THE JPL MECHANICALLY STEERED ANTENNA

N88-25715

JEFF B. BERNER, Mobile Satellite Program, Jet Propulsion Laboratory, California Institute of Technology, United States; DAVID J. BELL, Mobile Satellite Program, Jet Propulsion Laboratory, California Institute of Technology, United States.

CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY
4800 Oak Grove Drive 161-228
Pasadena, California 91109
United States

ABSTRACT

JPL has designed and developed a mechanically steered antenna for tracking satellites in a mobile environment. This antenna has been used to track an L-band beacon on the MARISAT satellite. A description of the antenna and the results of the satellite experiment are given.

INTRODUCTION

NASA has been developing the technology for mechanically steered vehicle antennae having 10 to 12 dBi of gain for use in L-band (1600 MHz) MSAT applications (Bell, 1986). While more expensive than omni-directional antennae, the directional antennae offer two major advantages. First, they save spacecraft power by a possible factor of ten through higher gain and better multipath discrimination. But, more importantly, due to narrower azimuthal beams, they allow two spacecraft to provide coverage of CONUS at the same frequencies. Through proper design of the vehicle's antenna, it is possible to keep the main beam of the antenna pointed toward the desired spacecraft while radiating considerably less energy toward the second spacecraft (also operating at the same frequency).

OPERATION

Figure 1 is a block diagram of the mechanically steered antenna developed at JPL. The radiating part is a linear array of four square microstrip patches tilted with respect to the ground plane to provide elevation coverage from 20° to 60° with a minimum of 10 dBic gain. This configuration provides up to 6 dB more gain than a low gain omnidirectional antenna. The rotating antenna platform is mounted on a fixed platform that includes a stepper motor, the motor driver and the pointing system hardware. A cylindrical radome, with a diameter of 20 inches and a height of 9 inches, covers the antenna system and produces insignificant effects on the RF pattern characteristics.

The initial pointing, or acquisition of the satellite, is achieved by seeking the direction of maximum power reception from a satellite transmitted pilot signal. Subsequent tracking uses a pseudo-monopulse radar technique. The 1 X 4 antenna array is divided into two identical subarrays and signals from each subarray are passed through a hybrid coupler producing sum and difference signals. The difference channel output is modulated by a square wave and added to the sum signal via a coupler. The composite signal is routed to a receiver which decouples and detects the difference signal. The difference signal is then normalized by detected sum signal to correct for signal fading up to 250 Hz. This normalized difference signal is the antenna tracking error signal (Jamnejad, 1988).

The pointing control computer that operates the pointing control loop uses the error signal to rotate the antenna platform azimuthally with a stepper motor. A vehicle turn rate sensor is used to maintain pointing toward the satellite when the received signal level fades below a prescribed threshold. This open loop tracking mode allows the antenna to point at the satellite even if it is blocked from the antenna's view. The rate sensor also serves as an inertial reference during the initial satellite acquisition (Berner, 1987).

The rate sensor, motor controller, motor, and drive assembly are placed on the fixed base plate of the antenna system. The antenna array, the sum/difference hybrid, the coupler, and the difference signal modulator are placed on a rotating circular platform, which constitutes a "ground plane" for the array and is stacked on top of the base plate assembly. RF connection between the fixed and moving parts is made through a single channel rotary joint which forms the common central axis of the fixed lower platform and rotating upper platform of the antenna. This rotary joint is surrounded by a set of five slip rings, which provide low frequency and DC signals for the modulator. This stacked configuration is easy to breadboard and simplifies the tasks of testing and trouble shooting at this experimental stage. It also explains the 9 inch height of the assembly (Figure 2).

