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CONTROLS-STRUCTURES-ELECTROMAGNETICS INTERACTION PROGRAM

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SUBJECTS TO BE DISCUSSED

This paper describes a 4 year technology development program involving Controls/Structures/Electromagnetics/Interaction (CSEI) for large space structures. The CSEI program has been developed as part of Langley Research Center's continuing effort following the successful kinematic deployment and RF tests of the 15 meter Hoop/Column antenna which has just been completed. One of the "lessons learned" in the program so far is the necessity and importance of being able to make reflector surface adjustment after fabrication and deployment. Cumulative manufacturing errors have proven to be much larger than expected even when great care is taken to maintain highly accurate templates, etc. during the fabrication and assembly stages.

- Program Objectives
- Ground-Based Test Configuration
- Intelsat Adaptive Feed
- Reflector Shape Prediction Model
- Control Experiment Concepts
- Master Schedule
- COFS-II Baseline Configuration

PROGRAM OBJECTIVES

The CSEI Program objectives are to extend the 15 meter antenna tests and examine interdisciplinary issues important in optimizing Large Space Antenna (LSA) performance for a variety of potential users. This will be accomplished by analytical code development as well as testing of the modified 15 meter antenna. New antenna features are being added which include automated remote control of the reflector surface and feed location, utilization of electronic adaptive feed compensation techniques, and incorporation of real-time antenna figure measurements for open and closed loop control tests of the flexible structure.

<table>
<tr><th colspan="2">(CSEI)
GROUND-BASED TECHNOLOGY DEVELOPMENT FOR LARGE SPACE ANTENNAS</th></tr>
<tr><td><u>Objective:</u>

Develop Methodology For Optimizing RF Performance Of Large Space Antennas By Application Of Controls-Structures-Electromagnetic Interactive Technologies.</td><td><u>Approach:</u>
Extend 15-Meter Antenna Tests To Include

