Cataloged

Report No. FAA-RD-74-69, II

INVESTIGATIONS TO PROVIDE IMPROVED GLIDE SLOPE OPERATION DURING PERIODS OF GROUND-PLANE SNOW COVER

Volume II - Details of 1972-1973 Investigations

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APRIL 1974

INTERIM REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-74-69, II		

4. Title and Subtitle	5. Report Date
INVESTIGATIONS TO PROVIDE IMPROVED GLIDE SLOPE OPERATION DURING PERIODS OF GROUND-PLANE SNOW COVER Volume II - Details of 1972-1973 Investigations	April, 1974
	6. Performing Organization Code
7. Author(s) J. J. Battistelli, R. H. McFarland	8. Performing Organization Report No. EER 5-18
9. Performing Organization Name and Address Avionics Engineering Center, Department of Electrical Engineering, Ohio University, Athens, Ohio 45701	10. Work Unit No. TRAIS 14668
	11. Contract or Grant No. DOT-FA69WA-2066-Mod 17
12. Sponsoring Agency Name and Address Department of Transportation, Federal Aviation Administration, Systems Research and Development Service, Washington, D. C. 20590	13. Type of Report and Period Covered Final Report 1972-73 Covers Modification 17 of Above Contract Only
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The results of the 1972-73 Ohio University Snow Data Collection program for investigating the effects of ground-plane snow covers on image glide slopes are presented. This investigation involved the most extensive instrumentation to date for gathering continuous, detailed information on glide slope performance in both the near and far-fields.

Experimental results were consistent with theory previously developed and provide a basis for some useful conclusions and recommendations, viz, effects of snow depth less than ten inches are not significant in terms of far-field performance. However, conventional near-field monitors may produce out-of-tolerance indications. Integral monitoring is found to provide excellent service and may be regarded as highly reliable and representative for depths up to at least 10 inches. For greater depths no conclusive, consistent data is yet available.

17. Key Words	18. Distribution Statement
Image glide path Environmental test Snow	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	58	

Form DOT F 1700.7 (8-69)

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I. SUMMARY

The results of the 1972-73 Ohio University Snow Data Collection program for investigating the effects of ground-plane snow covers on image glide slopes are presented. This investigation involved the most extensive instrumentation to date for gathering continuous, detailed information on glide slope performance in both the near and far-fields.

Experimental results were consistent with theory previously developed and provide a basis for some useful conclusions and recommendations, viz, effects of snow depth less than ten inches are not significant in terms of far-field performance. However, conventional near-field monitors may produce out-of-tolerance indications. Integral monitoring is found to provide excellent service and may be regarded as highly reliable and representative for depths up to at least 10 inches. For greater depths no conclusive, consistent data is yet available.

II. INTRODUCTION AND GENERAL DISCUSSION

In order to gain confidence in theoretical predictions and provide the maximum possible validity for recommendations that are directed towards minimizing image glide slope snow outages, it is necessary to have extensive experimental evidence. Acquisition of such evidence is most always time consuming, expensive and painfully difficult to obtain. Nature does not always cooperate in providing snow covers when the instrumentation is available to make complete sets of measurements. One of the most important dependent variables to measure is the path width and position in space. Tall towers do not intersect operating glide slope structures for obvious reasons and aircraft properly instrumented with ground tracking facilities are not commonly available. Such factors have insured that there will always be a paucity of data available.

Special sites with tall towers, special flights to sites of known snow problems, and special recording installations at commissioned facilities have been techniques used to increase the quantity of data. Cooperation by other organizations such as the Department of Transport in Canada and Michigan Technological University in Houghton, Michigan, have been available to increase information on snow effects. Much has been learned over the past years to permit the foregoing recommendations to be made. Special emphasis is given in this report to previously unpublished data obtained during the past winter (1972-73) at the Ohio University Snow Site 20 miles ENE of Muskegon and 40 miles NNW of Grand Rapids, Michigan.

Null-reference, capture-effect, and sideband-reference glide-slope systems were implemented and monitored in the far-field through the use of a 900-foot television transmitting tower upon which receiving probes were mounted at elevation angles of 3.0° and 2.3° as viewed from the glide-slope site. See Figures 1, 2, 3.

In addition to the far-field course and width monitors, conventional near-field monitoring was installed. The near-field monitors included path and width for the null-reference system at the 180° phase point, and path for the capture-effect system. See Figures 1, 4, 5.

An integral monitor was installed on the capture-effect and null-reference glide slope systems to obtain reference measurements independent of the ground plane and to provide an environment-free reference for data reduction. Additional data was obtained on the effects of the environment on the integral monitor. [1]

The far-field probe readings were verified by Ohio University flight checks using standard radio theodolite techniques. Results confirmed that the path structures were normal and that the far-field probes are an accurate measurement of the signal-in-space. See Table 1.

Contractual approval to implement the snow site was received on October 24, 1972, and data was obtained from November 16, 1972, through March 22, 1973. There was no data taken from the time period November 27 through December 4, 1972. The system was shutdown for maintenance, installation of near-field monitors and flight checking of the systems. The site was again shutdown from December 13 through December 18, 1972, to install automatic recording and switching circuitry. The period December 28 through December 30, 1972, was used to service the recording equipment. The period January 9 through January 11, 1973, was used to recalibrate all systems. On March 5,6, and 10 through 15 all systems were recalibrated. The system was finally shutdown on March 21, 1973.

III. THE 1972-1973 MICHIGAN FIELD EXPERIMENTS

A. Signal Format

From experience in operating the TU-7X transmitters the previous year and from conversations with NAFEC personnel who had used them prior to shipment to Ohio University, it was clear that transmitter instabilities would preclude resolution of path parameters to less than 7 microamperes unless frequent calibrations were made. It

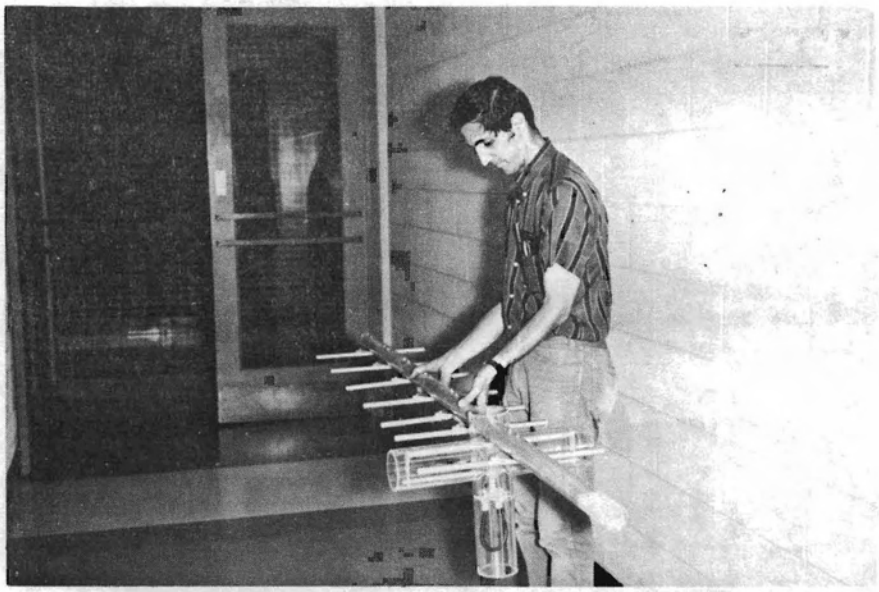


Figure 1. Antenna Probe.

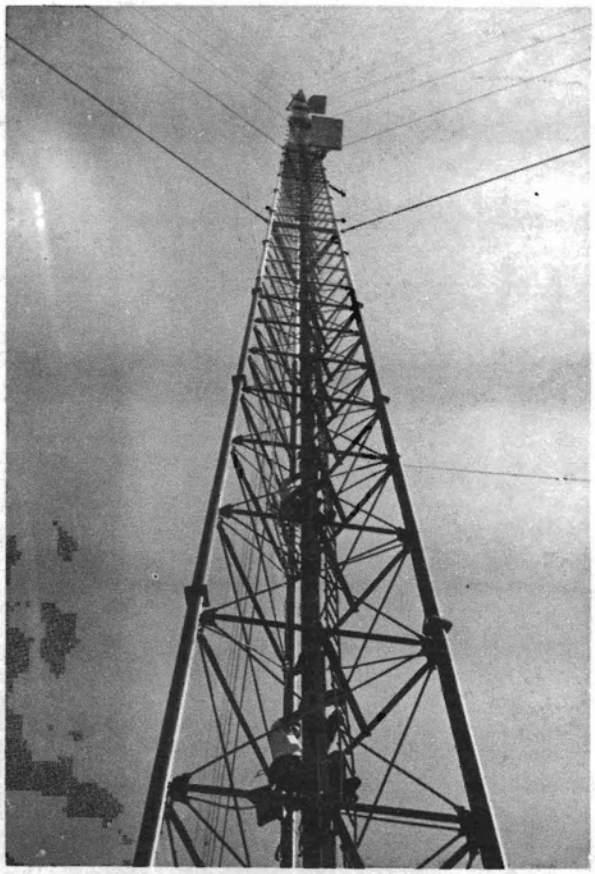


Figure 2. Two Such Antenna Probes Mounted on the 900-Foot WZZM-TV Tower Shown.

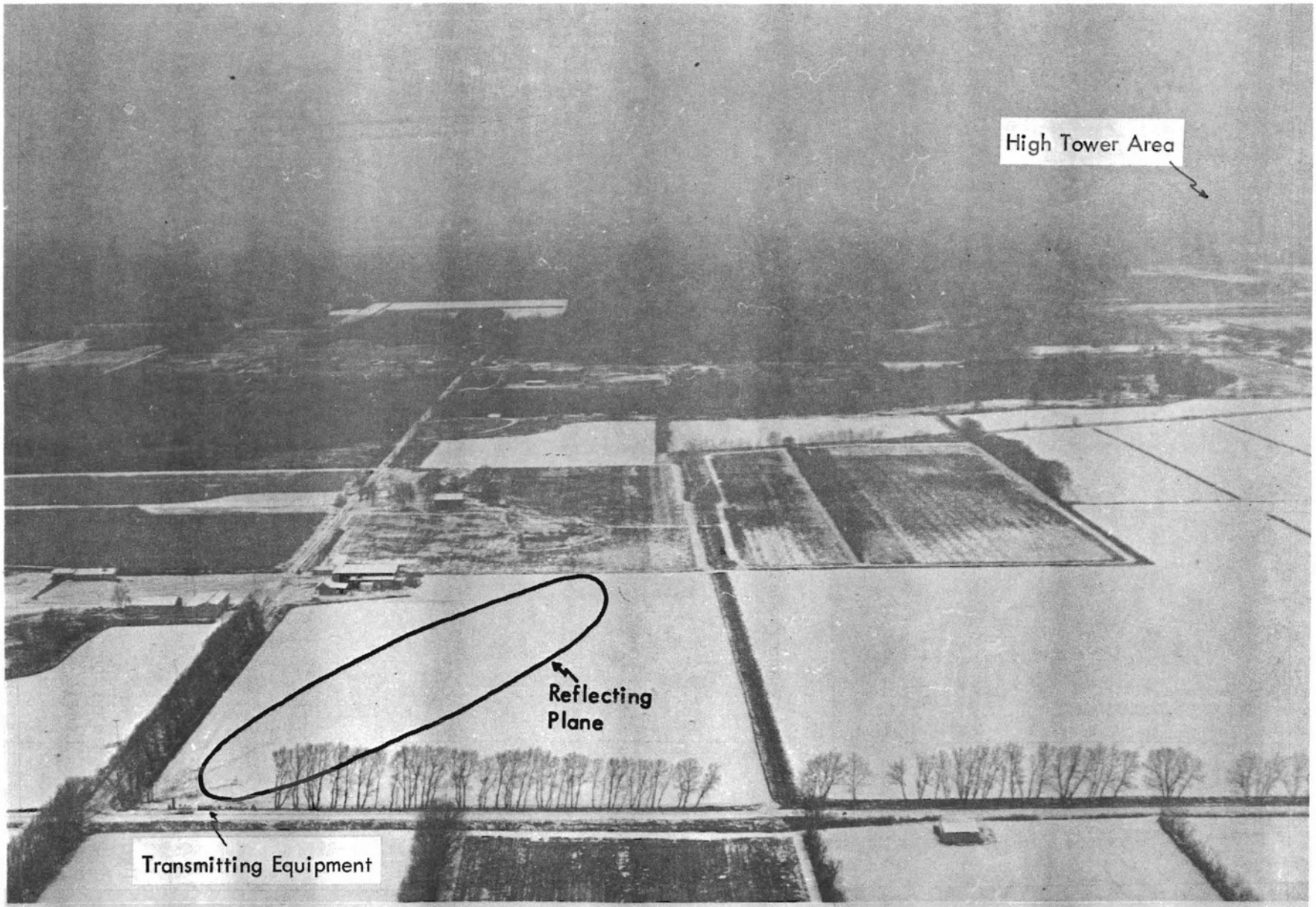


Figure 3. Ohio University Glide-Slope, Snow-Monitoring Site Looking North, Ravenna, Michigan.

Figure 4. Capture Effect and Null Reference Array with Near-Field Monitors Shown.

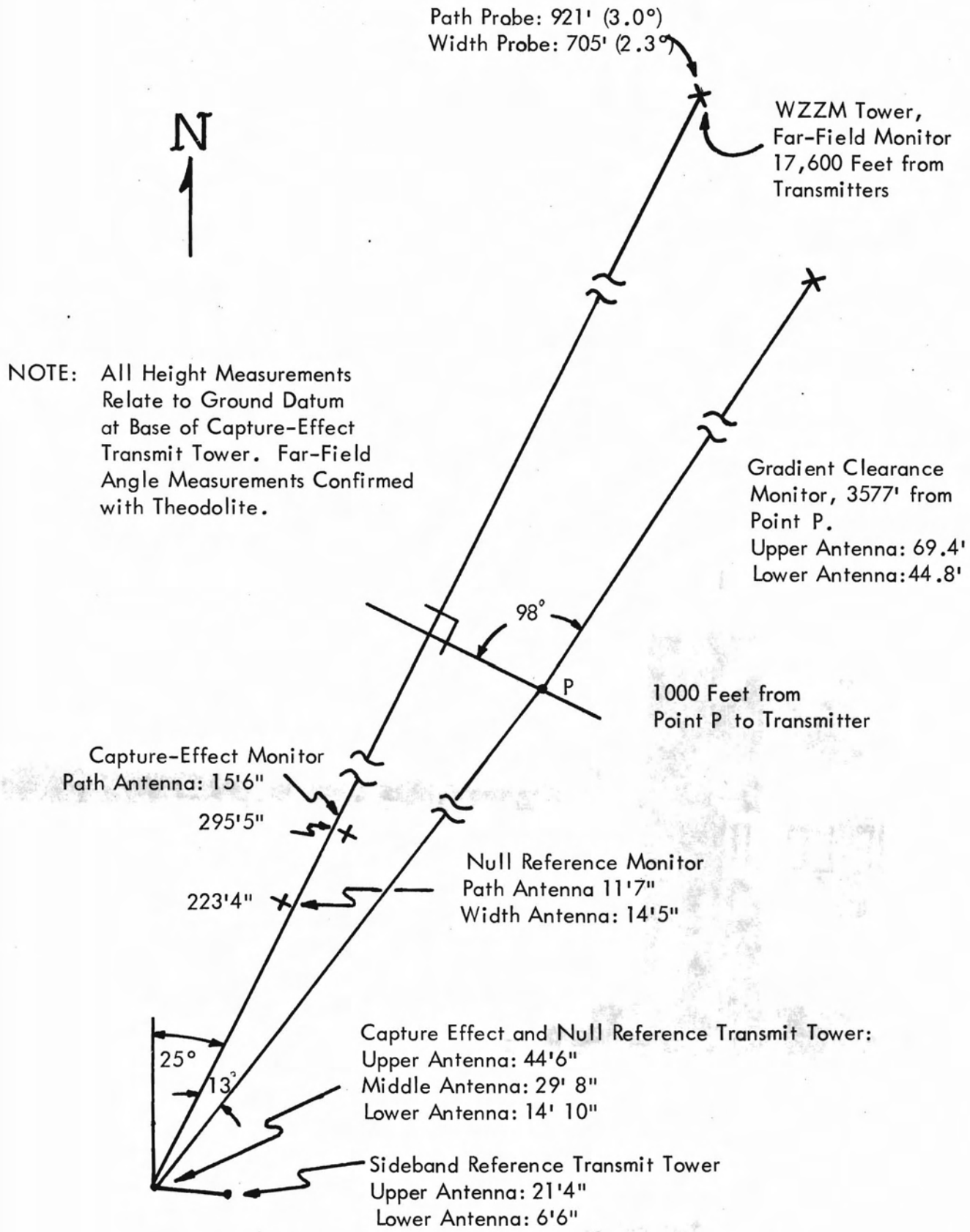


Figure 5. Antenna Locations.

PATH

	Angle Measured to Aircraft when Aircraft Receiver at 0 μa	Far-Field Monitor Reading in μa	Far-Field Probe Position Determined by Difference between Angle to Aircraft and Angle Equivalent of Far-Field Monitor Reading (2) (3)
Null Reference	2.98°	-0.5	2.98
Capture Effect	3.00°	-10.0	2.96
Sideband Reference	3.01°	0.0	3.01
Angle Measured to Probe Using the Theodolite	----	----	2.98

WIDTH

	Angle Measured to Aircraft when Aircraft Receiver at 150 μa	Far-Field Monitor Reading in μa	Far-Field Probe Position Determined by Difference between Angle to Aircraft and Angle Equivalent of Far-Field Monitor Reading (2) (3)
Null Reference	2.22°	+130	2.31
Capture Effect	2.24°	+130	2.33
Sideband Reference	2.26°	+140	2.31
Angle Measured to Probe Using the Theodolite	----	----	2.28

(1) Poor Tracking Conditions Necessited Calculation Based on 75 μa Point for Null Reference and Capture Effect. 150 μa Point Used for Sideband Reference, However.
(2) 1 μa = 0.00467°
(3) Comparison of Probe Position by Flight Test and by Direct Theodolite Measurement Within ± 0.02° Accuracy of Theodolite.

Table 1. Snow Site Flight Test, 2 Dec. 1972, Aircraft 2179D.

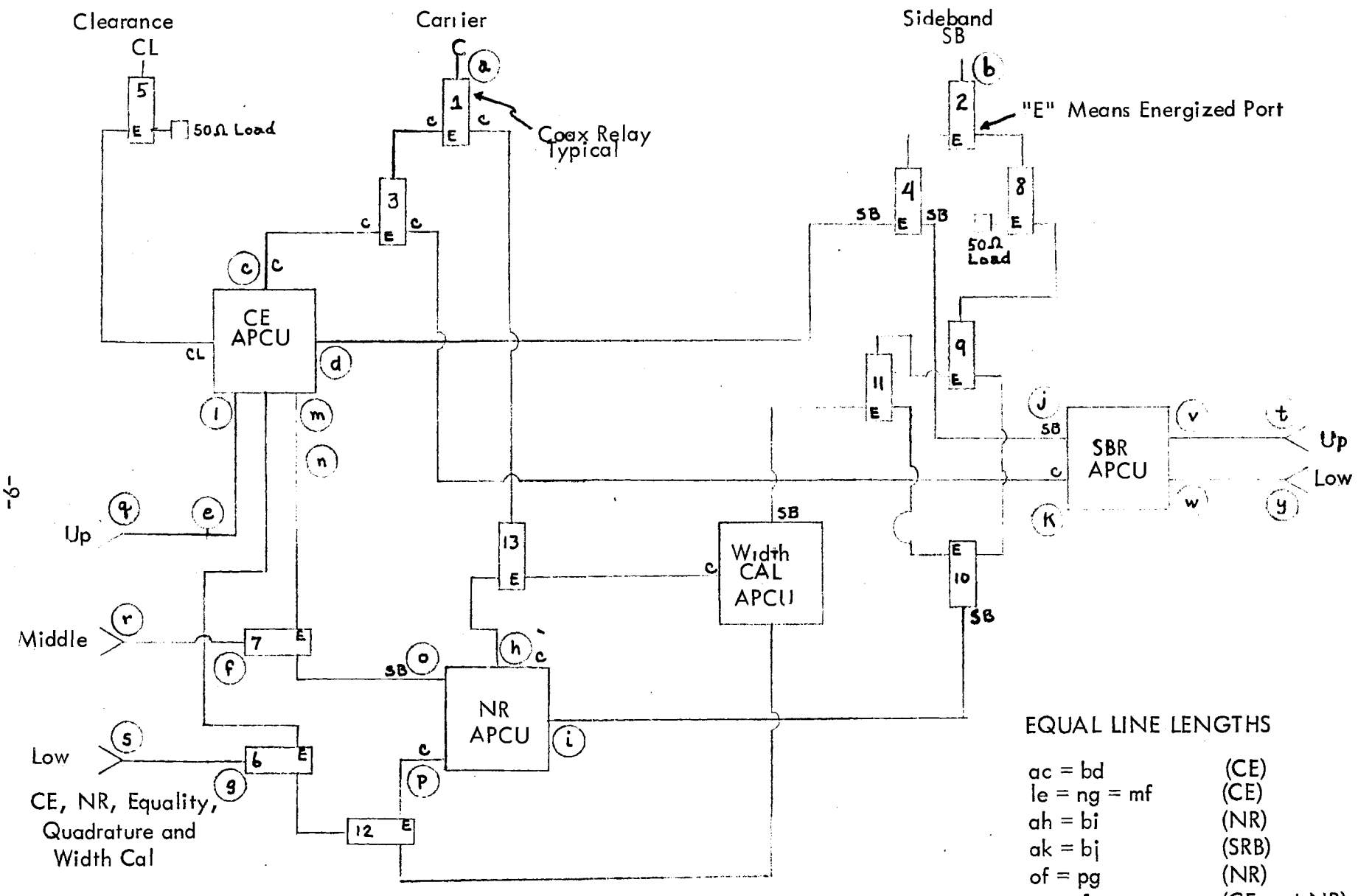
was decided to implement an automatic calibration capability to enable transmitter and instrumentation effects to be processed out of the data. In addition to the calibration signals, there were of course, the three types of glide path signals, viz, null reference, capture effect and sideband reference on a continual basis.

A basic time period of 40 minutes or 2400 seconds was established. This period was divided equally into six segments A through F, each 400 seconds in duration. A sequencer was designed and built to provide cycling of a coaxial relay network (Figure 6) to give the following signals in each segment.

