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THE EFFECTS OF PRIMARY POWER TRANSMISSION LINES ON THE PERFORMANCE OF LORAN-C RECEIVERS IN EXPERIMENTAL TERRESTRIAL APPLICATIONS

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JULY 1979

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. Abstract

Tests were conducted to measure the effect generated by high-voltage transmission lines with and without supervisory carrier signals on the performance of typical LORAN-C receivers which might be used for land vehicle applications of the LORAN-C Navigation System. The tests were performed on four high voltage transmission line configurations owned and operated by the Tennessee Valley Authority. Transmission lines were tested with 60Hz power impressed and absent and carrier signals impressed and absent. Data are plotted for three secondary time differences measured using the East Coast LORAN-C chain. Carolina Beach was the master and Nantucket,Mass., Jupiter, Florida, and Dana, Indiana were the secondaries. Signal to noise ratios for the secondaries as well as the master were also measured and recorded. The test area chosen had extremely good LORAN-C signal coverage. In general, with the carrier off and line de-energized, acceptable receiver performance was obtained to within approximately ±100 meters from the center of the line. With the line energized, useable performance degrades to a point about ± 200 meters and with asynchronous carrier signals performance is unreliable at distances less than ±300 meters. With synchronous interference the receivers would not operate properly at 1000 meters either side of the line.

. Key Words
LORAN-C
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PREFACE

The tests of the effects of Primary Power Transmission Lines on the performance of LORAN-C Receivers were performed after common interests were identified between the U.S. Department of Transportation, who recognized the future impact that power line carrier interference might have on the terrestrial users of LORAN-C, and the Tennessee Valley Authority, who recognized that the increasing terrestrial use of LORAN-C might likewise have a future impact on utility use of power line carrier.

A test program was devised by DOT/TSC and TVA to answer this question in a quantitive and qualitative manner. Special recognition should be given to Mr. Herbert Dobson of TVA for his many helpful contributions to and close association with the TSC. Other contributors from TVA who were involved with the test were:

John E. Hendrix, Area Superintendent (The Murfreesboro Area includes both Wilson and Murfreesboro Substations)

Leonard Bentley, Test Engineering Associate at Wilson
H.A. Pickle, Test Engineer at Murfreesboro

H.B. Cummings III, Chattanooga Central Laboratories of the Division of Power System Operations (PSO)

L.A. Bryant, Supervisor, PLC Engineering Section

R.E. Bratton, Communication Engineer

H.G. Davis, Communication Engineer of the Communication Engineering and Design Branch.

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LIST OF ILLUSTRATIONS (CONT.)

1. INTRODUCTION

LORAN-C is a highly accurate radionavigation system originally developed for the Department of Defense and subsequently designated for civil marine use in the coastal and confluence zone. With the advent of more economical and easier-to-operate receivers, more widespread uses are being contemplated. A large number of terrestrial applications are currently being investigated with respect to operational, technical, economic, and social factors. Several demonstration programs are in progress.

Some problems and limitations have already been identified with respect to the anticipated capabilities of LORAN-C. One of the problem areas is the influence of power transmission lines and LF carrier signals. Quantitative assessments of these influences have not previously been attempted.

The objectives of the tests described in this report were twofold. The first objective was to measure the effect of high voltage primary transmission lines and power line carrier (PLC) communications on typical LORAN-C receivers used in the LORAN-C Navigation System. The second objective was to provide quantitative data for input toward evaluating the impact which terrestrial use of the LORAN-C Navigation System might have on the utility use of Power Line Carrier.

The effect of PLC transmissions on the LORAN-C system performance is dependent upon the PLC transmission frequency, the available LORAN-C signal strength and the level of the PLC signals radiated from the transmission lines. As such, the tests are required to probe more than just the absolute microvolts/meter level of the power line carriers. When the shielding effect of a transmission line attenuates the LORAN-C signal below a usable level, the level of PLC interference is unimportant in an absolute sense and only of concern to the degree it prevents a LORAN-C receiver from coasting through an area of insufficient LORAN-C coverage. In the opposite sense, very low levels of PLC radiation are of concern when the LORAN-C signals are partially shielded but usable. For these reasons, the tests were structured to measure both the which provide a high impedance over a wide band of frequencies, and some with fairly high inductance are not tuned at all. Figure 32 shows an untuned 1.06 mH inductor (rated at 3000 amperes) applied in a 500-kV transmission line.

Various "tuning" methods from simple adjustable inductances to complex filters are used to counteract the reactance of the coupling capacitor at the frequency of the carrier signal. Figure 20 shows a simplified diagram of a "pi network" filter. Figure 39 shows components of this network used in conjunction with the line inductor and coupling capacitor of Figs. 32 and 33, respectively.

1.2 DEFINITION OF SYNCHRONOUS INTERFERENCE .

Synchronous interference is defined as a pulsed or continuous wave occurring at a frequency exactly equal to any one or more of the LORAN-C spectrum lines. At a group repetition interval (GRI) of 0.0993 seconds, and alternate phase coding, the LORAN-C spectrum has a component every $\frac{1}{2\ \mathrm{GRI}}$ or 5.03 5Hz. In order to synchronously interfere with a LORAN-C spectral line, the interfering frequency must be $f = 100\ \mathrm{kHz} \pm \frac{N}{2\ \mathrm{GRI}}$ where N = the spectral line above or below the center frequency, 100 kHz.

A frequency of 95000 Hz was selected as a synchronous interfering carrier at a power level of 1 watt. This frequency interferes with the 993rd line in the LORAN spectrum. The frequency of the interference signal was generated by a General Radio Frequency Synthesizer with a stability of better than one part in 10^7. Further, the synthesizer was calibrated by beating the synthesized frequency against the incoming LORAN-C 100 kHz, and counting the synthesizer frequency with a General Radio counter, also capable of measuring to one part in 10^7. The use of a 10 period average of 10.52631 seconds, assures that the absolute interfering carrier is 95000 $\pm$ 0.02 Hz. (Less than one beat in 50 seconds).

1.3 DEFINITION OF ASYNCHRONOUS INTERFERENCE

Asynchronous interference is defined as a pulsed or continuous wave occurring at a frequency which is between any two LORAN-C spectral lines. The average

2. OVERVIEW OF TESTS

Three sets of tests under varying conditions of power line structure and PLC interference were designed for the vehicle mounted LORAN-C Receivers. They are:

1) A test to determine the ability of Loran-C receivers to maintain lock (continue to properly track Loran-C signals) in the vicinity of the high voltage power lines with PLC and without PLC.
2) A test to determine the ability of Loran-C receivers to regain lock in the vicinity of high voltage power lines with PLC and without PLC.
3) A test to determine the ability of Loran-C receivers to maintain proper cycle identification and track while passing under high voltage power lines with PLC at moderate driving speeds.

Two sets of tests were designed to measure the fields radiated from the power line at each test site:

1) Measurement of the 60 Hz electric and magnetic fields in the vicinity of the energized high-voltage power line.
2) Measurement of the radiated field intensity of the applied carrier test signal in the vicinity of the high voltage power line.

In all cases, the interfering carrier signals had to be capable of being adjusted to provide interference which is either synchronous of non-asynchronous with the basic LORAN-C pulse spectrum.

The basic procedure for each test was as follows: The TSC LORAN-C mobile laboratory was driven to a point far West from the subject line and all LORAN-C receivers were then allowed to acquire at least two secondaries of the transmitting LORAN-C chain. Next, the TVA substation was requested to place the transmission line in the appropriate test configuration. The mobile vehicle then proceeded to a pre-marked 260 meter point and after allowing 12 minutes for the receivers to settle, the first data point was taken. The receivers are able to free-wheel for a brief period before being affected by any disturbing field. The interference generated by the transmission line with Loran signals was noted before recording both TD's and SNR's. The mobile laboratory continued to the next location toward the test transmission line and the procedure was repeated. When the vehicle reached the zero mark, the test was interrupted while the van proceeded to a point far East of the line and the procedure previously described was repeated from 260 meters to zero meters. To appropriately label the data plots, West is always negative meters and East is always positive meters. The point where a subject receiver was unable to recover functioning after losing lock under an activated transmission line was recorded.

The measurement procedures were designed to represent a preliminary investigation of the effects of high voltage power lines and PLC. The data procedures were also designed so as to characterize the general effects in an attempt to bound the PLC interference problem. To this end, the test sites were carefully selected so as to isolate measurement areas from other overhead cables and wires associated with secondary power distribution and phone lines.

3.1 TEST SITES

The test sites were selected by TVA personnel and represented fairly idealized conditions. The following criteria were considered in selection of the sites:

- The transmission line should cross the road nearly perpendicular to the direction of travel, permitting distance from the line along the road to represent perpendicular distance from the line
- The test zone should be free of other power lines and telephone cables which would shield the signals and provide an additional radiating

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Reference is made to Report #DOT-TSC-RSPA-79-8 entitled, "The Effects of Primary Power Transmission Lines on the Performance of Loran-C Receivers in Experimental Terrestrial Applications", date July 1978.

On Page	9	please replace Figure	41	with Figure	42.
"	9	"	42	"	43
"	11	"	42	"	43
"	18	"	23	"	22
"	18	"	31	"	31a
"	20	"	31	"	31a & b
"	23	"	40	"	40 a & b

Thank you.

4. DESCRIPTION OF THE EXPERIMENTAL EQUIPMENT USED FOR TESTING

4.1 TRANSMITTER SITE EQUIPMENT

Power Line Carrier transmitting equipment was supplied by the Tennessee Valley Authority and consisted of a portable power line carrier transmitter of adjustable output power between 0 Watts and 80 Watts, and an adjustable frequency between 50kHz and 150kHz.

A synthesized frequency source capable of providing an excitation signal to the PLC transmitter over the frequency range of 50kHz-300kHz was supplied by the Transportation Systems Center. The purpose of the synthesized frequency source was to generate stable carrier frequencies. Figure 34 is a photograph of the transmitter site.

4.2 MOBILE RECEIVER EQUIPMENT

The TSC Mobile LORAN-C Laboratory facility is shown in Figure 41. The block diagram describing the interconnection of the following equipment is shown in Figure 42.

<u>LORAN-C RECEIVERS</u>

- The Internav 204
- The EPSCO 4010-60
- The Micrologic ML200
- The Texas Instruments 9000A

LORAN-C Antenna and Multicoupler System

- Bayshore UPS 191B

Spectrum Analyzer Capable of Sweeping the Frequency range 50kHz to 300kHz

- Hewlett Packard 141.

4.3 PORTABLE EQUIPMENT

The following equipment was provided by TVA who also furnished personnel to perform the field strength measurements.

5. DESCRIPTION OF RECEIVER TESTS

The receiver tests were conducted using four LORAN-C receivers installed in the TSC mobile LORAN-C Laboratory. Several of the receivers had provisions for notching out interfering signals, but these provisions were not used for the tests. It was recognized that better receiver performance can be obtained in the presence of interfering signals through the proper use of notch filters, however, the admittance of this additional variable to the tests was undesirable. The East Coast (rate 9930) chain was used for all tests, using secondaries W (Jupiter Inlet, Florida), Y (Nantucket, Ma.) and Z (Dana, Indiana). A single set of measurements was also made using the Southeast (rate 7980) chain at the 161kV Murfreesboro-Watrace transmission line, Site 3.

As shown in Figure 42, the test configuration consists of a Bayshore UPS-191B stub antenna with a coupler driving all four receivers. The EPSCO and Internav receivers display time differences (TD) only, but have indicators for low signal level and incorrect cycle selection. The Texas Instrument and Micrologic receivers have both TD's and SNR readings displayed. The Micrologic receiver also indicates the envelope to cycle difference and its outputs are recorded automatically by the Tektronix 4051 data acquisition system.

Three LORAN-C receiver tests were specified to be performed under conditions of varying power line structure and PLC interference. These are:

- Test 1) A test to determine the ability of LORAN-C receivers to maintain lock (continue to properly track LORAN-C signal) in the vicinity of high voltage power lines with Power Line Carrier interference
- Test 2) A test to determine the ability of LORAN-C receivers to regain lock in the vicinity of high voltage power lines with Power Line Carrier interference
- Test 3) A test to determine the ability of LORAN-C receivers to maintain proper cycle identification and track while passing under high voltage power lines with Power Line Carrier interference at moderate driving speeds.

(2) Recycle the LORAN-C receivers to cause each receiver to go into the search mode.

(3) Allow 12 minutes for receiver relock, and record the lock or tracking status of each LORAN-C receiver.

(4) Repeat step #3, moving away from the power structure occupying the same points which were used in the previous tracking test.

5.3 TEST 3 - LORAN-C RECEIVER DYNAMIC TRACKING TEST

The purpose of this test is to determine the ability of the subject Loran-C receivers to maintain track on the correct LORAN-C cycle as the test van drives under the power structure at slow speed.

(1) At a point clear of the power line structure, verify that the Loran-C receivers are properly tracking the selected LORAN-C stations and are relocked as required.

(2) Accelerate the test van to 10 m.p.h.

(3) Drive under the power structure to a distance 260 meters past the power line.

(4) Note the occurrence of loss of track during the run and verify correct cycle tracking at the end of the run.

(5) Note differences between the present and previously measured time differences to identify cycle slips.

6. LORAN-C RECEIVER DATA

DISCUSSION

Data were collected both manually and automatically. The manual data were recorded on one of three test data sheets. A copy of each data sheet is located in Appendix B. They were a) LORAN-C Receiver Test Data Sheet, b) Spectrum Characteristics Test Data Sheet and c) Map of Test Area Data Sheet. A log of impromptu tests and test history was also recorded to aid data reduction and analysis. Manual data was recorded on three receivers. These were the Texas Instrument LORAN-C Receiver, the Epsco Receiver and the Internav 204. The Micrologic because of its digital output format was recorded automatically via its Tektronix 4051 data acquisition system. Two operators were required during the test period, one to tend the automatic data aquisition system and adjust receivers for the various tests, and a second to interpret the outputs of the receivers and direct the in-site placement of the mobile test vehicle. Table 2 is a matrix describing briefly each test performed during the test period.

The data from the Micrologic receiver has been plotted in this report only because it best exemplifies the conditions measured. The other three receivers were plotted manually and the results indicate that the receivers performed similarly to the Micrologic receiver. Since these data were deemed redundant, they were placed in Appendix A for review by the reader but are not analyzed or discussed in the main body of the report.

TABLE 2. MATRIX OF PLOTTED DATA

TD'S FIGURE	SECONDARY	SITE	ENERGIZED	CARRIER	SNR'S FIGURE
1	DANA	1	NO	OFF	7
	"	"	YES	"	
	"	"	"	95002.5	
2	"	2	"	OFF	8
	"	3	"	95001.25	
	"	"	"	85K	
3	JUPITER	1	NO	OFF	9
	"	"	YES	"	
	"	"	"	95002.5	
4	"	2	"	OFF	10
	"	3	"	95001.25	
	"	"	"	85K	
5	NANTUCKET	1	NO	OFF	11
	"	"	YES	"	
	"	"	"	95002.5	
6	"	2	"	OFF	12
	"	3	"	95001.25	
	"	"	"	85K	
	MASTER (Carolina Beach)	1	NO	OFF	13
		"	YES	"	
		"	"	95002.5	
		2	"	OFF	14
		3	"	95001.25	
		"	"	85K	
SOUTHEAST CHAIN					
15A	RAYMONDSVILLE,TX	3	YES	OFF	18
15B	GRANGEVILLE, LA	"	"	"	
15C	JUPITER, FL	"	"	"	
	MALONE, FL	"	"	"	

The manual data acquisition procedure used has introduced erroneous data points into the measurements. These points were plotted on the individual receiver time difference and signal quality vs distance graphs, however, where a single data point was obviously erroneous with respect to all other receivers and the continued performance of the receiver exhibiting the erroneous data points, the point was not considered in the construction of the summary data plots in the Appendix A.

For two transmission line structures, as shown in Figures 29 and 30, the field intensity of the E&H component of the 60Hz field was plotted as a function of distance. The purpose of this measurement was to determine the practicality of sensing the 60Hz field to indicate the presence of a high voltage transmission line.

The plots of signal strength and TDs vs distance are contained in Appendix A. These plots are indexed by test number and receiver model number.

7.1 500kV TRANSMISSION LINE TEST RESULTS

Figure 21 shows a map of the Wilson-Davidson 500kV T.L. test zone. The primary test zone is free of secondary power lines, however a single phone cable crosses the test zone in the region of approximately 210 meters from the transmission line. The effect of this phone line was noticed during early testing and resulted in the 200 meter test point being moved to 160 meters. The power line structure is shown in Figure 22.

Figure 27 is a plot of the field strength of the 85kHz and 95kHz PLC interference as a function of distance, with the signal strength expressed in dB above 1 microvolt/meter. Also indicated on the signal strength plots is the anticipated LORAN-C signal strength in the test zone. The carrier power level is one watt impressed on the 500kV Wilson-Davidson line at the Wilson substation. The field strength was measured at test site one in Lebanon.

The asynchronous carrier (9500 1.25Hz) interference test provided improved performance in the area of receiver locking ability, with all receivers capable of locking at 200 meters from the line and two of the receivers performing proper lock within 100 meters of the line. The quality of the navigation data is for the most part out of the 0.2μ sec quality limit inside the primary test zone.

The asynchronous (95002.5Hz) PLC interference had the least effect on the receiver performance. In this acceptable performance was obtained at distances of 80 to 100 meters from the line.

The out-of-band asynchronous interference test using an 85kHz synchronous carrier showed a slight improvement over the inband 95kHz synchronous test but the effect of the carrier is still marked. This test shows the susceptibility of LORAN-C receivers to interference outside of the authorized LORAN-C frequency allocation band.

The results of the drive-through tests are presented in Table 3. The drive-through tests were included in the original test plan to determine the effect of PLC on the coasting features of LORAN-C receivers. It is a well established fact that presently available LORAN-C receivers manufactured for the marine user community will "coast" through regions or areas of poor or nonexistent LORAN-C signals (e.g., when passing under bridges). The receivers will continue tracking when LORAN-C signals are present in regions of good signal. The drive-through tests were designed to determine the presence of power line carrier changes on the "coasting" properties of LORAN-C receivers. The significance of the drive through tests is diminished by the extended range at which the inband PLC interference affected the receiver.

The field strength of the 95kHz and 85kHz interfering test signals are plotted in Figure 27 and Figure 28. These profiles represent the carrier signal level produced by a 1 watt transmitter located a distance of 3.9 km away. The effect of a higher powered (10 watt or 100 watt) transmitter can be predicted by assuming a similar profile 10db or 20db higher. For example, the same degree of harmful interference which occurs within 100 meters of the line with 1 watt of 95kHz carrier power would occur within about 180 meters if a 10 watt carrier transmitter were used and within about 300 meters or more if 100 watts were used.

The 60Hz electric and magnetic field intensities are shown in Figure 29. Although substantial intensities do exist in very close proximity to the line, the expectation that these fields might serve as a remote indication of the line's presence was not fulfilled. Because of the three-phase vector relationships in the 60Hz power line current and voltage, these fields diminish rapidly with distance from the line.

7.2 161kV TRANSMISSION LINE TESTS

A map of the Murfreesboro-Watrace 161kV single circuit vertical transmission line test zone is shown in Figure 25. The selected area provided a clear primary test zone of ± 260 meters from the line and permitted additional testing to be done at distances up to 2640 meters from the line. The structure of the line is shown in Figure 26.

Figure 28 is a plot of the field strength of the 85kHz and 95kHz PLC interference as a function of distance, with the signal strength expressed in dB above 1 microvolt/meter. Also indicated on the signal strength plots is the anticipated LORAN-C signal strength in the test zone. The carrier power level is one watt impressed on the 161kV Murfreesboro-Watrace line at the Murfreesboro substation. The field strength was measred at test Site 3.

Figure 40 shows the existing spectrum and the spectrum with a 95002.5kHz test signal 260 meters from the Murfreesboro-Watrace 161kV line at Site 3. Here the 95002.5Hz carrier is visible. The strong internal carrier at 93kHz was removed prior to performing the receiver tests.

measure of the 95kHz signal amplitude at these distances. Figure 41 shows the amplitude of the 95kHz signal at distances up to 2600 meters from the transmission line. The PLC signal is induced into adjacent secondary distribution and telephone lines, providing relatively high amplitudes of PLC interference at substantial distances from the actual power line crossing. For example, secondary distribution lines across the road 800 meters east of the transmission line provided a 95kHz interfering signal reduced only 10dB from the level measured directly under the 161kV transmission line. Similarly, under another secondary line 1600 meters west of the transmission line, the interfering signal level was found to be 70dB above one microvolt per meter--less than 30dB below the maximum level directly under the transmission line.

Observation of typical high voltage transmission line configurations and secondary power distribution lines in the Murfreesboro area indicates that the test zone provided a fairly idealized situation with few secondary distribution lines in the area of the 161kV transmission line test zone. Typically, a variety of secondary lines might be found in any given area, creating a condition which could cause a large increase in the interference effect of PLC reradiation near a carrier transmitter.

The results of the drive-through tests for the Murfreesboro-Watrace 161kV transmission line are shown in Table 4.

The field strength of the 95kHz and 85kHz interfering test signals in the vicinity of the 161kV line are plotted in Figures 27 and 28. By the same reasoning as applied for the 500kV line, it can be estimated that the degree of harmful interference which occurs within 100 meters of the line with 1 watt of 95kHz carrier power would occur within about 190 meters with a 10 watt carrier transmitter and more than 300 meters if 100 watts were used. The 60Hz electric and magnetic field intensities are shown in Figure 30.

The map of the double circuit vertical test zone is shown in Figure 23. Figure 24 shows the transmission line structure. These measurements indicate that unacceptable performance occurs at a distance between 40 meters and 60 meters from the transmission line.

Receiver tests were performed at the Veals Road, Murfreesboro-Watrace test site using signals from the Southeast (rate 7980) chain. A map of the test zone is shown in Figure 25. Figures 15 through 17 and Figure 18 summarize the test results.

