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6. AUTHOR(S)
Mahlon C. Hawker

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Topographic Engineering Center
ATTN: CETEC-LO
Fort Belvoir, VA 22060-5546

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GPS AZIMUTH DETERMINATION USING SHORT BASELINE CARRIER WAVE INTERFEROMETRY

Mahlon C. Hawker
Physicist
U.S. Army Topographic Engineering Center
Fort Belvoir, Virginia 22060-5546
Telephone (703) 355-2799

ABSTRACT

The U.S. Army Topographic Engineering Center (TEC) is involved in research regarding the determination of azimuth by measurement of the carrier phase of GPS satellite signals between two or more antennas. TEC awarded three contracts to develop a GPS Azimuth Determining System (GPS ADS). Presented is a discussion of the three approaches, and test data from limited Government tests.

INTRODUCTION

Since the early 1960's, the TEC has been investigating and using satellites to determine position. Most recently, TEC has been studying the Global Positioning System (GPS) and it's application to tactical operations. The use of GPS broadcast signals to determine azimuth was part of these studies. These studies showed that azimuths could be determined using the standard GPS broadcast information.

In May 1989, TEC awarded three contracts for the design and delivery of technology demonstration models of azimuth determining systems utilizing modified commercial GPS positioning receivers. The intent of the program was to demonstrate the feasibility of determining azimuths of an accuracy of 0.5 to 3 mils, in real time, utilizing GPS receivers in a portable field equipment configuration. Contracts were awarded to: Magnavox Advanced Products and Systems, Torrance, California; Texas Instruments (TI), Plano, Texas; and Adroit Systems, Alexandria, Virginia. The three technology breadboard units were successfully demonstrated to the U.S. Army Field Artillery School on September 27, 1990.

DESCRIPTIONS OF THE SYSTEMS

The TEC approach was to utilize L1 carrier phase short baseline interferometry to determine an angle between the antenna baseline and each of three or more satellites. The phase difference L COS ϕ is the sum of N integral phase cycles, each cycle determined by the L1 carrier wavelength of 19 cm and a residual phase of less than 360°. The integer number N must be known in order to resolve angle ambiguities, the solution to this determination being the major difference among the three approaches. Solving three or more simultaneous equations, one for each satellite used in the azimuth determination, gives the orientation of the antenna baseline with respect to the satellites and thus can be referred to the earth's surface. The approach selected by Adroit Systems, Alexandria, Virginia utilized a dual baseline antenna.

The long baseline (0.85 meter) antenna pair resolves the measured phase into precise multiple solutions. Each quadrant (90°) has multiple solutions which exactly fit the residual phase measurements. Making simultaneous measurements to multiple satellites increases the total number of solutions. Only one solution is correct, but the residual differences are so similar that selection of one correct solution is very time-consuming and error-prone.

Adroit's solution was to use a very short baseline (0.14 meter) antenna pair that resolves an angle to only ½ to 1 degree. This coarse angle determination is not accurate enough to satisfy the accuracy requirements of the users, but it is more than adequate to determine which of the multiple solutions is correct. The short baseline has only two ambiguous solutions which are so far removed from the connect solution as to be inconsequential.

The Magnavox Marine Systems division approach used a dual frequency (L1 and L2) "wide-lane" ambiguity solution method. Subtracting the L2 signal from the L1 gives an effective wavelength of 86 cm. As with the Adroit approach, the accuracy of the angle determination does not meet the required specifications, but the ambiguous readings are sufficiently far apart that the correct high resolution (L1) solution can be selected.

Texas Instruments utilized a rather straight forward approach, using a two antenna single frequency (L1) baseline, and depended on mathematical computations to resolve the correct solutions. The TI-420 receiver used incorporated a two state Kalman filter, the only system to do so.

RESULTS OF TESTING

All three systems were demonstrated to the U.S. Army Field Artillery School, Fort Sill, Oklahoma in September 1990. The results (See Figure 1) were obtained during an informal demonstration by contractor personnel using their own measuring techniques, which are different for each system. The Adroit data is unique in that it was collected over a period of 1½ hours, as opposed to the approximately 15 minute data collection periods of the other two. It should be noted that all subsequent tests of the systems at Fort Belvoir, Virginia, by TEC showed results consistent with the Fort Sill, Oklahoma data.