SEGMENT	SIGNAL TRANSMITTED
A	Nominal Null Reference Glide Slope
B	Nominal Capture Effect Glide Slope
C	Nominal Sideband Reference Glide Slope and Sideband with Equal 90/150 Modulation
D	Equality; Carrier Energy (CSB) Radiated from Lower Antenna of Three Element Array
E	Width Calibration; Carrier Combined with Sideband Energy and Radiated from the Lower Element of the Three Element Array. This yielded unbalanced 90/150 Hz Modulation 0.175 DDM (150 μa) with 150 Hz Predominant.
F	Quadrature Null Reference Glide Slope System with Sideband Energy Shifted 90° from the Carrier

With the calibration signals, changes in the transmitting system parameters may be detected and accounted for in the data reduction system. Identical parameters were recorded for the integral monitor with the exception that no integral monitor was implemented for the sideband-reference system. With omni-directionally consistent information transmitted, a cross-check on all receiver and detector calibrations could be maintained.

The near-field data for path and width of the null-reference glide slope and the path for the capture-effect system were continually recorded. Environmental data was recorded throughout the time period and included snow depth, snow density, water content, temperature of the snow layer, air temperature and wind conditions.



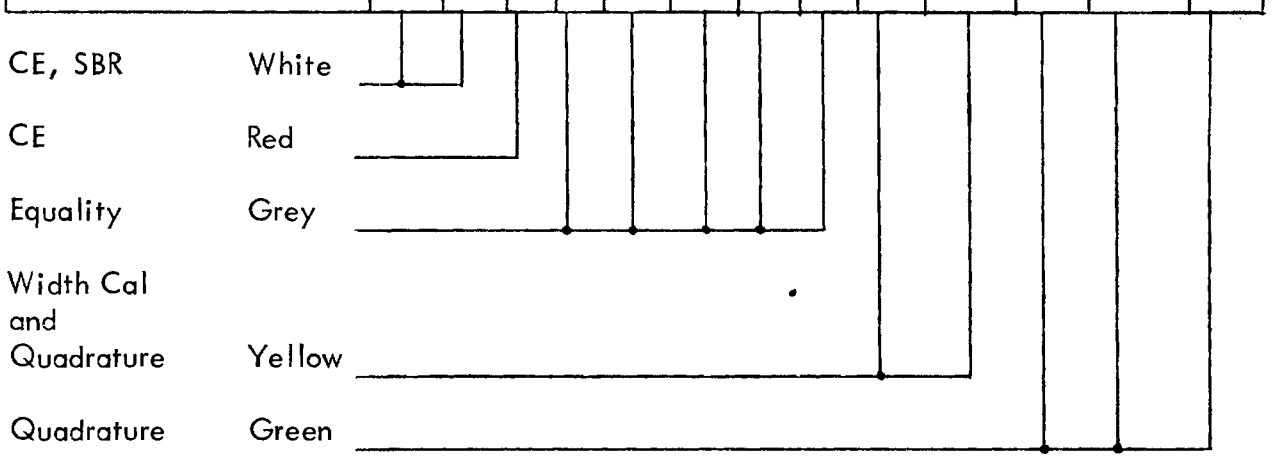
EQUAL LINE LENGTHS

ac = bd	(CE)
le = ng = mf	(CE)
ah = bi	(NR)
ak = bj	(SRB)
of = pg	(NR)
eq = fr = gs	(CE and NR)
vt = wy	(SBR)

Figure 6. Snow Site RF Switchover Network.

NOTE: See Table 2 for Relay Control.

Relay Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Capture Effect	1	1	1	1	1	1	1						
Sideband Reference	1	1	0	0	0								
Equality (Zero Cal)	0	0			0	0		1				0	0
Width Cal	0	0			0	0		0	1		1	1	1
Quadrature	0	0			0	0	0	0	1	1	0	0	0
Null Reference	0	0			0	0	0	0	0	0		0	0



NOTES:

1. "1" Is Energized Position of Relays, "0" Is De-energized, Blank is Either.
2. Each Signal Is on for 400 Seconds.
3. Lines Indicate Relays in Parallel

Table 2. Snow Site Switchover Relay Control.

B. Data Collection

Parallel Honeywell Electronic 17 dual channel recorders were used at each data collection location (far-field, near-field and integral monitors). A special buffer amplifier was fabricated to insure signal stability, to provide internal recorder calibration and to accommodate the wide range of input signal levels. The wide range of input signal levels was due to the external calibration signals which were radiated. For instance, the far-field path is normally around 0 microampere. To achieve a one-microampere resolution, full scale on the recorder was set at 50 microamperes. A radiated width calibration signal of 150 microamperes would obviously peg the recorder pen. To alleviate this problem a comparator was built into the buffer amplifier which upon sensing an input signal greater than 50 microamperes would change the recorder offset and sensitivity to accommodate the width calibration signal. Similar circuitry was used for the width channel to accommodate the radiated equality (0 microampere) calibration signal.

To insure accuracy of the data, provisions were made to calibrate manually the recording systems twice daily. The internal calibration on the buffer amplifier was used for this purpose. Receivers were calibrated manually approximately every other day with a Boonton 232 signal generator. The radiated equality and width calibration signals provided a means of monitoring receiver performance. This served as an alert for test personnel to replace a receiver that was deteriorating. Equipment at each of the three different physical locations was checked at least twice daily.

C. Data Processing

Data processing was accomplished using the IBM 360 computer. Raw data from the stripchart recordings was punched on IBM cards. For each basic time period, 24 pieces of information were compiled. This included null reference, capture effect, sideband reference, equality, width calibration and quadrature signals for both the path and width for both far-field and integral monitor locations. The total number of data inputs was in excess of 8000.

The transmission of two control signals, equality (0 microampere) and width calibration (150 microamperes), enabled normalizing of all recorded data using the computer. The normalizing was done in accordance with the equation:

$$\text{Data}_{\text{Normalized}} \quad \frac{\text{(Raw Data Value - Equality Value)}}{\text{Width Calibration Value - Equality Value}} \times 150$$

This process takes instrumentation error out of the data and allows meaningful quantitative comparisons to be made between the far-field and integral monitor data. All receiver/recorder systems are thus put on a common basis with the equality value negating offset errors and the width calibration value negating proportional errors. The offsets and proportional errors are taken care of regardless of whether they occur in the transmitter, receiver, or recorder subsystems.

The normalized data was further processed on the IBM 360/44 computer for mean, standard deviation, and correlation coefficients with respect to snow depth. The following paragraphs discuss observations of the normalized data on a per month basis.

D. Review of System Conditions on a Monthly Basis

1. NOVEMBER DATA (See Figures 7 through 12). With the exception of a 4-inch snow on November 17 and a 2-inch snow on November 26, each melting within 24 hours, no snow covers existed during the month of November. Because of the late start in setting up the facility, this condition was rather welcome as it permitted check-out and gathering of base-line information.

During the first day of the shake-down period a step displacement of 20 microamperes* occurred in the integral monitor width channel, otherwise all values recorded remained reasonably constant. Standard deviations of less than 6 microamperes were obtained for the far-field path indications and this is consistent with the known characteristics of the TU-7X transmitters.

2. DECEMBER DATA (See Figures 13 through 18). Just as November could be characterized as a no-snow month, December proved to be a month of almost continuous snow cover with the snow depth ranging from 1/2 inch to 10 inches, then decreasing to one inch.

The systems were shutdown from December 1 through December 4 for finalizing installation of the near-field monitors, flight check of the glide-slope systems and recalibration of the integral monitors. The data for all systems remained essentially constant as the snow depth steadily increased. On December 13 the systems were again shutdown to install automatic calibration equipment. The snow depth at shutdown was 5 1/2 inches. When data on the systems again became available, the snow depth was 9 inches. All system parameters were normal with the exception of the sideband reference far-field width. See Figure 16. On December 19, the width probe for the sideband reference system read 230 microamperes. Unfortunately this was the first data available after system adjustment and the width data was extremely noisy. On December 23 with a snow depth of 5 inches the width probe recorded 183 microamperes.

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* Microamperes are units of current in the standard course deviation instrument calibrated to 150 microamperes equalling 0.7 degree elevation angle.

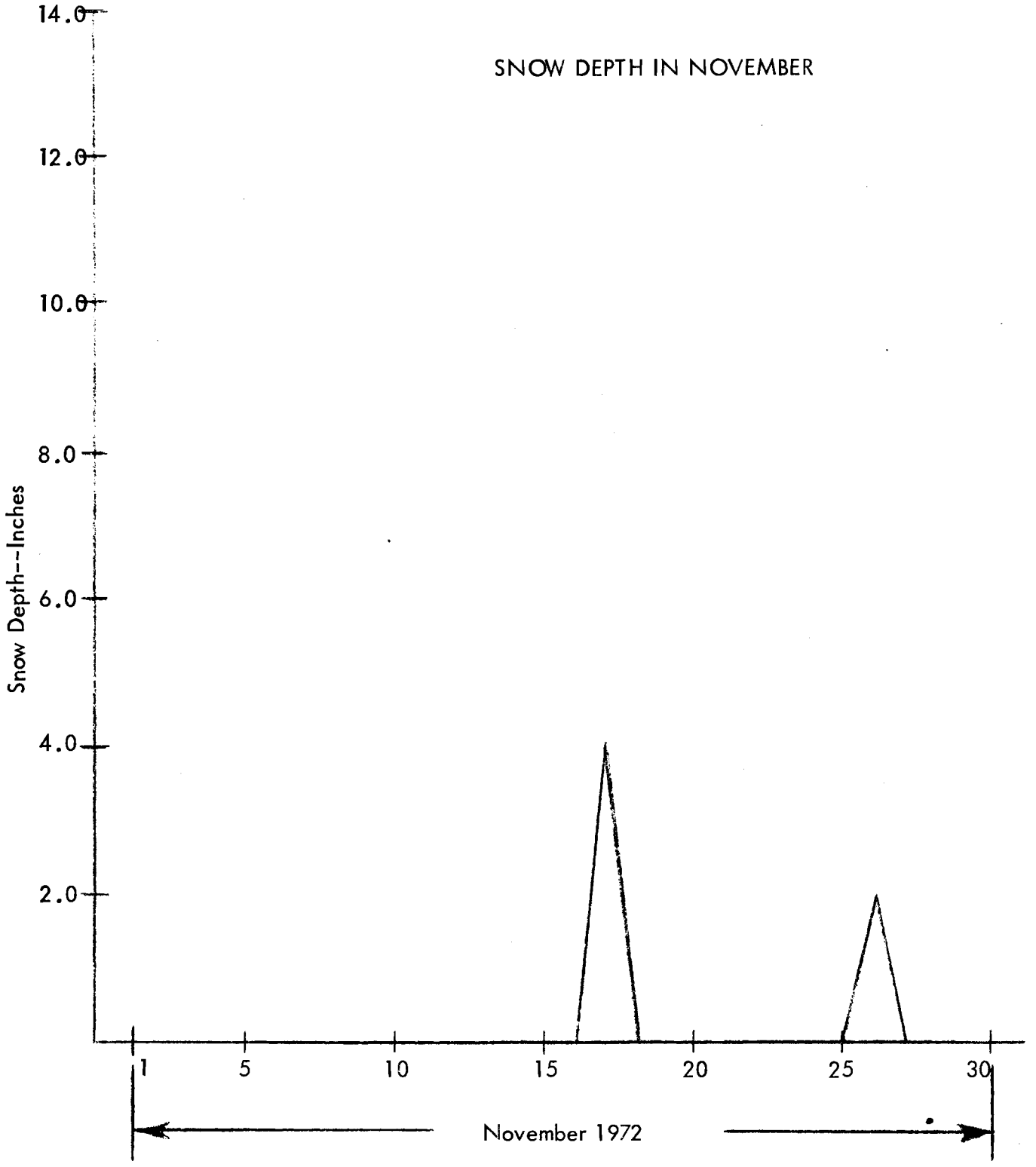

Figure 7. Snow Depth in November 1972.

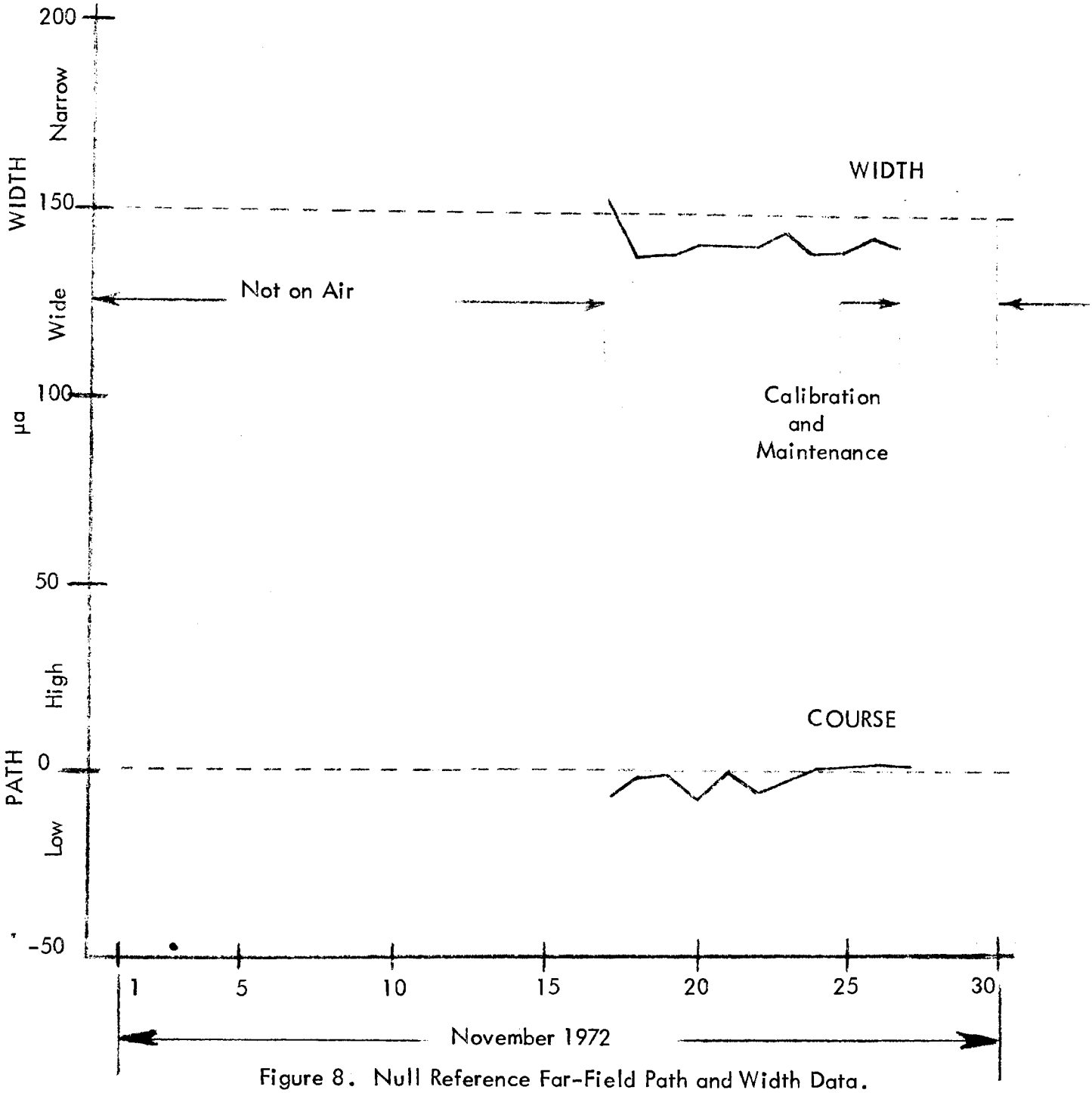

Figure 8. Null Reference Far-Field Path and Width Data.

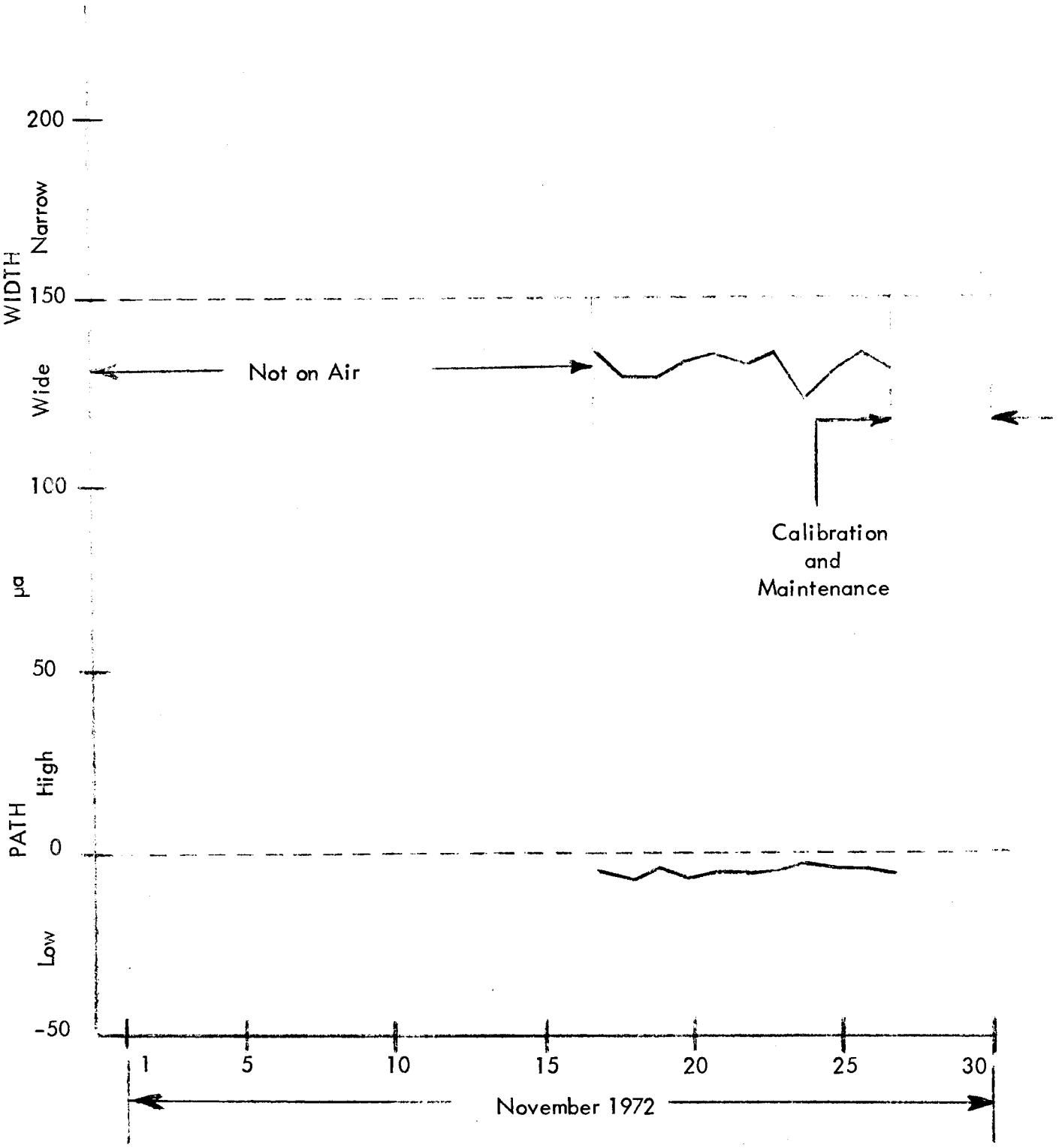

Figure 9. Capture Effect Path and Width Data.

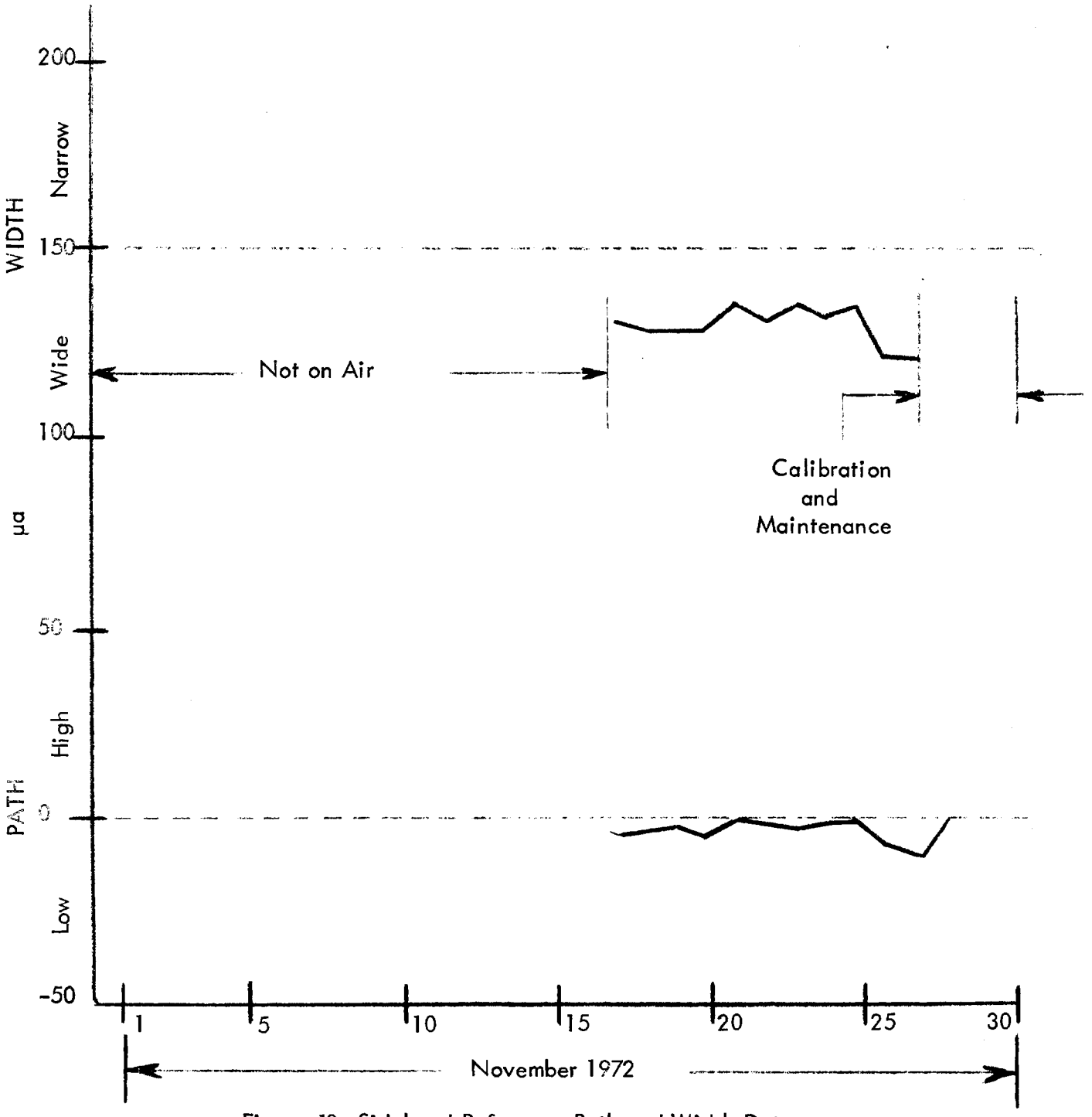

Figure 10. Sideband Reference Path and Width Data.

