AN INEXPENSIVE S-BAND ANGLE POINTING TECHNIQUE FOR STEERING A NARROW BEAM KU-BAND ANTENNA

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ABSTRACT

A recently tested antenna pointing control system for gimbaled antennas has been developed. A modified TDRSS user transponder produces pointing error signals from the S-band forward link which in turn drive the Steering Control Electronics (SCE) to precision steer a S-/Ku-band Data and S-band Tracking (KDST) planar array. A successful test of the pointing and data handling capabilities is described and plans for further tests, incorporating additional refinements, are presented.

INTRODUCTION

A proof of concept antenna pointing control system for gimbaled space antenna applications was developed and recently tested. The system was comprised of a modified S-band Tracking Data Relay Satellite System (TDRSS) user transponder that produces error signals from the synchronous orbiting TDRS satellite S-band forward link that in turn drives the SCE to precision steer a KDST planar array.

TDRS USER TRANSPONDER WITH ANGLE POINTING CAPABILITY

NASA has foreseen a need for a high data rate (up to 450 Mbps), Ku-band, Tracking and Data Relay Satellite System (TDRSS) return link. In order to obtain an acceptable bit error rate with reasonable transmitter output power, it was determined that a high-gain Ku-band antenna would be needed. Since a high-gain antenna has a narrow beamwidth, some kind of full- or part-time forward link autotracking is required. A cost effective implementation of the system, and the possibility of using a modified TDRSS User Transponder in an S-band forward link tracking system was the best solution. In this scheme, S-band planar array antennas would be colocated with the Ku-band planar array antenna (Figure 1). Amplitude comparison would be used for coarse acquisition (from ± 7° to within a range of ± 1°) and phase comparison would be used for fine acquisition and tracking (from within ± 1°). The antenna beams have narrow beamwidths in the plane along the length of the arrays and wide beamwidths in the plane along the width of the arrays. The larger angles of acquisition are obtained with the squinted beams with 5 db crossover points. Phase comparison must be done with antennas that have equal phase fronts (note arrows in Figure 1) that are directed orthogonally and 7° off axis. The pointing jitter must also be small enough to maintain the Ku-band return link (the Ku-band, -1 dB beamwidth is about ±0.26°).