• Surface Control For Reflector Figure Improvement.
• Integrated Structural-Dynamics-Electromagnetics Code Development
• Adaptive Feed Techniques For Surface Distortion Compensation
• Real Time Figure Meas.</td></tr>
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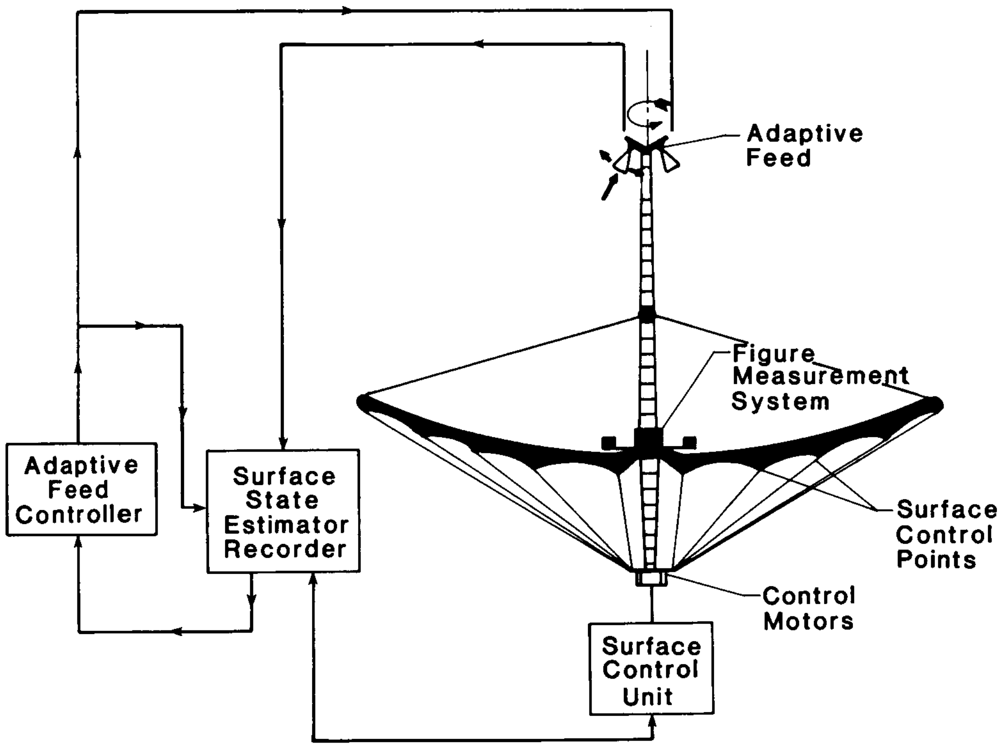
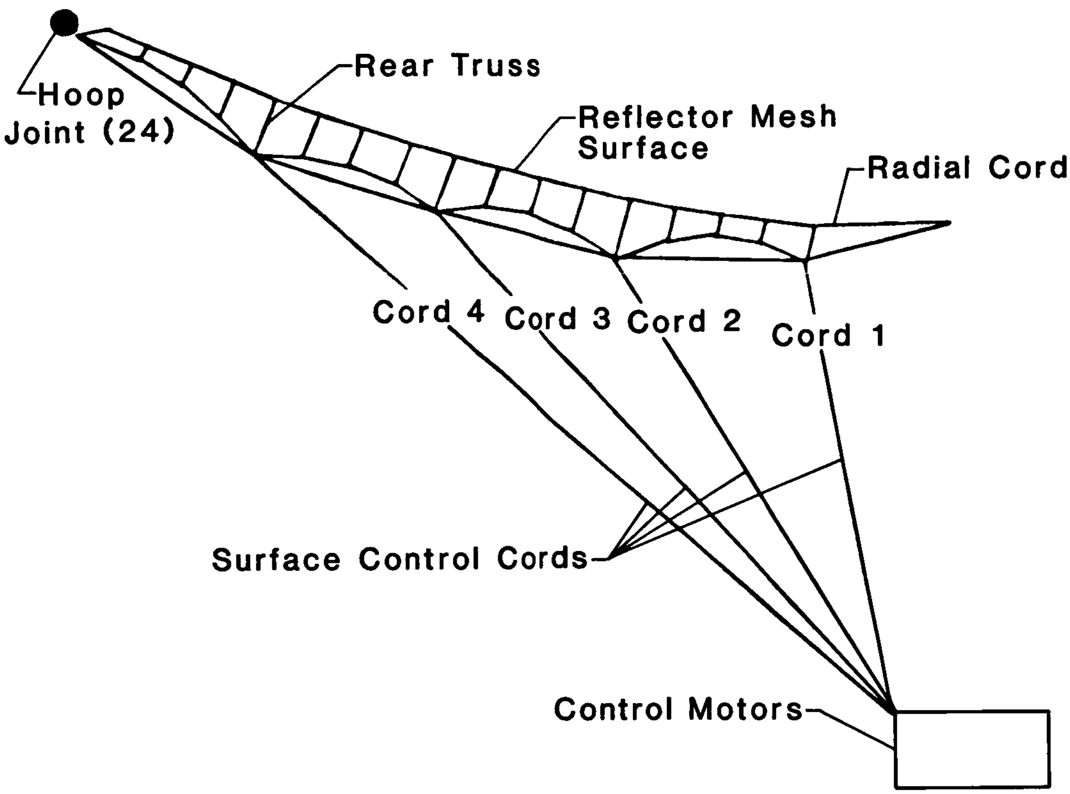
ANTENNA GEOMETRY

This chart shows the 15 meter Hoop/Column antenna geometry with interconnecting block diagrams for the remote surface control unit, adaptive feed controller, and surface state estimator-recorder. The antenna has been named Hoop/Column after its dominate structural members: a central telescoping column supporting a circumferential hoop. The hoop is supported by quartz cords attached to the top of the column and graphite cords attached to the opposite end of the column. The reflecting mesh surface is shaped by cord trusses and by graphite control cords as illustrated in the figure. Whereas these control cords were adjusted manually in the 1985 RF tests to improve the smoothness of the reflector surface, motorized control is now being added for more rapid remote actuation. Details concerning the surface control cords are shown on the next figure and in reference 1.