DEVELOPMENT STRATEGIES

Development of the 1 X 4 mechanically steered antenna was split into the parallel developments of pointing control software, signal processing hardware, platform structure, and RF elements. Interface signals were clearly defined at the outset. Efficient development was greatly facilitated by first constructing a working model of the antenna and platform with control interface signals identical to the final version. The RF portion of the antenna was modeled by a photoresistor "antenna" and circuitry that mimicked the RF sum and difference channel gain patterns. This circuitry also produced a normalized difference/sum tracking error signal modeling the output of the signal processing circuitry. A simple incandescent light near the software development station became the "satellite" test beacon. This model was demonstrated at the MSAT-X Industry Briefing (Bell, 1985). The model provided immediate feedback on software performance, speeded software development, and increased confidence and understanding of the entire pointing control loop. The success of this method was demonstrated during the final integration phase when the antenna immediately began tracking an RF beacon in the lab after phase delay corrections were made to the RF sum and difference channel circuitry.

The mechanically steered antenna has been the result of a low budget, low manpower development effort. Off-the-shelf components were employed as much as possible to speed development. JPL plans to demonstrate a reduced 5 inch height model that will eliminate costly prototype slip rings and rate sensor electronics. In a related effort, Teledyne Ryan Electronics is currently under contract to JPL to develop a flat plate mechanically steered vehicle antenna with a height of only 1.5 inches.

SATELLITE TEST

In August of 1987, the JPL MSAT Pilot Field Experiment (PiFEx) team went to Santa Barbara, CA, to conduct satellite tracking tests on the mechanical antenna. This test is referred to as the PiFEx Satellite-1a, or S-1a, test. The antenna was mounted on the MSAT-X Mobile Laboratory/Propagation Measurement Van (PMV). The tests used an L-band beacon on the MARISAT satellite. After acquiring the beacon, the tests consisted of tracking the satellite while driving through the surrounding mountains. Over 500 MBytes of data were collected during this two week experiment.

Test Conditions

The test conditions experienced were well below ideal for the antenna. There are few satellites on the west coast with an L-band beacon. In the JPL area, the highest possible elevation angle to a satellite occurs in Santa Barbara with the MARISAT satellite and the angle is only 13°. The antenna is only designed to operate in elevation angles as low as 20°. Also, the EIRP of the beacon is 4 dB less than the nominal configuration proposed for MSAT applications. The low received signal power and the additional multipath, both due to the low elevation angle, substantially increased the noise level on the difference channel signal, which is used as the error signal in closed loop tracking. Two important tracking loop parameters were modified to fit the antenna system for operation in this reduced signal level environment. First, the tracking loop bandwidth was reduced by a factor of 8 to combat the increased noise levels. Secondly, the closed loop/open loop handover threshold was increased to improve the response to quick vehicle turns that is lost when the tracking loop bandwidth is reduced. The result was a pointing control loop that was biased to depend more heavily on the open loop mode than is necessary for the expected MSAT satellite signal levels.

In addition to the control loop changes, a low noise amplifier and bandpass filter were added to the antenna just prior to the rotary joint to increase the overall signal level and to reduce the effects of RF losses in the rotary joint and the cabling to the receiver. Plots of the sum and difference/sum signals for the satellite test are given in Figures 3 and 4.

Acquisition Tests

Acquisition testing consisted of manually moving the antenna platform off-point and issuing the start acquisition command. These tests were performed both while the PMV was stationary and mobile. Figure 5 provides a histogram of the Time to Acquire. During the mobile tests, it was possible that the satellite was blocked. If the signal was not located, the antenna platform was scanned again, until the satellite was found. The mean time to acquire was 11.97 seconds, below the requirement of 15 seconds.

Closed Loop Tracking

As was mentioned earlier, the closed loop tracking capability was limited due to the adverse test conditions. For the closed loop to be used, the road that the PMV was on had to have a clear line-of-sight to the satellite and had to have turn rates less than 10 degrees/second. Figure 6 provides a scatter plot, generated from over one hour of data, of the PMV Turn Rate versus the Degrees Off Point when tracking in closed loop. As can be seen, the pointing error remains between ±2° for turn rates in the range of ±8 Degrees/sec. For turn rates greater than this, the antenna tracked in open loop mode. The specification that the antenna was designed to was a closed loop pointing error of ±2°.

