SURFACE ACCURACY MEASUREMENT SENSOR FOR DEPLOYABLE REFLECTOR ANTENNAS (SAMS DRA)

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OBJECTIVE

The objective of the Surface Accuracy Measurement Sensor program is to develop an optical measurement technology base from which a wide range of sensor systems for space applications can be derived. Example systems include:

Attitude transfer of isolated remote instruments: A typical instrument is positioned remote to the parent vehicle to minimize contamination of its functioning: it may be restrained at the end of a long flexible mast, or by a tether, or possibly at a short range free flyer.

Measurement of large antenna surface distortion: Distortions in the reflecting surfaces of large space antennas are to be measured in real time, providing 1) a means of assessing the antenna behavior, and 2) the sensor input for active surface control.

Aid in the manufacture and assembly of structures in space: The bending and twist of composite beams during the forming operation can be monitored, and the deformations of the resultant long beams during assembly can be continuously measured.

For the immediate program effort, however, the sensor system application is limited to large antenna surface distortion measurements.

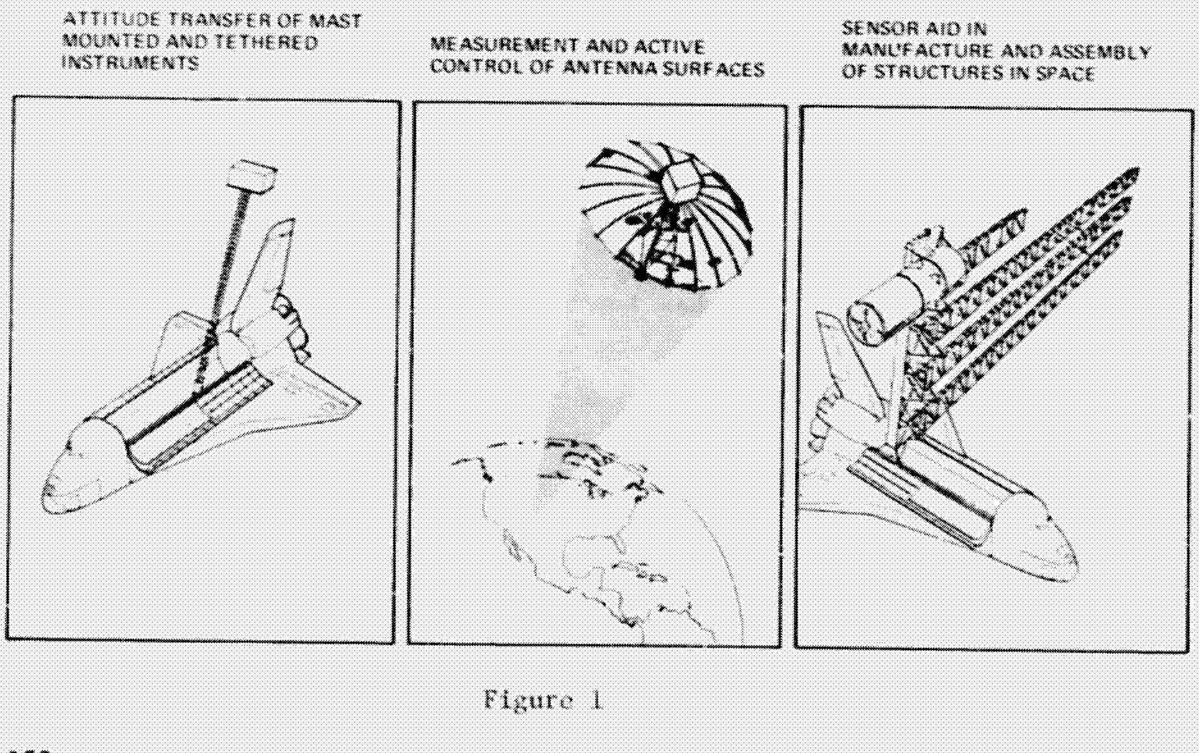

Figure 1

REPRESENTATIVE LARGE SPACE ANTENNAS

Of the candidate antennas for space applications, the nondeployable are limited (to be Shuttle compatible) to something less than 5 meters diameter, and the erectable antennas, although showing promise of hundreds of meters expanse, demand robotics, manipulators and/or extra-vehicular activities unavailable currently or in the near future. The deployable antenna, an antenna that can be stowed aboard the Shuttle in a single package and unfurled independent of Shuttle support, fills the gap, providing the technique for near-future realization of large, advanced space antennas. The current SAMS DRA program, thus, is specifically aimed at sensor systems for deployable antennas.

Representative of the deployable antennas are 1) the Harris Inc. Hoop-and-Column antenna, 2) the TRW Advanced Sunflower precision deployable antenna, 3) the Lockheed Wrap-rib configuration and 4) the General Dynamics Precision Erectable Truss Antenna (PETA). The Hoop-and-Column, the Wrap-rib and the PETA antennas provide mesh reflectors up to about 100 meters diameter. The TRW Advanced Sunflower, a solid surface antenna, may have a diameter perhaps as large as 30 meters.

