

GBT ARCHIVE L0555

FILE: LASER RANGING

KEYS: ALGORITHM, ANTENNA, CARDINAL POINTS, DATA ANALYSIS, FEEDARM, FOCUS TRACKING, LASER RANGING, MEASUREMENT PROGRAM, OPTICS, POINTING, PRECISION POINTING, VIBRATION MEASUREMENT

November 30, 1999

To: Distribution  
From: David H. Parker  
Subject: First differential (x,y,z) measurements of the GBT feed arm and future plans

Previous experimental data on the GBT feed arm movements (see memo L0535) have been simple distance measurements. In memo L0543 (attached), Michael Goldman outlined an algorithm for converting differential measurements into (x,y,z) coordinates. The data in this report demonstrates the method and instrumentation capability, and illustrate the power of this tool for measuring radio telescopes with an unprecedented accuracy.

This algorithm does not require absolute calibration of the lengths or instrument locations. Moreover, it can be applied to measurements of different targets within a locally rigid coordinate system to yield differential motions. Until the instrument and monument calibrations are complete and we can calculate absolute coordinates, this algorithm will be used to start gaining insight into the behavior of the GBT dynamics. The only constraints are that approximate coordinates must be known for the instruments and target(s), and the data points must be sampled in synchronization for vibrational work.

On the afternoon of October 15, 1999, five instruments measured targets on the feed arm tip. The attached drawing shows the geometry of the experiment. The telescope was located with the feed arm almost directly north. This was fortunate, because the axes of the telescope coincide with the coordinate system used for the ground lasers, i.e., x=east, y=north, and z=zenith for the lasers; and x=parallel to the elevation shaft, y=along the axis of symmetry, and z=zenith for the telescope. In this orientation, the telescope x and y axes were in the -x and -y ground directions. In general, an additional rotation transformation will be required to convert vibrations and deflections into the telescope coordinate system.

The first series of plots show the distance and signal amplitude between about 20:18 and 20:31 UT. It should be noted that there was an error in the IRIG clock at the time the data was taken, but the time was shifted to correct the error, and the time shown on the plots is correct.

From casual observations, it is evident that there is good agreement between ZY103 and ZY110, i.e., 180° phase shift. Other measurements are more confusing. For example, ZY101 and ZY112 are symmetric about the GBT center line, but the distances don't have the same characteristics.

The second series of plots expand on 4 minutes between 20:22:00 and 20:26:00. This was selected to include the large drift evident on a number of the plots. On the expanded plots,

vibrations are clearly visible riding on the larger drift of the feed arm. Unfortunately, all of the instruments did not take data in sync, due to improper software parameter settings which were not detected until later.

Instruments ZY101, ZY102, and ZY110 were in sync and their data was processed in the Excel spreadsheet, using equation 12.1 of Goldman's memo, to produce the X Translation, Y Translation, and Z Translation plots. Note that the major feed arm drift over the 4 minute interval was in the -x direction. This drift was about 2.7 mm, which corresponds to a pointing drift of about 7.5 seconds (see memos P0057 and L0554 for the coefficient).

The next plot is an expanded 30 seconds showing the data points for ZY102 and ZY110. Note the first order 180° phase shift of the vibrations. Closer inspection shows the vibrations must have several modes. For example, at 20:22:45 the distance to ZY102 was not changing, but the distance to ZY110 was changing at about 0.200 mm/800 ms or 0.25 mm/s. The noise level of the measurements is consistent with previous data in memo L0535.

Our first assumption was that the x drift was due to wind. The next plots show the wind speed and direction. The wind was out of the west, so a drift in the -x (west) direction would be due to a decrease in the wind speed. We were somewhat surprised that the drift does not seem to correlate with the wind speed measured at the GBT weather station located about 400 meters west and 300 meters south of the GBT. At 10 MPH average speed ( $\approx 4.5$  m/s) it would take about 1.5 minutes for the wind to reach the GBT. If the wind plot is shifted by about 1.5 minutes and compared to the first set of data (20:18–20:31) for ZY110, it still does not appear to have the characteristics of the motions.

The next plot is a parametric plot of x-y as a function of time. This is hard to interpret, other than to say it would probably be a pointing nightmare if not corrected in real time at the subreflector.

As usual, this experiment suggests the need for more detailed experiments. Ray Creager is writing code to facilitate these type synchronized measurements, which will insure all instrument parameters are set the same and plot the (x,y,z) coordinates in real time. We need to understand 7-second drifts of the pointing over 4 minutes, and the conditions under which it drifts or remains stable. Drifts of that magnitude—on that time scale—could not be corrected by offset pointing, since the telescope would have changed before it could be completed. This could have serious implications for holography also.

Future experiments will insure the instruments are synchronized. Additional targets at the base of the feed arm would be useful to sort out contributions from the feed arm and alidade. A 24-hour measurement of cardinal points on the telescope would chart the thermal deflections (and end years of debate). It would be useful to get the GBT weather station (on the 150-foot tower adjacent to the GBT) operational. We need to fix the problem

with the interface between Monitor & Control, and Ray's software (again) in order to let Ray's software regain access to the weather data in real time. Synchronization with the accelerometers would calibrate the accelerometers and cross check results. There is no shortage of productive experimental work.

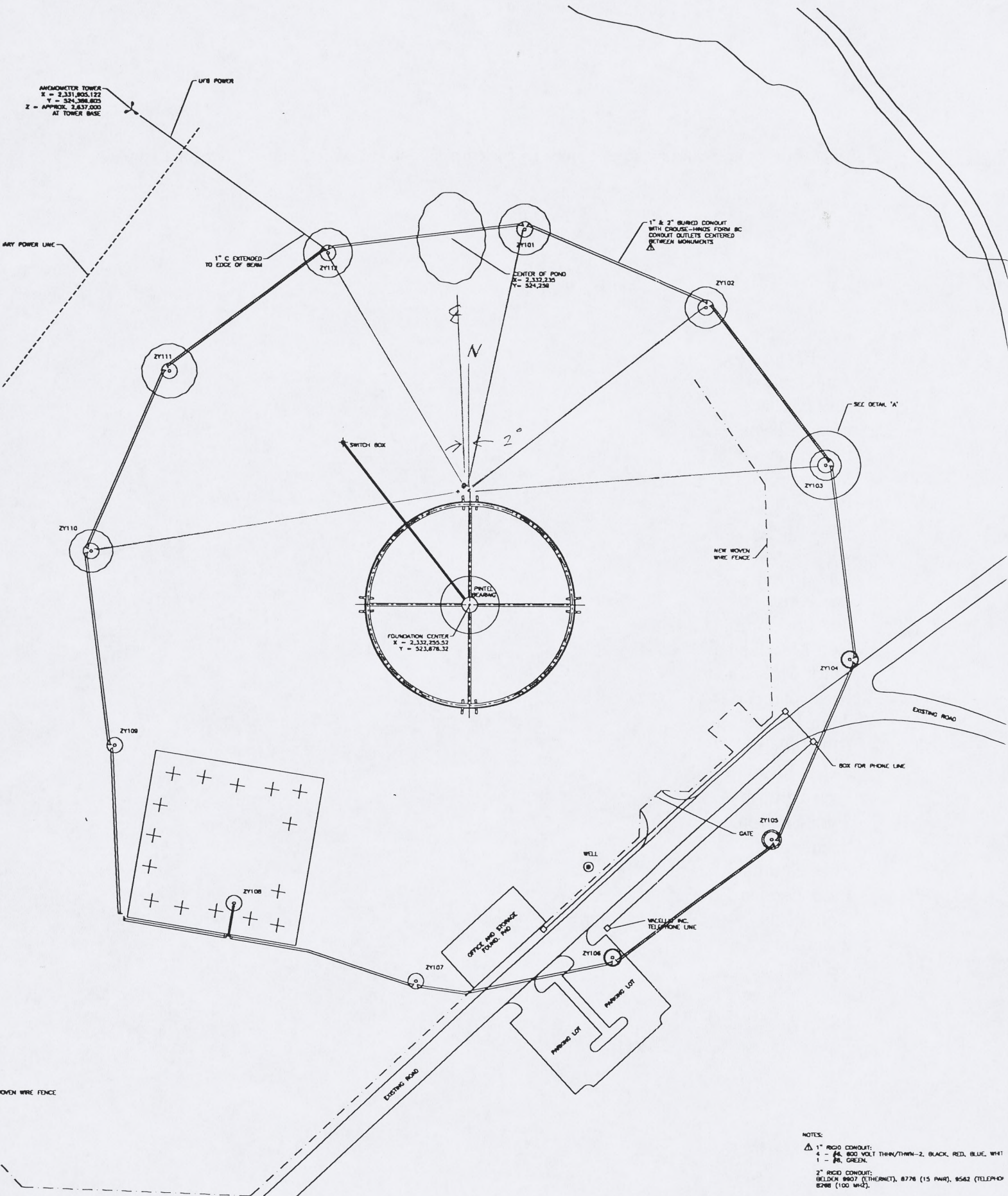
Unfortunately, Brian Ellison (the one who produced all of these plots, converted the data to [x,y,z], handles the experimental work, and helps with the instrument calibrations) is being transferred to OVLBI at the end of the year. He has been paid from the JPL GeoSAR project since 5/98, but those funds will be exhausted by the end of 1999.

The already taxed Metrology Group will not have time to do both the experimental work and complete the hardware—which we must give priority—due to the pressures to close out the materials budget in the first quarter of 2000, work with COMSAT on the feed arm instrument and spherical retroreflector installation, calibrate the surface retroreflectors for delivery to COMSAT, and calibrate the instruments—not to mention software development and testing.

Brian is working part-time with the GBT panel setting and we have made the commitment to do another round of laser-to-laser measurements for Don Wells' research, when the last 3 ground lasers are operational. This will probably consume the remainder of Brian's time in the Metrology Group. Due to the esoteric nature of the measurements, instrumentation, and software, it would be counterproductive to train part-time help, so I don't think we can

use telescope operators or astronomers to pick up the slack. We are in a bit of a situation.

cc: Dana Balser  
Joe Brandt  
Jim Condon  
Ray Creager  
Brian Ellison  
Rick Fisher  
Michael Goldman  
Bob Hall  
Dave Hogg  
Gareth Hunt  
Phil Jewell  
Lee King  
Jay Lockman  
Ron Maddalena  
Mark McKinnon  
Roger Norrod  
John Payne  
Bill Radcliff  
Jason Ray  
Fred Schwab  
John Shelton  
S. Srikanth  
Mike Sumner  
Paul Vanden Bout  
Don Wells  
gbtarchive  
M1123-1