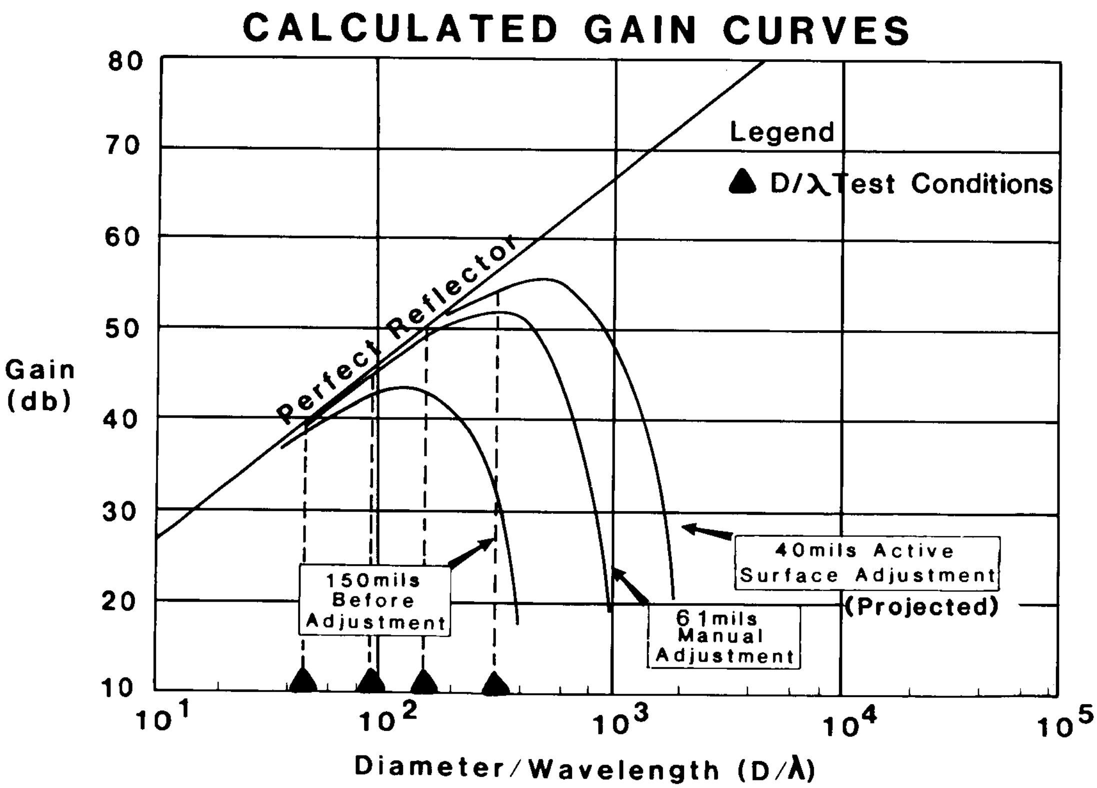


SURFACE SHAPE CONTROL CABLES

The geometry of one radial cord and its catenary rear truss cords is detailed in this chart. As can be seen, the reflector surface is shaped by the 4 cords which originate from the base of the column where the control motors are located. To minimize cost, only one quadrant of the reflector is planned for surface control so that there are a total of 28 control cords motorized on the antenna. Complete surface control is possible at a later time if funds become available. The control motor design is compatible with launch/stow requirements for potential future flight experiments on Shuttle as are planned in the COFS II Program (ref. 2).



