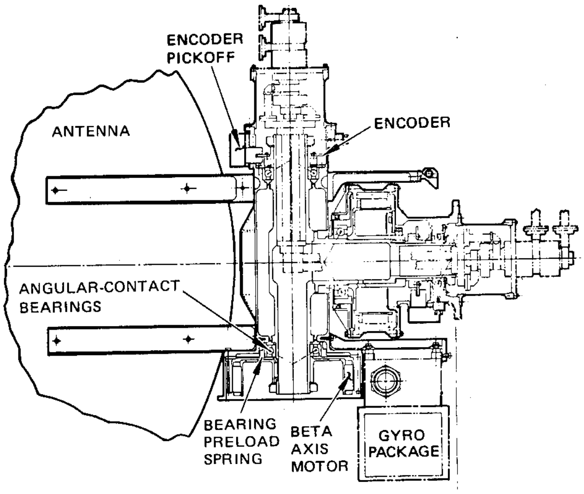

FIGURE 5. GIMBAL ASSEMBLY CROSS SECTION

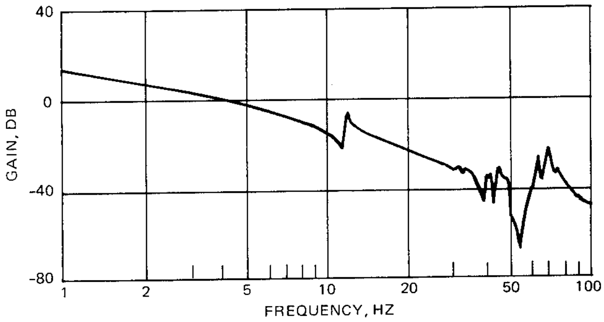

FIGURE 6. SERVO OPEN LOOP GAIN

The antenna reflector is the dominant load for the servo motors. Consequently, it is essential to keep the reflector weight to a minimum. A graphite-epoxy laminate of 0.016 inch thickness weighs just 2.95 pounds. Servo drive loads are distributed from the gimbal assembly to the reflector by four graphite ribs that radiate across the back of the reflector as shown in Figure 4. The entire antenna assembly, including reflector, ribs, feed, and feed supports, weighs less than 6 pounds. In addition to its light weight, the graphite-epoxy provides excellent dimensional stability over the operating temperature range of -250 to +250°F. While graphite reflects microwaves as well as aluminum, it does not reflect visible energy very well, thus minimizing the thermal problem when the sun's rays will focus on the feed.

The gimbal assembly is shown in cross section in Figure 5. The inner gimbal axis is just long enough to hold the torque motor, the microwave rotary joint, the digital shaft angle encoder, and the cable wrap. The inner gimbal is supported at the end of the outer gimbal axis, which also has a motor, rotary joint, angle encoder, and cable wrap. Inertial stability is provided by two rate-integrating gyros that sense inertial rates about the two gimbal axes. The gyros are mounted to the antenna support arms so as to sense directly the antenna motion. The gimbals are also provided with a locking mechanism so that the antenna can be locked at the stow gimbal angles before the deployed assembly is returned to the stowed position.

The antenna is inertially stabilized by closing the output of the gyros back to the torque motors. The antenna is moved by sending precession signals to the gyros. To move the antenna to a designated angle in Orbiter coordinates, a microprocessor transforms the commands into antenna coordinates. The command coordinates are compared with the shaft angles from the shaft angle encoders to provide error signals. The error signals are shaped and then precess the gyros until the antenna reaches the commanded position. To track, angle error signals from either the radar signal processor or the communications angle tracking circuits are selected to precess the gyros. In search, the microprocessor calculates rate commands which precess the gyros to create a spiral search pattern. Whether manually directed by the Orbiter crew or automatically controlled by internal events, the antenna is supervised by the microprocessor.