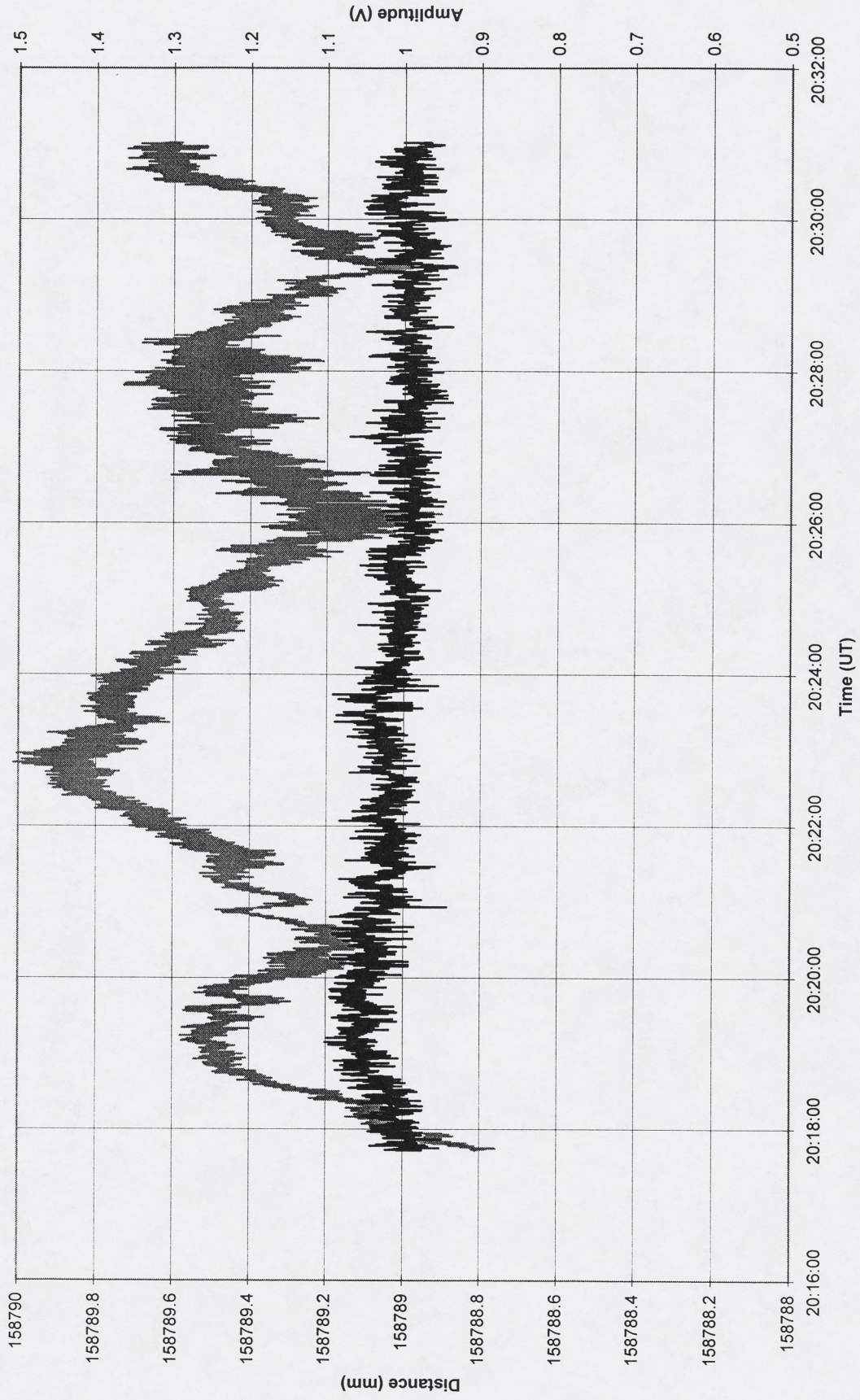
NOTES:

△ 1" RIGID CONDUIT:  
 4 - #4, 800 VOLT THIN/THIN-2, BLACK, RED, BLUE, WHI  
 1 - #8, GREEN.

2" RIGID CONDUIT:  
 BELLON 8807 (ETHERNET), 8778 (15 PAIR), 8562 (TELEPHO  
 BONE (100 PAIR).

# ZY101 to ZEG41040L 10-15-1999 Distance & Amplitude vs. Time

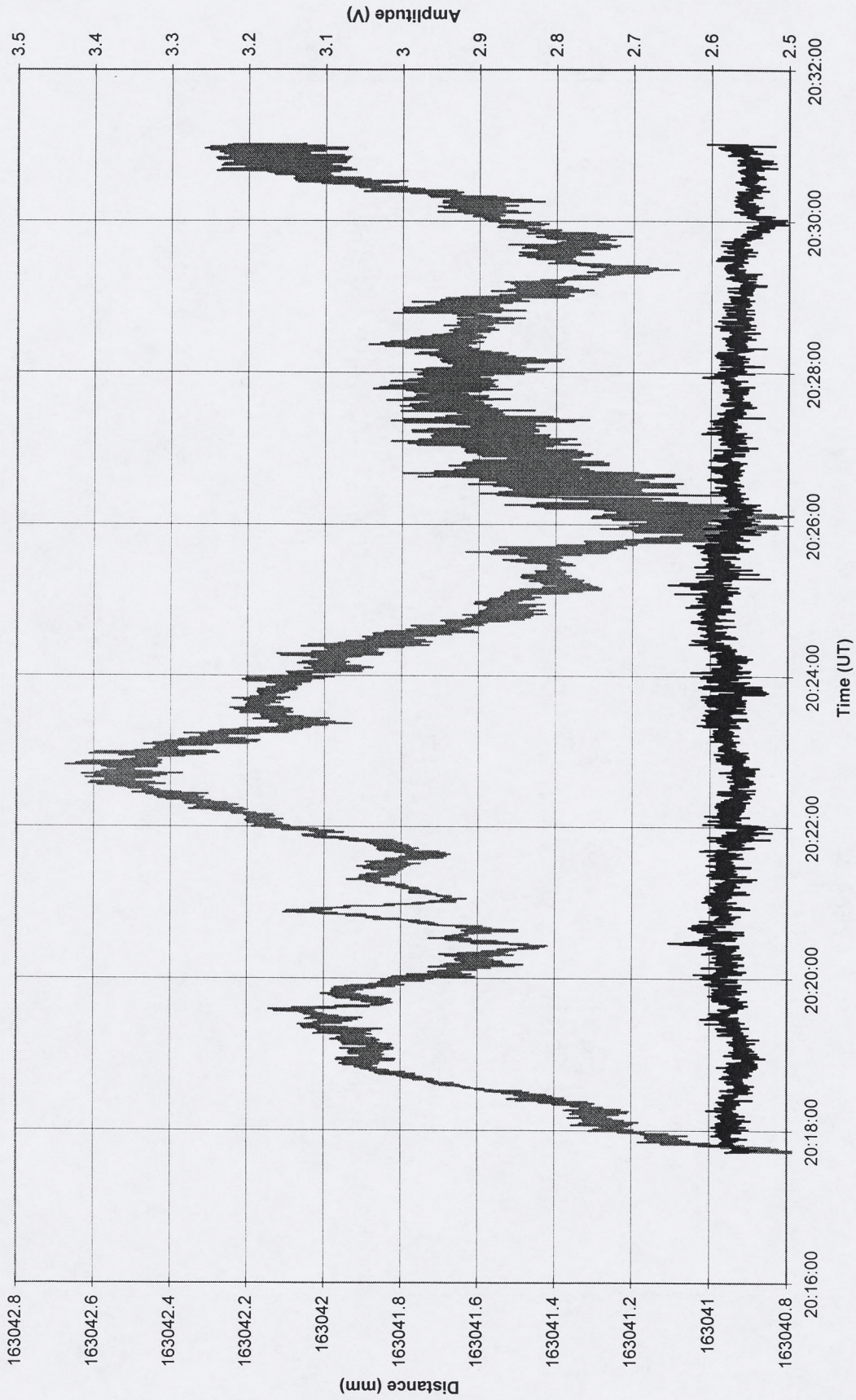
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Distance Amplitude

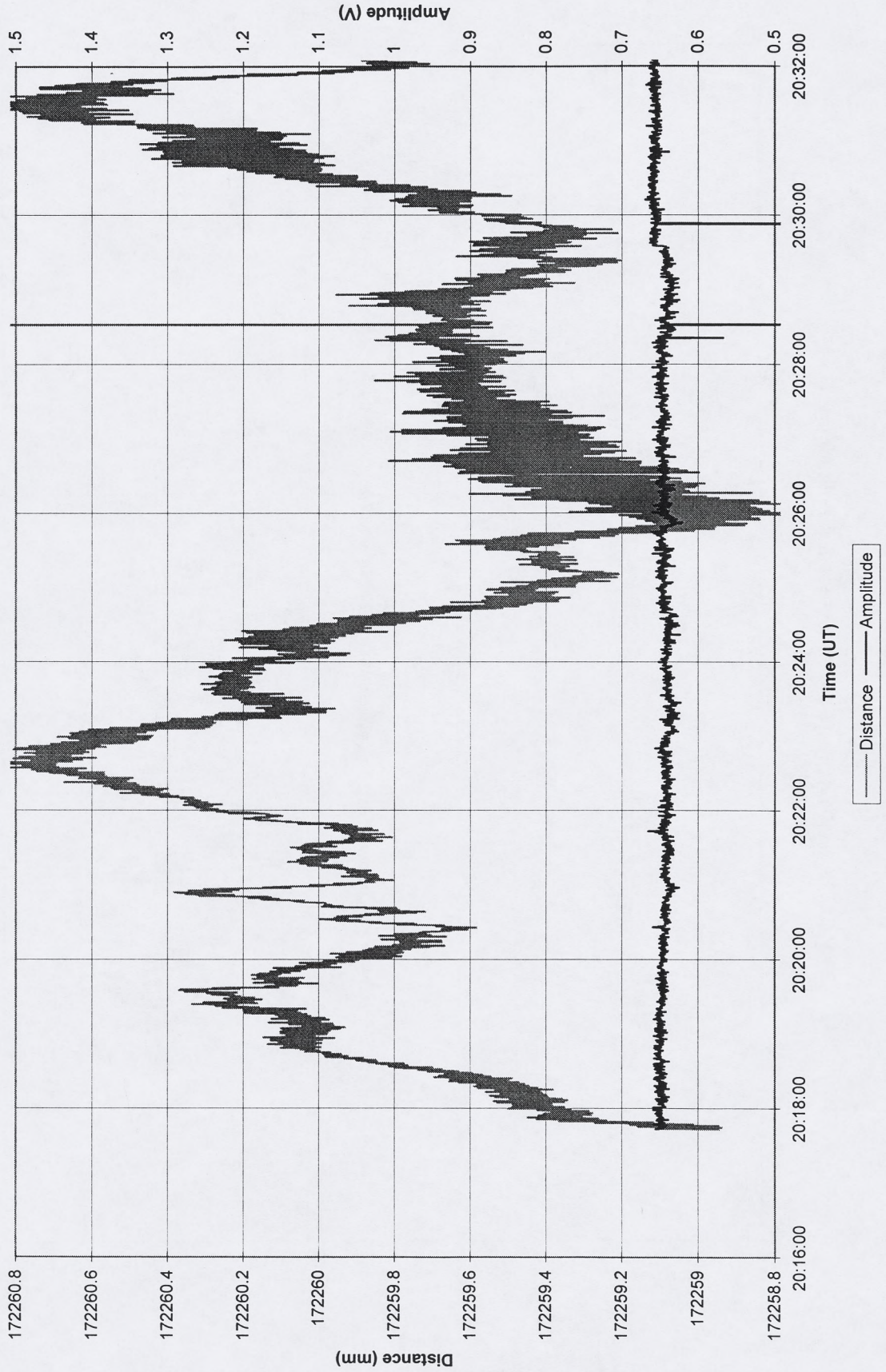
ZY102 to ZEG41040L 10-15-1999 Distance & Amplitude vs. Time