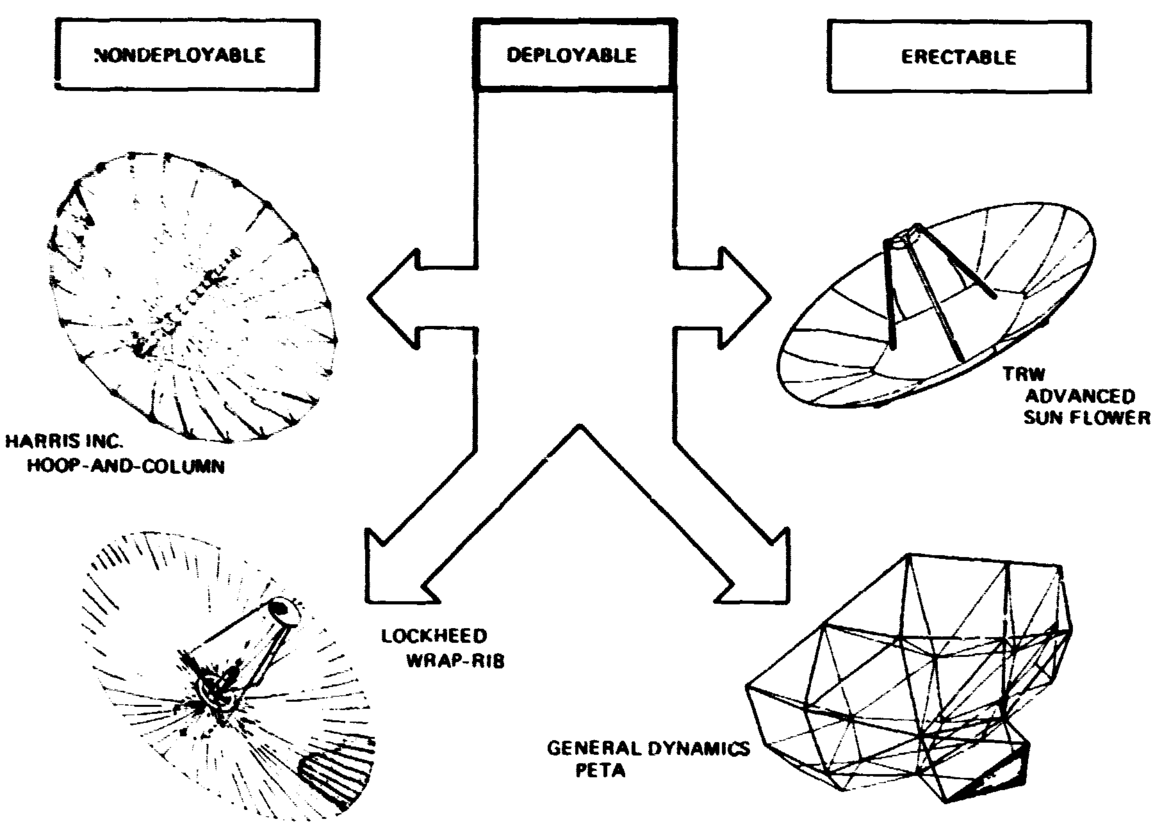

Figure 2

SENSOR SYSTEM REQUIREMENTS

In addition to providing the necessary measurement range and required accuracy, the SAMS DRA must be compatible with the space operation. If it is part of an active surface control system, its measurements must be made in real time, with signal outputs that conveniently interface with on-board microprocessors and that do not demand excessive computer manipulations. The measurement system must have long term stability, and must be unconfused by bright backgrounds such as glints from local structure and the sunlit earth.

Since the sensor likely will be operating with the antenna activated, the sensor elements cannot degrade the microwave properties of the antenna and cannot be affected by microwave interferences from the antenna and drive.

And for maximum assurance of success, the sensor system must rely solely upon established component technologies.

- REAL-TIME MEASUREMENT OUTPUTS
- IMMUNITY TO BACKGROUND (SUNLIGHT GLINTS, EARTHSHINE, ETC.)
- MEASUREMENT STABILITY
- COMPATIBILITY WITH SIMPLE REAL-TIME DATA PROCESSING (I.E., LINEAR RESPONSES)
- DIRECT INTERFACE WITH MICROPROCESSORS, FEEDBACK CONTROLLERS AND CONVENTIONAL RECORDERS
- MODULAR SYSTEM ELEMENTS: SIMPLE, RUGGED, INEXPENSIVE (EXPENDABLE IF NECESSARY)
- RELIANCE UPON EXISTING TECHNOLOGY BASE

Figure 3

TECHNICAL APPROACH

The two approaches toward the optical measurement of remote target displacements or deformations are: 1) optical ranging, in which the basic measurement is target-to-sensor range, and 2) optical angular sensing, in which the principal measurements are of target angular displacements lateral to the line of sight. For antenna distortion measurements, the techniques have constraints as illustrated in Figure 4.