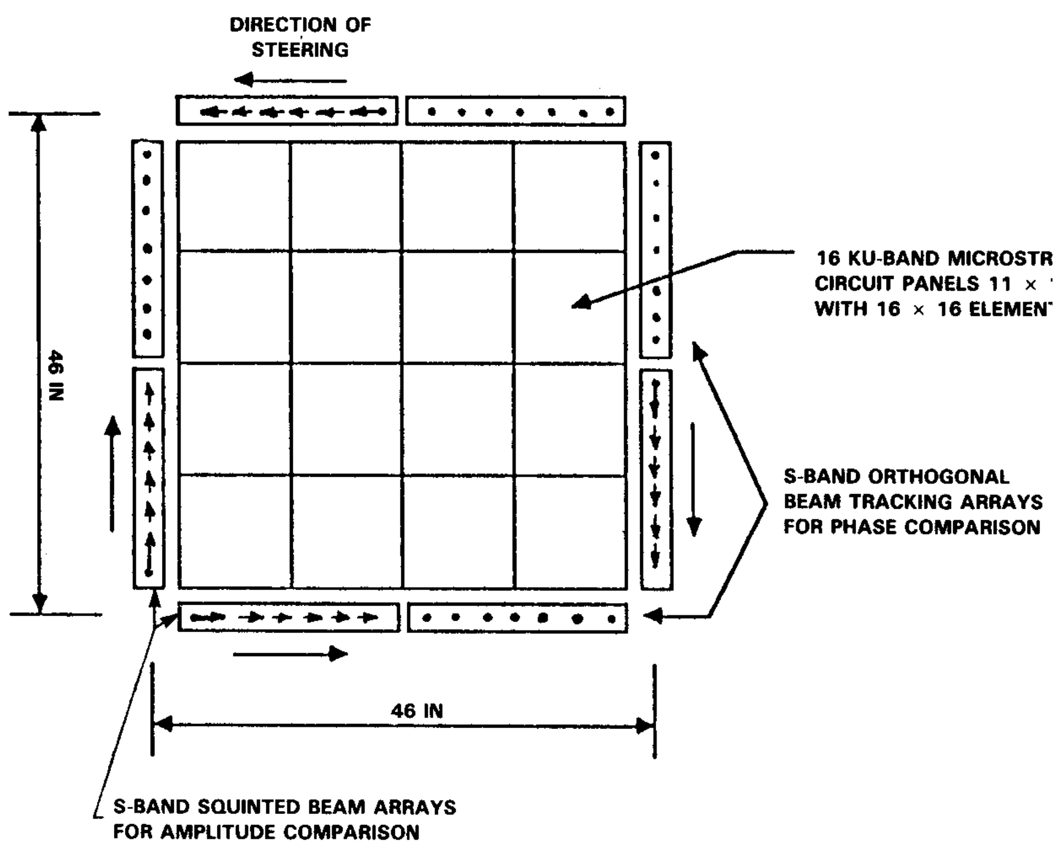


Figure 1 - Antenna Array Configuration

Several different methods for pointing the antenna using a modified S-band TDRSS User Transponder have been investigated. Conventional single-channel autotracking methods were found to be incompatible with the configuration of the S-band tracking antennas coupled with the requirement that both amplitude and phase comparison be performed. Fortunately, a new pointing and control concept, using an antenna lobe switching method, was devised that allows both amplitude and phase comparison to be used. Shown in Figure 2 is a block diagram of the proposed tracking system.

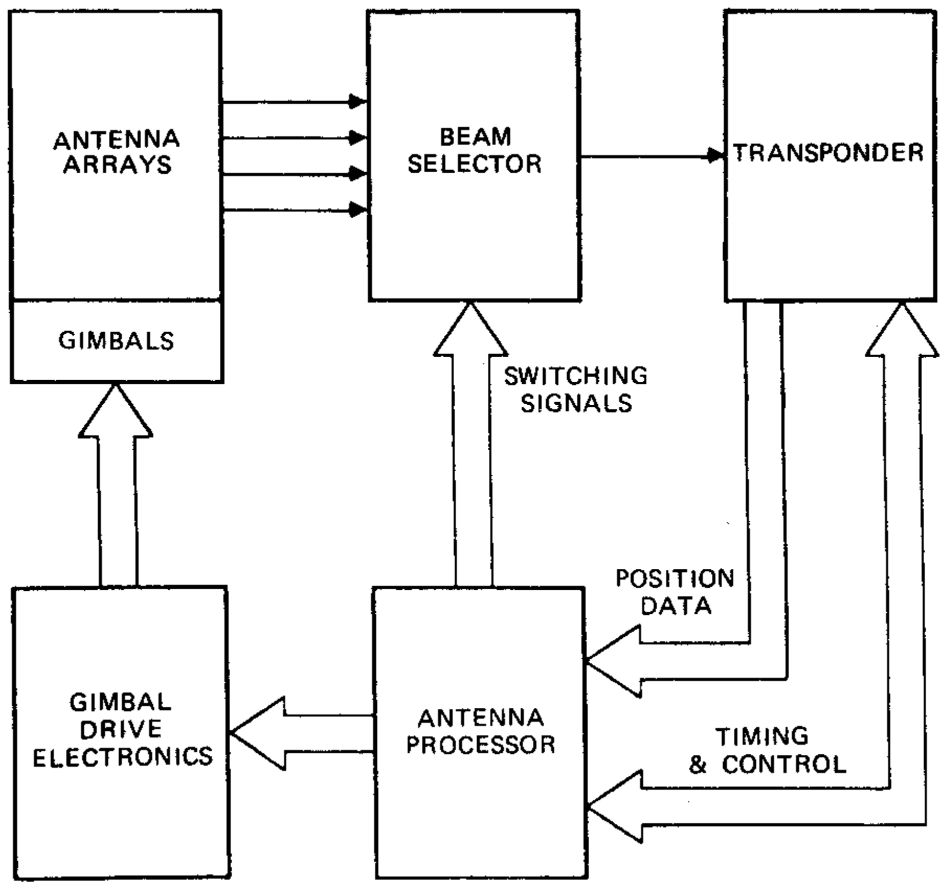


Figure 2. Lobe Switching Approach Block Diagram

Using this method, amplitude comparison is performed by conventional means using the carrier IF AGC voltage as an indication of the received signal strength. The new concept involves the method for deriving the phase comparison error signal. Shown in Figure 3 is a simplified block diagram of the carrier tracking signal processing. The loop is a digitally implemented Costas type, second order phase locked loop. A second order phase locked loop will have zero steady-state phase error for a step input in phase. Therefore, when a phase step is applied to the loop by switching from one antenna to another, the Numerically Controlled Oscillator (NCO) frequency momentarily increases or decreases in order to re-acquire the new phase angle. The NCO word is proportional to the instantaneous frequency of the NCO output. Since frequency is the rate of change of phase

