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An Antenna Servo Test Bed for the Deep Space Array Network

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This article presents the development and functions of the servo test bed and the antenna pointing computer as a first step in the development of the Deep Space Array-Based Network (DSAN) antenna servo system. The test bed will assist in the development of servo control algorithms, monitor and control interfaces, and antenna pointing and calibration software. The test bed is used in a laboratory environment and contains motors 1/10 the actual size and many of the same components that will be used in the larger 6-m breadboard antennas.

I. Introduction

When completed, the Deep Space Array-Based Network (DSAN) will consist of numerous 12-m antennas arrayed together to form a large single aperture. Before committing to the large array, a prototype array of antennas will be built. First, three 6-m breadboard antennas will be built, followed by a small number of 12-m prototype antennas. Gradual development using the breadboard and prototype antennas will allow optimization of fabrication techniques, minimization of cost, and gradual development and testing of control software.

The DSAN antennas will use DC brushless motors and a digital control system unlike the DC brush motors and analog control system used in most of the present deep-space antennas. Since this will be a somewhat new technology, the antenna servo test bed has been assembled to provide a means of developing new servo control algorithms, monitor and control interfaces, and antenna pointing and calibration software before the 6-m antennas are completed.

In order to operate the antenna servo system, a control computer, called the Antenna Pointing Computer (APC), is developed in parallel with the servo test bed. The APC will generate the necessary commands to the servo system in order to verify proper dynamic operation and pointing accuracy.

II. Servo Test Bed

The test bed is a scaled-down version of the 6-m antenna (see Fig. 1). Minex Engineering performed the detailed mechanical design and fabrication of the test bed, based on a sketch from JPL. Minex also selected the amplifiers, motors, gear boxes, encoders, pinon gears, main gear, and lead screw actuator.

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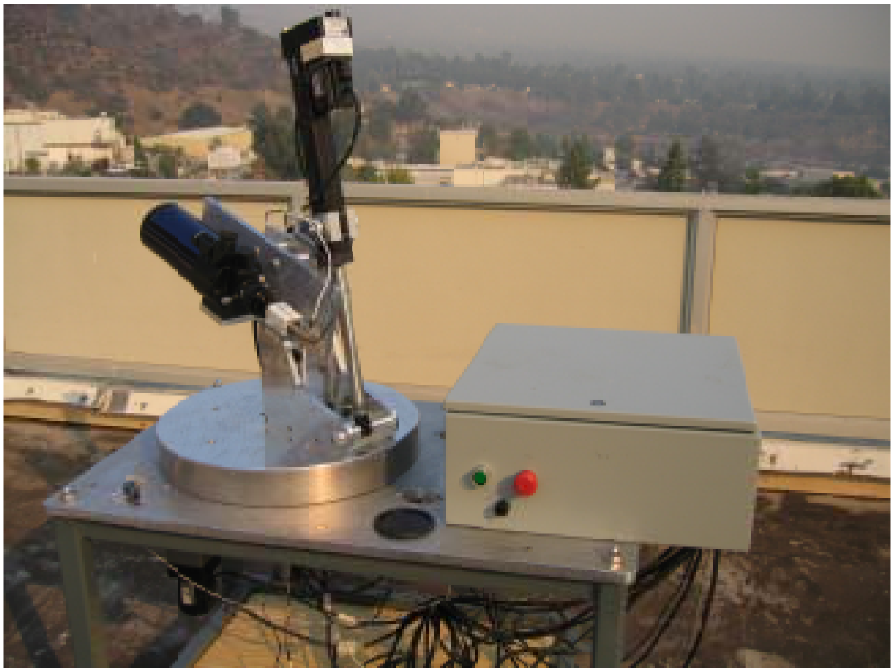


Fig. 1. Photograph of the test bed.

The design is very sturdy and includes both caster wheels and retractable leveling legs. Dual azimuth motors are provided specifically so that anti-backlash algorithms could be developed.

The test bed was designed to be a scaled-down version of what will be installed in the 6-m antennas, called the breadboard array. Table 1 shows the differences between the components in the test bed and ones to be used in the breadboard array. Notice the similarity between the components in the test bed and those in the breadboard. A block diagram of the test bed is shown in Fig. 2.

The servo motors used are Glentek model GMBM60100. These motors are three-phase DC brushless and deliver 0.186 Nm of torque at 5000 revolutions per minute (rpm). These motors include a 3000-line quadrature encoder. The encoder signals are first sent to the servo amplifiers, where they are used if the amplifier is operated in velocity mode, and then sent to the servo controller, where the velocity of the motor is considered in the control algorithms.