> Target ranging: Ideally, the range measurement is made from the center of curvature of the reflecting surface, at a distance approximately twice the height of the feed point. More practically, the sensor head is at or just below the feed. Angular definition of the target requires auxiliary sensing, such as angle encoders at the sensor pointing means.

> Angular measurement: The ideal angular measurement is from a line of sight tangent to the reflecting surface; and here, the best position for the sensor is at or below the apex of the reflecting surface. Conversion of angular deflections to lineal deflections at the target requires a knowledge of target-to-sensor range (at reduced accuracy).

It is quite possible that the ultimate sensor system may be a hybrid, with both ranging and angle sensing capabilities. For its simplicity and compatibility with the antenna configurations, however, the angle sensing (triangulation) technique is the focus of the current effort.

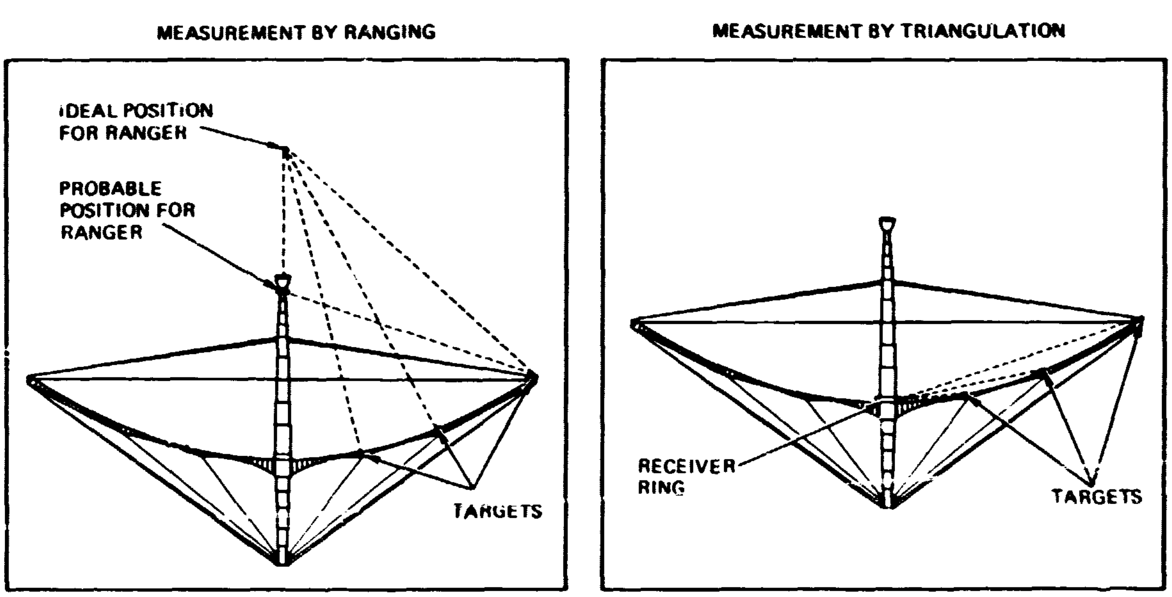

Figure 4

CURRENT PROGRAM

The following pages summarize the programmed effort under Contract NAS1-15520 for NASA Langley Research Center. This effort has been divided into three phases:

Phase 1: System Definition and Conceptual Design: After a review of the requirements for the four representative deployable antennas, conceptual sensor designs for each configuration are formulated and performance estimates made.

Phase 2: Proof of Concept Demonstration: The most critical areas, as pointed up by the conceptual design studies, are to be simulated in the Proof of Concept test. Results of the test establish the initial level of verification of the ultimate sensor system performance.

Phase 3: Fabrication and Test of a Breadboard Unit: The deliverable breadboard unit is a basic sensor receiver and suitable targets for test and evaluation by LaRC.

PROGRAM DESCRIPTION AND SUMMARY OF RESULTS

Figure 5

PROGRAM FLOW CHART

The central line of development is an iterative series of conceptual designs that become the basis for the breadboard. Paralleling this sequence, sensor system requirements, as established by the various antenna configurations and their interfacing, are continuously updated and refined, with the changes reflected in the sensor configurations. Along another parallel route, the characterization of the key components in the sensor system are validated and refined, leading to a final component selection for the breadboard.