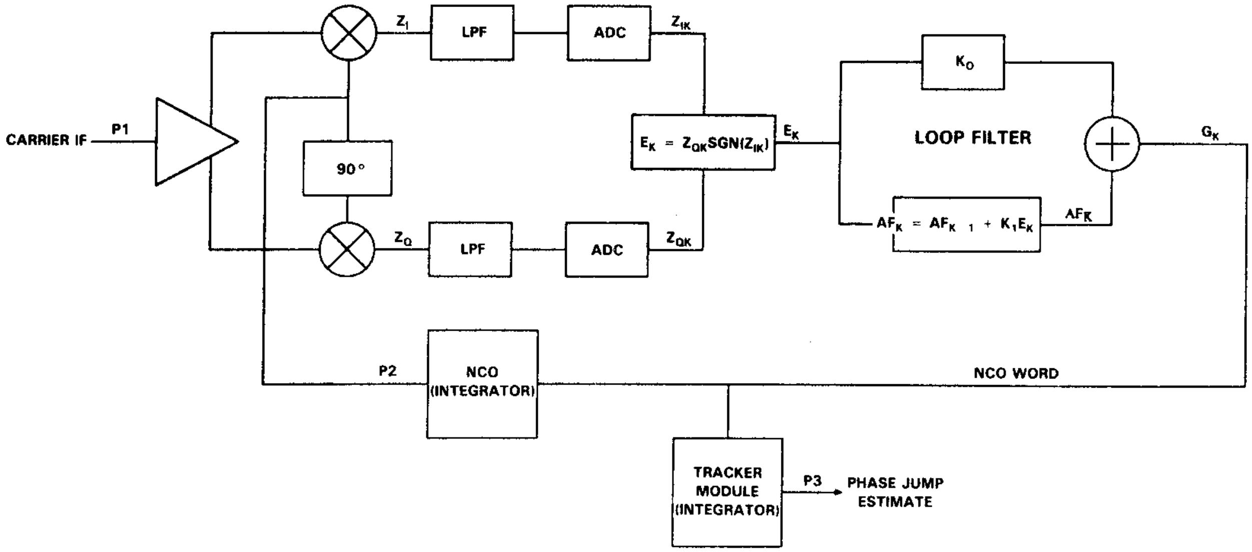


Figure 3. Simplified Block Diagram of the Carrier Tracking Signal Processing

(the derivative of phase), it is conceptually possible to integrate the change in the NCO word until the new phase angle is re-acquired in order to obtain an estimate of the phase step.

Shown in Figure 4 is a block diagram of the module that performs these functions. The NCO word is a 24-bit word that is sent over a 16-bit bus. The most significant 8 bits, or the high byte, are sent first followed by the remaining 16 bits in the word. This data transfer is controlled by the 12 Control Bit and the Receiver Carrier Strobe. The NCO word is updated at a rate of 2,000 times per second. Prior to receiving a start input from the Antenna Processor, the accumulator is cleared, and the two's complementer is set so that it does not complement. The Antenna Processor sends a start pulse to the tracker module and switches from one antenna to another. The antenna switching pattern is shown in Figure 5. The tracker module then accumulates 200 NCO word samples. This takes about 100 ms to accomplish and has been determined to be long enough for the phase locked loop to have re-acquired the new phase angle. The tracker module then subtracts the next 200 NCO word samples by accumulating the two's complement of the NCO word (Figure 6). The subtraction performs the Doppler compensation. After this process has been completed, the 8 bits representing the phase jump estimate are latched into the output register, the accumulator is cleared, and the Data Ready output goes high indicating that valid data may be clocked out of the tracker module by use of the Serial Tracker Clock and the Serial Data Output. The entire process for the four antennas is repeated every 0.65 seconds.