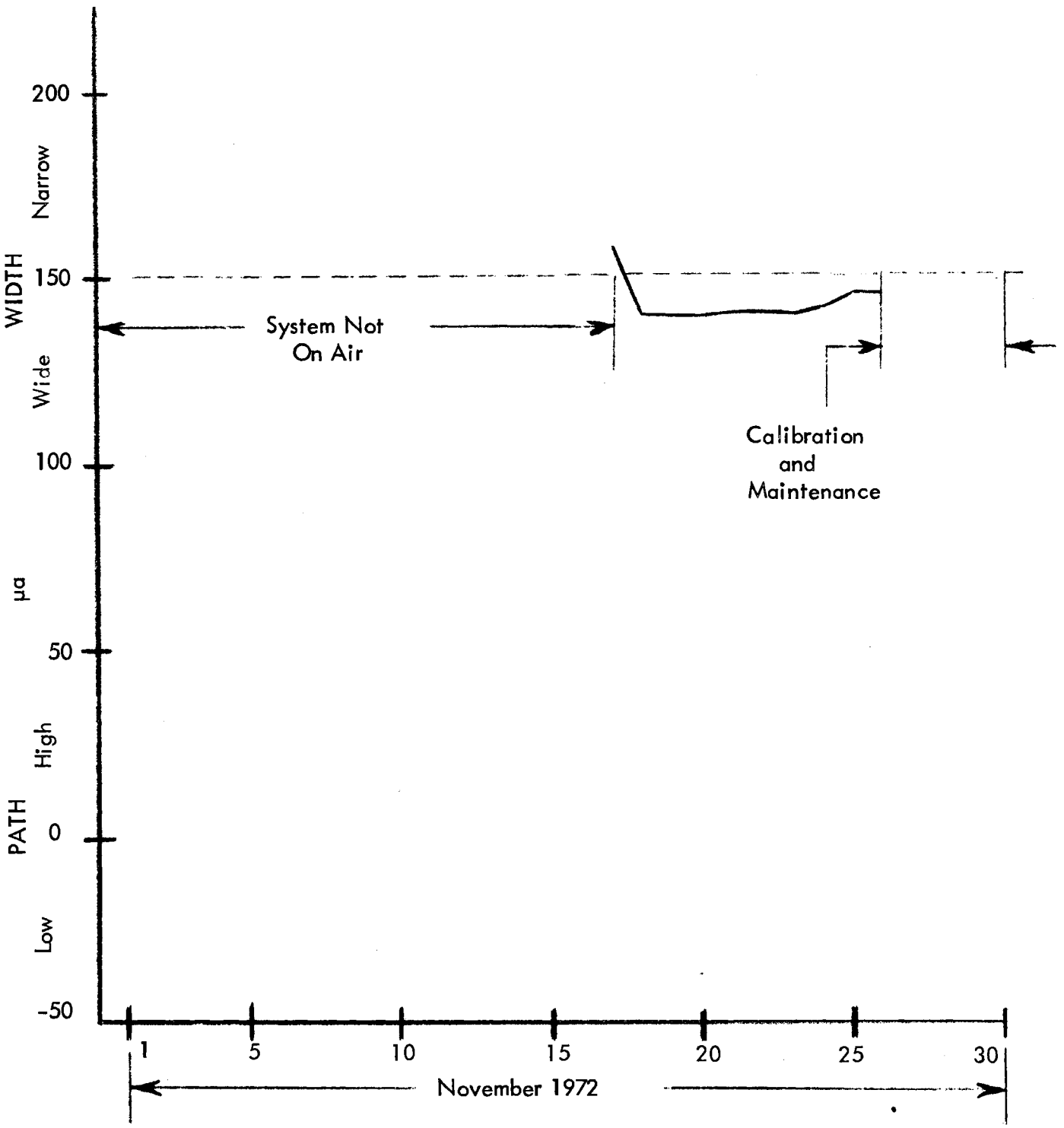

Figure 11. Integral Monitor Width Data--Null Reference.

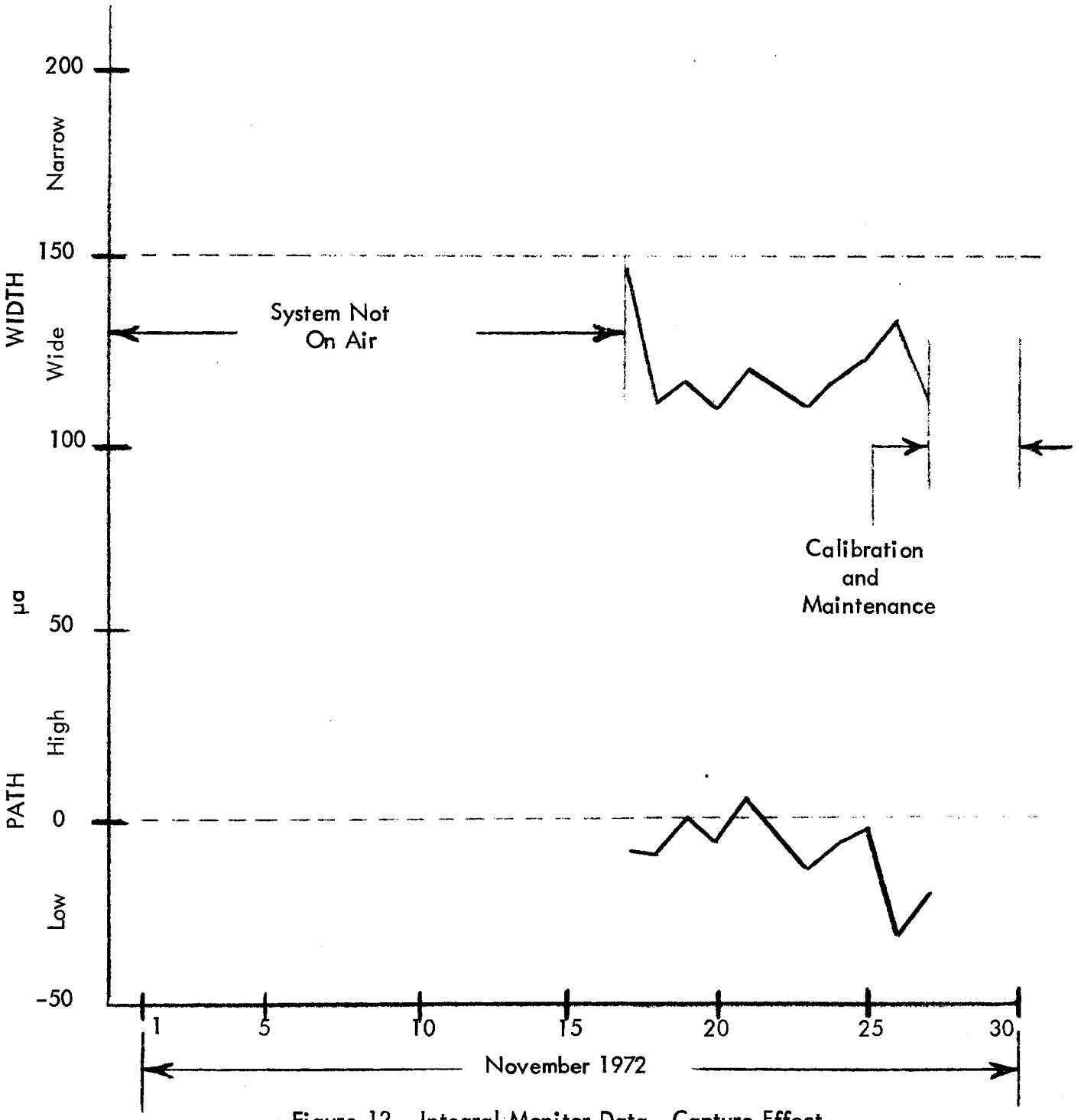

Figure 12. Integral Monitor Data--Capture Effect.

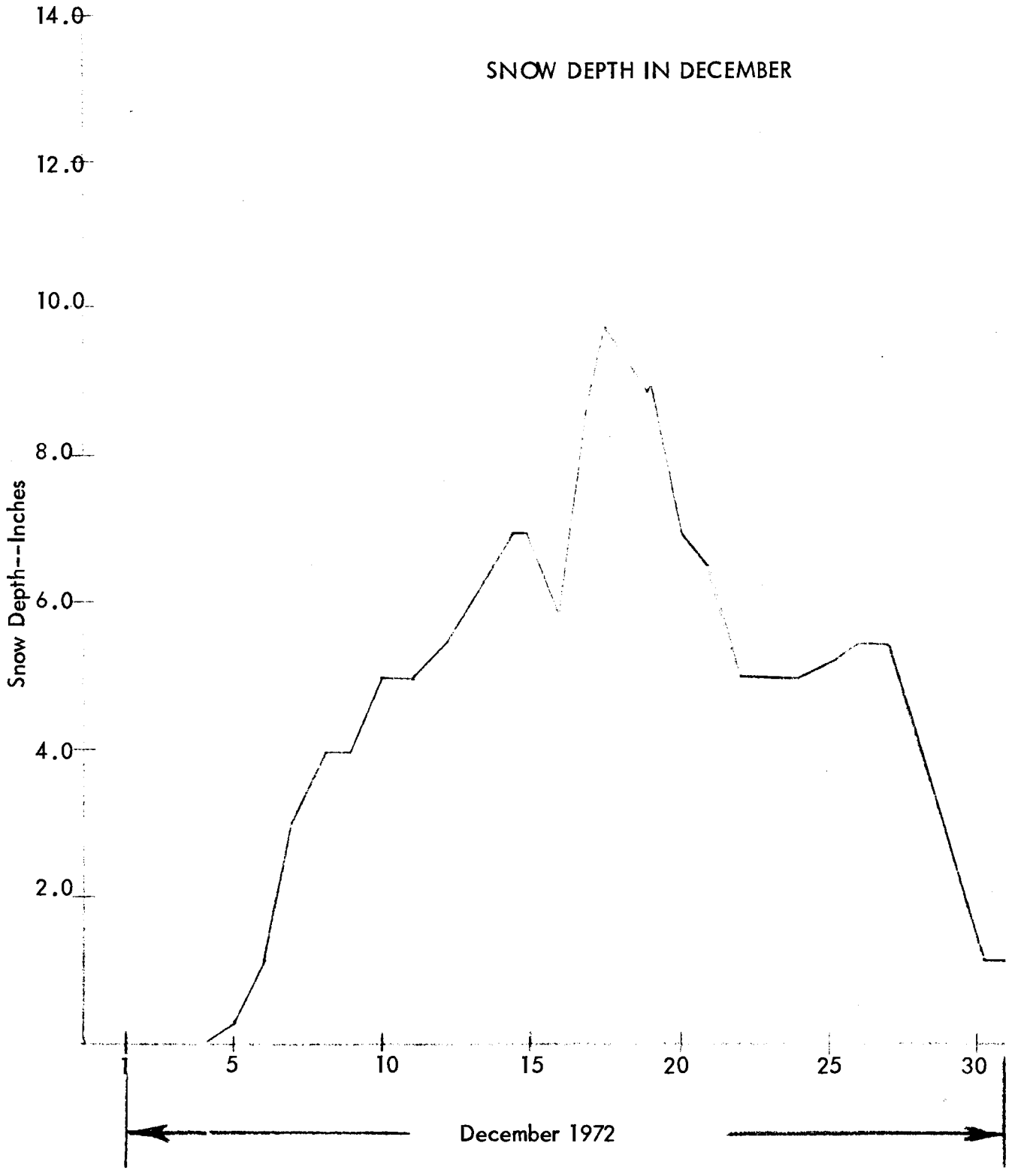

Figure 13. Snow Depth in December 1972.

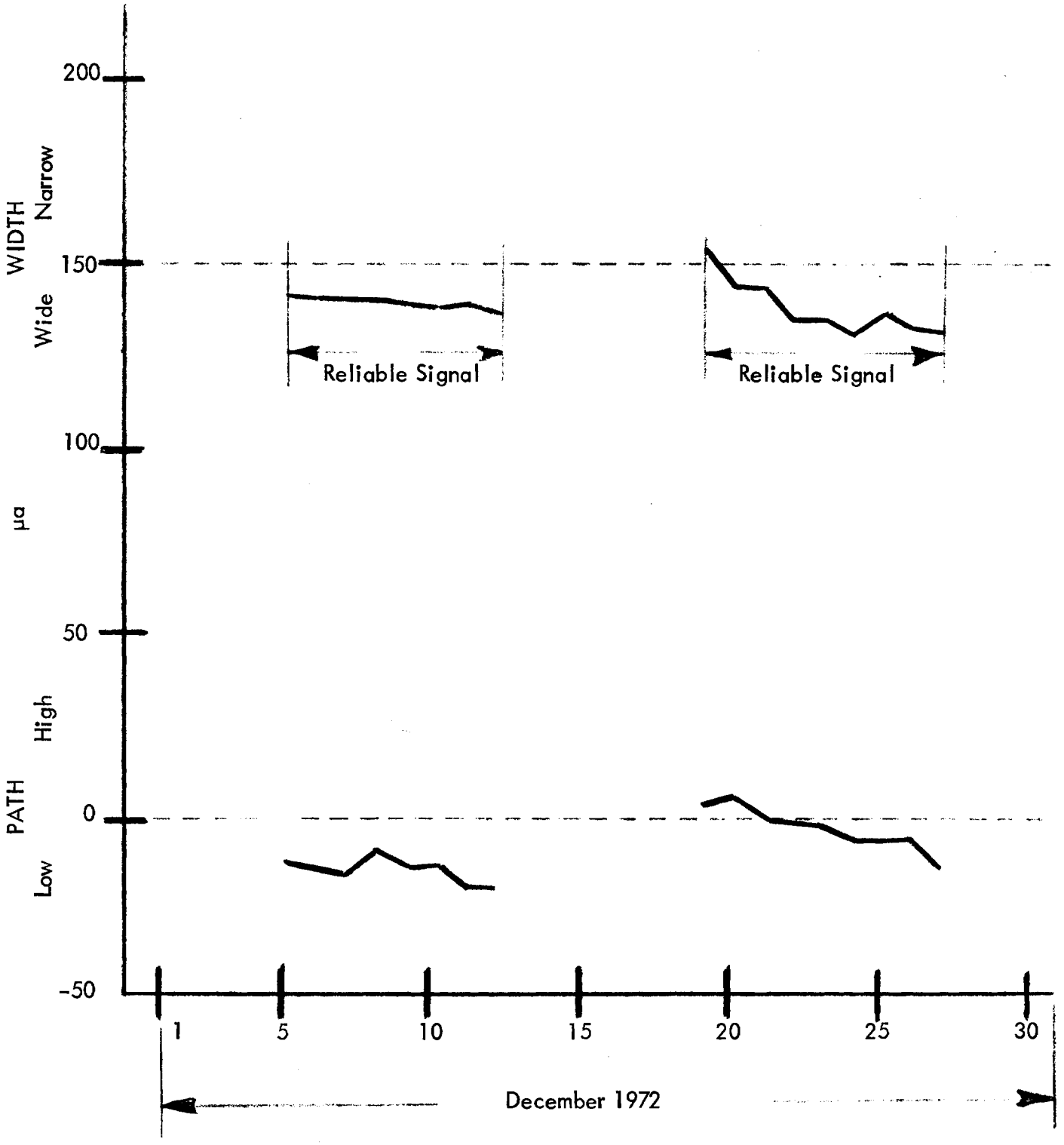

Figure 14. Null Reference Path and Width Data.

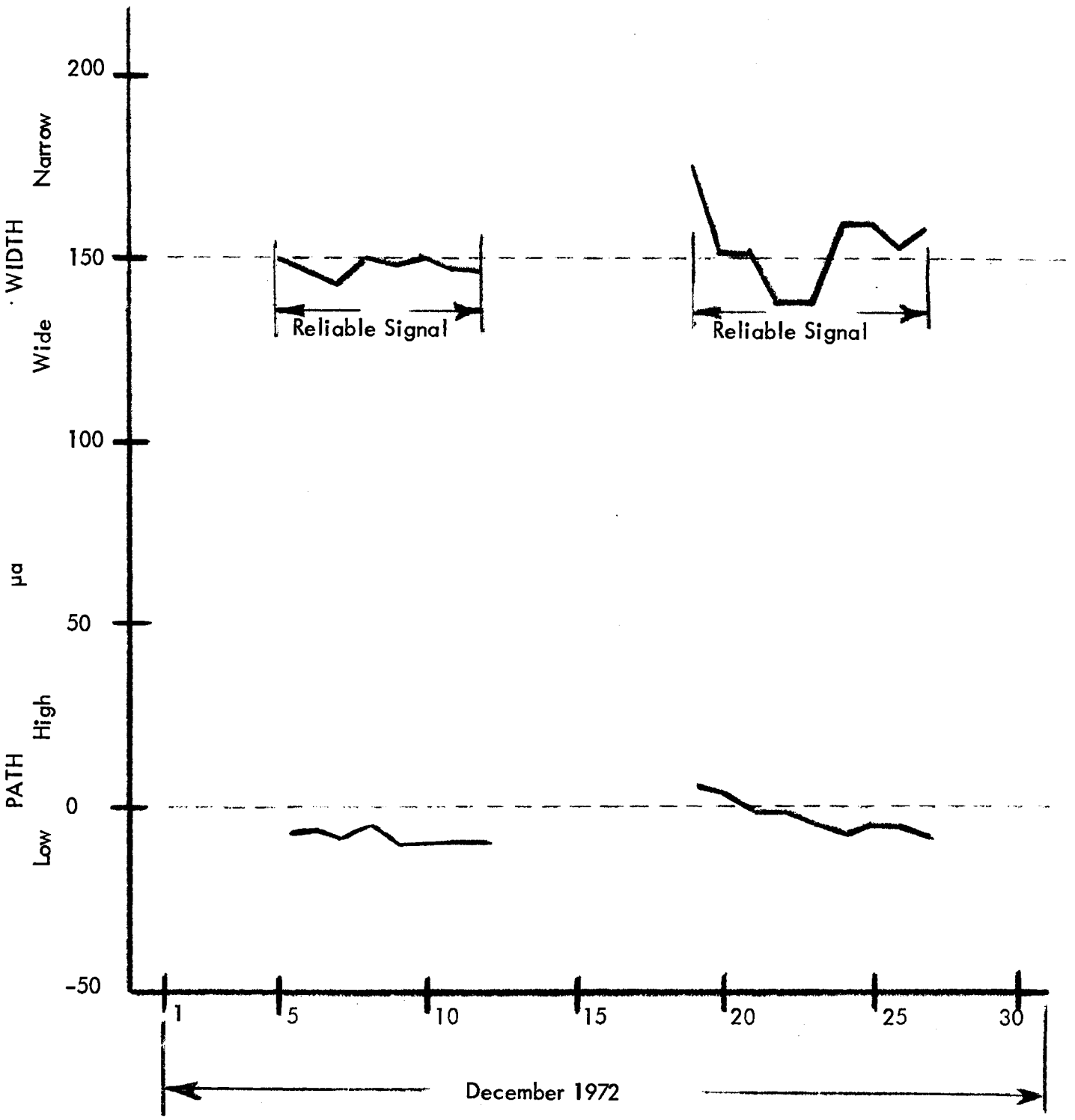

Figure 15. Capture Effect Path and Width Data.

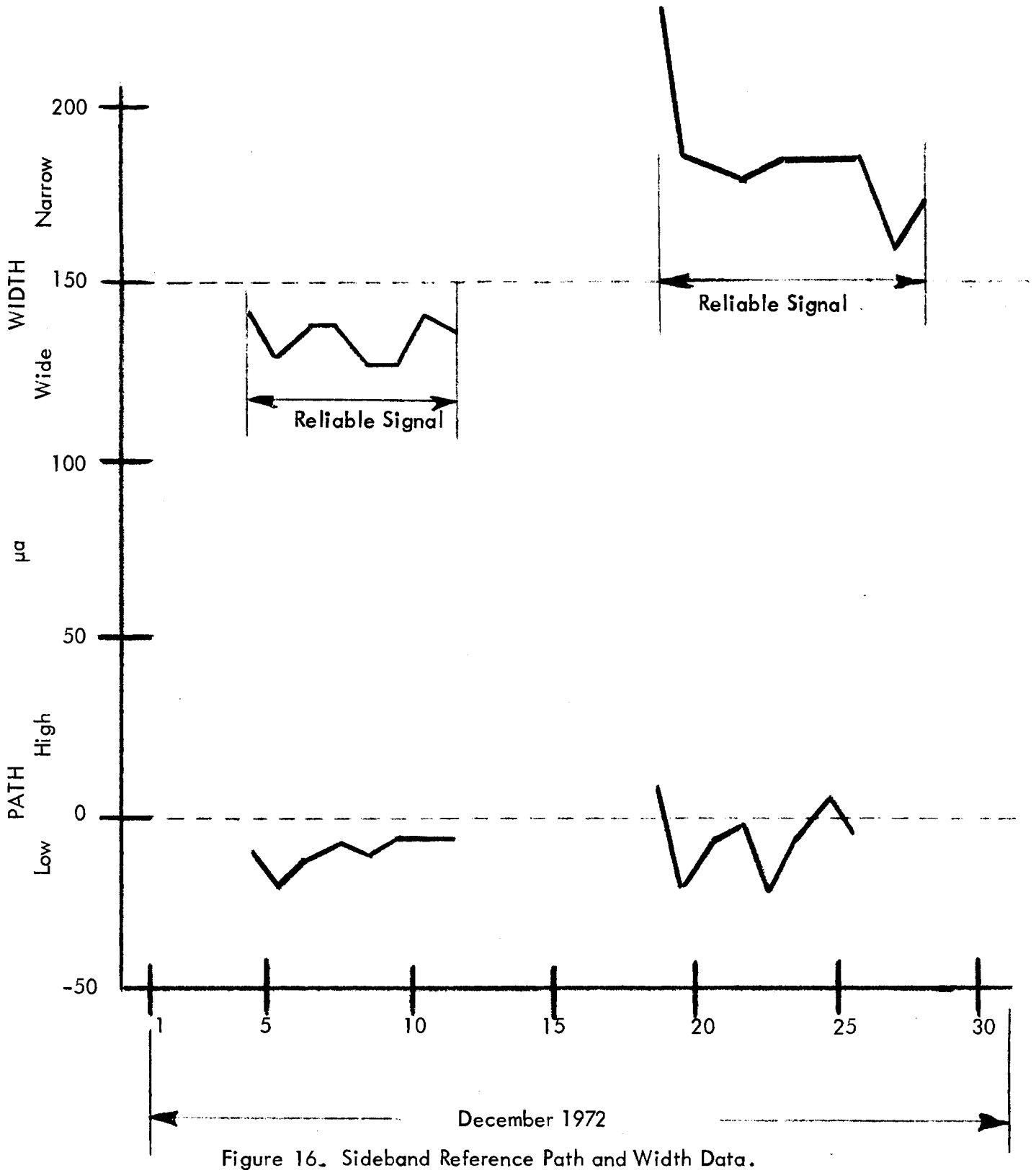

Figure 16. Sideband Reference Path and Width Data.