8. FIGURE 1 - FIGURE 48

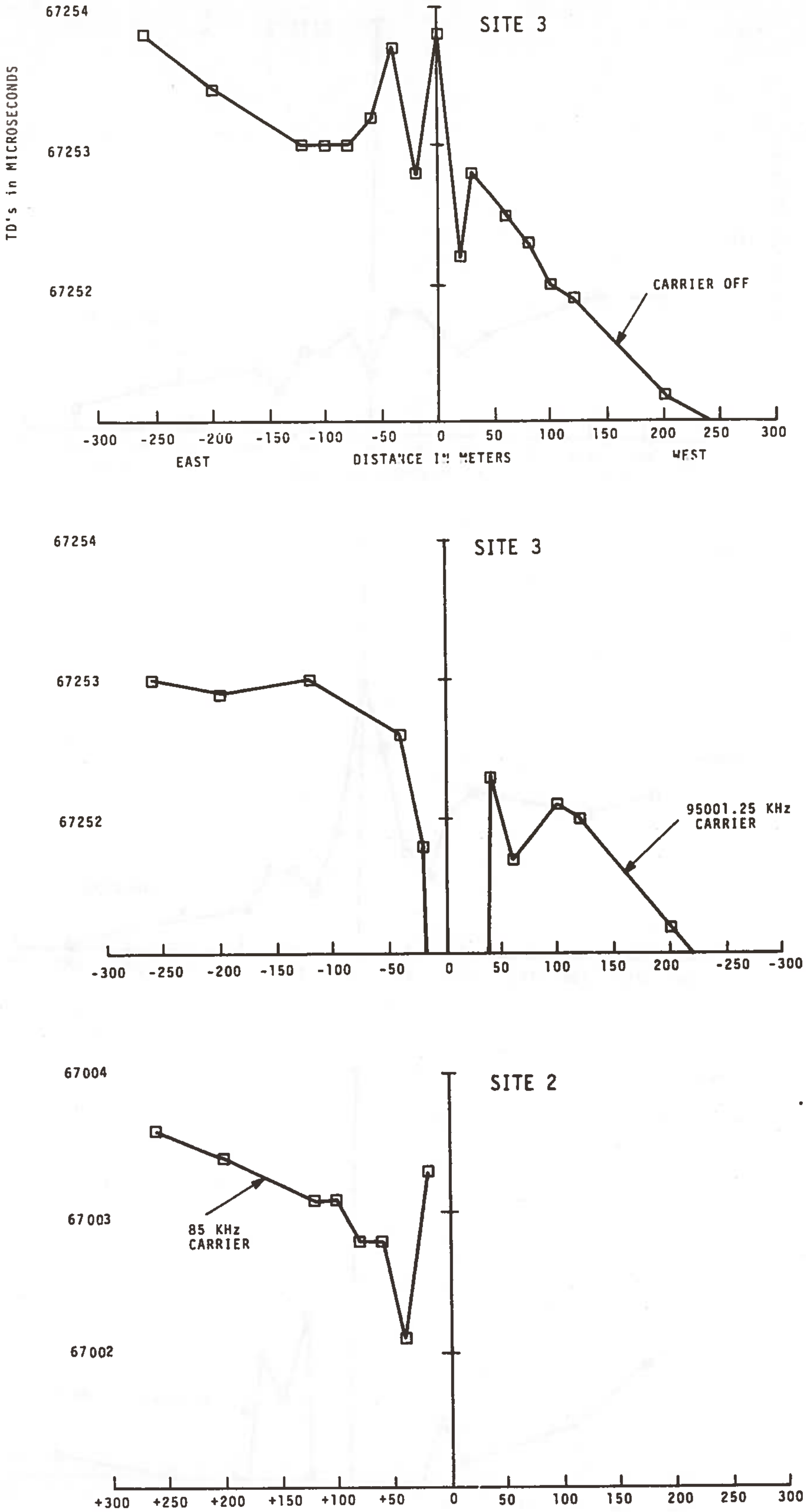


FIGURE 2. 161 KV TRANSMISSION LINE ENERGIZED SECONDARY DANA

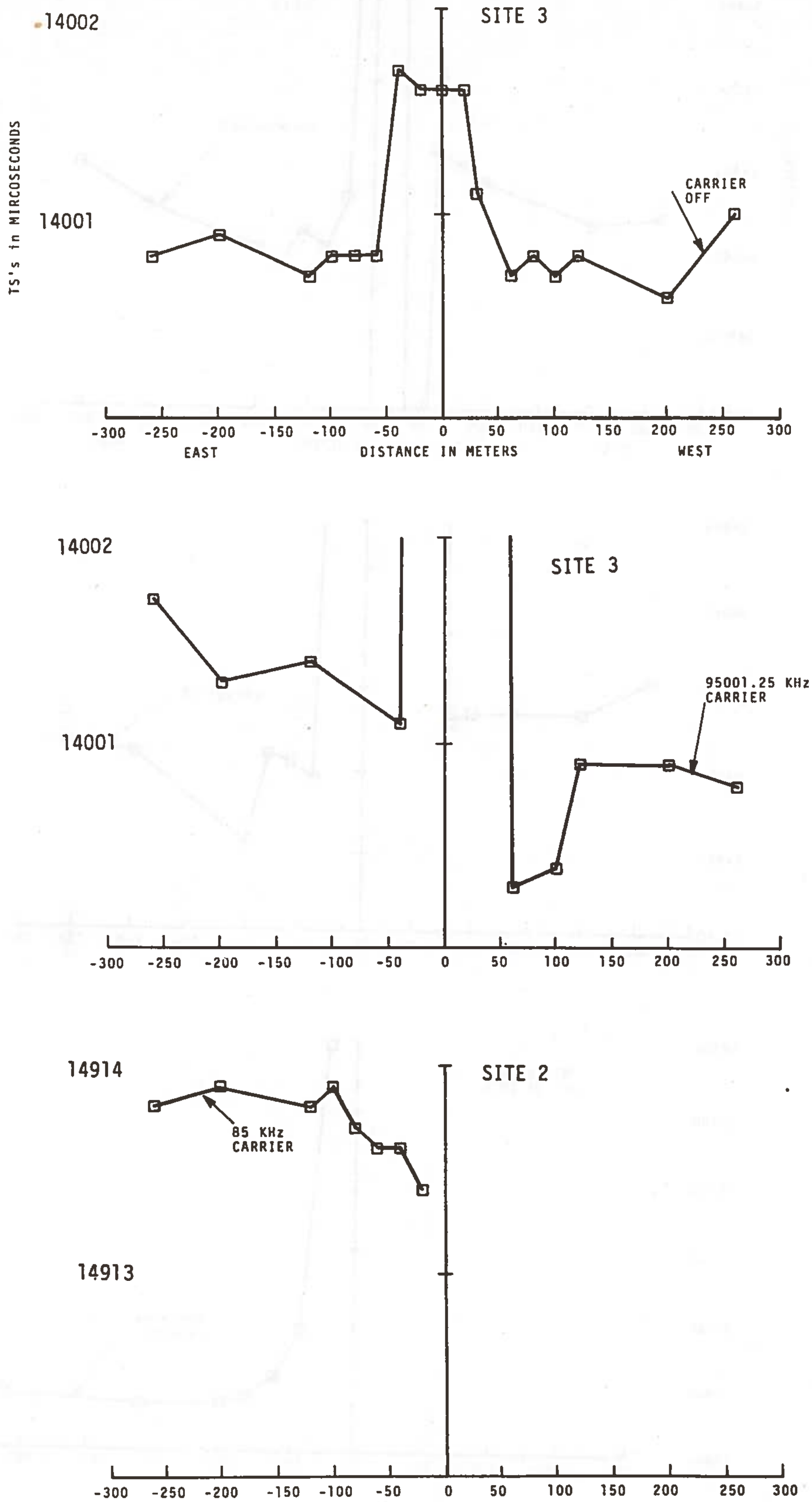


FIGURE 4. 161 KV TRANSMISSION LINE ENERGIZED SECONDARY JUPITER

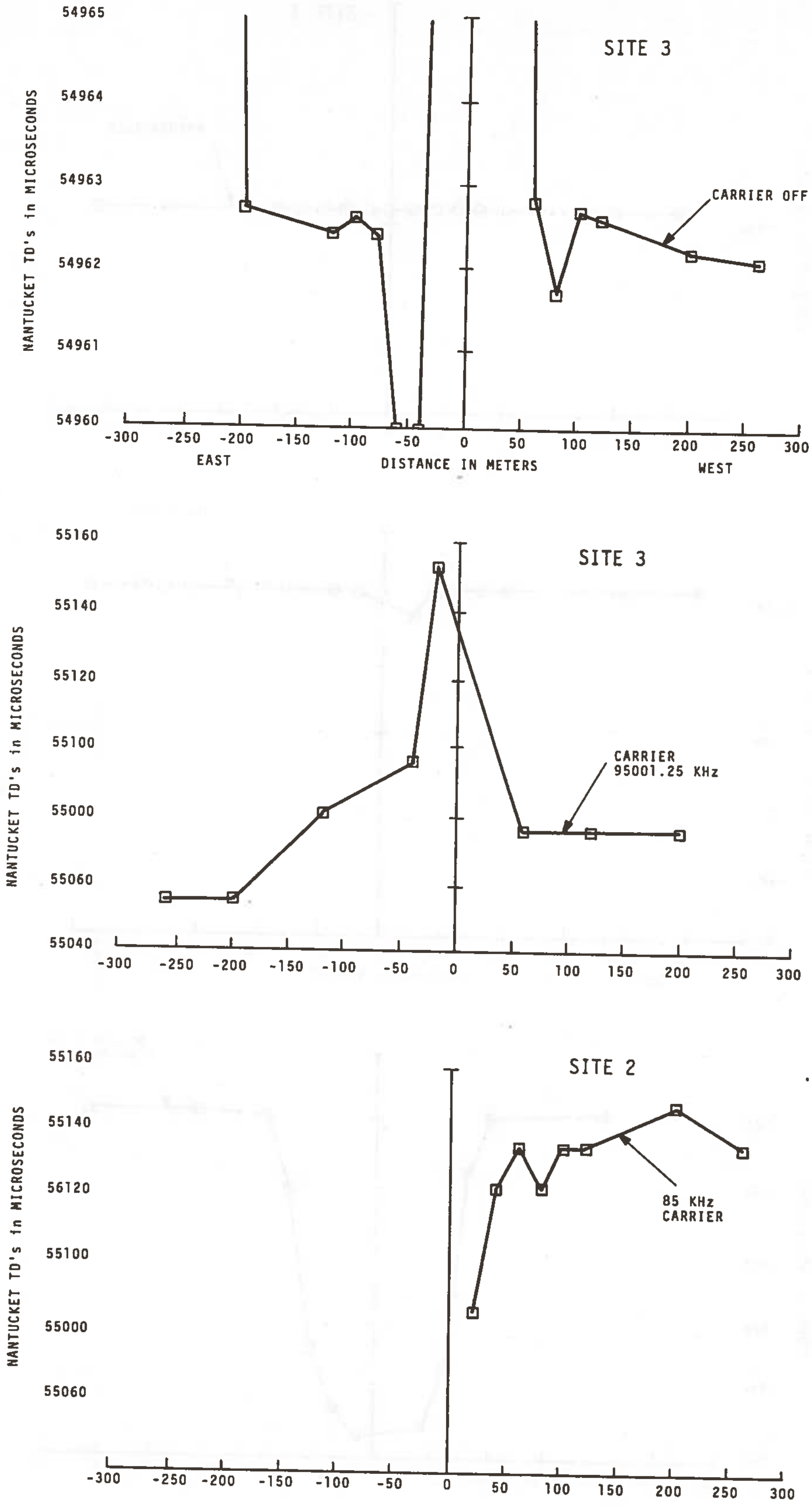


FIGURE 6. 161 KV TRANSMISSION LINE ENERGIZED SECONDARY NANTUCKET

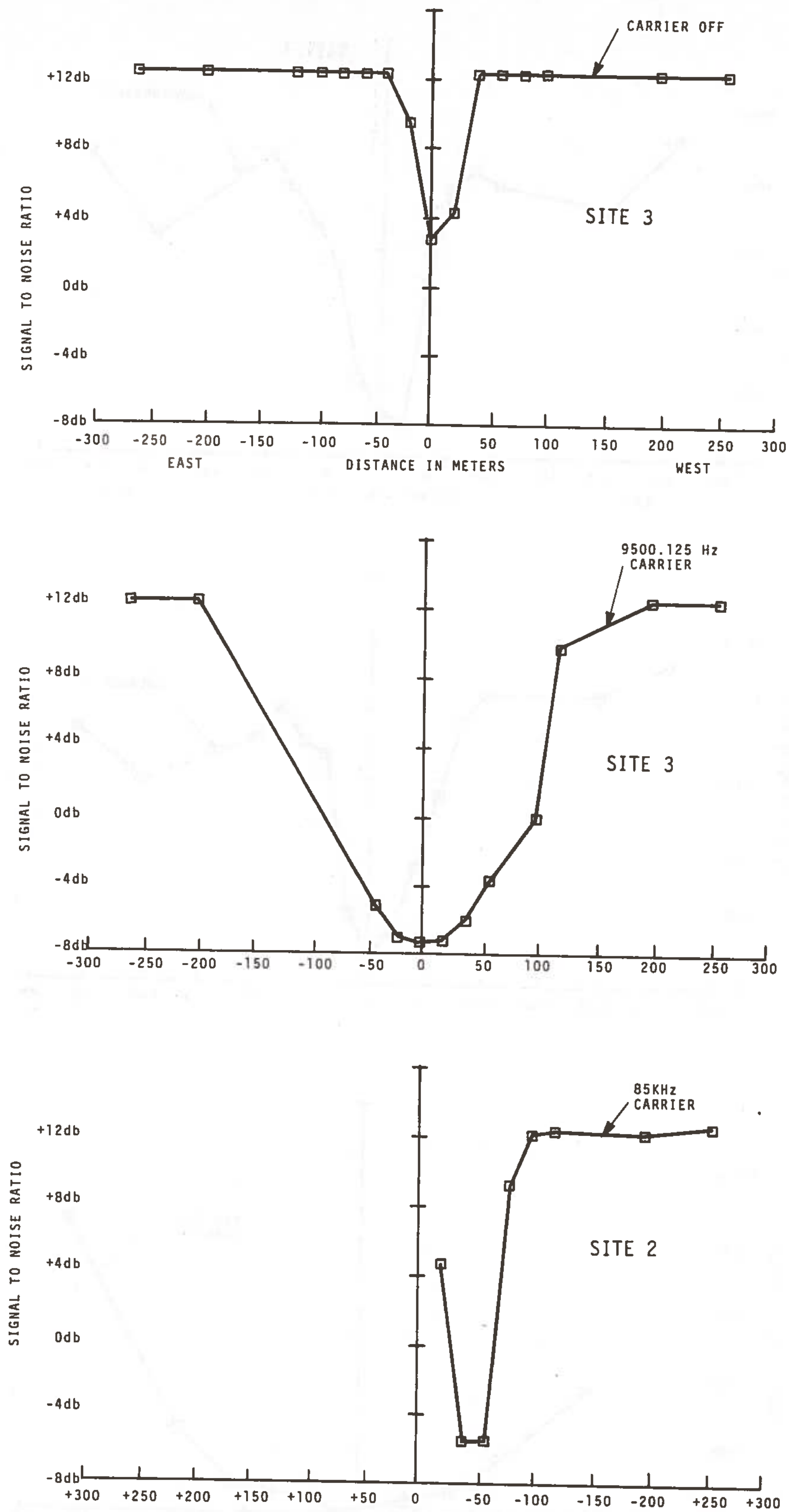


FIGURE 8. 161 KV TRANSMISSION LINE ENERGIZED SECONDARY DANA

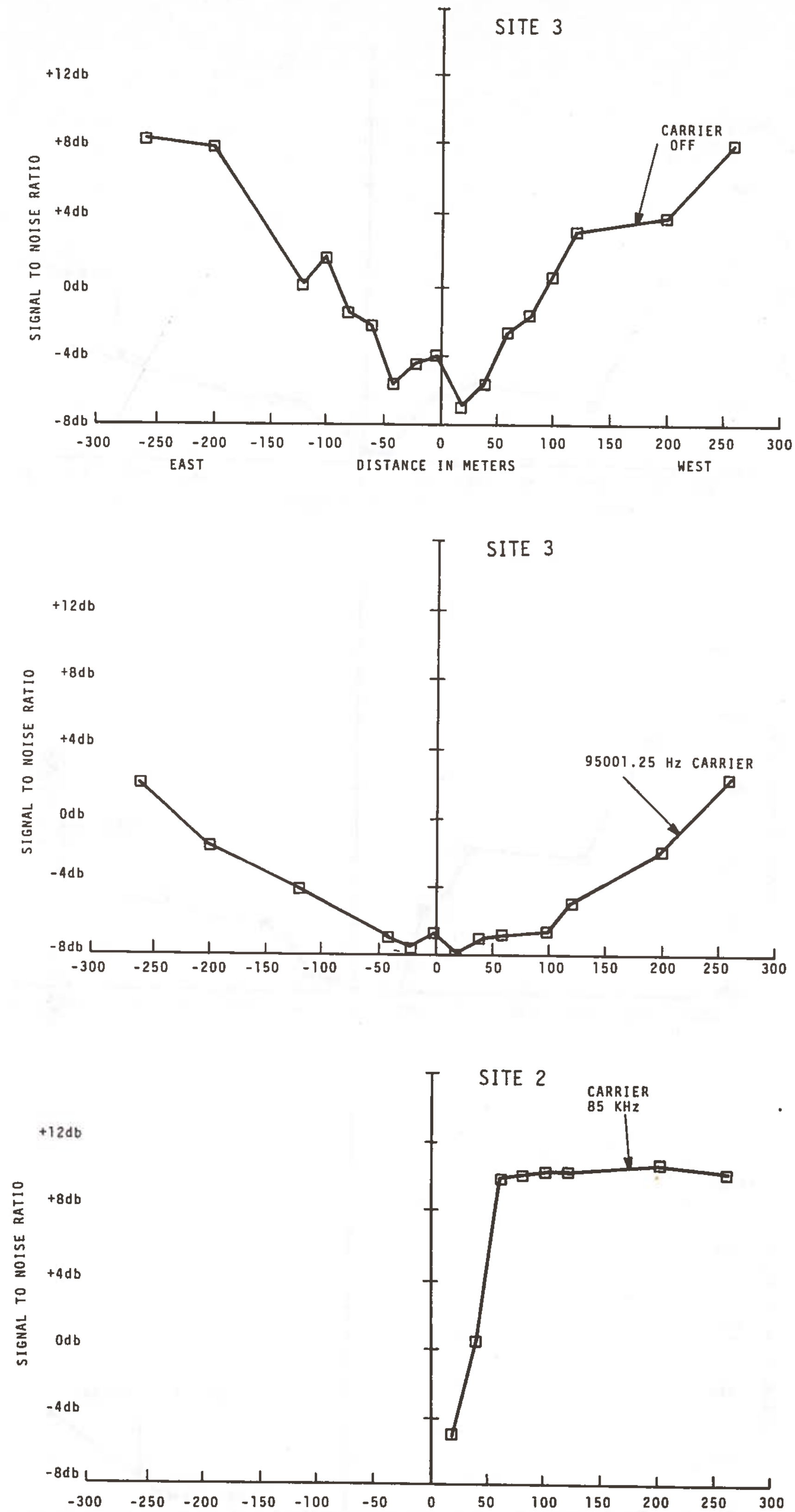


FIGURE 10. 161 KV TRANSMISSION LINE ENERGIZED SECONDARY JUPITER

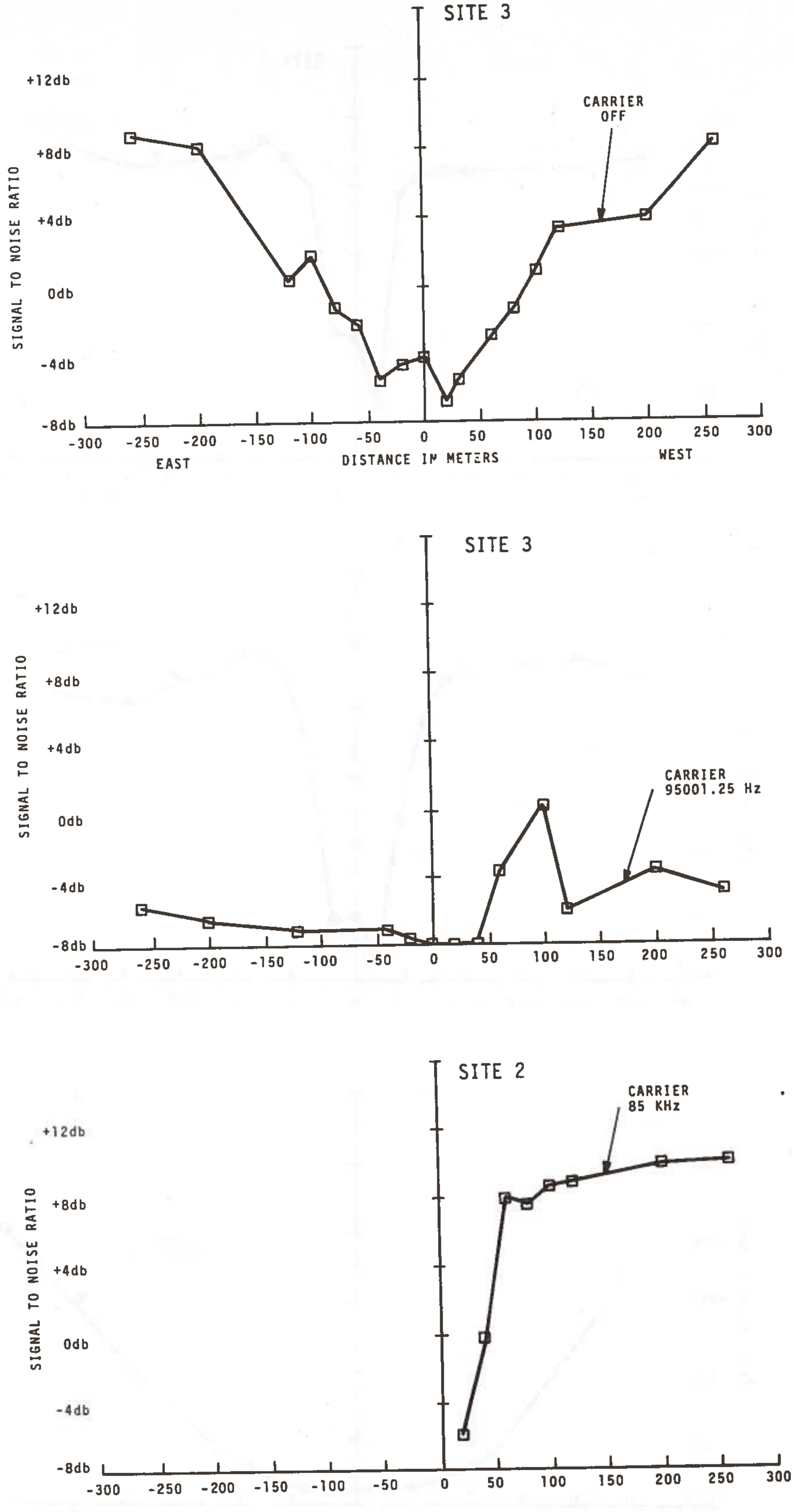


FIGURE 12. 161 KV TRANSMISSION LINE ENERGIZED SECONDARY NANTUCKET

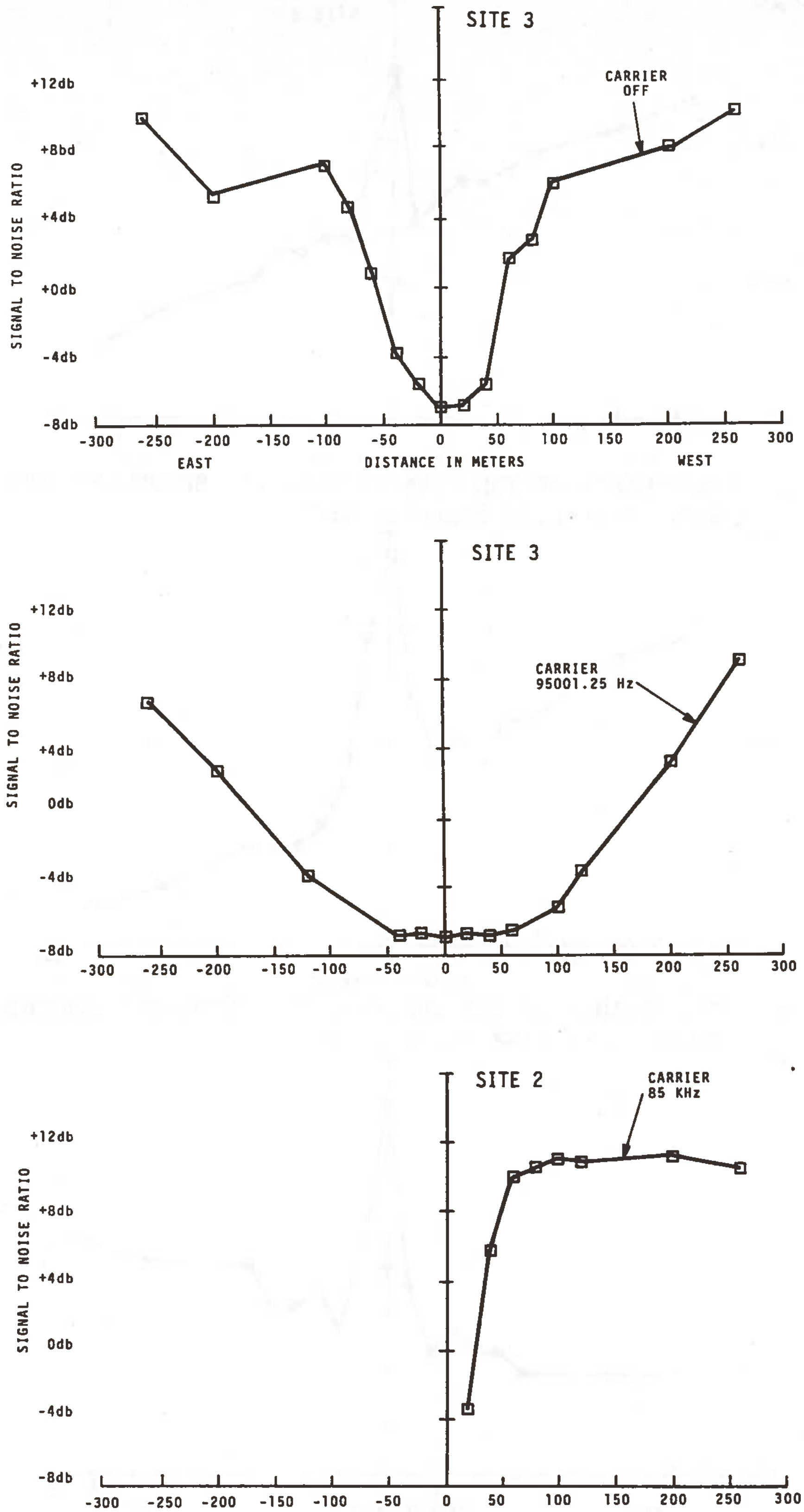


FIGURE 14. 161 KV TRANSMISSION LINE ENERGIZED, MASTER STATION - CAROLINA BEACH

SITE 3

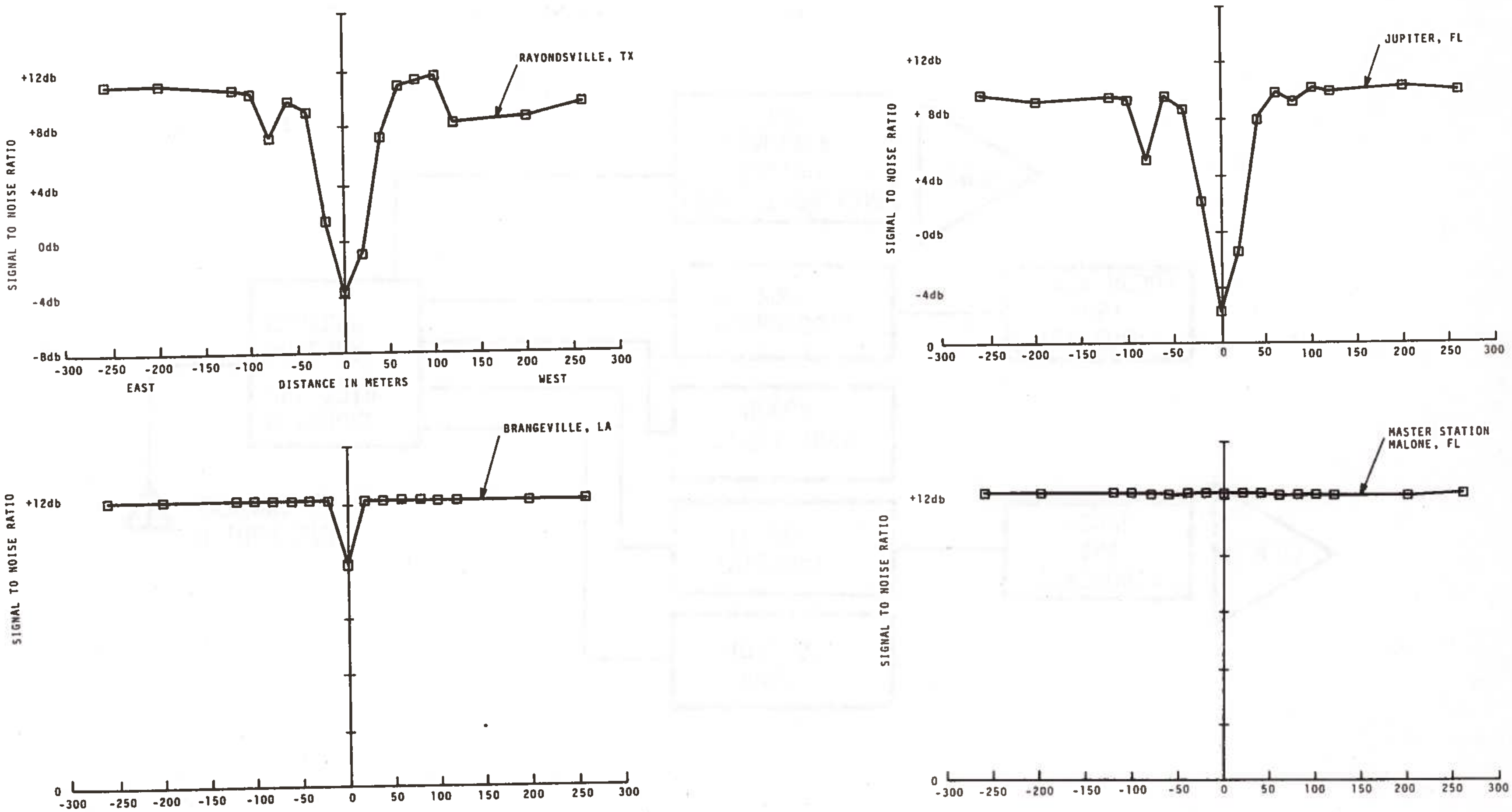


FIGURE 18. SOUTHEAST CHAIN 161 KV LINE ENERGIZED CARRIER OFF

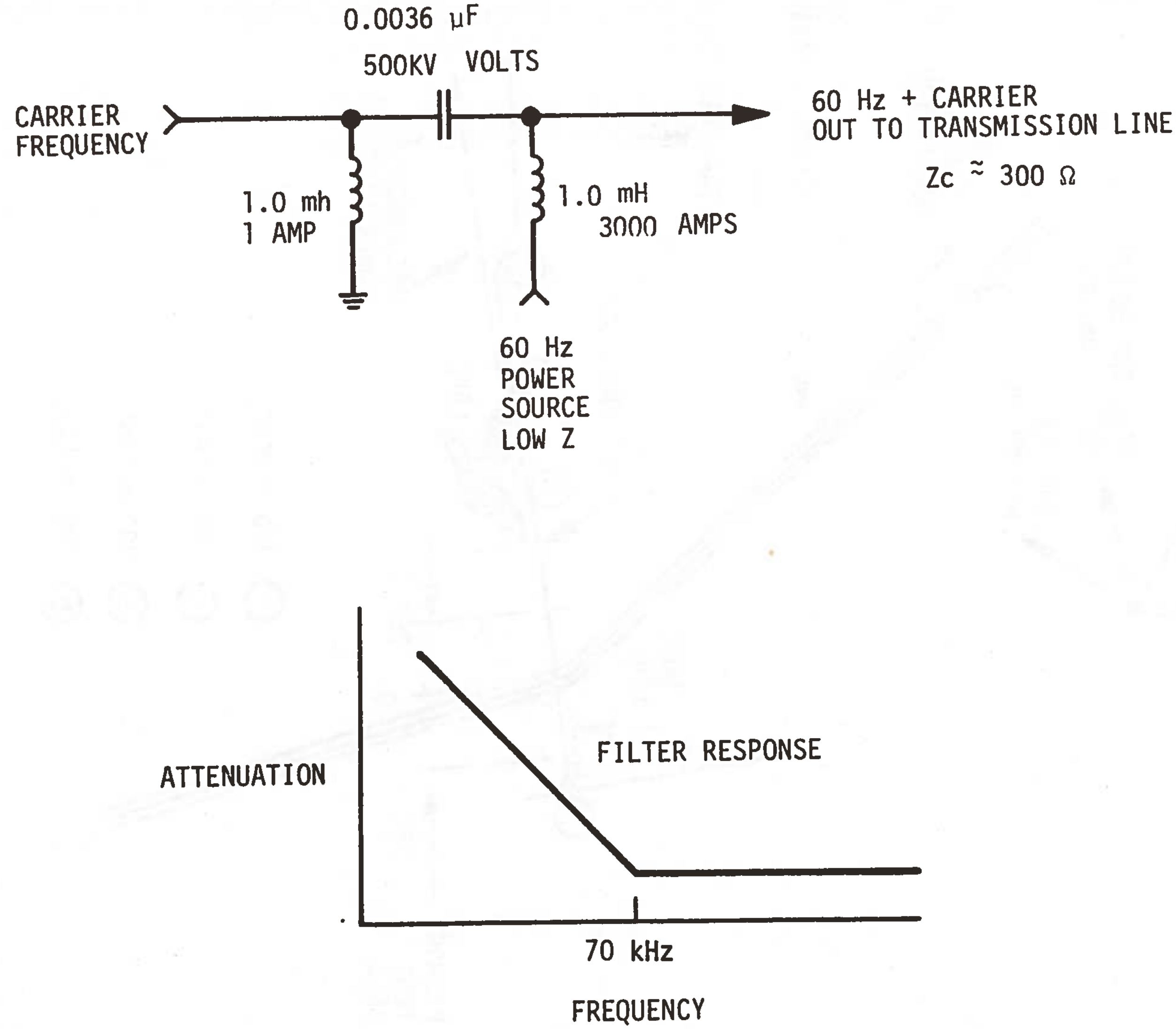


FIGURE 20. FILTER NETWORK TO INJECT CARRIER SIGNALS ON THE TRANSMISSION LINE

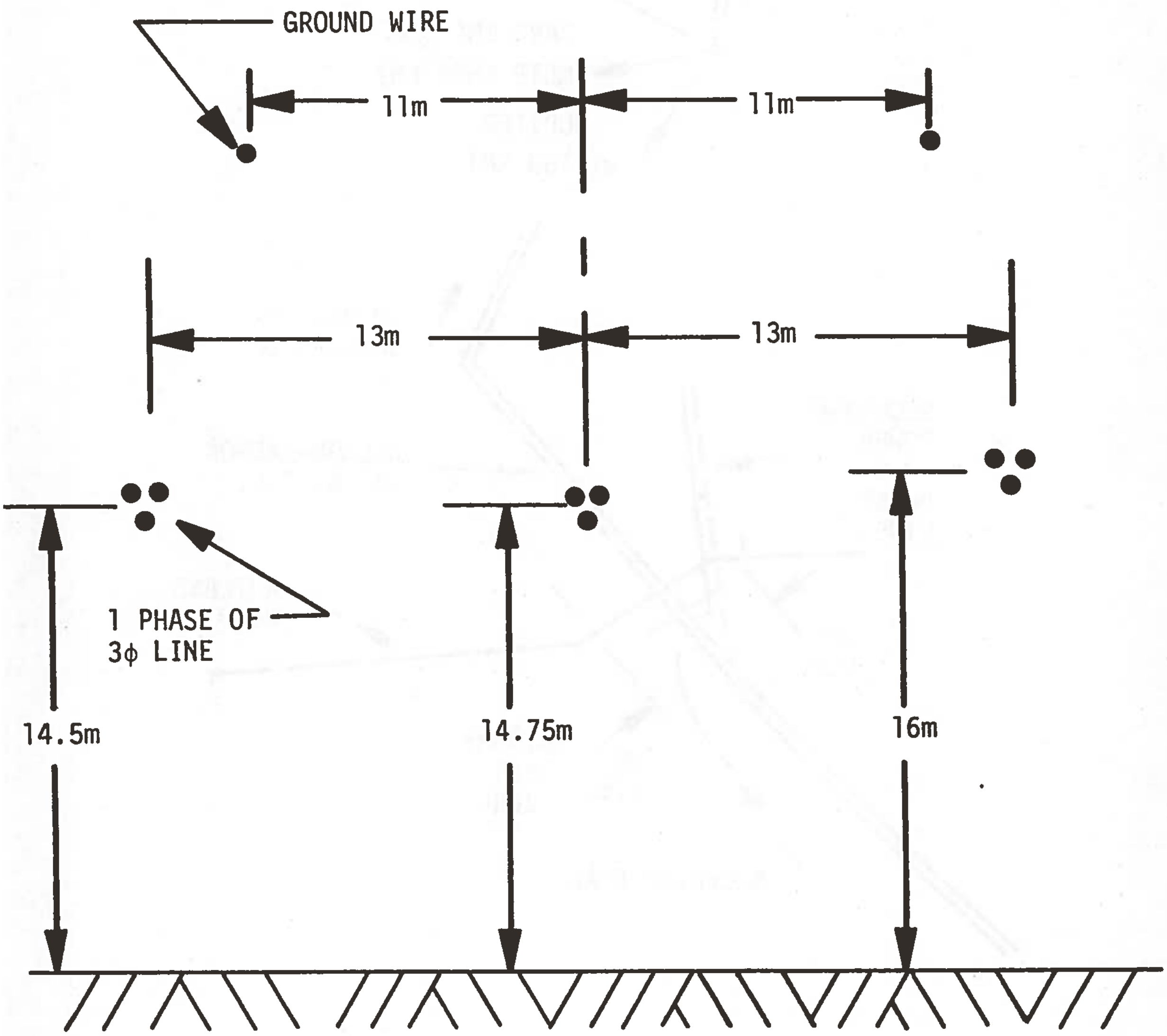


FIGURE 22. WILSON-DAVIDSON 500 KV LINE LOOKING NORTH TOWARD SUBSTATION, SITE 1

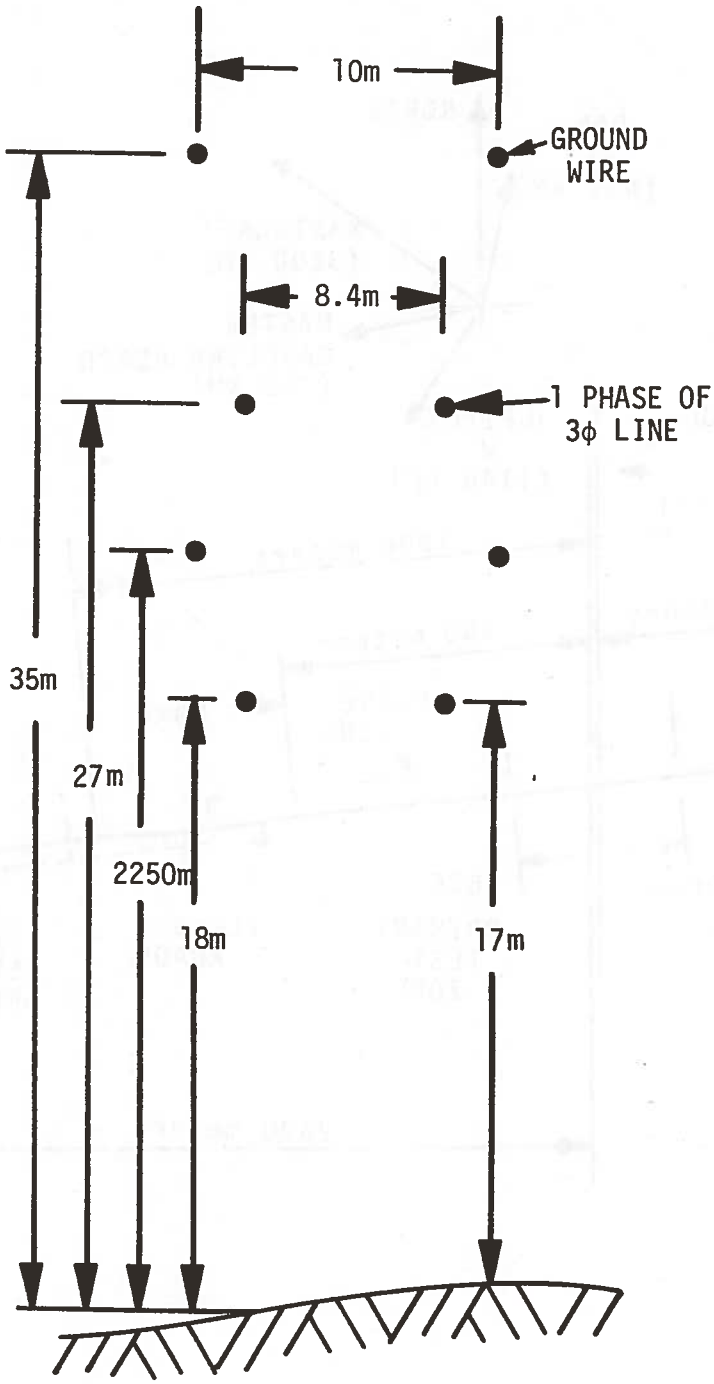


FIGURE 24. WILSON-RADNOR 161 KV LINE LOOKING NORTH (DUAL CIRCUIT), SITE 2

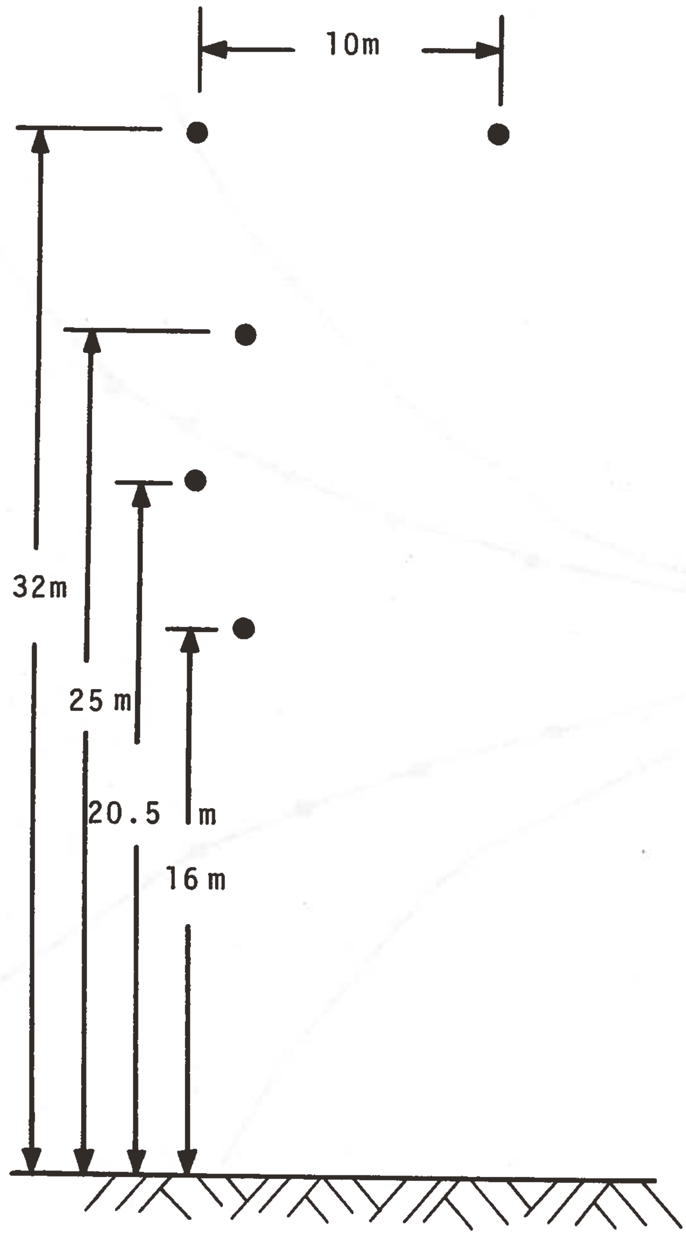


FIGURE 26. MURFREESBORO-WATRACE 161 KV LINE SINGLE CIRCUIT VERTICAL LOOKING NORTH, SITE 3

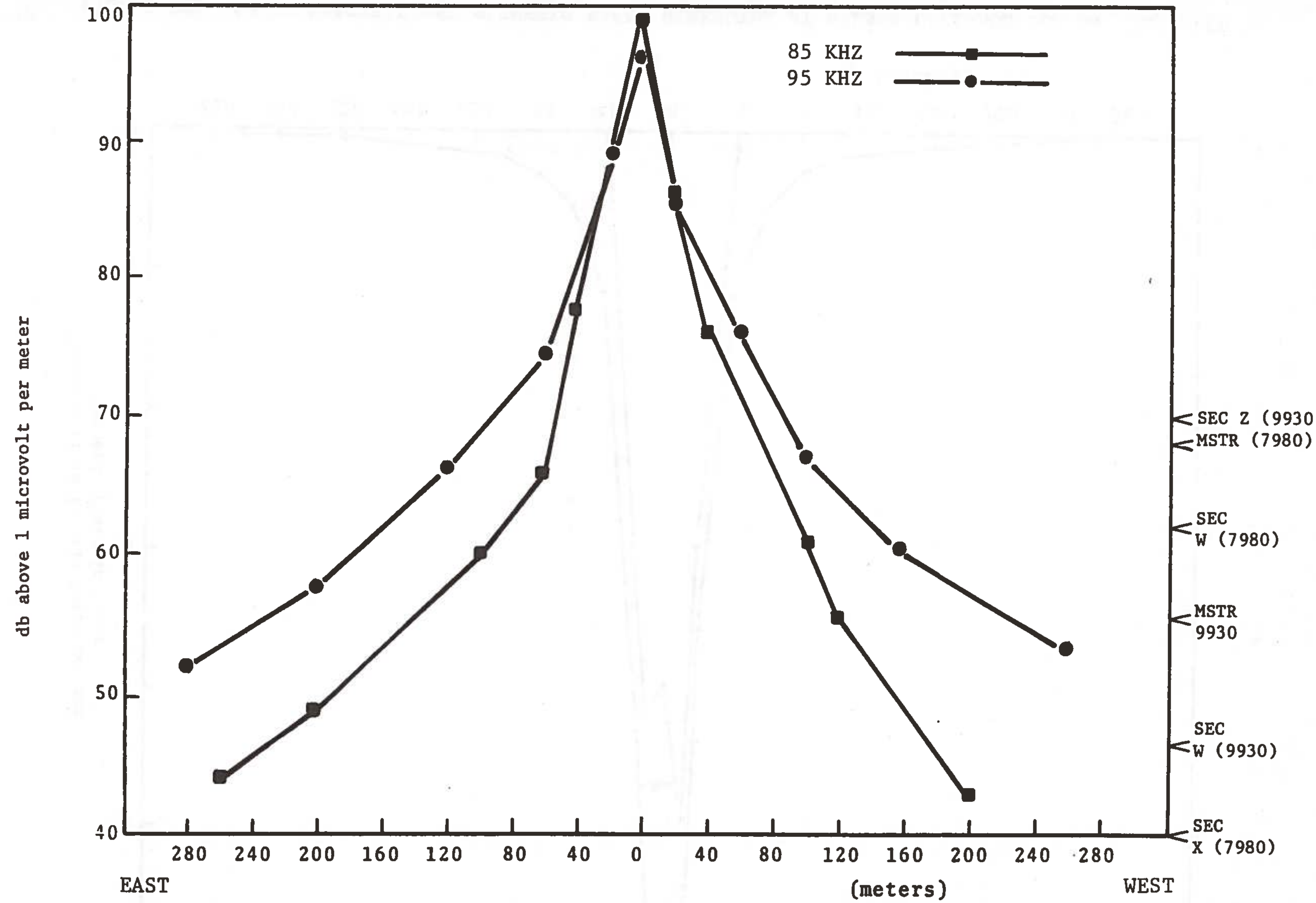


FIGURE 28. 85KHZ AND 95KHZ PLC RADIATION FIELD STRENGTH AT SITE 3

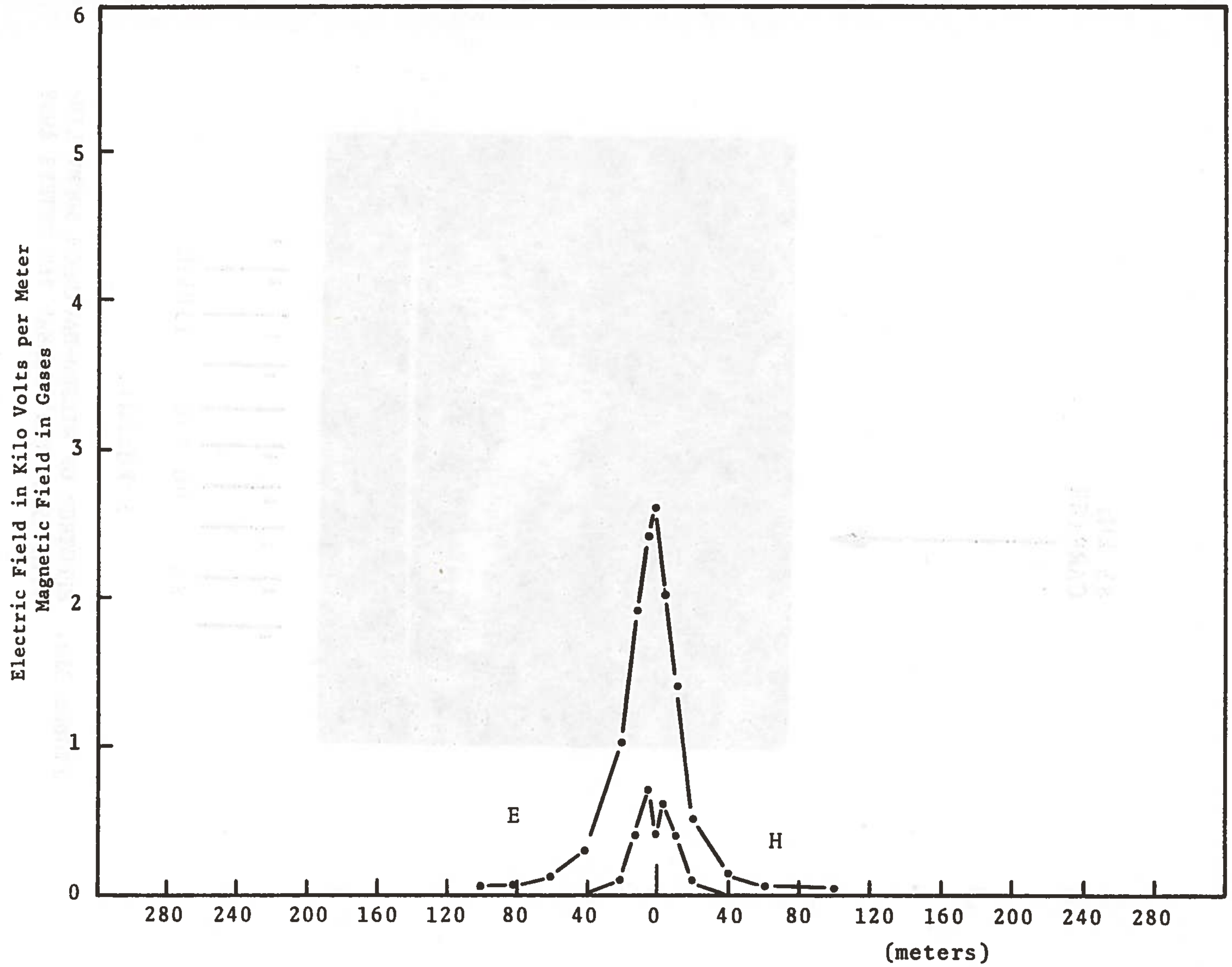