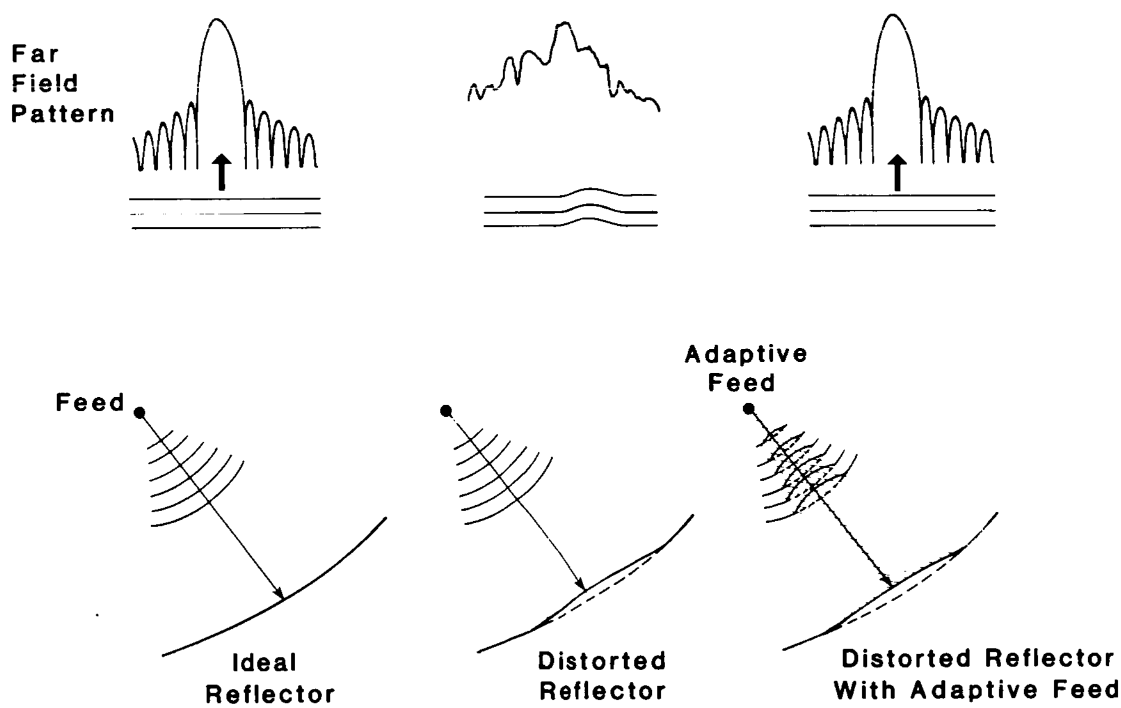
This graph shows the importance of reflector surface smoothness for achieving RF gain values near the diffraction limit (straight line function). The lower curve labeled "Before Adjustment" shows the Ruze calculated gain as a function of D/ for the 4 wavelengths tested at the Martin Marietta Near-Field Facility in 1985, before the reflector surface smoothness was manually adjusted using the control cords. As expected, boresite gain for the highest test frequency (11.6 GHz) showed serious performance loss for this 150 mils RMS surface accuracy. This condition was greatly improved by the control cord adjustment of the reflector surface to an RMS error of 61 mils as seen by the curve labeled "Manual Adjustment". Still further improvement is anticipated after the motorized control cord system has been put in place, since finer surface control will be possible and the structure will not be subject to hystersis errors which may have been introduced by cord tension release when the manual method was used. Although the Ruze model is useful in showing gain trends for random roughness reflector surfaces, more exact calculations are possible (ref. 3).



PHASE COMPENSATION

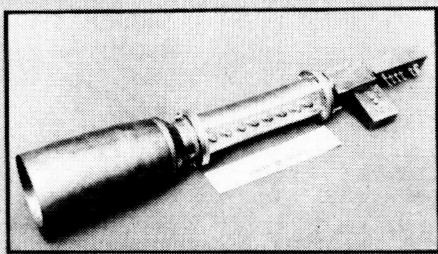
Several researchers have suggested that compensation for distortions in large parabolic reflectors is possible by means of an electronically controlled feed array. The principle of this concept is shown here. On the left side of this figure is shown an ideal reflector-feed combination working together to form an undistorted plane wave in the aperture plane of the antenna with a corresponding well formed far field pattern.

If a physical distortion in the reflector occurs, as shown in the center depiction, a proportional phase distortion will occur in the aperture plane with a resultant field pattern degradation in shape and boresite gain. For a feed that has phase front adjustment capability as is planned in the CSEI Program, a compensating distortion can be introduced to offset the phase perturbation caused by the physical reflector warp as shown on the right side of the chart. This type of performance correction would be possible for both rapid and slowly changing conditions.