Open Loop Tracking

The purpose of the open loop tracking is to keep the antenna platform pointed at the satellite while the signal is blocked. This tracking method uses an angular turn rate sensor to provide the tracking information. The problem with using a rate sensor is that the sensor has a drift that varies with temperature and time. For the S-1a experiment, the rate sensor was temperature controlled by an oven, leaving only the drift with time. Because of the drift, the antenna pointing system was designed to operate in open loop for time periods of less than 10 seconds. The goal was to keep the pointing error between ±2° in the 10 second period. Figure 7 provides a scatter plot of the Time Spent in Open Loop versus Degrees Off Point which shows that the open loop tracking keep the error between ±1.2°. Figure 8 shows a scatter plot of the open loop error versus the turn rate. Both figures were generated from 10 minutes of data. As can be seen, over a range of ±8 degrees/sec, the antenna tracked within ±1°.

Closed Loop/Open Loop Handover

When the signal fades the tracking mode switches to open loop. When the fade ends, closed loop tracking takes over again. If the transfer to open loop is too slow, closed loop tracking will continue with a difference/sum signal that is noise dominated, causing the antenna pointing error to grow. If the transfer occurs too soon, the antenna will be rapidly switching back and forth between open and closed loop. Due to the poor signal conditions, the transfer had to be quicker than it would be for the MSAT system. Figure 9 shows a one minute history of the pointing error as the antenna switches between closed and open loop. The closed-to-open loop transfers occur at 35 seconds, 45 seconds, and 52 seconds. As can be seen, the transfer, which occurs 70 msec after the fade occurs, should have occurred sooner.

CONCLUSIONS

The JPL mechanically steered antenna has demonstrated that mechanically steered antennae can track a satellite. This low cost breadboard antenna tracked the satellite over a variety of environmental conditions and in all cases the antenna tracked the satellite within ±2°.

ACKNOWLEDGMENTS

The authors would like to thank the people involved in the experiment and the data analysis that followed: Richard Emerson, Loretta Ho, Walt Mushagian, Jim Parkyn, and William Rafferty.

REFERENCES

Bell, D., and Naderi, F. M. 1986. "Mobile Satellite Communications - Vehicle Antenna Technology Update," <u>AIAA Space System Technology Conference</u>, June 9-12, 1986.

Bell, D. 1985. "Vehicle Antenna Pointing Techniques for Mobile Satellite Communications," <u>Mobile Satellite Industry Briefing</u>, November 13-14, 1985.

Berner, J. B., and Winkelstein, R. 1988. "Antenna Pointing System," <u>MSAT-X Quarterly</u>, Number 13, January 1988.

Jamnejad, V. 1988. "A Mechanically Steered Monopulse Tracking Antenna for PiFEx: Overview," <u>MSAT-X Quarterly</u>, Number 13, January 1988.