FIGURE 30. 60 HZ ELECTRIC AND MAGNETIC FIELD STRENGTHS AT WILSON-RADNOR 161 KV DOUBLE CIRCUIT VERTICAL LINE, SITE 2

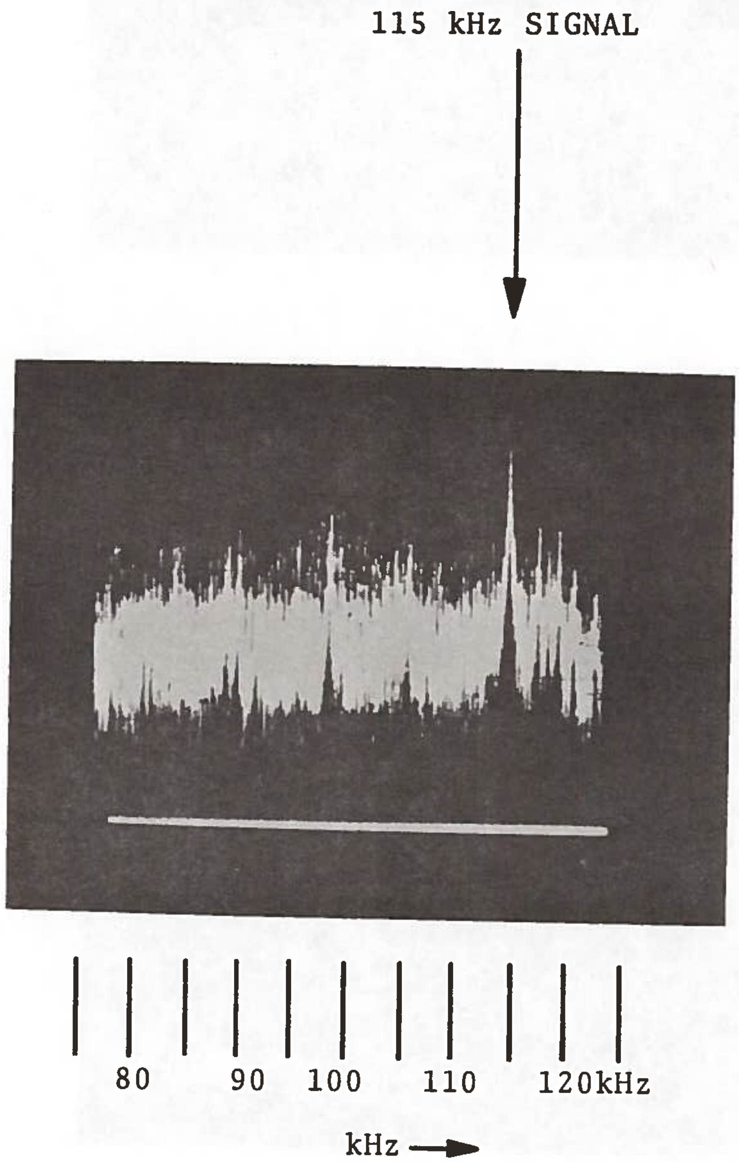


FIGURE 31b. SPECTRUMS MEASURED ON THE WILSON-DAVIDSON 500KV LINE

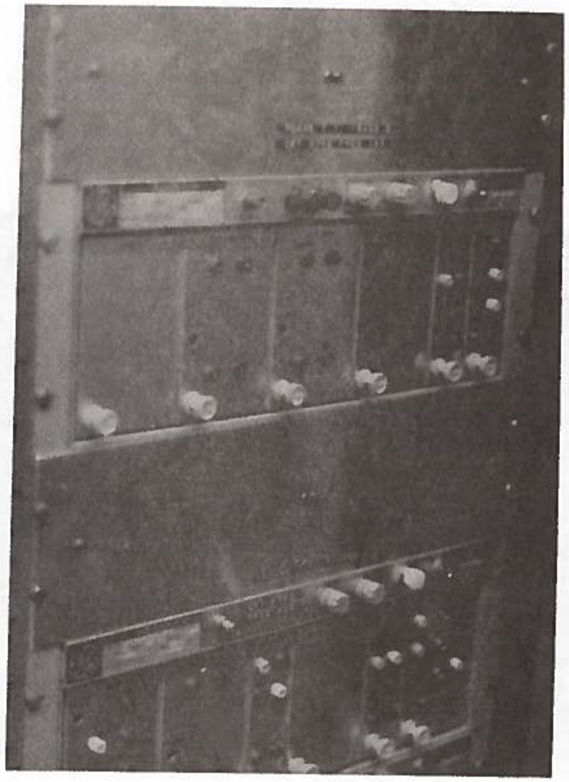


FIGURE 34. TYPICAL POWER LINE CARRIER TRANSMITTER

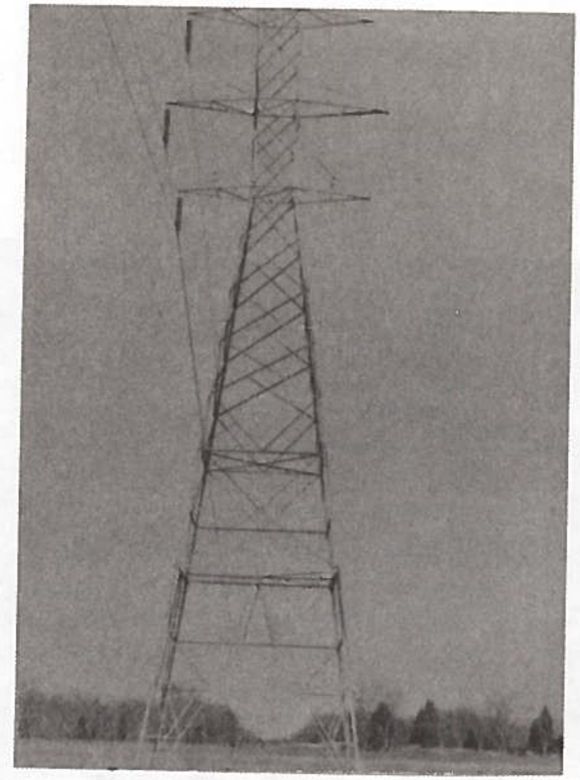


FIGURE 35. 161KV TRANSMISSION LINE

FIGURE 38. TEST EQUIPMENT AT THE TRANSMITTER SITE

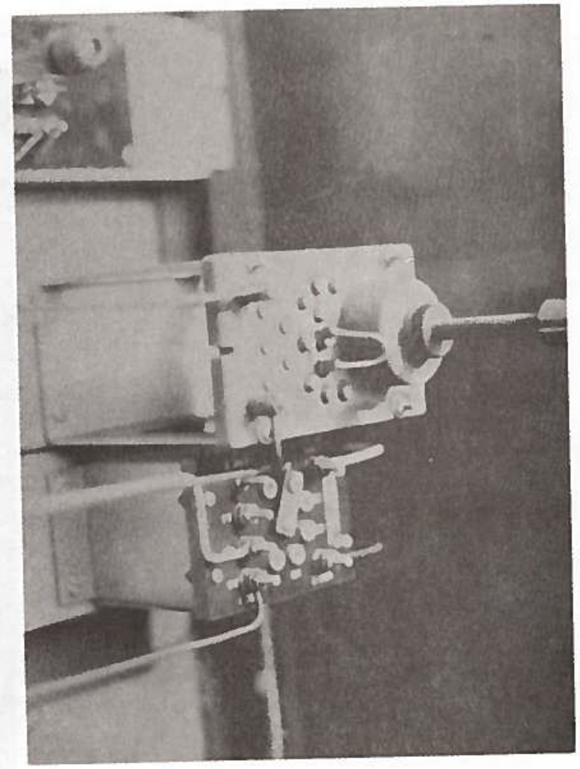


FIGURE 39. LOW VOLTAGE INDUCTOR LEG OF PI FILTER AND ASSOCIATED COMPONENTS

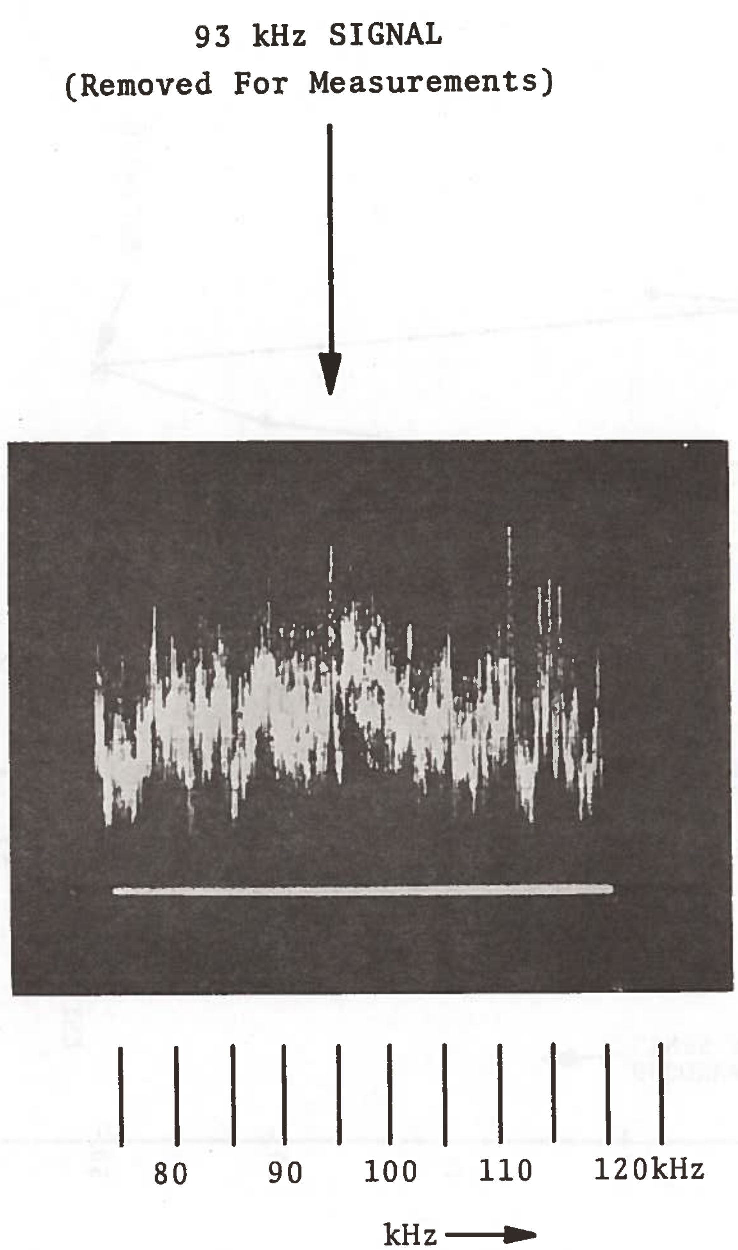


FIGURE 40b. SPECTRUMS MEASURED ON THE MURFREESBORO-WATRACE 161 KV TRANSMISSION LINES

FIGURE 42. DOT/TSC MOBILE LORAN-C LABORATORY

RUN NUMBER 4 DATE 7/12/78

TDA	TDB	MILES	DIST.	ALARM 1	ALARM 2
14041.0	44355.0	0.00	8775	4	4
14040.9	44354.9	0.00	8776	4	4
14040.9	44354.8	0.00	8776	4	4
14040.9	44354.9	0.00	8776	4	4
14040.9	44355.0	0.00	0000	4	4
14040.8	44354.9	0.23	0000	4	4
14040.7	44354.9	0.23	0000	4	4
14040.9	44354.9	0.23	0000	4	4
14040.9	44355.0	0.00	0000	4	4
14041.0	44354.9	0.00	0000	4	4
14041.0	44354.9	0.00	0000	4	4
14040.9	44355.0	0.00	0000	4	4
14040.9	44355.0	0.00	0004	4	4
14040.9	44354.9	0.01	0047	4	4
14040.9	44354.9	0.02	0119	4	4
14041.0	44354.8	0.04	0227	4	4
14041.0	44354.8	0.07	0362	4	4
14041.2	44354.7	0.10	0519	4	4
14041.4	44354.6	0.13	0682	4	4
14041.5	44354.4	0.16	0857	4	4
14041.6	44354.1	0.20	1045	4	4
14041.8	44353.6	0.28	1454	4	4
14042.0	44353.3	0.32	1675	4	4
14042.2	44353.3	0.36	1899	4	4
14042.3	44353.1	0.40	2123	4	4
14042.6	44352.9	0.44	2349	4	4