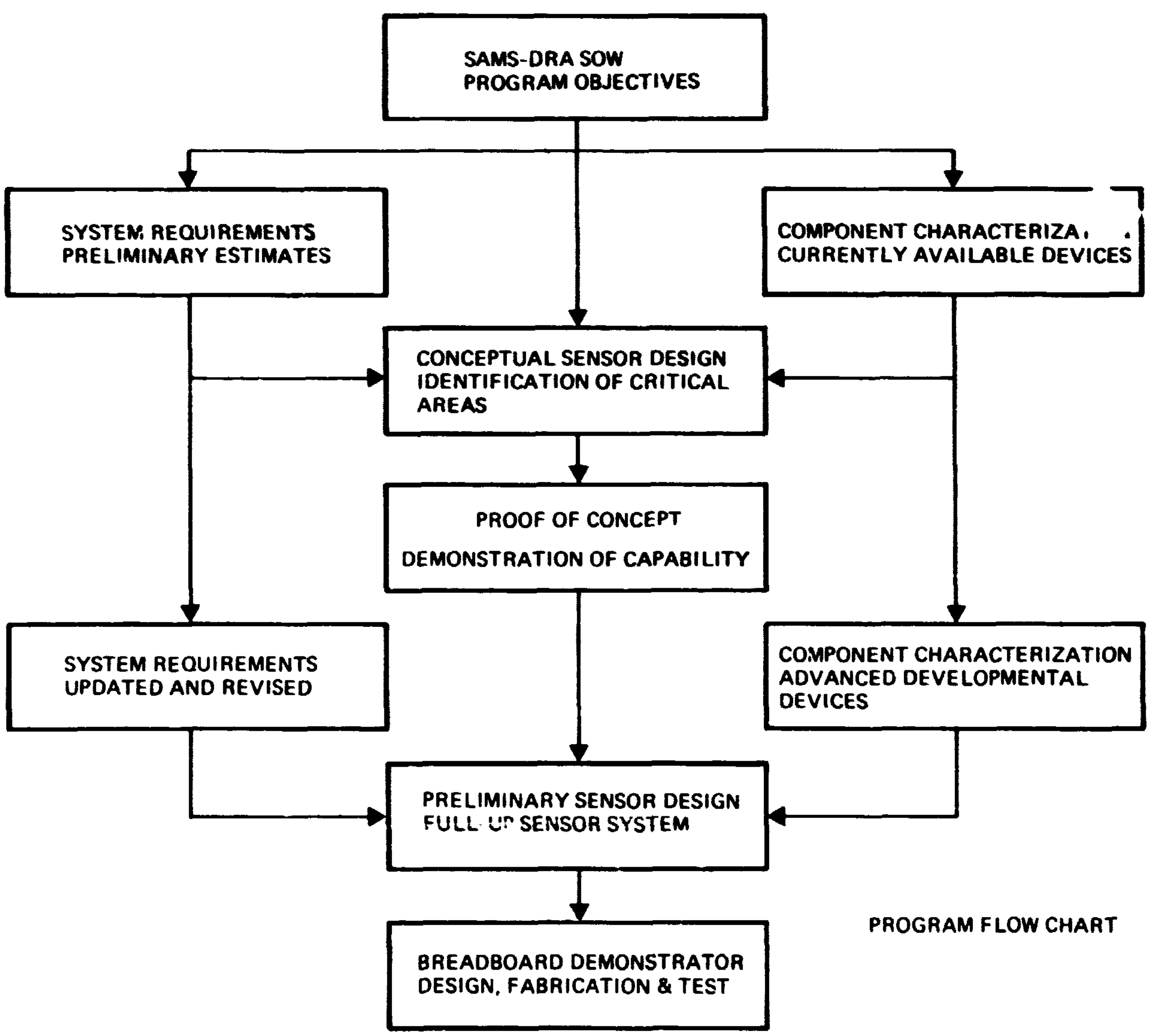

Figure 6

PROGRAM SCHEDULE

Starting in September of last year, Phase 1, System Definition and Conceptual Design, was completed in March, 1979, and Phase 2, Proof of Concept Demonstration testing was completed in August (Demonstration for NASA in September). Phase 3, Breadboard Fabrication and Test, is in progress.

The following pages gives a very brief review of the Phase 1 effort, and then discuss the tests and results of the Proof of Concept Demonstration.