File: zy102.19991015.211652.xls Disk: B293



ZY103 to ZEG41040L 10-15-1999 Distance & Amplitude vs. Time

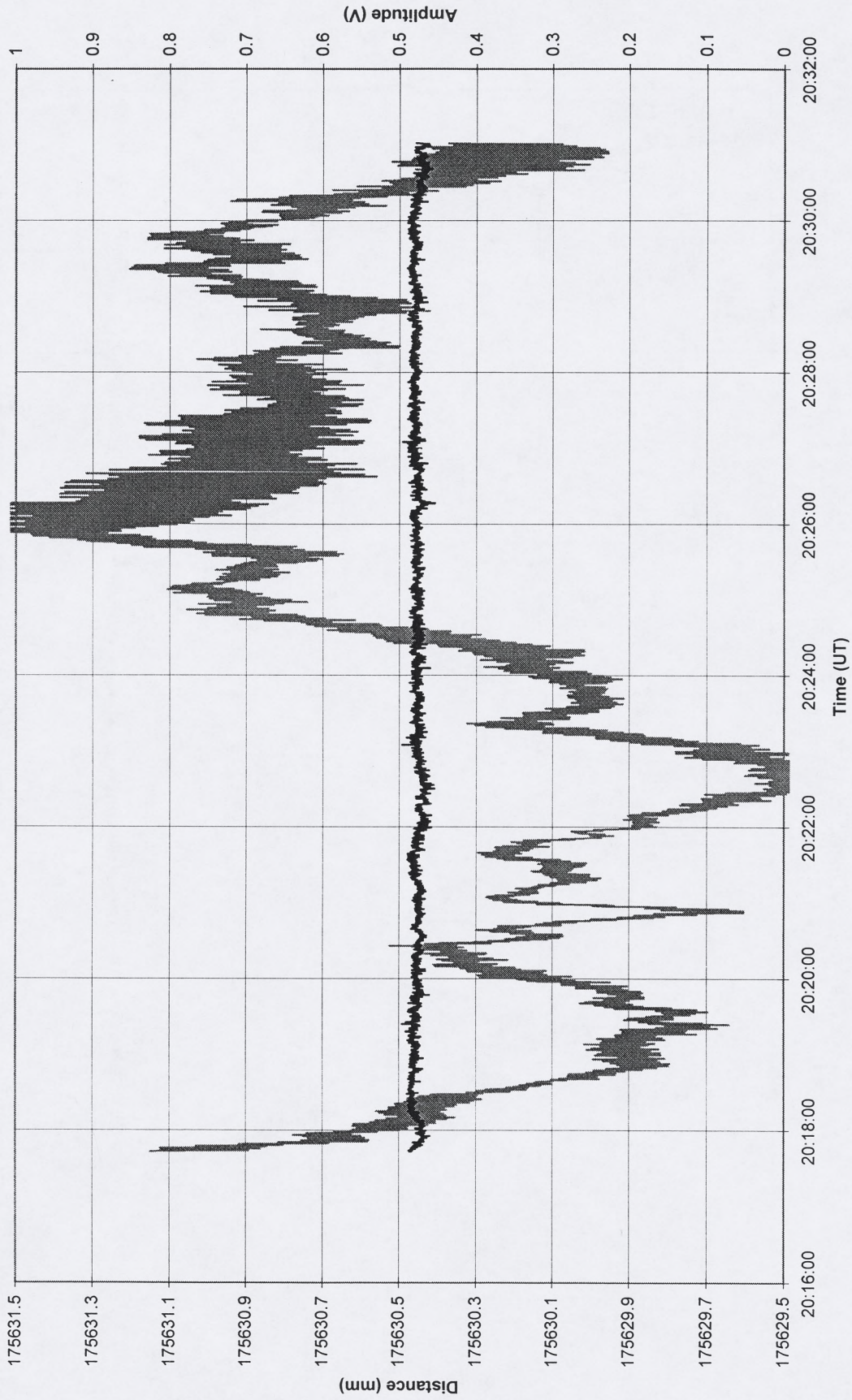
File: zy103.19991015.211650.xls Disk: B294





ZY110 to ZEG41040R 10-15-1999 Distance & Amplitude vs. Time

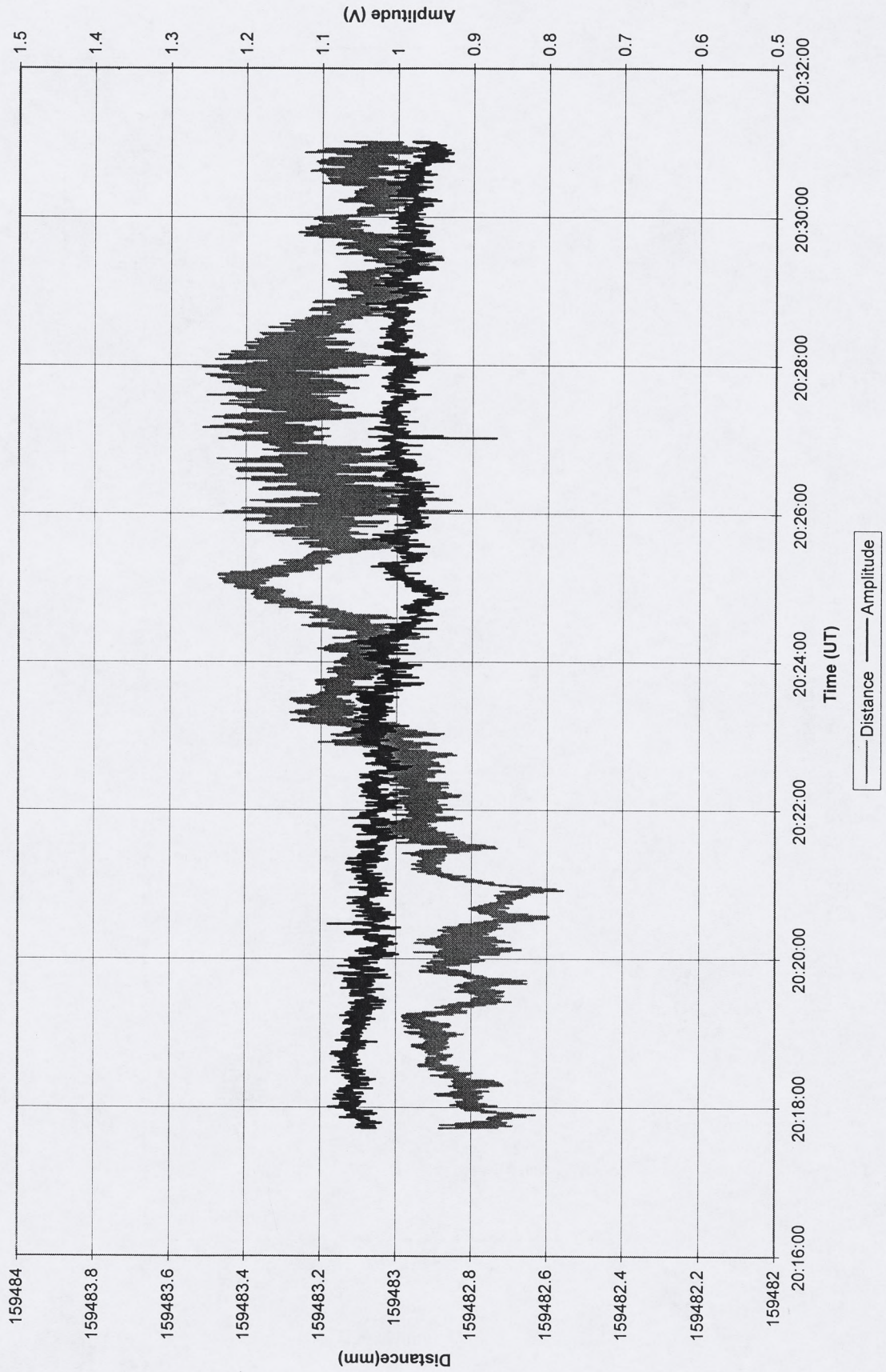
File: zy110.19991015.211648.xls Disk: B295



Distance (mm) — Amplitude (V)

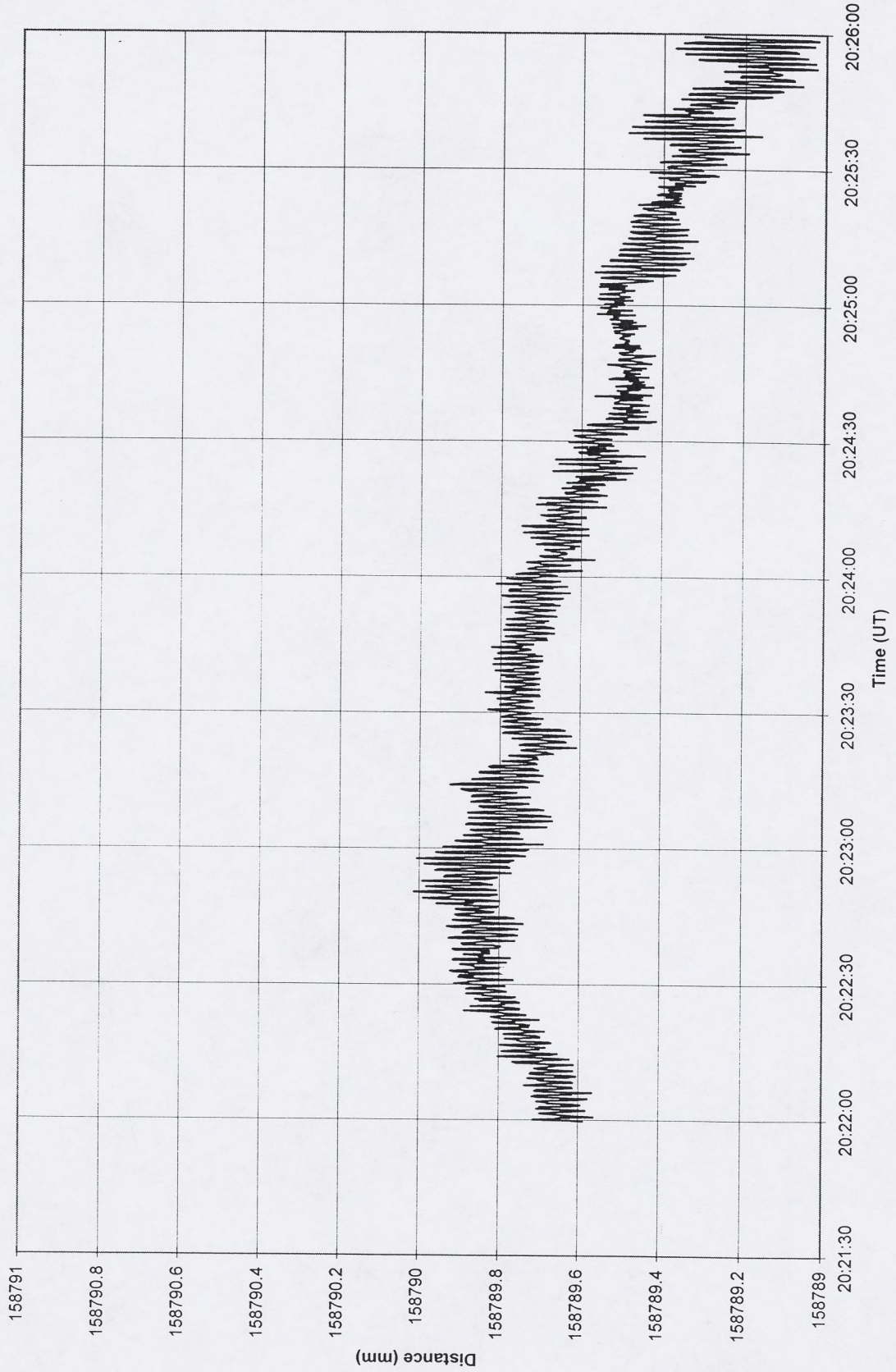
# ZY112 to ZEG41080 10-15-1999 Distance & Amplitude vs. Time