FIGURE 44. LORAN EXPERIMENT DATA

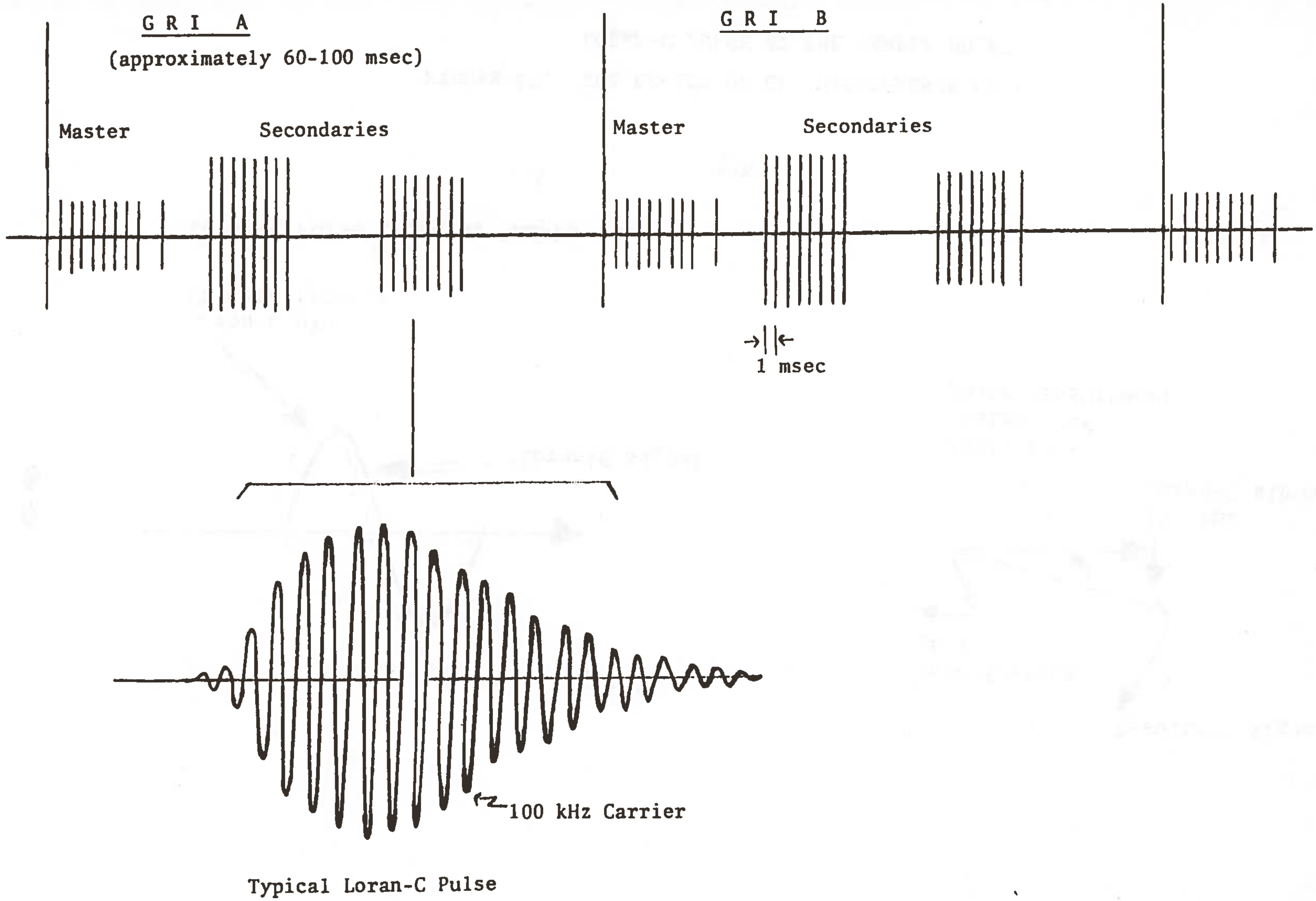


FIGURE 46. LORAN-C SIGNAL STRUCTURE

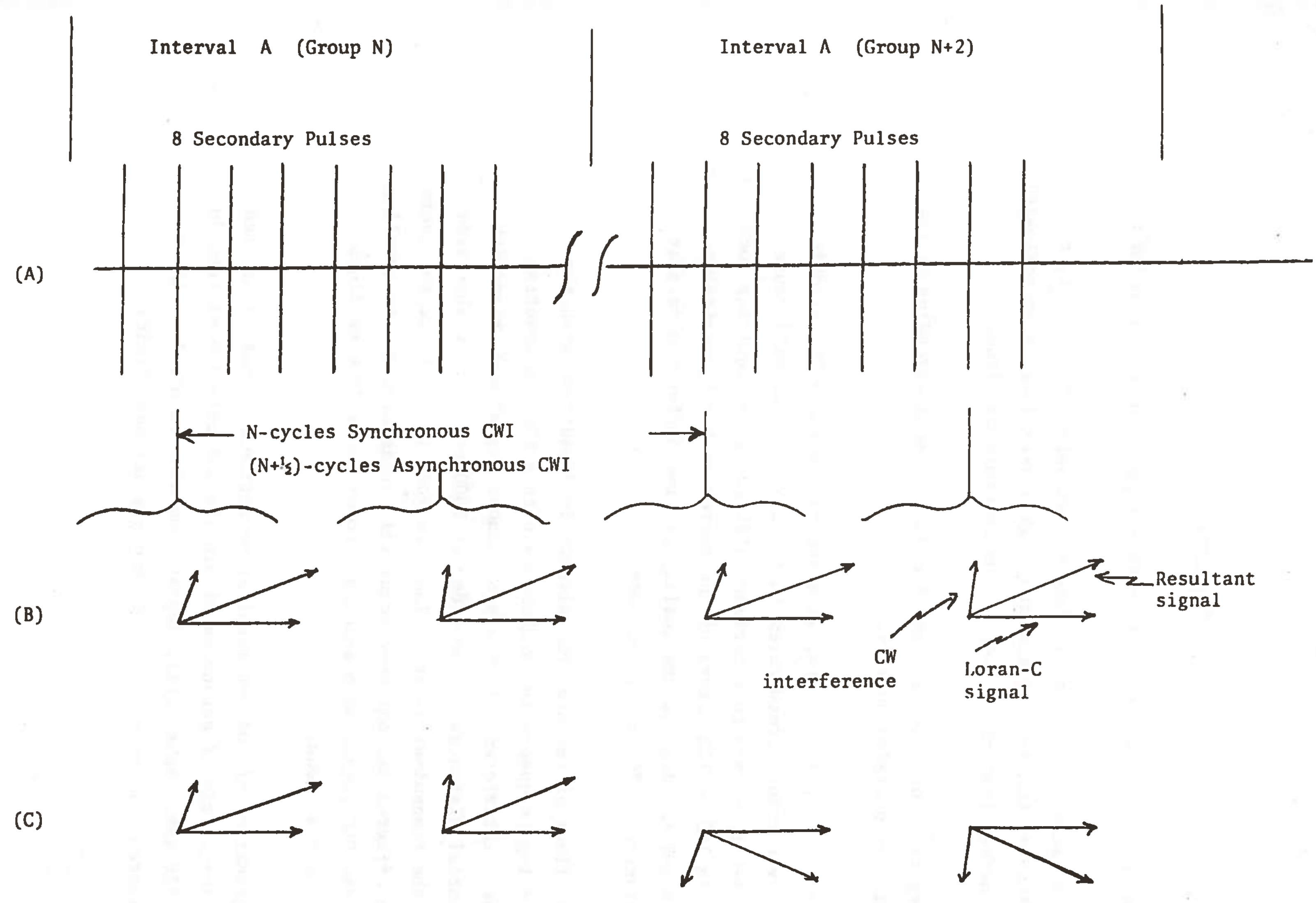


FIGURE 48. SIGNAL VECTORS FOR INTERVALS A & B WITH INTERFERENCE ADDED
(A) Loran-C Pulses (B) Vector Resultants For Synchronous Interference
(C) Vector Resultants For Asynchronous Interference

- A substantial amount of carrier reradiation occurs from secondary distribution and telephone lines in the vicinity of a PLC transmitter. This increases the number of places where LORAN-C problems might occur due to PLC interference.

- It is possible for an operating LORAN-C receiver to be transported beneath a transmission line with radiated PLC interference present without loss of lock. In this event, its output data is valid immediately after it emerges from the line's zone of influence. However, if a receiver loses lock due to interference from a transmission line, it will not provide valid data until it has been allowed sufficient time to reacquire lock outside the direct influence of the line.

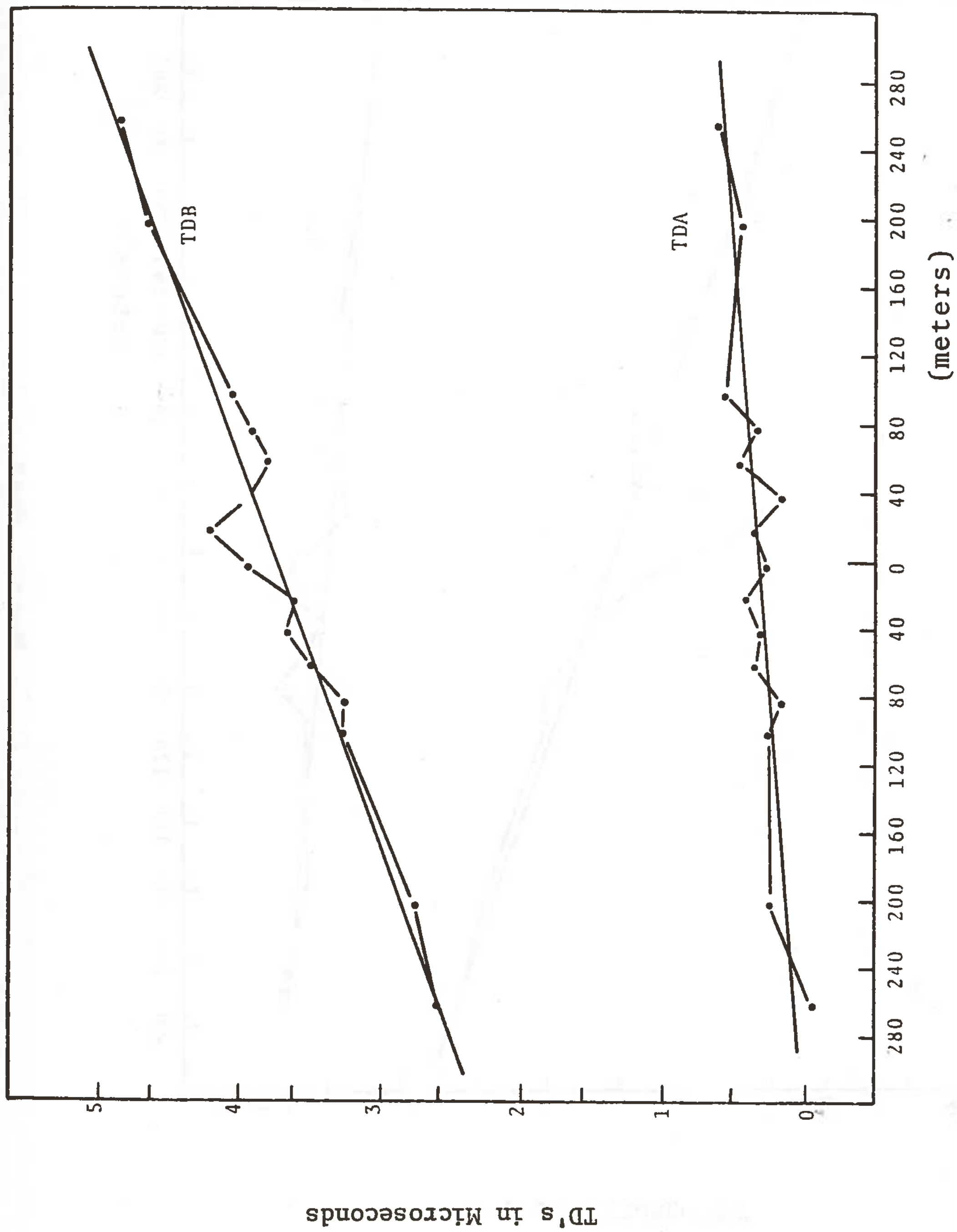
- Substantial 60Hz electric and magnetic fields exist in close proximity to an energized power transmission line; however, the intensity of these fields drops rapidly as a function of distance from the line. The LORAN-C receiver is influenced by the line at a greater distance then practical detection of the 60Hz fields can be made. This precludes the measurement of 60Hz field intensity as an indication of power line proximity.

APPENDIX A

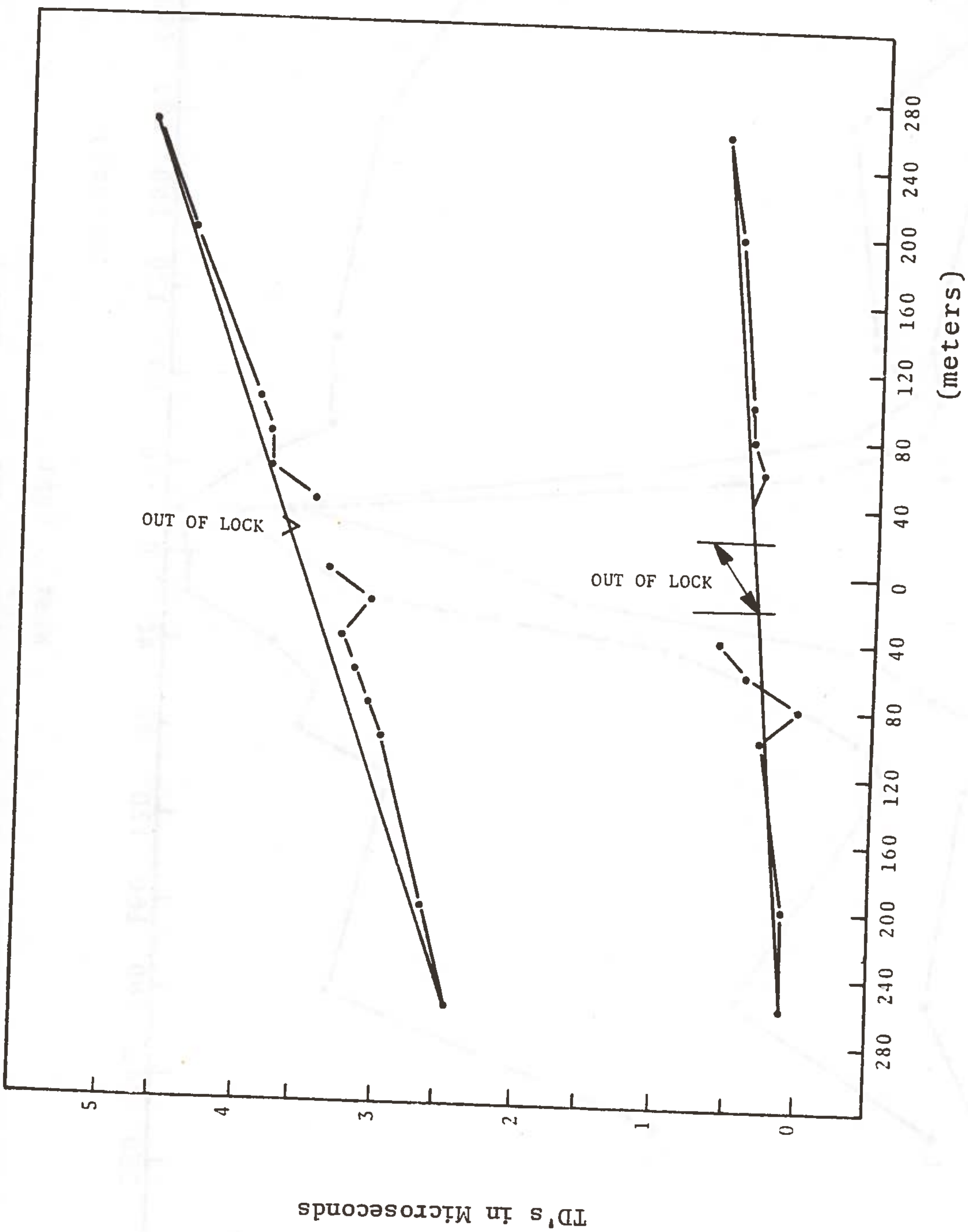
LORAN-C PERFORMANCE TEST DATA

In Appendix A are the results of all tests (1 through 12) plotted for all receivers, in this order:

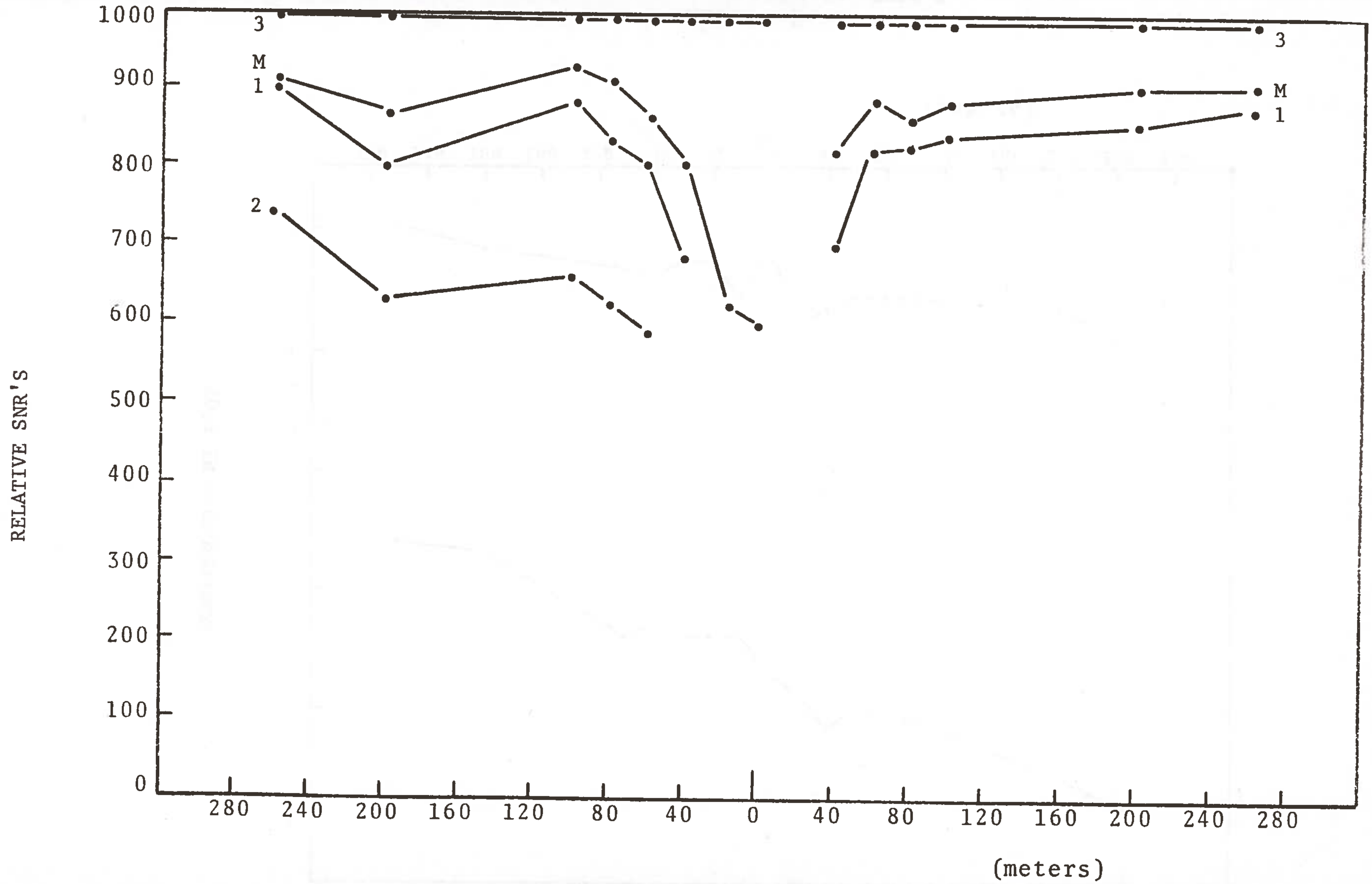
TD Performance of Epsco 4010
" " " Internav 204
" " " Micrologic ML200
" " " TI 9000A
Relative SNR's of Micrologic ML200
" " " TI 9000A.