Figure 2 shows the results of the three systems located parallel to each other and separated by three feet. They were not boresighted to a common azimuth, as the intent was to determine their responses over a period of time. This figure is a graphic example of the large differences in the response of the three technologies to what is essentially the same input. While the ultimate output of each system is a digital azimuth display, the plots of these azimuth values bear little resemblance to each other over an extended period of time.

Multipath tests using these systems are not considered to be effective. The greatly varying responses to what is assumed to be effectively the same stimuli negates any real attempt at using one system as a standard "reference" unit under benign, no multipath conditions (if this is possible), and introducing deliberate multipath conditions to the second instrument. Only two identical matched and calibrated ADS units should be used to try to determine the effects of multipath at a particular location. We do not have this capability at this time.

The Adroit antennas were removed from their mount and attached to a roof top fixture which allows the long baseline to be spaced 0.842 meter, 1.498 meters, and 2.216 meters. Figures 3, 4, and 5 show one half hour of 0.842 meter data, recorded every 10 seconds on four different days. Three days are consecutive and all times are referred to the same sidereal time. The July 31 through August 2 data show excellent correlation. It should be noted that the majority of the descenders, momentary large negative excursions in the data average, occurred on August 2. These momentary excursions are a result of measurement and computation errors attributed to the hardware and should be disregarded. The exact mechanisms inducing these errors have not been determined.

Figure 6 data shows the effect of rotating the mounting structure 90° CCW. The time corresponds to the August 1 and 2 1.498 meters baseline data. Some of our data indicates the presence of a one-hour cyclic variation in calculated azimuths with peak-to-peak variations of nominally 10 mils to as much as 20 mils.

CONCLUSION

TEC has successfully demonstrated the ability to measure azimuths using short baseline interferometry with GPS carrier phase measurements. The initial proof-of-concept brassboard demonstration units did not achieve all design and performance goals but did identify several problem areas that require addressing in our follow-on work. The ability of our crude first generation system to achieve an 8-mil probable error accuracy actually exceeded our initial expectations.

TEC has prepared specifications for a second generation ADS whose design will specifically address those problem areas presently identified as major accuracy degraders. The U.S. Army Field Artillery School, the Multiple Launch Rocket System (MLRS) and Trailblazer are actively involved in setting the requirements. It is anticipated that the second generation ADS will be sufficiently perfected so as to lead directly into full scale development for several Army weapon systems.

The Adroit system has been modified by the manufacturer to add a carrier phase logging capability and some software enhancements. An external 386 laptop computer is now used as a display and data logging facility. New antennas incorporating improved environmental shielding have been added.

DEMONSTRATION RESULTS

STATION / TARGET	DAVIS (ADROIT) AZIMUTH (MIL) TRUE	MEASURED	Δ	σ	DAVIS - 1 (MAGNAVOX) AZIMUTH (MIL) TRUE	MEASURED	Δ	σ	DAVIS - 2 (TEXAS INSTRUMENT) AZIMUTH (MIL) TRUE	MEASURED	Δ	σ
MB - 4	6323.009	6322.08	0.93	4.61	6294.142	6296.25	-2.15	1.87	6340.992	6337.56	3.43	2.96
MB - 2	1000.269	999.44	0.83	4.93	972.41	976.63	-4.22	2.69	986.871	984.67	2.20	9.10
ART	5014.67	5014.62	0.05	7.19	5022.815	5023.38	-0.56	2.18	5042.057	5054.16	-12.10	5.82
SIGNAL MTN	4733.951	4729.56	4.37	5.35	4736.629	4744.01	-7.38	2.95	4738.046	4737.51	0.54	6.49
WATER TOWER	2431.887	2431.97	-0.08	5.52	2434.569	2429.42	-5.36	1.72	NO MEASUREMENT			
WRONG WAT TOWER									1907.36	1903.44	3.92	5.67

POSITION	DAVIS TRUE	MEASURED	DELTA	DAVIS - 1 TRUE	MEASURED	DELTA	DAVIS - 2 TRUE	MEASURED	DELTA
N	553065.711	553057.6	-8.11	553093.37	553086	-7.37	553051.06	553044.40	-6.61
E	3837262.031	3837258.5	-3.53	3837246.96	3837239	-7.04	3837235.46	3837228.00	-7.46
ELEV	363.955	364.0	0.05	363.955	416	52.05	363.955	371.60	7.65