File: zy112.19991015.211645.xls Disk: B297



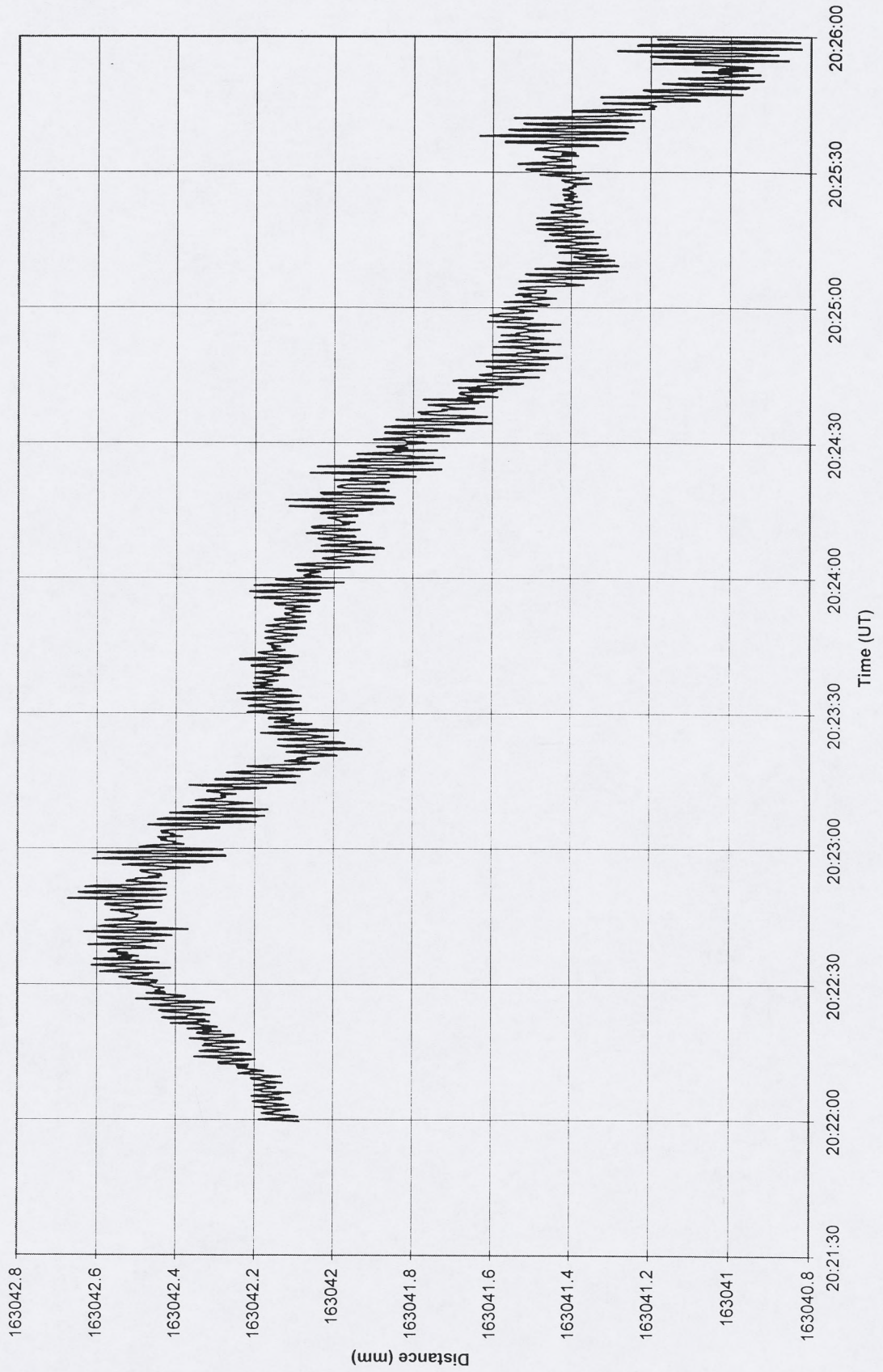
ZY101 to ZEG41040L 10-15-1999 Distance vs. Time

File: zy101.19991015.211656.xls Disk: B293



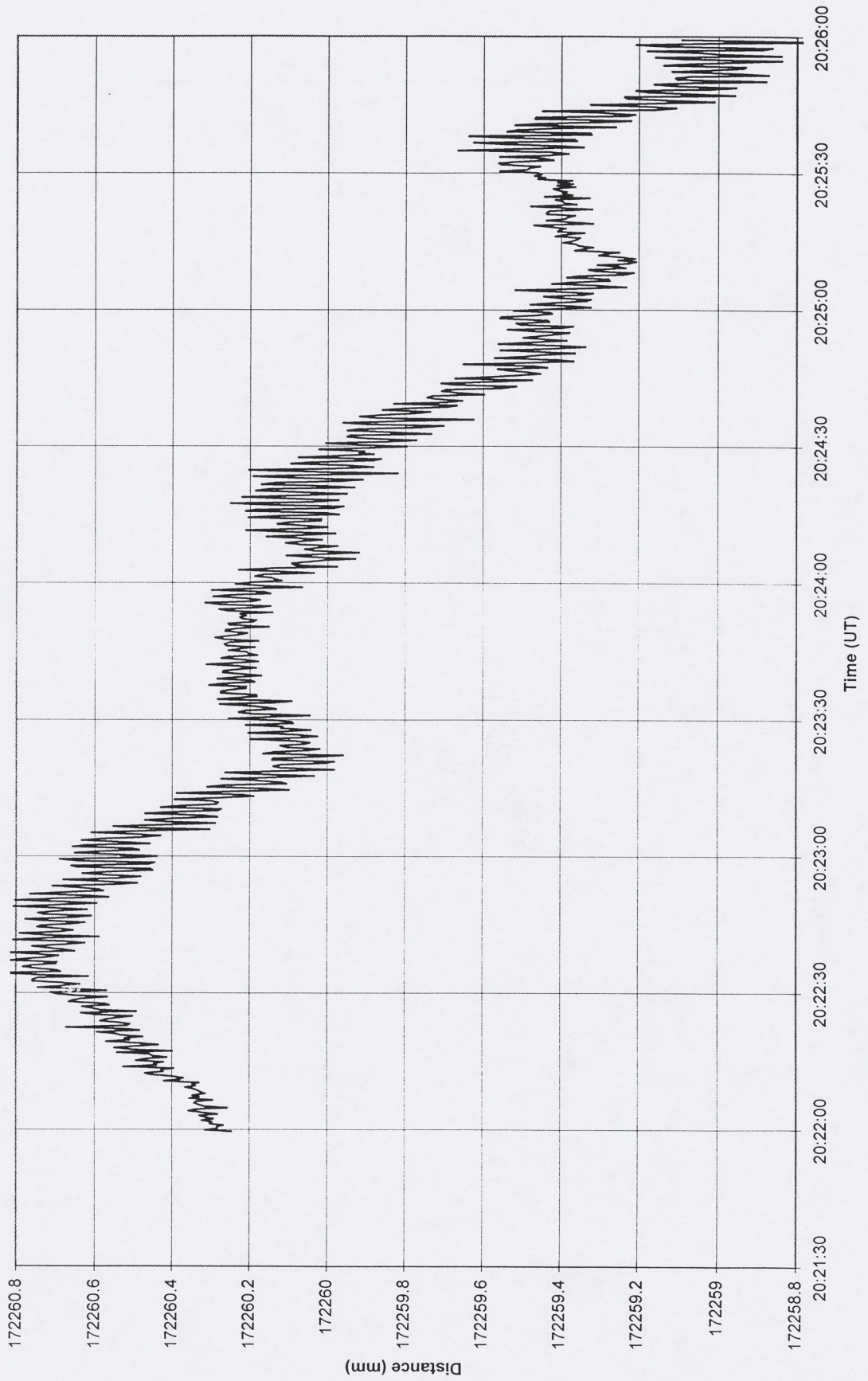
ZY102 to ZEG41040L 10-15-1999 Distance vs. Time

File: zy102.19991015.211652.xls Disk: B293



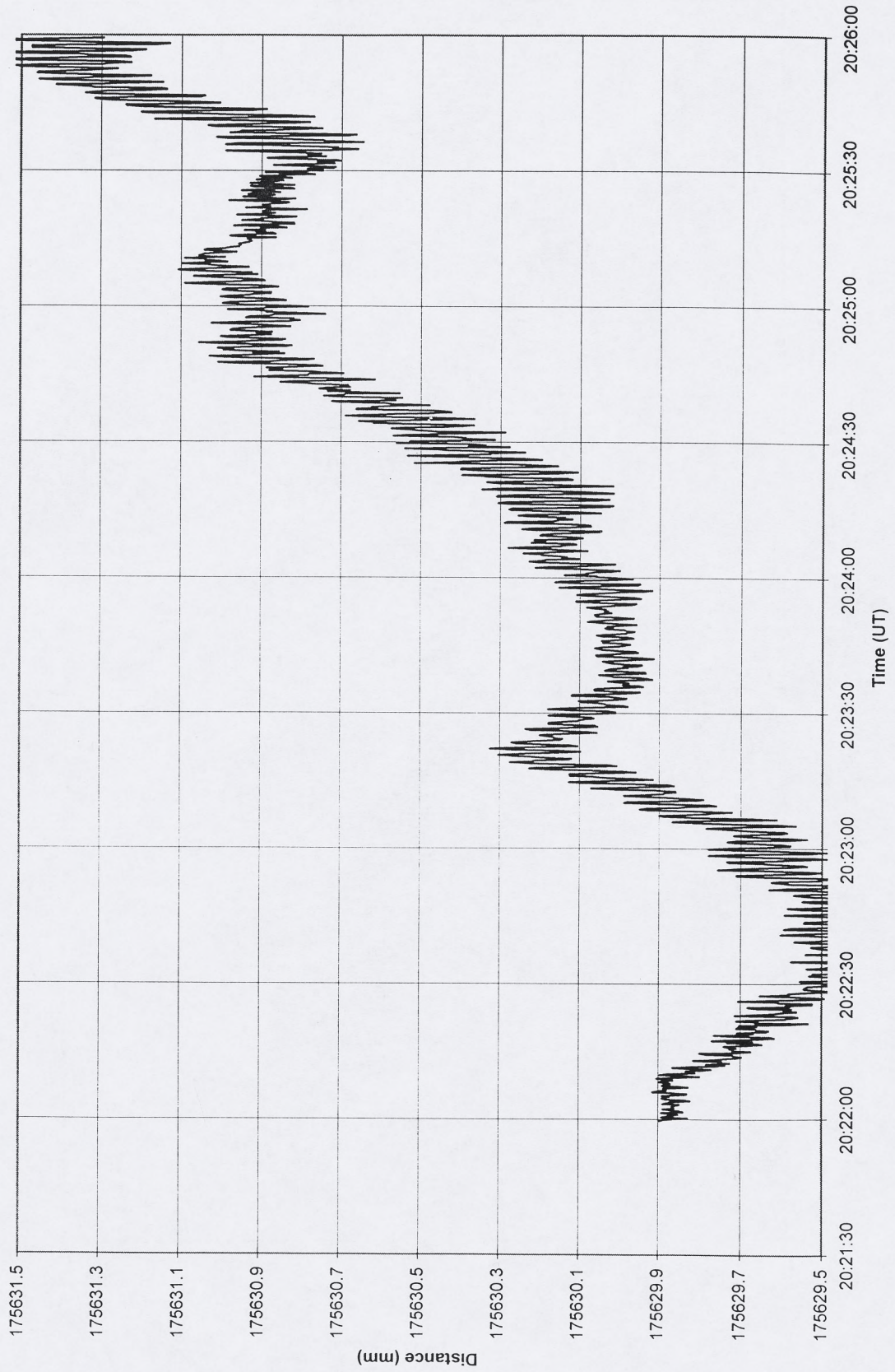
ZY103 to ZEG41040L 10-15-1999 Distance vs. Time

