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Volume 2

Uplink ATCRBS Environment Measurements Along the Boston-Washington Corridor Volume 2: Interrogator Characteristics

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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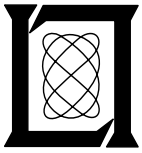

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16. Abstract

Airborne measurements of the Air Traffic Control Radar Beacon System (ATCRBS) 1030 MHz uplink environment due to ATC ground interrogators are described. The measurements were made using a special purpose airborne sensor-recorder during a flight from Boston to Washington (at 8500 feet) and back (at 17,500 feet) on 16 December 1977. Data were recorded at 24 locations between Boston and Washington.

Volume 1 of this report summarized the measured distributions of pulse, interrogation, and suppression rates with received power. This volume presents specific characteristics of the sources of the interrogations observed from the air during this flight. These characteristics include the identities of 46 of the interrogators, the approximate locations of 22 unidentified interrogators, the interrogation repetition interval (PRI), scan period, and mode interlace of all interrogators, and the radiated P1, P2, and P3 levels in the form of antenna patterns for six selected interrogators. It was found that approximately 40% of the interrogators employ the standard AAC or 2ACA mode interlaces while 20% transmit no Mode C interrogations. The distributions of PRI's and scan periods were found to be relatively free of bunching which would cause undesired synchronization effects. The antenna plots measured from the air show relatively large scan to scan variations due to aircraft motion. In addition, some of the interrogator sites were found to suffer from reflections and sidelobe punch-through effects.

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1.0 INTRODUCTION

1.1 Background

Volume 1 of this report described the airborne ATCRBS interrogation environment observed during an Airborne Measurement Facility(AMF) flight between Boston and Washington, D.C.* Total event counts (pulses, suppressions, interrogations, number of interrogators seen) were given for all measurement locations, and distributions of events vs. amplitude were plotted for selected locations. This information was given with minimum regard to the originating interrogators.

This volume of the report presents specific characteristics of the sources of the airborne ATCRBS interrogation environment observed during the same flight. These characteristics include the approximate locations of the unidentified interrogators, the PRF, scan period, mode interlace of all interrogators, and for selected interrogators, the radiated P1, P2 and P3 levels in the form of antenna patterns.

1.2 Recording and Processing of Measurements

The AMF records the level, time of arrival and duration of each pulse whose amplitude exceeds a preselected threshold (generally set at -76 dBm) for at least 375 nsec, provided its leading edge rises at least 6 dB in an interval of 125 nsec. An estimate of the relative bearing of the source of each pulse is also recorded. All data included in this report were obtained from an antenna mounted on the underside of a twin-engine Piper Navajo aircraft. The pulse information is digitized with 1 dB resolution and recorded, together with aircraft position and time of day data, for later analysis.

The AMF uplink analysis program a) associates the valid pulses into ATCRBS interrogation modes and suppression pairs; b) provides amplitude distributions and total event counts for each mode; c) arranges the interrogations into a time-ordered interrogation file; d) calculates all interrogation repetition intervals (PRI's) present in the interrogation data; and e) associates all interrogations from a given interrogator, thereby permitting identification of interrogator dwell time, beamwidth and scan period. The mode interlace pattern of the interrogator is also determined, and deviations of the actual time of occurrence of the interrogations from the expected time are calculated.

An antenna pattern plotting program operates on the data from the uplink analysis program to provide plots for a specified interrogator over a few scan intervals, of the level of received P1, P2, and P3 pulses, their amplitude and delay if reflected, and of the levels of sidelobe punch-through if it occurs.

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*For a description of the flight path refer to: F. Nagy, Jr., "Uplink ATCRBS Environment Measurements Along the Boston-Washington Corridor, Volume 1: The RF Environment," Project Report ATC-83, Vol. 1, Lincoln Laboratory, M.I.T. (27 June 1978), FAA Report No. FAA-RD-78-33.

Volume 1 summarized the findings of the first two steps (a and b) of this analysis process. The remaining steps in the uplink analysis are reported in this volume.

2.0 INTERROGATOR CHARACTERISTICS

This section presents information on the 68 ground interrogators observed during the AMF flight of 16 December 1977:

1. Interrogator characteristics:

    a) Basic: Name (if identified), location, pulse repetition interval (PRI), scan period, mode interlace, and PRI stagger period for each interrogator observed.

    b) Additional: Peak received power, total interrogations, percentage of interrogations received in the mainbeam, measured beamwidth, site clock error and distance from the AMF (when known) for all interrogators seen at three locations along the higher altitude portion of the flight path.

2. Number of interrogations received in a 1-minute recording interval:

    a) From each interrogator "seen" at each measurement location.

    b) At each pulse repetition frequency, repeated for each of three widely separated, high altitude measurement locations.

2.1 Basic Interrogator Characteristics

Table 2-1 lists these characteristics of the observed interrogators:

Interrogator ID number
Interrogator name (if known)
Pulse repetition interval (average value if staggered PRI is in use) and pulse repetition frequency
Scan period
Mode interlace
PRI stagger period

PRF's observed ranged from 202.2 to 445.3 interrogations per second, corresponding to a PRI range of 4944.8 to 2245.5 μs. Interrogators are listed in Table 2-2 in order of increasing PRI value. The individual PRI's of some of the interrogators employing staggered PRI are given in Table 2-3 (Tables 2-1 and 2-2 list average PRI).

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*Interrogator ID numbers were assigned from 1 to 78 before 10 interrogators (24, 30, 40, 43, 60, 63, 66, 70, 71, and 75) were recognized as being accounted for twice; hence a total of 68 interrogators are actually listed.

TABLE 2-1

INTERROGATOR CHARACTERISTICS

Interrogator ID	Name	PRI (μsec)	PRF (sec^{-1})	Scan Period (sec)	Interlace Pattern	Stagger
1	Logan	2267.5	441.0	4.57	AAC	8
2	Falmouth	2499.3±7	400.1	4.68	A	5
3	Quonset Pt.	2599.0±7	384.8	3.91	AAC	5
4	Winthrop	2860.8	349.5	11.89	AAC	1
5	W. Cummington	2899.0±7	345.0	12.04	2ACA	5
6	Windsor Locks	2961.0±7	337.7	4.70	AAC	5
7	Montauk Pt.	3014.7	331.7	11.40	2ACA	1
8		3298.0±5	303.2	9.95	2AC	5
9		3519.7	284.1	4.69	AC	1
10	Calverton	3547.8±1	281.9	10.21	2AC	1
11	North Truro	4134.7	241.9	11.98	2ACA	1
12	JFK En-Route	2821.4	354.4	9.60	AAC	1
13	Islip	3095.0±7	323.1	4.71	A	5
14	White Plains	2912.1	343.4	4.03	A	1
15		3304.0±5	302.7	9.91	2AC	5
16		3634.0±5	275.2	19.60	2AC	5
17	No. Smithfield	3999.9	250.0	9.30	12AC	1
18	Albany	2629.9	380.2	3.92	AAC	1
19	Trevose	2740.0±7	365.0	12.03	AAC	5
20	Elwood	2780.8	359.6	9.60	AAC	1
21	Gibbsboro	3040.0	328.9	11.77	2ACA/4	1
22		3118.8	320.6	1.19	A	R†
23	McGuire	3342.2	299.2	3.92	AC	1
24	(Number not used)					
25	Rome	2566.0±6	389.5	1.19	A	R†
26		3483.0	287.1		A	R†
27	Benton	2777.5	360.0	12.04	AAC	1
28	Atl.City NAFEC	2629.2	380.3	3.92	AAC	1

†R = nonrepeating random stagger.

TABLE 2-1 (Continued)

Interrogator ID	Name	PRI (μsec)	PRF^{-1} (sec)	Scan Period (sec)	Interlace Pattern†	Stagger
29		2666.0	375.1	3.51	C	1
30	(Number not used)					
31	Lakehurst	3334.5	299.9	3.86	8*AC	1
32	Willow Grove	3336.4	299.7	3.76	2*AC	1
33	Allentown	2290.6	436.6	4.71	A	8
34	Philadelphia	2267.6	441.0	4.68	AAC	8
35	Atlantic City	2914.7±7	343.1	4.67	AAC	5
36	Ft. Meade	2706.2	369.5	11.98	2ACA/4	1
37	Dover	4439.8	225.2	4.67	AC	1
38	Suitland	2861.4	349.5	10.10	AC	1
39	Curtis Bay	3139.2	318.6	11.7	2AC	1
40	(Number not used)					
41	NAS Patuxent	2504.7	399.2	3.92	AC	1
42	Balt. Wash.	2966.7±7	337.1	4.70	AAC	5
43	(Number not used)					
44	Andrews	2596.1±7	385.2	4.69	AAC	5
45	Langley	3332.4	300.1	7.71	2	1
46	Dulles	2625.3	380.9	3.91	AAC	1
47	Richmond	2563.1	390.1	3.92	A	1
48		3882.0	257.6	7.50	AC	1
49	Cape Charles	4146.3	241.2	12.02	2ACA	1
50	Norfolk	2532.0	394.9	4.03	ACA	1
51		3414.9	292.8	7.80	4*12AC	9
52		3068.5	325.9	9.78	12AC	1
53		4944.8	202.2	11.65	4*12AC	2
54		3641.2	274.6	3.85	2*AC	1
55		3746.9	266.9	11.96	1AC	1
56		3751.4	266.6	3.93	2AC	1

†"n*XY" indicates that the interlace pattern consists of n X-mode transmissions followed by a n Y-mode transmissions, e.g., 2*AC = AACCAACCAACC ... "/" is used to indicate "and or".

TABLE 2-1 (Continued)

Interrogator ID	Name	PRI (μsec)	PRF (sec^{-1})	Scan Period (sec)	Interlace Pattern	Stagger
57		3039.9	328.8	11.77	2ACA	1
58		2568.0	389.4	3.91	A	1
59		2715.5	368.3	3.94	A	1
60	(Number not used)					
61		2970.4	336.7	12.02	2AC	1
62		3311.9±5	301.9	10.14	Var.	5
63	(Number not used)					
64		2736.4	365.4	3.95	A	1
65		3468.7±1	288.3	9.09	12AC	3
66	(Number not used)					
67	Binghamton	2501.0	399.8	3.92	AAC	1
68	Saratoga Sprgs.	3079.9	324.7	11.85	A	1
69	Orange	3999.9	250.0	9.36	12AC	1
70	(Number not used)					
71	(Number not used)					
72		2768.1	361.3	3.85	AC	1
73	Pease	3503.2	285.5	4.69	AC	1
74	Portland	2498.2	400.3	3.94	A	1
75	(Number not used)					
76	JFK	2245.5	445.3	4.69	AAC	40
77	Newark	2359.9	423.8	4.69	AAC	40
78	Washington	2245.5	445.3	4.69	AAC	40

TABLE 2-2

INTERROGATORS LISTED BY PRI VALUE

PRI (μsec)	Interrogator ID	Name	PRI (μsec)	Interrogator ID	Name
2245.5†	76	JFK	2966.7†	42	Balt.-Wash.
2245.5†	78	Washington	2970.4	61	
2267.5†	1	Logan	3014.7	7	Montauk Pt.
2267.6†	34	Philadelphia	3039.9	57	
2290.6†	33	Allentown	3040.0	21	Gibbsboro
2359.9†	77	Newark	3068.5	52	
2498.2	74	Portland	3079.9	68	Saratoga Sprgs.
2499.3†	2	Falmouth	3095.0†	13	Islip
2501.0	67	Binghamton	3118.8	22	
2504.7	41	NAS, Patuxent	3139.2	39	Curtis Bay
2532.0	50	Norfolk	3298.0†	8	
2563.1	47	Richmond	3304.0†	15	
2566.0	25	Rome	3311.9†	62	
2568.4	58		3332.4	45	Langley
2596.1†	44		3334.5	31	Lakehurst
2599.0†	3	Quonset Pt.	3336.4	32	Willow Grove
2625.3	46	Dulles	3342.2	23	McGuire
2629.2	28	Atl. City NAFEC	3414.9†	51	
2629.9	18	Albany	3468.7	65	
2666.0	29		3438.0	26	
2706.2	36	Ft. Meade	3503.2	73	Pease AFB
2715.5	59		3519.7	9	
2736.4	64		3547.8	10	Calverton
2740.0†	19	Trevose	3634.0†	16	
3768.1	72		3641.2	54	
2777.5	27	Benton	3746.9	55	
2780.8	20	Elwood	3751.4	56	
2821.4	12	JFK Enroute	3882.0	48	
2860.8	4	Winthrop	3999.0	17	No. Smithfield
2861.4	38	Suitland	3999.9	69	Orange
2899.0†	5	W. Cummington	4134.7	11	No. Truro
2912.1	14	White Plains	4146.3	49	Cape Charles
2914.7†	35	Atl. City	4439.8	37	Dover
2961.0†	6	Windsor Locks	4944.8†	53	

Numbers not used in Table are 24, 30, 40, 43, 60, 63, 66, 70, 71, and 75.

†PRI average value.

TABLE 2-3

INTERROGATORS EMPLOYING STAGGERED OR RANDOM PRI

5-Pulse Stagger

±3.6 and ±7.2 μsec

(2) Falmouth
(3) Quonset Point
(5) West Cummington
(6) Windsor Locks
(13) Islip
(18) Trevose
(35) Atlantic City
(42) Baltimore-Washington
(44) Andrews

5-Pulse Stagger

±2.5 and ±5.0 μsec

(8) Unknown
(15) Unknown
(16) Unknown
(62) Unknown

8-Pulse Stagger

(1) Logan (Q Crystal)
(34) Philadelphia (Q Crystal)
(33) Allentown (R Crystal)

40-Pulse Stagger

(76) John F. Kennedy (P Crystal)
(78) Washington (P Crystal)
(77) Newark (U Crystal)

Random (Nonrepeating)

(22) Unknown
(25) Rome
(26) Unknown

Scan periods varied from 1.19 secs. to 19.60 secs. The highest scan rates (Interrogators 22 and 25) are probably those of ramp testers; the lowest scan rate (interrogator number 16, not identified) is probably that of a shipborne interrogator. The 3.92 and 4.69 sec. scan periods are believed to be those of terminal interrogators (4.69 probably ASR-7), and scan periods from 9.5 to 12.0 secs. those of long range interrogators.

Terminal interrogators use the AAC mode interlace and enroute interrogators the 2ACA mode interlace. These two interlaces account for 40-percent of the total interrogators whose characteristics were measured. Thirteen interrogators transmitted only Mode A. Unusual mode interlaces were:

Mode 2 only: (45) Langley
Mode C only: (29) Unknown
AAAAAAAACCCCCCCC: (31) Lakehurst
11112222AAAACCCC: (51), (53) Unknowns
Modes A and C, randomly: (41) NAS Patuxent
Different interlace every 10 minutes: (62) Unknown

Mode 4 interrogations were received from Gibbsboro (21) and Fort Meade (36).

2.1.1 Interrogator Locations

The geographical locations of nearly all of the 46 interrogators whose angle-of-arrival (AOA) data and published interrogation parameters permitted accurate identification are shown on the map of Fig. 1-1 in Volume 1 of this report.

Comparison of the measured and true AOA values for each measurement location from which 23 of the 46 identified interrogators were observed has established that the standard deviation of the AMF AOA measurement is about 13.5 degrees.

The identities of 22 interrogators remain unknown. The available AOA data for these interrogators does not permit their location precisely, as indicated in Table 2-4 and Fig. 2-1a through 2-1f*. In this figure, the approximate relative distance estimate to the interrogator is shown by the length of the angle-of-arrival vector. The distance estimate is obtained from the peak interrogation power measurement assuming a nominal interrogator transmit power of 250 W. Ordinarily, location of the source of interrogations is simply a matter of triangulation based on the intersections of the AOA rays from measurements at several aircraft locations. If only one ray is established, possibly due to the great distance from aircraft to interrogator, or the fact that the interrogator does not operate continuously, the geographical region of position uncertainty is defined by a 27° angular wedge.

*It is seen in these figures that there are occasional anomalies in the angle-of-arrival measurements. These anomalous estimates are caused primarily by the circuit used to digitize the output of the angle-of-arrival receiver. The transfer function for the digitizer includes discontinuities at certain azimuths. An improved circuit will provide more consistent azimuth estimates in future measurements.

