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TEST BED CONCENTRATOR (TBC)

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ABSTRACT

A point focussing concentrator design was adapted from an existing communications antenna for use in a solar test bed application. The structure design, configured for use with JPL's spherical radius mirror panels, made no attempt toward optimization. The key objectives of stiffness, pointing accuracy, and timely delivery were exceeded. The system weight is approximately 16,000 Kg (36,000 lbs) and has a calculated 1 sigma system error of 0.03 degrees. The completed installation of two concentrators was accepted one month ahead of schedule.

INTRODUCTION

The Test Bed Concentrator construction program required the integration of an existing proven satellite communications antenna design, with the latest development in mirrored panels, toward the objective of providing a high concentration point focussing solar collector. It is planned that this device be used to test receiver-engine systems operating on gas cycle principles as well as on high temperature steam cycles. Thus, it was imperative that the concentrator exhibit unusually high stiffness characteristics and pointing accuracy. Moreover, because of the increasing urgency of the overall solar programs, it was necessary that the TBC be ready for use in a relatively short time scale.

The Jet Propulsion Laboratory contracted with E-Systems to provide the collector primarily because of the company's extensive background and inventory of applicable structural designs. The program that ensued represented a truly cooperative effort between client and contractor that met or exceeded all technical and schedule goals.

REQUIREMENTS

The key contractual technical requirements for which E-Systems was responsible included:

- The development of a concentrator structure by adapting an existing, proven antenna structure design
- The design of the mirror panel geometry and mounting requirements (for integration into the JPL mirror design)
- The design of an interface structure for integrating the spherical radius mirror panels with the concentrator structure
- The design of a sun tracking control system which interfaces with existing JPL facilities
- The fabrication, installation, (including mirrors) and checkout of two TBC's at the JPL Edwards AFB site.

In support of these activities JPL was responsible for:

- Monitoring and approving the design activity
- Constructing the foundation to the E-Systems design
- Fabricating the mirror panels
- Aligning of the mirror panels after installation
- Providing site power and control system facilities and interfaces

Within the framework of these general requirements, the key design criteria are shown in Table 1.

TABLE 1 - KEY DESIGN REQUIREMENTS

• **PHYSICAL**	
Aperture Diameter	11 M (35 feet)
Rim Angle	45 Degrees
F/D Ratio	0.6
Focal Point Load	500 KG (1100 pounds)
Receiver Mounting	76 CM (30 inch) inside dia. ring
• **TRACKING CONTROL**	
Azimuth	
Travel	± 178 Degrees
Slew Rate (13 M/S Wind)	2028 Degrees/Hour
Elevation	
Travel	0 to 90 Degrees
Slew Rate (27 M/S Wind)	168 Degrees/hour
Tracking Accuracy (Operating Wind)	0.05 Degree
Pointing Accuracy	1.0 Degree
• **ENVIRONMENTAL**	
Operating Wind	13 M/S (30 MPH) Gusting
Survival Wind	45 M/S (100 MPH)
Seismic	0.25 G, Any Direction
Ice	0.4 CM (1 inch) Radial
Snow	0.4 KG/M^2 (10 lb/ft^2)

These specifications define a full motion structure, one capable of boresight pointing anywhere within a hemispherical envelope at rates deemed consistent with defocussing necessities. With only few exceptions, the requirements are also consistent with normal design criteria of antenna structures.

The most notable difference is in the anticipated focal point load. The collector requirement of 500 Kg (1100 pounds), the expected weight of the receiver and gas cycle engine, is an order of magnitude greater than the subreflector or feedhorn weight of comparably sized microwave antennas. Moreover, the f/D ratio of the TBC (0.6) is about double that normally encountered in microwave dishes. Thus, the moments and bending loads induced by the focal point requirements have an unusually high impact on the stiffness requirements of the structure and the accuracy characteristics of the design.

Additional design requirements were imposed relative to the mirror panels. The JPL designed mirror facets employ a thin, second surface glass mirror bonded to a spherically contoured foam glass substrate. The maximum size of foam glass blanks available from the manufacturer was 61 x 71 cm (24 x 28 inches). Thus the size of the mirror panels was limited accordingly. Other requirements included:

- Minimizing the number of panel sizes and shapes for maximum manufacturing and cost efficiencies
- A three point mount to minimize installation stresses
- Two degrees of radial adjustment to allow installation latitude
- Minimum inter panel gaps to maximize surface utilization

DESIGN

A 13 meter diameter communication antenna was selected for the TBC application. The antenna was originally designed for the RCA Domestic Satellite System and five units were subsequently constructed in continental U.S. Only the reflector structure was used for the TBC since the antenna was a limited motion satellite tracker with a maximum of 60 degrees of azimuth coverage. Therefore, an entirely new pedestal was designed for the TBC to enable full sky coverage.