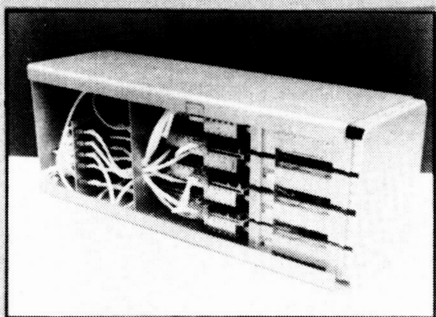


INTELSAT MULTI-HORN FEED

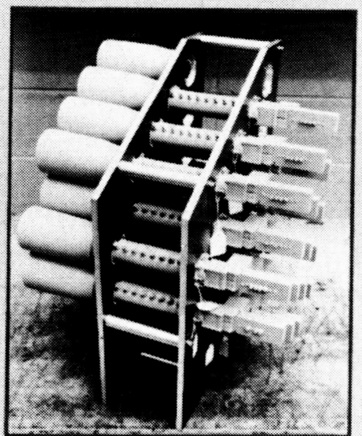
One of the feed designs being considered for compensation tests in the early phases of the program is the Intelsat multimode horn array. This photo shows the 24 element horn array mounted in the strong-back structure and the beam forming electronics network which controls the signal phase and amplitude to each active horn. This design, as well as an advanced feed design, is being evaluated for possible tests with the 15 meter antenna as part of the 4 year CSEI ground-based program.



SINGLE MULTIMODE HORN CONFIGURATION WITH POLARIZER



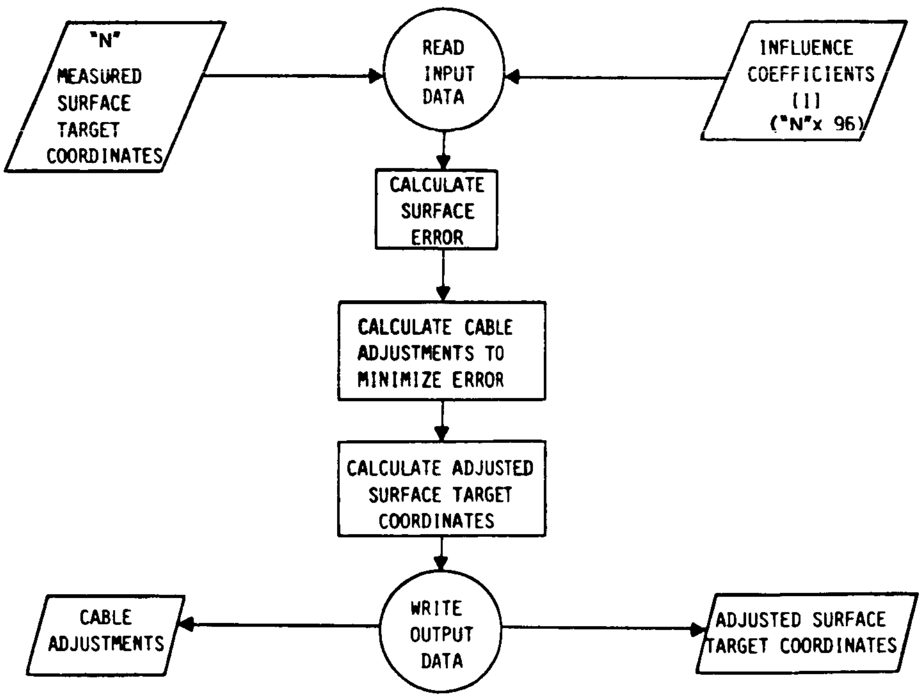
Beam Forming Network Assy.