TABLE 2-4

APPROXIMATE LOCATIONS OF UNIDENTIFIED INTERROGATORS

BASED ON ANGLE-OF-ARRIVAL (AOA) MEASUREMENTS

AOAs Established	Interrogator ID No.	Measurement Location	AOA*	Approximate Location
(1) One	9	A	41°	Toward Portland, ME, in ocean
	22	D	291°	Toward Binghamton, NY (WNW of Location D)
	59	O	268°	Toward Dulles Airport (West of Location O)
	64	P	245°	Toward Andrews AFB (WSW of Location P)
	65	P	217°	Toward Patuxent R. NAS (SW of Location P)
(2) Two	15	N	86°	Toward Delaware Bay and
		O	70°	S. New Jersey
	26	E	152°	Midway between JFK and
		F	103°	Bethpage, LI
	53	N	154°	Off Virginia Beach, in
		O	171°	Atlantic Ocean
	54	N	163°	Off Virginia Beach, in
		O	183°	Atlantic Ocean
	56	N	161°	Off Virginia Beach, in
		O	173°	Atlantic Ocean
(3) Three	16†	C	132°	South of White Plains, NY
		E	183°	
		F	199°	
	29	F	84°	Northern NJ or Long Island
		G	62°	
		H	74°	
	48	M	151°	Between Virginia Beach
		N	166°	and Cape Charles
		O	212°	
	51	N	165°	Near Cape Charles
		O	179°	
		P	195°	
	52†	N	247°	Central Maryland or
		O	243°	Eastern Virginia
		P	212°	
	55	N	167°	Off Cape Charles, in
		O	171°	Atlantic Ocean
		P	173°	

TABLE 2-4 (Continued)

AOAs Established	Interrogator ID No.	Measurement Location	AOA*	Approximate Location
	57†	N	171°	Off Cape Charles, in
		O	165°	Atlantic Ocean
		P	110°	
	61	N	138°	Between Patuxent River NAS
		O	198°	and Cape Charles
		P	209°	
	62†	O	59°	Coastal NJ or Long Island
		P	40°	
		Q	45°	
(4) Four	8	A	167°	20-80 SSE of Montauk Pt.
		B	162°	Long Island
		C	137°	
		D	133°	
		E	143°	
	58	O	315°	≈30 nmi south of Harrisburg,
		P	278°	Pennsylvania
		Q	270°	
		R	256°	
	72†	U	47°	Southeastern Massachusetts
		V	14°	
		W	23°	
		X	94°	

*AOA is expressed as a bearing in degrees referenced to True North from measurement location.

†Set of AOAs appears to contain an anomalous measurement.

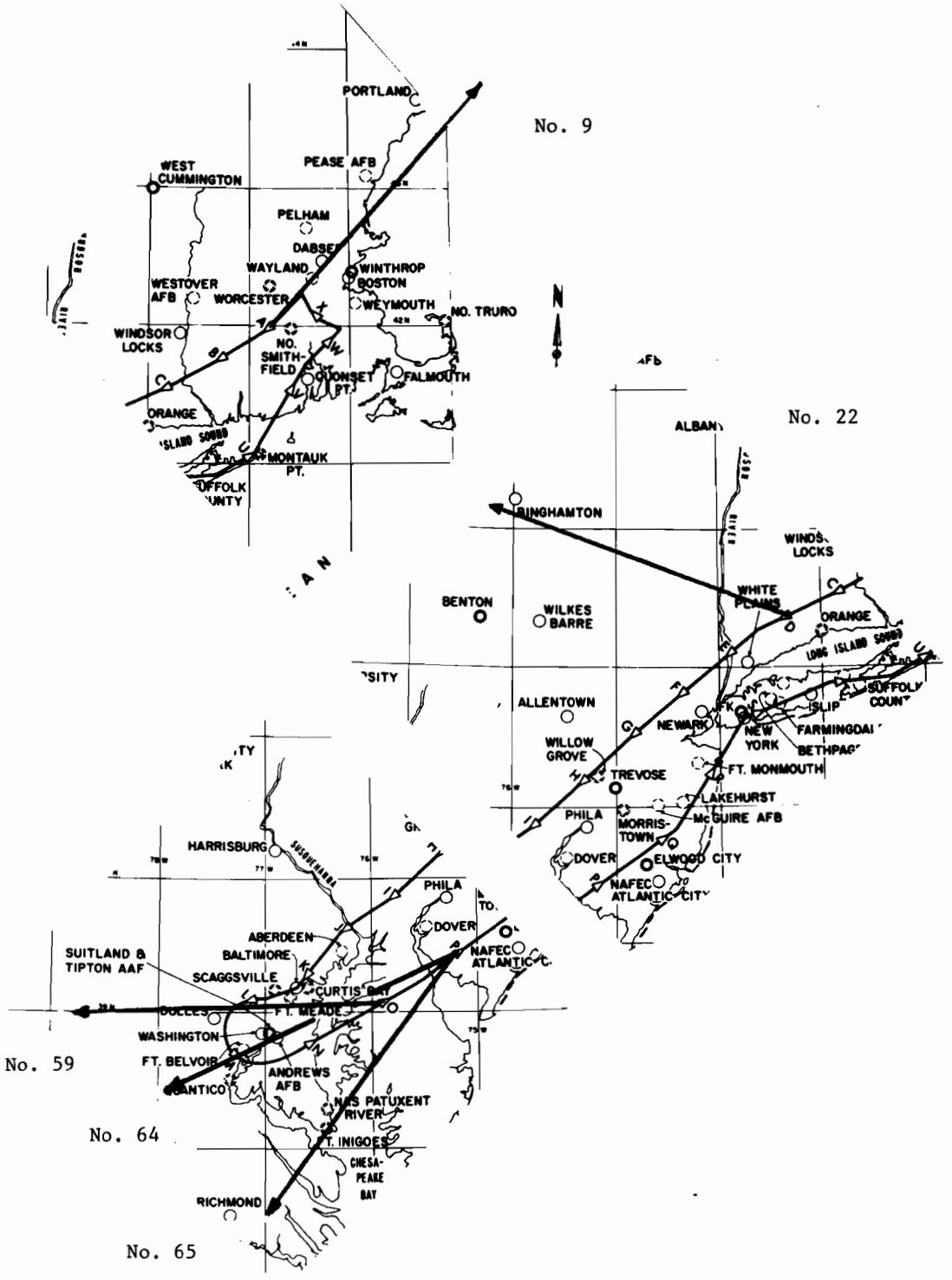


Fig. 2-1a. Angle-of-Arrival Rays for Unidentified Interrogators 9, 22, 59, 64 and 65.

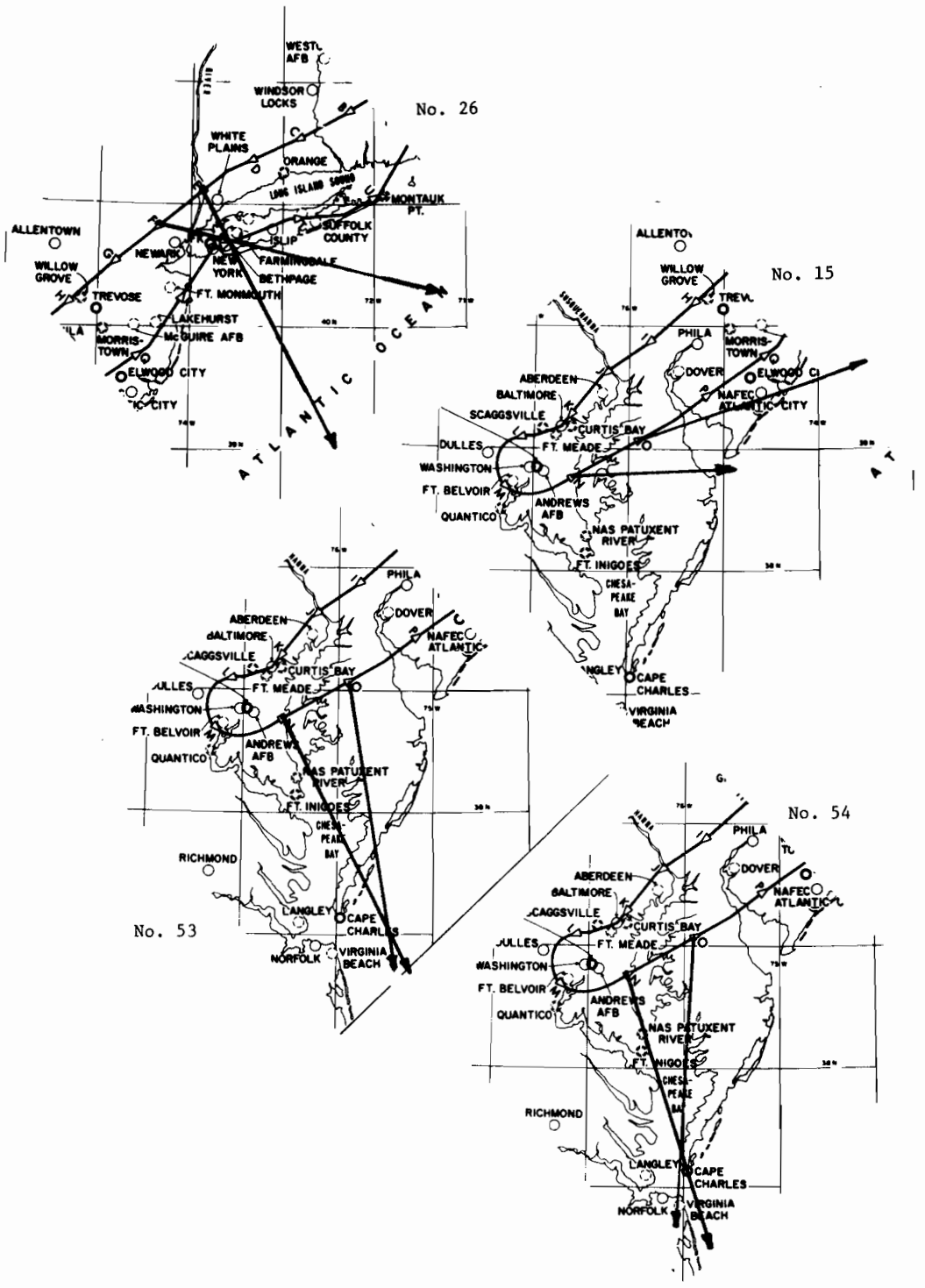


Fig. 2-1b. Angel-of-Arrival Rays for Unidentified Interrogators 15, 26, 53 and 54.

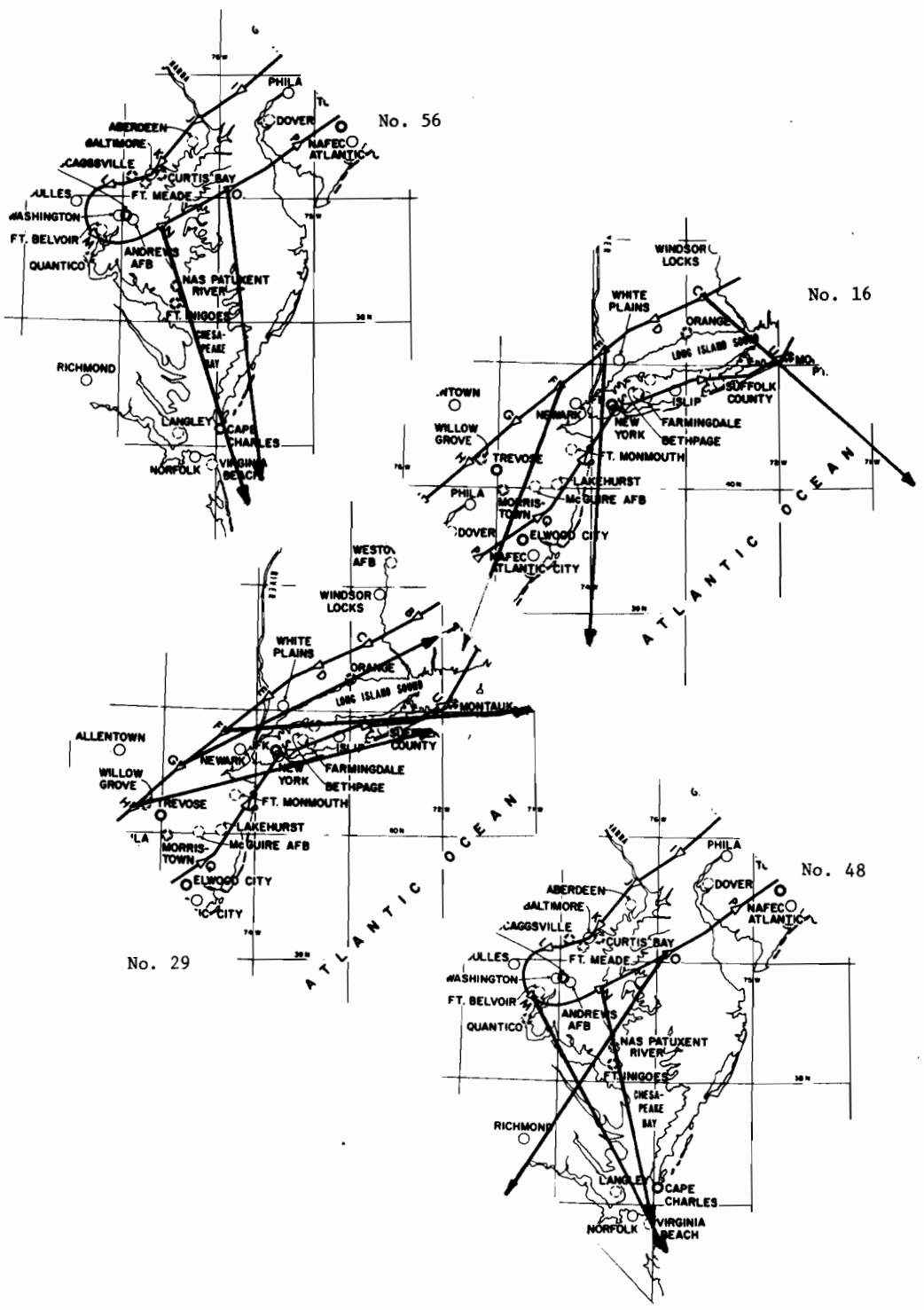


Fig. 2-1c. Angle-of-Arrival Rays for Unidentified Interrogators 16, 29, 48 and 56.

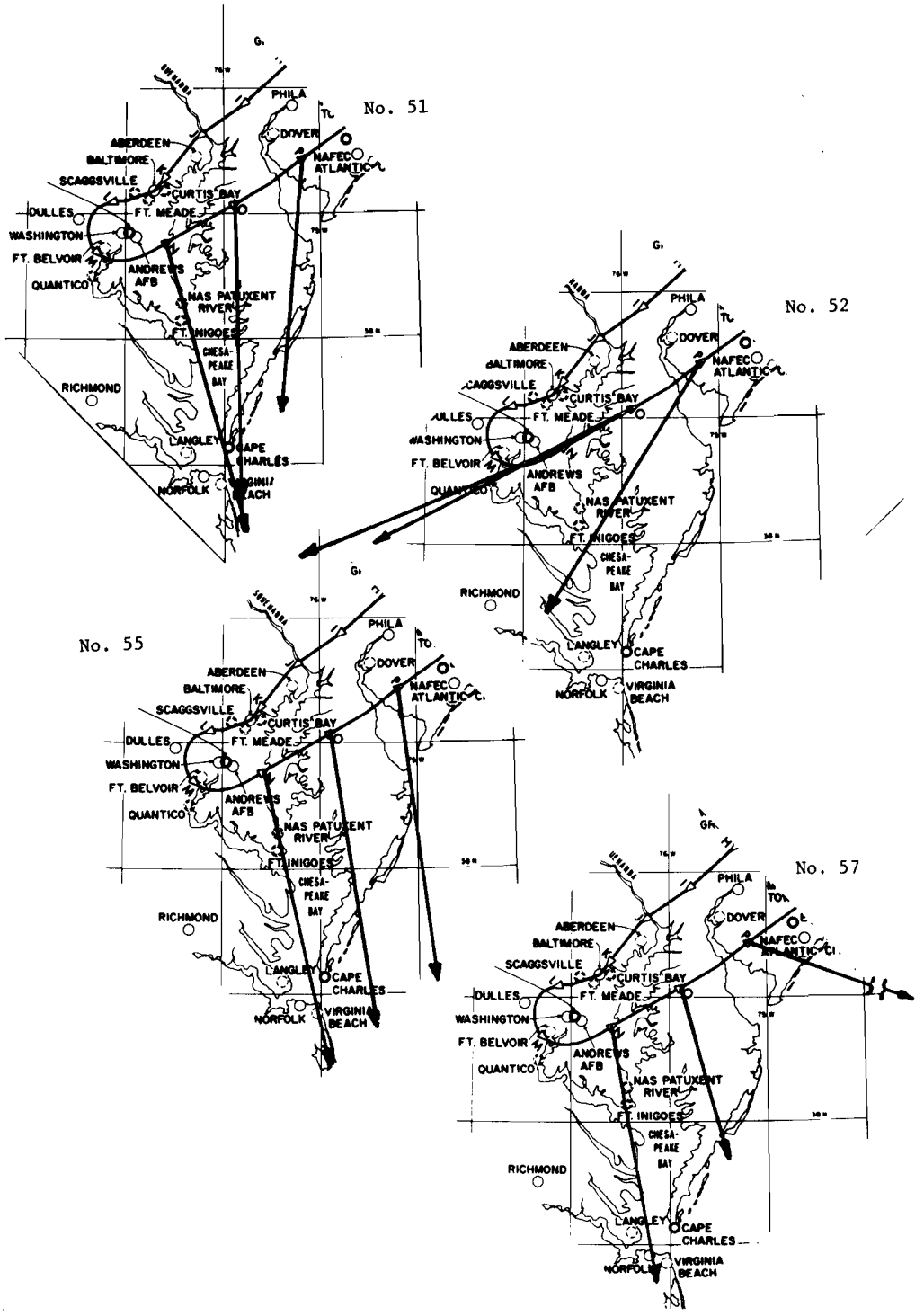


Fig. 2-1d. Angel-of-Arrival Rays for Unidentified Interrogators 51, 52, 55 and 57.