Figure 1 shows the completed Test Bed Concentrator. The primary subsystems comprising the assembly are described below.

Reflector Support Structure

The Reflector Support Structure is a structural steel space frame consisting of eight truss beams radiating from a central hub, all interconnected with appropriate diagonal and intercostal members. The hub, which employs shear webs, is unusually large (it is unchanged from its 13 meter configuration) and exhibits exceptionally high stiffness characteristics. The only major modification required to adapt this structure to the TBC was an increase in the section modulus of the members comprising the two vertical radial beams which form the primary load path for the focal point mass. A parallel tube matrix serves as the interface structure for mounting the rectangular mirror panels on the radial reflector structure. Mirror attachment is effected by specially designed clamps which provide maximum adjustability for panel gapping and alignment.

Receiver Support

The receiver support structure is a tubular bipod interfacing the toroidal receiver ring at the focal plane with the periphery of the Reflector Support Structure. It is stabilized laterally and torsionally by adjustable rods which also attach at the periphery of the dish. The total structure thus minimizes the amount of surface blockage as compared to the more conventional, but no more stable, quadrapod mount.

Pedestal

The pedestal is an elevation over azimuth, wheel and track alidade. It is a fully triangulated, structural steel space frame, designed to transmit all loads from the elevation axis to ground in tension or compression. The azimuth axis is defined by the pintle bearing which is bolted to the foundation and reacts all radial and uplift loads. Gravity loads are reacted by the three railroad type wheels which ride on a 9 meter (29 ft) diameter track bolted and grouted permanently to the foundation.

Drives and Control

In azimuth, a 3 HP DC servo motor drives one of the three alidade wheels through a 740 to 1 gear reducer. Since the wheel to track ratio is 23 to 1, the overall speed reduction is over 17,000 to 1.

An identical 3 HP motor is used in elevation to drive a 20 ton screw type linear actuator through a single helical gear box. The total speed reduction in this axis is 160,000 to 1.

The control system provides for active sun tracking as well as program tracking. Active tracking (auto tracking) is accommodated via two photocell sensors, one for each axis, which generate error voltages as a function of position error. The auto tracking mode is used only after the concentrator has been positioned by program (or manually) to within 2.5 degrees of the sun.

Program tracking (Memtrack) employs the closed loop position control method, implemented through the use of a microprocessor. Aximuth and elevation angle data may be entered into memory as a function of time by recording actual sun position when in the autotrack mode. Ephemeris data may also be entered manually.

The Concentrator Control Unit (CCU) generates motor drive commands in all modes of operation. The motor commands are produced as a result of input commands from the front panel rate controls, from the internal tracking routine, or from the position commands. The closed loop output of the CCU is a low voltage analog signal proportional to the concentrator position error for each axis. Identical DC motor controllers provide the interface between the command output of the CCU and the high current requirements of the drive motors in both axes. The angular position of the concentrator is reported through the use of a multispeed synchro (analog) data package mounted on each axis and a synchro-to-digital converter within the CCU. The converted synchro information is also used to provide position loop feedback.

Weight Summary

A weight summary of the system is shown in Table 2. It is important to recognize here that no attempt was made to optimize the design of the TBC. The design employed was expedient and achieved the primary purposes of stiffness and a timely delivery.

TABLE 2 - STRUCTURE WEIGHT SUMMARY

E-Systems	
• Reflector Support Structure	12,000
• Receiver Support	1,300
• Panel Support Tube Matrix and Clamps	800
• Alidade	9,500
• Track	2,500
• Ancillary Equipment/Hardware	4,500
Subtotal	30,600 pounds
JPL	
• Mirror Panels & Bkts	3,600
• Focal Point Package	1,100
Subtotal	4,700
TOTAL WEIGHT ON CONCRETE	35,300

Analysis

The structure was comprehensively analyzed using both computer and manual methods. Several proprietary and library programs were employed of which the principal one was SPACE. This is a finite element program which relates applied loads to displacement and rotation at the joints, which in turn are used to calculate internal loads and stresses in the structural elements.