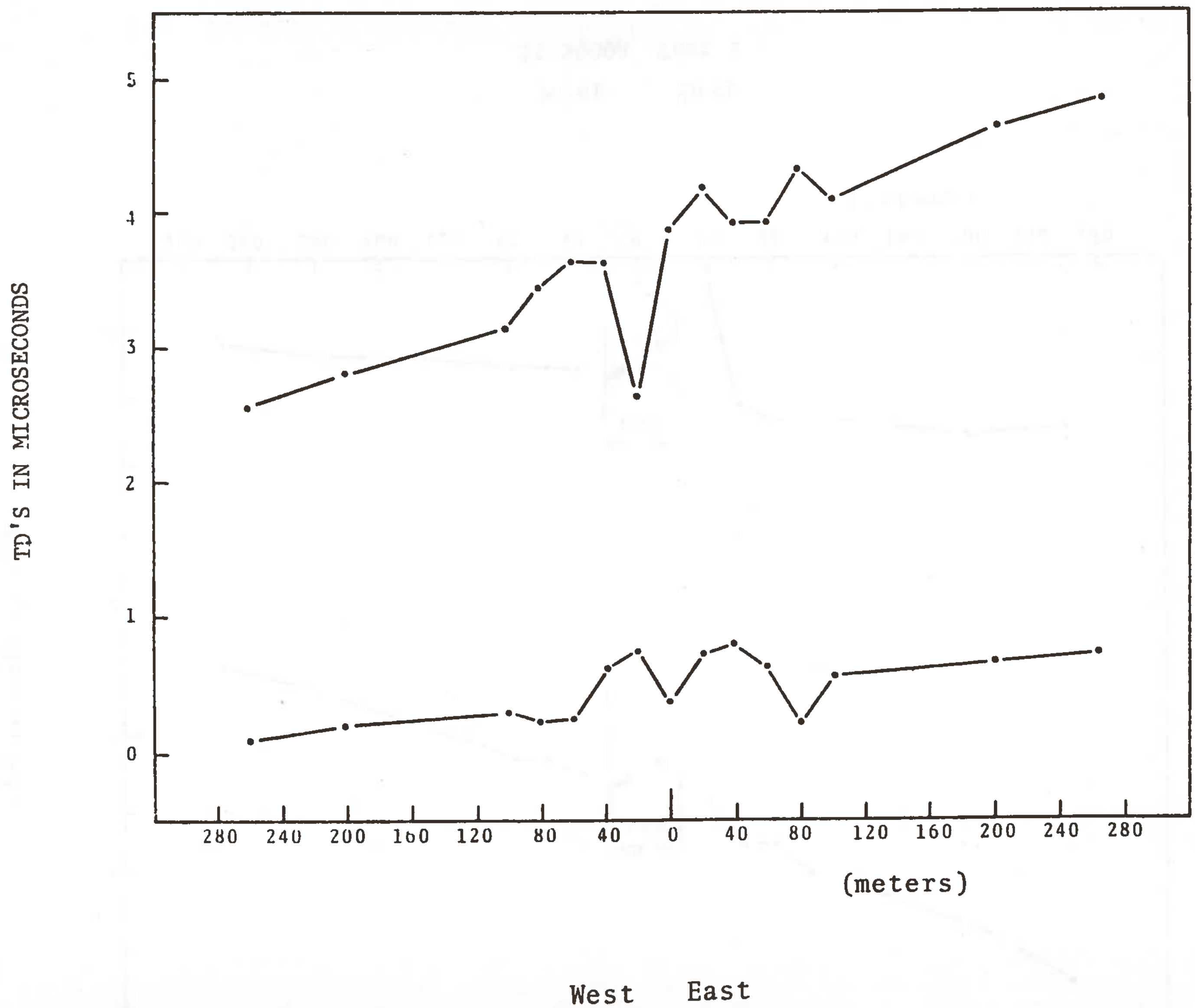
West East
Internav 204 Test 1



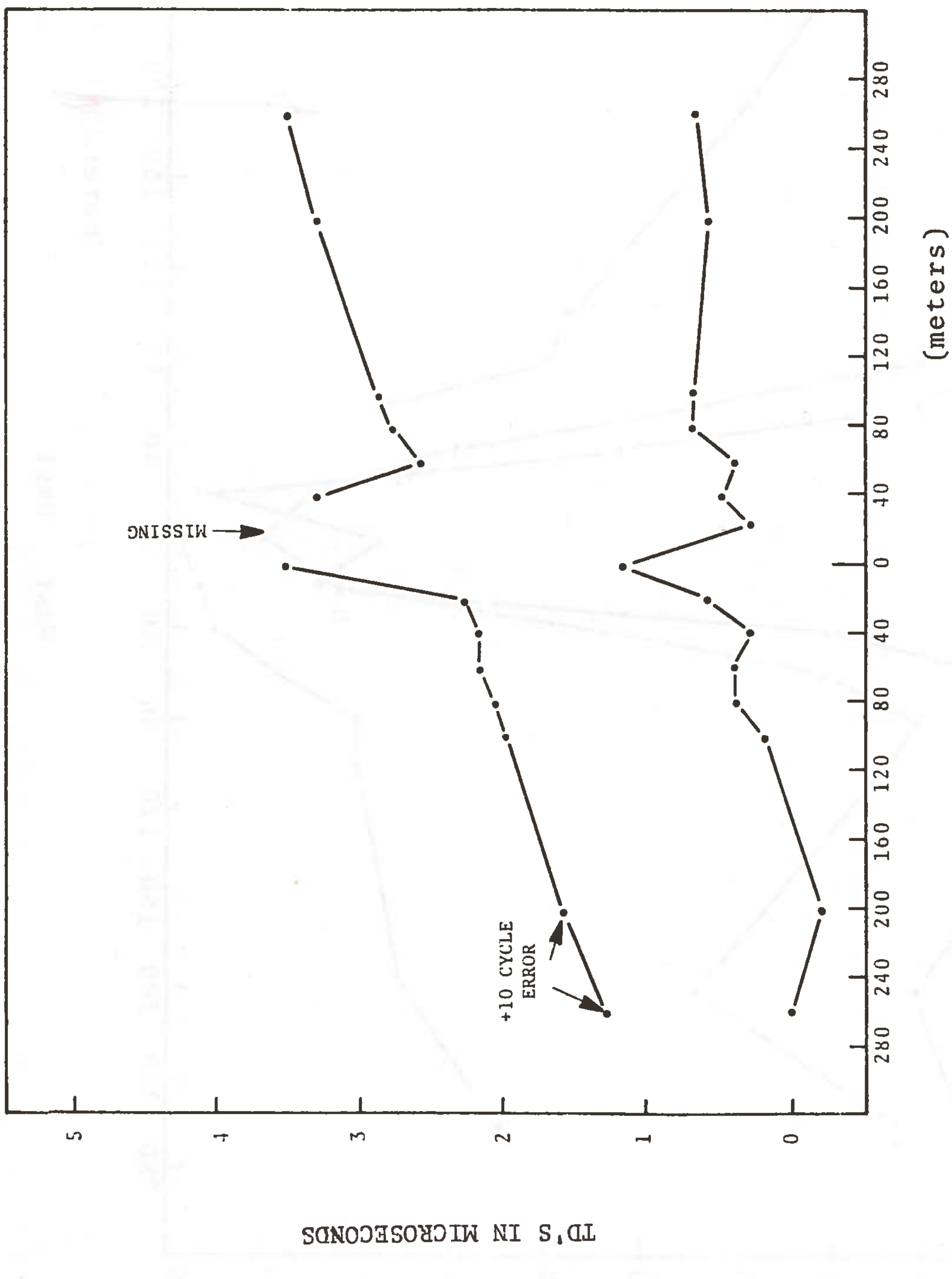
West East
TI 9000A Test 1



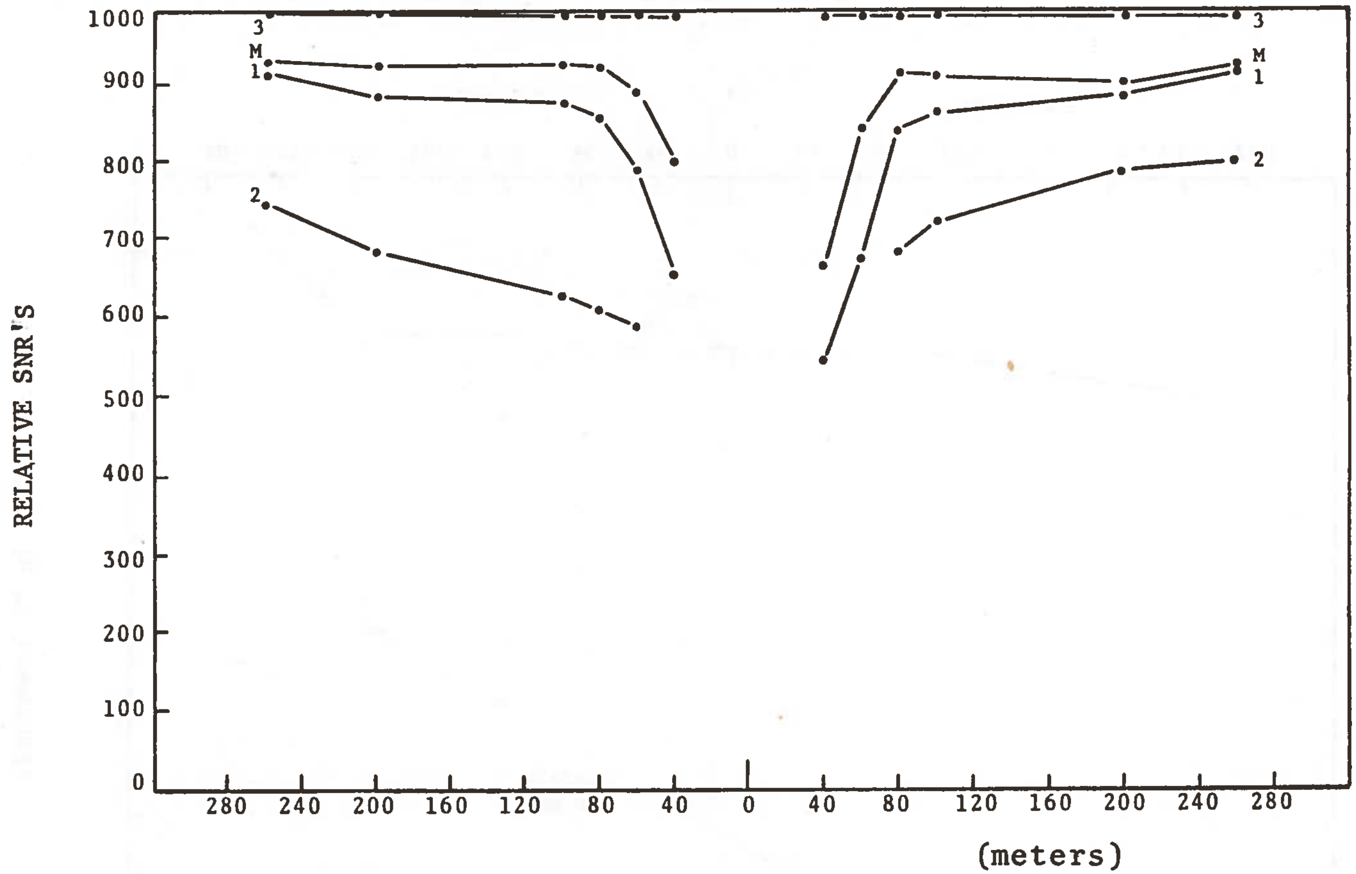
West East
TI9000A Test 1



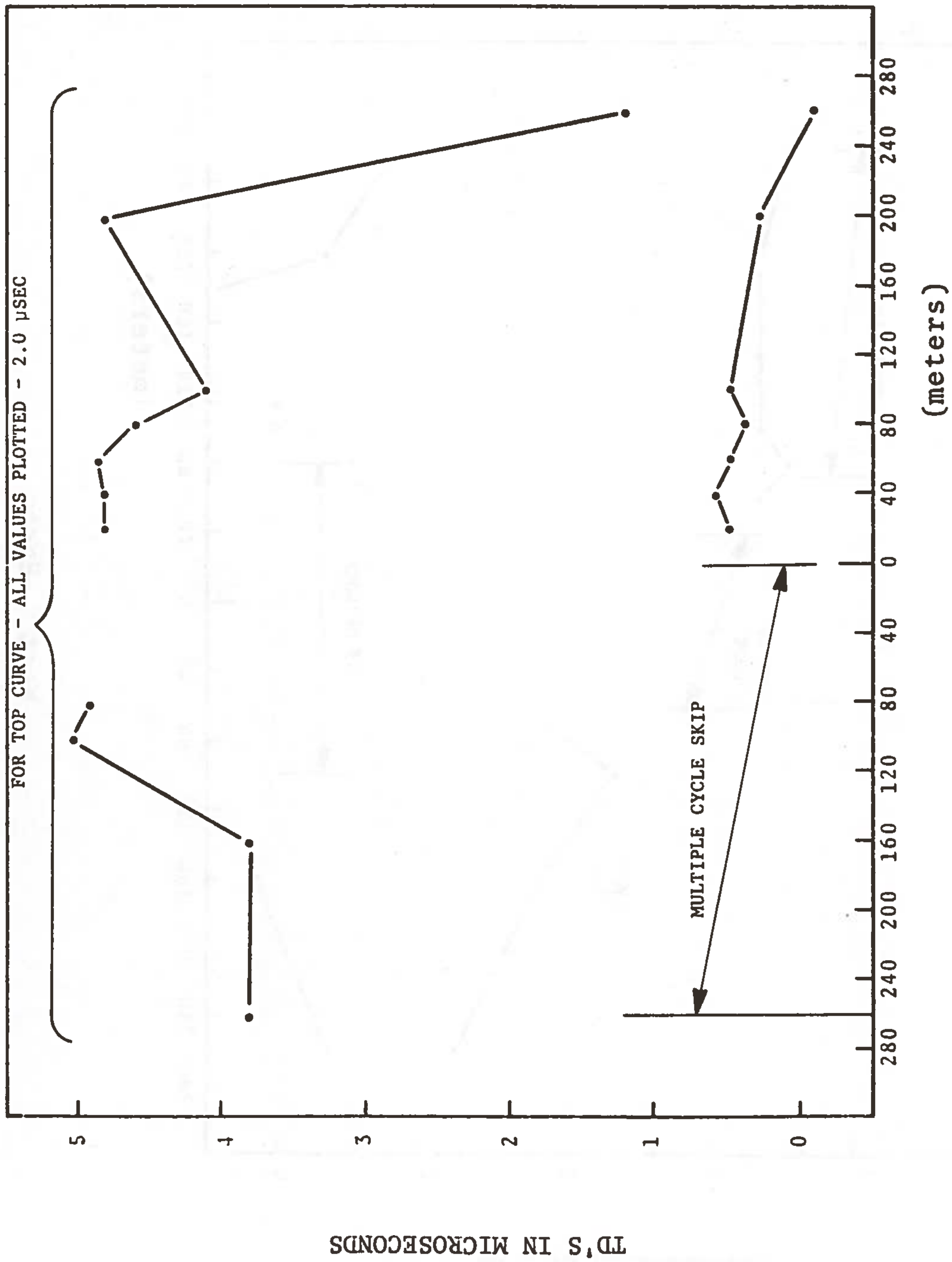
INTERNAV 204 TEST 2



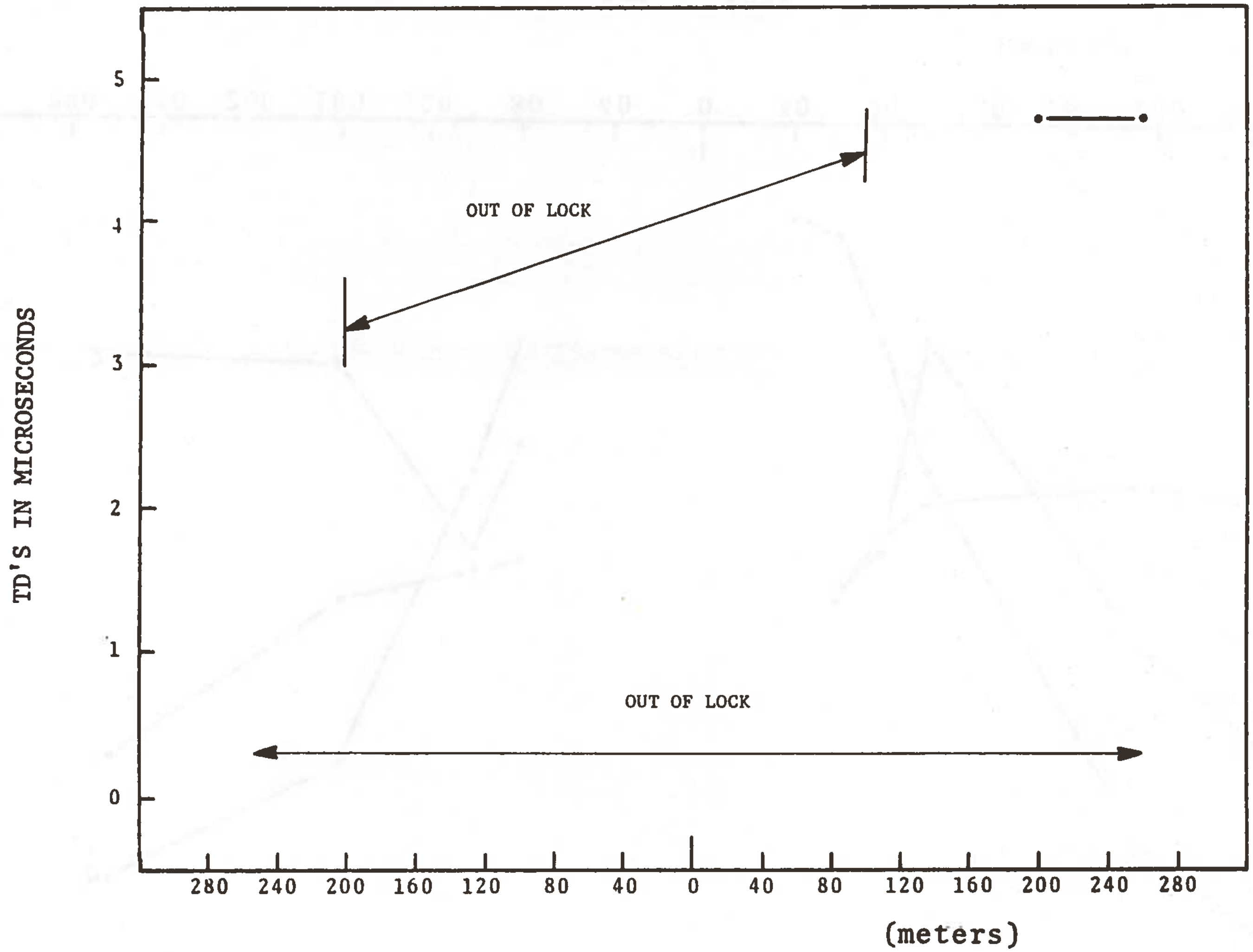
West East
MICROLOGIC ML200 TEST 2



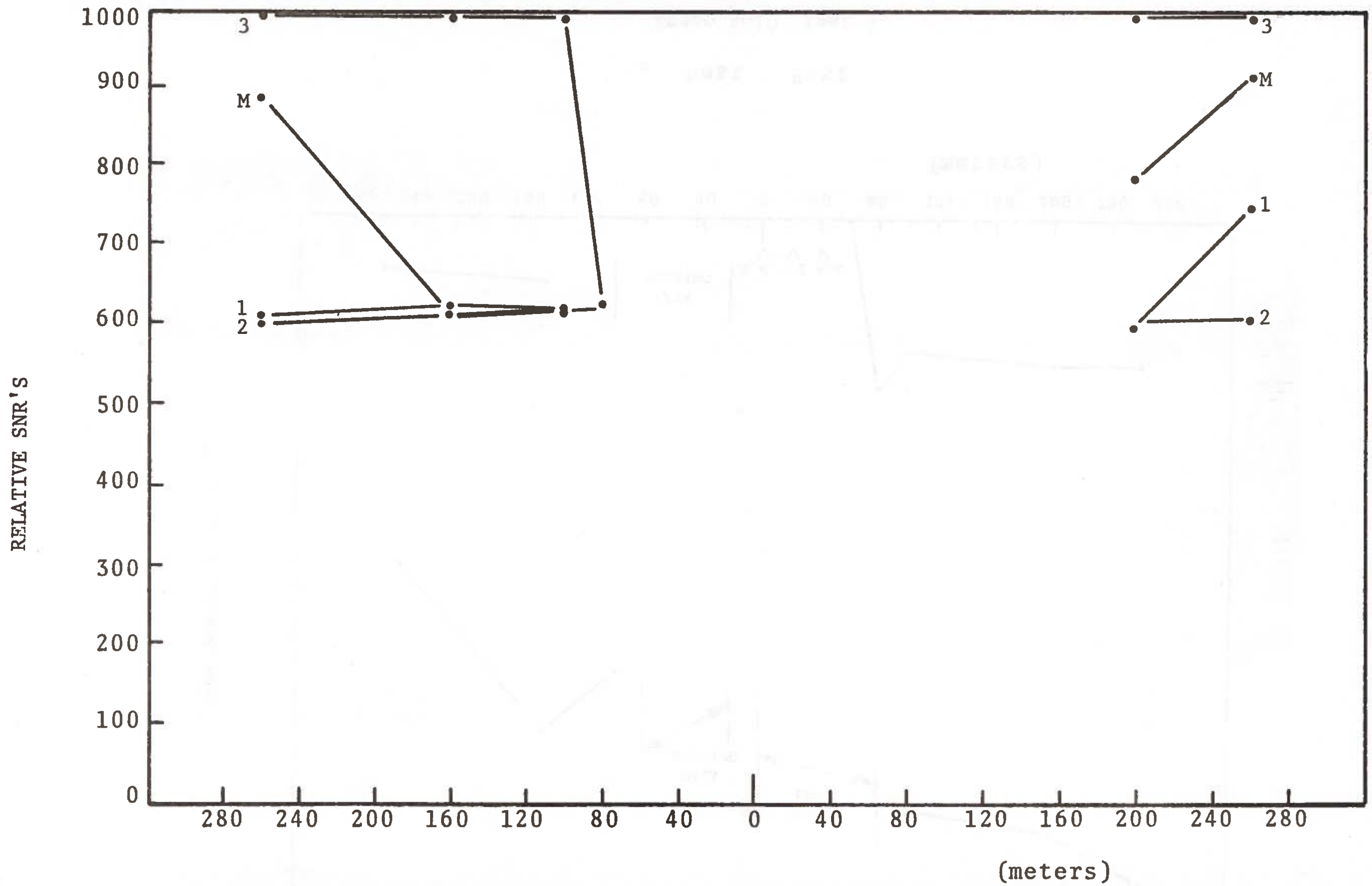
West East
TI90Q0A TEST 2



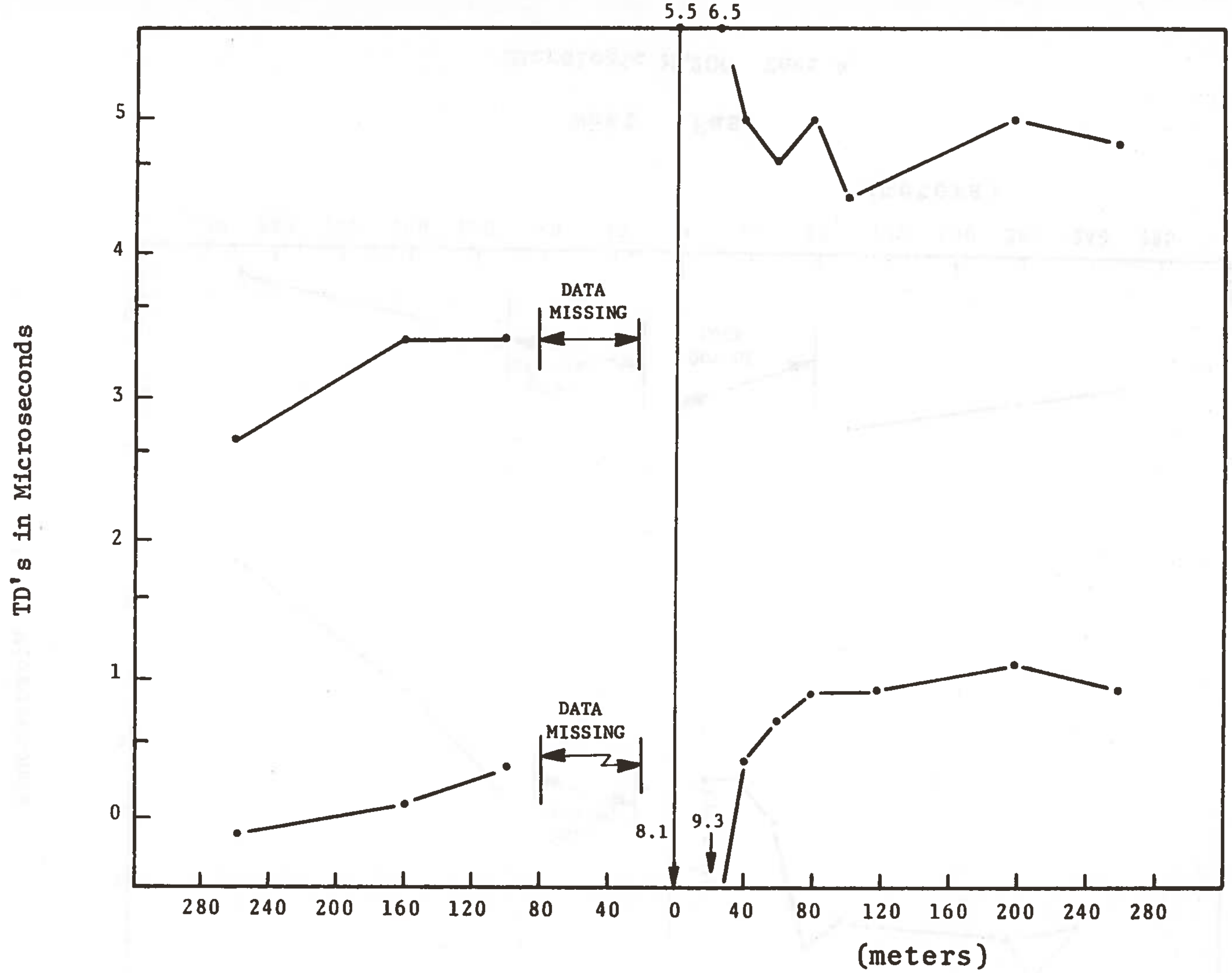
West East
INTERNAV TEST 3



West East
TI9000A TEST 3

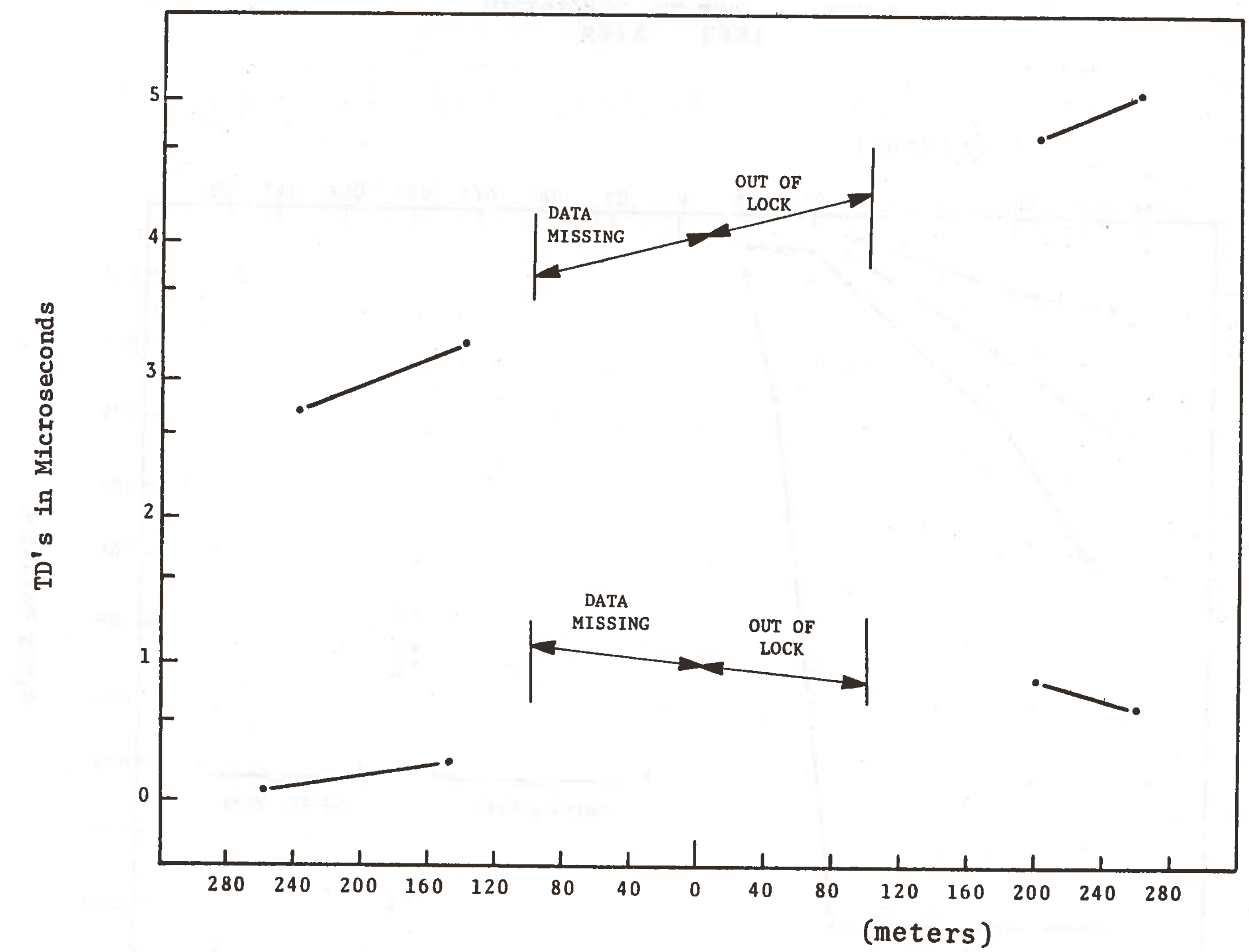


West East
TI9000A TEST 3



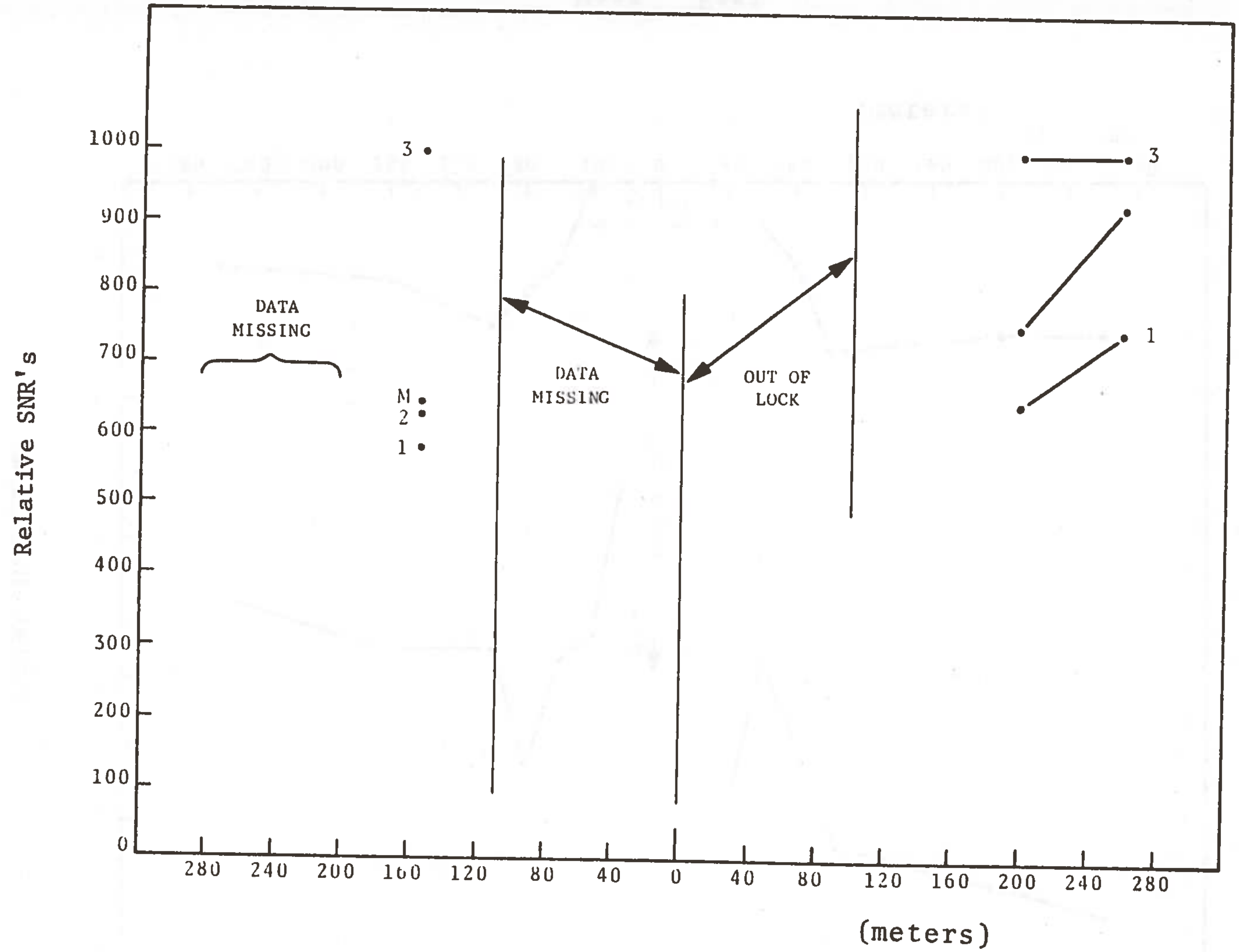