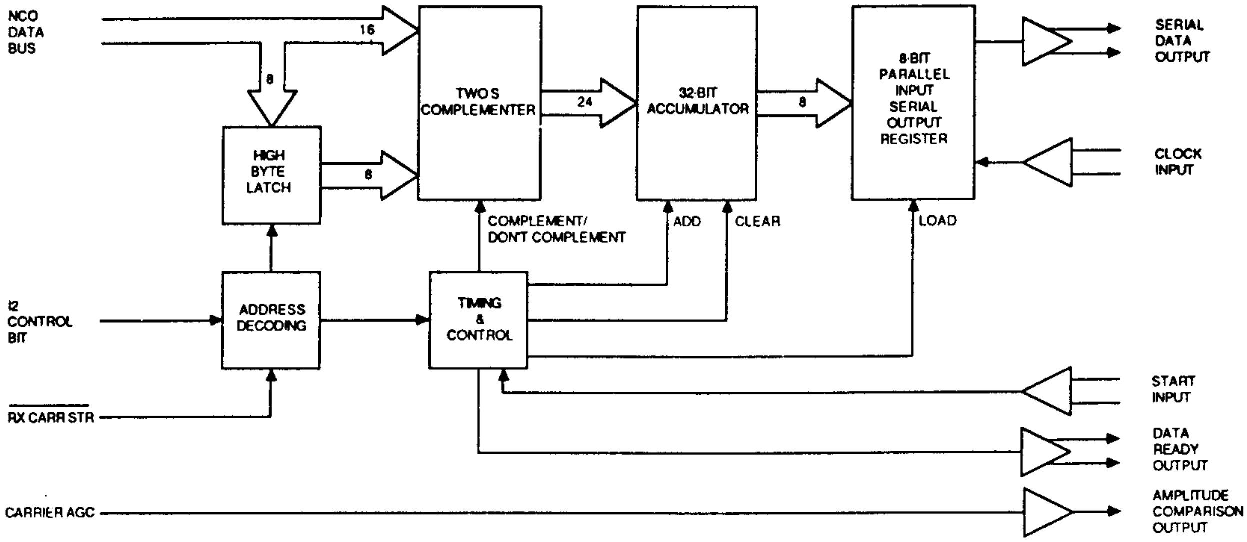


Figure 4. Tracker Module Block Diagram

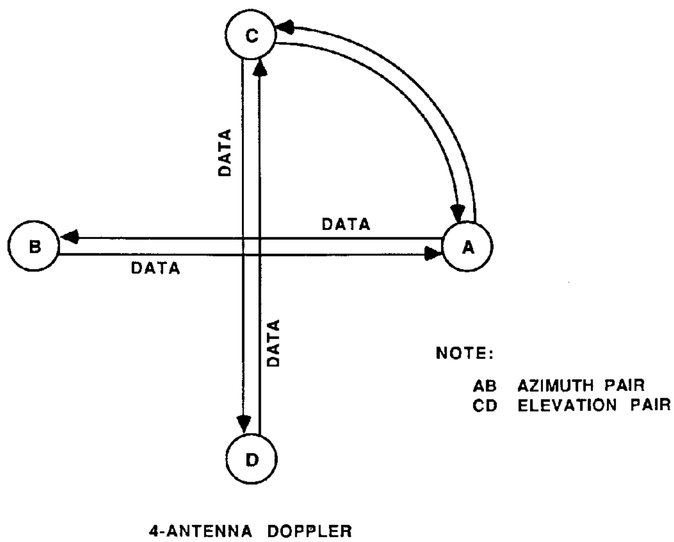


Figure 5. KDST Step II Antenna Switching Patterns

The installation of this module in the Second Generation TDRSS User Transponder is easily accomplished (which means lower cost) and presents a low risk as far as interference with other transponder functions is concerned (due to the digital implementation). The module design also requires the use of only one part type not already used in the transponder (exclusive-ored gates). The module could be installed in place of the optional Doppler Processor module. The Doppler Processor module has the same inputs, except for the Carrier AGC, so the only major change involved with the installation of the tracker module would be connecting the outputs to unused pins on an existing D-type connector (J8). The mechanical configuration of the transponder would remain unchanged, and since all of the inputs except for the Carrier AGC are digital, no degradation or discernable effects on other transponder functions should occur.