File: zy103.19991015.211650.xls Disk: B294



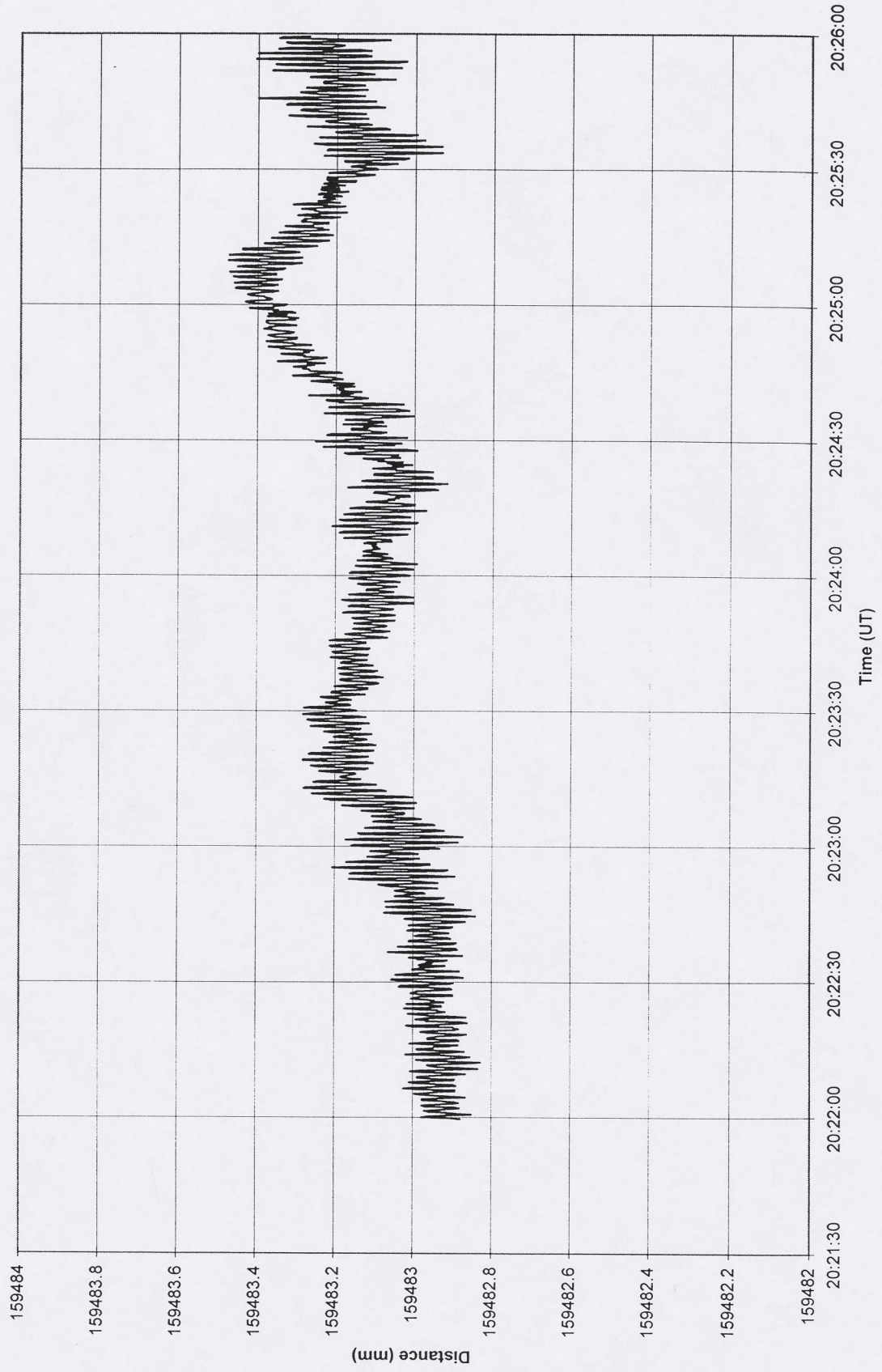
ZY110 to ZEG41040R 10-15-1999 Distance vs. Time

File: zy110.19991015.211648.xls Disk: B295

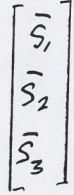


ZY112 to ZEG41080 10-15-1999 Distance vs. Time

File: zy112.19991015.211645.xls Disk: B297



EQ 12.1 MEMO L0543



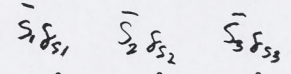
ZY101 to ZEG41040L Time Distance  
 ZY102 to ZEG41040L Time Distance  
 ZY110 to ZEG41040R Time Distance  
 ZY110 to ZEG41040R Time Distance

	X	Y	Z
ZY101	701305341.5	159814047.1	807543.9
ZY102	701362414.6	159789797.2	807543.7
ZY110	701169783.7	159712049.4	807543.3
ZEG41040L	701290381.5	159727791.4	940354.5
ZEG41040R	701284104.3	159727549.9	940329.4
GBT	701288568.9	159695168.8	807435.4
ZY101-41040L	14960.5	86255.7	-132810.6
ZY102-41040L	72033.6	62005.8	-132810.6
ZY110-41040R	-114320.6	-15500.5	-132766.1

159067.6517  
 163316.4638  
 175902.2638

MINVERSE

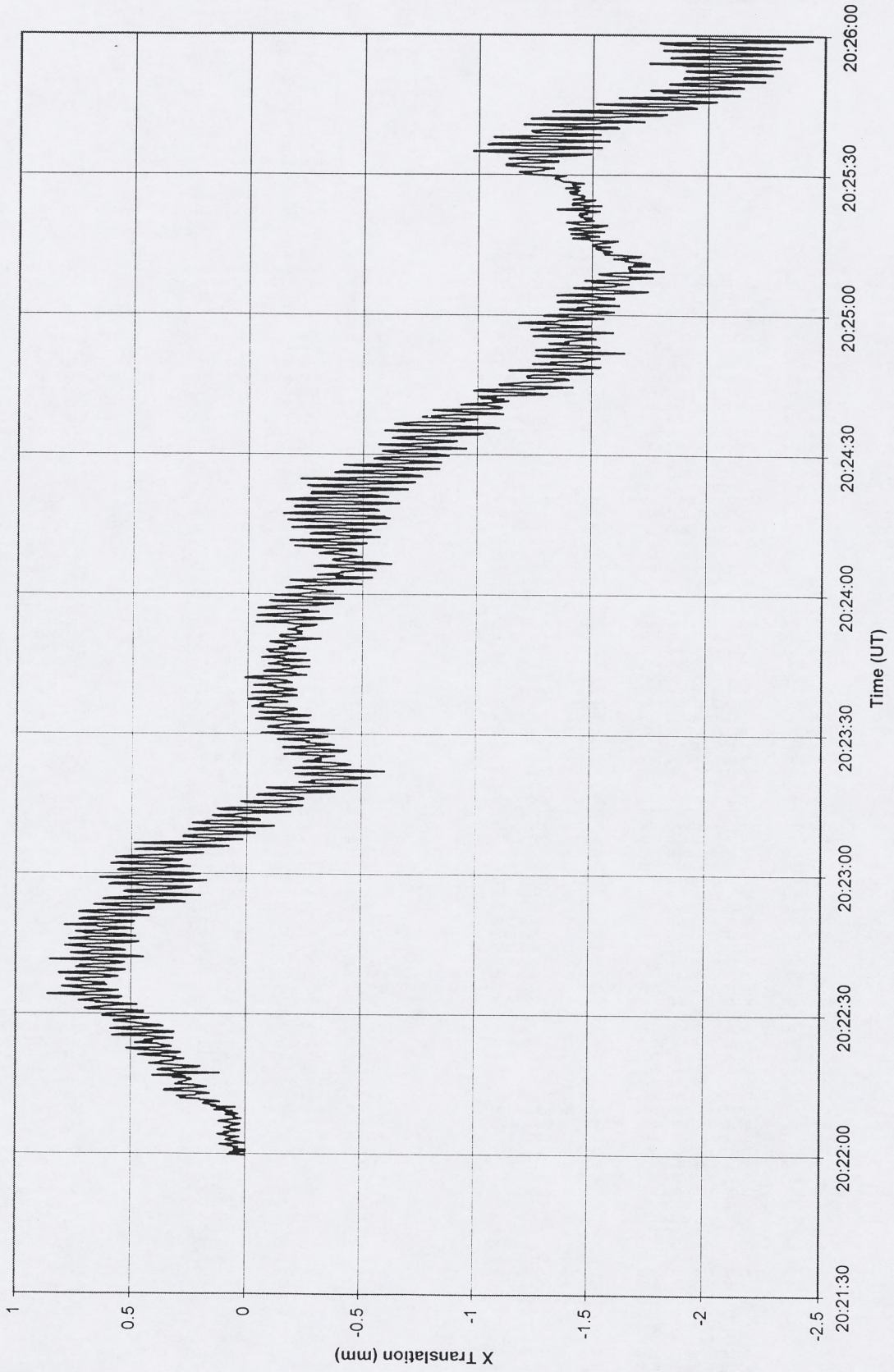
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2.08397E-05	-1.4458E-05	-6.38285E-06
5.02885E-06	-8.10825E-06	-4.45093E-06