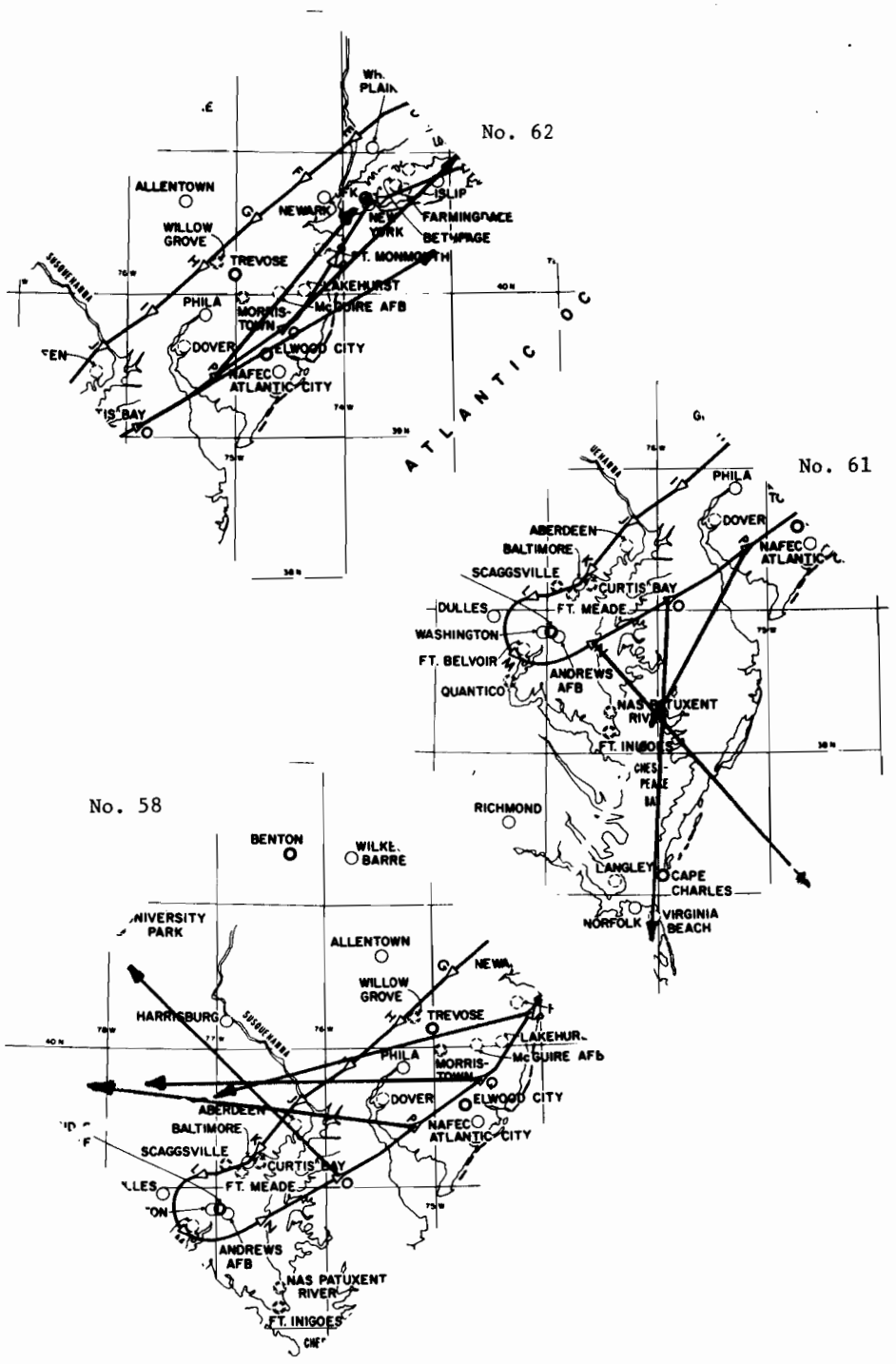


Fig. 2-1e. Angle-of-Arrival Rays for Unidentified Interrogators 58, 61 and 62.

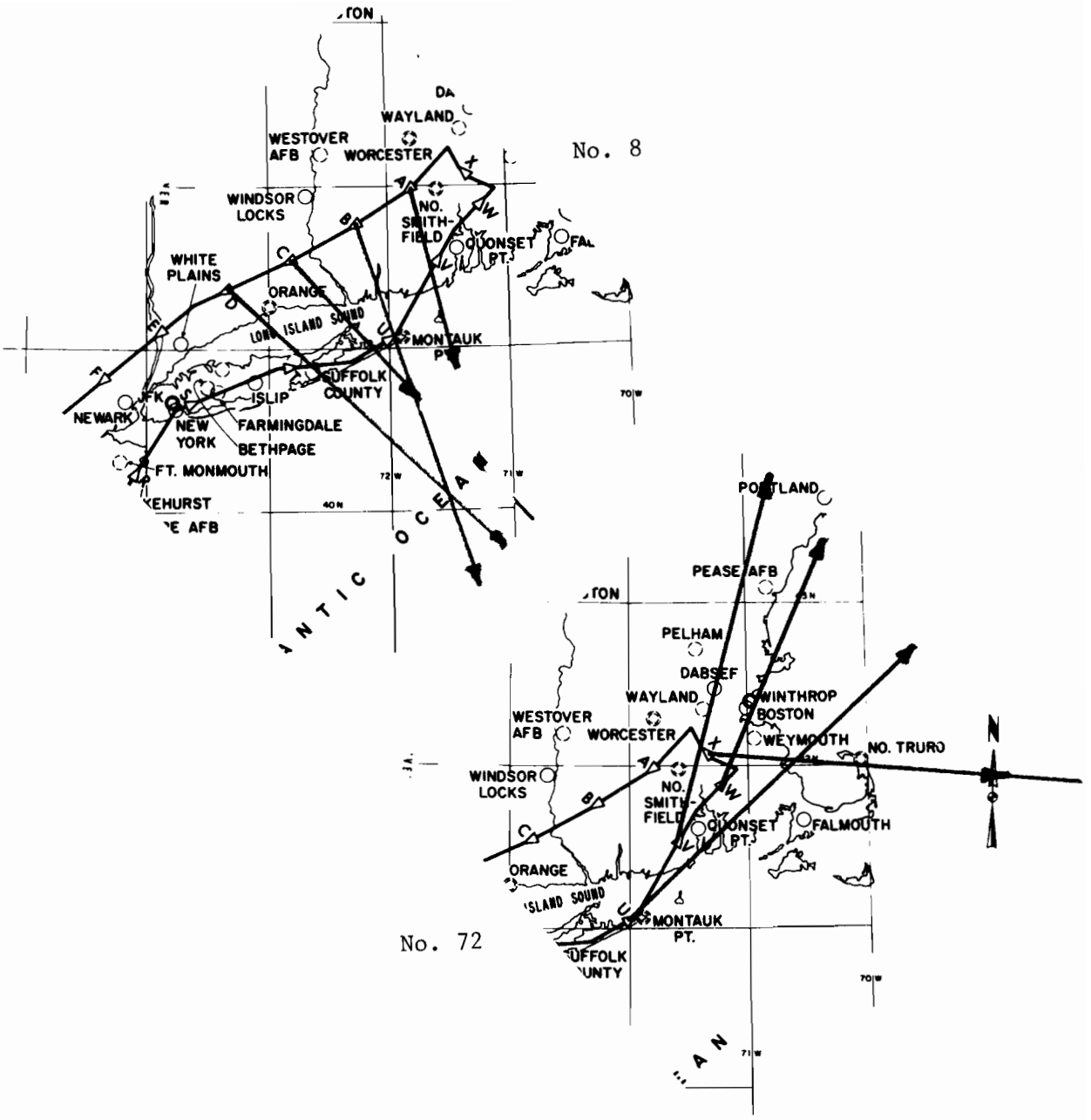


Fig. 2-1f. Angle-of-Arrival Rays for Unidentified Interrogators 8 and 72.

The area within this wedge is very large*. If two intersecting rays are established, each with an angular uncertainty of 13.5°, the "region" of uncertainty tends to reduce to a smaller wedge determined by the area common to the individual wedges. If three or more AOA measurement values are available, the uncertainty region becomes smaller if their intersections fall close together, and large if they do not.

Despite the poor definition of the areas in which these unidentified interrogators fall, many of them could be located if their transmission characteristics were given in available military, FAA or ECAC documents. Such information has not been located. In addition, the approximate locations of a number of the interrogators suggest that they are shipborne or mobile and thus not identifiable by location.

2.2 Additional Interrogator Characteristics

Tables 2-5, 2-6, and 2-7 provide additional characteristics of all interrogators observed at measurement locations N (near Washington, D.C., the most southern point of observation), S (near New York) and W (near Boston, the most northerly point of observation):

Number of interrogations received during 32 sec. period
Proportion received on the interrogator mainbeam
Distance from the AMF to the interrogator
Peak power of the mainbeam**
Beamwidth of interrogator mainbeam
Total observed PRI drift in a stated observation interval

2.3 Interrogation Rate at Each Measurement Location

Fig. 2-2 depicts the number of interrogations received in a 1-minute interval from each interrogator at each of the 24 measurement locations. The size of the character plotted at each interrogator-measurements location coordinate indicates the received interrogation rate and provides the following information:

---

*The uncertainty area is limited by the range of the radio horizon. This range is approximately 115 nmi at 8500 ft. altitude; and 160 nmi, at 17,500 ft. altitude.

**Received at AMF receiver via 2.0 dB cabling loss.

TABLE 2-5

ADDITIONAL INTERROGATOR PARAMETERS
(NEAR WASHINGTON: LOCATION N)

Interrogator ID	Name	No. Ints. Received (in 32 secs)	Received In Main-beam (%)	Dist. to Interrogator (nmi)	Peak Power (dBm)	Beamwidth (Degrees)	PRI Drift Max. (μs)	PRI Drift In (secs)
15		227	100	∿100	-53			
19	Trevose	81	96	109	-57	3.41		
20	Elwood	27	100	99	-59			
21	Gibbsboro	210		98	-49			
23	McGuire	96	100	117	-61	4.11	0.2	23
27	Benton	19	100	156	-74			
28	Atl. City NAFEC	157	99	101	-61	4.59	2.0	27
31	Lakehurst	99	90	127	-73	4.62	1.6	27
32	Willow Grove	118	97	108	-61	4.71	3.8	26
33	Allentown	113	98	123	-71	2.99		
34	Philadelphia	141	100	88	-62	4.12		
35	Atlantic City	108	91	100	-65	3.89		
36	Ft. Meade	457	34	22	-40	6.76	3.0	12
37	Dover	86	99	54	-61	3.95	3.9	28
38	Suitland	151	64	18	-42	3.41	0.5	20
39	Curtis Bay	285	76	25	-44	7.68	0.6	26
41	NAS Patuxent	171	94	30	-46	4.85	10.2	27
42	Balt-Washington	142	99	26	-56	4.65		
44	Andrews	181	97	~15	-45	4.87		
46	Dulles	159	97	43	-57	4.68	3.1	28

TABLE 2-5 (Continued)

Interrogator ID	Name	No. Ints. Received (in 32 secs)	Received In Main-beam (%)	Dist. to Interrogator (nmi)	Peak Power (dBm)	Beamwidth (Degrees)	PRI Drift Max. (μs)	PRI Drift In (secs)
47	Richmond	134	99	83	-65	3.88	2.0	27
48		201	74	∿ 30	-56	9.21	6.4	23
49	Cape Charles	91	89	102	-56	3.94	4.5	24
50	Norfolk	119	96	112	-71	3.52	1.8	24
51		225		∿110	-72			
52		501	89	∿ 30	-59	19.35	11.9	20
53		145		∿120	-74			
54		189	100	∿120	-62	8.30	25.3	23
55		208	99	∿120	-63	7.05	3.2	24
56		85	100	∿120	-60	3.98	5.0	24
57		101		30-100	-61			
61		206	89	∿100	-60	6.26	0.6	24
78	Wash. (ASR-7)	150		22	-51			

TABLE 2-6

ADDITIONAL INTERROGATOR PARAMETERS
(NEAR NEW YORK: LOCATION S)

Interrogator ID	Name	No. Ints. Received (in 32 secs)	Received In Main-beam (%)	Dist. to Interrogator (nmi)	Peak Power (dBm)	Beamwidth (Degrees)	PRI Drift Max. (μs)	PRI Drift In (secs)
3	Quonset Pt.	120	99	114	-70	3.23		
5	W. Cummington	108	97	143	-58	3.24		
6	Windsor Locks	110	96	88	-65	3.66		
7	Montauk Pt.	174	79	83	-54	4.85	0.2	23
10	Calverton	199	66	42	-51	4.21	19.4	31
12	JFK En-Route	305	48	7	-37	4.48	1.8	29
14	White Plains	165	96	23	-51	6.23	3.2	28
18	Albany	56	99	125	-73			
19	Trevose	119	98	70	-51	3.29		
21	Gibbsborrow	184	88	78	-51	6.82	1.2	23
23	McGuire AFB	140	97	58	-57	5.17	1.5	32
27	Benton	125	86	128	-57	3.19	13.2	24
28	Atl. City NAFEC	136	99	84	-69			
31	Lakehurst	87	76	50	-72	4.85	4.1	19
32	Willow Grove	177	62	74	-61	4.15	4.0	30
33	Allentown	92	66	83	-73	2.53		
34	Phila. (ASR-7)	151	96	89	-63	4.03		
35	Atlantic City	100	99	84	-72	3.46		
36	Ft. Meade	146	99	170	-64	4.33	0.7	24
37	Dover	43	76	125	-72	2.60	14.1	23
62		997	37	~75	-48	12.61		
63	Islip	146	95	25	-51	4.97	0.9	23
67	Binghamton	116	95	140	-72	3.06	12.0	31
68	Saratoga Sprgs.	132	92	140	-57	4.18	1.2	24
69	Orange	582	72	47	-56	20.58	0.6	28
76	JFK (ASR-7)	211		5	-45			
77	Newark (ASR-7	211		24	-51			

TABLE 2-7

ADDITIONAL INTERROGATOR PARAMETERS
(NEAR BOSTON: LOCATION W)