Δ = TRUE AZIMUTH - MEASURED AZIMUTH

σ = STANDARD DEVIATION ABOUT THE MEAN

Figure 1

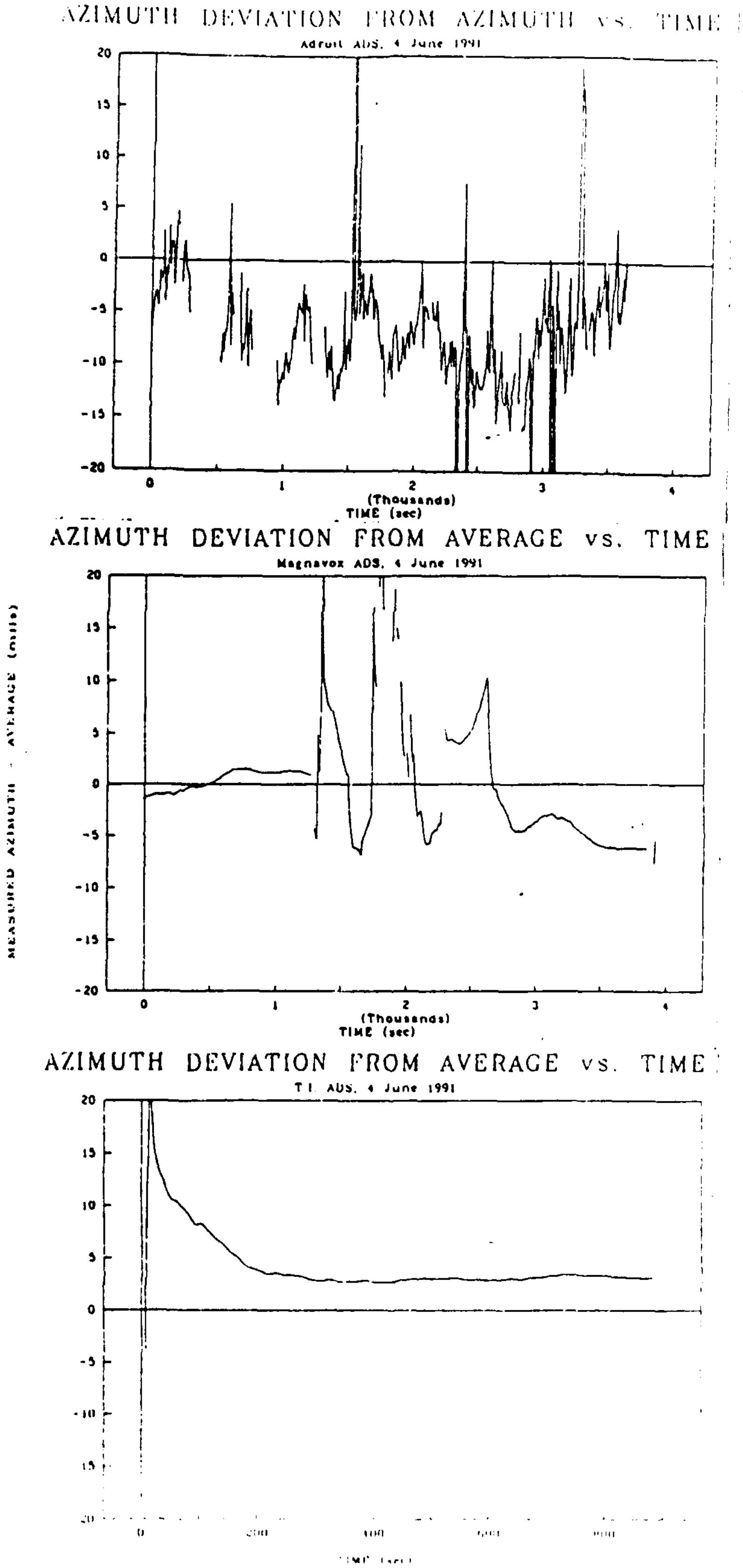

AZIMUTH DEVIATION FROM AZIMUTH vs. TIME
Adroit ADS, 4 June 1991
(Thousands)
TIME (sec)
AZIMUTH DEVIATION FROM AVERAGE vs. TIME
Magnavox ADS, 4 June 1991
MEASURED AZIMUTH - AVERAGE (mils)
(Thousands)
TIME (sec)
AZIMUTH DEVIATION FROM AVERAGE vs. TIME
T I ADS, 4 June 1991