The system design was predicated on stiffness consideration rather than on stress. Thus, as the result of maintaining deflections within specified limits, the members are relatively lightly loaded and exhibit stress ratios generally well under 1.

In Table 3 the calculated system error analysis is compared to the specified requirements.

TABLE 3 - ERROR ANALYSIS

1 SIGMA

	SPECIFICATION	PREDICTED
Reflector Assembly		
• Reflector Support Structure	-	.0070
• Panel Support Tube Matrix	-	.0248
• Receiver Support Structure	-	.0019
TOTAL STRUCTURAL ERROR	$.02^{\circ}$	$.0258^{\circ}$
Control System		
• Servo Limit Cycle	-	.0001
• Servo Angular Error	-	.0001
• Servo Wind Gust	-	.0003
• Servo Bias	-	.0010
• Sensor Error	-	.0067
TOTAL CONTROL ERROR	$.05^{\circ}$	$.0068^{\circ}$
Combined System Error	$.07^{\circ}$	$.0267^{\circ}$

The predicted combined system error is thus only about one third of that specified. As a result of this increased accuracy, improved performance of the TBC in the form of higher concentration ratios can be anticipated.

Installation

The design, as well as the program plan for the TBC, gave heavy consideration to minimizing on site installation time. To accomplish this objective it was necessary to ensure that all parts fit properly prior to arrival on site. Thus, the key acceptance criteria for the steel fabrication phase was trial assembly of the reflector structures and pedestals at the fabricator's facility in Birmingham, Alabama.

The reflector structure was designed so that it could be completely constructed at ground level, including mirror panels and placed on the pedestal in a single lift. A 45 ton, 100 ft. boom hydraulic crane was employed for a total of 3 days to place both reflector assemblies. (see Fig. 2) This served the dual purpose of minimizing both assembly time (construction directly on the pedestal is commonplace in antennas) and costly large crane expenses. For the remainder of the installation, an inexpensive 7 ton crane served more than adequately. It is noteworthy that the E-Systems installation team consisted of one supervisior and three ironworkers full time, supported part time by the control system subcontractor. Installation of the TBC's, including tracking and control system operational checkout, required a total of two months.

Acceptance of the installation by JPL on 17 October 1979 represented completion of the entire contract one month ahead of schedule.

TABLE 4 - KEY EVENTS

	CONTRACT	ACTUAL
DESIGN START	13 Sept. 1978	13 Sept. 1978
FABRICATION START	-	5 Apr. 1979
INSTALLATION START	-	13 Aug. 1979
FINAL ACCEPTANCE	13 Nov. 1979	17 Oct. 1979

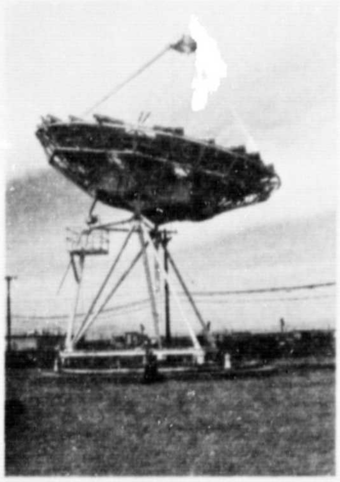

Fig. 1

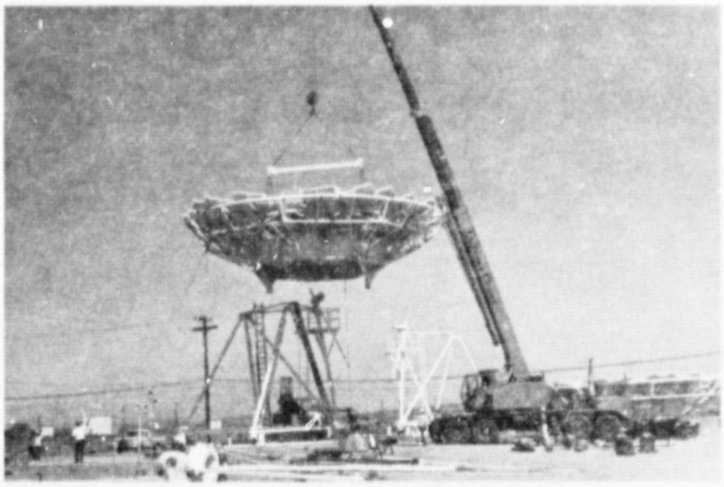

Fig. 2