Interrogator ID	Name	No. Ints. Received (in 32 secs)	Received In Main-beam (%)	Dist. to Inter (nmi)	Peak power (dBm)	Beamwidth (Degrees)	PRI Drift Max. (μs)	PRI Drift In (secs)
1	Logan	228	95	29	-46	5.56		
2	Falmouth	162	88	33	-56	5.25		
3	Quonset Pt.	185	63	18	-43			
4	Winthrop	94	95	33	-46	3.57	1.6	36
5	W. Cummington	98	95	102	-57	3.13		
6	Windsor Locks	117	85	65	-61	4.13		
7	Montauk Pt.	402	55	57	-49	7.22	3.7	57
10	Calverton	94	95	92	-63	3.65	26.8	51
12	JFK En-Route	86	100	137	-62	2.79	1.0	48
13	Islip	106	78	107	-69	3.51	0.6	56
14	White Plains	57	77	123	-75		1.9	56
68	Saratoga Sprgs.	27	86	128	-76	2.29	1.1	12
69	Orange	245	100	88	-67	12.90		
72		154	57	∿15	-59	4.03	14.3	54
73	Pease AFB	108	84	74	-59	4.38	18.1	51
74	Portland	58	82	112	-74	2.57	0.7	55
76	JFK (ASR-7)	205		136	-74			

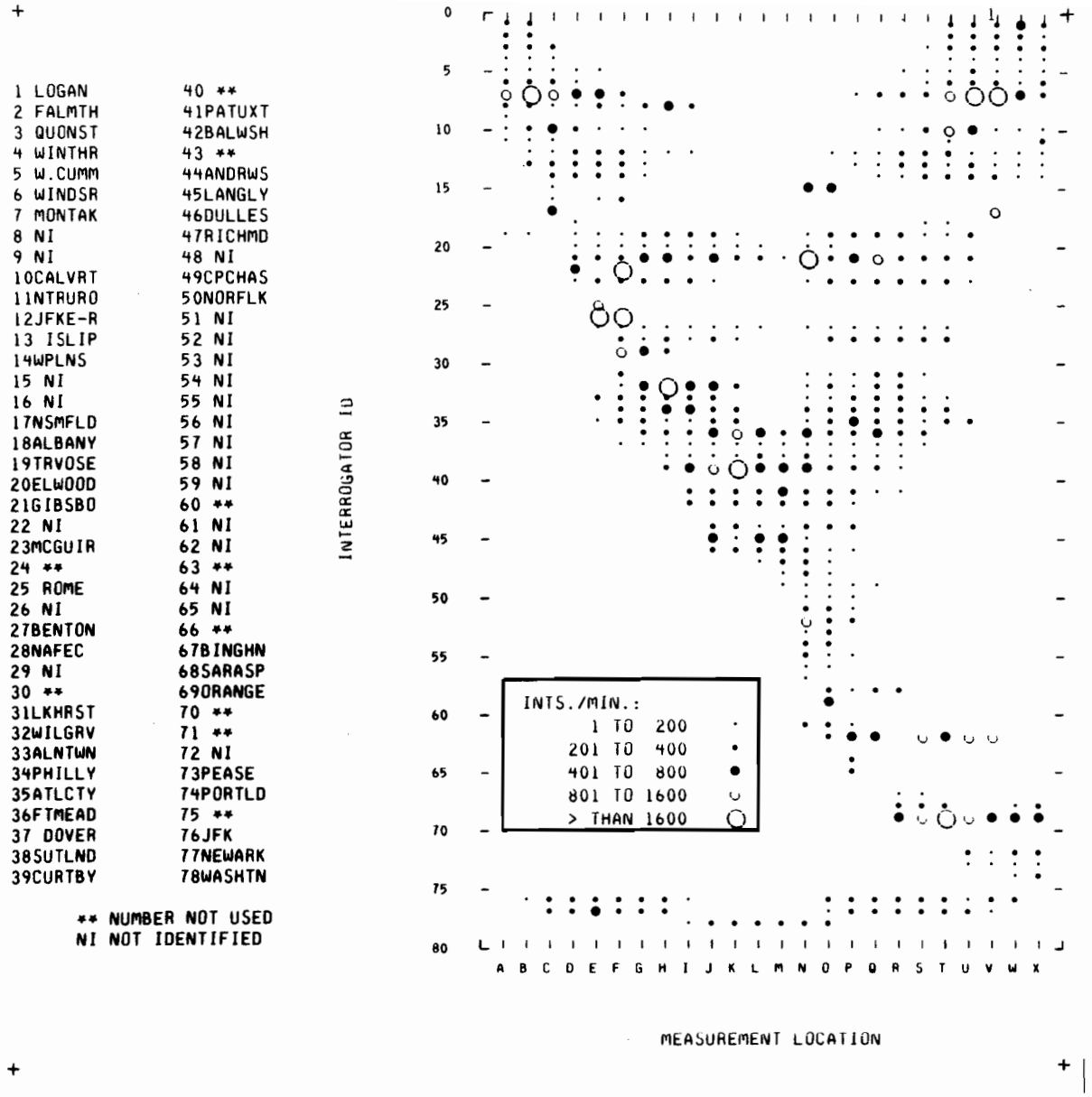


Fig. 2-2. Number of Interrogations Received in One Minute.

The identity of each interrogator contributing to the environment at a given location.

The number of interrogators contributing to the environment at a given measurement location.

The relative contribution of each interrogator to the total environment at a given location.

The rate at which the contribution of a particular interrogator diminishes as the "receiver" moves away from it.

An indication of which interrogators do not employ SLS.

2.4 Interrogation Environment at Three Locations

Fig. 2-3, depicts the number of interrogations received versus PRI in a 1-minute period at (a) a position between Washington and Philadelphia (Position 0), (b) a position near New York (Position S), and (c) a position near Boston (Position W).

Interrogators employing 5-pulse stagger are shown as single bars since PRIs are too close for separation. Those with 8-pulse stagger and more widely dispersed PRIs appear as 8 short bars whose sum is the total number of interrogations. Also, the number of interrogations received per minute at each of the 40 PRIs making up the 40-pulse staggered PRI ensemble is small (less than 10) so the interrogators employing this stagger are not shown.

In Fig. 2-3(a) for Location 0, the eight contributions from Philadelphia and from Allentown are identified. These interrogations plus JFK and Newark (using 40-pulse stagger and therefore not shown) together with the 34 single line contributors account for the 38 interrogators observed at this location. PRIs at this location appear to be fairly uniformly distributed with some gaps and some bunching at a PRI of 3300 μsec.

In Fig. 2-3(b) for Location S, one 8-pulse contributor, Philadelphia, plus the 40-pulse contributors at Allentown, JFK and Newark (not shown) increase the 23 single line contributors shown to the total of 27 interrogators observed at this location. Some bunching of emissions occurs near PRIs of 2900, 3030 and 3330 μsec.

In Fig. 2-3(c), for Location W near Boston, one 8-pulse contributor, Logan, plus the 40-pulse contributors, JFK and Newark, increase the 14 single line contributors to the total of 17 interrogators observed at this location.

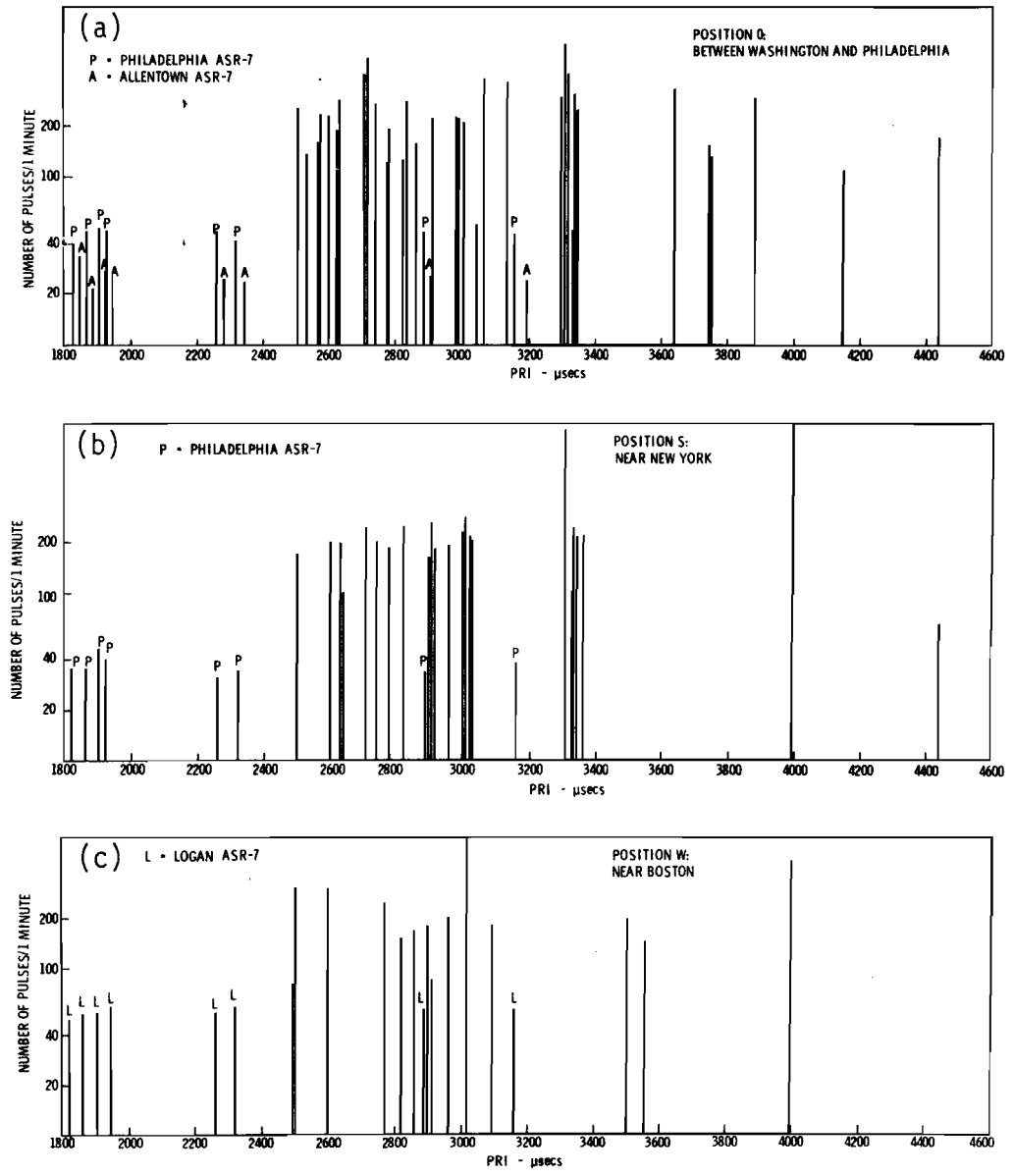


Fig. 2-3. PRF Environment at Three Locations.

3.0 IN-FLIGHT ANTENNA PATTERNS

3.1 Introduction

This section presents antenna patterns for 6 major East Coast interrogators measured during the 16 December 1977 flight*. The patterns presented are for four FAA interrogators (terminal and en-route) and non-FAA interrogators at Willow Grove, PA (Navy) and Montauk Point, NY (Air Force). The FAA interrogators use improved sidelobe suppression (ISLS), Willow Grove uses conventional SLS, and Montauk Point no SLS.

The in-flight antenna patterns presented are plots of the power levels of the P1, P2, and P3 pulses of an interrogator, as received and recorded by the AMF, against time. P2 and P3 pulse are plotted 10 dB below their actual received power to prevent the P1-P3 pulses from overlapping on the mainbeams (where they have equal power), and to prevent the P1-P2 pulses for interrogators with ISLS from overlapping on the sidelobes. Some of the plots also show the amplitude and delay of reflected P1-P3 pulses (shown along top of plot) in their proper positions with respect to mainbeams.

Some of the plots also indicate the occurrance of sidelobe punchthrough. The amplitude of the P1 pulse is compared with its P2 pulse amplitude (when both are present on a given PRI) and a point (.) plotted near the horizontal axis when P1 exceeds P2. This point is plotted 1 dB above the axis when the P1 excess is from 1 to 4 dB ("mild" punch-through), 2 dB above when the P1 excess is from 5 to 9 dB ("average" punch-through), and 3 dB above when the P1 excess is more than 9 dB ("hard" punch-through).

Antenna patterns are presented for the following interrogators:

A/C Location	Interrogator Name
H	Willow Grove
H†	Philadelphia
M	Washington
S	JFK ARSR
U	Montauk Pt.
W	Logan

*Data is available to permit plotting the antenna patterns of many of the other interrogators observed on this flight.

†Location H† is approximately midway between location H and location I.

The antenna patterns and the reflection and the punch-through measurements provide information on the performance of each interrogator and permit the determination of mainbeam structure, sidelobe structure, scan period, type of SLS and scan-to-scan changes due to motion of the measuring aircraft.

Tables 3-1 and 3-2 tabulate information obtained from the antenna patterns of the six interrogators.

3.2 The Antenna Patterns

For each interrogator a composite antenna pattern is shown first. The composite pattern is made up of individual single-scan plots scaled such that each scan of the antenna takes up exactly one line and the mainbeams from scan-to-scan are aligned vertically. The composite pattern makes scan-to-scan differences easy to detect. Each composite plot is followed by individual plots, presented to a larger scale*.

The antenna patterns are presented in the following figures:

Fig. 3.1a to 3.1h	Willow Grove
Fig. 3.2a to 3.2j	Philadelphia
Fig. 3.3a to 3.3i	Washington
Fig. 3.4a to 3.4i	JFK PRSR
Fig. 3.5a to 3.5h	Montauk Pt.
Fig. 3.6a to 3.6g	Logan

*For most interrogators, these plots are the only ones which show reflections and punch-throughs, since the composites were made up before these capabilities were added to the antenna pattern plotting program.

TABLE 3-1

INTERROGATOR PARAMETERS DETERMINED FROM THE ANTENNA PATTERNS SHOWN

Plot No.	Interrogator	A/C Loc	MAXP1* (dBm) (=M)	AVP1SL** (dBm) (=P1)	AVP2SL*** (dBm) (=P2)	(M-P1) (dB)	(M-P2) (dB)	(P2-P1) (dB)	DIST (NM)	ELEV (Deg)	AMF AZIM (Deg)
1	Willow Grove	H	-36	-	-	-	-	-	6	13	250
2	Philadelphia	H†	-43	-70.5	-68	27.5	25	2.5	16	5	310
3	Washington	M	-47	-68.5	-65	21.5	18	3.5	15	5	227
4	JFK ARSR	S	-38	-61	-57	23	19	4	7	22	105
5	Montauk Pt.	U	-32	-	-	-	-	-	7	22	255
6	Logan	W	-47	-70.5	-67	23.5	20	3.5	30	6	195

*MAXP1 is the mainbeam power level (in dBm) for the P1 pulse of the strongest scan received.

**AVP1SL is the average sidelobe level (in dBm) for the P1 pulse.

***AVP2SL is the average sidelobe level (in dBm) for the P2 pulse.

TABLE 3-2

OBSERVATIONS FROM INTERROGATOR COMPOSITE ANTENNA PATTERNS

Plot No.	Interrogator	Period of Plot	Uses SLS	Reflections	Punch-Through	Observations
1	Willow Grove (Navy)	6 scans 10.0-32.4 secs	Yes	Yes	Yes	SLS evidenced by variation in power level of P1 on the sidelobes. Exhibits systematic reflections, usually delayed by 1.5 μsec, (3.6 and 6.6 μsec delays also occur) 105 and 125 degrees after mainbeam passage; peak amplitude of these reflections is -75 dBm. Heavy sidelobe punch-through lasting about 1/2 sec apparently caused by large P1-P3 sidelobes ≈120 degrees (1.3 sec) after the mainbeam. Punch-through also occurs just before the last mainbeam. Omni antenna rotation shown by P2 nulls at centers of the mainbeams and on the sidelobes. Near the end of the recording period (at 30.25 secs) steady P2 reflections were noted (a rare occurrence). This effect is due to high P2 power near leading and trailing edges of the mainbeams (only 6.8 dB down from P1-P3 peaks).
2	Philadelphia (FAA ASR-7)	3 scans 5.5-30.0 secs	Yes	Yes	Yes	ISLS evidenced by P1 power staying high. P2 ≈4 dB higher on scan 1 than on the rest of scans. Variable P1 peaks give rise to a large number of minor punch-throughs near the mainbeams. Scan-to-scan differences minor.