The most difficult servo problem involves the structure of the deployed assembly and the structure of the Orbiter itself. Figure 6 is the open loop transfer function of the antenna servo in a high gain state. The gain peak at 12 Hz is caused by the structural resonance of the deployed assembly and its mounting. It is necessary to stiffen both the deployed assembly and the Orbiter structures to move the resonance out of the servo passband. A computer model of the structure is shown in Figure 7. Analysis of the model shows a low frequency resonance below 10 Hz

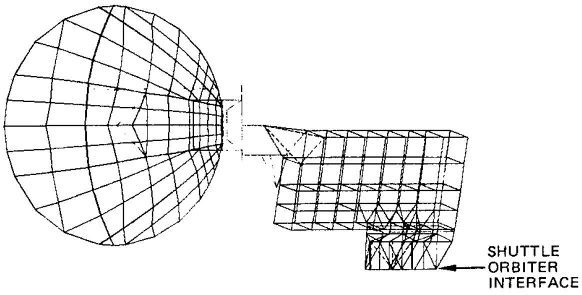

FIGURE 7. COMPUTER MODEL - STRUCTURE

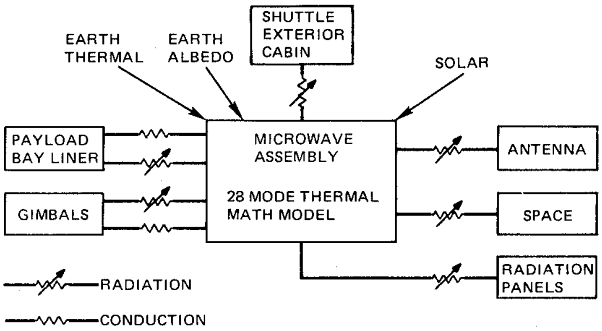

FIGURE 8. DEPLOYED ASSEMBLY - THERMAL ENVIRONMENT

and several more in the vicinity of 20 Hz. As the structure was stiffened, the low frequency resonance moved up, but the lowest resonant frequency remained below 20 Hz. The Orbiter structure limited the attainable stiffness and has to be stiffened by carrying torsion loads from the deployment mechanism mounting to the bulkhead.

The microwave assembly is shown in Figure 8. Total dissipation in this unit is about 210 W which must be radiated to space without overheating any of the electronics within. As shown in Figure 8, the thermal environment is quite complicated. Direct solar energy is a major source of heat, but there are numerous other sources, including sunlight reflecting off the cabin, off the radiator panel, and off the earth (albedo). In addition, the cabin, the radiator panel, the payload bay, and the earth are sources of IR energy. A computer model of the thermal environment shown in Figure 9 takes 154 nodes and 990 coefficients to account for all sources and sinks of thermal energy. The transmitter temperature variation is shown in Figure 10. As a result of the analysis, the entire assembly was covered with a silvered teflon to help reduce solar heat loads. Extending the thermal radiator by 6 inches could drop the unit temperature about 10°F, but such extension was rejected because it adds considerable weight. Finally, a concerted effort is being made to reduce dissipation within the unit.