RADIATING SOURCE ARRAY

REFLECTOR SHAPE CONTROL ALGORITHM

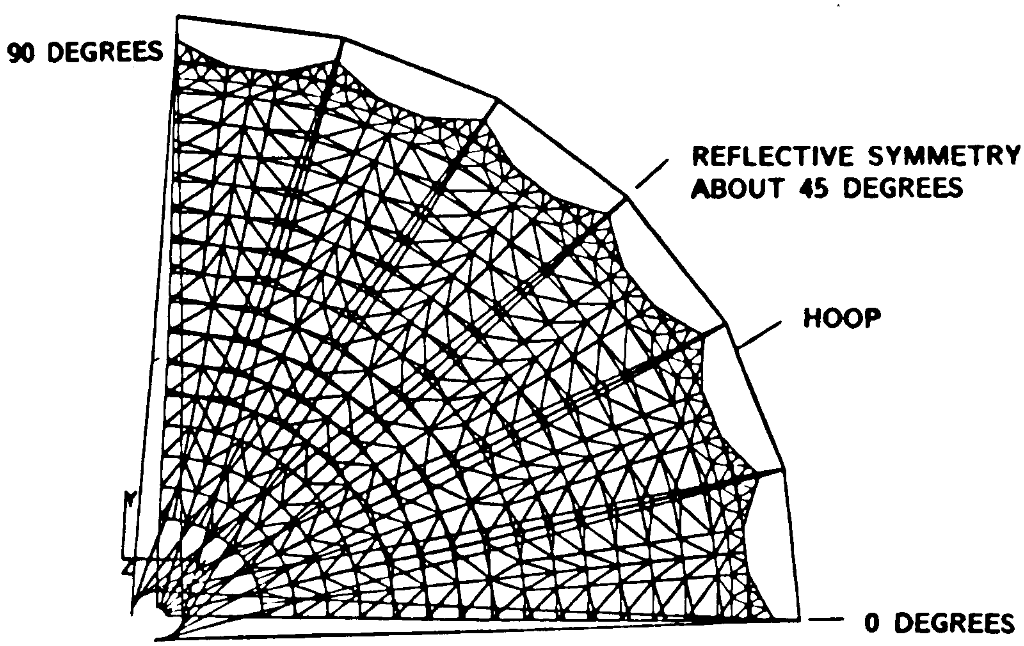
The procedure for surface adjustment is shown in this chart. Surface figure data will be provided by the optical sensor to the algorithm which will then determine the extent of deviation from an ideal parabolic reflector surface. Subsequently, these residuals will be used to set the control cable adjustments necessary to optimize the surface shape using influence coefficients derived from a finite elements model (EAL). This cable adjustment information is fed to the control circuit of the motorized control cords and implemented as a surface change. The intent of the design is to have the ability to control the surface up to approximately 15 Hz for small surface displacements. Initial tests will be restricted to quasi-static type surface adjustments with man-in-the-loop review at each step of adjustment. Later tests in the program may include closed loop surface control experiments.



ANTENNA STRUCTURAL MODEL

The Engineering Analysis Language (EAL) finite-element program was used to structurally model and analyze the antenna. A separate paper on this model is given by W. K. Belvin et. al. (ref. 4). The reflector shape for each quadrant is that of a parabolic segment with the vertex located about 50 cm from the column center. The design of the Hoop/Column antenna can accommodate other reflector shapes as needed by the user such as spherical, parabolic torus, and planar.

Although the minimum number of optical targets needed for surface definition has not yet been determined, it is expected that there will need to be at least one for every surface control cord. Measurements will also be required for the feed location relative to the surface in order to complete the definition of antenna figure. The optical system required to accomplish this has not yet been selected but several sensor candidates are available including a recently demonstrated laser radar sensor as well as a number of conventional angle sensing systems. The measurement accuracy goal is 7 mils RMS with each target sampled 100 times each second.



TOP VIEW

CONTROL EXPERIMENT CONCEPTS

The Hoop/Column antenna is a flexible structure which will experience excitation of flexible motion of the support structure, and static and dynamic distortion of the reflector surface. It is expected that such structural vibrations will degrade the R-F performance of the antenna. The purpose of the controls investigations is to demonstrate and define the performance improvement realized through active control of the structural dynamics.

It is intended to perform ground-based experiments which admit a high degree of fidelity to the on-orbit mission environment of the antenna. This should include both maneuvering of the structure and the rejection of on-board disturbances. The reflector shape sensors and cord actuators described in this paper will permit some damping augmentation of the reflector surface, but additional sensors and actuators will be needed for the slew maneuver.

OBJECTIVE:

- Demonstrate That Active Control Of The Structural Dynamics Can Improve The R-F Performance Of The Hoop-Column Antenna.

APPROACH:

- Emulate The Dynamic Environment Which Might Be Expected On-Orbit-i.e. Slew Maneuvers And On-Board Disturbance Sources.
- Use Base-Line Sensors And Actuators For Dynamic Shape Control.
- Add Cord Actuators For Hoop Control And Torque Actuators On Column For Slew Control (Phase III).