TABLE 3-2 (Continued)

Plot No.	Interrogator	Period of Plot	Uses SLS	Reflections	Punch-Through	Observations
3	Washington National (FAA ASR-7 using a 4 ft. open array.)	3 scans 7.0-21.0 secs	Yes	Yes	No	ISLS evidenced by P1 power staying high. 1st mainbeam reflected at 10.2 secs (6 μsec delay, -72 dBm amplitude) with mainbeam pointing to Northeast (300 deg.) Few scan-to-scan differences.
4	New York-JFK (FAA ARSR)	3 scans 1.7-30.5 secs	Yes	No	Yes	ISLS evidenced by P1 power staying high. Large number of sidelobe punch-throughs associated with P1 peaks (particularly on scan 1). Scan-to-scan differences: a downward trend in P1-P2 level in scan 1; an upward trend in P1-P2 level in scan 2.
5	Montauk Point (Air Force Enroute radar)	1 1/4 scans 0.1-14.0 secs	No	Yes	Yes	No SLS as evidenced by no P2 pulses. Strong peaks extend for 90 degrees on both sides of the mainbeam. Many reflections, most with delays of 2 μsecs (1.5, 2.5, 4.0 and 4.5 μsec delays occur) and usually at a level of -70 dBm. Most occur when the antenna points more than 45 degrees away from the AMF.
6	Logan (FAA)	3 scans portions of 44.9-56.3 secs	Yes	Yes	Yes	ISLS evidenced by P1 power staying high. Note three reflected mainbeams at 1.66 sec (130 deg.) after the mainbeam (delay of 10 μsec and at amplitude of -68 dBm). Minor punch-throughs just before the mainbeams. Insignificant scan-to-scan differences.

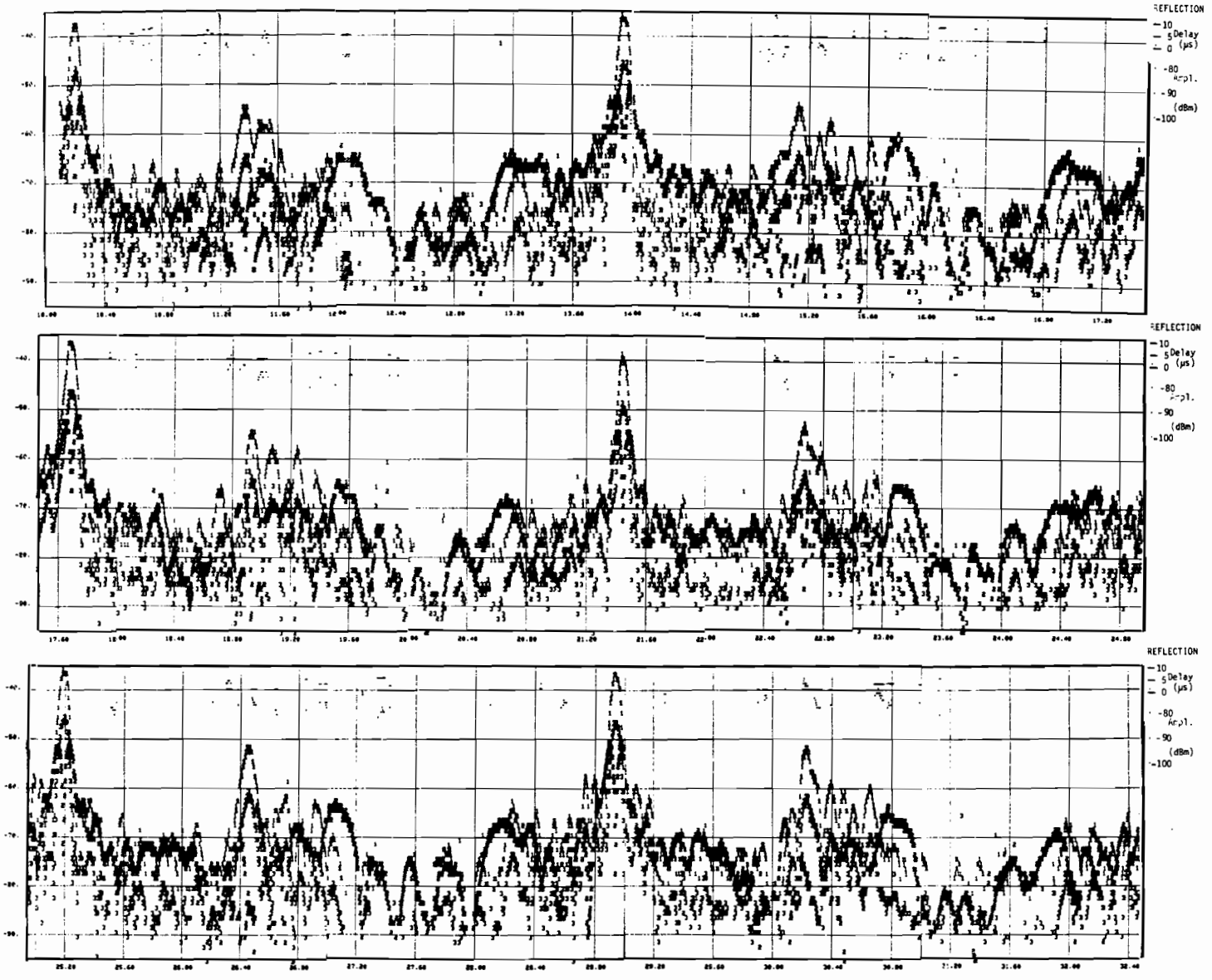


Fig. 3-1a. Antenna Pattern, Composite - Willow Grove (Navy).

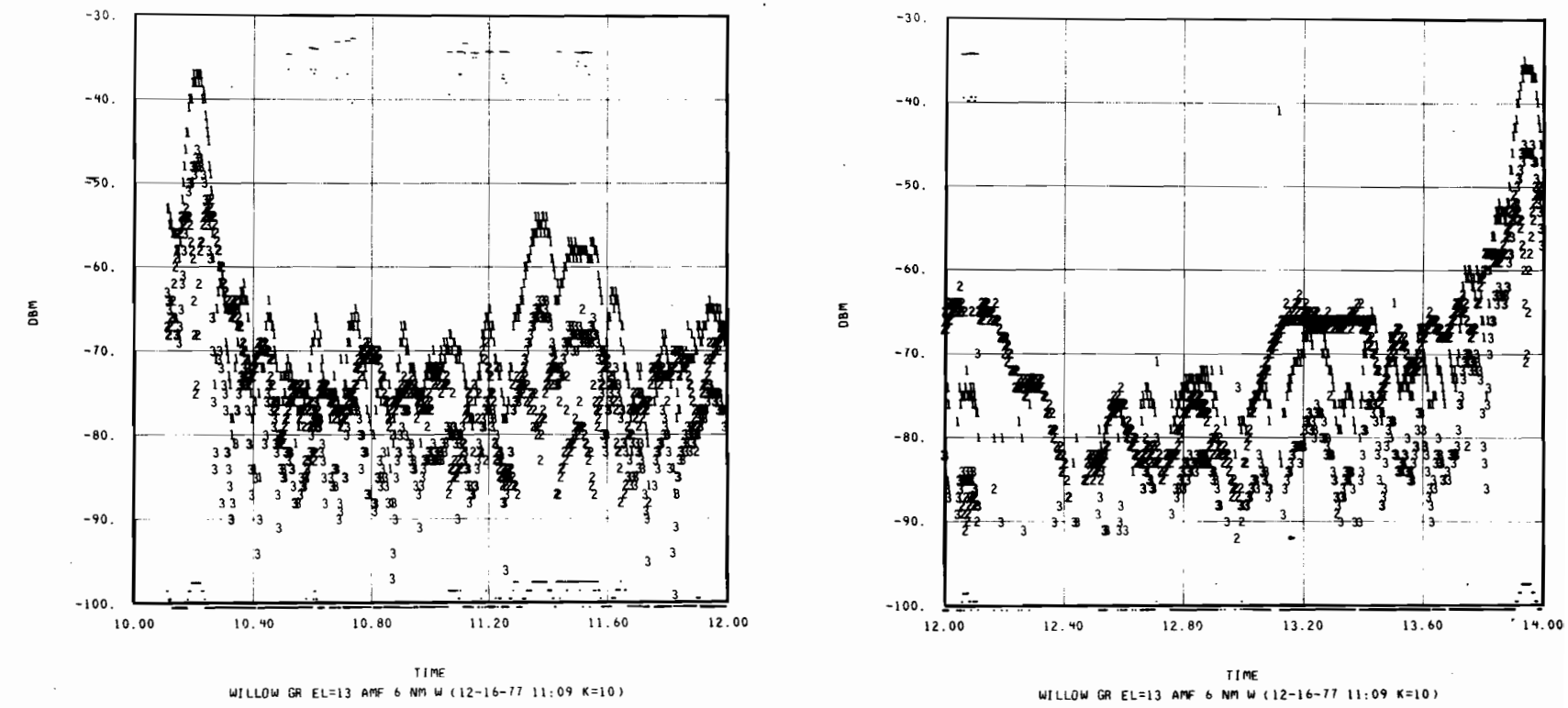
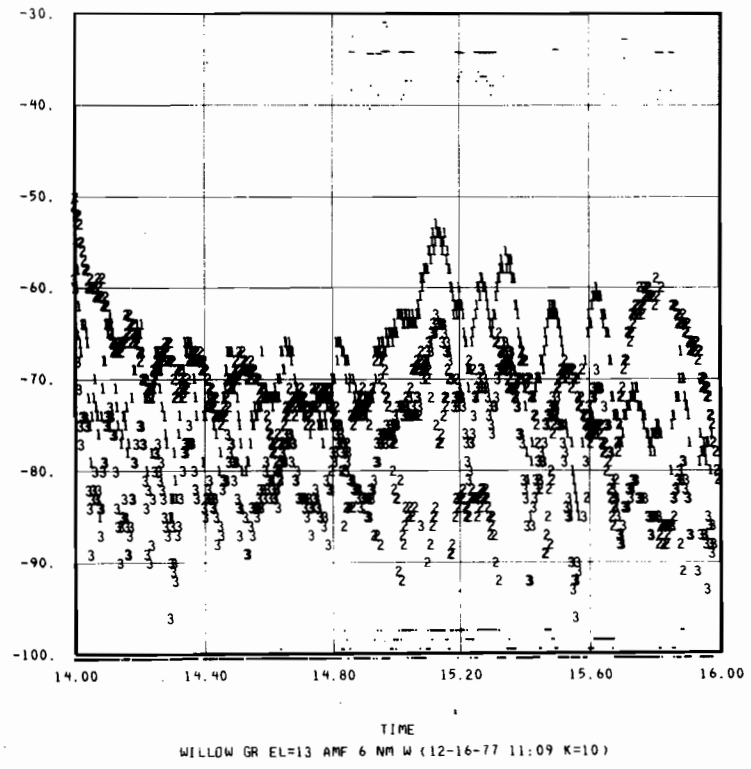


Fig. 3-1b. Antenna Pattern, Detail - Willow Grove, 10.00-14.00 Secs.



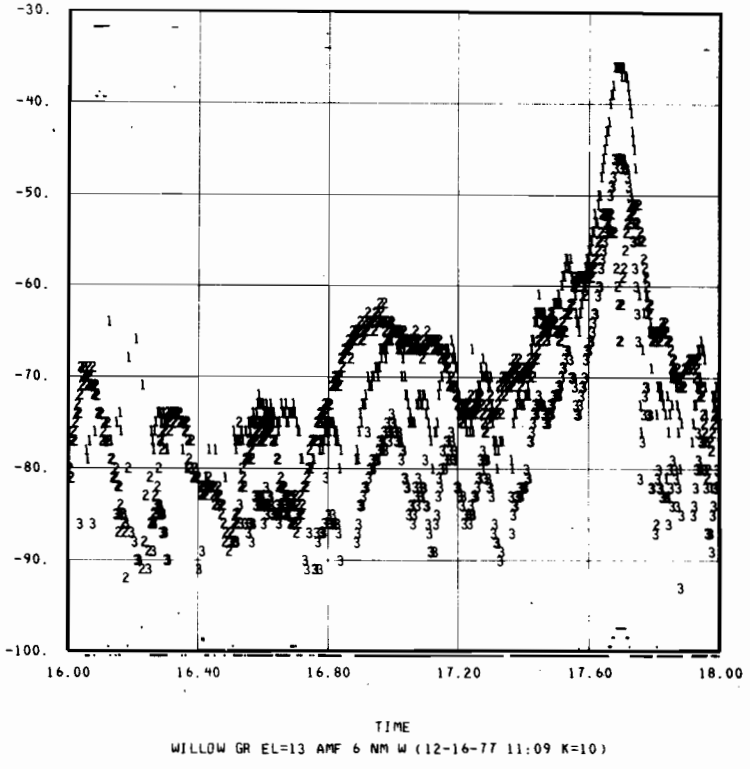


Fig. 3-1c. Antenna Pattern, Detail - Willow Grove, 14.00-18.00 Secs.

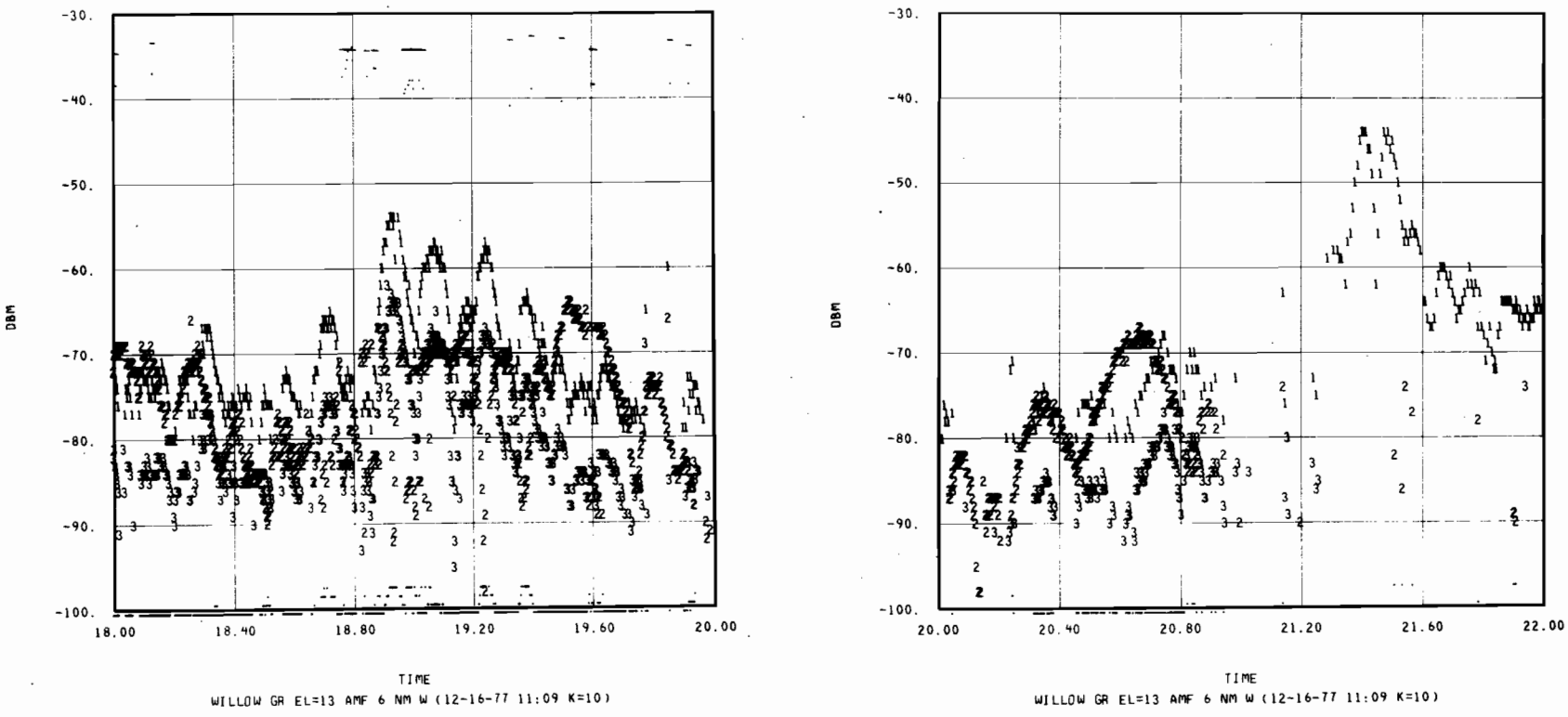


Fig. 3-1d. Antenna Pattern, Detail - Willow Grove, 18.00-22.00 Secs.