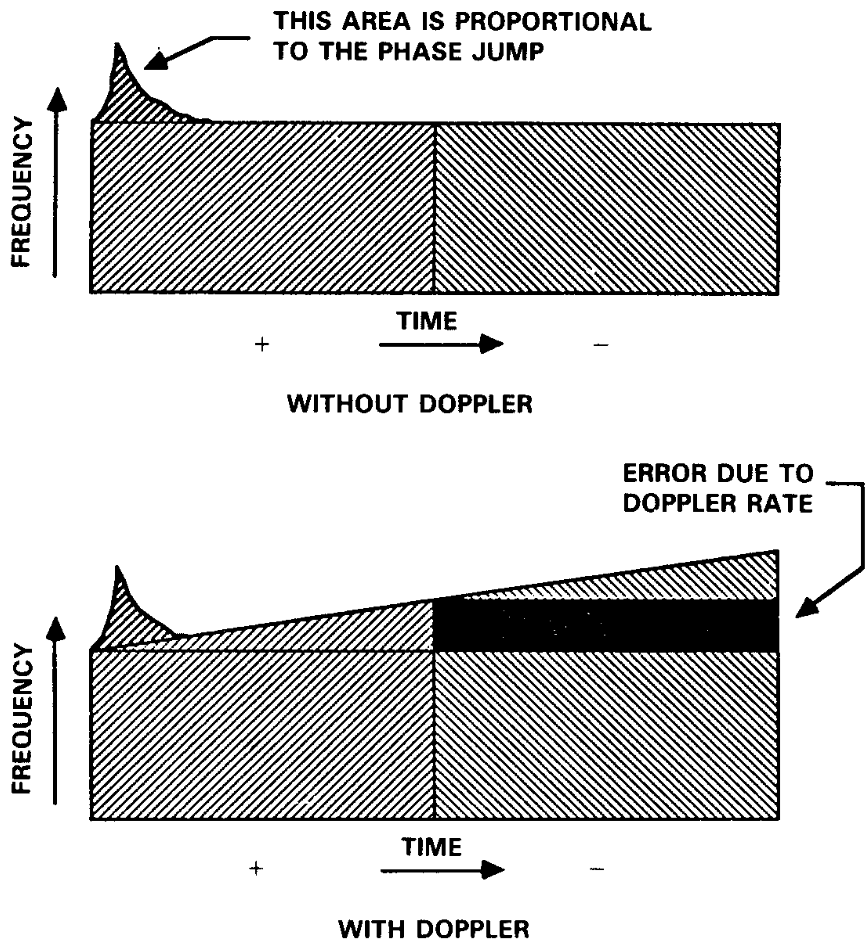


Figure 6. Doppler Rate Error

GIMBAL/ANTENNA POINTING

Antenna pointing for the KDST incorporated an existing flight-type gimbal developed for the Solar Maximum Mission. In the KDST test configuration, only one gimbal was available and it was used to provide azimuth pointing and tracking for the phased array K-band antenna. Elevation positioning for these tests was done manually by adjusting the elevation bracket on the antenna mount. Figure 7 shows the KDST