Figure 2

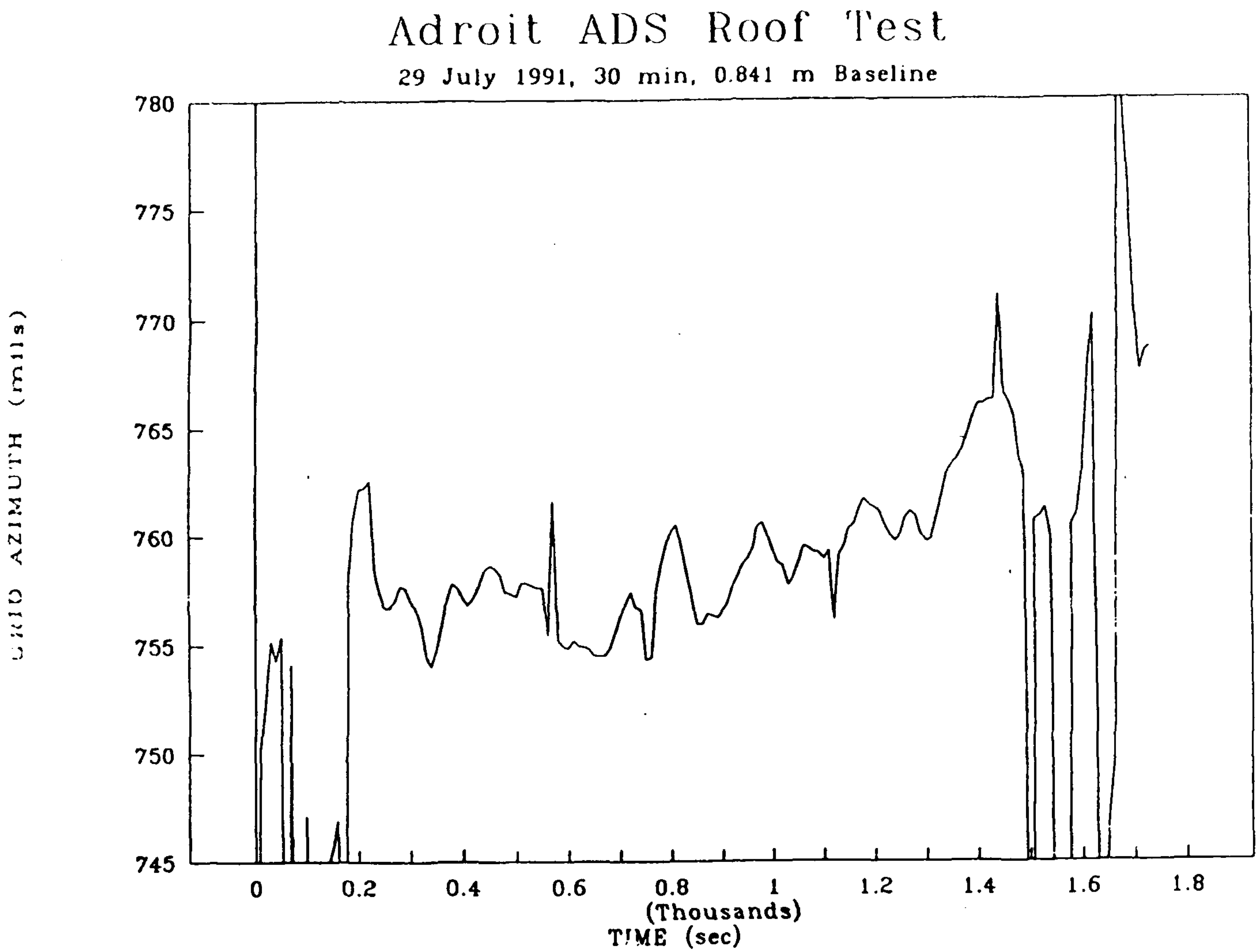

Adroit ADS Roof Test
29 July 1991, 30 min, 0.841 m Baseline
780
775
770
765
760
755
750
745
GRID AZIMUTH (mils)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
(Thousands)
TIME (sec)