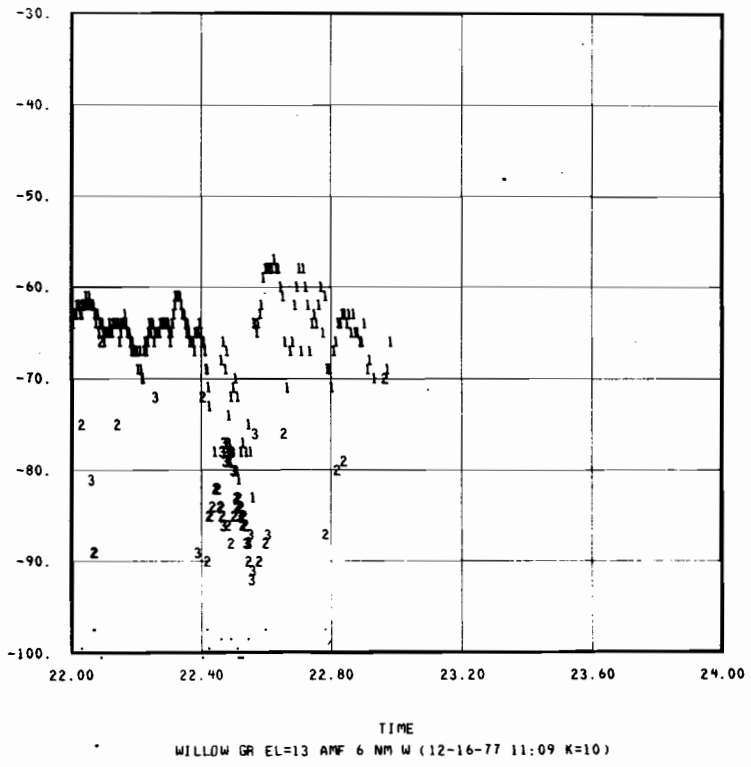


Fig. 3-1e. Antenna Pattern, Detail - Willow Grove, 22.00-24.00 Secs.

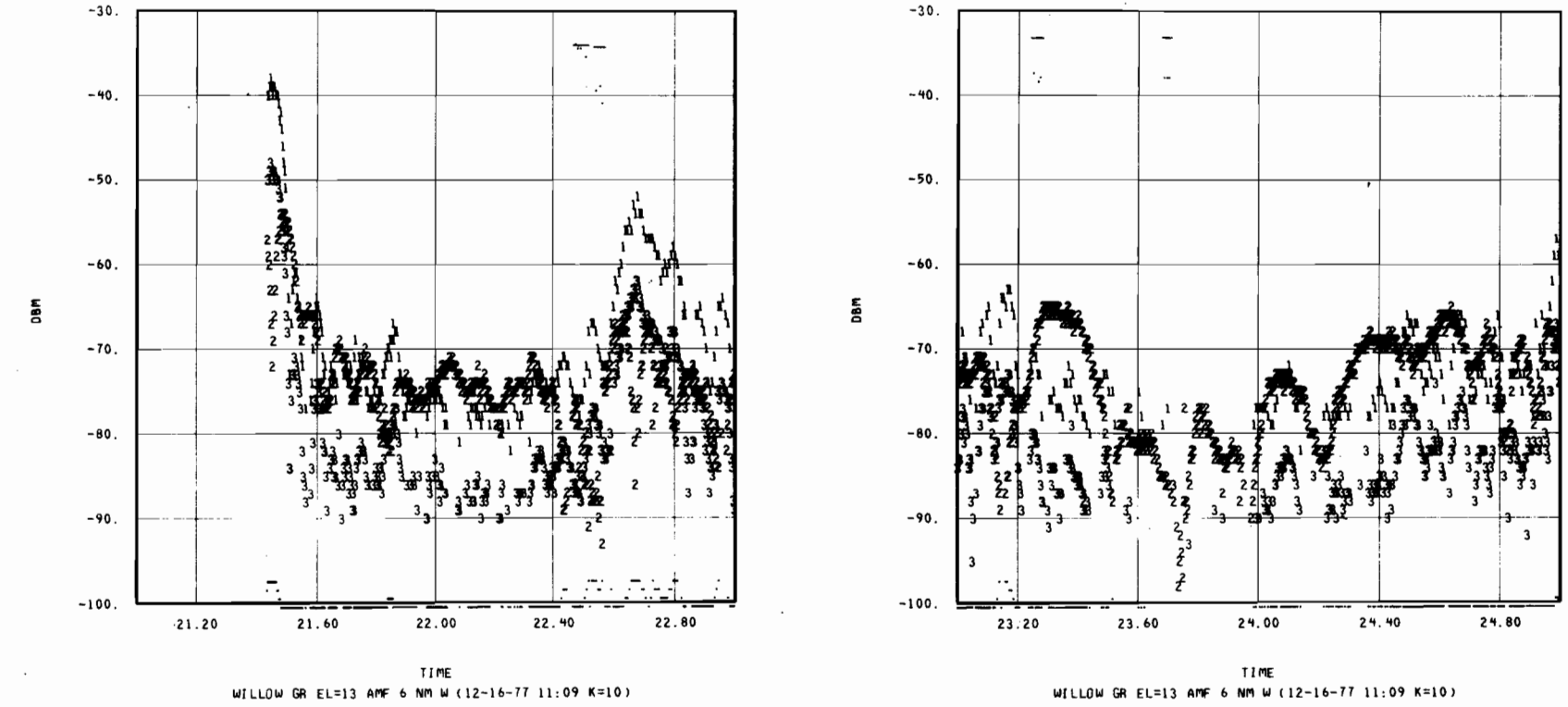
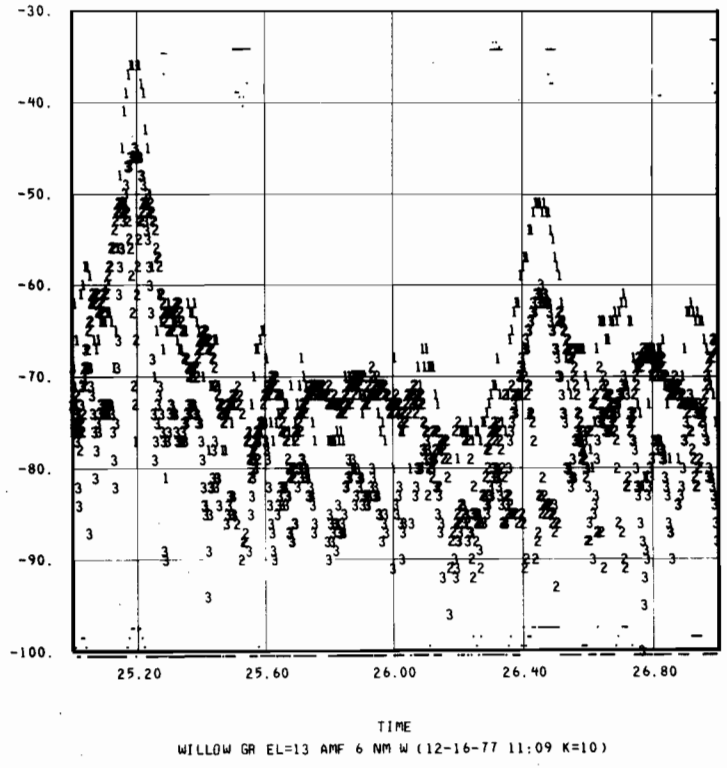


Fig. 3-1f. Antenna Pattern, Detail - Willow Grove, 21.20-24.80 Secs.



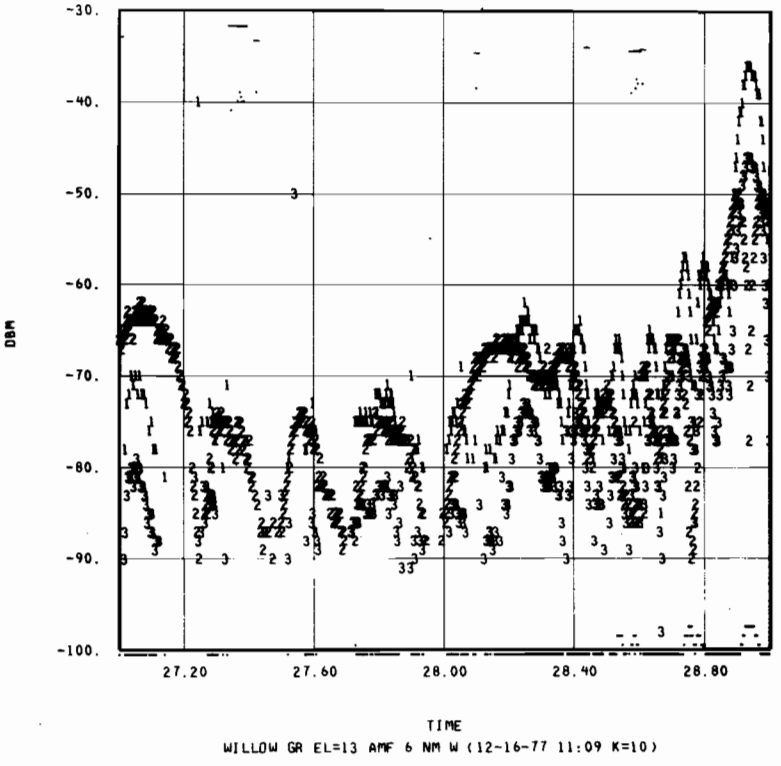


Fig. 3-1g. Antenna Pattern, Detail - Willow Grove, 25.20-28.80 Secs.

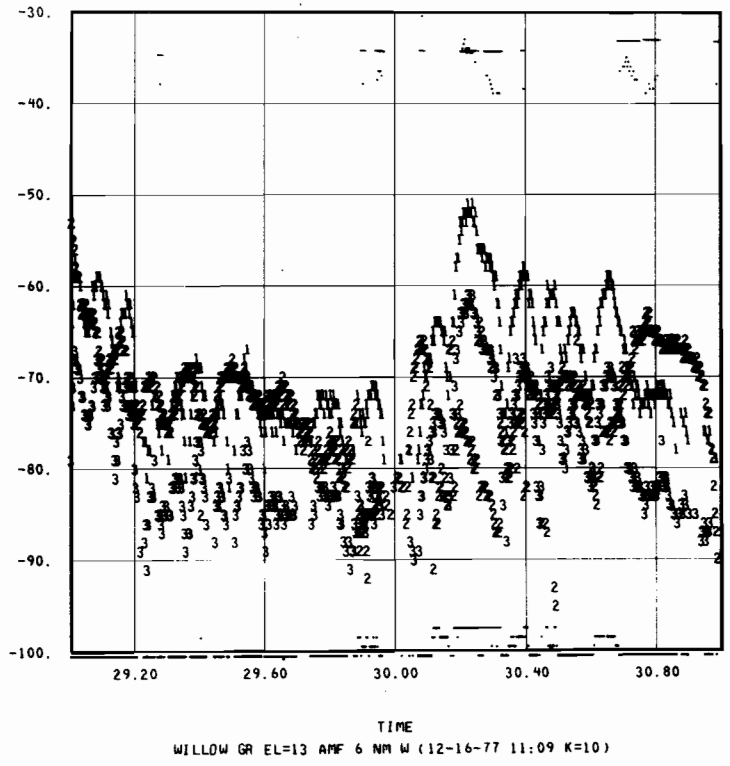


Fig. 3-1h. Antenna Pattern, Detail - Willow Grove, 29.20-30.80 Secs.

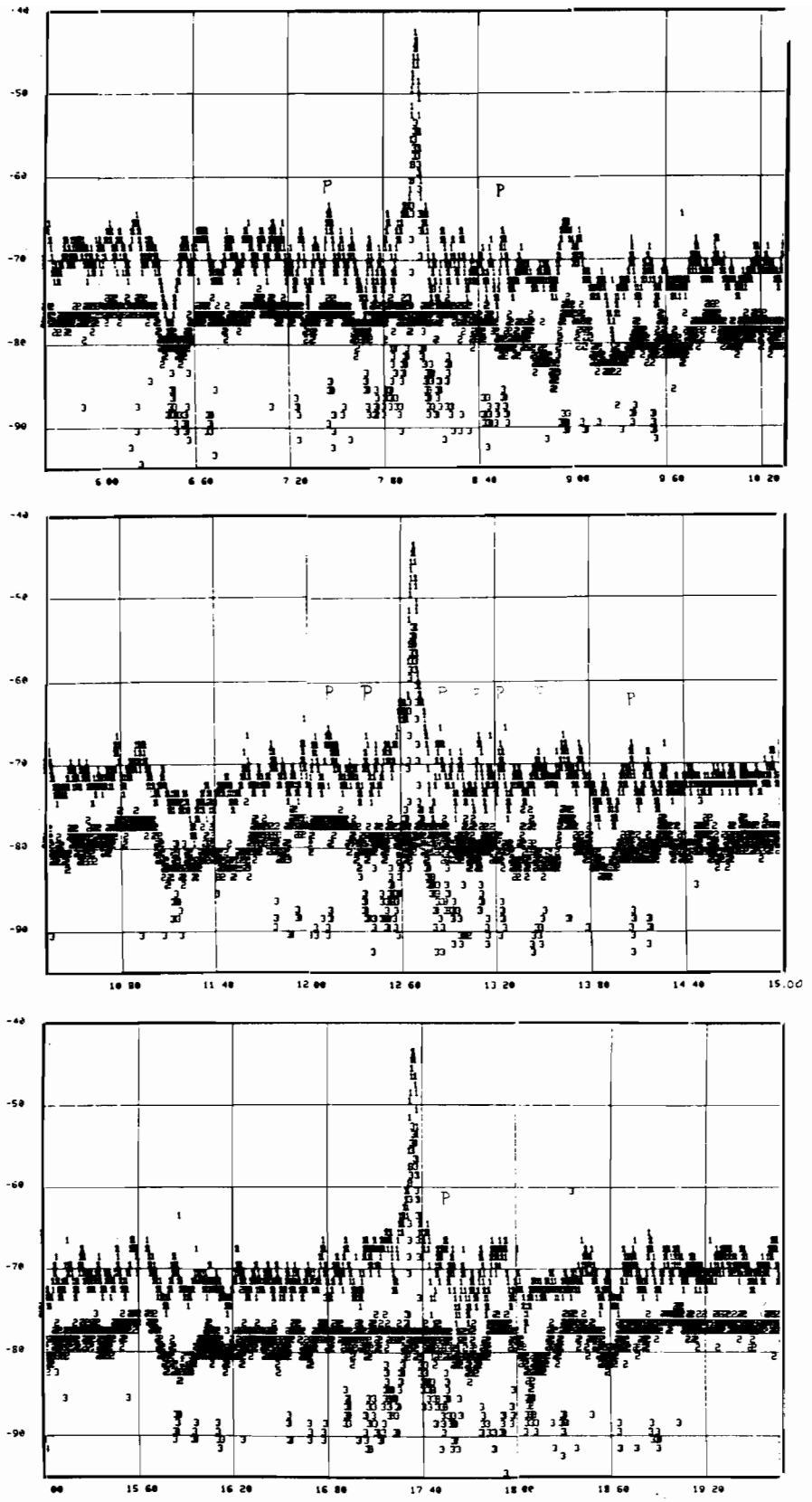


Fig. 3-2a. Antenna Pattern, Composite - Philadelphia (ASR-7), 6.00-19.20 Secs.