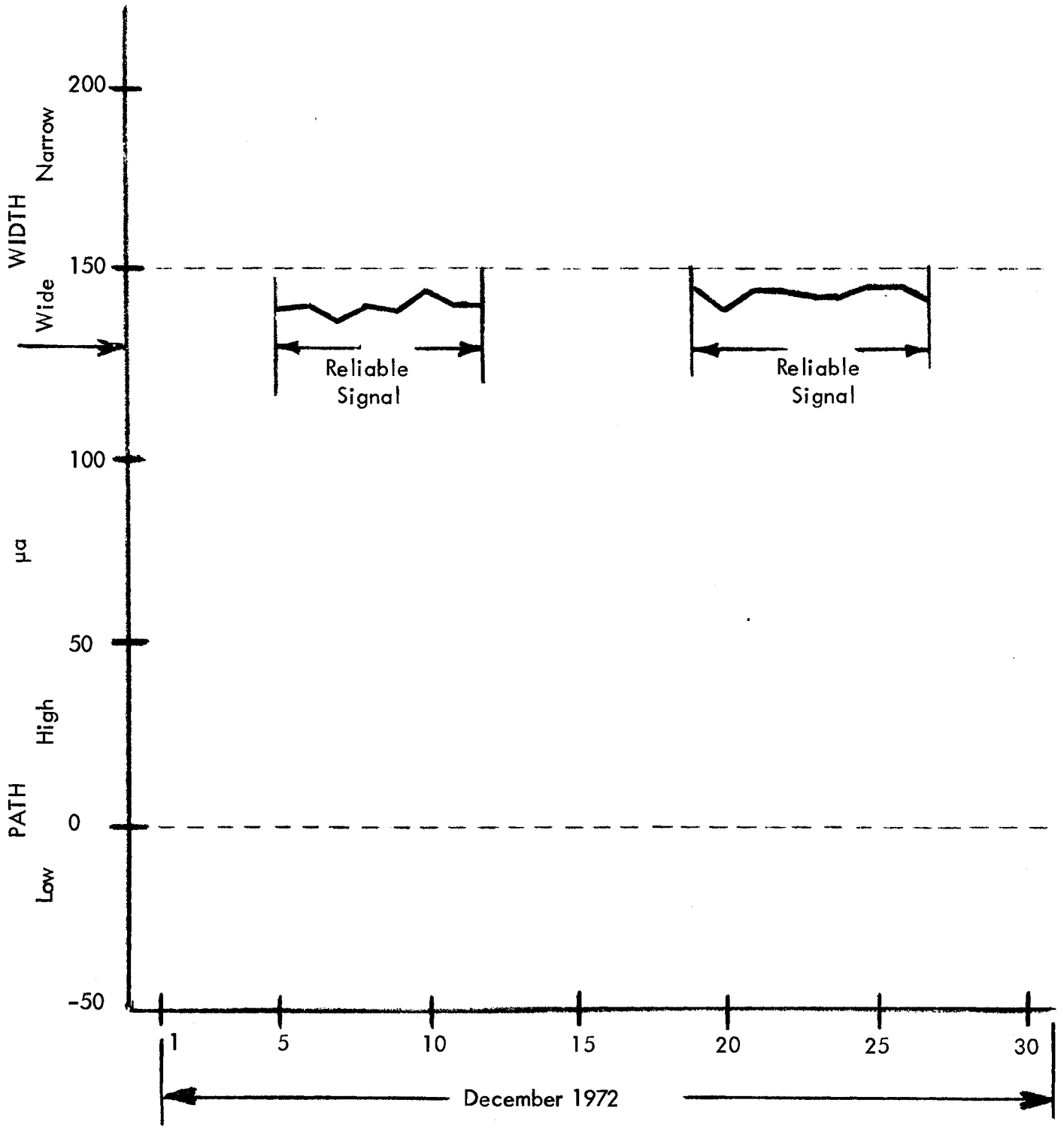

Figure 17. Integral Monitor Width Data--Null Reference.

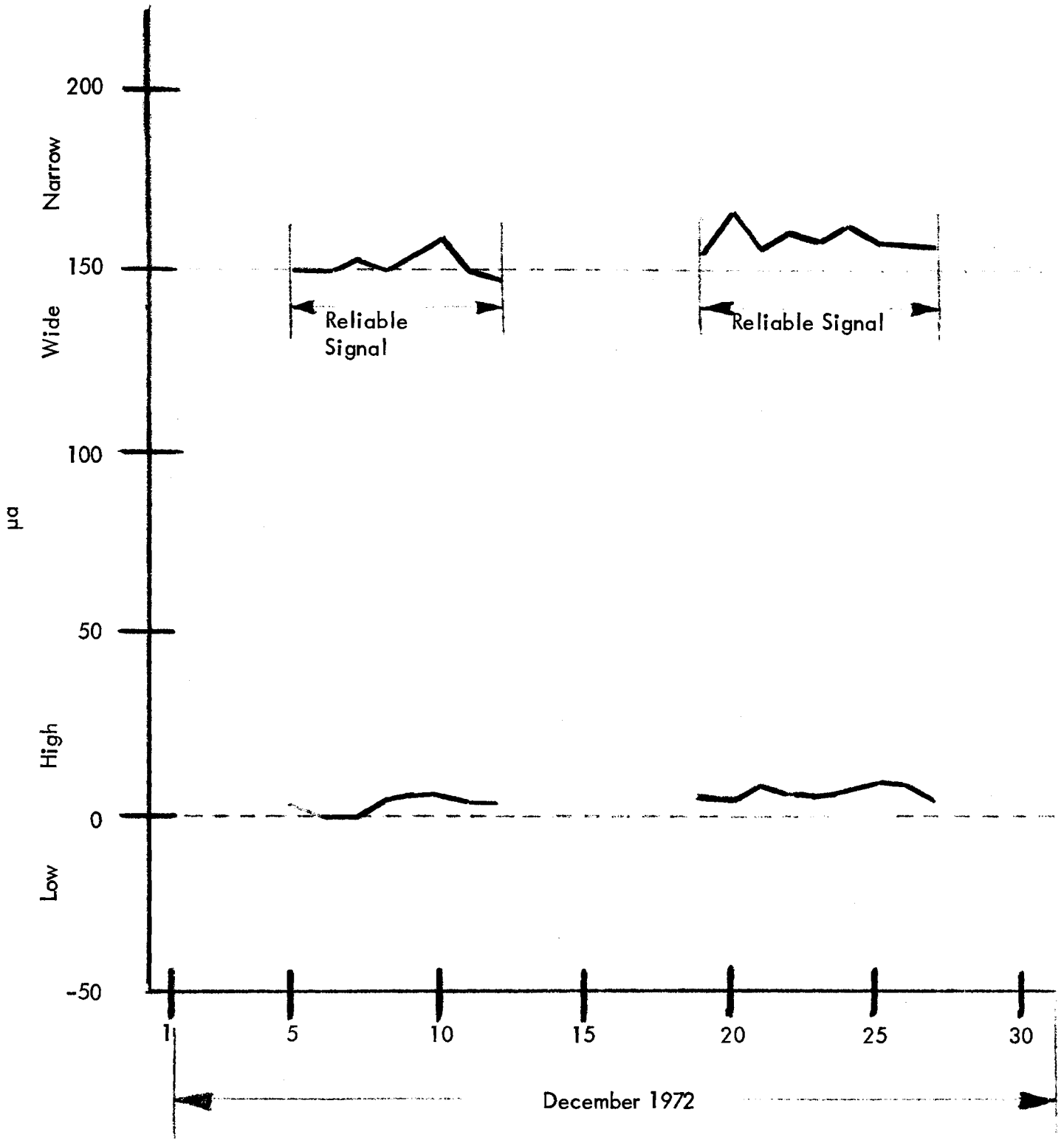

Figure 18. Integral Monitor Path and Width Data--Capture Effect.

On December 24 with 5 inches of snow the far-field probe recorded 112 microamperes. The path probe was normal during this time period. No correlation between the large excursions of the width reading and the environment could be ascertained. It is thought that either an intermittent coaxial relay or coaxial connector in the sideband reference APCU was a source of the instability. This instability continued through the month of January.

3. JANUARY DATA (See Figures 19 through 24). The month of January can be classed as a no-snow month. One inch of snow cover existed for 5 days with a maximum depth of 1 1/2 inches on January 15. On January 16 and the 15 days following, the ground was bare.

The site was deactivated during January 9 through 11 to conduct an experiment with an auxiliary monitoring system. The data recorded during the month is normal with the exception of the sideband reference system. See Figure 22. This system exhibited a slow continuous drift in path angle until system tolerances were exceeded. During the same time period the width increased until it was at the tolerance limit. No environmental factors could be correlated with the system drift. Integral monitor data for the same time period indicate that the transmitting parameters were stable. The source of the sideband-reference drift is attributed to instabilities in the sideband APCU or coaxial connectors.

4. FEBRUARY DATA (See Figures 25 through 30). February provided the second month for snow data. A 1 inch snow fell, then melted. Immediately thereafter the snow layer built to a 6-inch depth, receded slightly to a 4 1/2 inch depth, and then increased to a 6-inch depth. Eventually a depth of 10 inches was recorded.

Data on all systems looked normal with the exception of the sideband-reference system which again was noisy. See Figure 28.

5. MARCH DATA (See Figures 31 through 36). March data provided the final no-snow month for baseline data. The statistics of the systems did not materially differ from previous months.

E. Analysis of Data

Table 3 gives a comparison of the far-field integral monitor statistics for the data gathered at the snow site. With the exception of the sideband-reference system, which had an incipient fault, the data is consistent from month-to-month with or without snow cover. The Pearsons product-moment bivariate correlation coefficients were calculated for the glide slope, integral monitor parameters and snow depth. The results are shown in Table 4.

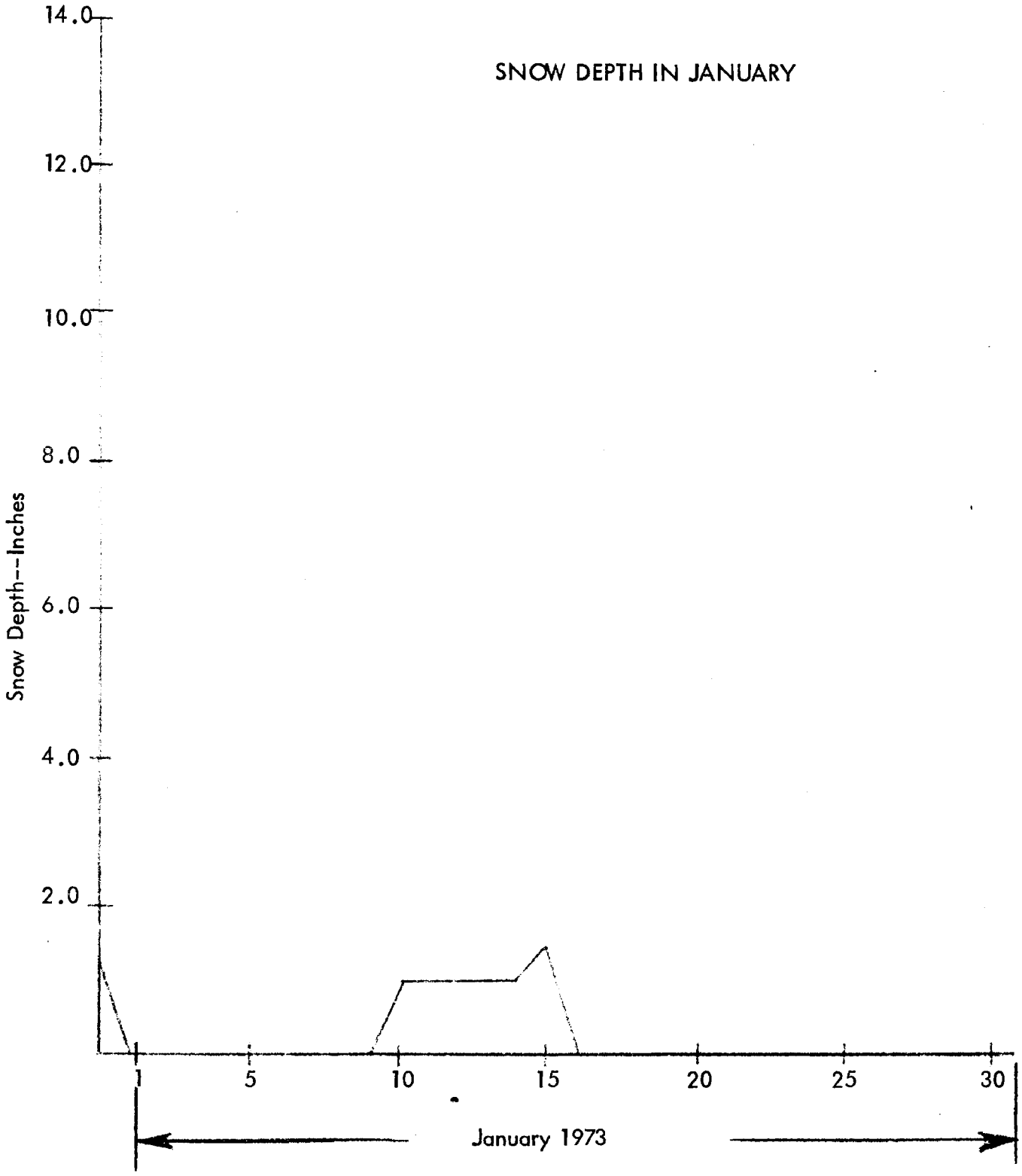

Figure 19. Snow Depth in January 1973.

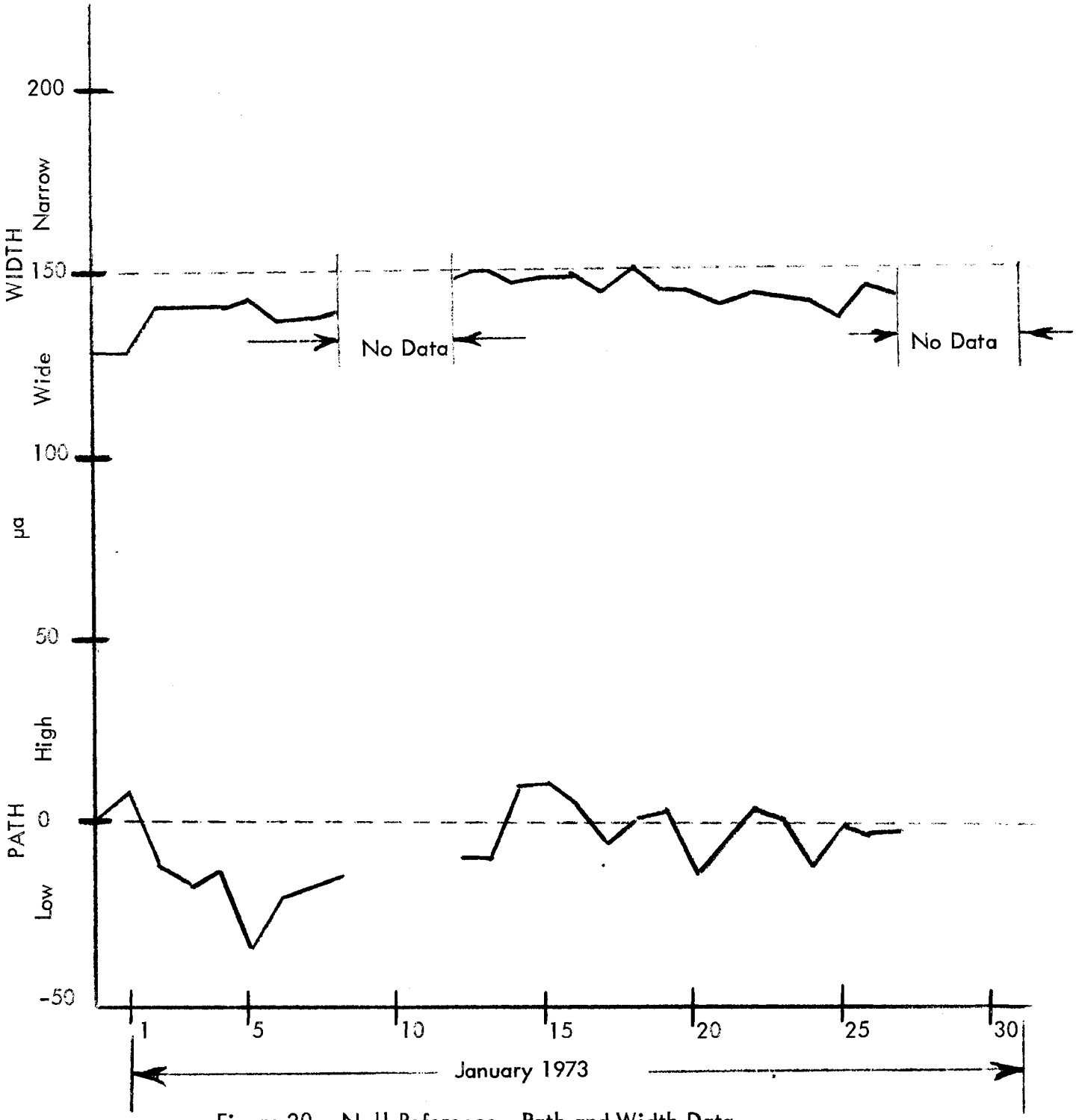

Figure 20. Null Reference--Path and Width Data.

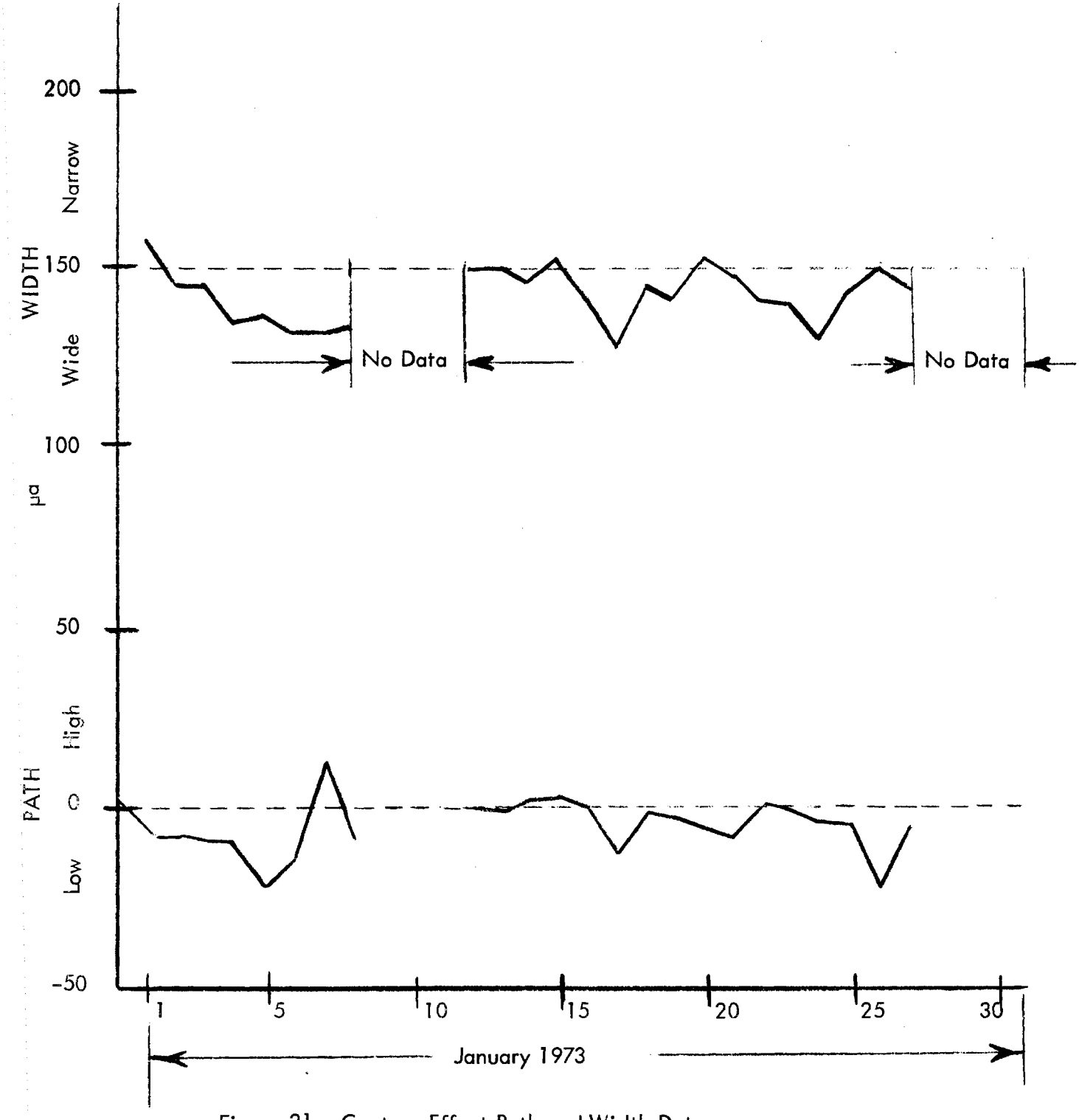

Figure 21. Capture Effect Path and Width Data.