test configuration, and the laser interferometer, shown in the figure, was used to measure gimbal rotation and pointing performance.

Control law implementation included a 2-Hz analog position loop closed around an internal gimbal resolver and a 0.025-Hz digital tracking loop closed around antenna phase error from the NASA standard transponder. Figure 8 shows a simplified block diagram of the control law implementation.

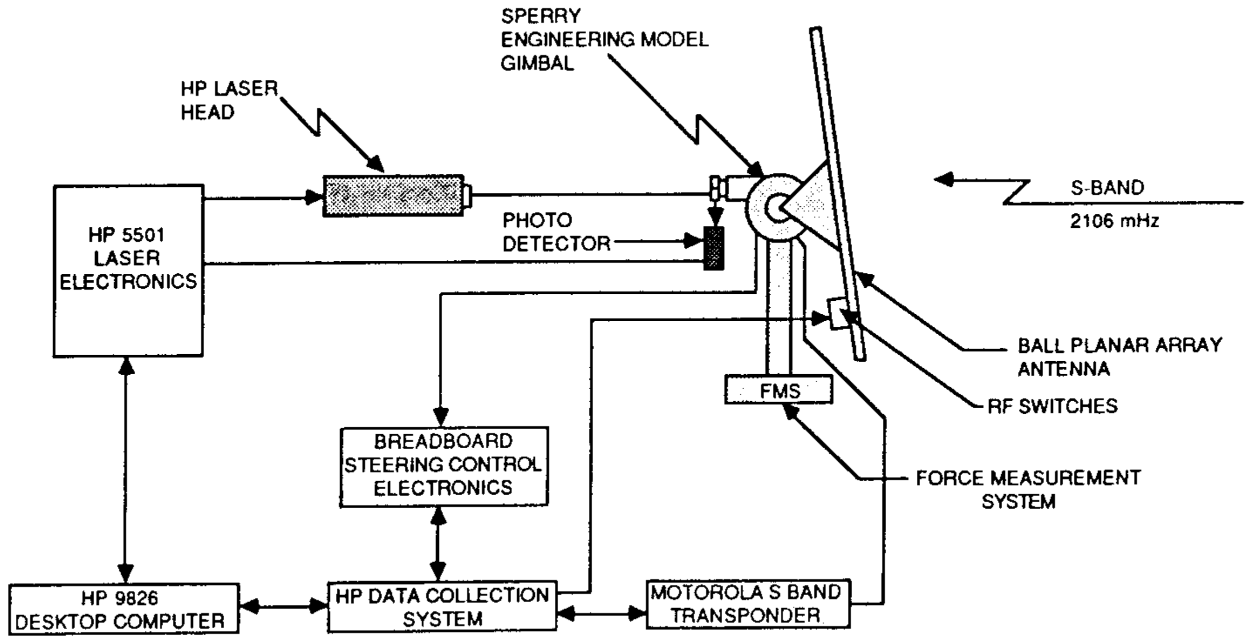
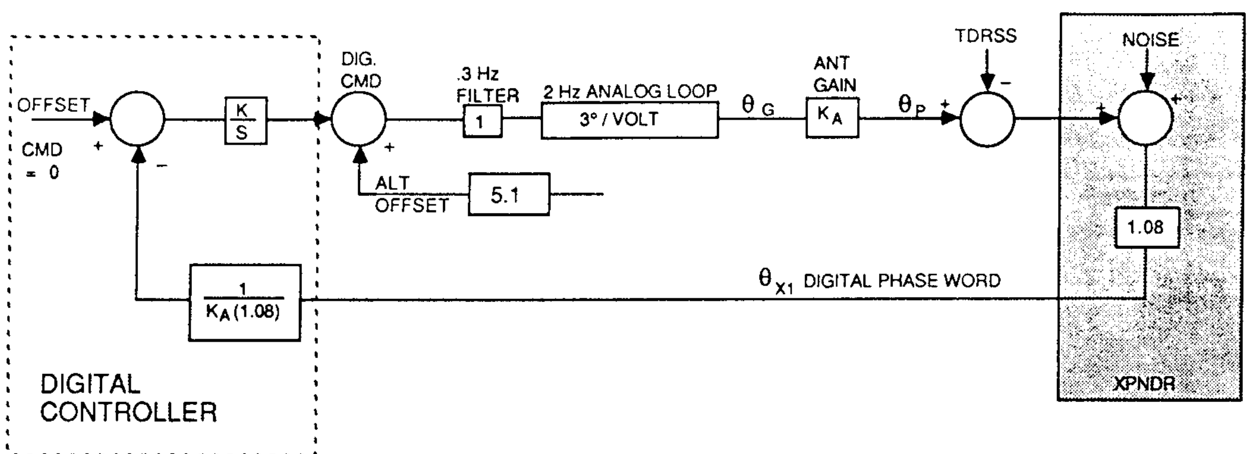