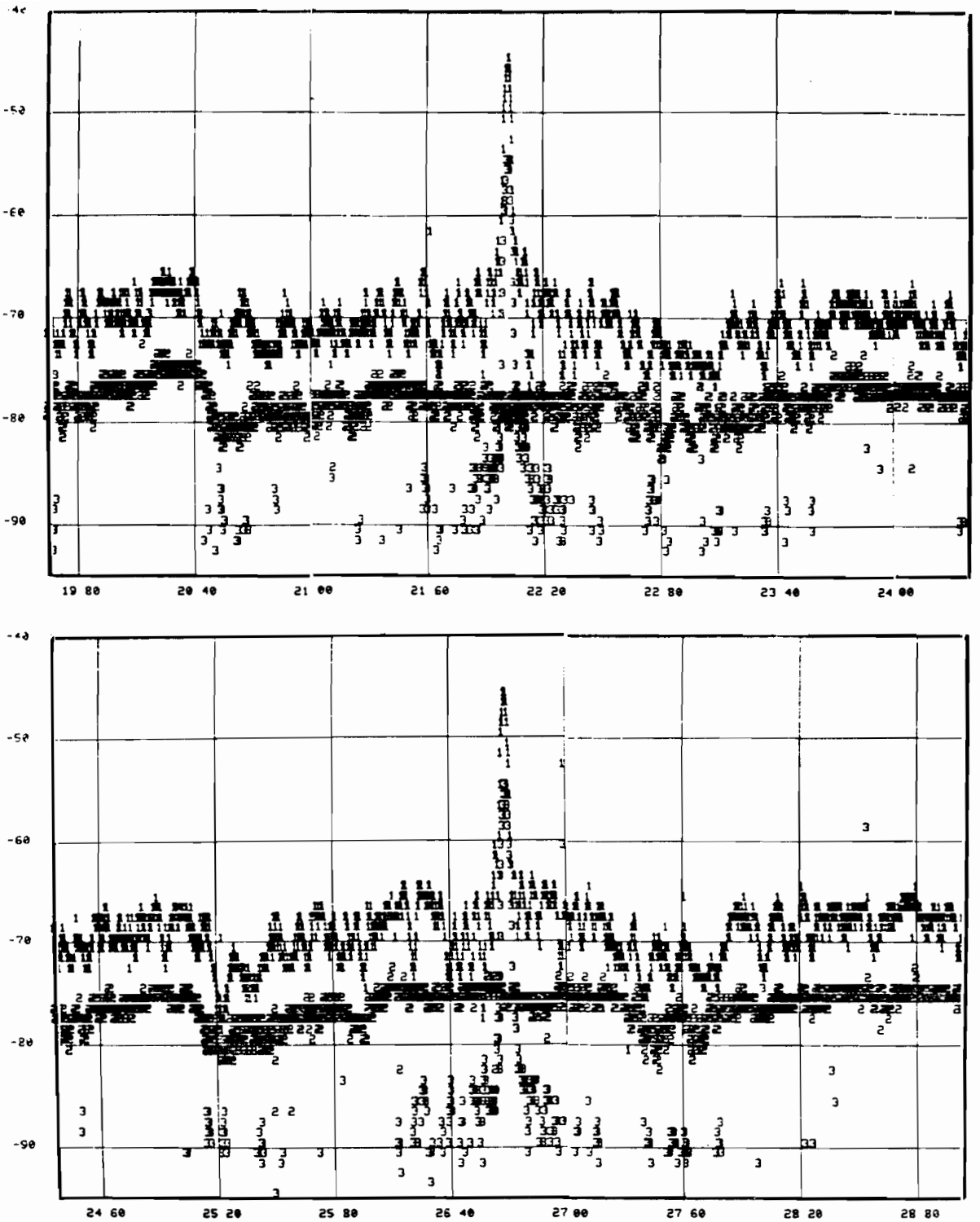


Fig. 3-2b. Antenna Pattern, Composite - Philadelphia (ASR-7), 19.80-28.80 Secs.

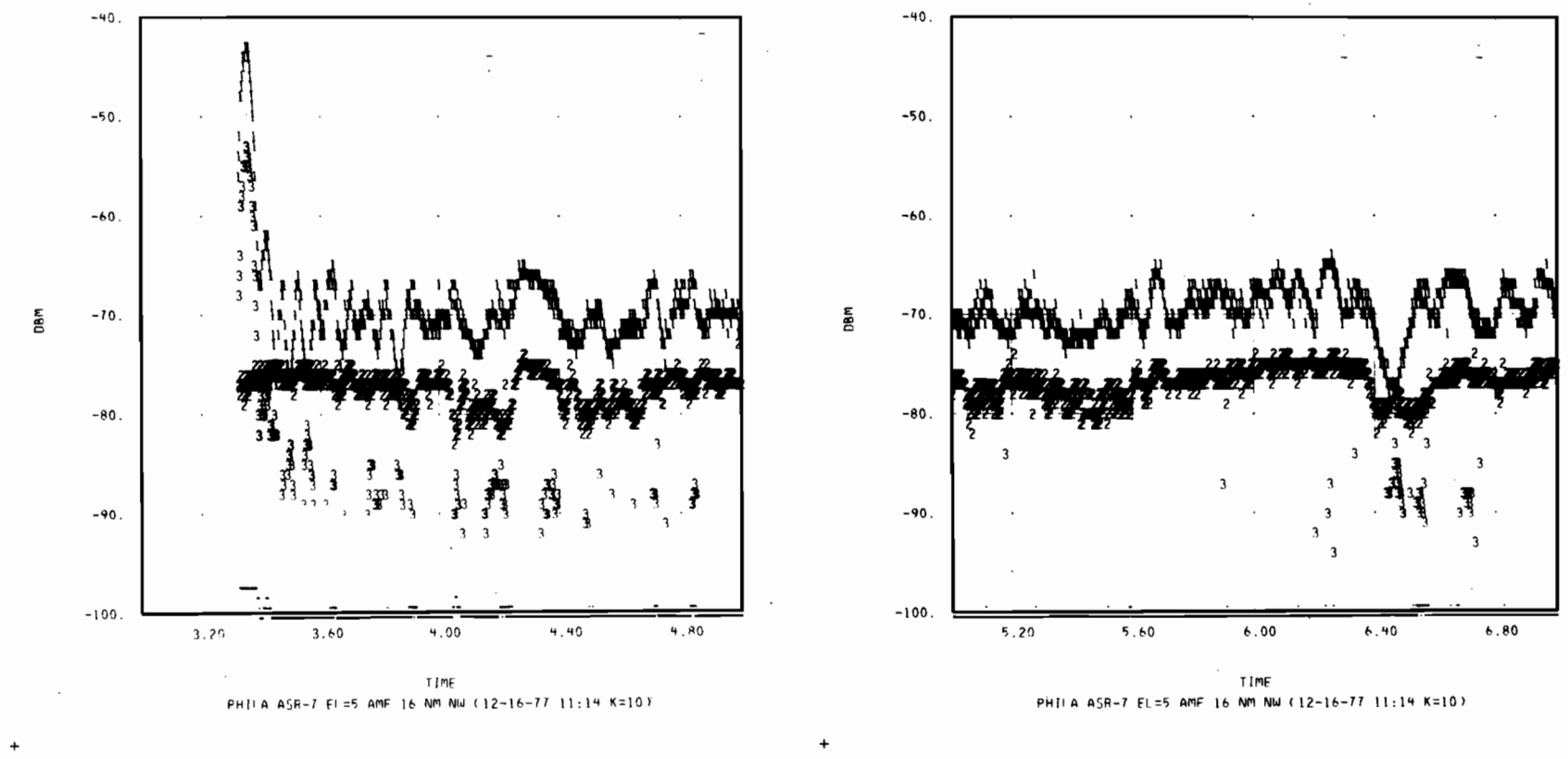
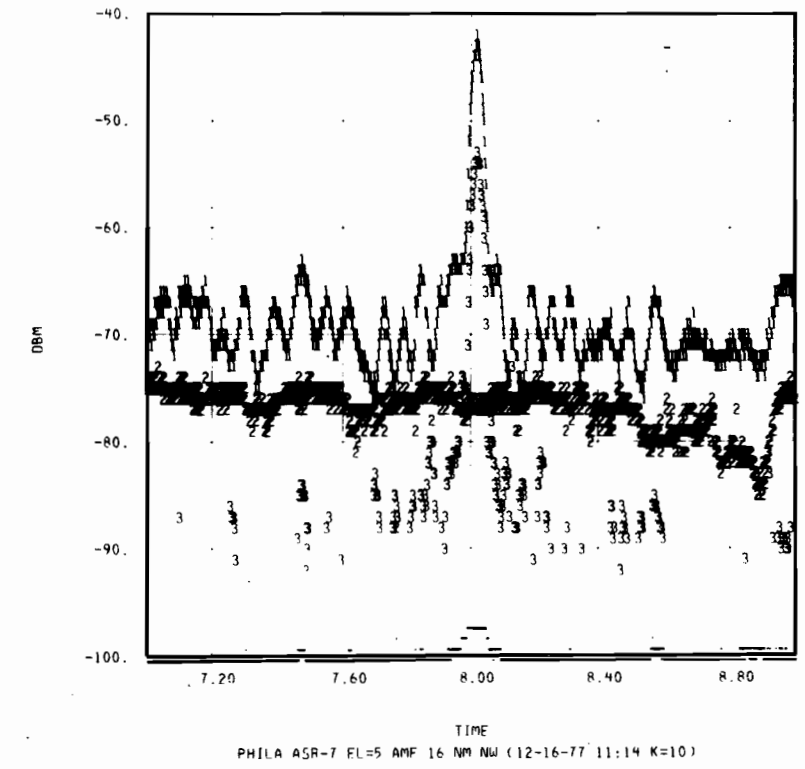


Fig. 3-2c. Antenna Pattern, Detail - Philadelphia (ASR-7), 3.20-6.80 Secs.



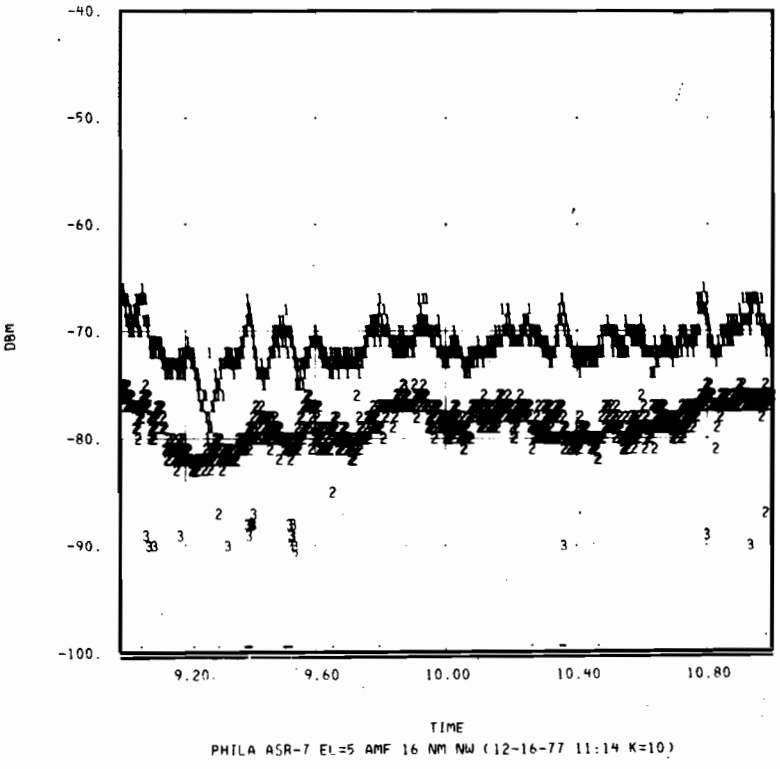
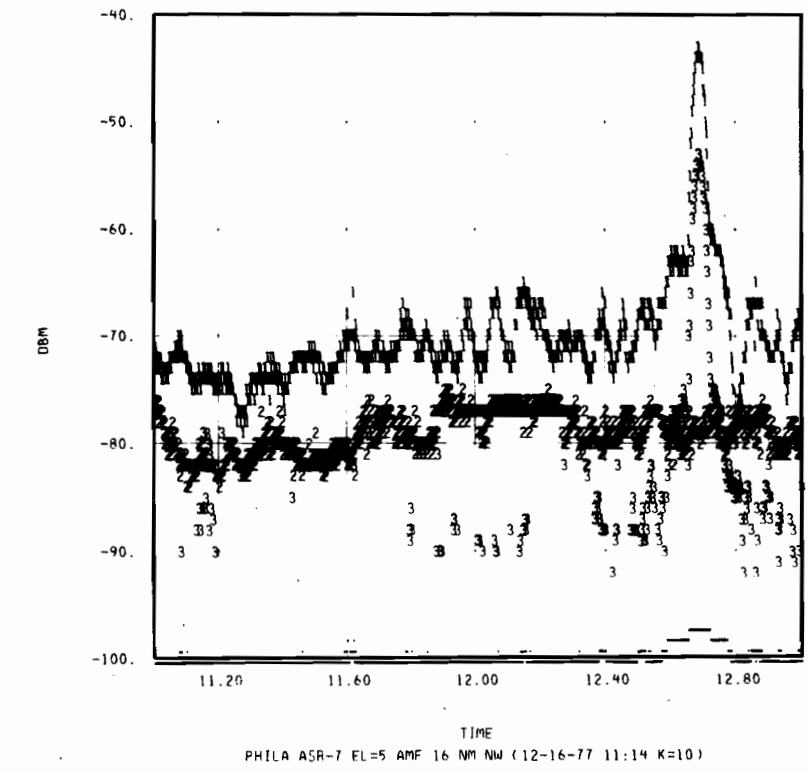


Fig. 3-2d. Antenna Pattern, Detail - Philadelphia (ASR-7), 7.20-10.80 Secs.



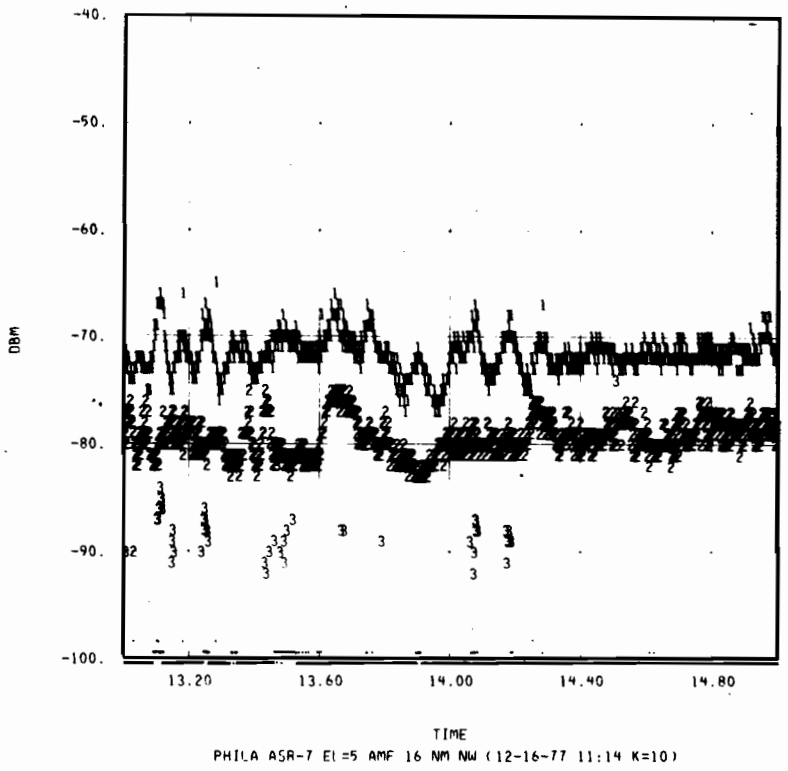
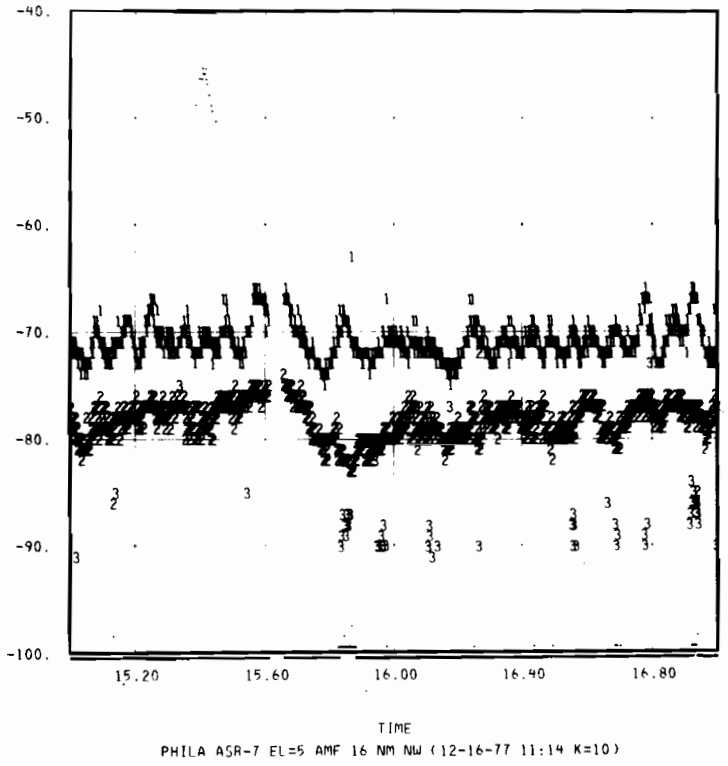


Fig. 3-2e. Antenna Pattern, Detail - Philadelphia (ASR-7), 11.20-14.80 Secs.