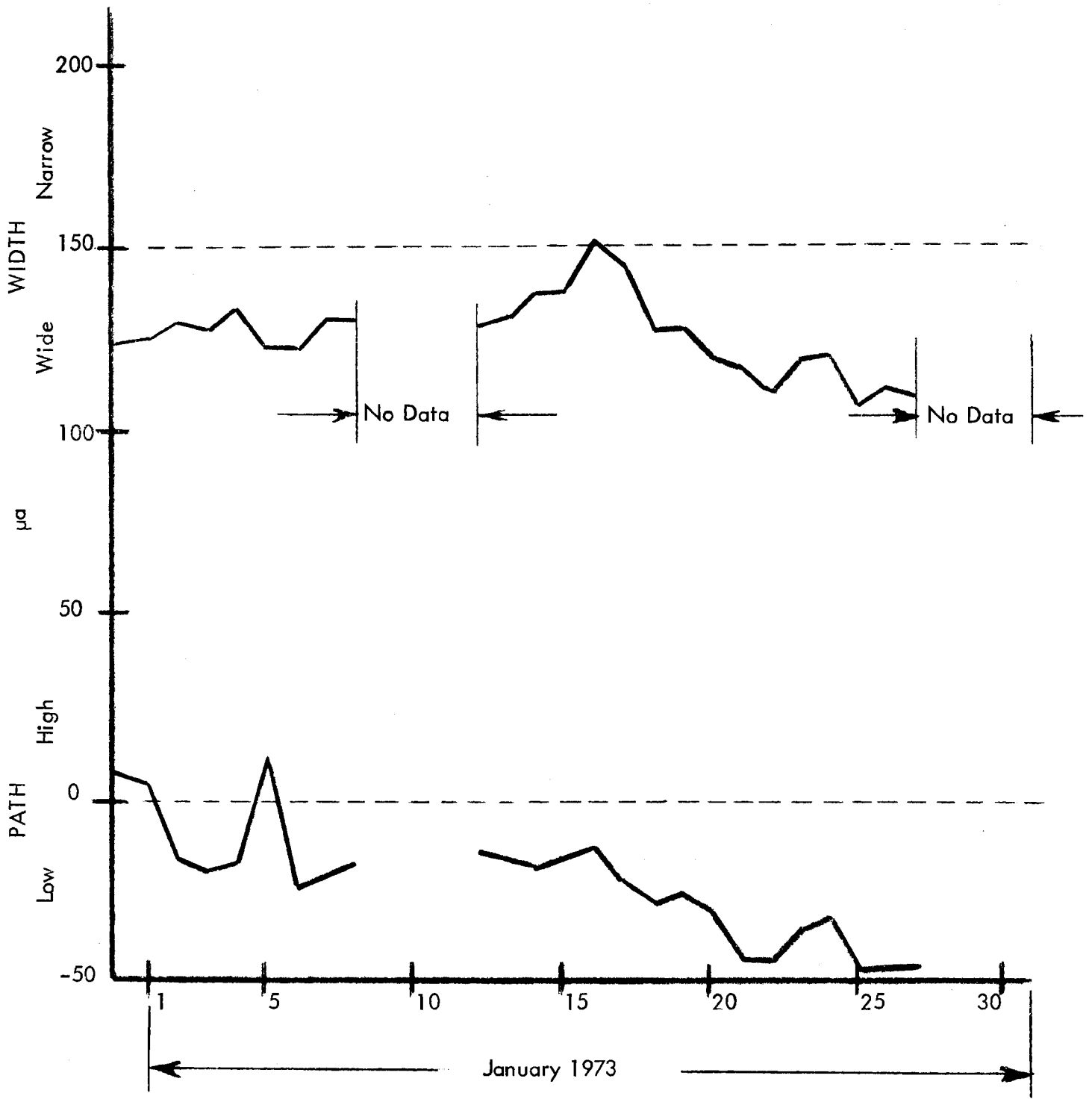

Figure 22. Sideband Reference Path and Width Data.

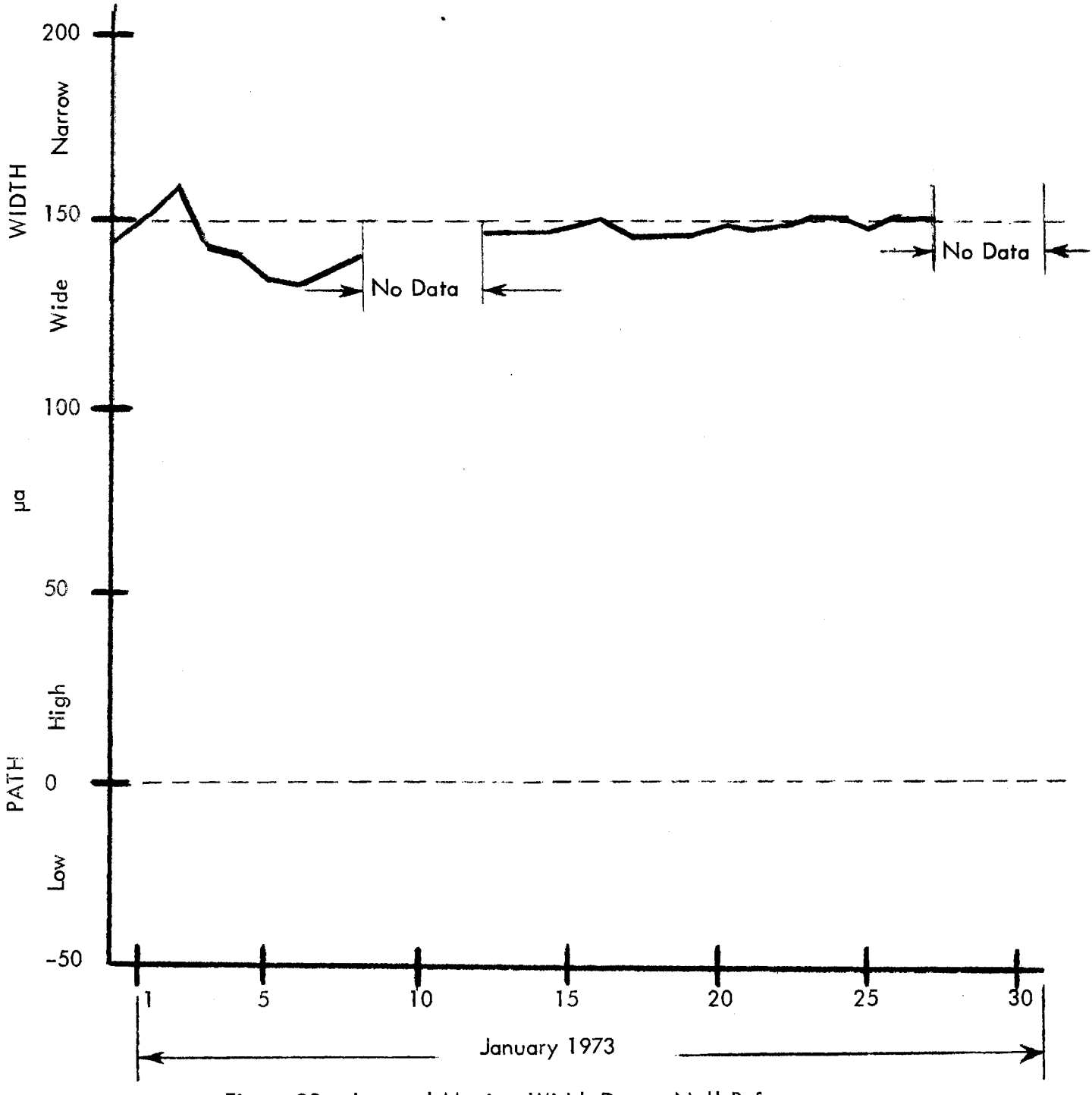

Figure 23. Integral Monitor Width Data--Null Reference.

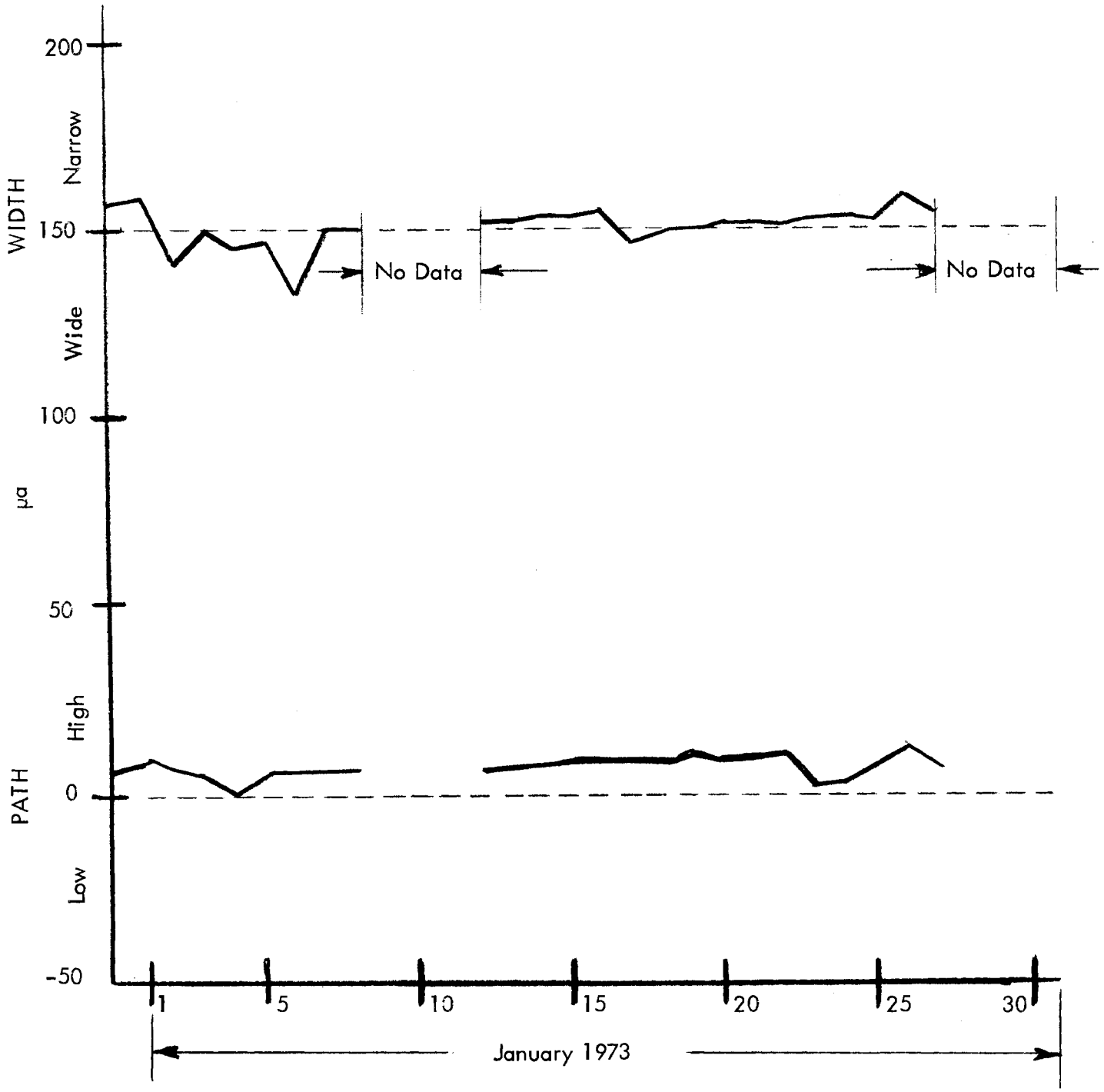

Figure 24. Integral Monitor Path and Width Data--Capture Effect.

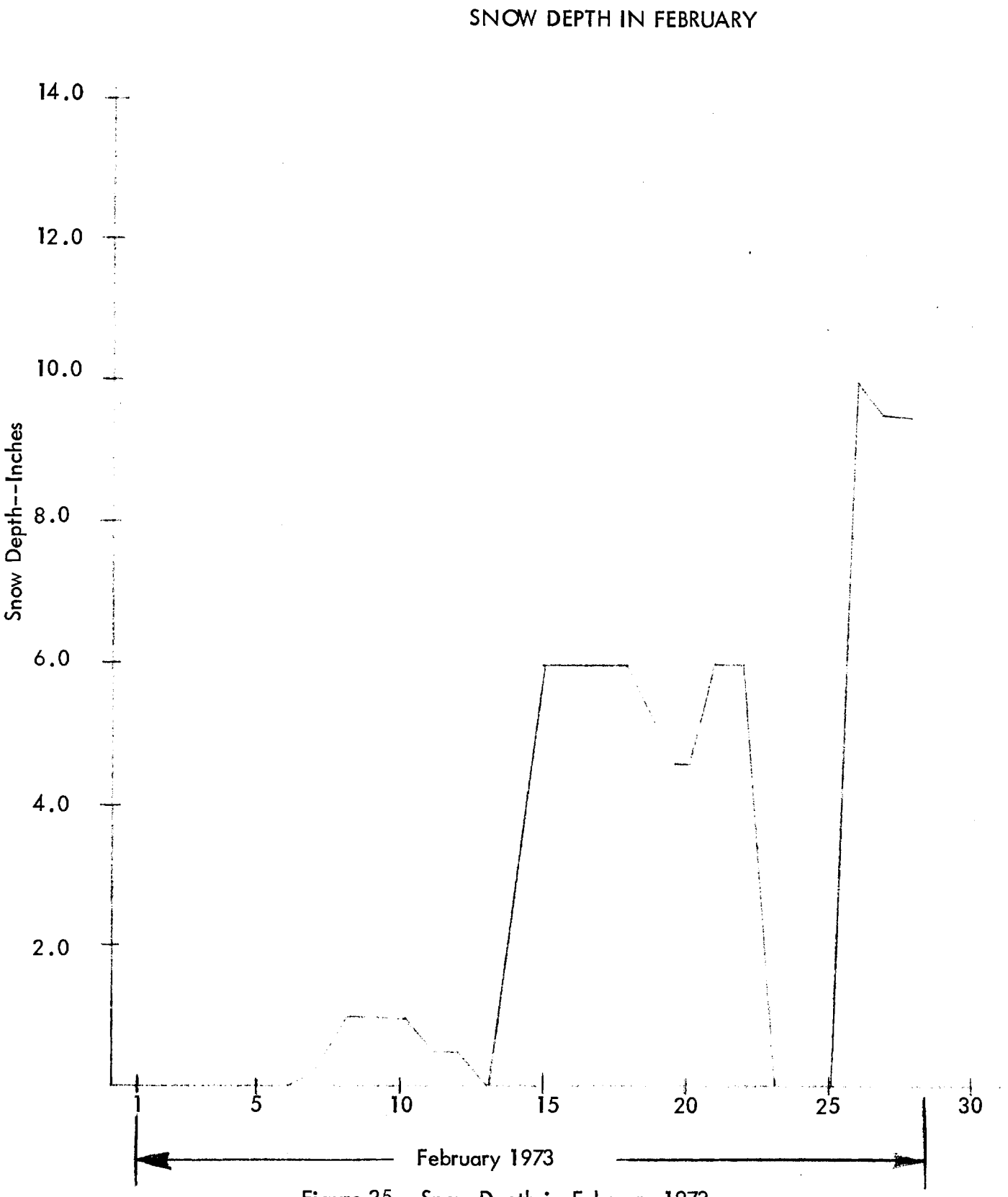

Figure 25. Snow Depth in February 1973.

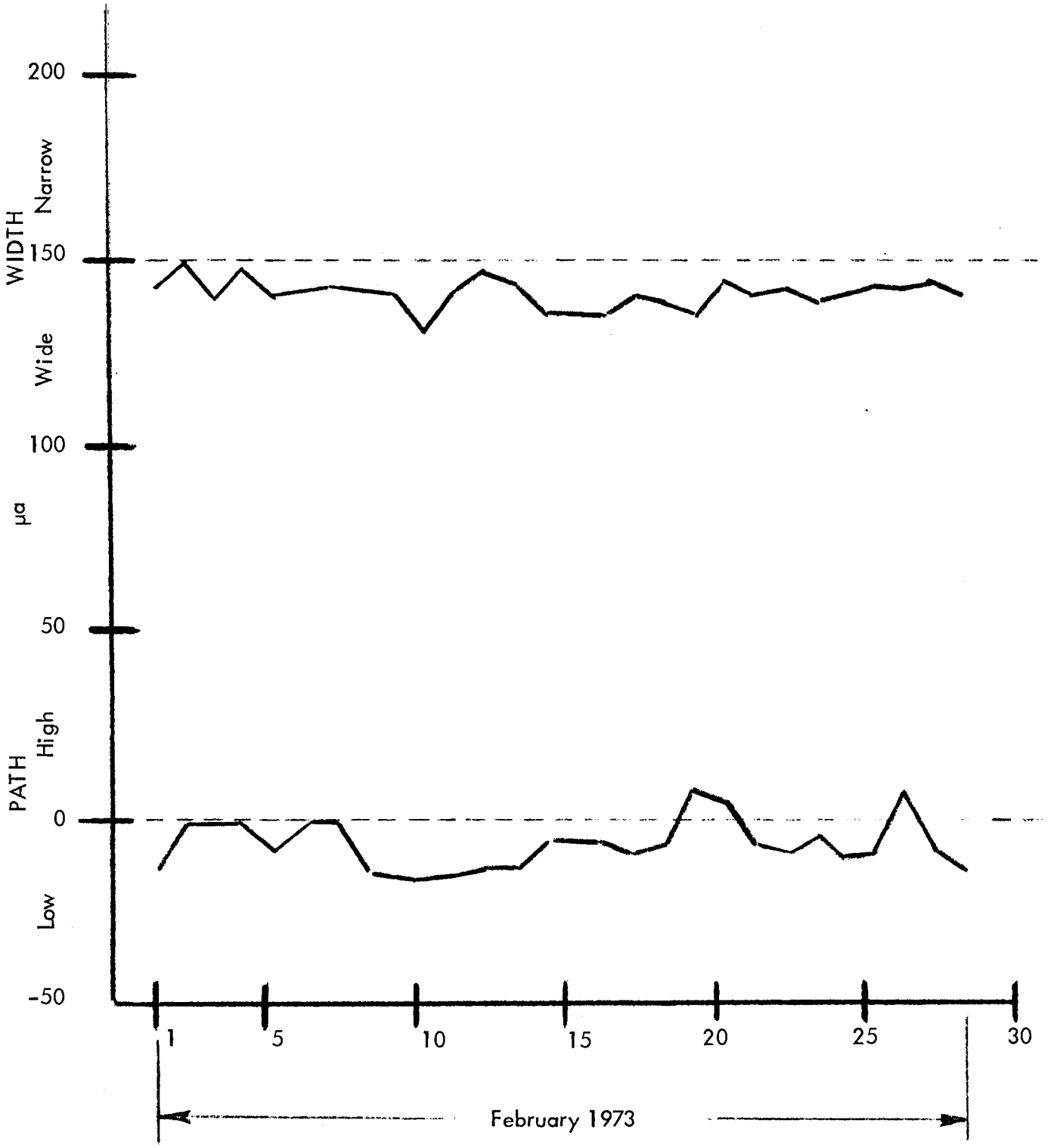

Figure 26. Null Reference Path and Width Data.

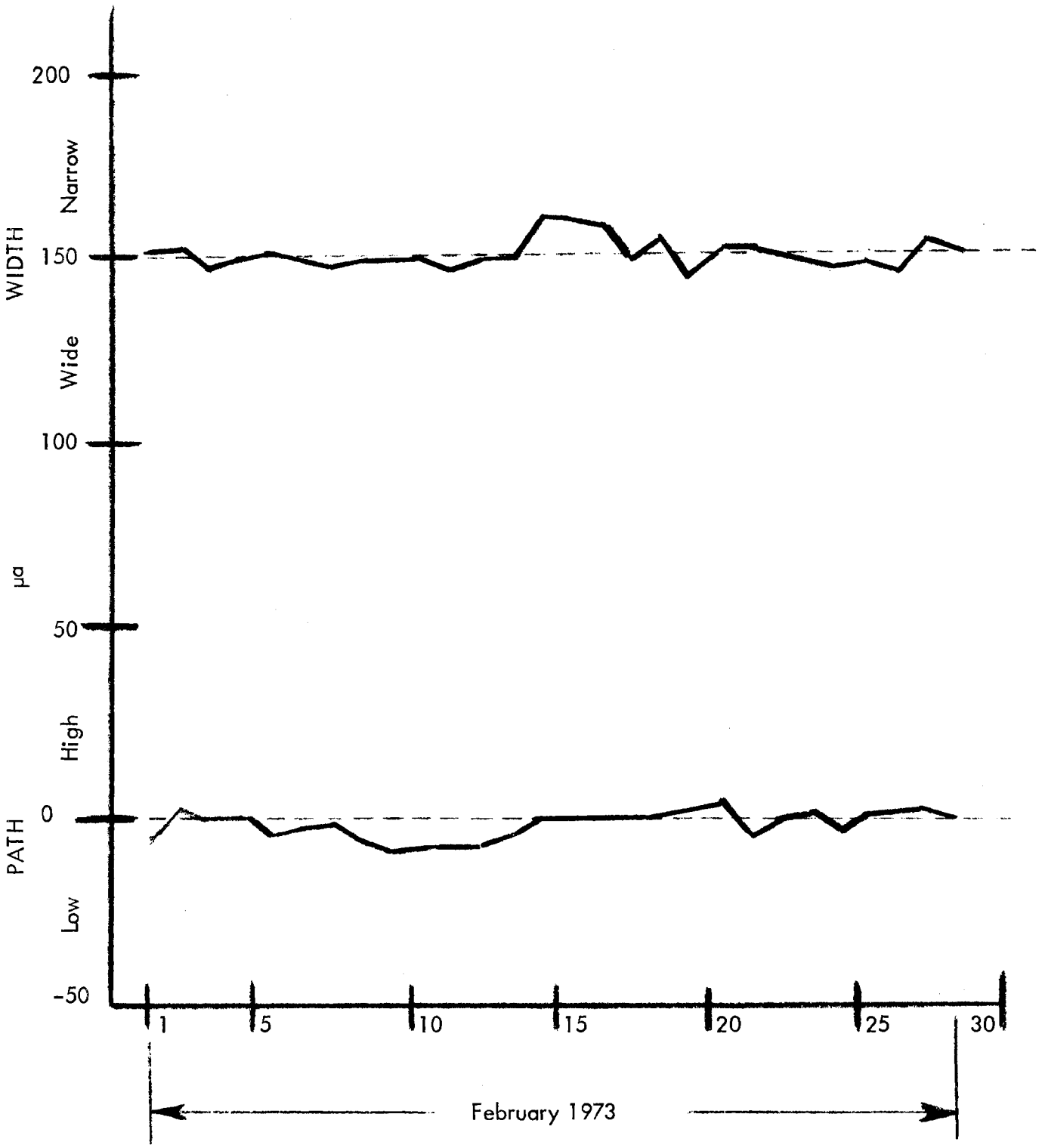

Figure 27. Capture Effect Path and Width Data.