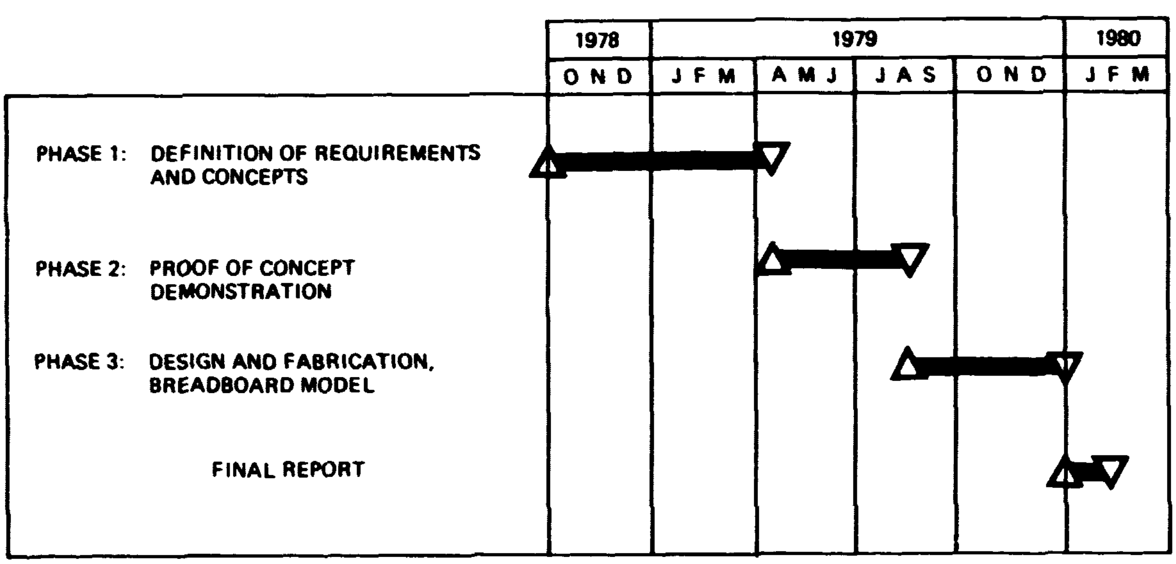

Figure 7

PHASE 1. DEFINITION OF REQUIREMENTS AND CONCEPTS

As discussed earlier, requirements for the four representative deployable antennas are to be defined; and from these requirements, conceptual designs for a suitable sensor system for each configuration is to be made. It is assumed at the outset that primary intent of the measurement system is to determine the behavior of an active, in-operation antenna. A reduced number (perhaps a hundred or less) target sample points at the antenna surface are adequate. It assumes that the fine-grain characterization of the antenna surface, demanding thousands of sample points, has been established by non-operational (e.g., photogrammetric) testing.

- SENSOR REQUIREMENTS FOR FOUR REPRESENTATIVE DEPLOYABLE ANTENNAS ARE TO BE DEFINED
- CONCEPTUAL SENSOR SYSTEM CONFIGURATIONS ARE TO BE ESTABLISHED FOR EACH OF THE ANTENNAS
- SENSOR COMPONENT CHARACTERISTICS ARE TO BE DEFINED
- PRELIMINARY ESTIMATES OF SENSOR SYSTEM PERFORMANCE ARE TO BE MADE

Figure 8

TYPICAL SENSOR SYSTEM CONFIGURATION

A typical sensor configuration is shown for the Harris Hoop-and-Column antenna. The coordinate reference system for all measurements is established at the antenna hub, near the apex of the reflecting surface. At this hub, a ring of optical, dedicated (i.e., non-scanning) receivers provide simultaneous coverage of the entire reflecting surface as represented by sample point targets at the mesh tie points and at the hoop. The targets may be active (i.e., light emitting diodes) or passive (i.e., retroreflectors, illuminated by light emitting diode projecters situated at the receivers). To minimize the number of receivers, each has multiple target coverage.

Range to the hoop segments, needed to convert the angular motions to lineal displacements, is determined stoichiometrically (noting that the separation between two adjacent targets at the hoop can be estimated, for example, by the hoop segment temperature). Range interpolation appears adequate for the intermediate targets between the hoop and the hub.