The servo amplifiers are Glentek model 9800 amplifiers. These amplifiers are sized to match the motors' required current. These amplifiers have built-in power supplies where the breadboard amplifiers, model 9815, require an external power supply. The amplifiers include a digital signal processor (DSP) that performs many control algorithms. The amplifiers can be operated in either velocity mode or current mode. In this application, the active anti-backlash technique used requires that the current mode be used. Basically, the amplifiers are configured such that a ±10-VDC analog input from the controller will provide ±1.65 A of current. The servo motors and amplifiers used in the test bed are sized to be about 1/10 that of the ones to be used in the 6-m antenna.

Glentek provides a software configuration package called Motion Meystro. This software can be used to operate a single amplifiers/motor combination. The software configures the amplifiers' parameters and sets the operating mode, current limits, bandwidths, gains, etc.

The servo controller is a four-axis Douloi model MSB V4E2. This unit was selected because it is a stand-alone module rather than a personal computer (PC) board that plugs into a PC computer. The

Table 1. Differences between the test bed and breadboard components.

Parameter	Simulator	Breadboard	Comment
Power	115-VAC single phase	115-VAC 3-phase	
Motor size	1.5 A	15 A	
Servo amplifiers	Glentek 9800	Glentek 9815	Same interface to the controller
Servo controller	Douloi MSB-V4E2	Douloi MSB-V4E3	
Azimuth total gear reduction	2900:1	1740:1	
Motor gearbox reduction ratio	290:1	87:1	
Pinion teeth	16	16	
Main gear teeth	160	320	
Elevation gear reduction	90 motor revolutions = 1 deg	48 motor revolutions = 1 deg	
Azimuth–elevation limit switches	Yes	Yes	
Motor brakes	No	Yes	
Elevation drive method	Lead screw actuator	Lead screw actuator	Breadboard lead screw actuator has a brake
Azimuth drive method	2 motors with active anti-backlash	2 motors with active anti-backlash	
Azimuth encoder	Differential, multi-index, Gurley, 144,000 counts rev	Differential, Multi index, Gurley, 144,000 counts rev	2.5-mdeg step
Elevation encoder	Differential, multi-index, Gurley, 144,000 counts rev	Differential, multi-index, Gurley, 144,000 counts rev	2.5-mdeg step
Control interface	Serial RS-232	Serial RS-232	

controller, as configured, contains a 140-MHz Intel 486 processor. The controller has four 12-bit digital-to-analog converters (three of them used), inputs for six quadrature encoders (five used), one user serial input port, optically isolated digital inputs and outputs, and emergency stop controls.

Douloi supplies a software development system for use with their controllers. The software development system allows software to be written in Pascal. The development process allows the user to generate control screens using graphical user interface (GUI) components such as are available in Visual Basic, i.e., control buttons, text input boxes, labels, etc. Although the supplied software does not provide the capability of Visual Basic, it is sufficient for the development of the desired application. Once the software is developed, it can be saved into flash memory. When the controller is powered up, with the software development computer disconnected, the program runs stand-alone.

The controller incorporates a multitasking operating system. In this application, so far, only three tasks are needed: (1) monitoring the serial port, (2) calibrating the axis encoders, and (3) controlling the servo loop. The first task monitors the serial port for commands. When a command string is received, it is parsed, and the desired action is carried out. Commands include

- Set the desired azimuth (AZ) and elevation (EL) at a particular time
- Return the current azimuth and elevation
- Return the servo pointing error

- Set the servo control parameters
- Set the logging parameters
- Start logging the performance parameters into a buffer
- Return the logged performance parameters from the buffer
- Start the main servo loop task
- Start the encoder calibration task
- Stop all tasks other than the communication task (which is never stopped)
- Set the encoders to a specified azimuth and elevation

The second task is to calibrate the differential encoders. The Gurley differential encoders used in this application generate a quadrature encoded signal that can be monitored to determine axis motion. The encoder actually has 3600 quadrature encoded lines that are interpolated to 36,000 lines, and then the quadrature effectively results in 144,000 lines per revolution (2.5 mdeg per step). While some differential encoders have only one index used as a zero reference, these encoders have 48 index signals spaced at different intervals. By knowing how the indexes are spaced, the encoder can be calibrated as to absolute position by moving a maximum of 15 deg in any direction. The calibration task moves first in elevation and then in azimuth until two indexes have been crossed. The controller has a built-in function that accurately latches the encoder count whenever an index is crossed. So, by slowly moving in elevation (or azimuth) and monitoring when the index is crossed and noting the latched value at the index crossing, the