West East

Internav 204 Test 4



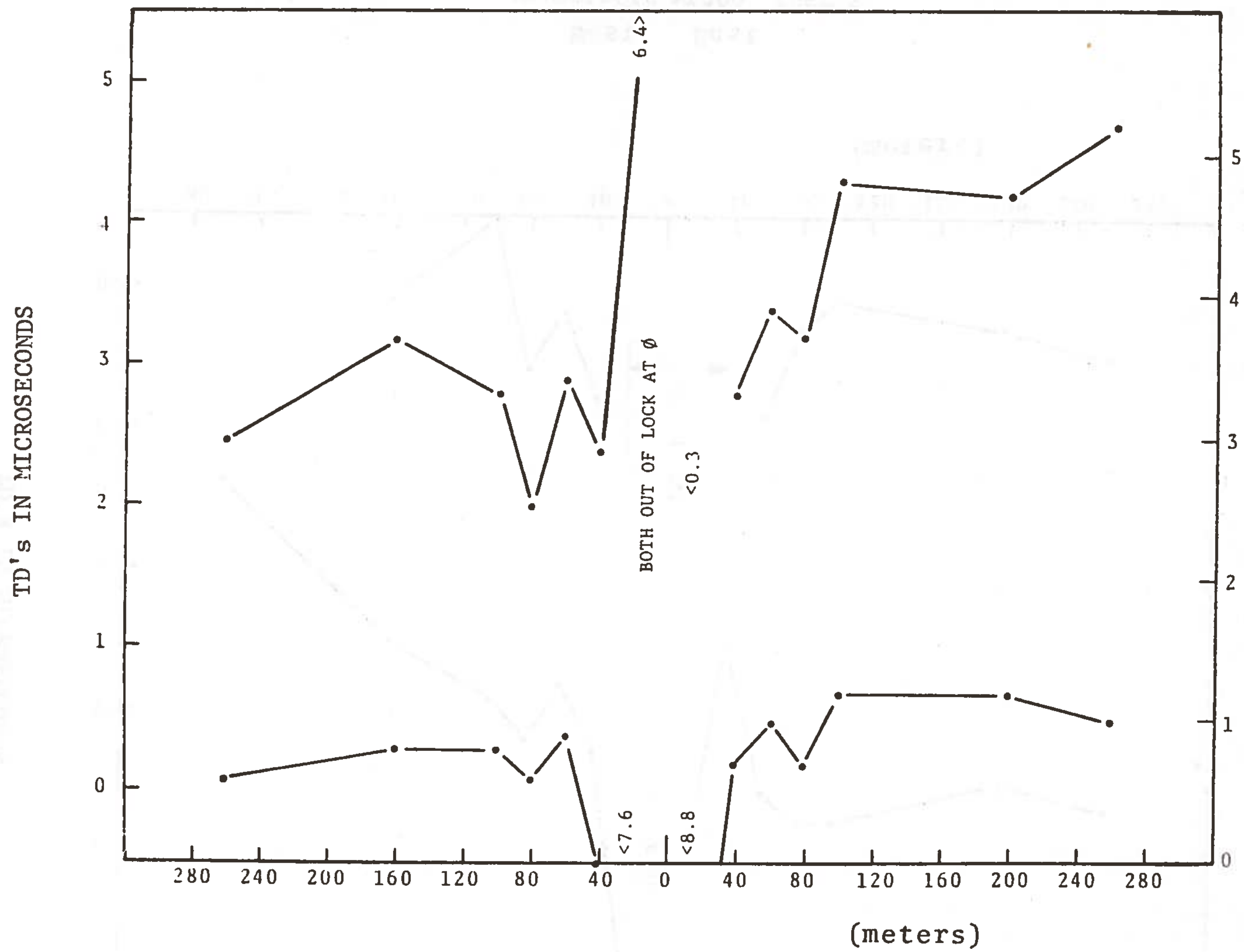
West East

TI 9000A Test 4

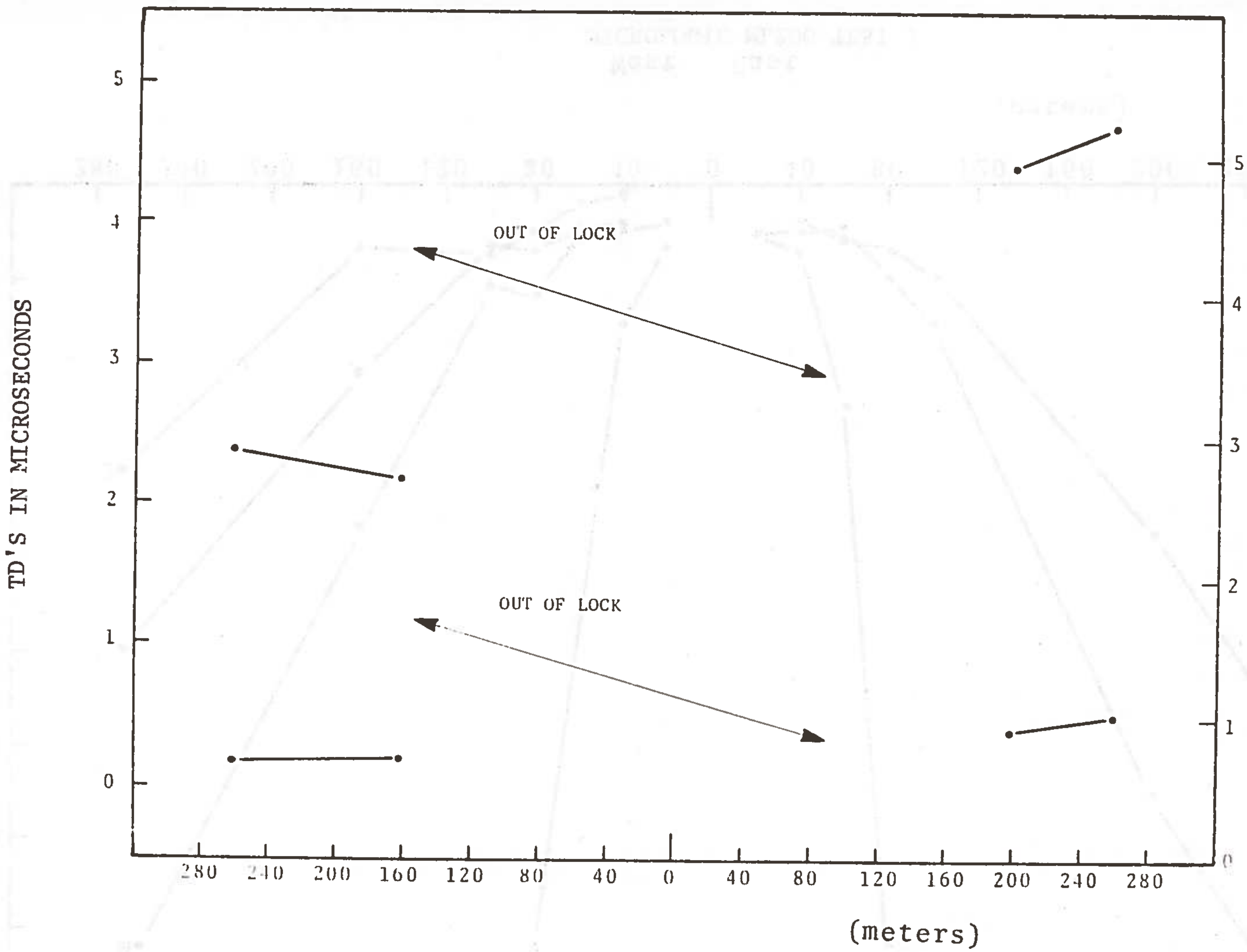


West East

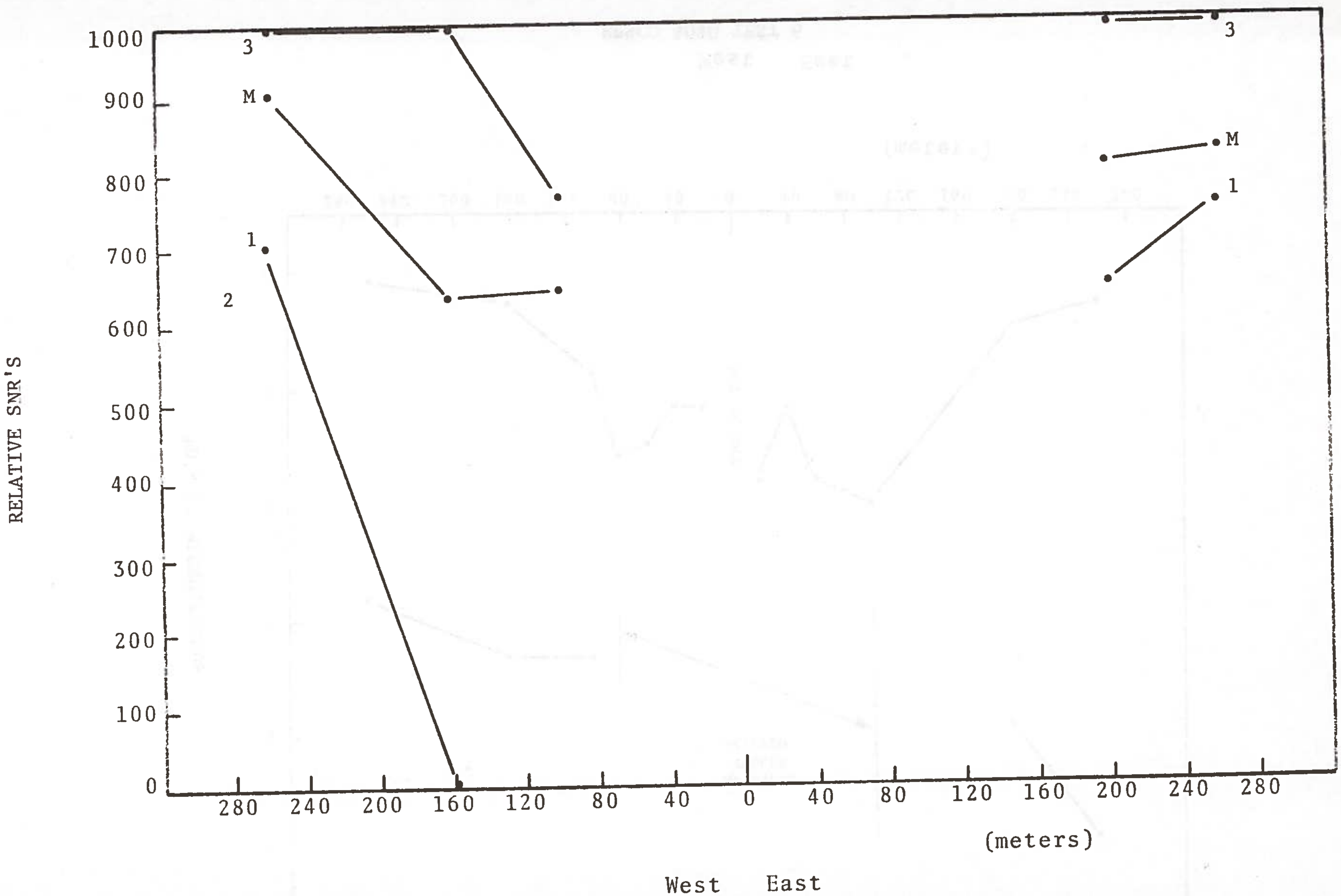
T I 9000 A Test 4



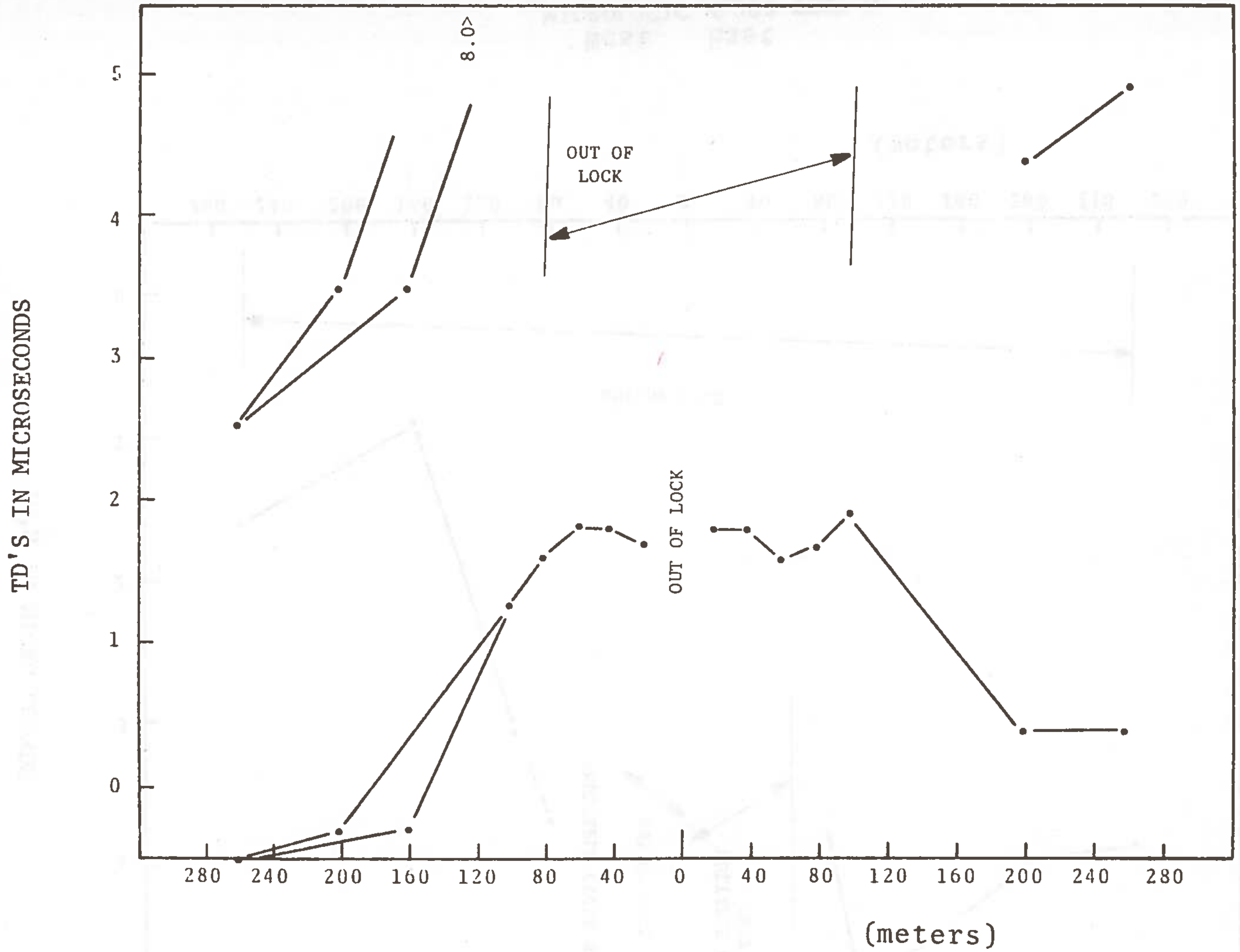
West East
INTERNAV 204 Test 5



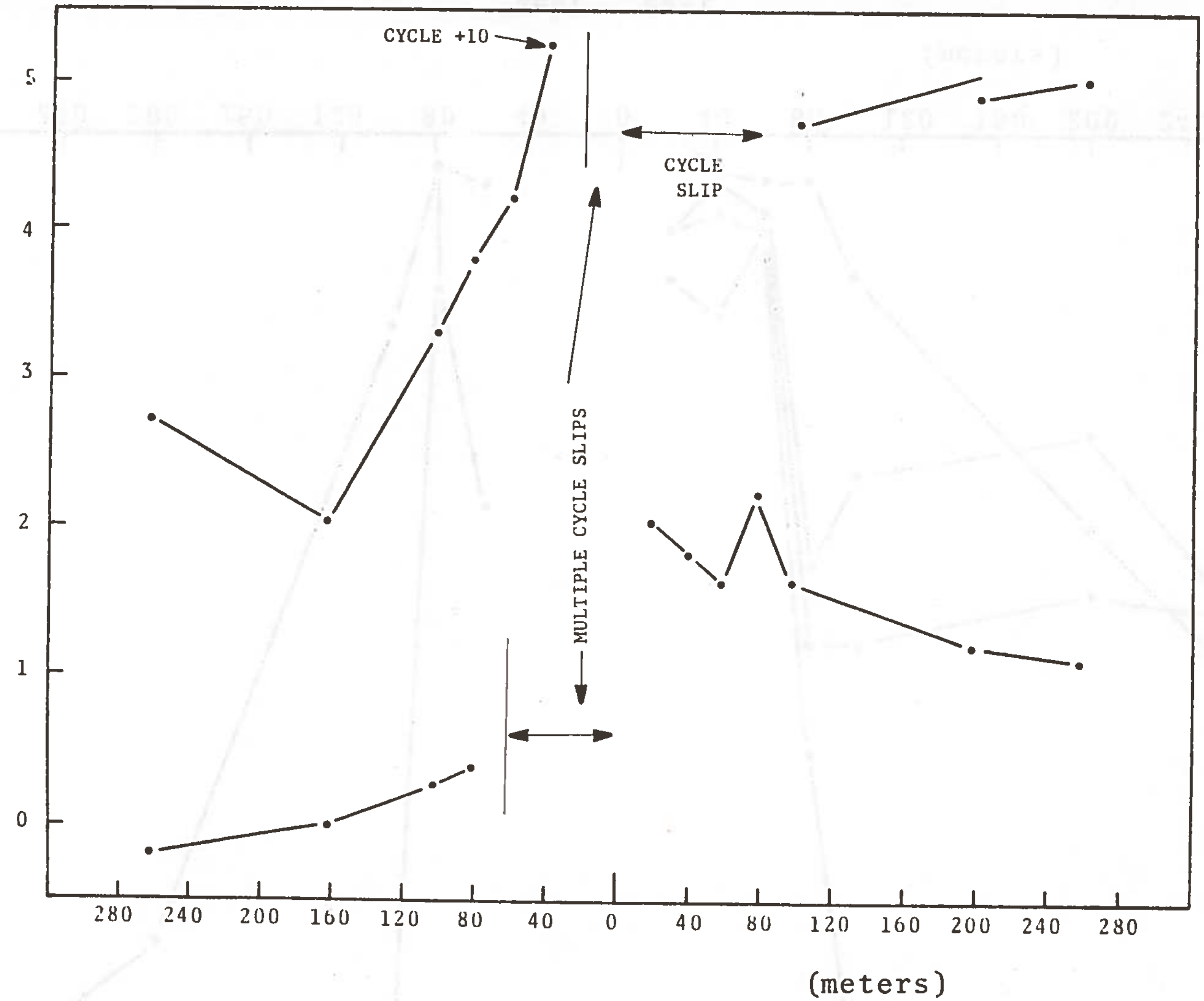
West East
TI9000A TEST 5



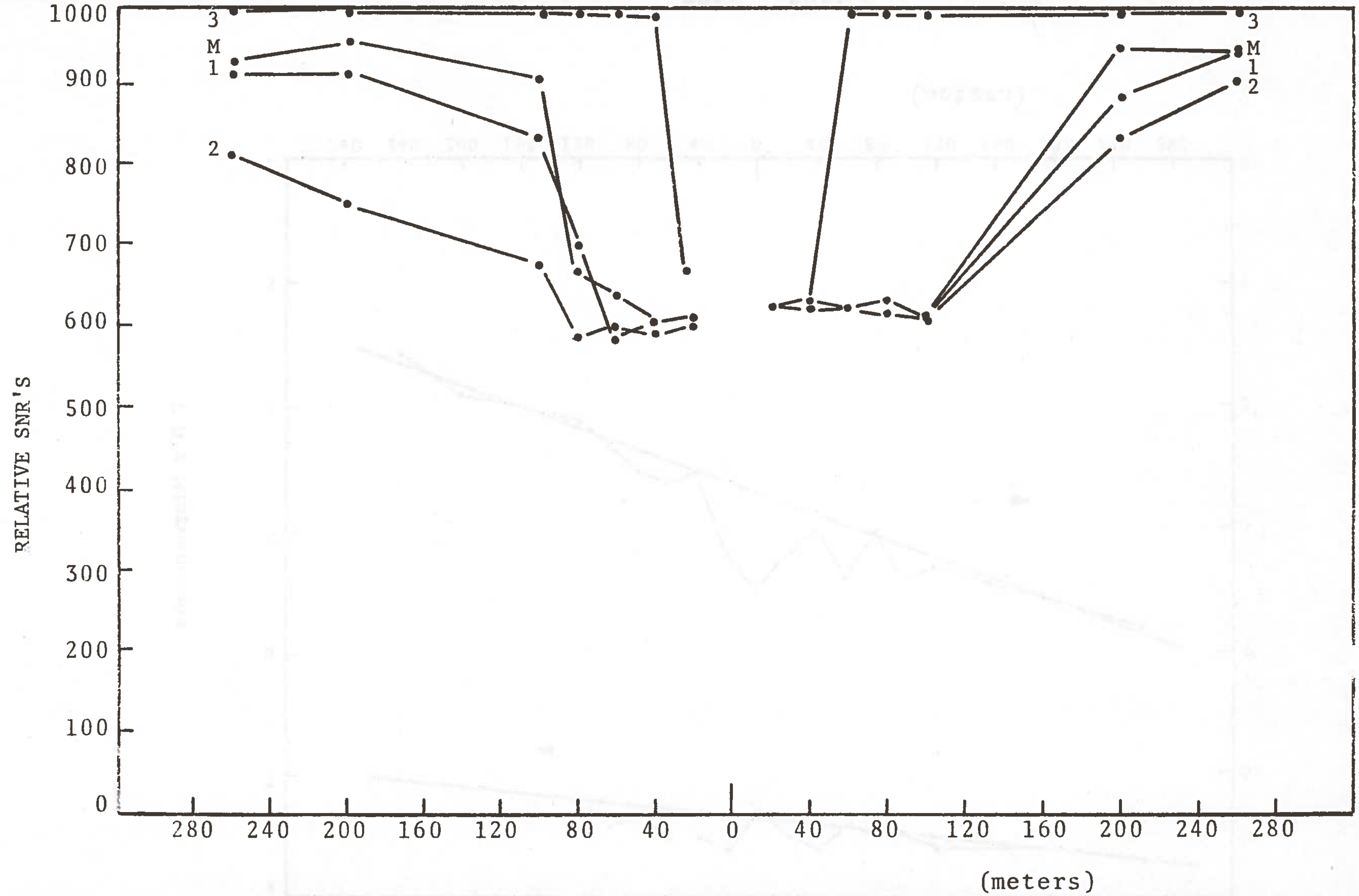
TI9000A TEST 5



West East
INTERNAV 204 TEST 6

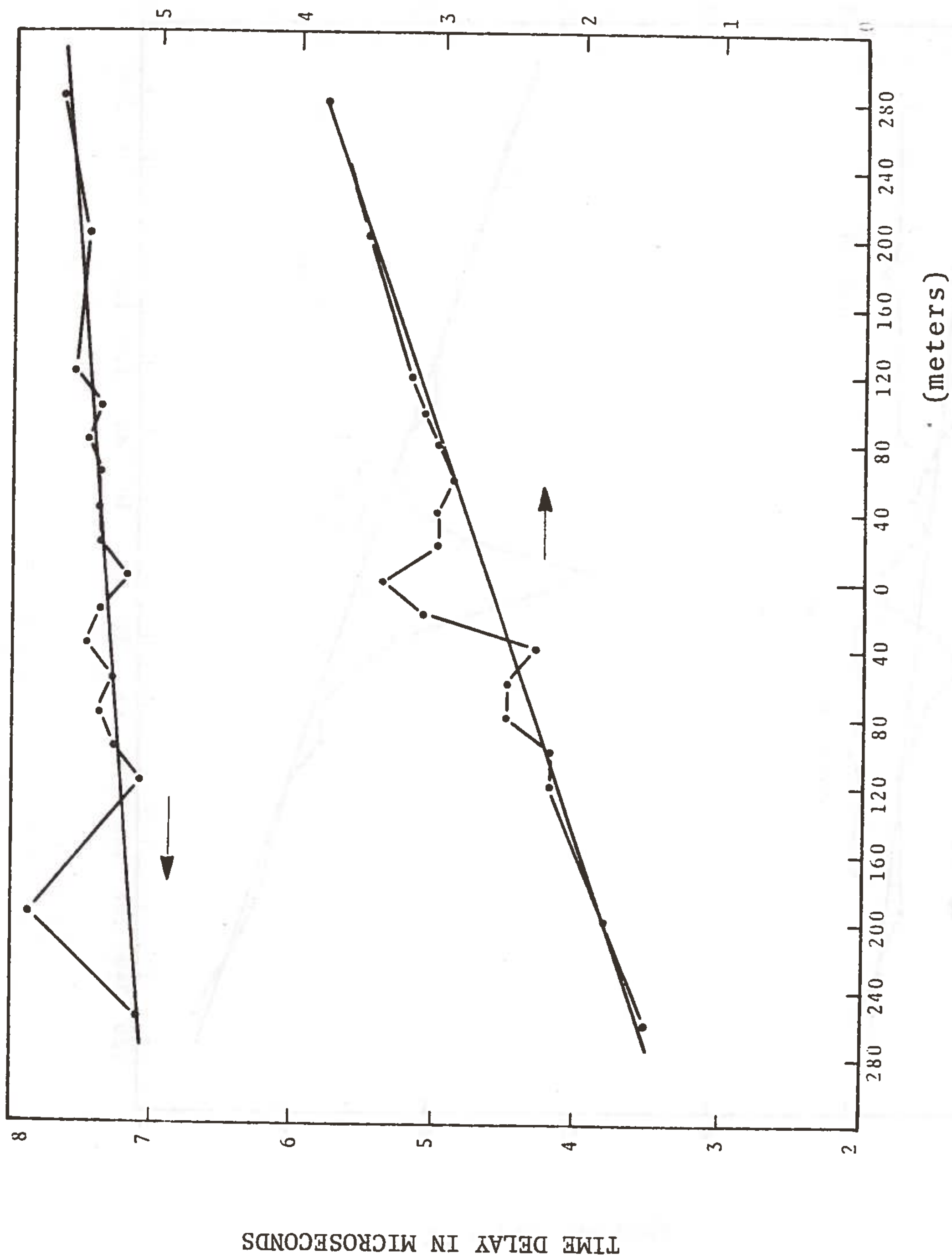


West East
TI9000A TEST 6

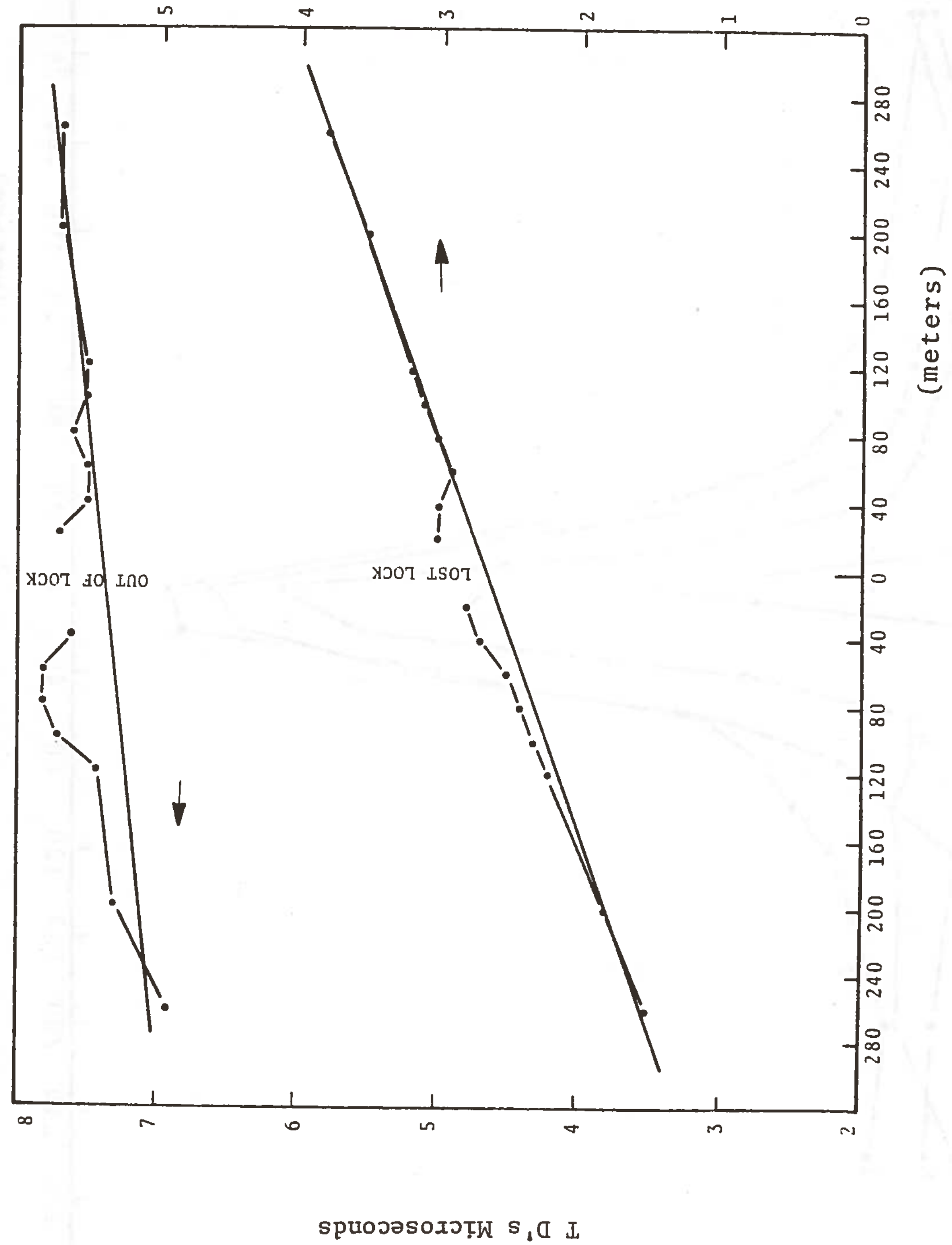


West East

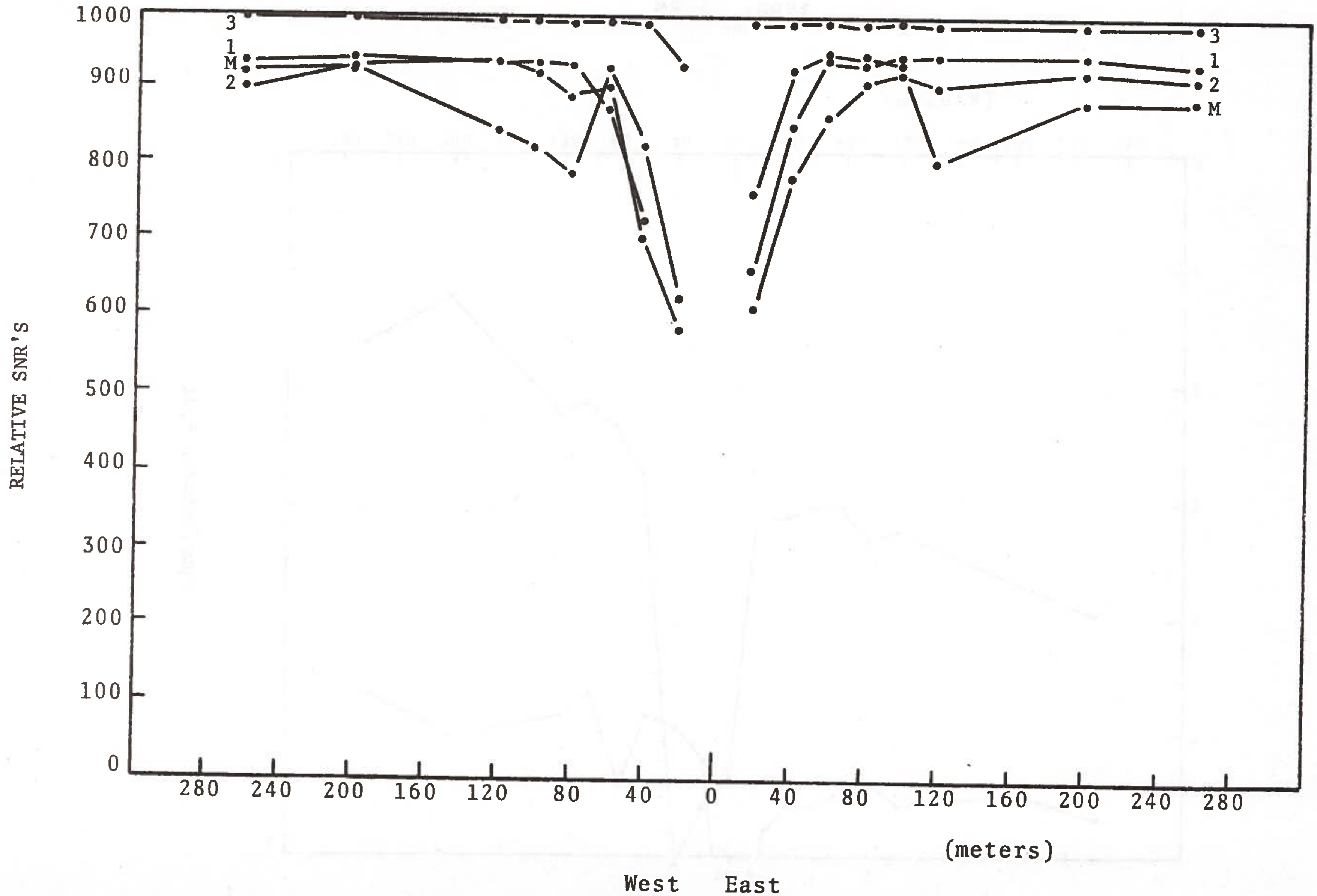