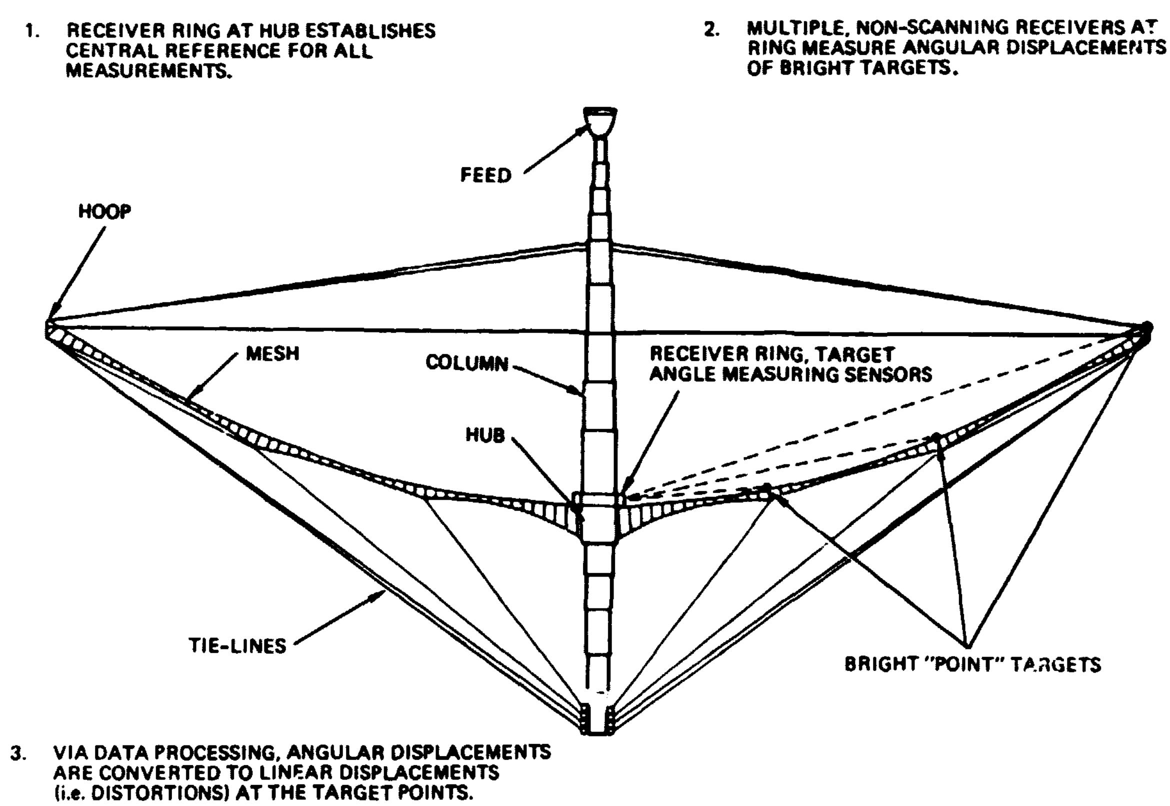

Figure 9

CONCEPTUAL CONFIGURATIONS SUMMARY

In the baseline antennas selected, it was assumed that the maximum diameter, Shuttle compatible, for the TRW Advanced Sunflower was 12.5 meters (this has later been revised upward), while the three deployable mesh antennas were 100 meter diameter. For all antennas, the minimum wavelength usable corresponded to 90 dB theoretical gain (10^4 wavelengths across the antenna). At this mimimum wavelength, the required accuracy in measuring surface deformation was a thirtieth of a wavelength. These requirements thus represent the most difficult cases (excluding the special applications where exceedingly high side lobe rejection is demanded).

From a sensor system viewpoint, the most challenging configuration is that for the Harris Hoop-and-Column. The preliminary estimate is that 120 sample points are needed for a 40 gore antenna, and two-thirds of these samples are at the unsupported mesh tie-points.

	TRW ADVANCED SUNFLOWER	HARRIS MAYPOLE	GENERAL DYNAMICS PETA	LOCKHEED WRAP-RIB
ANTENNA CHARACTERISTICS				
ANTENNA TYPE	PRECISION DEPLOYABLE	MESH DEPLOYABLE	MESH DEPLOYABLE	MESH DEPLOYABLE
DIAMETER RANGE	3 METERS TO 30 METERS	15 METERS TO 100 METERS	15 METERS TO 100 METERS	15 METERS TO 100 METERS
FREQUENCY RANGE	100 GHz TO 30 GHz	0.6 GHz TO 30 GHz	0.6 GHz TO 30 GHz	0.6 GHz TO 30 GHz
BASELINE ANTENNA MODEL				
CONSTRUCTION	36 FOLDING STIFF PANELS	40 GORE	8 BAY	80 RIB
DIAMETER	12.5 METERS	100 METERS	100 METERS	100 METERS
MAXIMUM FREQUENCY	240 GHz	30 GHz	30 GHz	30 GHz
MINIMUM WAVELENGTH	1.25 MILLIMETERS	1 CENTIMETER	1 CENTIMETER	1 CENTIMETER
SURFACE MEASUREMENT REQUIREMENTS				
MAXIMUM EXCURSION OF SURFACE (NORMAL TO OR TANGENTIAL IN SURFACE)	5 CENTIMETERS	50 CENTIMETERS	10 CENTIMETERS	20 CENTIMETERS
REQUIRED MEASUREMENT ACCURACY	40 MICROMETERS	333 MICROMETERS	333 MICROMETERS	333 MICROMETERS
NUMBER SAMPLE POINTS	36 AT PANEL TIPS	40 AT HOOP - 80 AT MESH	48 AT NODES	80 AT RIB TIPS
LOCATION	-	AT TENSION STRINGER TIE POINTS	-	-
TOTAL NUMBER OF SAMPLES	36	120	48	80

Figure 10

PHASE 2. PROOF OF CONCEPT DEMONSTRATION OB. ECTIVES

Of the sensor configurations for the four representative deployable antennas, that for the Harris Hoop-and-Column is the most demanding. Sampling targets at the hoop segments are at a range of about ' meters from the receivers. These targets, however, can be active (l. : emitting diodes). Intermediate targets at the mesh tie points are at lesser range, but may be required to be passive. Therefore both sensing modes, active with a light emitting diode target and passive with a retroreflector target, must be demonstrated. Moreover, estimated excursions of the targets from their nominal positions may be as large as 50 centimeters, total. With these conditions, the overall measurement accuracy at any target point is to be 333 micrometers.