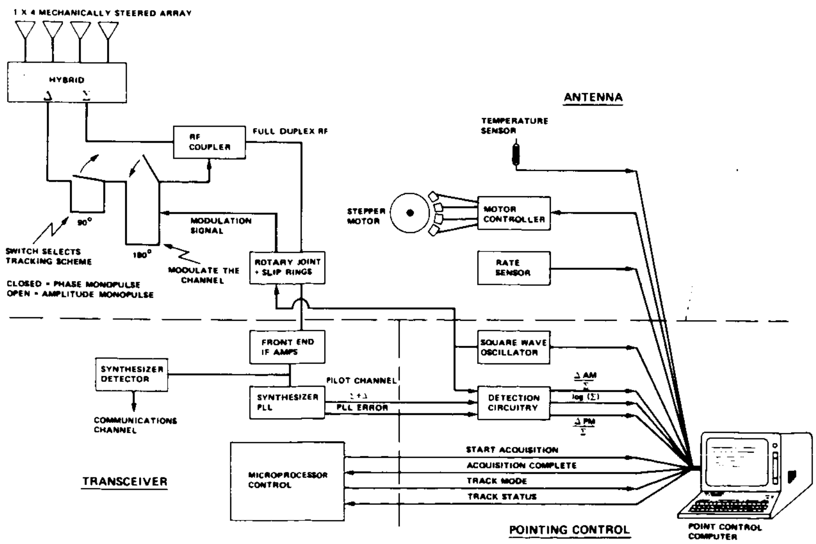

Figure 1: Antenna System Block Diagram

ORIGINAL PAGE IS
OF POOR QUALITY

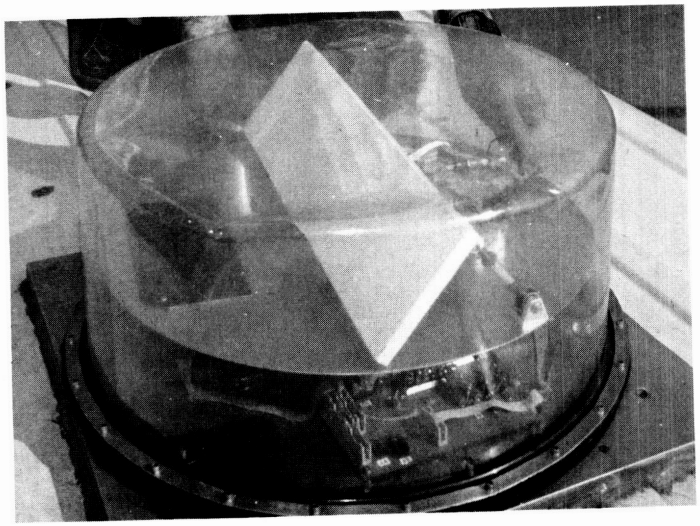

Figure 2: JPL Mechanical Antenna

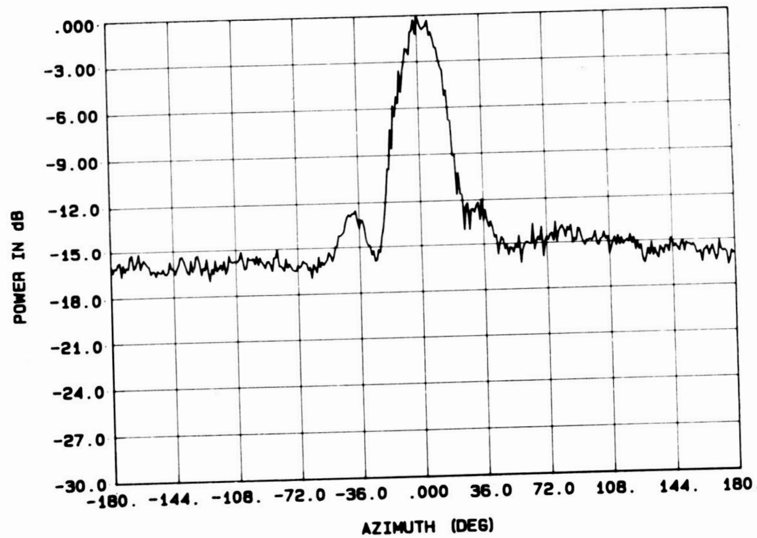

Figure 3: Received Sum Signal