Figure 3

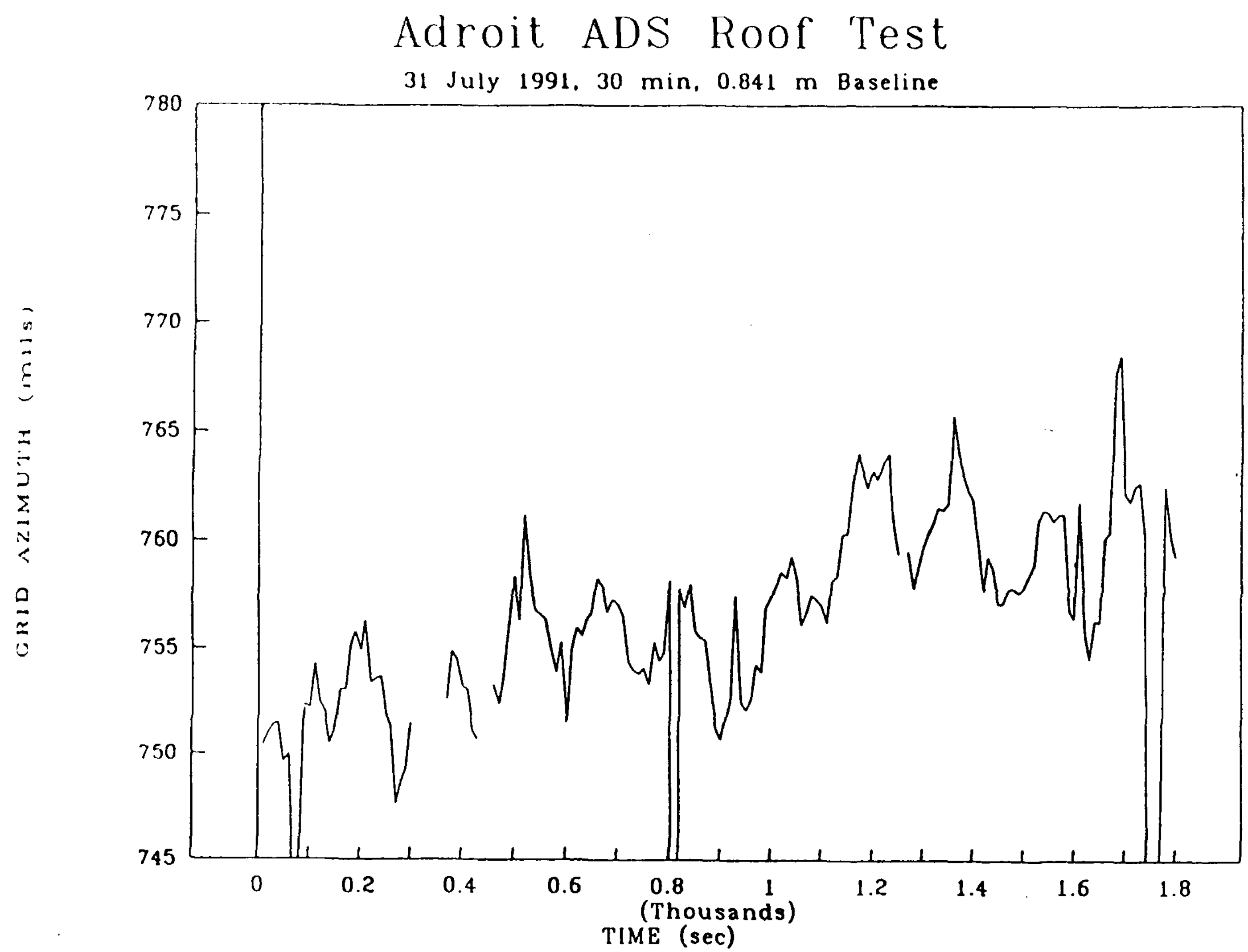