TEST PHASES

Two primary controls experiments are presently envisioned. The first is to use the planned reflector shape sensors and cord actuators to control the nominal shape and augment the damping of the reflector surface. The reflector shape adjustment would be accomplished in a quasi-static manner for Phases I and II. Damping augmentation would be accomplished using the actuator/load-cell micro-controller assemblies as decentralized control systems which implement local damping loops.

The second control task will be to implement a rapid slew maneuver of the antenna and maintain surface accuracy during that maneuver (Phase III). It may be possible to suspend the Hoop/Column antenna from a universal joint located in the center of the column. To accomplish the slew, it would be necessary to instrument the hoop with accelerometers and the column with angular rate sensors and accelerometers. These will provide feed-back for rigid body attitude control and structural vibration suppression. Actuators will consist of hoop cord actuators similar to those used for the surface cords. Scissors gyros (SG's) are proposed for each end of the mast to provide the slew control torques. The bandwidth of the SG's may be sufficient for column vibration suppression.

SHAPE CONTROL:

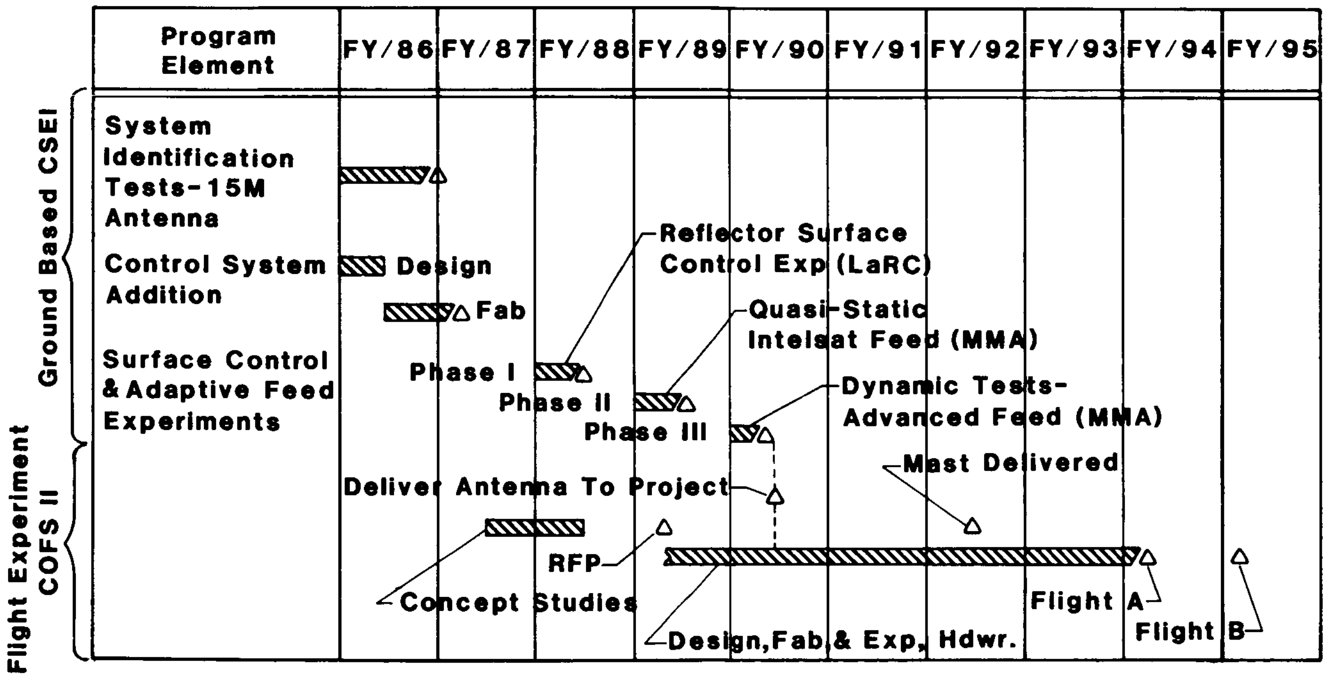
- Use Optical Sensor And Cord Actuators To Perform Quasi-Static (Automated) Shape Adjustments Of One Quadrant.
- Use Load Cells And Cord Actuators/Micro-Controllers To Augment Mesh Damping.