Since it is impractical to realize a full scale demonstration, the Proof of Concept test was devised for a tenth scale. That is, the target-receiver distance was about 4.5 meters, the consequent maximum target excursion, 5 centimeters, and the required accuracy, 33.3 micrometers. To account for the change in target radiant power received, the target brightness was correspondingly scaled down.

- MOST DEMANDING APPLICATION IS THE HARRIS HOOP-AND-COLUMN ANTENNA
- BOTH ACTIVE (LED) AND PASSIVE (RETROREFLECTOR) TARGETS ARE TO BE USED
- TARGET-RECEIVER RANGE IS TO BE ONE-TENTH SCALE
- MEASUREMENT ACCURACY AND TARGET EXCURSION ARE SCALED ACCORDINGLY
- TARGET BRIGHTNESS IS REDUCED TO ACCOUNT FOR SCALING
- DEMONSTRATION IS TO BE: 1) MEASUREMENT ACCURACY
  2) MAXIMUM TARGET EXCURSION
  3) SIGNAL - TO - NOISE

Figure 11

PROOF OF CONCEPT SETUP

The Proof of Concept setup consisted of a single axis receiver viewing a target mounted on a precision two-axis traverse. Incremental adjustment accuracy of the traverse was 2.5 micrometers (.001 inches). Signals from the detector were amplified, electronically bandpassed, and fed to a systems voltmeter. Its digital output was sent to a mini-processor that computed the measured coordinate, X, of the target. Additionally, the computer gave as outputs 1) the signal sum (measure of the incident flux at the detector) and 2) the rms variation, or noise, in the signals.

The test consisted of performing a traverse at the target, recording the computer output at each traverse increment. From the results, the maximum measureable excursion at the target, the linearity of the response, the measurement accuracy, and the system noise could be determined. From the scale factor, these values could immediately be extended to the full size antenna sensor.