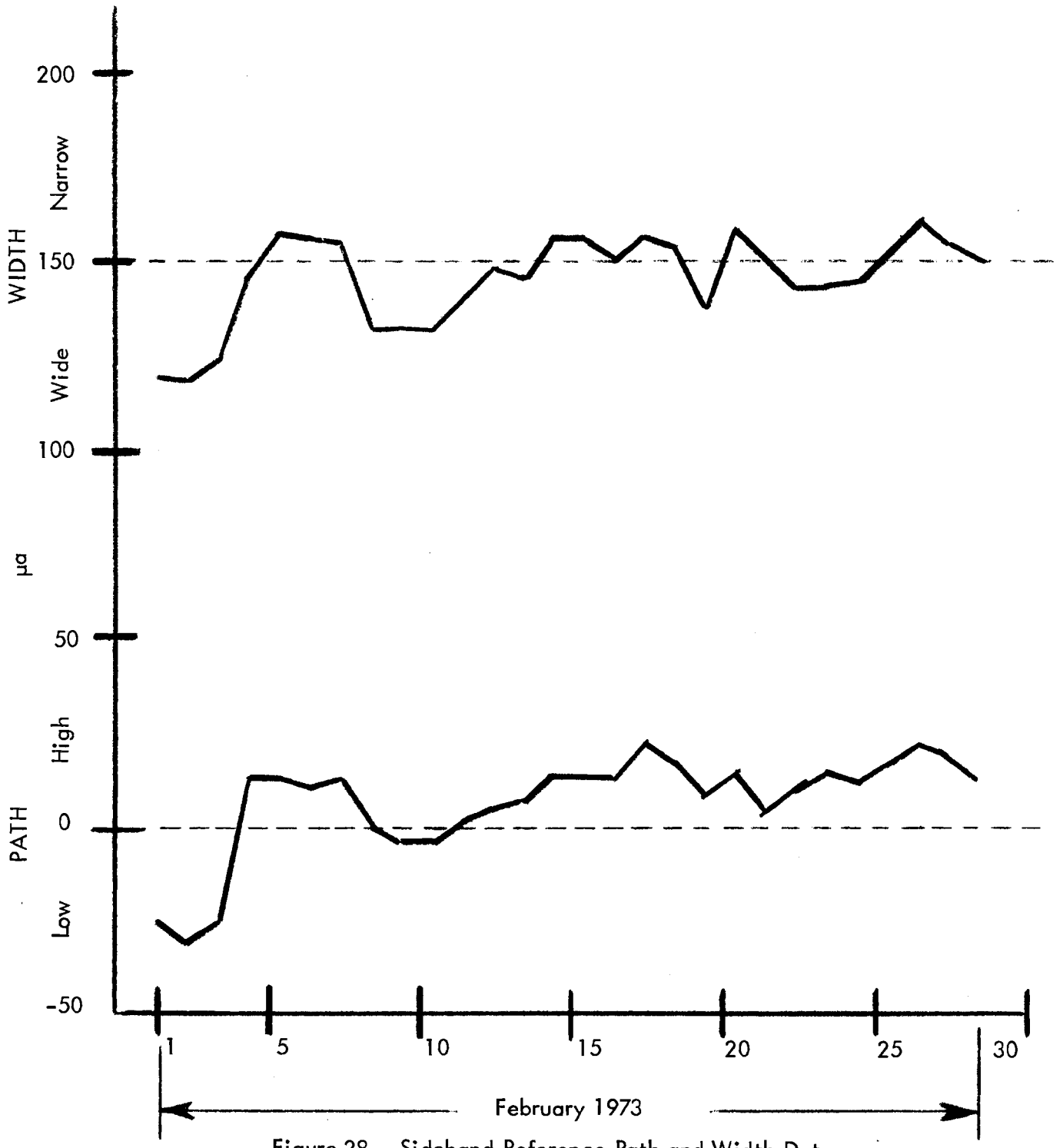

Figure 28. Sideband Reference Path and Width Data.

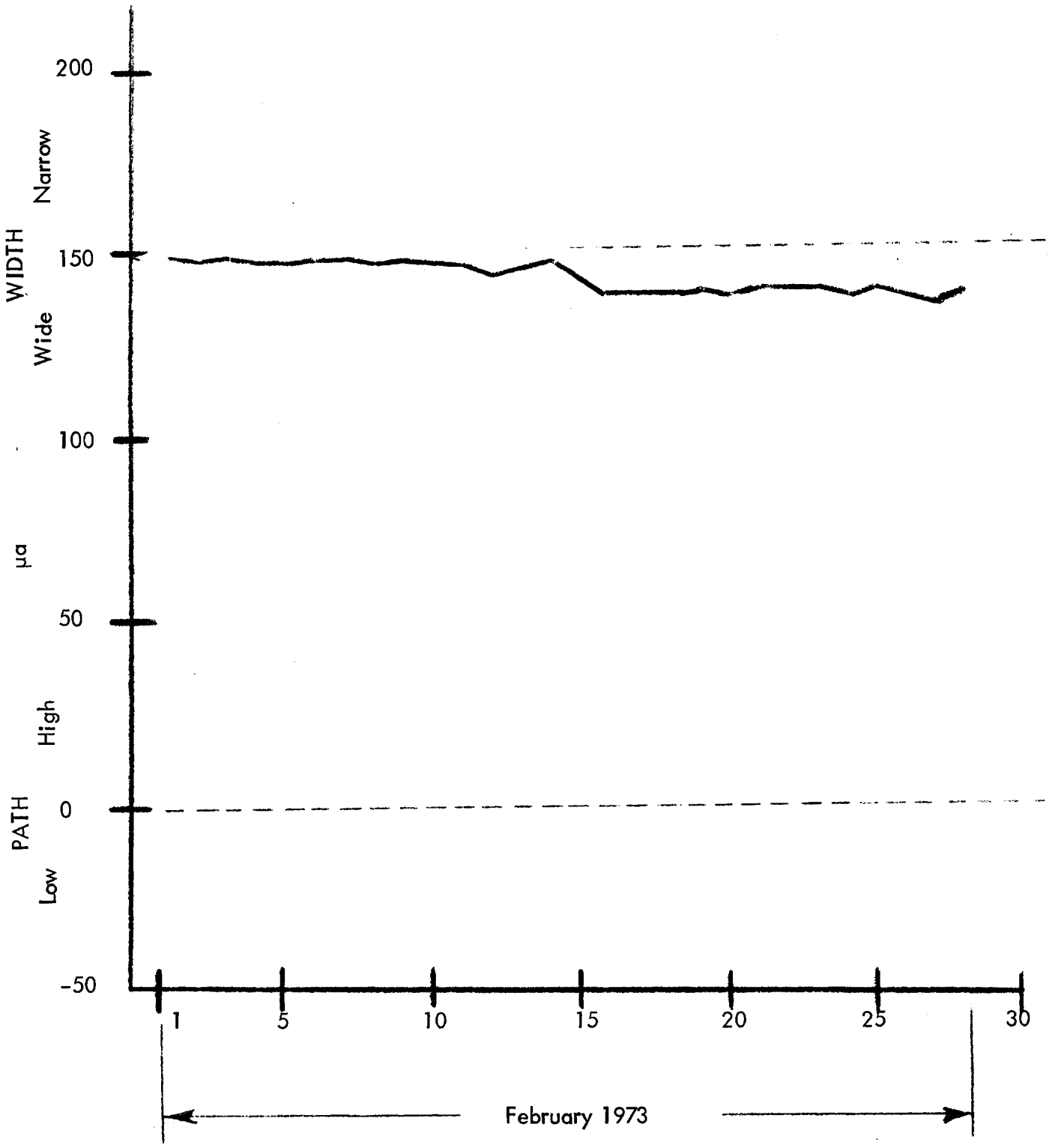

Figure 29. Integral Monitor Width Data -- Null Reference.

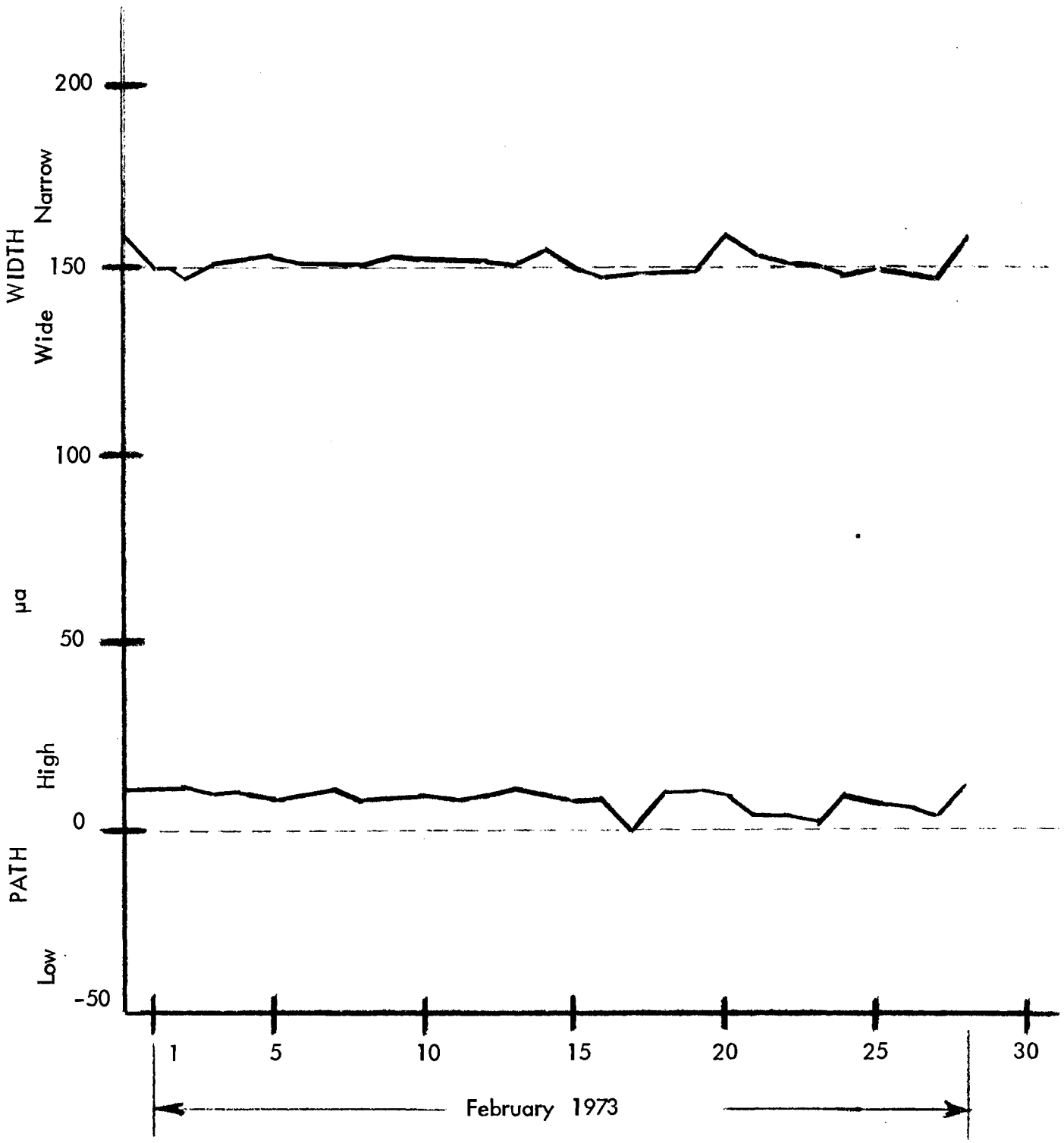

Figure 30. Integral Monitor Path and Width Data.

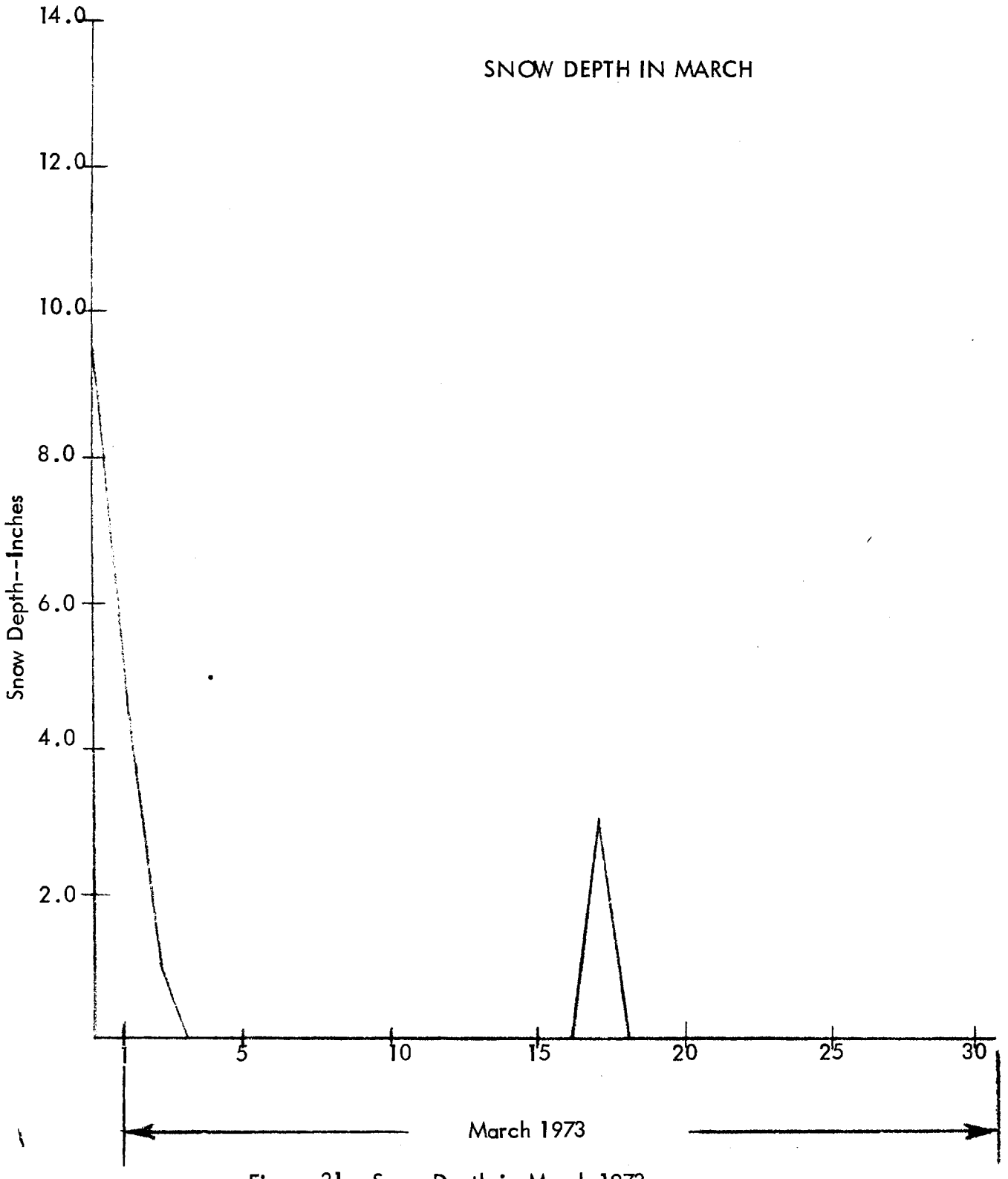

Figure 31. Snow Depth in March 1973.

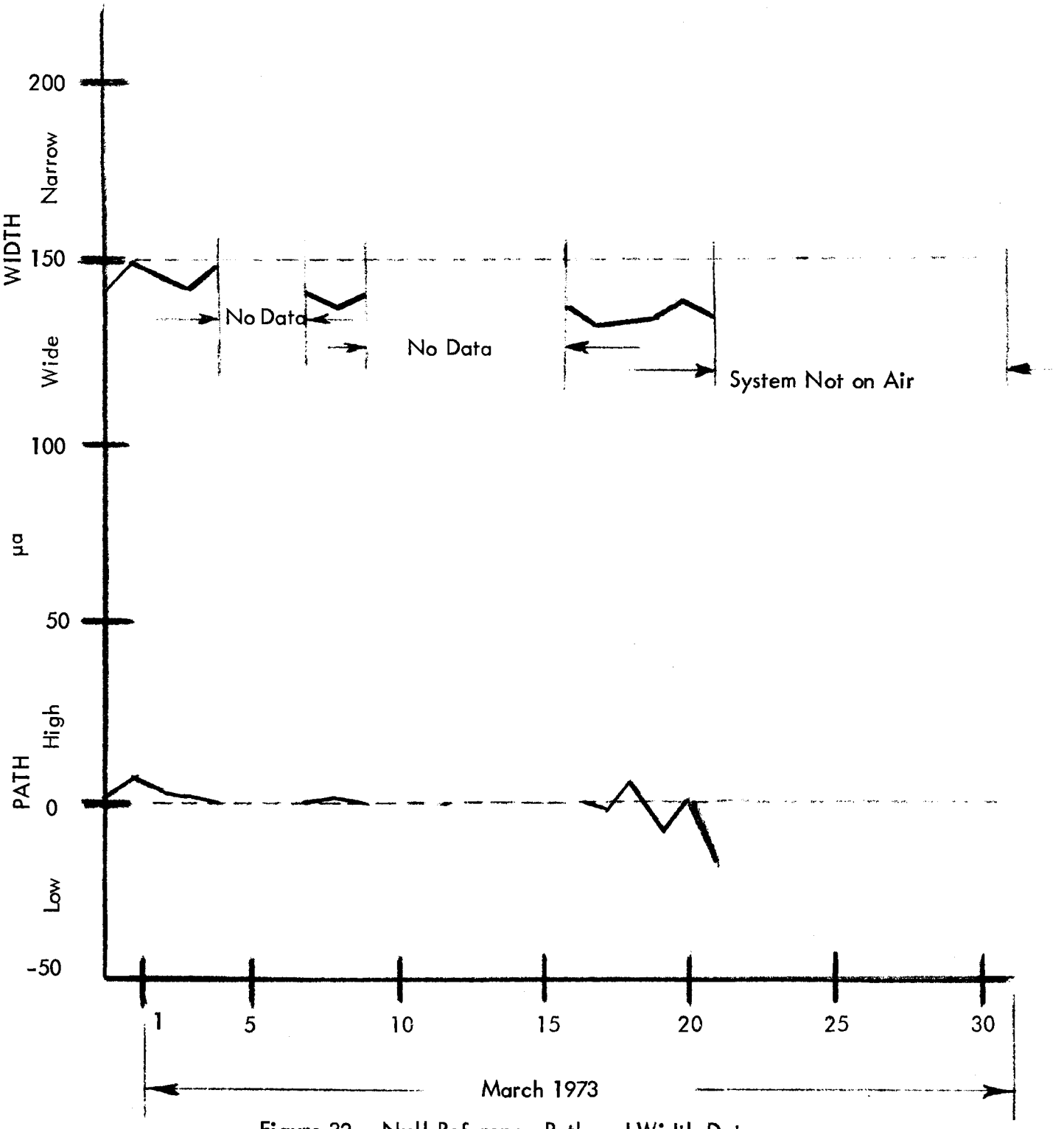

Figure 32. Null Reference Path and Width Data.

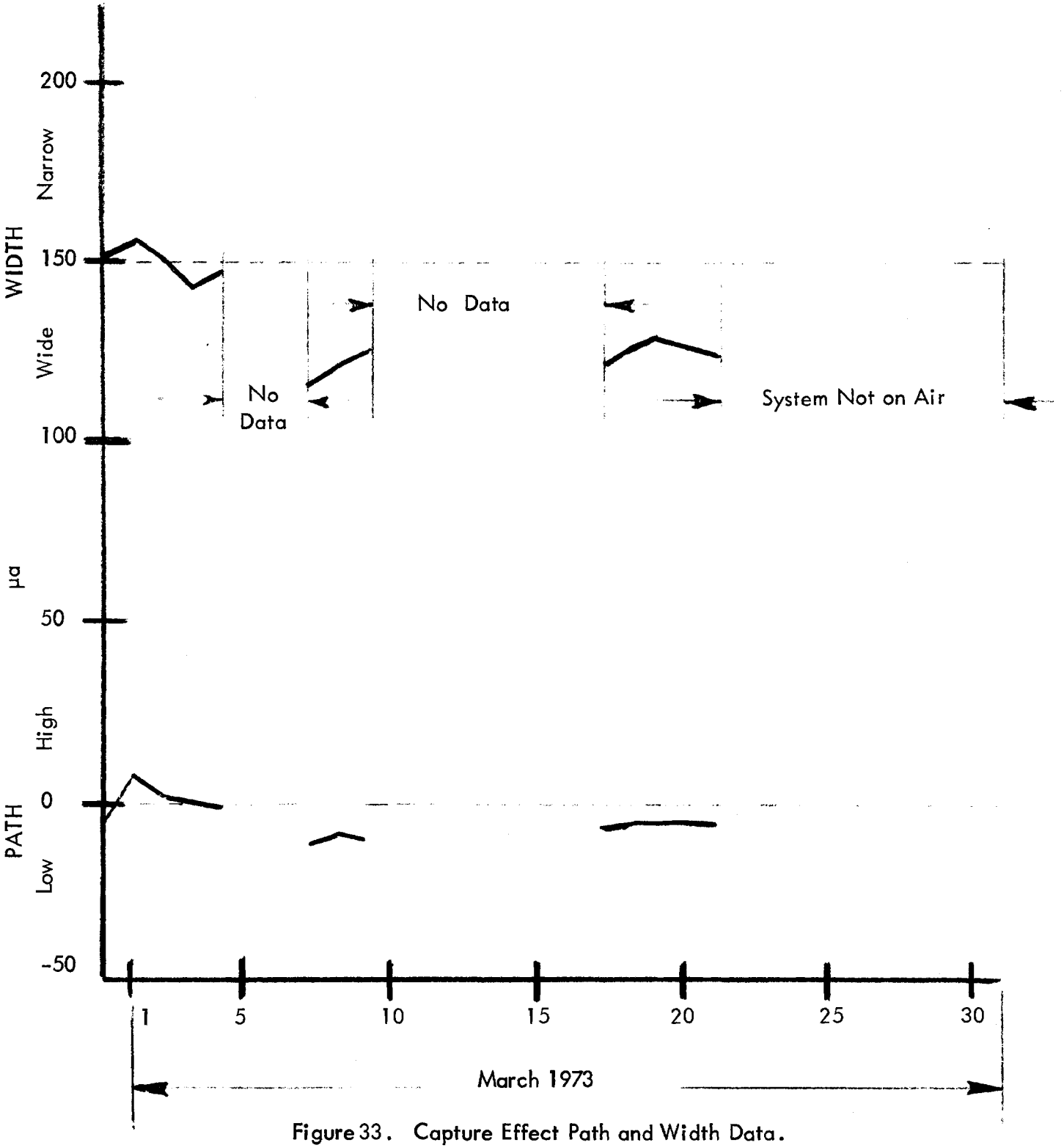

Figure 33. Capture Effect Path and Width Data.