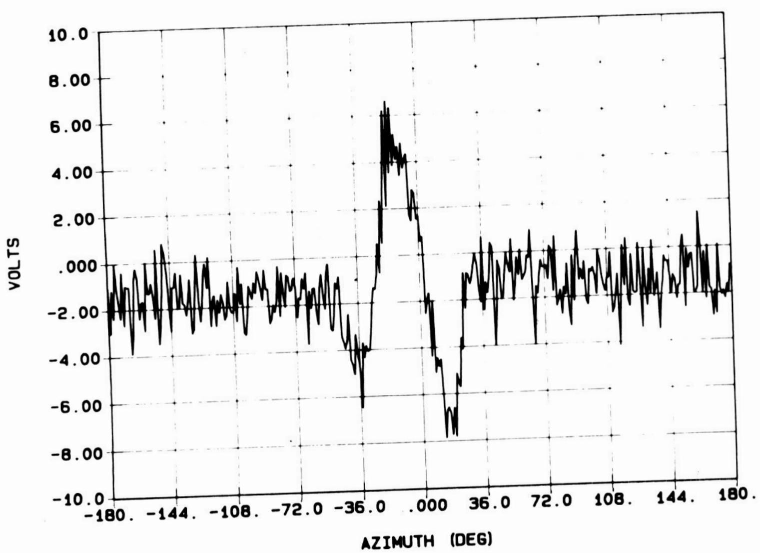

Figure 4: Difference/Sum Signal

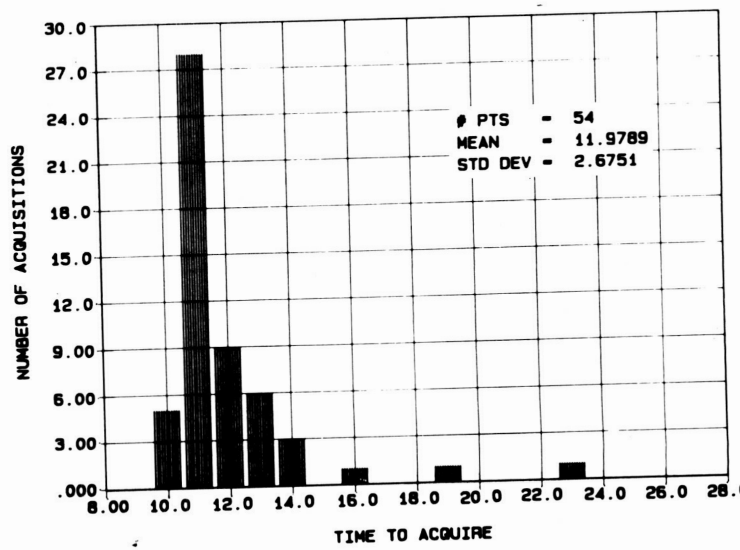

Figure 5: Acquisition Time Histogram

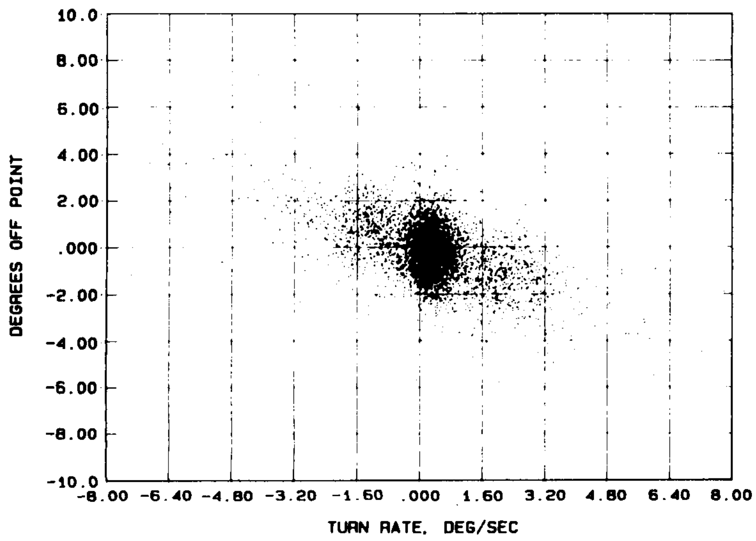

Figure 6: Closed Loop Error Versus Turn Rate