Time	ZY101 to ZEG41040L Distance	ZY102 to ZEG41040L Distance	ZY110 to ZEG41040R Distance	X	Y	Z	$\delta_x$	$\delta_y$	$\delta_z$
20:22:00	158789.5888	163042.0856	175629.896	0	0	0	0	0	0
20:22:00	158789.6171	163042.1457	175629.8901	4507.98	9816.95264	-1030.787384	0.075425919	-0.0414094	-0.0523404
20:22:00	158789.7125	163042.1872	175629.8671	19676.67	16594.58589	-5076.539913	0.032052643	0.20253399	-0.0130067
20:22:00	158789.6585	163042.1544	175629.8279	11098.15	11239.43904	-11971.90944	0.064168697	0.14519705	-0.01796482
20:22:00	158789.646	163042.1259	175629.8918	9101.85	6581.653491	-740.5486171	-0.00198725	0.09924907	-0.0042977
20:22:01	158789.5621	163042.0881	175629.8813	-4247.11	411.5574856	-2594.558686	0.048527939	-0.0778981	-0.0131469
20:22:01	158789.6104	163042.0946	175629.8752	3443.81	1464.94868	-3665.803596	-0.00323631	0.0739861	0.02175648
20:22:01	158789.6364	163042.1322	175629.8518	7581.16	7605.647717	-7780.158011	0.041935105	0.09786621	0.01108494
20:22:01	158789.6717	163042.1647	175629.863	13186.71	12921.59862	-5797.739275	0.048463181	0.12499252	-0.0126523
20:22:01	158789.6956	163042.1801	175629.8913	16994.79	15436.67216	-826.7407372	0.030595168	0.1362597	-0.0360204
20:22:02	158789.661	163042.1643	175629.8387	11486.28	12853.0057	-10075.68282	0.07402187	0.11785316	-0.0016065
20:22:02	158789.6224	163042.1391	175629.8483	5352.63	8742.33031	-8388.779914	0.075833357	0.03869469	-0.0066296
20:22:02	158789.5828	163042.1313	175629.8632	-949.63	7453.763409	-5778.390025	0.108712326	-0.0906742	-0.0394934
20:22:02	158789.6228	163042.1088	175629.8877	5417.84	3790.575123	-1459.988958	0.000134625	0.06742098	0.0030089
20:22:02	158789.7032	163042.1754	175629.8608	18200.52	14659.28579	-6200.555506	0.025874055	0.20692652	-0.00026474
20:22:03	158789.6907	163042.1728	175629.8665	16220.13	14246.09514	-5183.840304	0.035578853	0.1651401	-0.0108694
20:22:03	158789.6962	163042.1963	175629.8668	17090.23	18084.03204	-5138.10571	0.071582944	0.12749185	-0.03781164
20:22:03	158789.6153	163042.1406	175629.8578	4226.43	8975.872849	-6719.467242	0.083723912	0.0011935	-0.0216167
20:22:03	158789.5951	163042.113	175629.8479	1013.26	4476.504271	-8466.17692	0.065113745	0.01043298	0.00648124
20:22:03	158789.6119	163042.1281	175629.8883	3680.83	6931.150724	-1352.688562	0.050632224	-0.0148694	-0.0316685
20:22:04	158789.6768	163042.1597	175629.8766	14004.32	12091.95098	-3419.540397	0.025487472	0.13884662	-0.0123988
20:22:04	158789.676	163042.1849	175629.8709	13877.06	16217.32486	-4418.665369	0.076239609	0.0829272	-0.0420413
20:22:04	158789.7032	163042.2028	175629.8221	18200.52	19145.58906	-13002.69682	0.095368048	0.18548048	-0.0058355
20:22:04	158789.6692	163042.1939	175629.836	12789.04	17677.37405	-10559.4141	0.11893598	0.07833915	-0.0320193
20:22:04	158789.6014	163042.1304	175629.8838	2007.43	7310.44292	-2142.48982	0.071588213	-0.03051793	-0.0396406
20:22:05	158789.5775	163042.1243	175629.89	-1795.87	6323.613477	-1062.449795	0.090397532	-0.122071	-0.0555758
20:22:05	158789.6257	163042.1332	175629.8876	5875.96	7777.130007	-1479.338208	0.041576812	0.01945377	-0.0269252
20:22:05	158789.7024	163042.1756	175629.8724	18078.04	14691.94908	-4160.089014	0.021773411	0.1900778	-0.009698
20:22:05	158789.7147	163042.2058	175629.8904	20034.57	19625.73946	-981.534743	0.052334264	0.1400303	-0.0540108
20:22:05	158789.7048	163042.1974	175629.8332	18450.26	18252.248	-11043.14538	0.077724604	0.19109333	-0.006058
20:22:06	158789.6161	163042.1373	175629.8296	4432.55	8433.662191	-11683.42969	0.09001056	0.04313689	0.00545784
20:22:06	158789.6174	163042.1349	175629.8672	4554.11	8044.969008	-5069.50382	0.065817169	0.0109498	-0.0197647
20:22:06	158789.5654	163042.1071	175629.9139	-3709.46	3508.037642	3141.614787	0.06354414	-0.1480757	-0.0610815
20:22:06	158789.6894	163042.1796	175629.9004	16013.34	15343.58177	765.1749349	0.033724586	0.10699157	-0.0472867
20:22:06	158789.7088	163042.1818	175629.8794	19086.53	15712.67698	-2916.459864	0.021274439	0.18919882	-0.0184381
20:22:07	158789.704	163042.1988	175629.8798	18332.55	18484.15737	-2853.135046	0.059171896	0.13301177	-0.0449835
20:22:07	158789.6545	163042.1755	175629.8867	10449.15	14673.98427	-1634.132219	0.080836129	0.016031	-0.0591597
20:22:07	158789.6139	163042.1478	175629.8263	4005.32	10158.28405	-12253.35309	0.114102046	0.01481237	-0.007685
20:22:07	158789.6178	163042.1444	175629.8502	4622.51	9606.274399	-8052.806554	0.091080139	0.0088438	-0.0180818
20:22:07	158789.6619	163042.1647	175629.8892	11627.85	12923.23178	-1192.617483	0.049502781	0.06308888	-0.0410019
20:22:08	158789.7343	163042.1997	175629.8854	23152.30	18637.67485	-1866.32323	0.01647084	0.22493573	-0.0263827
20:22:08	158789.6972	163042.1833	175629.8697	17255.66	15960.91801	-4624.471042	0.044598853	0.15835694	-0.0220558
20:22:08	158789.6796	163042.1744	175629.8739	14449.71	14499.23566	-3880.404383	0.050267996	0.11626546	-0.0276267
20:22:08	158789.6133	163042.1286	175629.8978	3906.70	7014.442122	318.3831314	0.045090319	-0.0220326	-0.0386458
20:22:08	158789.6183	163042.1504	175629.8886	4697.27	10576.37419	-1294.640812	0.083141866	-0.0467602	-0.0563717
20:22:09	158789.6904	163042.1695	175629.8638	16159.68	13694.08549	-5657.017447	0.031105802	0.17488116	-0.0045915
20:22:09	158789.7012	163042.1872	175629.8663	17882.39	16597.85222	-5226.056851	0.0480459	0.16604876	-0.0213909
20:22:09	158789.6859	163042.2048	175629.9034	15455.01	19468.95665	1298.158853	0.084057593	0.03230949	-0.0859163
20:22:09	158789.726	163042.2086	175629.8609	21833.63	20081.39239	-6168.893094	0.055995147	0.20404436	-0.0255697
20:22:09	158789.6249	163042.1586	175629.7989	5755.07	11962.46869	-17078.35273	0.132073629	0.05659606	0.00830169
20:22:10	158789.6063	163042.1326	175629.8413	2794.82	7669.341138	-9618.336877	0.089127077	0.00875208	-0.0053197
20:22:10	158789.6211	163042.1747	175629.8956	5149.02	14553.13009	-79.15603146	0.121178787	-0.1026001	-0.0917545
20:22:10	158789.6986	163042.1864	175629.8797	17478.35	16455.7669	-2867.207229	0.045335374	0.14462896	-0.0327697
20:22:10	158789.7204	163042.2397	175629.8101	20942.85	25167.06707	-15108.24716	0.045825298	0.16901051	-0.0314968
20:22:10	158789.7183	163042.2289	175629.8154	20607.21	23404.88243	-14179.4831	0.126164698	0.18156557	-0.0230303
20:22:11	158789.6671	163042.2097	175629.8326	12453.41	20270.83949	-11159.24088	0.152980711	0.03767889	-0.0520658
20:22:11	158789.6133	163042.1761	175629.7973	3908.29	14781.77314	-17366.83248	0.18141821	-0.0214177	-0.0229017
20:22:11	158789.6484	163042.192	175629.7706	9485.20	17367.07276	-22056.38736	0.175218989	0.08735794	0.00505441
20:22:11	158789.7001	163042.2092	175629.8229	17702.64	20182.6486	-12861.97499	0.111101359	0.15922173	-0.0173744
20:22:11	158789.7093	163042.2404	175629.8648	19178.79	25281.3886	-5489.910279	0.136329472	0.06920278	-0.0841054
20:22:12	158789.6838	163042.2425	175629.8224	15116.20	25627.6195	-12939.372	0.195681602	0.02708258	-0.0741859
20:22:12	158789.6675	163042.2168	175629.7606	12528.17	21432.01955	-23813.65118	0.199864191	0.10321769	-0.0047811
20:22:12	158789.6533	163042.2445	175629.7377	10263.04	25952.61927	-27854.12684	0.281889933	0.01644398	-0.0348424
20:22:12	158789.6118	163042.215	175629.7832	3664.92	21134.78358	-19843.53664	0.262530609	-0.1025331	-0.0646137
20:22:12	158789.704	163042.2865	175629.7265	18324.59	32810.27758	-29818.95515	0.295379469	0.09783736	-0.0411604
20:22:13	158789.757	163042.2903	175629.7511	26755.18	33429.24698	-25482.96385	0.217597156	0.23690328	-0.0230822
20:22:13	158789.7642	163042.2904	175629.7451	27911.60	33442.3123	-26540.13658	0.210590491	0.26756165	-0.0126672
20:22:13	158789.6958	163042.2279	175629.8144	17025.01	23236.66647	-14357.1444	0.155778566	0.11047954	-0.0388899
20:22:13	158789.6795	163042.2201	175629.7632	14432.21	21959.53173	-23358.06426	0.188128966	0.1323626	-0.001511
20:22:13	158789.6226	163042.1979	175629.7428	5374.90	18338.80572	-26955.26597	0.235184555	0.01891976	-0.0016902
20:22:14	158789.6682	163042.2854	175629.71	12629.97	32628.99631	-32712.54772	0.350518173	0.00025341	-0.0554488
20:22:14	158789.7229	163042.322	175629.6977	21330.97					