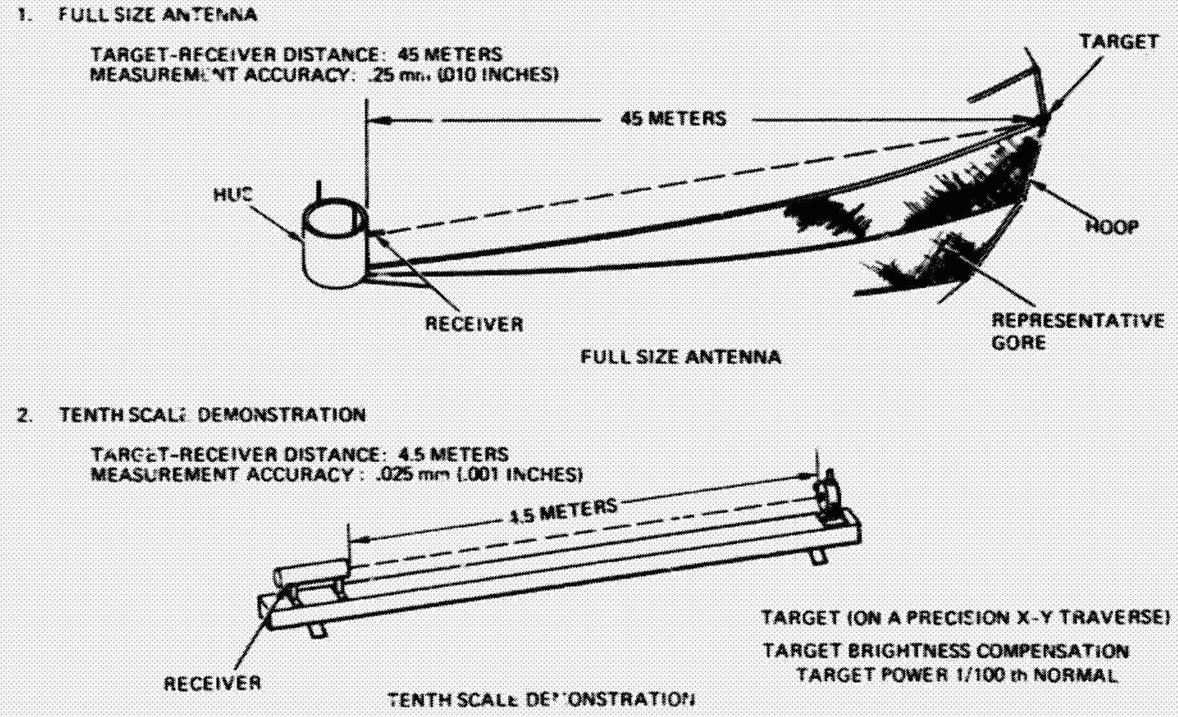

Figure 12

PROOF OF CONCEPT SETUP PHOTO

As shown in the photo, the setup was made on a 5 meter optical bench. At the extreme right the x-y traverse (moved forward in the picture) carried either a light emitting diode target or a retroreflector. In the retroreflector (passive target) mode, the target was illuminated by a light emitting diode projector - diode and beam shaping horn shown to the right of the receiver aperture. At the receiver, an objective lens imaged the target on a single axis, silicon PIN detector. Immediately aft of the detector is an electronic box enclosing the dual channel preamplifier-postamplifiers. Support electronics, including the 9825A Hewlett-Packard computer, are to the left of the setup shown.

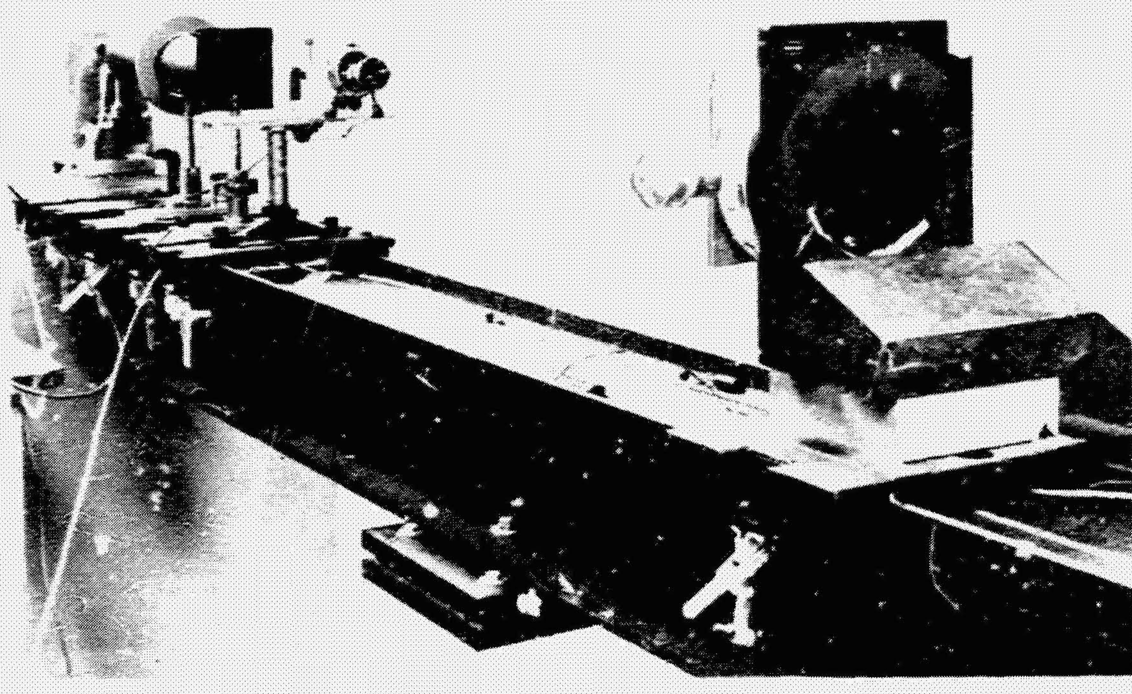

Figure 13

PROOF OF CONCEPT RESULTS

A comparison of the required and the measured performances for the Proof of Concept is made below:

	Required	Measured
Max. Target excursion		
At test setup	± 2.5 cm*	± 2.75 cm
Extrapolated to antenna	± 29.7 cm	± 25 cm
Deviation from linearity		
At test setup	31 µm**	8.8 µm
Extrapolated to antenna	333 µm	94 µm
Noise		
At test setup	31 µm	1 µm
Extrapolated to*** antenna	333 µm	11 µm

* The scaling was actually 10.7·1.
** This is the total measurement error allowed. In an error budget, at least half of this can be allocated to the sensor itself.
***Noise measure for the active target.

	DEMONSTRATION	FULL SIZE ANTENNA
RECEIVER - TARGET RANGE	4.5 METERS	45 METERS
MAXIMUM DEFORMATION MEASURED	± 2.5 CM	± 2.5 CM
MEASUREMENT SYSTEMATIC ERROR (DEVIATION FROM LINEAR)	7.5 µm (.0003 IN)	75 µm (.003 IN)
RANDOM ERROR (APPROXIMATELY ONE SECOND RESPONSE TIME)	2.5 µm (.0001 IN) RMS	25 µm (.001 IN) RMS

Figure 14