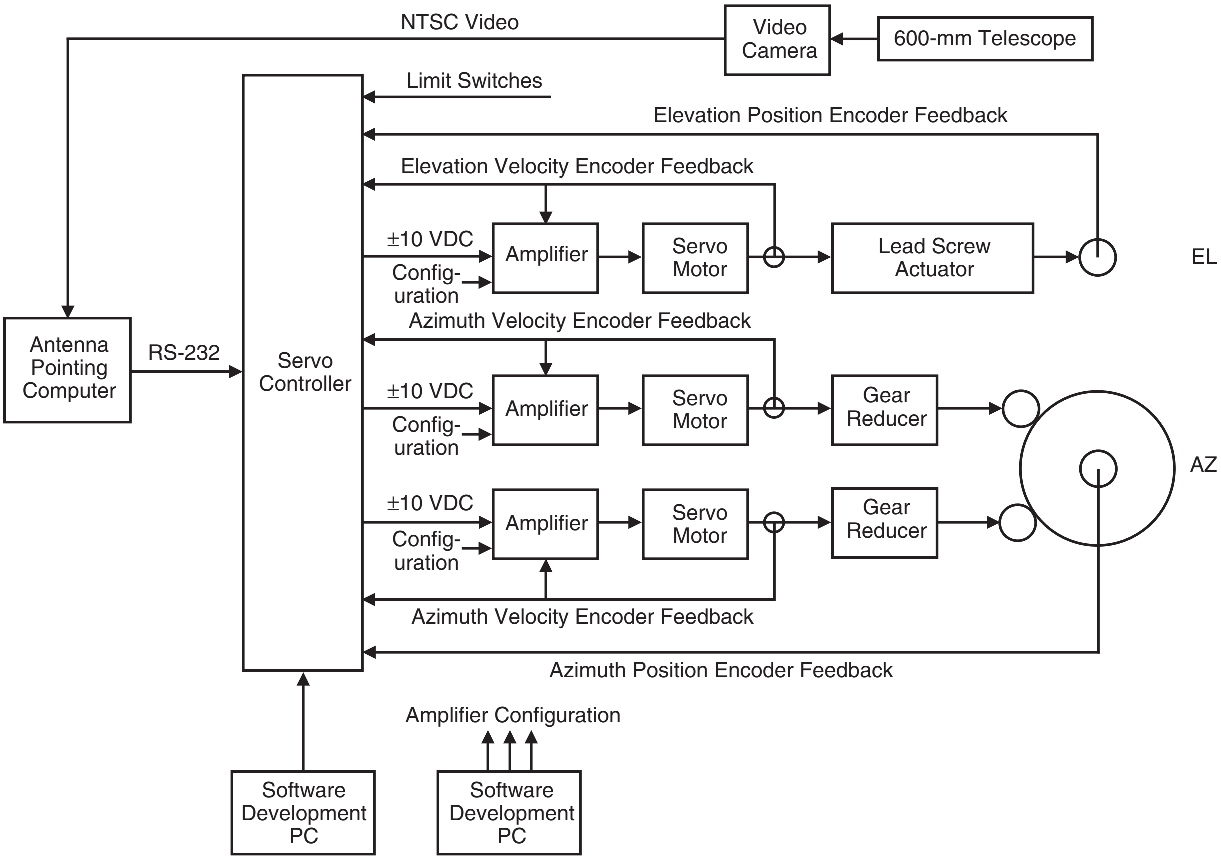


Fig. 2. Block diagram of the servo test bed.

distance between indexes is established and the absolute position determined. As long as the controller retains power, the calibration is maintained.

The third task is the feed-forward servo control loop. The servo loop operates at a 200-Hz update rate. The initial loop is a standard position integral derivative (PID) control loop with a command preprocessor. The more advanced final servo loop will be of the linear quadratic Gaussian (LQG) type [1]. The active anti-backlash algorithm is contained within the servo control loop.

Azimuth and elevation commands are sent from the APC every second. A part of the servo loop is an interpolator that calculates the desired azimuth and elevation at the 200-Hz loop update rate between the 1-s inputs from the APC.

The azimuth and elevation positions are determined from the 144,000-line axis encoders. The motor velocities are determined from the difference in motor encoder counts between successive loop update times, 5 ms.

The servo amplifiers are operated in a torque mode. The servo loop outputs from the servo controller are calculated numbers that are applied to a digital-to-analog converter. The analog output is applied to the servo amplifiers that give a current (torque) proportional to the applied voltage.