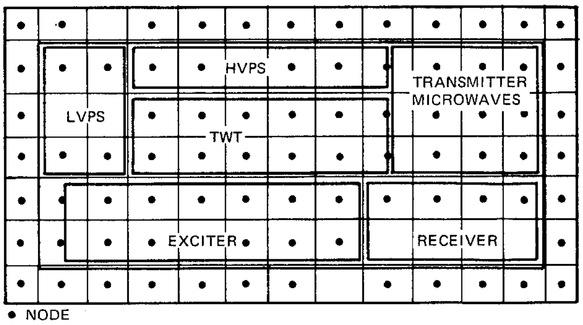

FIGURE 9. COMPUTER MODEL - THERMAL ENVIRONMENT

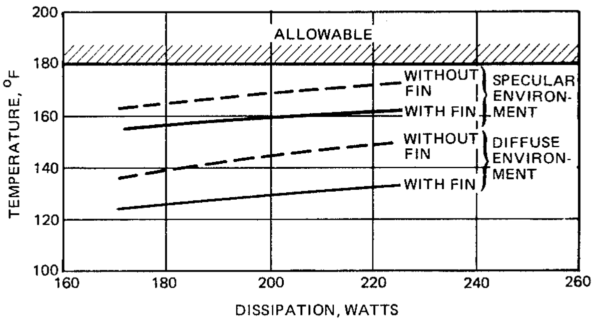

FIGURE 10. TRANSMITTER TEMPERATURE VARIATION

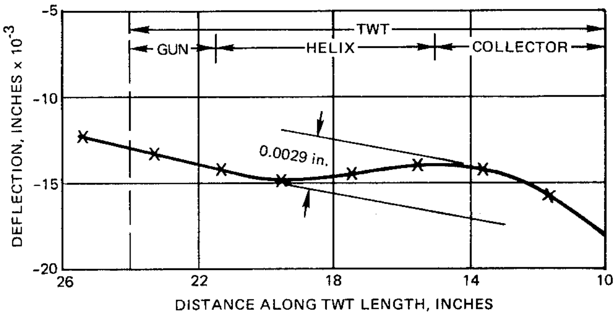

FIGURE 11. TWT DEFLECTION VERSUS STRUCTURAL LOAD

The TWT is a major source of heat in the microwave assembly and is mounted directly to the baseplate. The baseplate is 0.25 inch thick to spread the heat from the TWT. To take advantage of the strength of the baseplate, it is made an integral part of the deployed assembly's load-bearing structure. However, the presence of loads in the baseplate causes deflections which could be transmitted to the TWT. Since deflection of the TWT could affect the electron ballistics, it is calculated, and the results are shown in Figure 11. The TWT will tolerate 0.005 inch deflection. Pressurization of the microwave assembly proves to be the largest contributor to deflections.

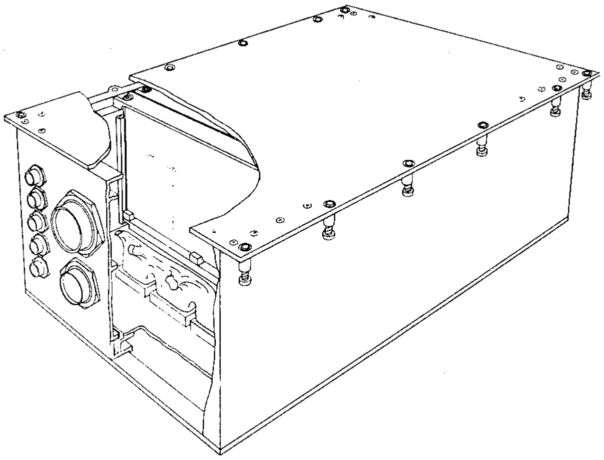

FIGURE 12. AVIONICS BAY UNIT

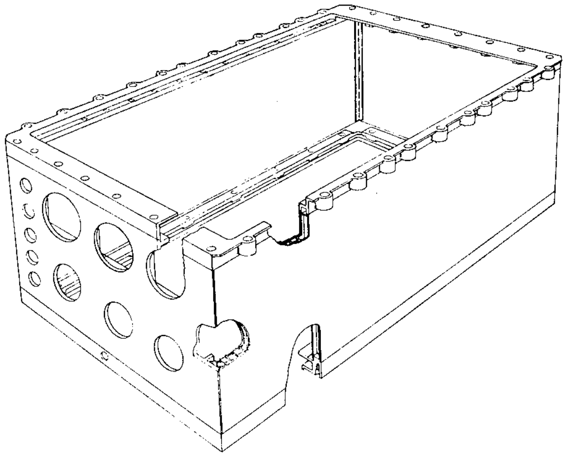

FIGURE 13. DIP — BRAZED STRUCTURE

The electronics not required in the deployed assembly are located in four units within the avionics bay. A typical unit is shown in Figure 12. The units are sealed, purged, and then back filled with nitrogen to meet flammability and outgassing requirements. The units must be pressure tested in a 36 psia ambient since the Orbiter cabin is pressurized as part of its normal checkout. To meet the stresses imposed by the pressure test, the dip-brazed structure shown in Figure 13 is used in the sidewalls and covers. This lightweight hollow structure is about 10 percent lighter than the tape-milled structure it replaces, saving about 8 pounds of the system weight.

Key requirements of the Ku band subsystem relate to performance: kilobits or megabits of data transferred with minimum error, and the acquisition and tracking of a target at some range. None of the requirements are difficult to achieve until the restraints on weight, cooling, and stowage are imposed. Then solutions are heavily dependent on the mechanical design of the subsystem. In particular, the achievement of a lightweight antenna assembly employing an extremely light reflector greatly simplifies the accomplishment of the subsystem requirements.