TI9000A TEST 6



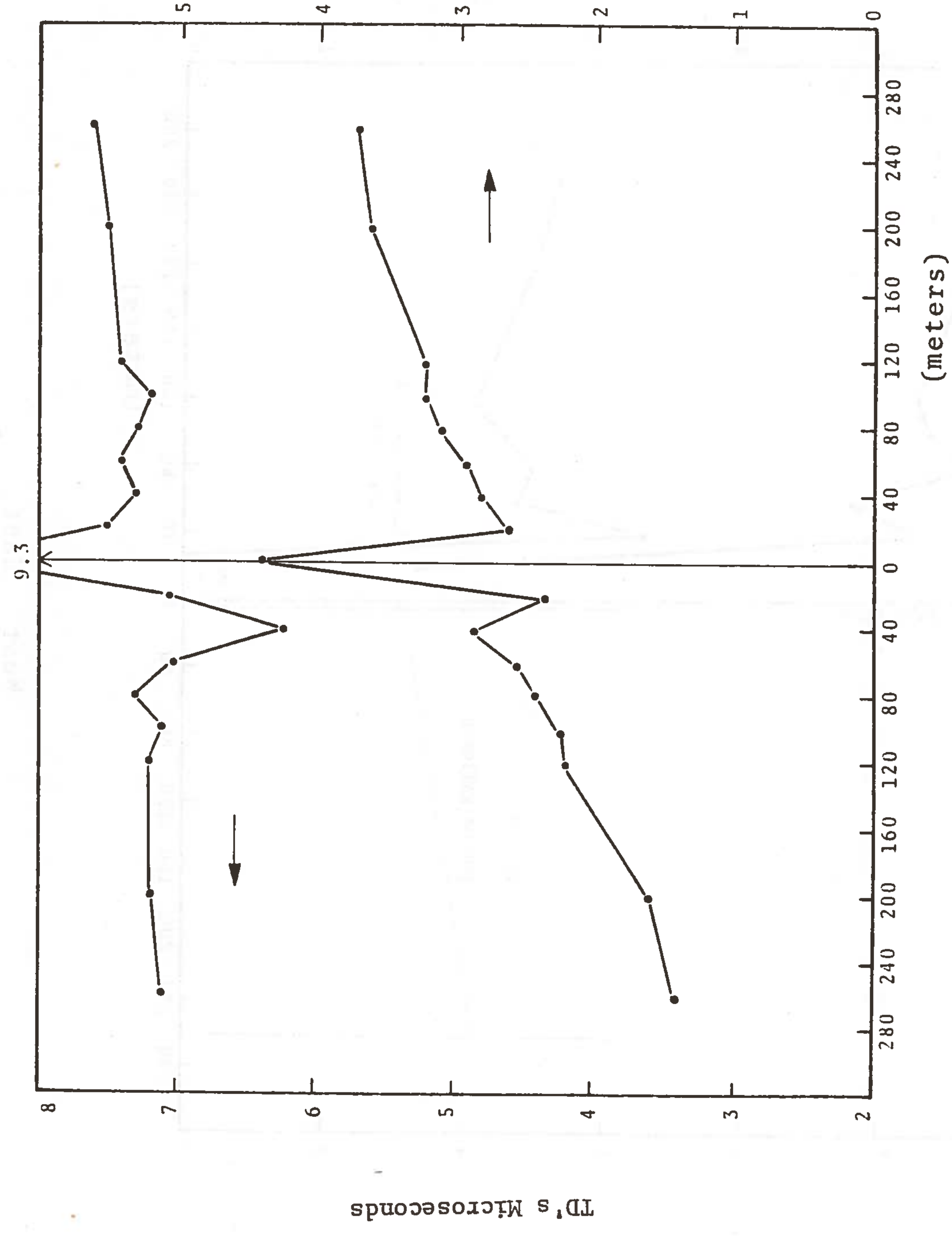
West East
INTERNAV 204 TEST 7



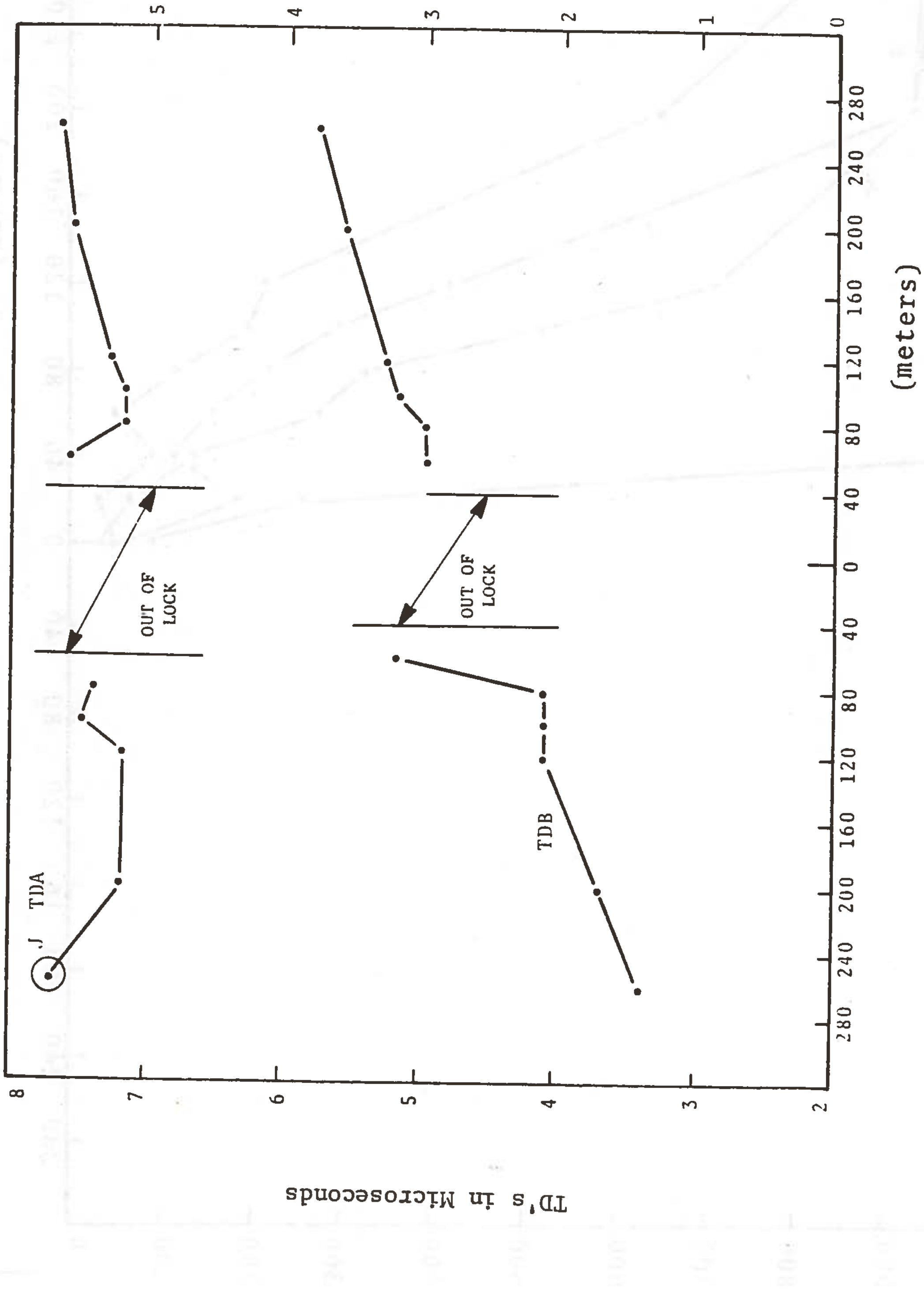
West East
T I 9000 A Test 7



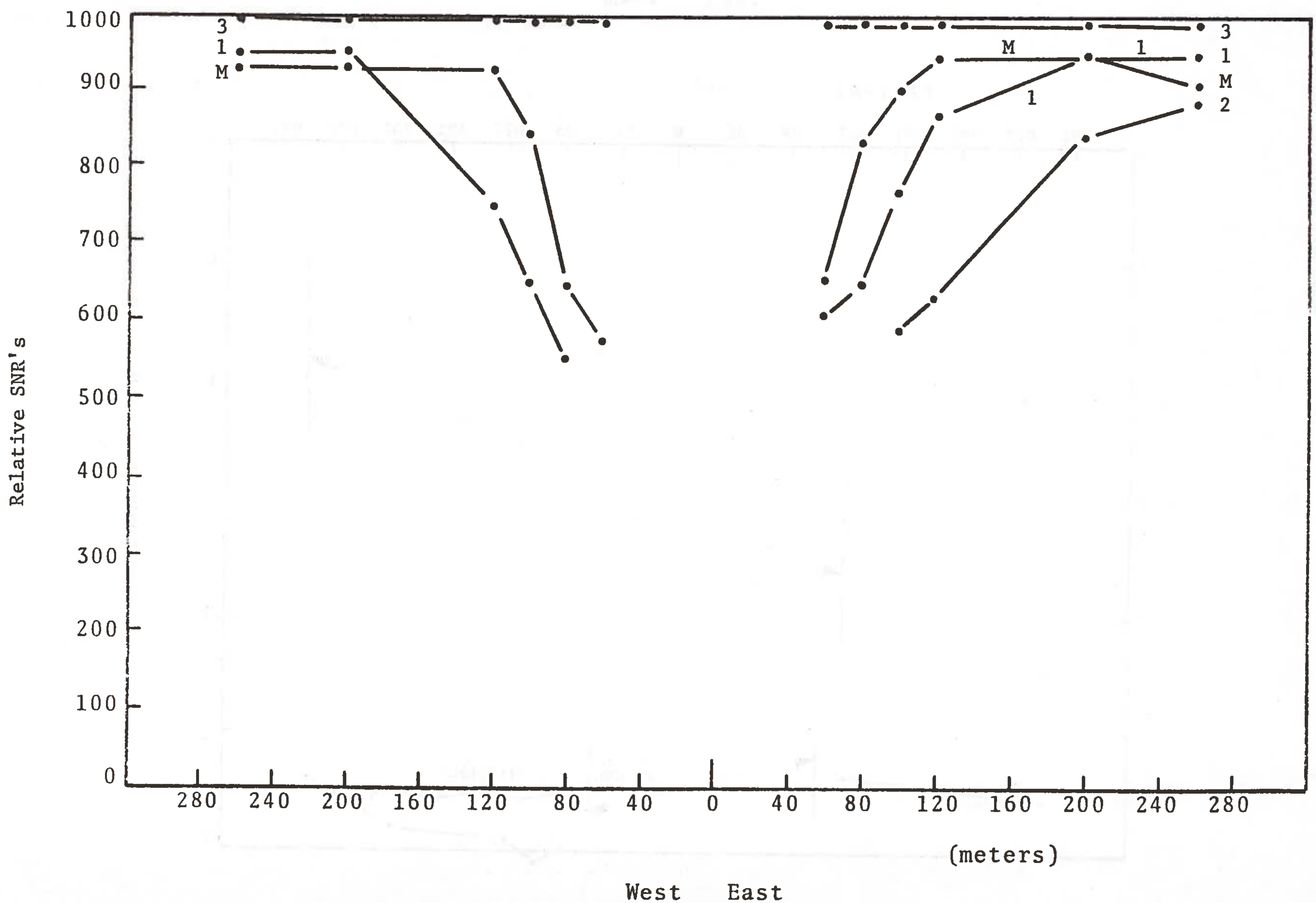
TI9000A TEST 7



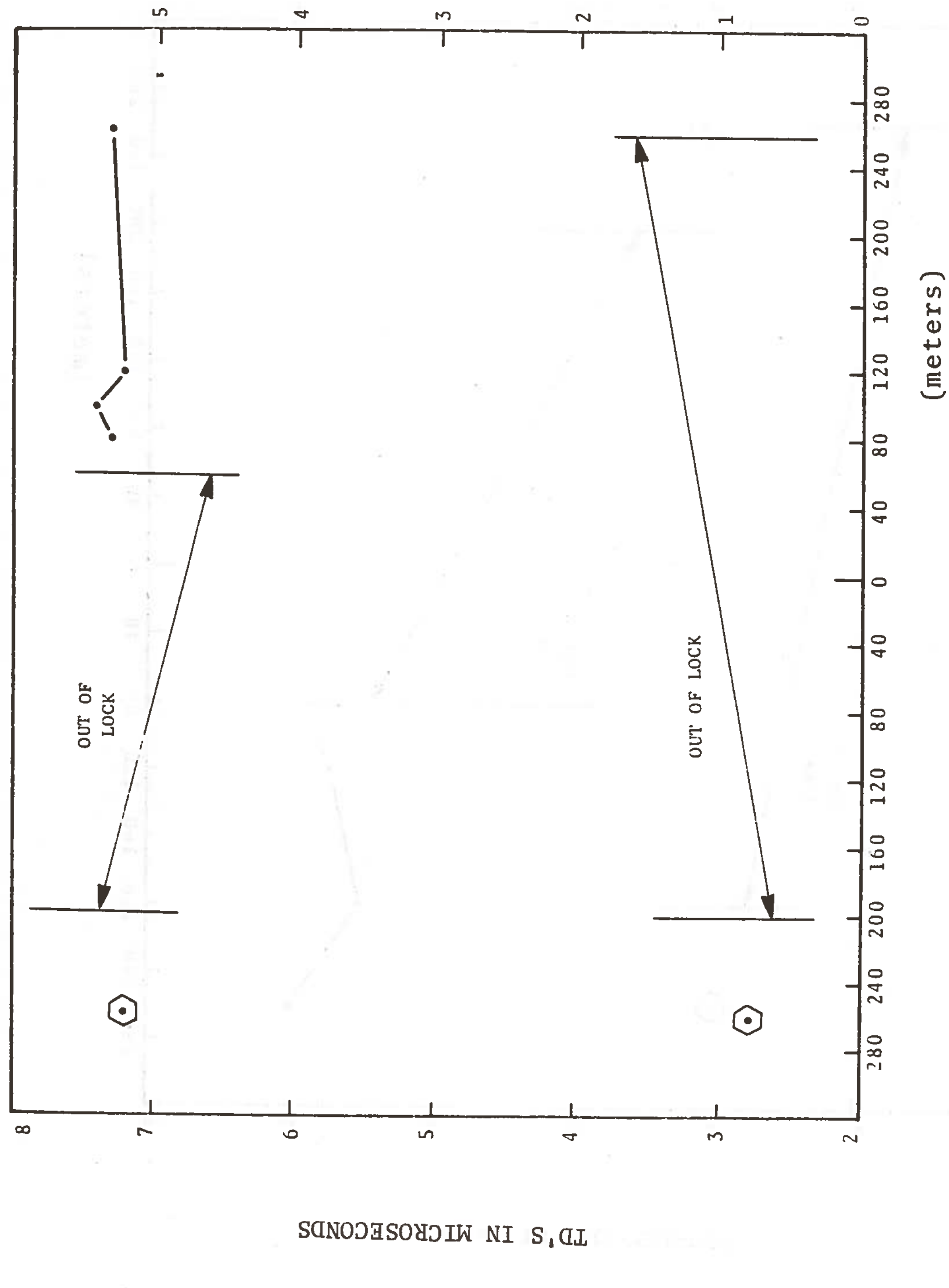
West East
Intervav 204 Test 8



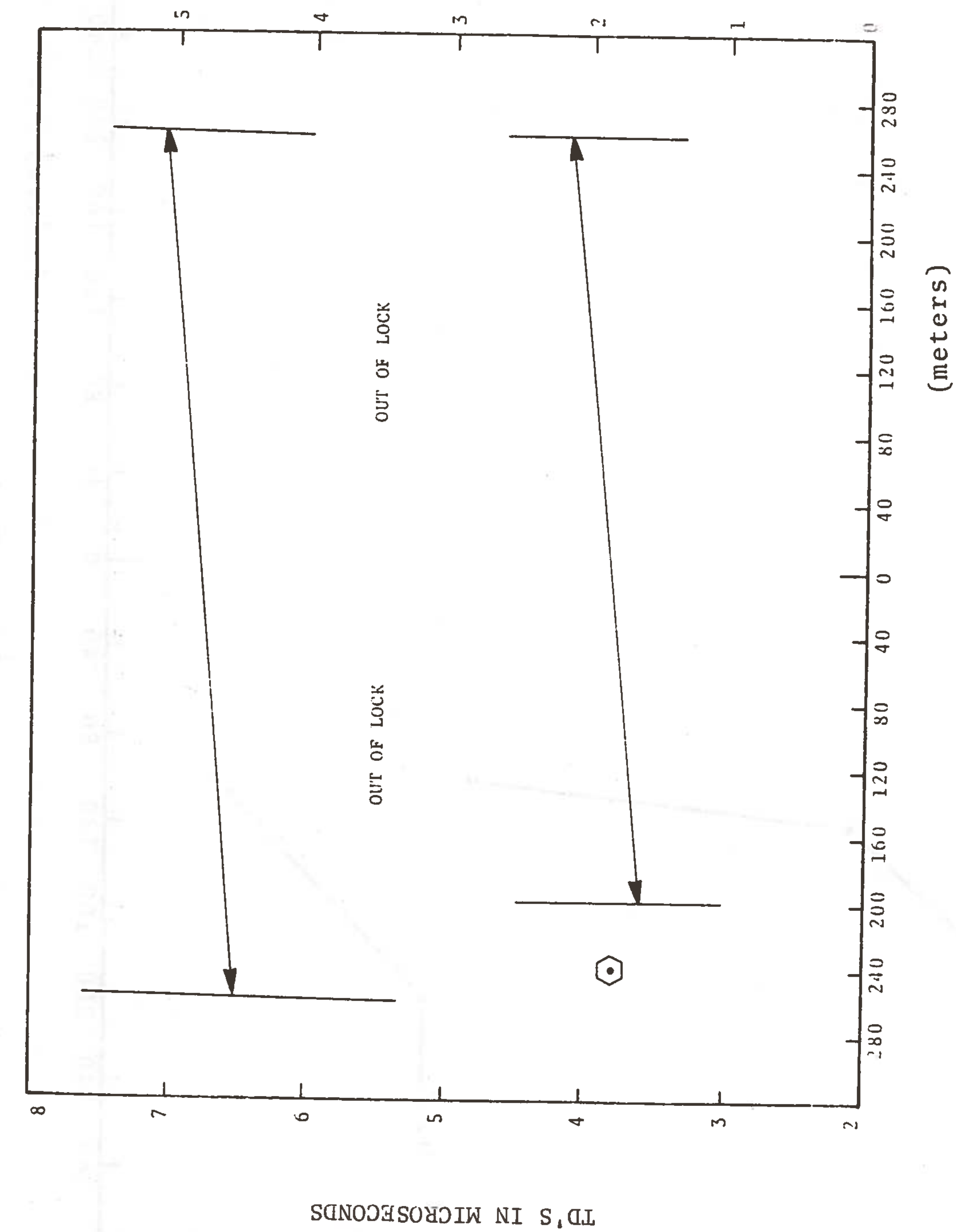
West East
TI 9000 A Test 8



TI 9000A Test 8



West East
INTERNAV 204 TEST 9



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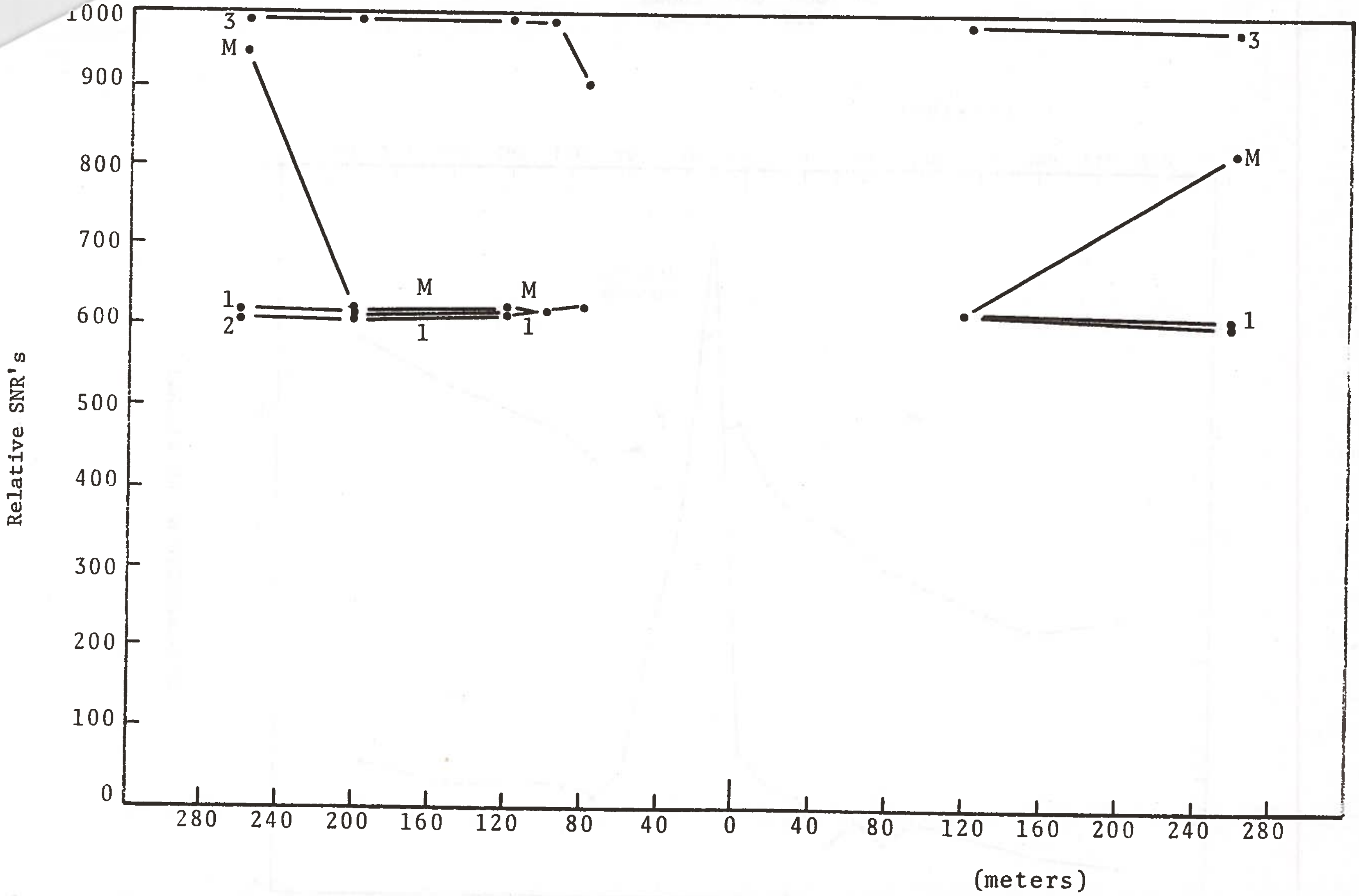
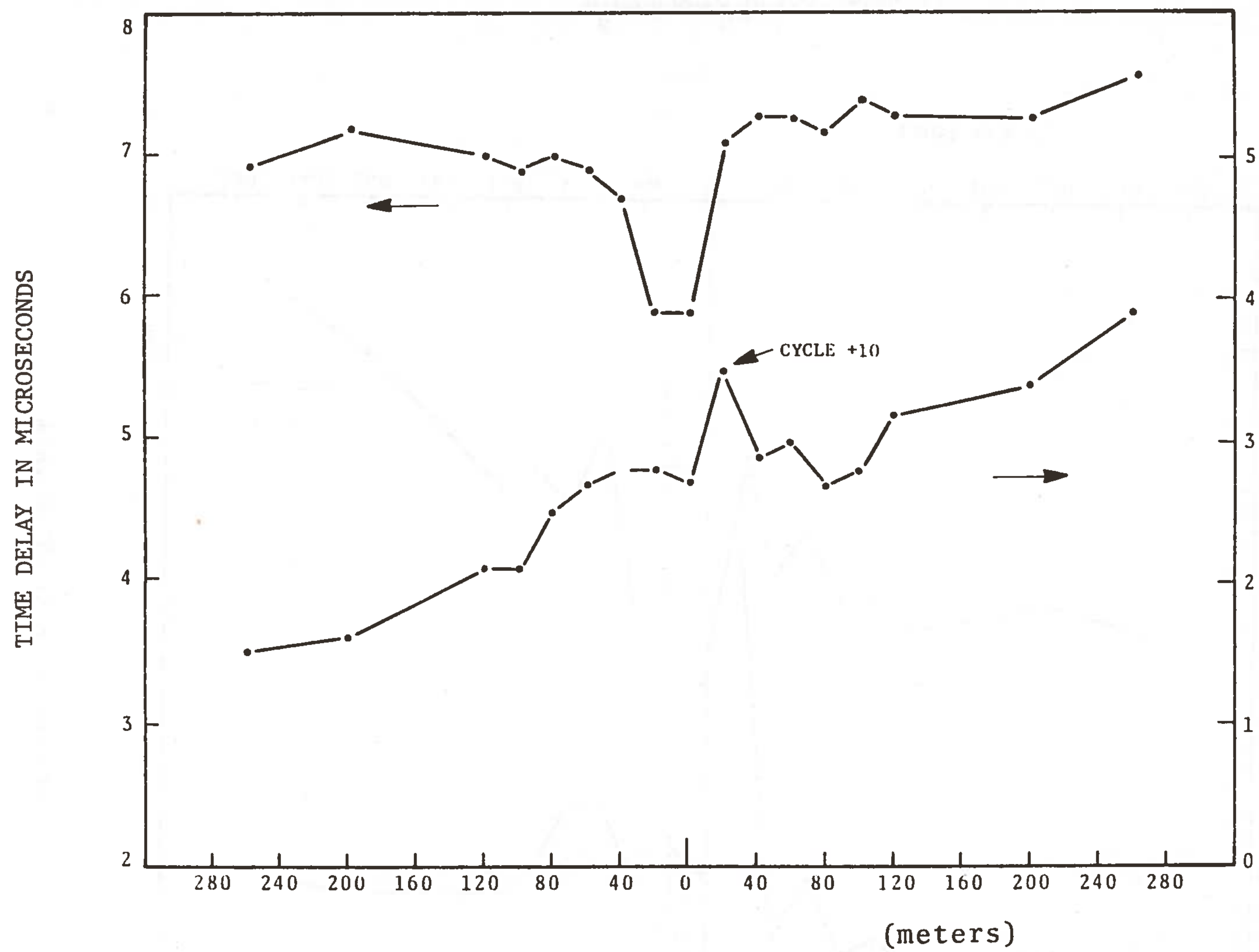
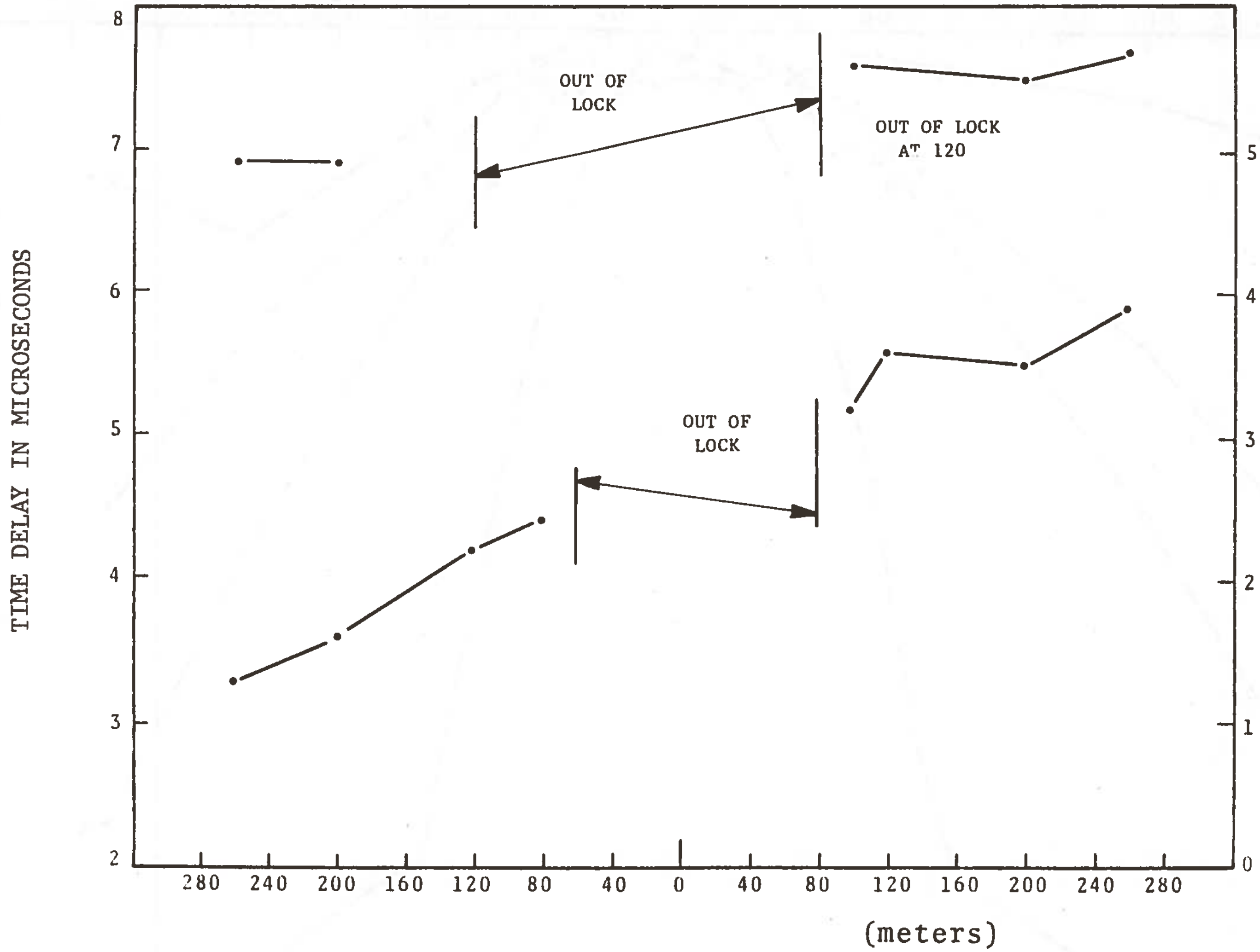
TI9000A TEST 9