An optical telescope is attached to the test bed in lieu of a real microwave antenna. The telescope is the optical tube from a Meade ETX90-RA. Attached to the telescope is a PC-164-EX charge-coupled device (CCD) camera with a sensitivity of 0.003 lux, easily sufficient to see stars brighter than a magnitude of 5. As will be described later, the telescope is used to verify proper pointing and tracking performance in real time when the APC controls the test bed. The telescope has a 1250-mm focal length and when used with the 8.5-mm PC-164 CCD results in a field of view of 180 × 120 mdeg.

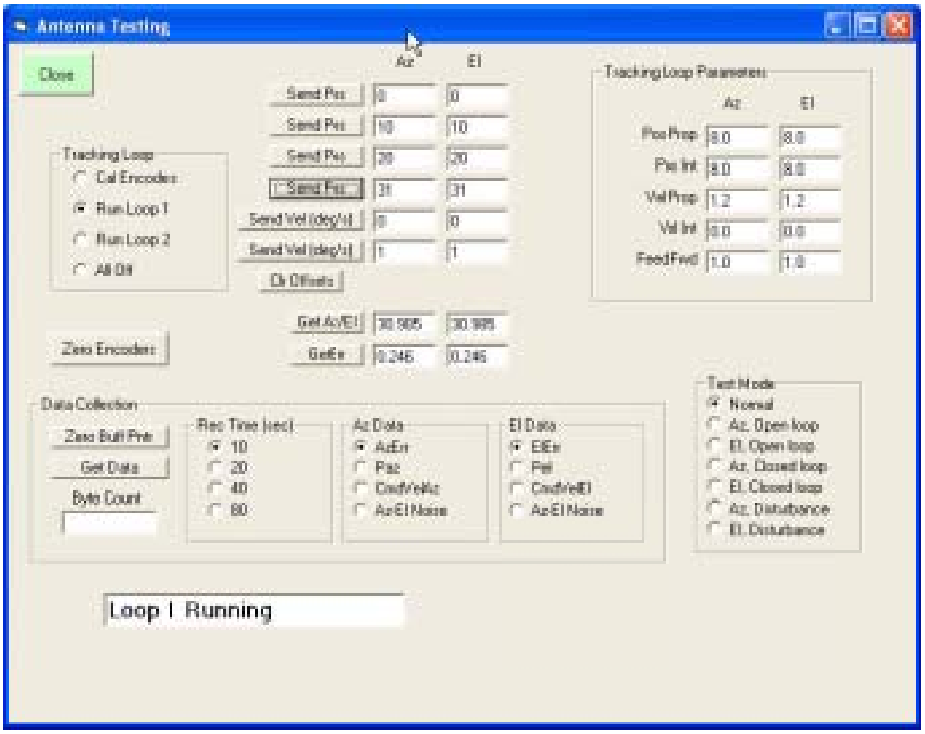
III. Antenna Pointing Computer

The APC, a standard PC programmed in Visual Basic (VB), remotely controls the test bed. Visual Basic was selected because it provides a graphical user interface and allows rapid software development. Another important benefit of VB is that, due to its popularity, most special-purpose hardware is supplied with drivers for VB. In this application, a video frame grabber module, with its drivers and interface, is required.

Communication between the APC and the servo controller is via serial RS-232 at 115.2 kbaud. The breadboard system will use a fiber-optic link to carry the serial signal from the APC to the antenna.

When completed, the APC will have multiple screens that will be used to monitor and control different aspects of the breadboard array. So far, two screens have been implemented. The first screen, shown in Fig. 3, is the antenna maintenance screen. In this mode of operation, servo maintenance and testing is performed. Specifically, it will

- Send servo control parameters to the controller
- Perform axis encoder calibration
- Specify logging parameters
- Retrieve logged data and save them to a file for post-analysis
- Start and stop specific tasks
- Command position and velocity offsets to the servo system



	Az	El
Send Pos	0	0
Send Pos	10	10
Send Pos	20	20
Send Pos	31	31
Send Vel (deg/s)	0	0
Send Vel (deg/s)	1	1
Get Az/El	30.985	30.985
Get Err	0.246	0.246

Tracking Loop Parameters

	Az	El
Pos Prop	8.0	8.0
Pos Int	8.0	8.0
Vel Prop	1.2	1.2
Vel Int	0.0	0.0
FeedFwd	1.0	1.0

Tracking Loop
- ○ Cal Encoders
- ● Run Loop 1
- ○ Run Loop 2
- ○ All Off

Data Collection

Rec Time (sec)
- ● 10
- ○ 20
- ○ 40
- ○ 80

Az Data
- ● AzErr
- ○ Pos
- ○ CmdVelAz
- ○ Az-El Noise

El Data
- ● ElErr
- ○ Pos
- ○ CmdVelEl
- ○ Az-El Noise

Test Mode
- ● Normal
- ○ Az. Open loop
- ○ El. Open loop
- ○ Az. Closed loop
- ○ El. Closed loop
- ○ Az. Disturbance
- ○ El. Disturbance

Loop 1 Running

Fig. 3. The antenna maintenance screen.