Figure 7. Test Set Up for TDRS Tracking Experiment



NOTE:

K_A = 51

K = 0.105 AT 0.05 Hz CROSS-OVER

K = 0.052 AT 0.025 Hz CROSS-OVER

Figure 8. KDST Step II Simplified Block Diagram

The 2-Hz analog position loop allowed the digital controller to perform an open loop scan and an acquire maneuver on the forward link S-band signal. The digital controller was implemented with off-the-shelf laboratory equipment and included an UP6944A multiprogrammer and an HP9826 instrument controller. The programming language was HP Basic and Figure 9 shows the implemented system flow diagram.

The selected bandwidths for the test configuration were primarily dictated by the speed and computational requirements of the instrument controller and were limited by a cycle time of 1.5 seconds for the antenna switching pattern. As shown in the system flow diagram of Figure 9, the digital controller performed three functions (i.e., scan, acquire, and track).

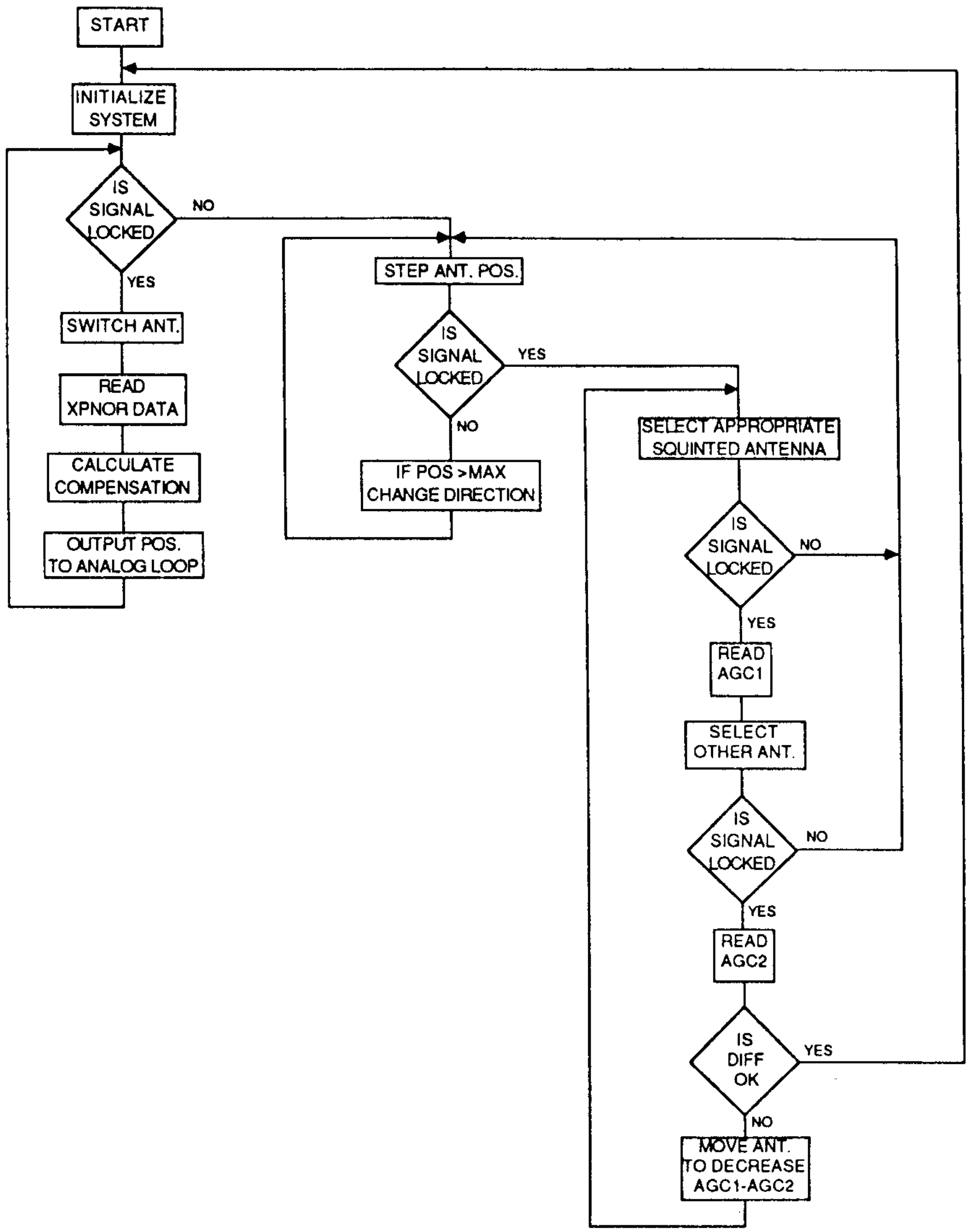


Figure 9. KDST System Flow Diagram

In the scan mode, the digital controller issues scanning step position commands to the 2-Hz analog gimbal loop until a TDRS forward link signal is detected on one of the squinted S-band antenna elements. Once the forward link signal is found, the controller enters the acquire mode.

In the acquire mode, the controller switches between opposite squinted antennas and measures the AGC value of the received signal as determined by the transponder. Based upon the difference in the received signal levels the controller rotates the gimbal until the AGC values on each squinted antenna are nearly equal. When this condition is satisfied, the S-band boresight of the received signal is within 1° and the controller enters the phase tracking mode.

In the phase tracking mode, the controller issues start commands to the transponder and switches between opposite pair nonsquinted S-band antennas. The phase jumps detected by the transponder during antenna switching are output to the controller as a digital word. The controller numerically integrates the phase jump error and updates the position command to the 2-Hz analog loop to force the phase error to zero. This phase tracking aligns the antenna to within 0.1° of the S-band boresight.

If continuous tracking is not required, the controller can be commanded to hold the gimbal position and the S-band antennas and transponder can be used to receive low rate data. Only occasional updates of the antenna tracking may be required.

TRACKING PERFORMANCE

KDST azimuth tracking performance on NASA's TDRS S-band forward link was measured recently in Phoenix, Arizona. Figure 10 shows the measured KDST mean azimuth gimbal angle values compared to the TDRS satellite predicted values for a series of 79 test runs conducted on May 1, 1987. The upper and lower bounds indicated on the plot represent ±0.1° from the predicted TDRS azimuth values that was set as a tracking accuracy goal for each axis (elevation over azimuth, 2-axis configuration) derived from the overall tracking accuracy requirements budget.

The data in Figure 10 include all the configurations used that day. These configurations consisted of added RF attenuation between the tracking antenna and transponder, various data rates with the corresponding transponder phase-locked loop bandwidths, and different user service conditions (Single Access and Multiple Access) which alter the satellite radiated power. It is remarkable that most of the data was contained within the ± 0. 1° band.