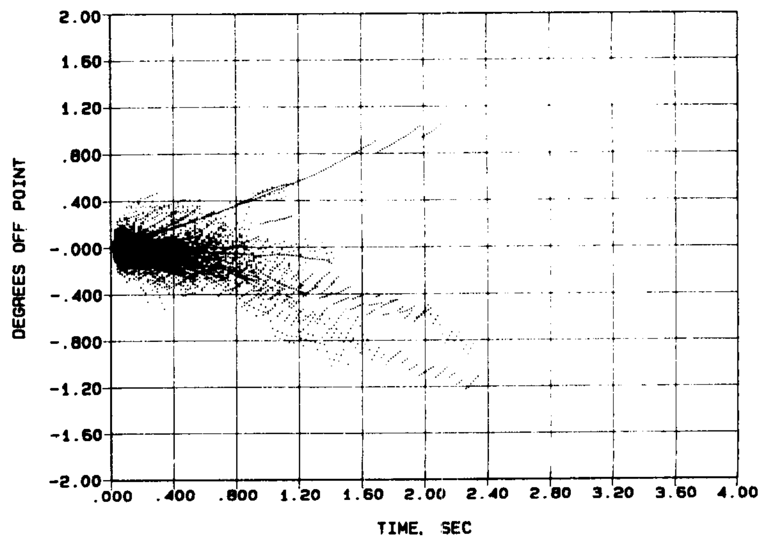

Figure 7: Open Loop Error Versus Time in Open Loop

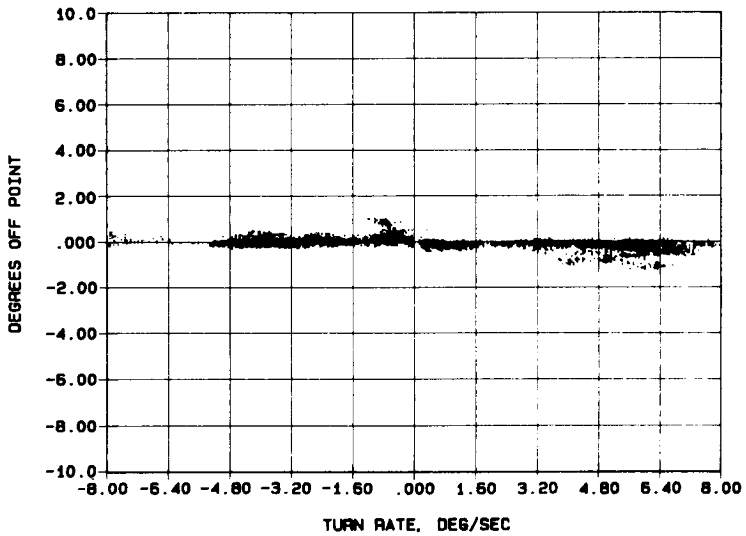

Figure 8: Open Loop Error Versus Turn Rate

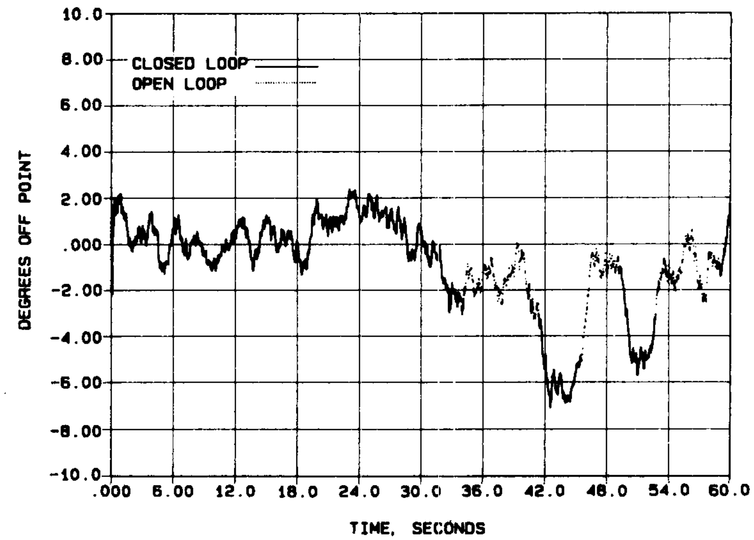

Figure 9: Pointing System Error Versus Time