The second screen, shown in Fig. 4, is the antenna pointing calibration screen. This screen is designed to perform antenna pointing calibration. The heart of this package is the ability to point to and track a target, normally a star. The APC contains the algorithms to convert the right ascension and declination of any star to azimuth and elevation in real time. The APC also has the capability to incorporate the fourth-order pointing model, perform manual offsets, measure pointing error, and record the data to a file for post-processing. Post-processing of the error data results in a new improved pointing model that is loaded into the APC for improved pointing performance.

The APC contains a Picollo video frame grabber that is connected to the PC-164 CCD mounted on the telescope. Eurosys software drivers and a VB interface are supplied with the Picollo frame grabber. Additional software written in C scans the captured video image and determines the coordinates of the star in the field of view. By knowing that the field of view is 180 × 120 mdeg and the star location, the pointing offset can be measured.

The process of gathering antenna pointing data is automatic. When commanded to start, the APC will open a file of about 40 stars positioned reasonably uniformly around the sky. As the right ascension and declination of each star are loaded, the APC will command the test bed to track that star. When the servo error has reached less than 2.5 mdeg, the video frame grabber captures the image. The pointing error is measured and saved to a file; then the next star is loaded and the process continues. The entire data-gathering process takes less than an hour. Once the data have been collected, a Matlab script processes the data to create a set of parameters for the improved pointing model.

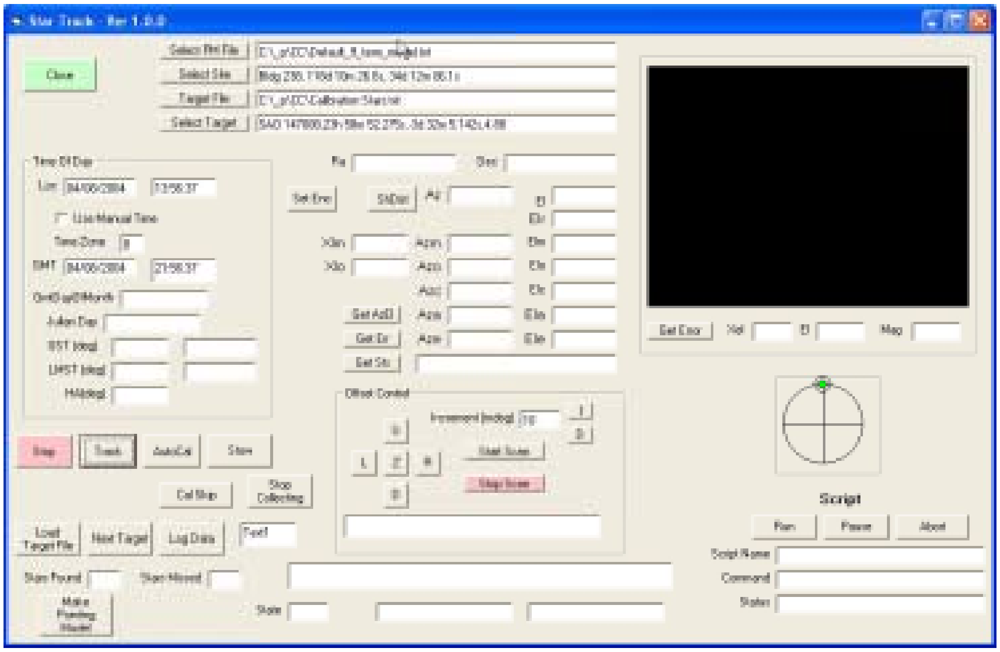


Fig. 4. The antenna pointing calibration screen.

IV. Conclusions

This article showed that the servo test bed can successfully simulate the DSAN antenna pointing and tracking tasks and that the APC accurately controls the test bed motions. The test bed has proven invaluable in accelerating the development of new algorithms and techniques required for the DSAN antennas.

Reference

[1] W. Gawronski and H. Cooper, "Control System of the Array Antenna Test Bed," *The Interplanetary Network Progress Report*, vol. 42-157, Jet Propulsion Laboratory, Pasadena, California, pp. 1–12, May 15, 2004. http://ipnpr/progress_report/42-157/157A.pdf