SLEW MANEUVER-RAPIDLY SLEW 10 DEGREES

- Suspend H/C From A Fixed Universal Joint.
- Instrument Hoop With Accelerometers And Column Ends With Angular Rate Sensors.
- Add Hoop Cord Actuators Around The Hoop To Control The Out-Plane Motion.
- Add Scissor Gyro Torquers To Ends Of Mast To Effect Slew.

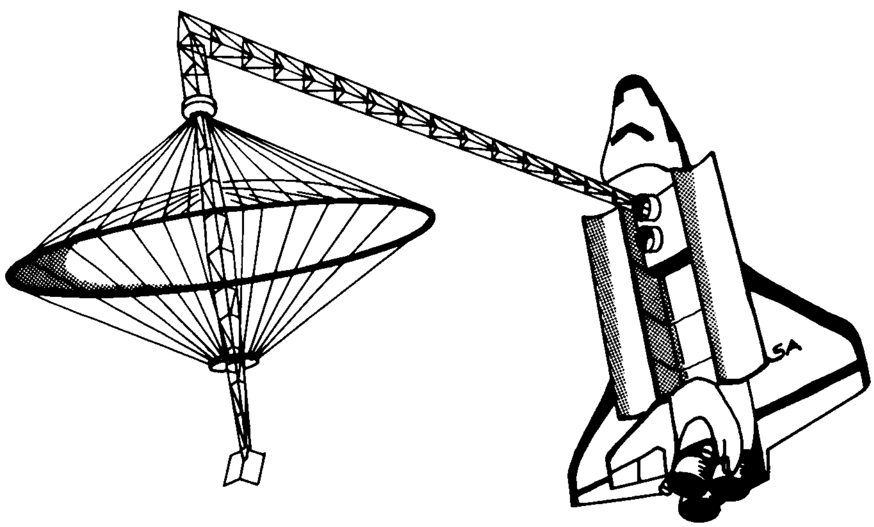
PROGRAM SCHEDULE

Static and dynamic testing of the antenna has just been completed in the Langley 16 meter vacuum chamber (ref. 4). Completion of this structural dynamics testing marks the beginning of the CSEI program. The design and fabrication of the CSEI surface adjustment system has now started and is expected to be completed by spring of 1987. The first testing phase of the CSEI program will begin with an evaluation of the surface adjustment system in the fall of 1987 to determine its ability to upgrade the reflector surface smoothness prior to going to the MMA Near-Field Facility for quasi-static RF testing (Phase II). Phase III of the program will include a return to the MMA facility with an advanced adaptive feed design and possibly closed loop surface control experiments. After completion of these three phases of testing, the antenna will be transferred to the COFS II Project Office for refurbishment as a potential flight article in that program. Flight tests are currently planned for FY 1994-95.



BASELINE CONFIGURATION FOR COFS II

This artist's sketch shows the baseline Hoop/Column configuration for COFS II flight experiment described in more detail by J. S. Pyle (ref. 2). The baseline configuration will utilize a portion (30 to 40 meters) of the COFS I MAST mounted on the STEP pallet in the Space Shuttle bay as the basic structure for the flight system. The tip of the Mast will be modified with an adapter structure for the purpose of mounting a two degree-of-freedom gimbal and the Hoop/Column antenna (baseline configuration). Shape control of one quadrant of its surface and control of the hoop also will be part of the baseline capability.



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1. James B. Miller, Elvin L. Ahl, Jr., David H. Butler, and Frank Peri, Jr.: Surface Control System for the 15 Meter Hoop/Column Antenna, NASA CP-2447, Part 1, 1986. pp. 533-546.

2. Jon S. Pyle and Raymond Montgomery: COFS II 3-D Dynamics and Controls Technology, NASA CP-2447, Part 1, 1986, pp. 327-346.

3. M. C. Bailey: Hoop/Column and Tetrahedral Truss Electromagnetic Tests, NASA CP-2447, Part 2, pp. 737-746, 1987.

4. W. K. Belvin and Harold H. Edighoffer: 15 Meter Hoop/Column Antenna Dynamics: Test and Analysis, NASA CP-2447, Part 1, 1986, pp. 167-186.