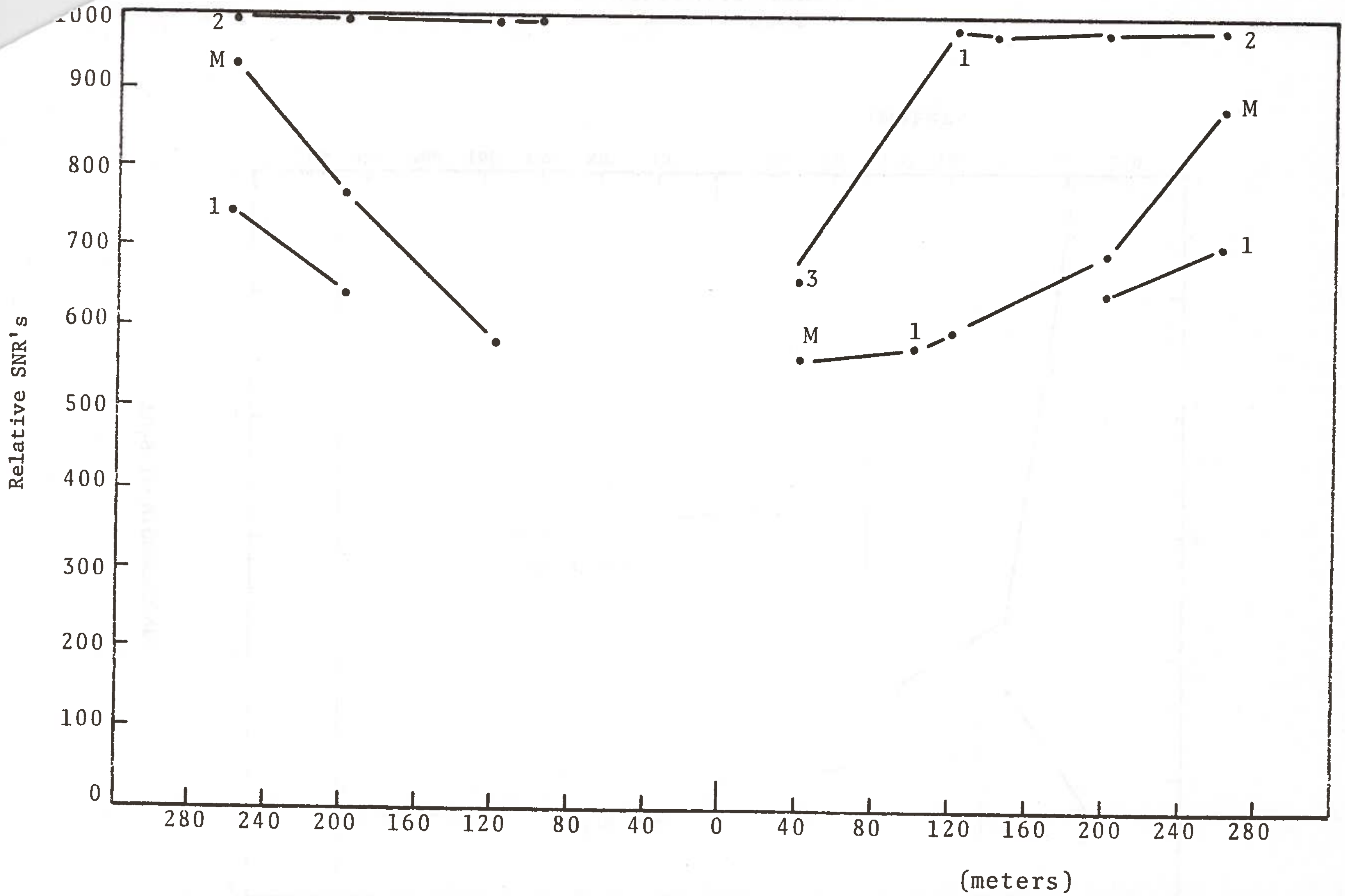
T I 9000A Test 9



West East
INTERNAV 204 TEST 10

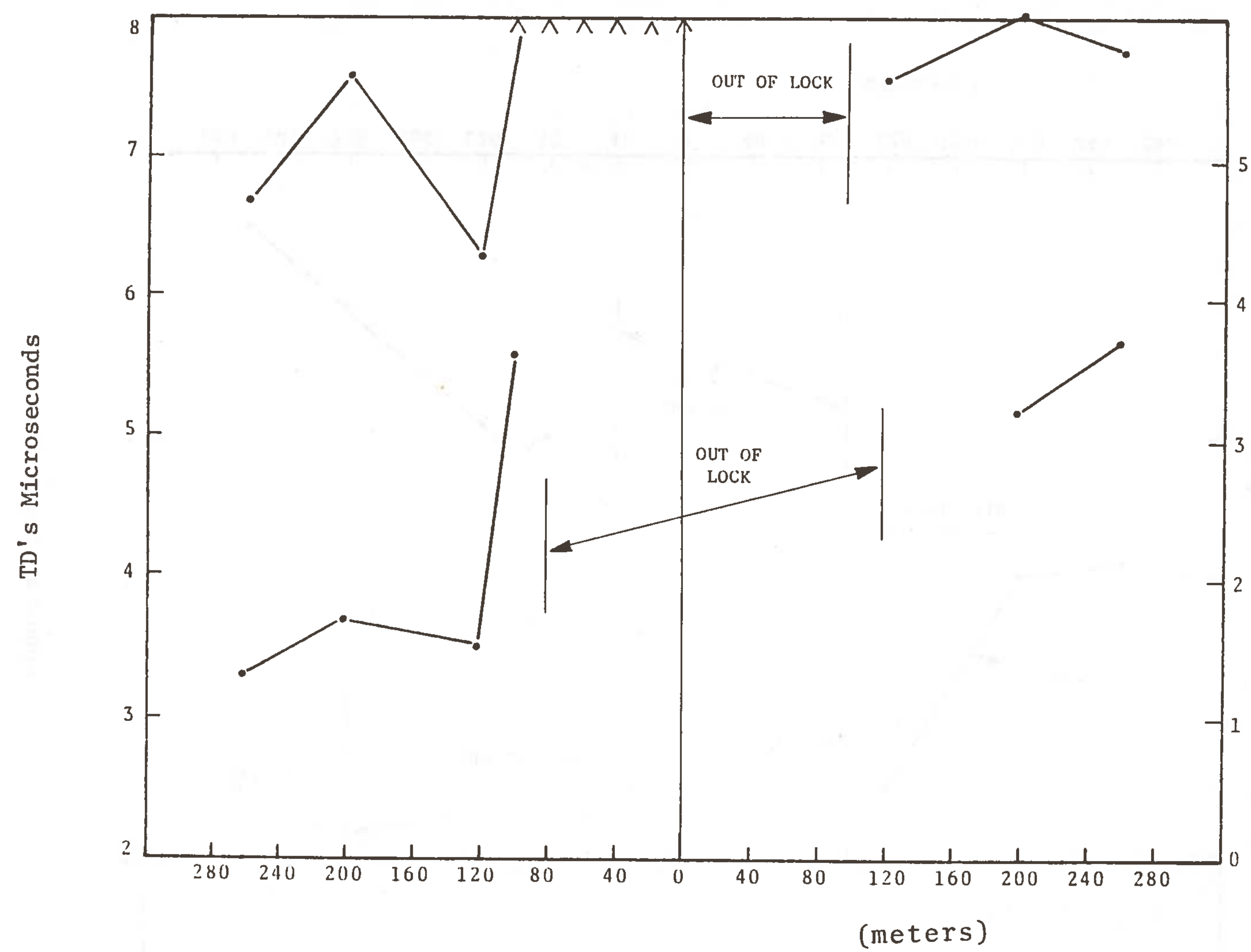


West East
TI9000A TEST 10

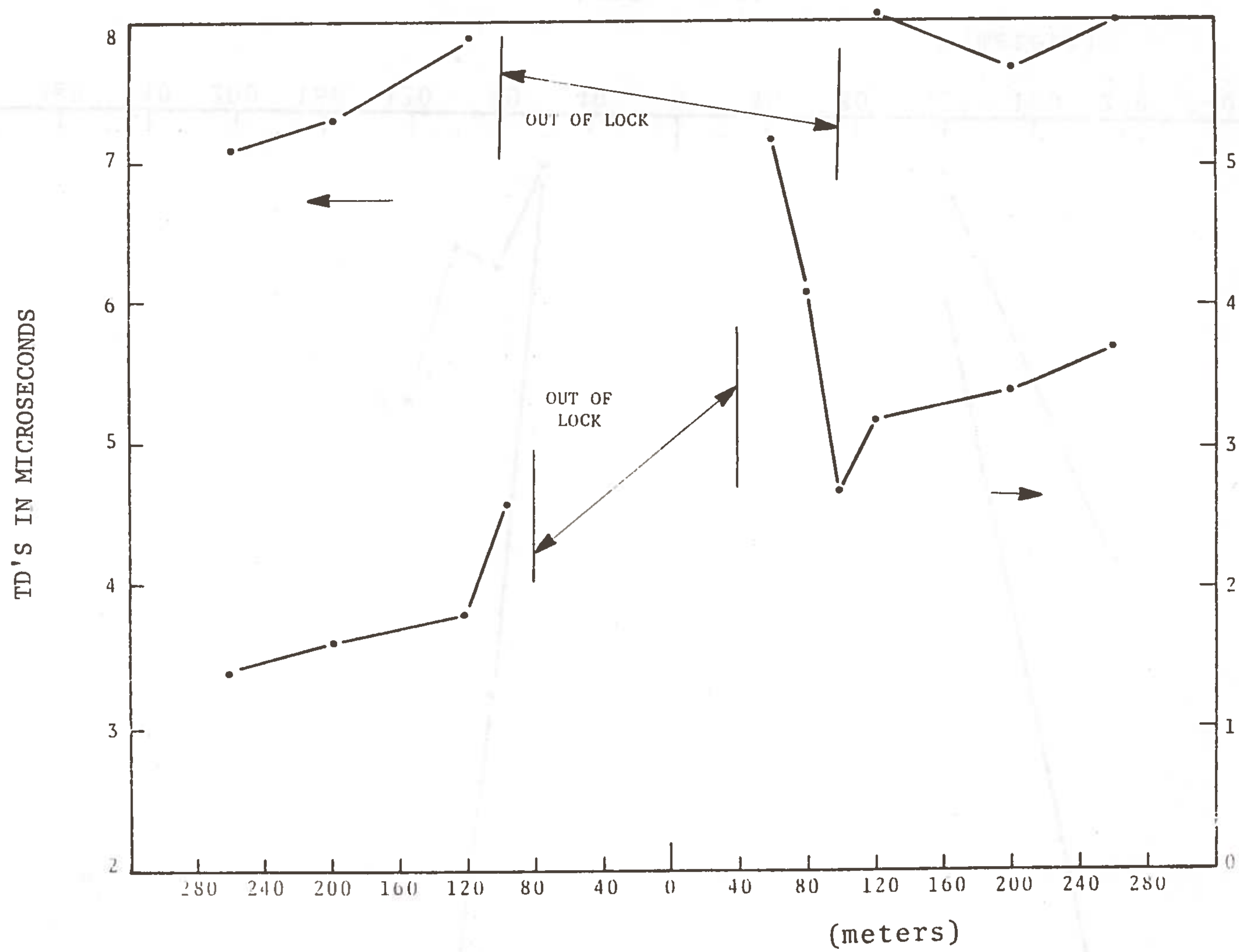


West East

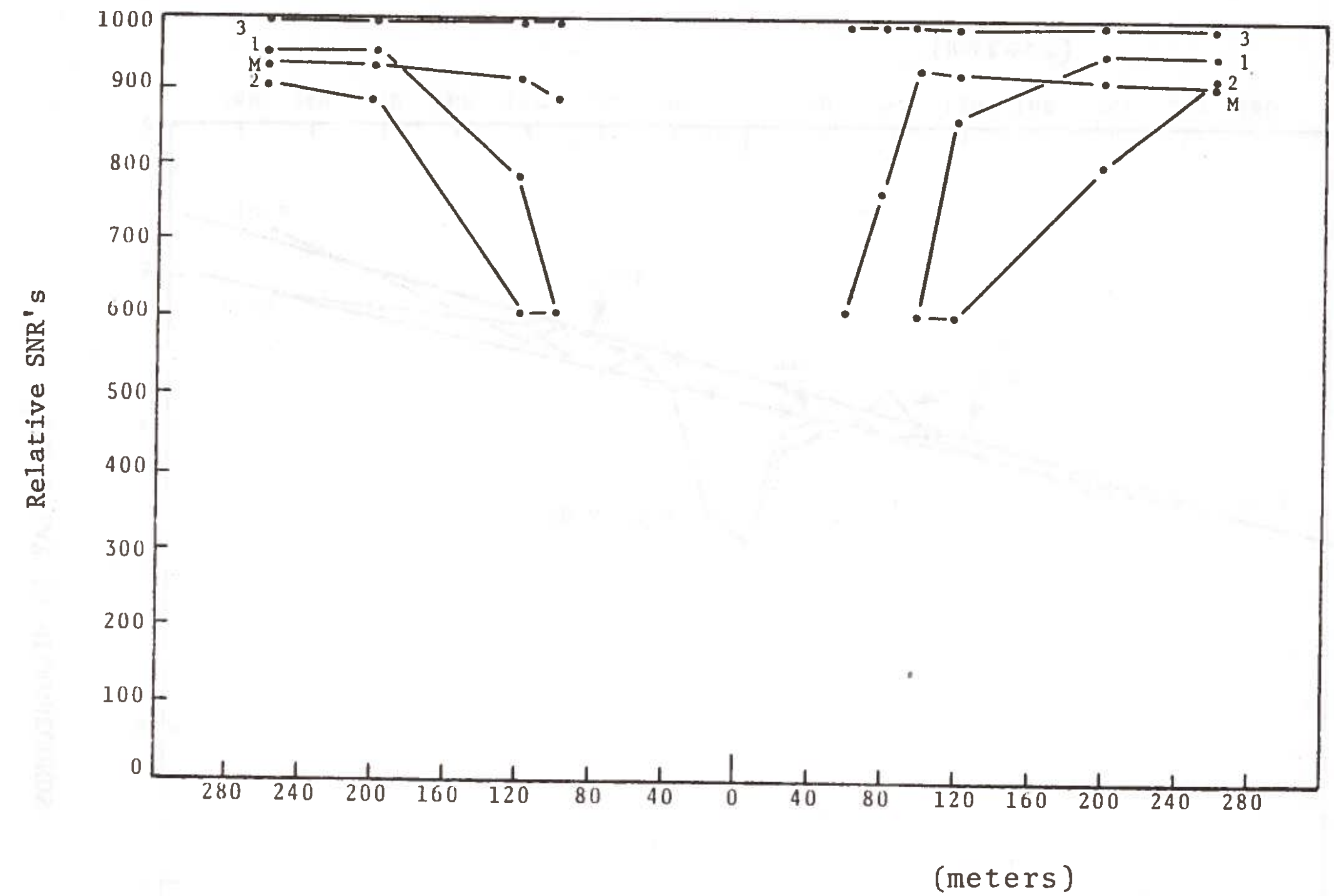
T I 9000A Test 10



West East
INTERNAV 204 TEST 11

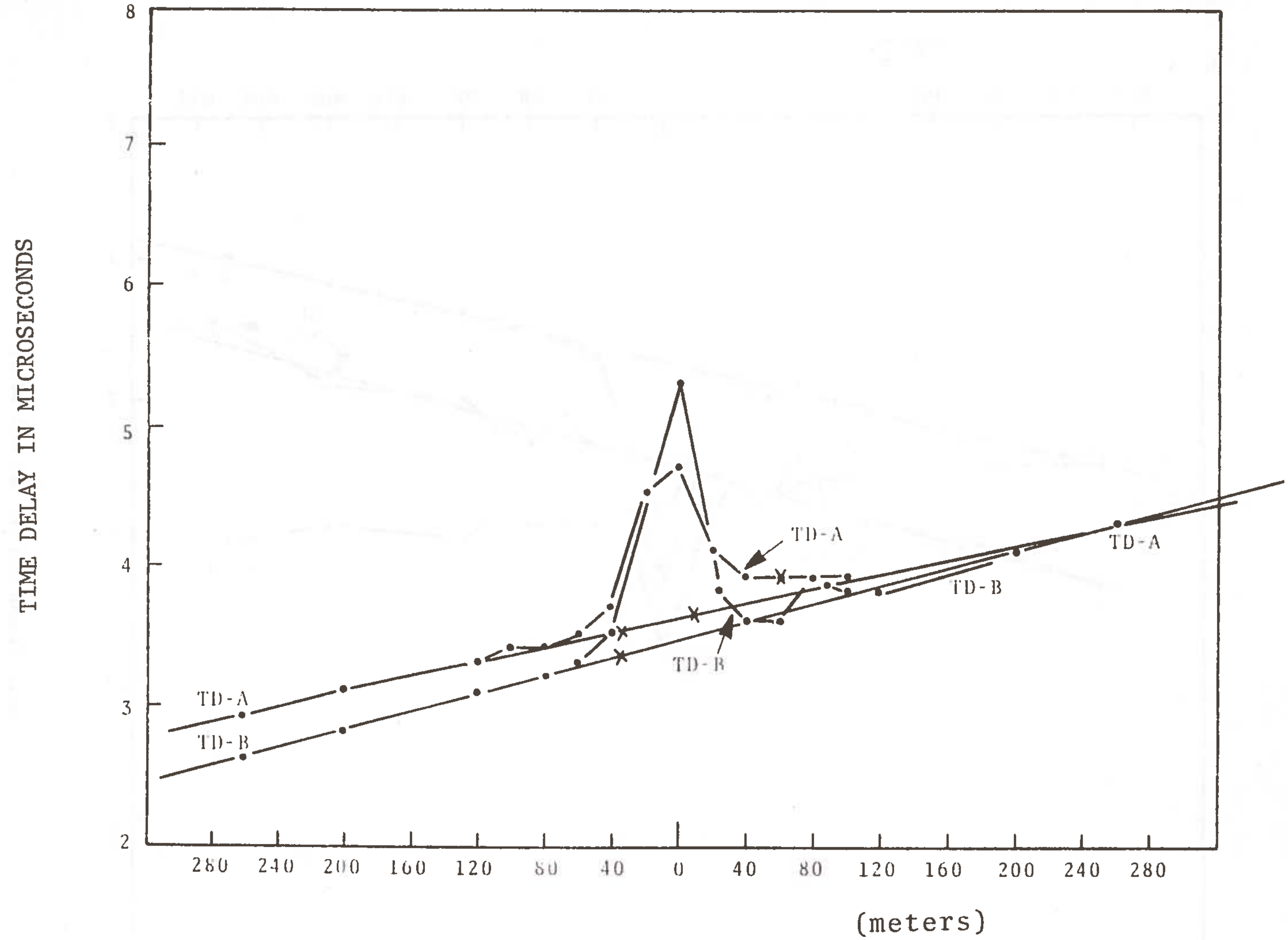


West East
TI9000A TEST 11



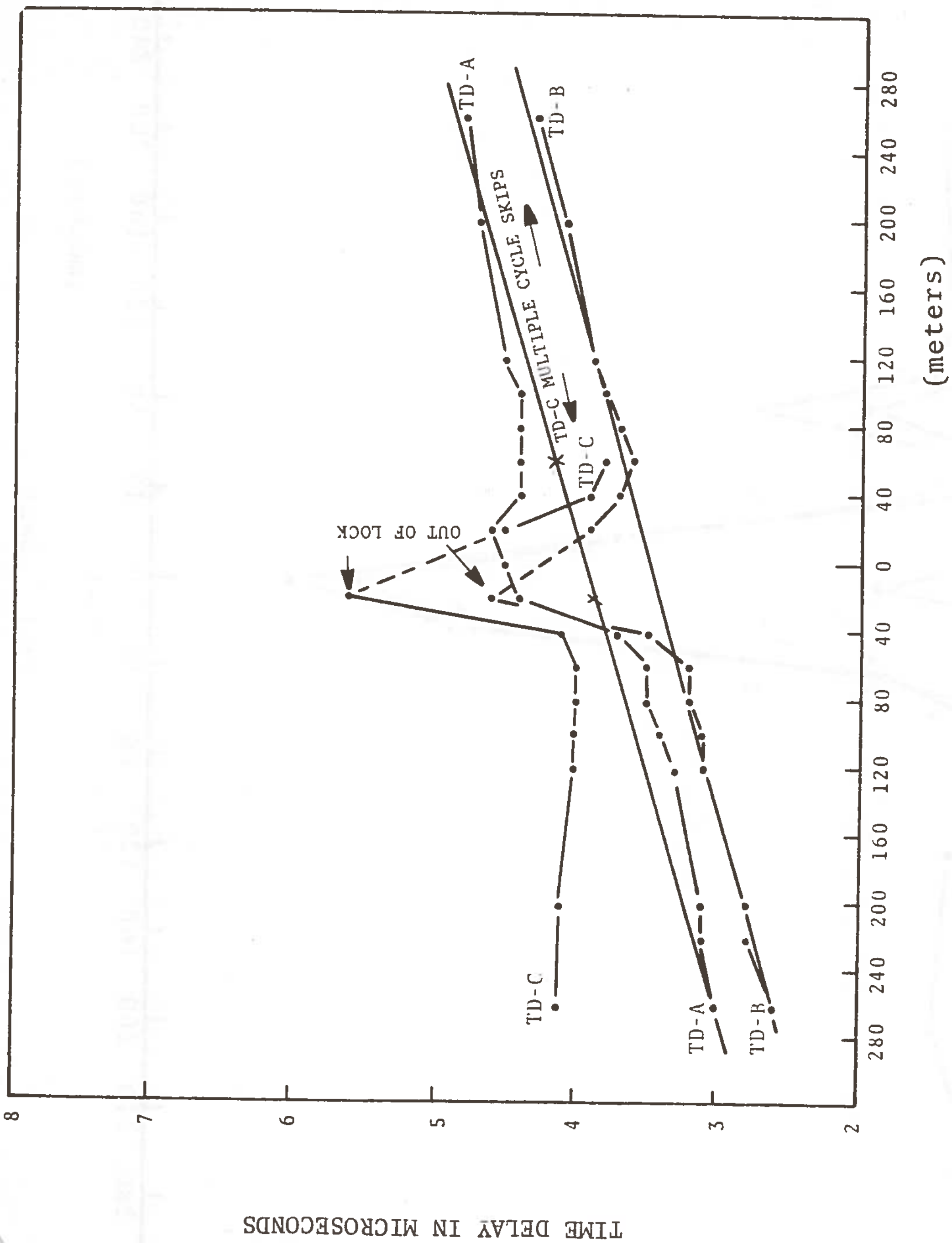
West East

T I 9000A Test II

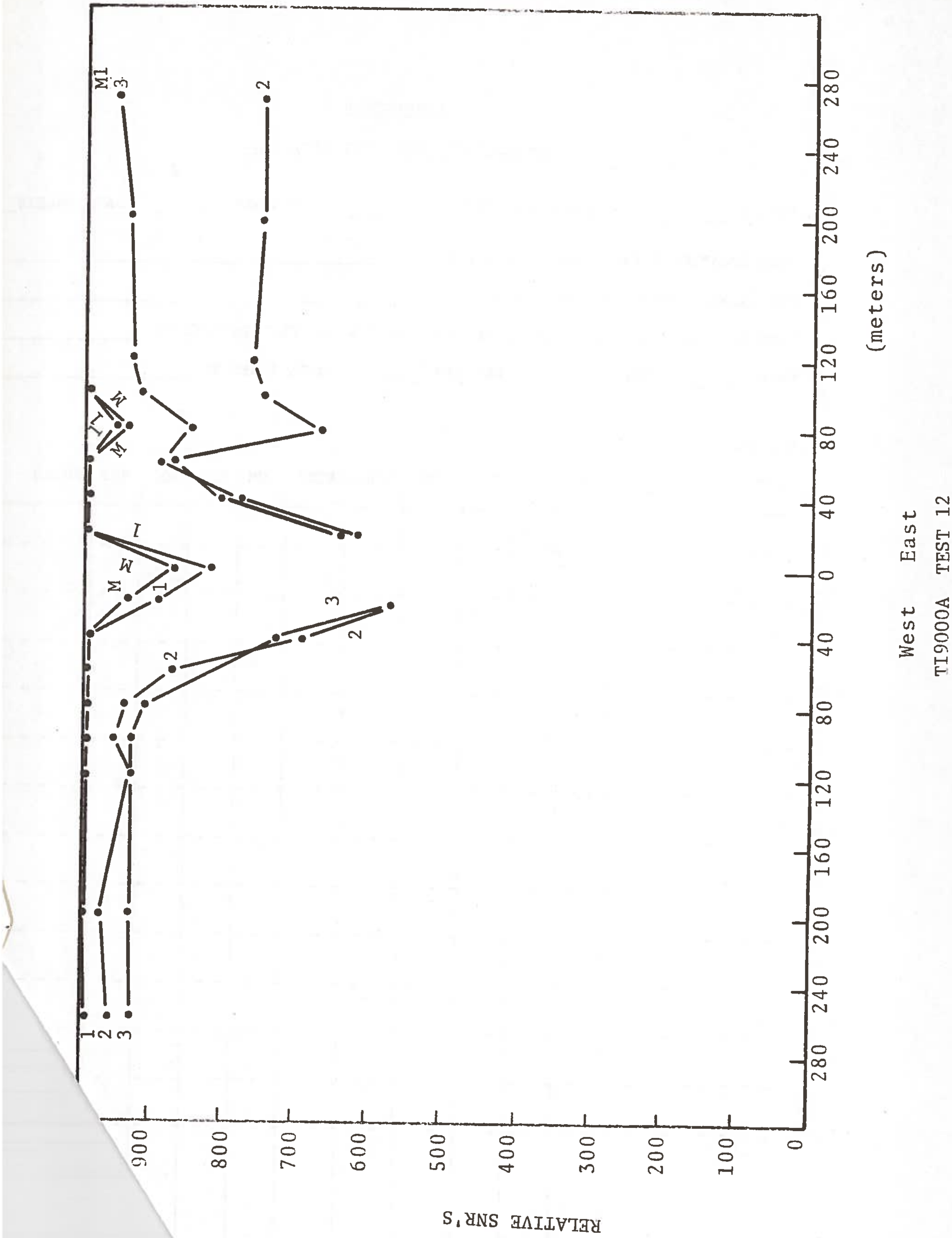


West East

INTERNAV 204 TEST 12



West East
TI9000A TEST 12


RELATIVE SNR'S
0
100
200
300
400
500
600
700
800
900
280
240
200
160
120
80
40
0
40
80
120
160
200
240
280
(meters)
West East
TI9000A TEST 12
1
2
3
M
I
M1

SPECTRUM CHARACTERISTICS TEST DATA SHEET

TEST # ________ SPECTRUM ANALYZER:MODEL# ______ SERIAL # ________ DATA SHEET# ______

TEST LOCATION (State Road or Route #) ______________________________

TVA TRANSMISSION LINE IDENTIFICATION ______________________________

SIDE OF LINE : N S E W DISTANCE FROM TVA LINE TO PLC TRANSMITTER ________

DATE __________ TIME __________ WEATHER ______________ DATA TAKEN BY __________

DISTANCE FROM LINE (UNITS ________)	FREQUENCY OF SPECTRAL LINE	LEVEL

APPENDIX C

DESCRIPTION OF A DATA ACQUISITION SYSTEM FOR AUTOMATICALLY MEASURING LORAN-C

C.1 INTRODUCTION

The expanding Loran-C grid on both East and West Coasts and the possible mid-continent chain has made position location available to a larger user group than the maritime community it was designed to serve. New Loran receivers using advanced microprocessor technology are smaller, lighter, and capable of improved operation in difficult environments encountered in large cities, near power lines, etc.

Many potential users have become interested in possible applications of Loran for their own diverse needs. In particular, state traffic departments would like to identify a highway site where accidents have occurred to direct rescue vehicles and to accumulate a data base for future traffic pattern studies. Police units could use LORAN coordinates to direct officers in rural areas or, conversely, officer's location and status might be transmitted to a dispatch station for constant monitoring in high crime areas. Another example of a unique terrestrial application of Loran is in population location information gathered by the Bureau of Census in remote areas where no address is possible.

All of the above depend on the reliable, repeatable precision of Loran coordinate data, over both short and long periods of time (minutes to years).

The Department of Transportation is conducting experiments to determine the variation in Loran data for both long term seasonal changes due to ground conductivity, and short term jitter from interference, man-made and natural. Shown in Figure 42 is a mobile data collection facility which can be driven along a roadway while recording Loran coordinates, odometer measured distance and time.

C.2 LORAN-C

Loran-C is a pulsed low frequency hyperbolic radionavigation system. It derives its high accuracy from time difference measurements of the pulsed signals and inherent stability of low frequency propagation over sea water. Hyperbolic [na]vigation systems operate on the principle that the difference in time of arrival

Figure 43 is a block diagram of the equipment configuration. The experiment is controlled by a Tektronix 4051 Graphic Computing System operating from a real-time BASIC program stored in 30K of RAM. Data are sampled at a four second rate on command from the Micrologic Loran receiver. All data are loaded in parallel (broad side) to a shift register whose length is sufficient to accommodate all sources simultaneously to insure accurate tracking of distance, time and Loran coordinates.

During the four second interval between sample commands the data are formatted into eight bit bytes and transmitted over the General Purpose Interface Buss to the Tektronix controller where processing and recording is accomplished before the next sample command. The data is also recorded on magnetic tape for further analysis back in the lab. The software allows the operator to control navigation system mode, data gathering, memory, inspection, and other system functions, all through the User Definable Keys. This presents a complex, advanced test system that is simple and easy to use.

C.4 DATA COLLECTION AND PRESENTATION

The New East Coast chain has three operational secondary stations, (at Caribou, Maine (1400 μsec), Carolina Beach, North Carolina (44300 μsec) and Nantucket, MA. (25000 μsec). The master is located at Seneca, NY. The two secondaries providing the optimum crossing angles, i.e. the LOP's of each station cross at nearly right angles in the Boston area are Caribou and Carolina Beach. The secondary transmitter located in Nantucket, MA. provides an exceptionally strong signal, however, it is not preferred over those stations which have good crossing angles.

Typical data is shown in Figure 44 and can be displayed in tabular form on the screen of the Tektronix controller. This allows monitoring of the results as the experiment progresses. The new East Coast Chain was used to collect this data in order to demonstrate the efficacy of this technique.

The first two columns are the time difference measurements, in microseconds, between the master station and secondary A (TDA) and secondary B (TDB).

APPENDIX D
SELECTION OF PLC TEST FREQUENCIES

INTRODUCTION

This appendix discusses the rationale behind the selection of the PLC test frequencies described in the test plan and final report as in-band/out-of-band, synchronous/asynchronous frequencies.

A. Basic Loran-C Signal Structure

All Loran-C transmitters transmit on a common frequency of 100 kHz. Transmissions from various Loran-C transmitters are time multiplexed with each transmitter sending out a burst of pulses and then remaining silent for a predetermined period. A typical transmission sequence is shown in Figure 46. First, the Master station transmits a burst of 8 pulses, separated by a 1 msec time interval, and followed 2 msec later by a 9th pulse (the 9th pulse is used for control and identification purposes). Following transmission by the Master station, the associated Secondary stations transmit bursts of 8 pulses, separated by 1 msec. As shown in the expanded view, each pulse consists of a burst of 100 kHz carrier. The shape of the pulses is carefully controlled to limit the energy of the transmitted signal to the frequency spectrum between 90 and 110 kHz, and to provide an amplitude phase relationship during the leading edge of the pulse, which will permit identification of a given cycle inside the pulse.

The transmission from each station are repeated periodically at a time interval known as the Group Repetition Interval (GRI). Typically, the GRI ranges from 60 to 100 msec, although shorter intervals are permitted.

To identify the Master transmitter and to provide a degree of immunity against skywave interference, the Loran-C pulses are phase coded. This is accomplished by shifting the phase of the pulse either 0 or π radians. unique phase code is assigned to the Master station to assist in receiver similar time of arrival measurement for a Secondary station. Prior to subtraction, the time of arrival individual measurements are averaged over successive GRI to reduce the effect of noise and interference. For example, if a GRI of .0993 seconds is considered (this corresponds to the Loran-C chain with rate 9930), and a receiver integration time of approximately 10 seconds is assumed, each time difference measurement will be the average of 100 Loran-C GRI with each interval comprised of eight individual pulse measurements for the Master and Secondary stations (an 800 pulse average for each station).

C. Definition and Description of Synchronous and Asynchronous Interference

The terms synchronous and asynchronous interference as applied to this report are defined with reference to Figure 48. Selecting one pulse in the A GRI, synchronous interference is defined as a CW signal which interferes with the same relative phase each time the selected pulse occurs in the A interval. This condition occurs when the interfering signal has an integral number of cycles between the repetitions of the selected Loran-C pulse. The uniformity with which the Loran-C pulses occur implies that a synchronous frequency for the selected A GRI pulse will be synchronous to all Loran-C pulses from either the Master or Secondaries, although the exact phase relationship may be different for each pulse in the A&B GRI. Synchronous interference, therefore, is a CW signal which adds a constant phase shift to each Loran-C pulse, and hence a constant error in the measured time difference equal to the average phase disturbance affecting all pulses in GRI A and B. Phase vector pictures for the condition of synchronous CW interference are shown below each pulse in Figure 48, on line B.

Asynchronous interference is defined as a CW signal which disturbs the phase of a selected Loran-C pulse in two adjacent A GRI in such a manner that the average phase disturbance is 0. This occurs when the phase of the interfering CW signal slips an odd number of 1/2 cycles over a period of GRI. The phase diagrams for this case are shown in Figure 48, line C.

The beat frequency at which this occurs is related to the receiver tracking bandwidth and for a receiver which has an averaging time of approximately 10 seconds, the receiver will start to reject beat frequencies when the difference between the interference and the Loran-C signal synchronous frequency exceeds .016 kHz. Frequencies which are far enough removed from synchronism not to be tracked by the receiver, and which are not asynchronous, are referred to in this report as non-synchronous interference. When the relatively small receiver tracking bandwidth ($\pm$ 016 Hz for a typical 10-second time constant) is compared to the approximate 5 Hz spacing between synchronous interference frequencies, it is seen that typical Loran-C interference will be non-synchronous except in those cases when the transmission originates from a precisely controlled communication station.

D. In-Band and Out-of-Band Interference

The shape of the Loran-C pulses is controlled such that 99% of the transmitted energy is contained in the frequency band between 90 and 110 kHz. Available Loran-C receiver bandwidths vary from relatively narrow band receivers with 18 kHz bandwidths, to wideband receivers exhibiting 40 kHz bandwidth. Typical receiver bandwidths are in the region of 24 kHz. For the purpose of this report, out-of-band interference was considered to be interference which was removed from the 100 kHz LORAN-C center frequency by $\pm$ 15 kHz or greater.

E. Selection of Test Frequencies

As demonstrated earlier, frequencies removed multiples of 5 kHz from the 100 kHz Loran-C center frequency provide synchronous interference if the assigned chain GRI is a multiple of 100 microseconds. Further frequencies which are multiples of 1 kHz will interfere with each pulse in the burst of 8 pulses from any given station with the same relative phase difference, due to the 1 msec spacing between pulses. For this reason, 95 kHz was selected as the test synchronous CW interference frequency, as it provided ...t only constant but identical phase disturbance of all Loran-C pulses ...ived from a given station.

APPENDIX E

REFERENCES

1. LORAN-C User Handbook #CG462 DOT/Coast Guard, August 1974.
2. Operator's Manual ML-200 Micrologic, Inc., Chatsworth, CA, September 1977.
3. 4051 Graphic System Reference Manual, Tektronix, Beaverton, Oregon, January 1976.
4. American Practical Navigator, Bowditch, Defense Mapping Agency, 1977.

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