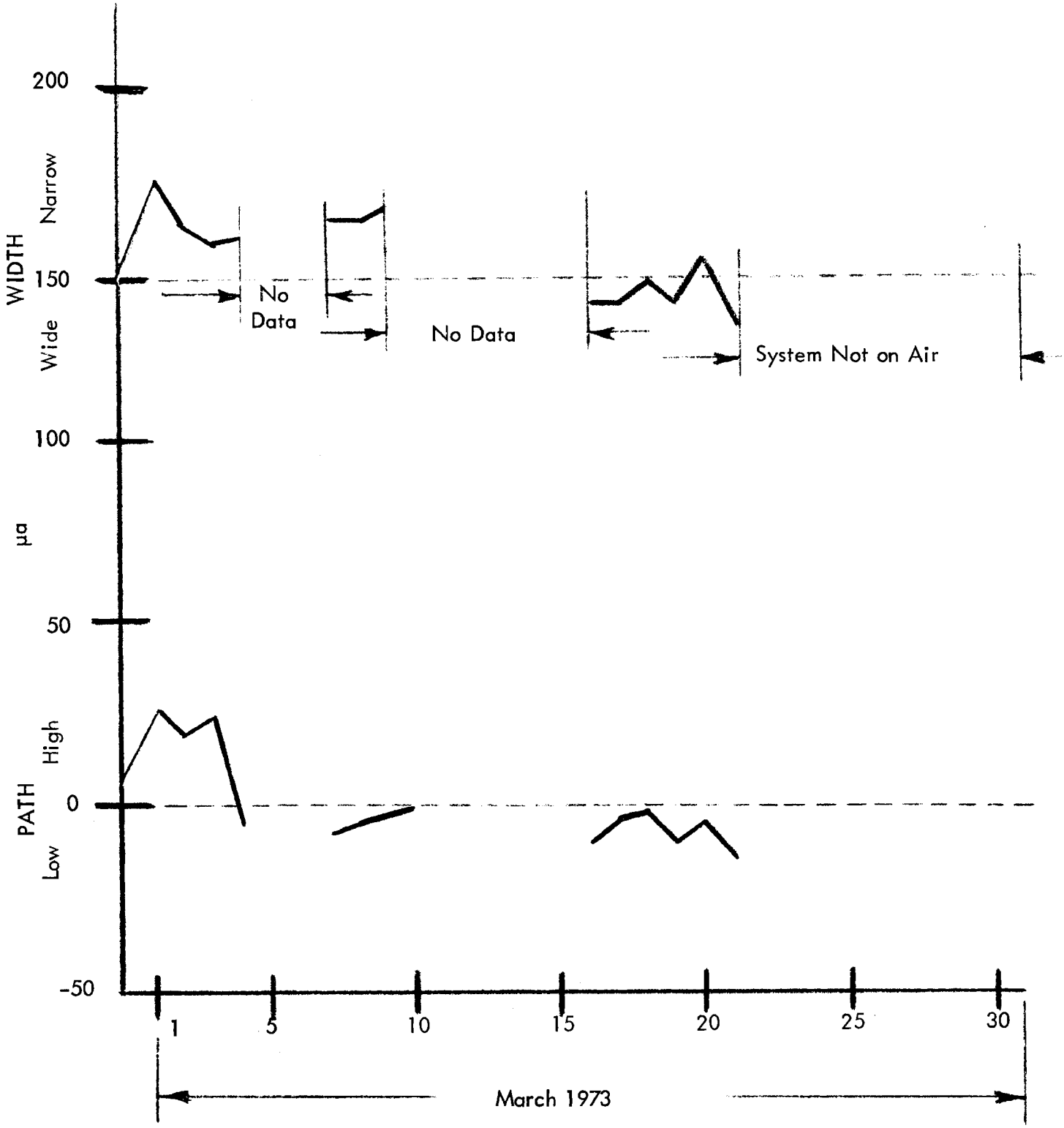

Figure 34. Sideband Reference Path and Width Data.

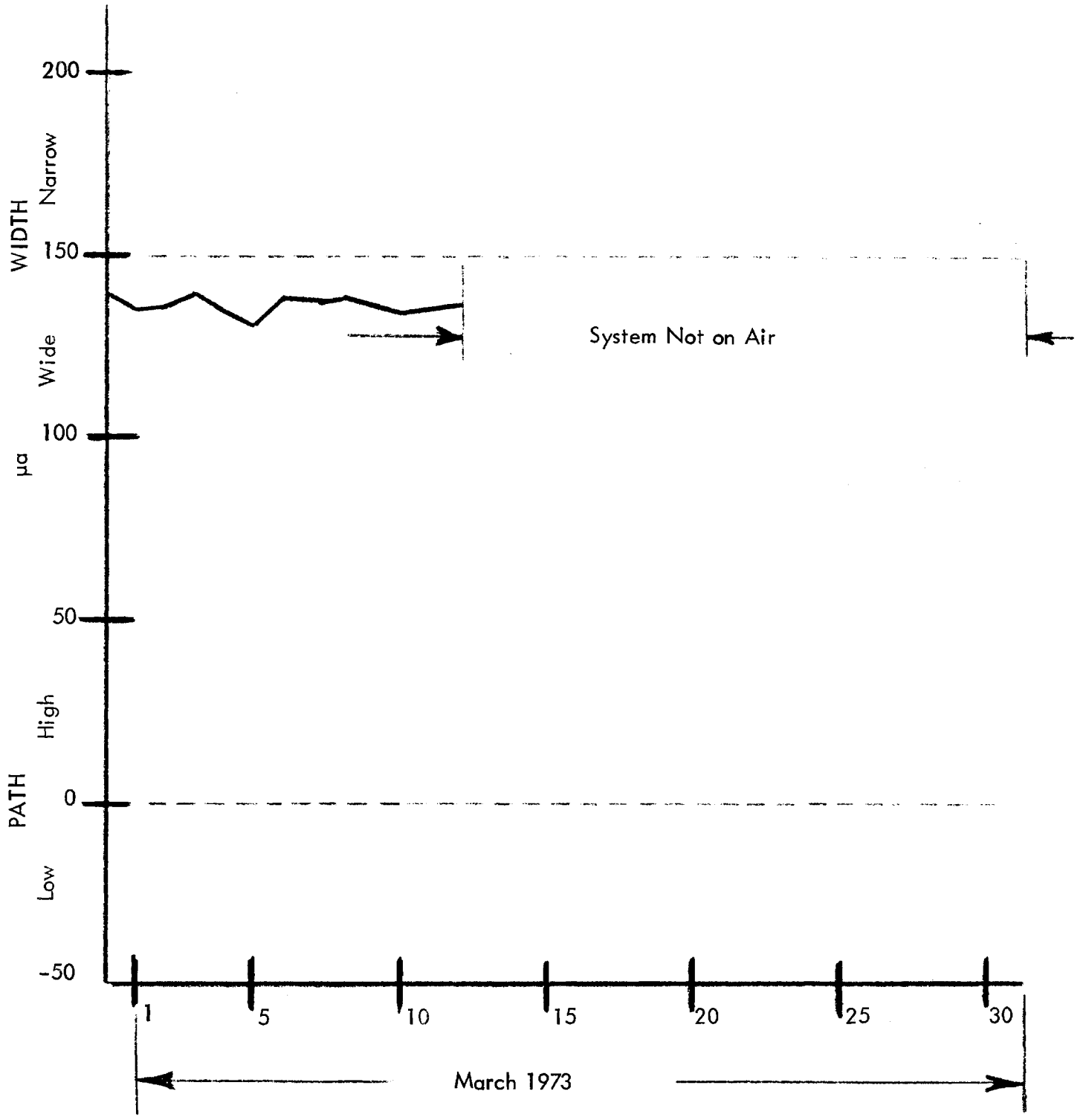

Figure 35. Integral Monitor Width Data--Null Reference.

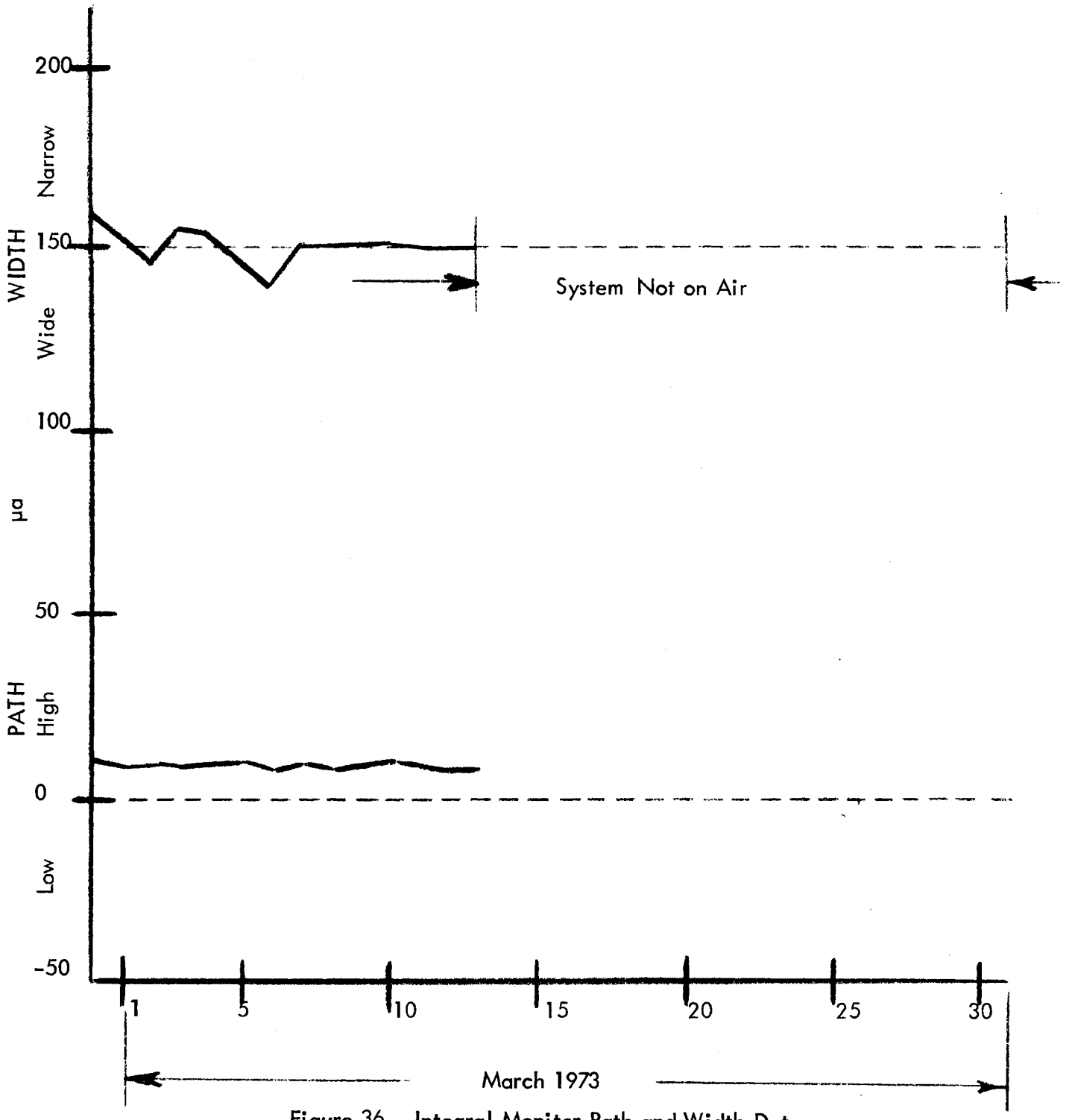

Figure 36. Integral Monitor Path and Width Data.

	NOV		DEC		JAN		FEB		MAR	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Null Reference, Far-Field, Path	-2.03	3.33	-6.43	8.29	-6.75	10.80	-6.92	6.79	-0.71	6.38
Capture Effect, Far-Field, Path	-5.31	1.31	-4.72	4.75	-4.16	8.01	-1.52	3.85	-4.26	6.18
Sideband Reference, Far-Field, Path	-3.43	3.00	-4.81	6.27	-24.55	15.05	6.82	13.66	6.79	14.42
Null Reference, Far-Field, Width	141.46	4.88	138.8	6.4	142.17	5.07	140.92	4.14	138.79	6.26
Capture Effect, Far-Field, Width	131.23	3.92	148.31	11.99	142.57	7.93	152.78	4.22	133.43	13.46
Sideband Reference, Far-Field, Width	130.03	5.10	156.63	31.08	125.84	11.32	144.97	12.23	153.83	12.40
Null Reference, Integral Monitor, Width	141.24	6.72	142.08	2.61	146.06	6.17	144.29	3.77	136.39	2.46
Capture Effect, Integral Monitor, Path	(-8.49)[1]	(9.92)[1]	5.94	2.88	7.58	2.66	8.13	2.99	8.93	1.07
Capture Effect, Integral Monitor, Width	(119.81)[1]	(11.44)[1]	156.24	5.26	150.12	5.52	151.48	2.98	149.99	4.16

NOTES:
1. Integral Monitor Fault Corrected on 29 NOV 1972
2. $\bar{x}$ is Average Value in μa
3. σ is Standard Deviation in μa

Table 3. Comparison of Far-Field Statistics for Null Reference, Capture Effect and Sideband Reference Systems as well as Associated Integral Monitor Data.

	Coefficient of Determination		Correlation Coefficient	
PARAMETER	DEC	FEB	DEC	FEB
Null Reference Path Position, Far-Field	.04	.04	.21	.20
Capture Effect Path Position, Far-Field	.04	.23	.19	.48
Sideband Reference Path Position, Far-Field	<.01	.23	.05	.47
Null Reference Width, Far-Field	.08	.07	.29	-.26
Capture Effect Width, Far-Field	.14	.16	.37	.40
Sideband Reference Width, Far-Field	.18	.21	.42	.46

Table 4. Correlation Coefficients of Path Parameters with Snow Depth.

The coefficient of determination is defined as the ratio of explained variation to total variation. If one assumes that path position is linearly related to snow depth, Table 4 demonstrates that the coefficient of determination is quite low indicating that for snow depths up to 10 inches there is not a linear relationship between path position and snow depth. The correlation coefficient, which is essentially the square root of the coefficient of determination, was used for the calculation. The correlation coefficient is defined as:

$$R = \frac{\Sigma (x-\bar{x})(y-\bar{y})}{\sqrt{\Sigma (x-\bar{x})^2 (y-\bar{y})^2}}$$

where:

x = Path position in μa

$\bar{x}$ = Average of path position in μa

y = Snow depth in inches

$\bar{y}$ = Average of snow depth in inches

The integral monitor data remained stable and consistent with the far-field data throughout the entire winter season. From Table 5 it can be seen that the coefficient of determination between the far-field and integral monitors is quite high indicating that there is a very good linear relationship between the two. The major

Null Reference

Far-Field Average Width	141 μa
Integral Monitor Average Width	143 μa
Far-Field Width Standard Deviation	5.3 μa
Integral Monitor Width Standard Deviation	5.5 μa
Correlation Coefficient between Far-Field and Integral Width Monitors	0.93
Coefficient of Determination	0.86

Capture Effect

Far-Field Average Width	148 μa
Integral Monitor Average Width	152 μa
Far-Field Width Standard Deviation	8.9 μa
Correlation Coefficient between Far-Field and Integral Width Monitors	0.95
Coefficient of Determination	0.90
Far-Field Average Path	-3.2 μa
Integral Monitor Average Path	7.3 μa
Far-Field Path Standard Deviation	5.9 μa
Integral Monitor Path Standard Deviation	2.9 μa
Correlation Coefficient between Far-Field and Integral Path Monitors	0.89
Coefficient of Determination	0.79

Table 5. Path Parameter Statistics.

conclusion reached for the integral monitor as implemented at the snow site is that it is quite capable of accurately monitoring system parameters independent of environmental factors such as freezing rain, blowing dust and low temperatures. The integral monitor gave an accurate measurement of the far-field conditions. It can be concluded that the integral monitor provides a consistent, accurate and representative monitor under a wide variety of environmental conditions and with snow depths of up to 10 inches.

IV. ADDITIONAL DATA COLLECTION

A. Data Acquisition Attempts by Canadians and Michigan Technological University

Communications were maintained with the Department of Transport, Ottawa, Canada, in an attempt to acquire data which they were planning to collect at six of their major airports. They had recently acquired new mobile tower equipment which could probe as high as 125 feet. A letter of June 11, 1973 indicated they had obtained no data because of a light snow season and initial technical difficulties with the mobile mast vehicles.

Because of the history of extremely deep snow layers which typically exist in the Houghton, Michigan area, special attention was given to a image glide slope facility at Houghton. The existence of Michigan Technological University in Houghton and the close relationship of the administration of that university with Airport Authority provided an opportunity for additional snow data collection. Two days of meetings and the presentation of a seminar on snow effects further heightened the interests in learning more about operation of glide slopes in the presence of snow.

A glide-slope receiver, antenna and signal calibrator together with a small amount of funding was provided by Ohio University to the Electrical Engineering Department at Michigan Tech for the purpose of obtaining snow measurements on the glide slope with an erectable tower near the approach end of the instrument runway. Thaws and unusually light snowfalls during the last two months of the winter prevented any significant data from being obtained.

B. Aircraft Data Collection

Two light aircraft, a Beechcraft 35 and a Piper PA28 were made available with specially calibrated instrumentation for collecting data on path conditions in space given various snow conditions that could be found at commissioned facilities. Two teams of two men were on standby to be dispatched to facilities where interesting snow conditions would be reported by local maintenance personnel. Coordination with the FAA Central, Great Lakes, and Eastern Regions was accomplished in order that information could be obtained.

The data collection techniques which had proved successful in airborne data collection during the past two winters were used. This involved a theodolite on the ground which was used to continually track the aircraft during a flight run on the glide path. When the pilot was precisely on the path as indicated on a large scale microammeter in the cockpit, he would key a tone which was transmitted to the ground observer. The elevation angle shown on the theodolite at the time the tone was received was recorded and processed as numerical data.

Data collection flights were made to Niagara Falls and Rochester, New York, and Houghton and Marquette in the upper peninsula of Michigan where snow was affecting glide-path near-field monitor performance. No out-of-tolerance conditions of the far-field path positions were observed. The maximum deviation from normal was found at Marquette, when a 0.15 degree high path was observed with 16 inches of snow on the ground. At this particular site the data had to be reduced from a permanent type theodolite tracking location which had been located 190 feet from the point specified in the US Flight Inspection Handbook OAP 8200.1, Change 17 dated August 1970. This incorrect location produced an apparent flare when inside the middle marker. The melting snow conditions occuring in New York were producing anomalous readings on the near-field monitors which were rapidly recovering during the period when flight measurements were taken. No far-field effects of ground plane snow cover were noted.

The only other reported snow effect was at Macon, Georgia, where a freak snow storm dumped 16 1/2 inches of snow in central Georgia. This was record snowfall exceeding the previous greatest amount by 10 inches. A system outage occurred but rapid melting and prime outages prevented any useful measurements from being made.

C. Gradient Data Gathering and Analysis

During the data gathering period at the Ravenna, Michigan, Snow Site an additional monitoring system was installed. This system called a gradient monitor was implemented to determine the efficacy of sampling the below-path DDM gradient and predicting the glide-slope angle and width. The work was done under Modification 16 of this contract and is mentioned here for synoptic purposes.

The GCM site was located approximately 4,600 feet from the glide slope antenna array directly in line with the far-field tower monitors. Five antenna probes were mounted uniformly between elevation angles of 0.867° and 1.247°.

The upper and lower antennas were sampled periodically and their readings recorded. A complete description of the results of the program will be given in the Report for Modification 16.[2]

A very detailed analysis of the far-field, integral monitor and gradient monitor was made for a time period when near maximum snow cover depths were recorded. In Figures 37 through 40, detailed plots of the far-field and integral monitor behavior are shown during a time when 7 inches of snow cover was recorded. Commencing at 0900 EST on February 23, 1973, the null-reference glide slope started to increase in angle and changed a total of 18 microamperes. At 1200 EST the glide slope stabilized at 12 microamperes into the 150 Hz. At 1600 EST the glide slope angle started to return to normal with some overshoot. At 2200 EST the glide slope attained 13 microamperes into the 90 Hz side and then returned to the normal 5-6 microamperes reading in the 90 Hz side. This excursion is considered to be the result of surface warming and is consistent with previous findings.[3,4]

The far-field, null reference width did not change value appreciably; however, the indications are that the null structure moved upward and that the phase relation of the carrier and sideband in space changed from optimum resulting in apparent course widening. This is believed to have been just sufficient to have equaled the upward structure shift at the 2.3° angle. The gradient clearance monitor showed a widening which apparently was greater than the upward structure shift as seen in Figure 41. It is interesting to note that neither the sideband reference nor the capture effect systems were affected.

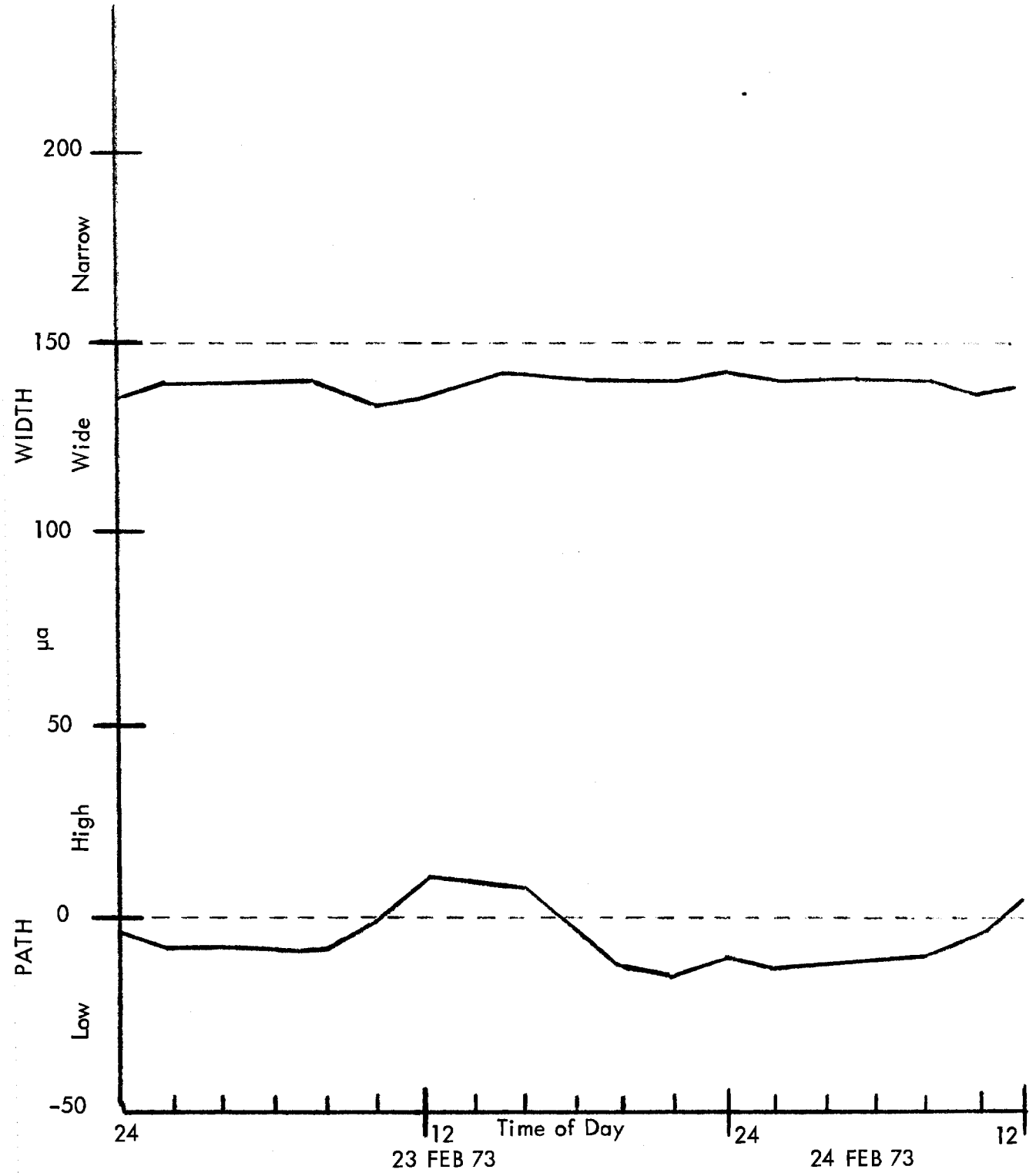

Figure 37. Far-Field Monitor Null Reference.