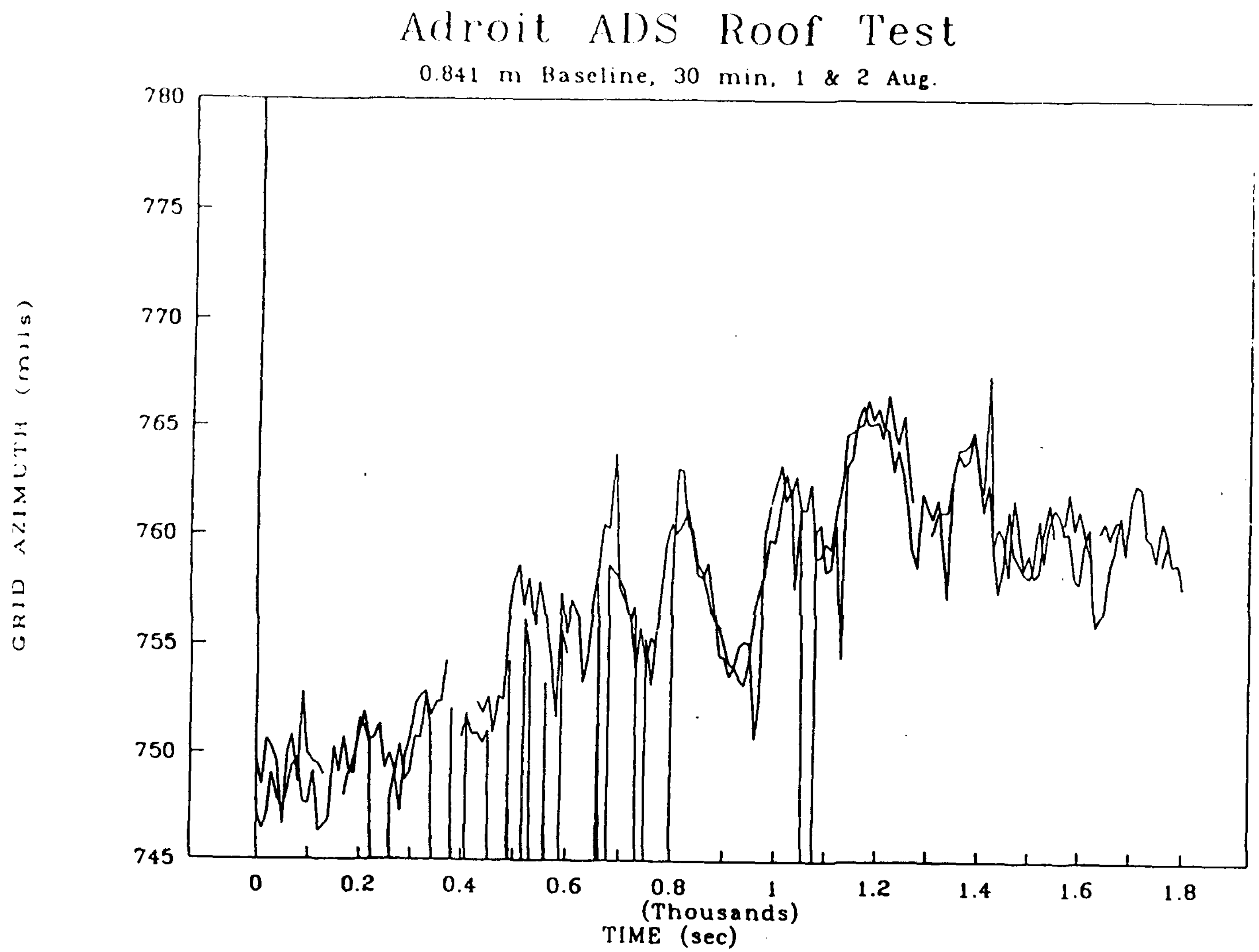