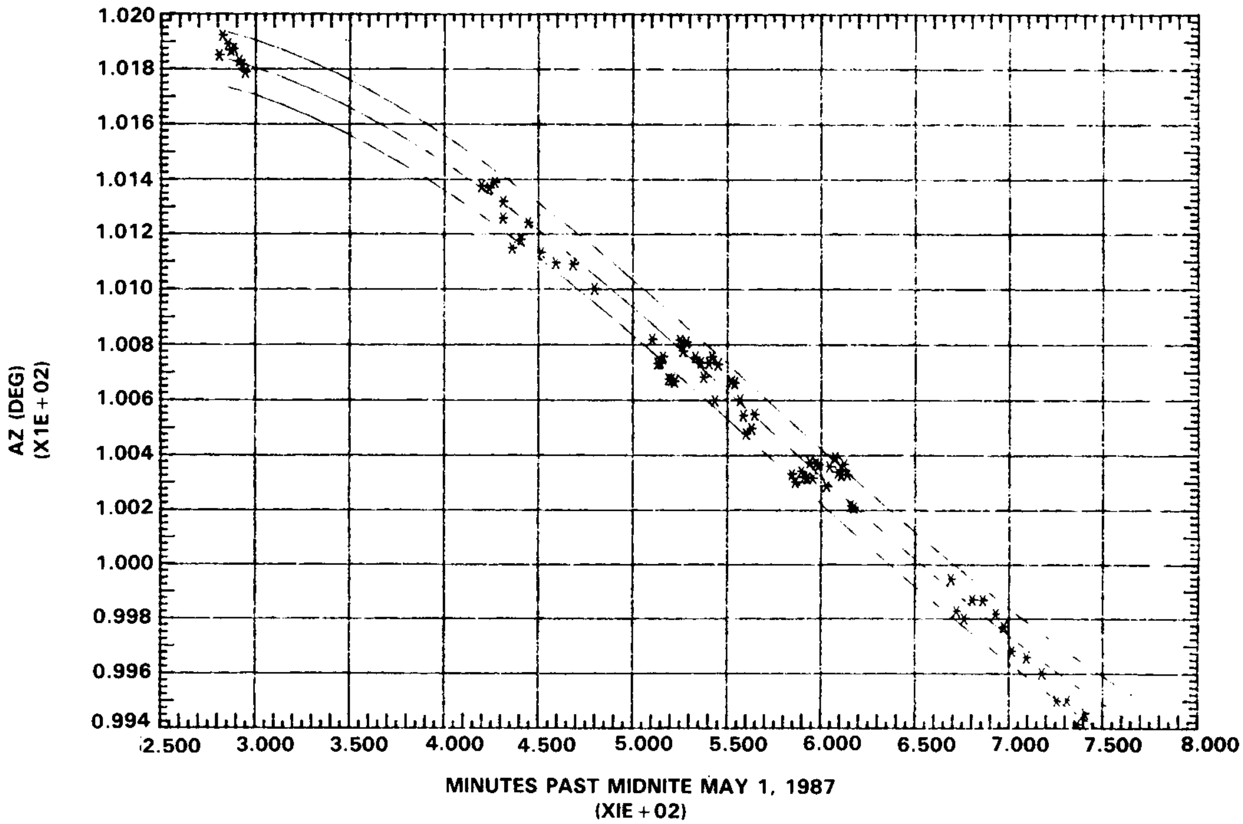


Figure 10. Azimuth Angle Versus Time

There is considerable evidence from the tracking antenna phase-jump data that much better performance can be expected in an on-orbit, atmosphere-free, ground-reflection-free path between TDRS and a KDST-equipped user satellite. The phase data from 27 of the 77 runs, representing the TDRS SSA mode (highest radiated power) with the 0-dB RF attenuation and for the 125-bps bandwidth setting, showed that the system followed the instantaneous azimuth angle of arrival within about ±0.007 equivalent peak gimbal degrees as compared with the ±0.125 degree peak* gimbal data. The ratio of the standard deviation of the run-to-run gimbal angles' values ranged from 12 to 20 times that of the phase-angle data. Consequently, it is theorized that the gimbal angle data contains the effects of lateral perturbations in the angle of arrival due to the turbulent atmosphere, and that the phase-derived data represents the potential KDST tracking capability in the absence of other system-inherent perturbating factors. Further data analysis is continuing in an attempt to separate the various factors.

Elevation angles were set manually during the test runs to approximate the TDRSS predicted values. Since the vertical half-power beamwidth of the azimuth tracking antennas is about 22°, the setting was not critical. The TDRS elevation angles ranged from

* While not directly comparable, it is noted that the jitter from strip chart data in the same range of RF signal input levels obtained previously with a signal generator/horn antenna simulation of the TDRS signal was approximately one-third of this value.

5.8° to 7.6° during the May 1, 1 987 tests. Examinations of the elevation tracking array phase-jump data showed severe perturbations occurred in the phase values owing to ground reflection encountered at this low elevation angle.

On May 13, 1987 the 40-dB gain Ku-band KDST return link array boresight was determined to be offset 0.1° from the S-band tracking boresight by means of a series of carrier-to-noise density measurements performed at the TDRSS White Sands Ground Terminal with the KDST transmitting. The tracking loop was digitally offset appropriately in preparation for Ku-band return link bit error rate characterizations at a 10-Mbps data rate. The 10-Mbps rate was a limit imposed by the data generating equipment rather than the KDST itself. During these tests, the KDST elevation angle was frequently set to accommodate the 0.95° half-power beamwidth of the Ku-band antenna.

CONCLUSION

The results of the KDST breadboard tracking tests with the TDRS S-band forward link indicate that with an atmosphere-free propagation path, it is able to point its 40-dB gain Ku-band planar array with sufficient precision to hold the pointing loss to 1 dB or less (±0.26° overall, two axes).

In order for TDRSS and Space Station users to receive high command rates (1 Mbps) and transmit high data rates (300 Mbps), a Ku-band monopulse receiver is not required to precisely steer the narrow beam planar array. The simple addition of the angle tracking module to the present second generation TDRS user S-band transponder is the angle tracking receiver solution for nearly all NASA missions.