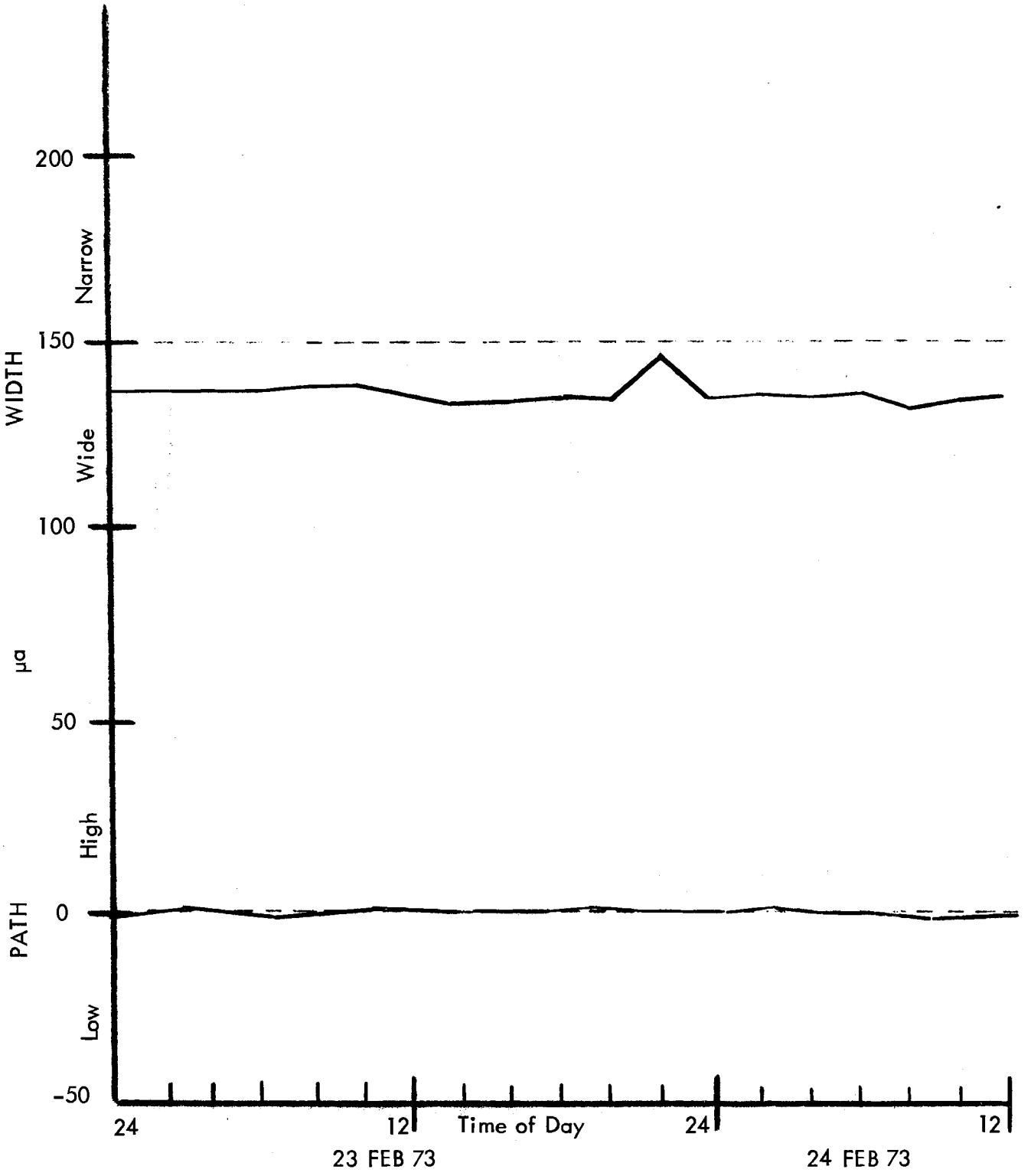

Figure 38. Integral Monitor Null Reference.

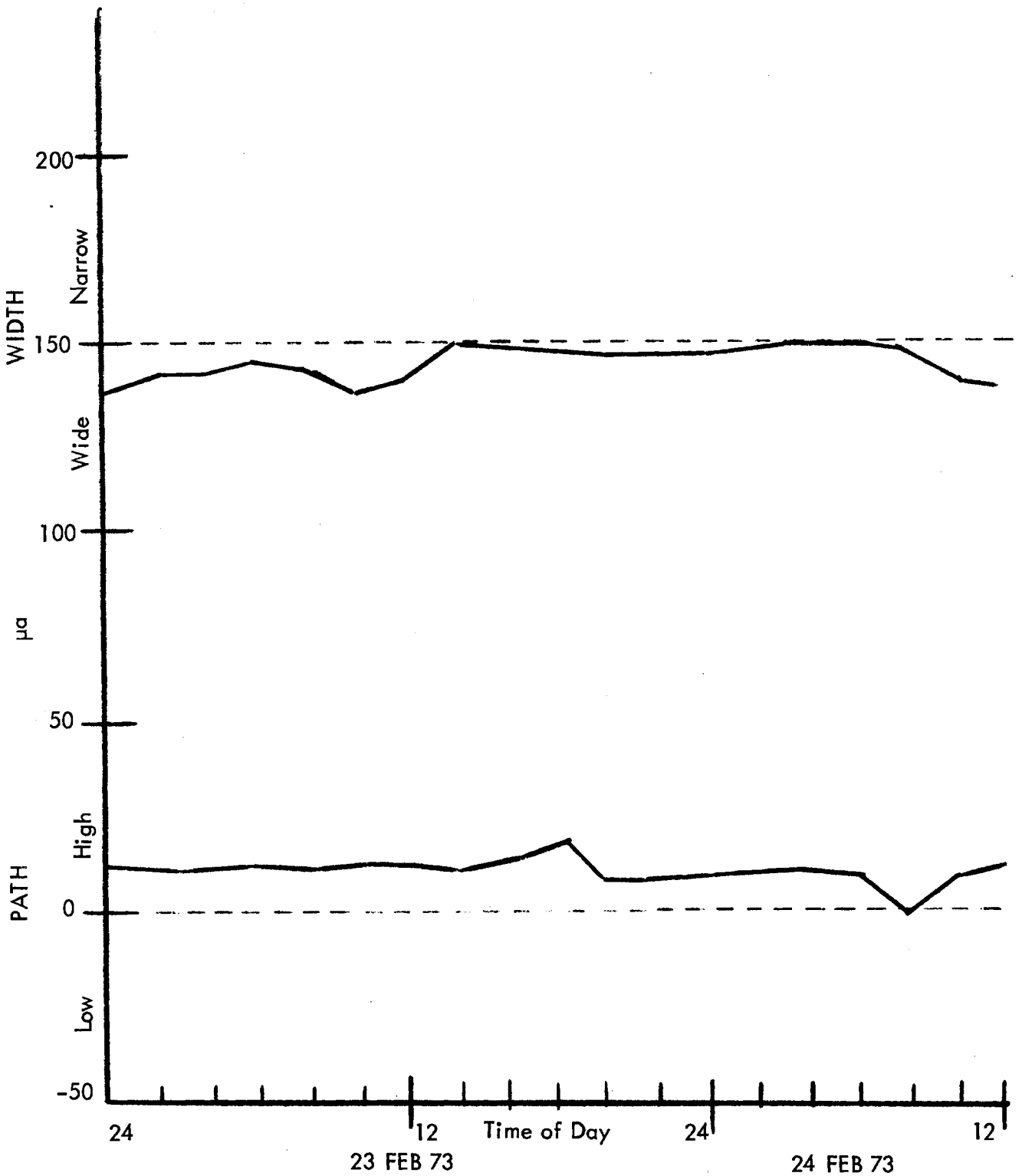

Figure 39. Far-Field Monitor Sideband Reference.

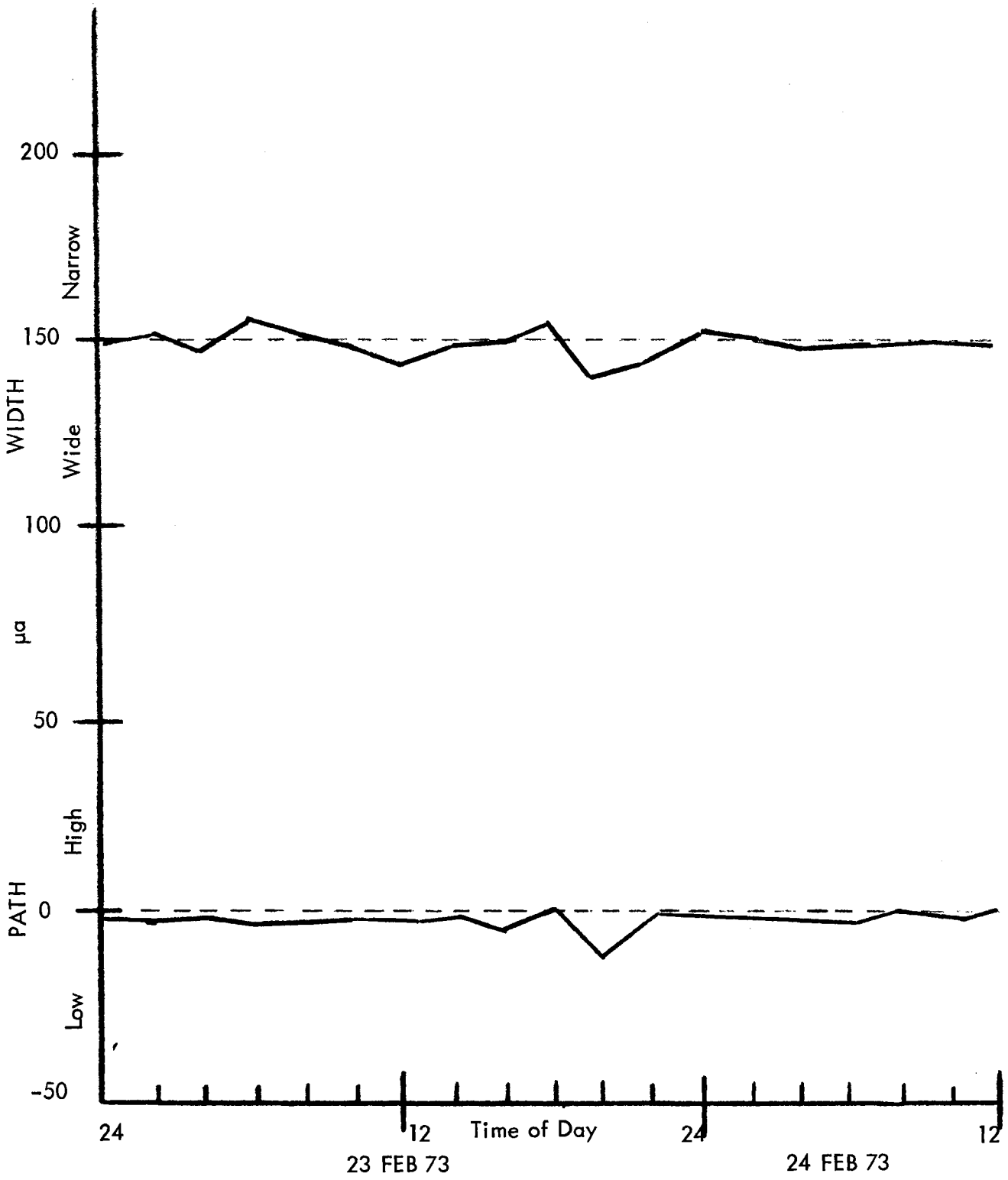

Figure 40. Far-Field Monitor Capture Effect.

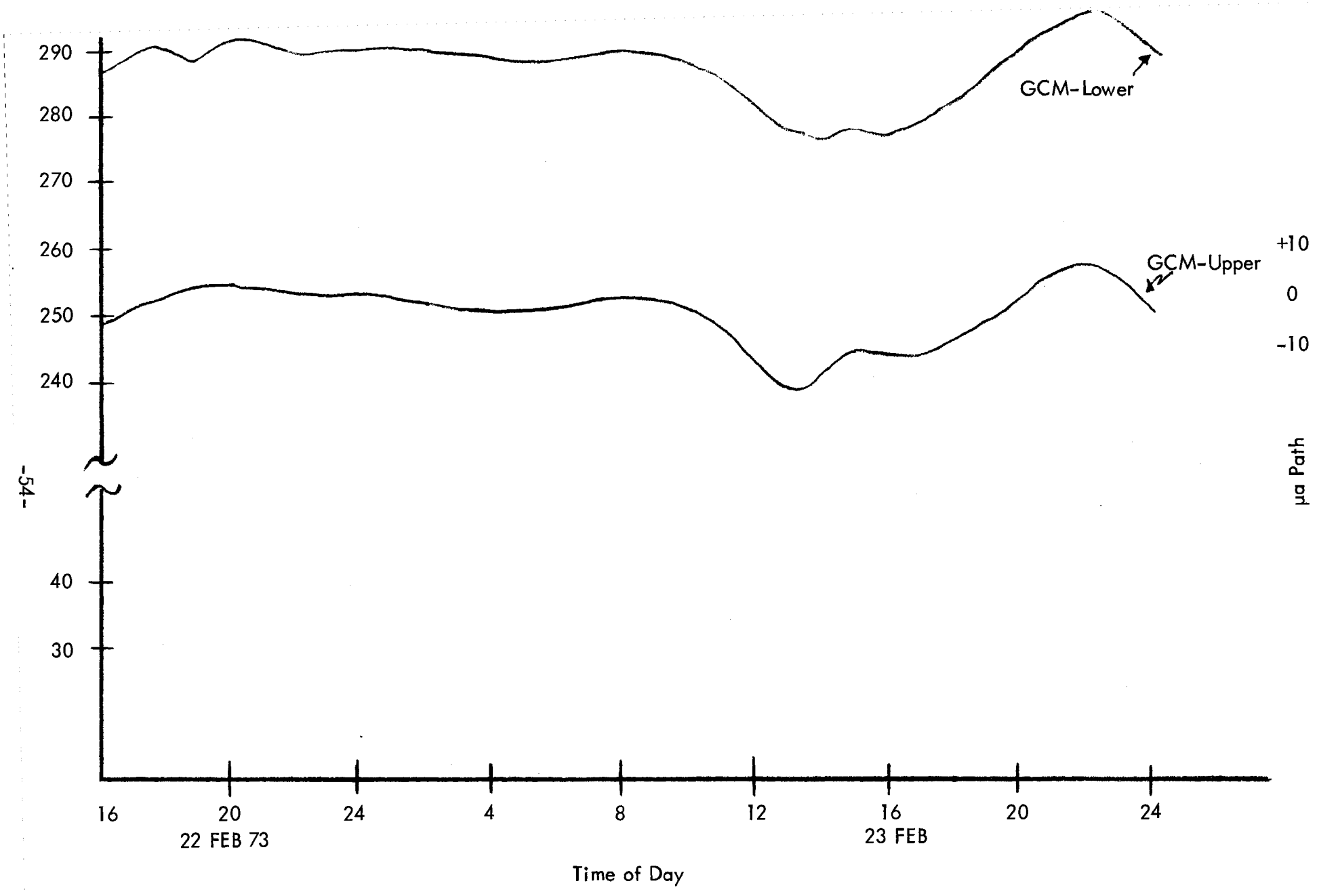

Figure 41. GCM Monitor and Far-Field Path Compared.

V. CONCLUSIONS AND RECOMMENDATIONS

Several conclusions can be safely drawn from the experimental results of this investigation. First, effects of snow depths of less than 10 inches are not significant in terms of the far-field glide slope performance, even though the near-field monitors may be disturbed to the extent of producing out-of-tolerance conditions.

Second, integral monitoring appears to be an effective and reliable way of assessing far-field path conditions at least with snow depths no greater than 10 inches. No firm evidence is yet available for depths greater than 10 inches.

Experimental results appear to be consistent with theoretical predictions obtained from mathematical models developed earlier in this snow investigation program. (See references under Number 4 in the Bibliography)

The recommendation is made that integral monitoring be implemented for providing both course and width protection provided snow depths of 10 inches are not exceeded. Also an alert monitor should be used to call attention to when snow depths of 10 inches are exceeded, and a tilt monitor should be used to detect when the system antennas have changed physical orientation.

Further, data collection efforts should be continued at selected locations to provide a general monitor of effects of peculiar snow conditions. Certainly not all possible snow conditions have yet been observed.

VI. ACKNOWLEDGMENTS

For the second year, the WZZM-TV Corporation of Grand Rapids, Michigan, and Mr. Robert Stream, flying farmer, Ravenna, Michigan, have made major contributions to the Ohio University Snow Data Collection Program. Without their cooperation none of the results provided herein would have been available and we are indeed grateful for their contributions.

WZZM-TV has provided the use of their transmitter building for housing the far-field receiving and recording equipment and their 900-foot tower for supporting the probes used to measure the glide slope signal parameters. The WZZM-TV personnel associated with the transmitting station have generously contributed time and effort to take readings from recorders and meters during times when it was not possible for Ohio University project personnel to be present. This has resulted in significant savings of project man hours and money which would have otherwise been necessary to collect these data.

In particular we are indebted to Messrs. Dale Wolters, chief engineer; John Hauser; Marty Miller; Doren Dittlow; and Robert Pratt of the staff.

Mr. Robert Stream, owner and operator of a large farm in Ravenna Township, has generously made available several acres of farm land which includes the transmitting antennas and monitor probe structures for the Ohio University Glide Slope Transmitting Site. He has been most helpful in providing assistance by furnishing men and machinery for locating vehicles and towers at the test site.

We wish to recognize fully the many and voluntary contributions made by these men and their organizations. Certainly the monitoring of instrument landing glide slopes has been aided substantially by the help they have so generously provided.

VII. INVESTIGATORS

Mr. Jack B. Morehart as project engineer served as coordinator and organizer of the Ravenna, Michigan snow site and supervised the collection of the data.

Mr. Joe Zerlaut was the on-site technician who daily checked the automatic data collection and supplemented this with direct readings of critical parameters.

Mr. Joe Battistelli performed much of the analysis of the data which was collected and wrote a major portion of the report.

Mr. Tran Han Ban assisted by Mr. Richard Shutte reduced the analog strip chart data by putting it in a form for IBM 360/44 computer processing.

Messrs. Richard Zoulek, Douglas Reeder and Harry Hooghkirk were responsible for the physical installation and removal of the snow site transmitting and receiving equipment.

Mr. William Hartmann was the pilot on data collection flights in New York. Mr. Douglas Reeder was the ground-based technician during aircraft tracking operations.

Mr. Larry Mitchell designed and built the equipment for automating the calibration of the three glide slope systems.

Dr. Richard McFarland served as project director, flew calibration flight checks and other data collection in Michigan and formulated the conclusions and recommendations presented.

VIII. REFERENCES AND BIBLIOGRAPHY

[1] J. J. Battistelli, "The Design and Testing of a Glide Path Integral Monitor," No. 35, Avionics Engineering Center, Department of Electrical Engineering, Ohio University, Athens, Ohio, May 5, 1972.

[2] Jack E. McDonald, Stefanik, M., "Below Path Clearance Monitor," Avionics Engineering Center, Department of Electrical Engineering, Ohio University, Athens, Ohio, unpublished report.

[3] Jack B. Morehart, et. al., "Snow Effects on Image Glide Path Systems, Winter 1971-1972," Report No. FAA-RD-72-85, Avionics Engineering Center, Department of Electrical Engineering, Ohio University, Athens, Ohio, July 1972.

[4] "Earth Cover and Contour Effects on Image Glide Paths, Phase III," Avionics Research Group, Department of Electrical Engineering, Ohio University, Athens, Ohio, Report Number RD 68-60, I, September, 1968.

"Instrument Landing System Improvement Program," Third Interim Report, Contract FA69WA-2066, SRDS Report Number 72-71, Avionics Research Group, Department of Electrical Engineering, Ohio University, Athens, Ohio, June 1972.

"Instrument Landing System Improvement Program," Interim Report, Contract FA69WA-2066, SRDS Report Number RD 71-30, Avionics Research Group, Department of Electrical Engineering, Ohio University, Athens, Ohio, October 1971.

David A. Hill, M. S., "The Effects of Irregular Contour on Image-Glide Path Systems," Avionics Research Group, Ohio University Research Institute, Ohio University, Athens, Ohio, June 1966.

Donald K. Luttermoser, M. S., "The Effects of a Ground Covering of Snow Upon the Image-Type, Null Reference Glide Slope Monitor," Avionics Research Group, Ohio University, Athens, Ohio, Technical Report 5-3, June 1966.

"Earth Cover and Contour Effects on Image Glide Paths, Phase II," Avionics Research Group, Department of Electrical Engineering, Ohio University, Athens, Ohio, Report Number RD 66-39, July 10, 1966.

"Earth Cover and Contour Effects on Image Glide Paths," Final Report, Avionics Research Group, Department of Electrical Engineering, Ohio University, Athens, Ohio, Report Number RD 65-30, May 21, 1965.

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