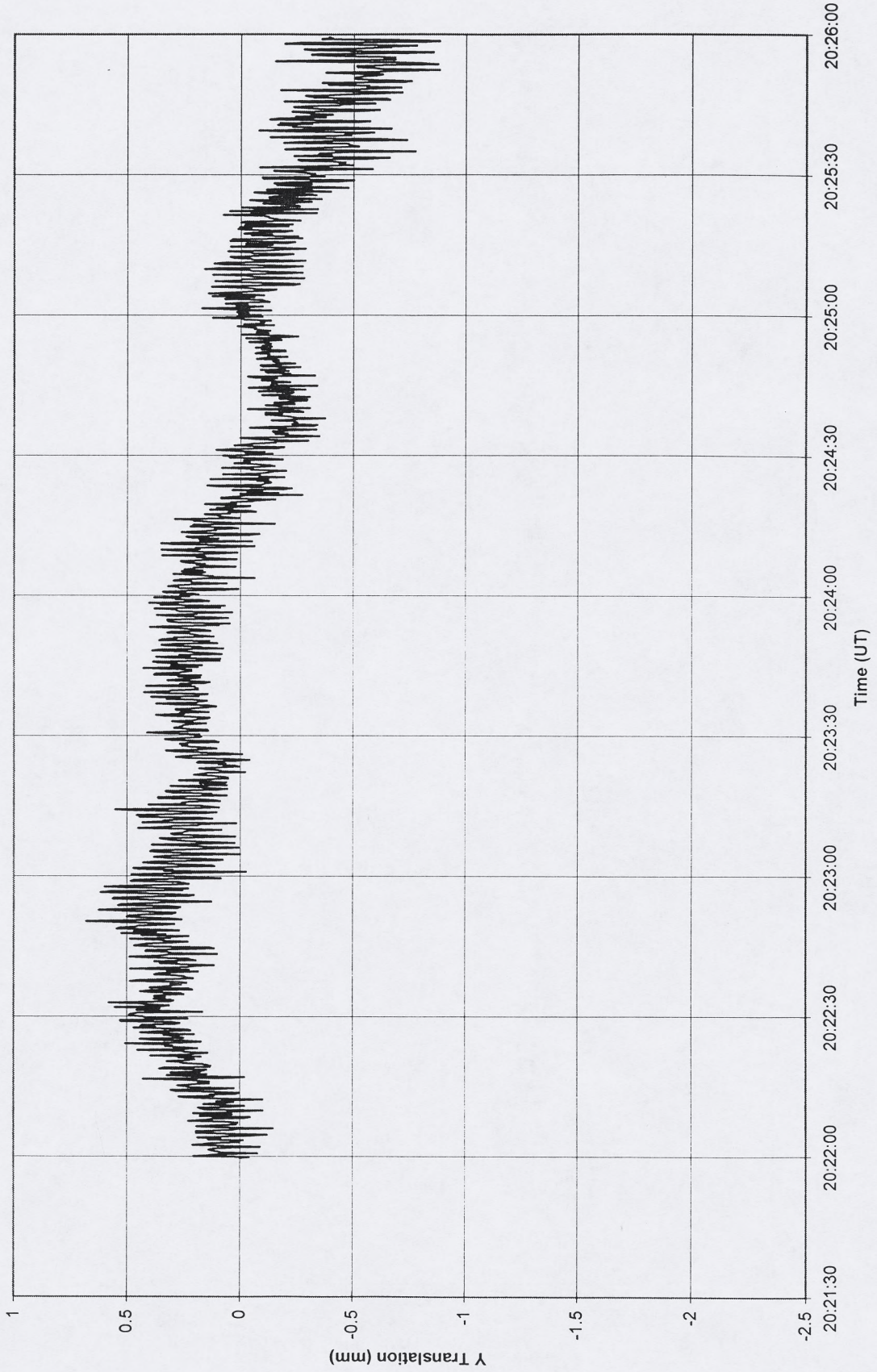


X Translation of Feedarm Tip vs. Time 10-15-1999  
File: Parker.matrix.1015.xls Disk: B297



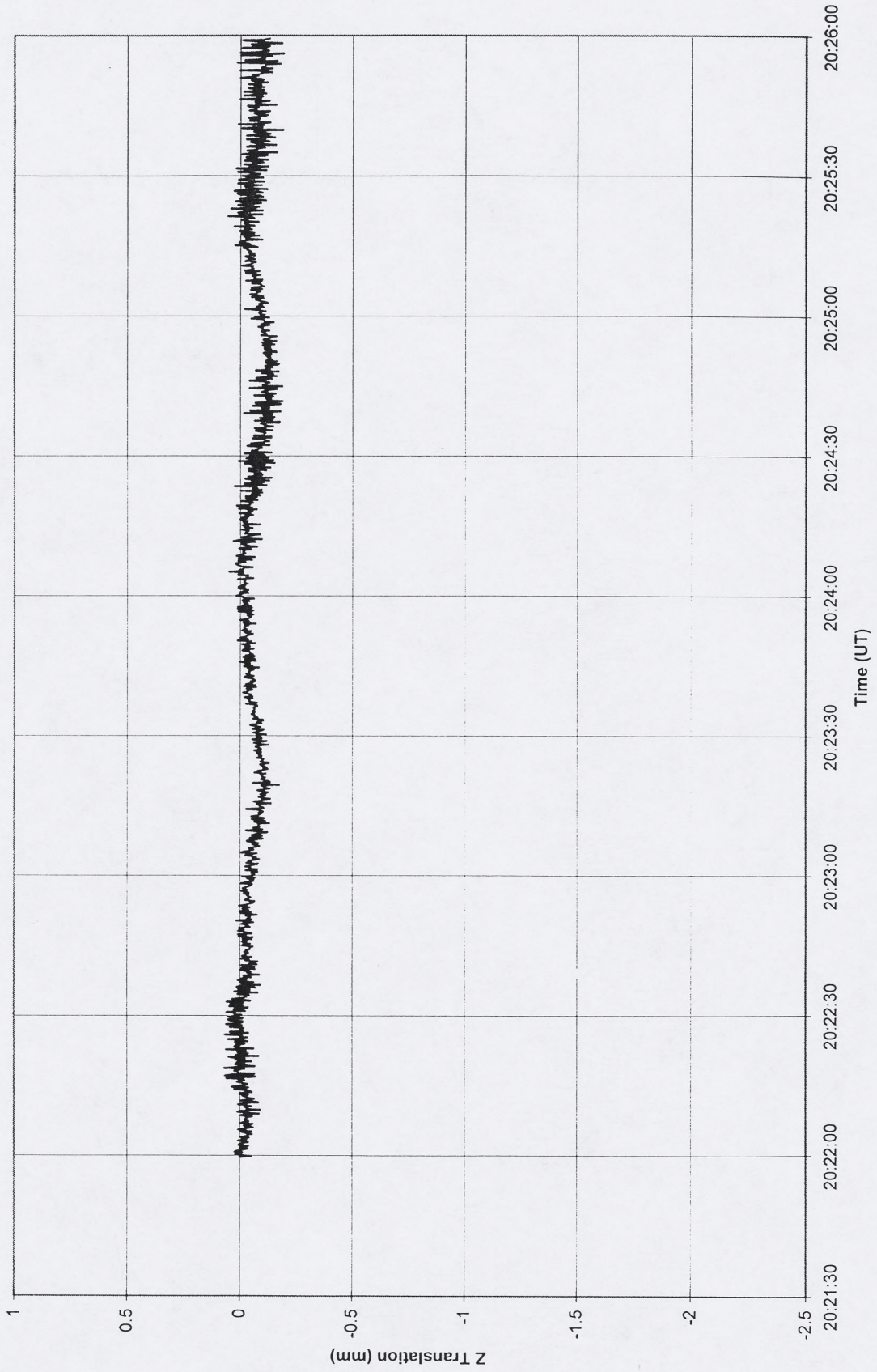
# Y Translation of Feedarm Tip vs. Time 10-15-1999

File: Parker.matrix.1015.xls Disk: B297



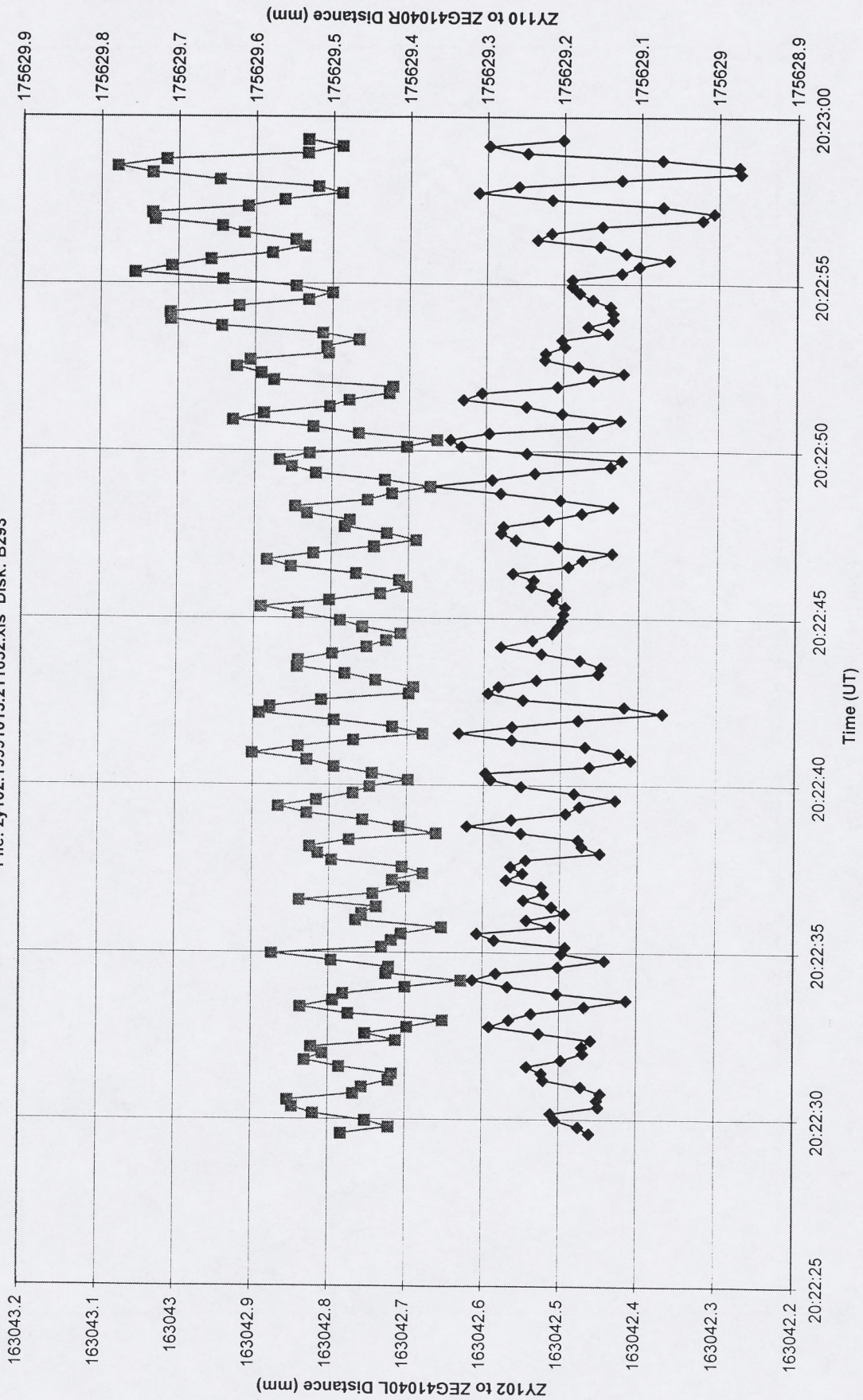
# Z Translation of Feedarm Tip vs Time 10-15-1999