Adroit ADS Roof Test
31 July 1991, 30 min, 0.841 m Baseline
780
775
770
765
760
755
750
745
GRID AZIMUTH (mils)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
(Thousands)
TIME (sec)

Figure 4



Adroit ADS Roof Test
0.841 m Baseline, 30 min, 1 & 2 Aug.
780
775
770
765
760
755
750
745
GRID AZIMUTH (mils)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
(Thousands)
TIME (sec)

Figure 5

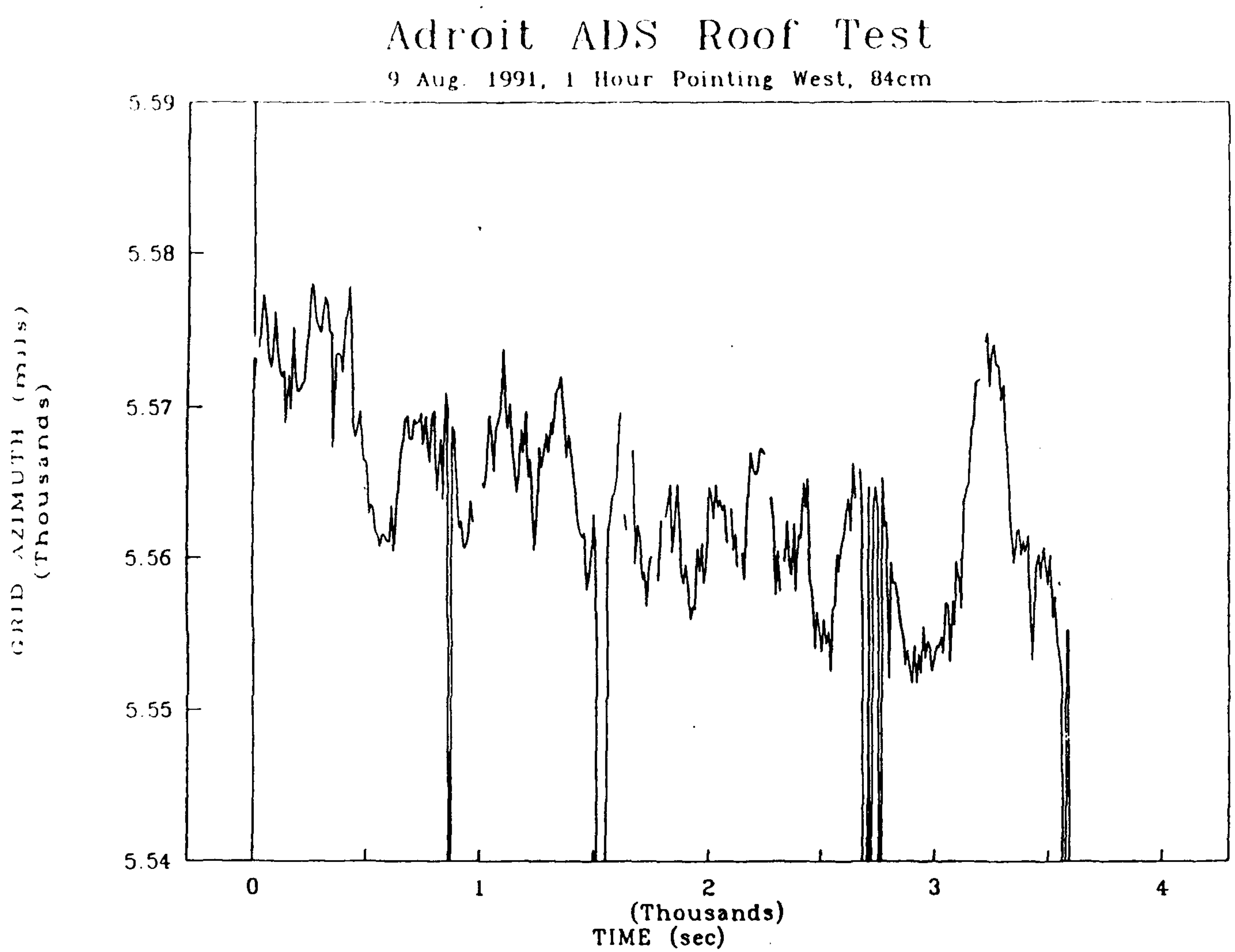

Adroit ADS Roof Test
9 Aug. 1991, 1 Hour Pointing West, 84cm
GRID AZIMUTH (mils)
(Thousands)
5.59
5.58
5.57
5.56
5.55
5.54
0
1
2
3
4
(Thousands)
TIME (sec)

Figure 6