File: Parker.matrix.1015.xls Disk: B297



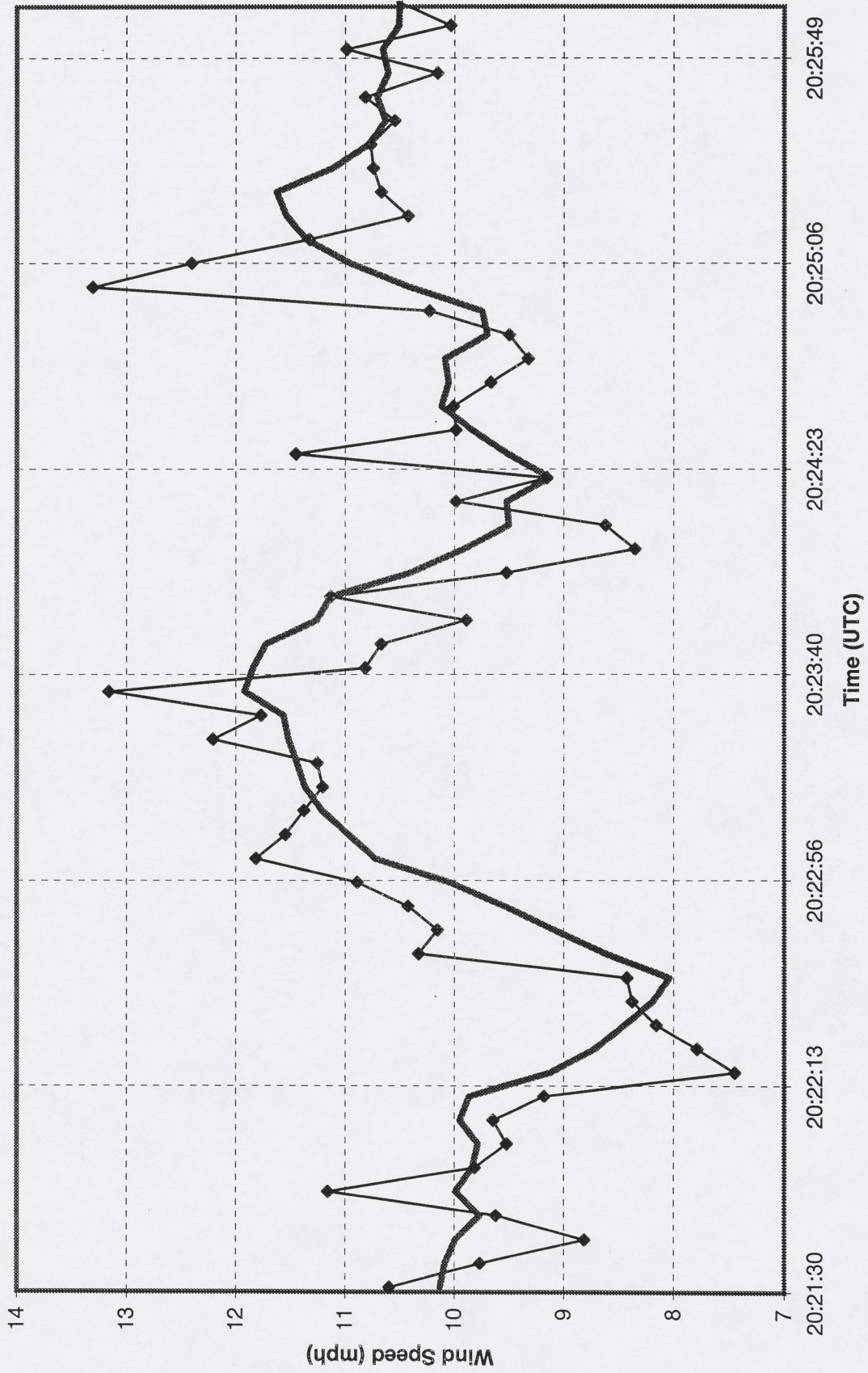
# ZY102 to ZEG41040L & ZY110 to ZEG41040R 10-15-1999 Distance vs. Time

File: zy102.19991015.211652.xls Disk: B293

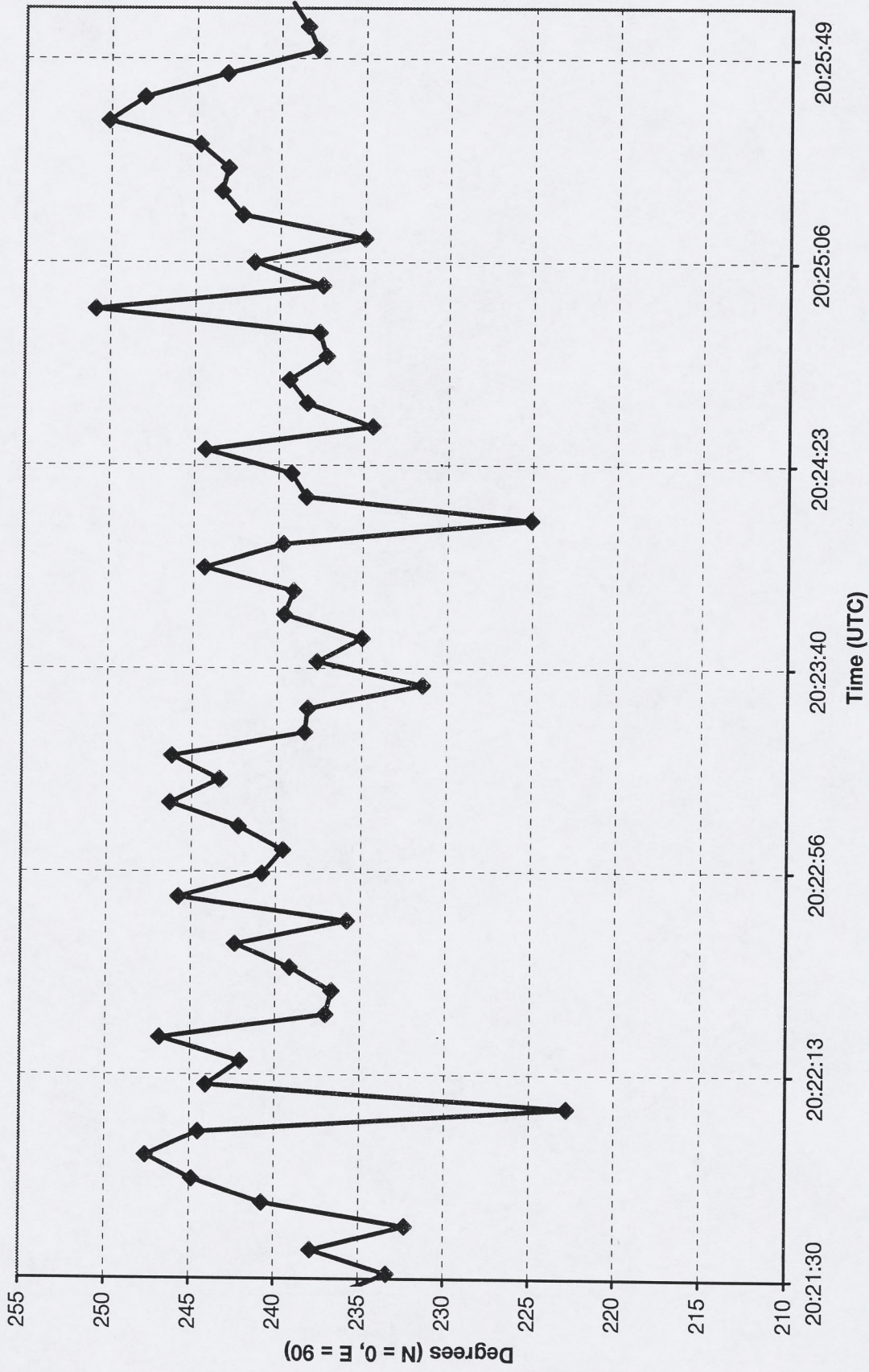


—◆— ZY102 to ZEG41040L —■— ZY110 to ZEG41040R

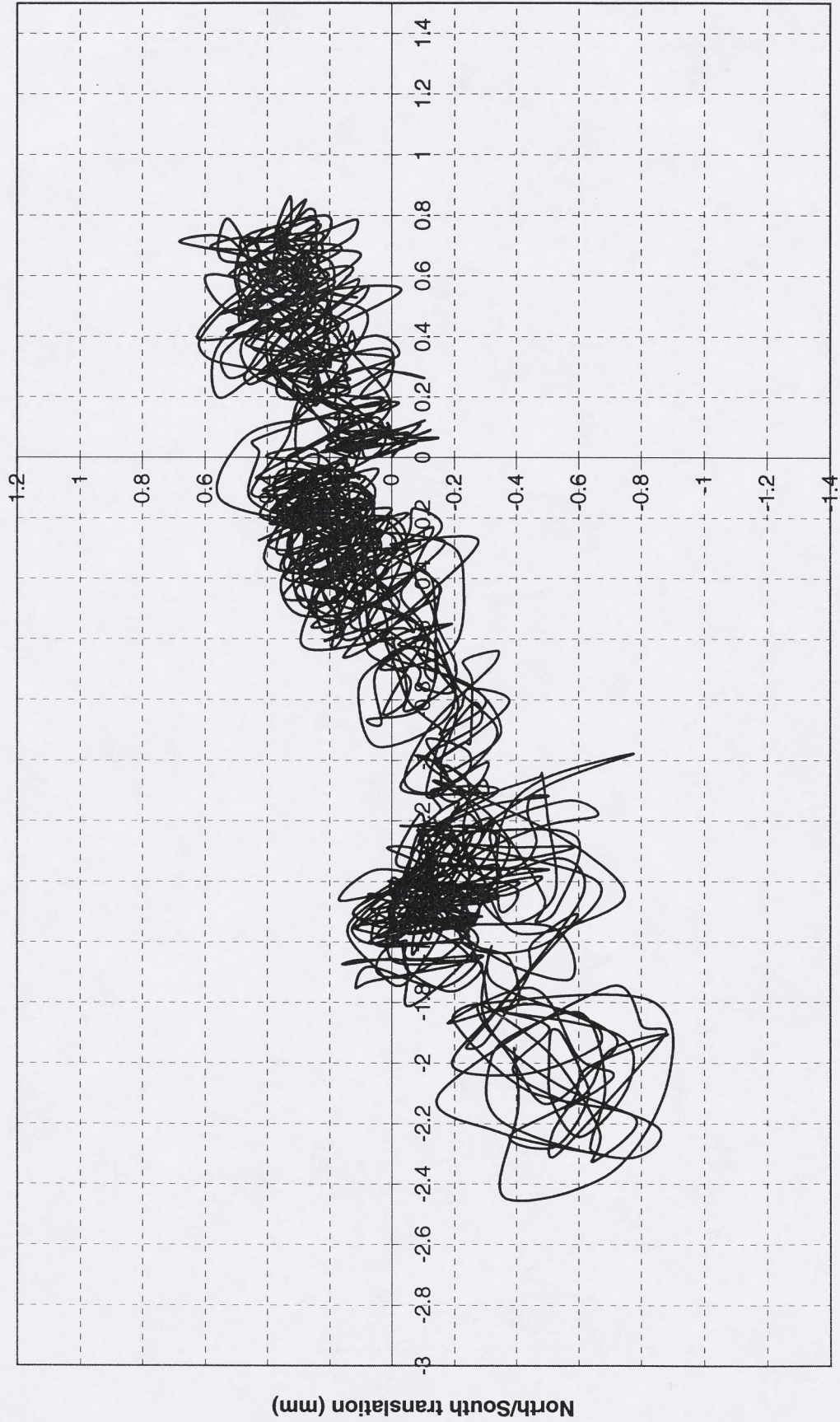
Wind Speed 10/15/1999



# Wind Direction 10/15/1999



# Translation of Tip of Feedarm



East/West translation (mm)