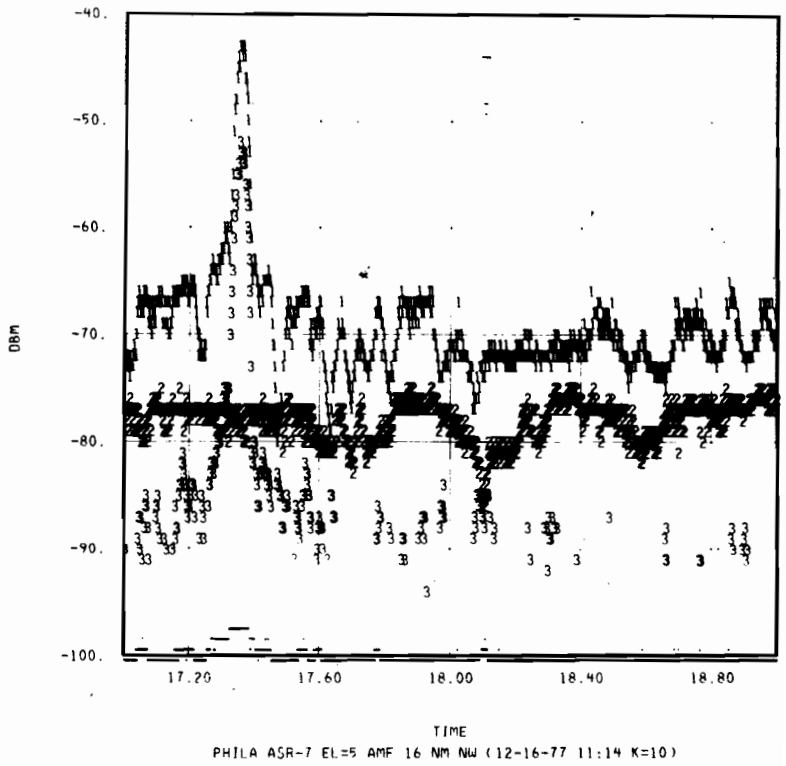
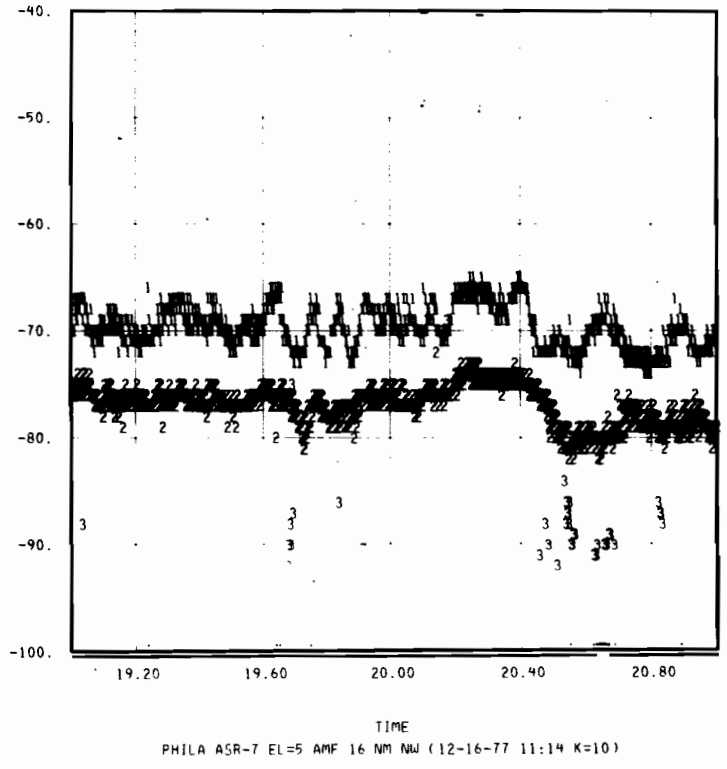


Fig. 3-2f. Antenna Pattern, Detail - Philadelphia (ASR-7), 15.20-18.80 Secs.



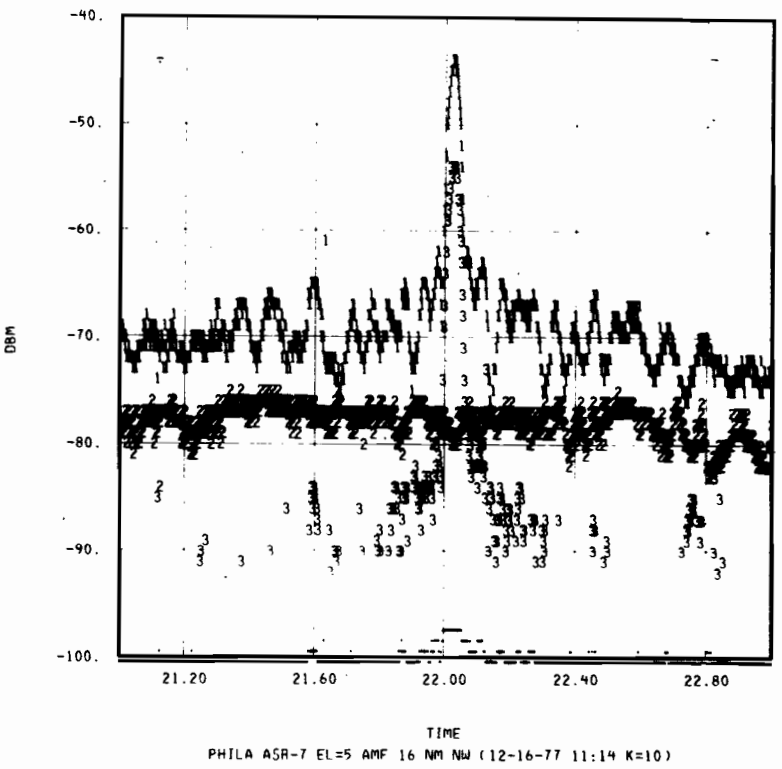


Fig. 3-2g. Antenna Pattern, Detail - Philadelphia (ASR-7), 19.20-22.80 Secs.

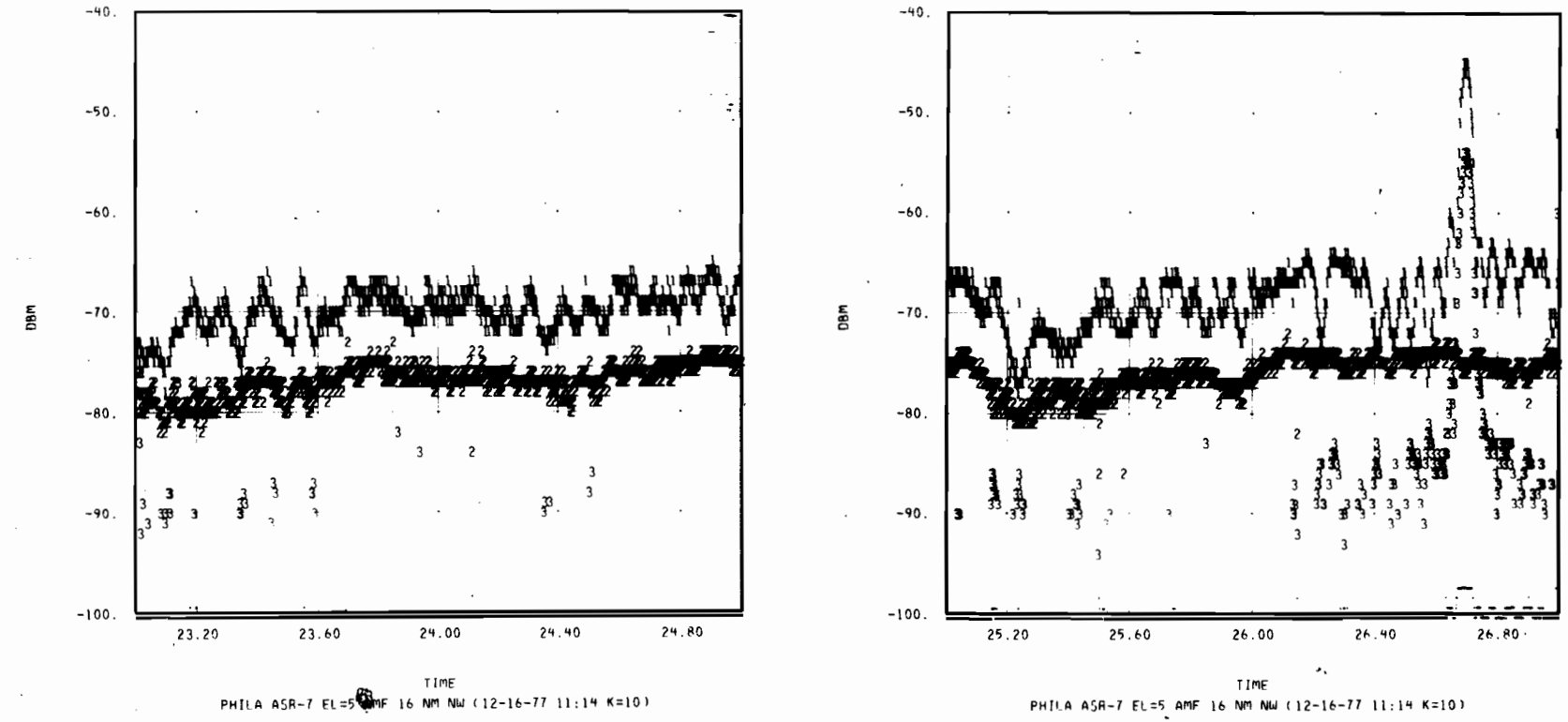


Fig. 3-2h. Antenna Pattern, Detail - Philadelphia (ASR-7), 23.20-26.80 Secs.

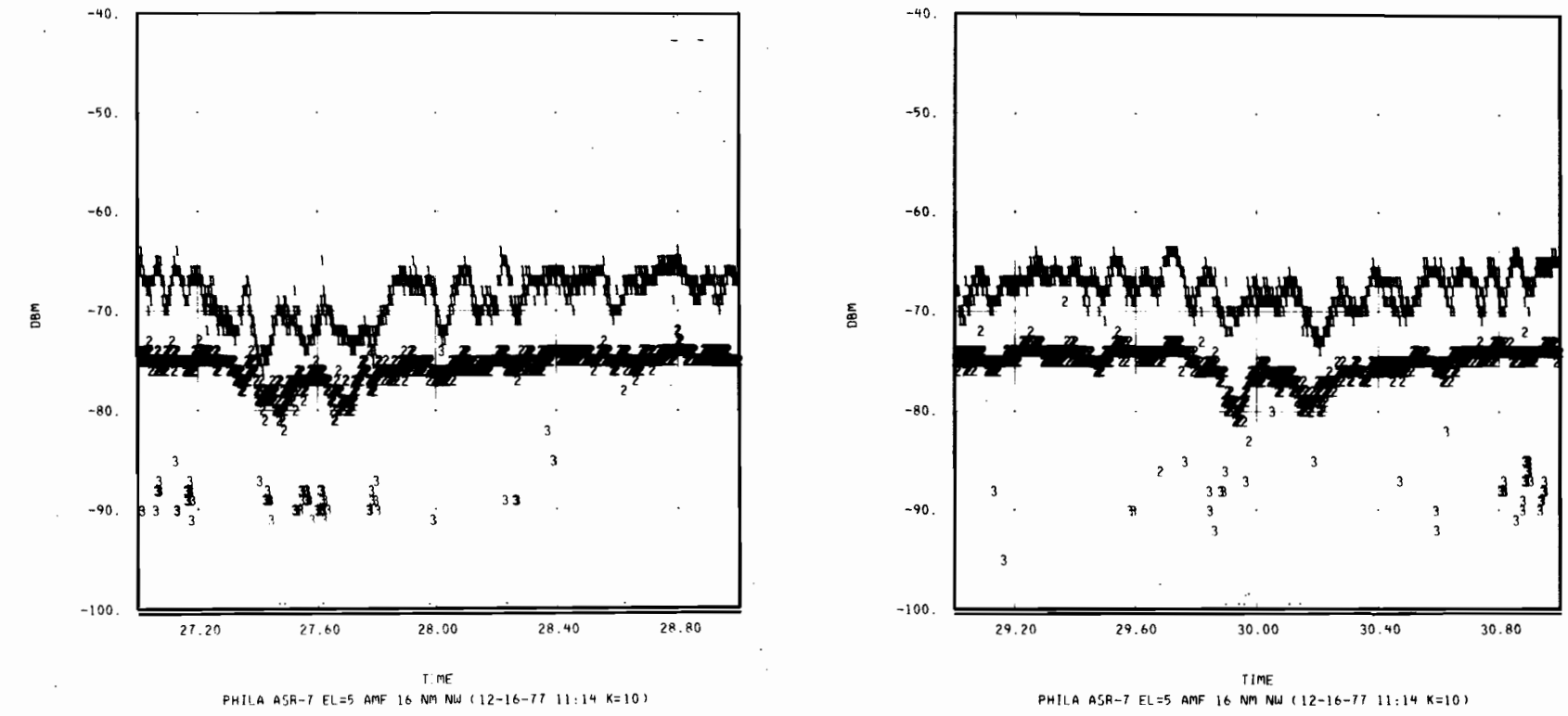


Fig. 3-2i. Antenna Pattern, Detail - Philadelphia (ASR-7), 27.20-30.80 Secs.

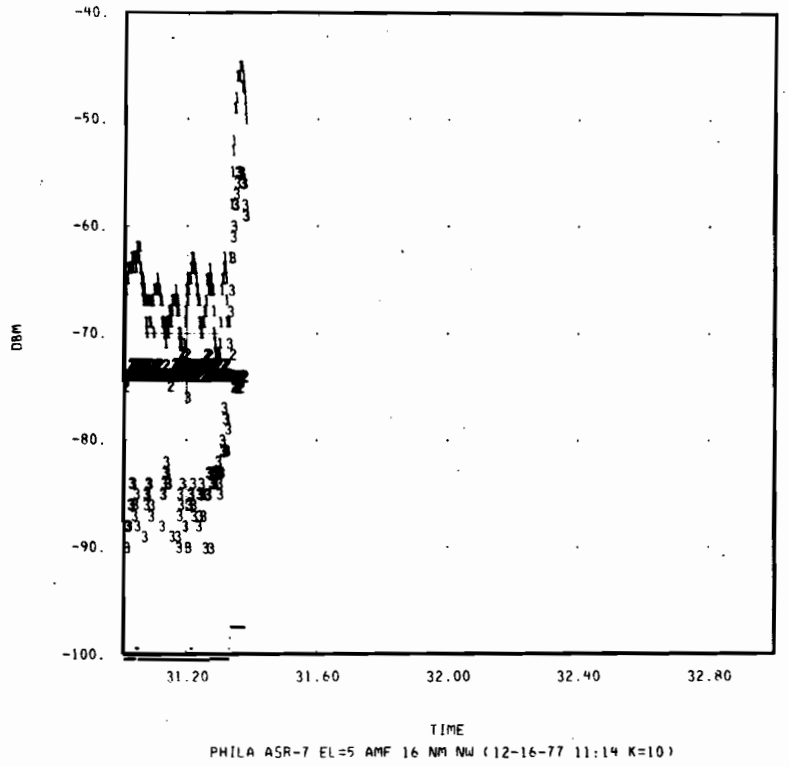


Fig. 3-2j. Antenna Pattern, Detail - Philadelphia (ASR-7), 31.20-32.80 Secs.

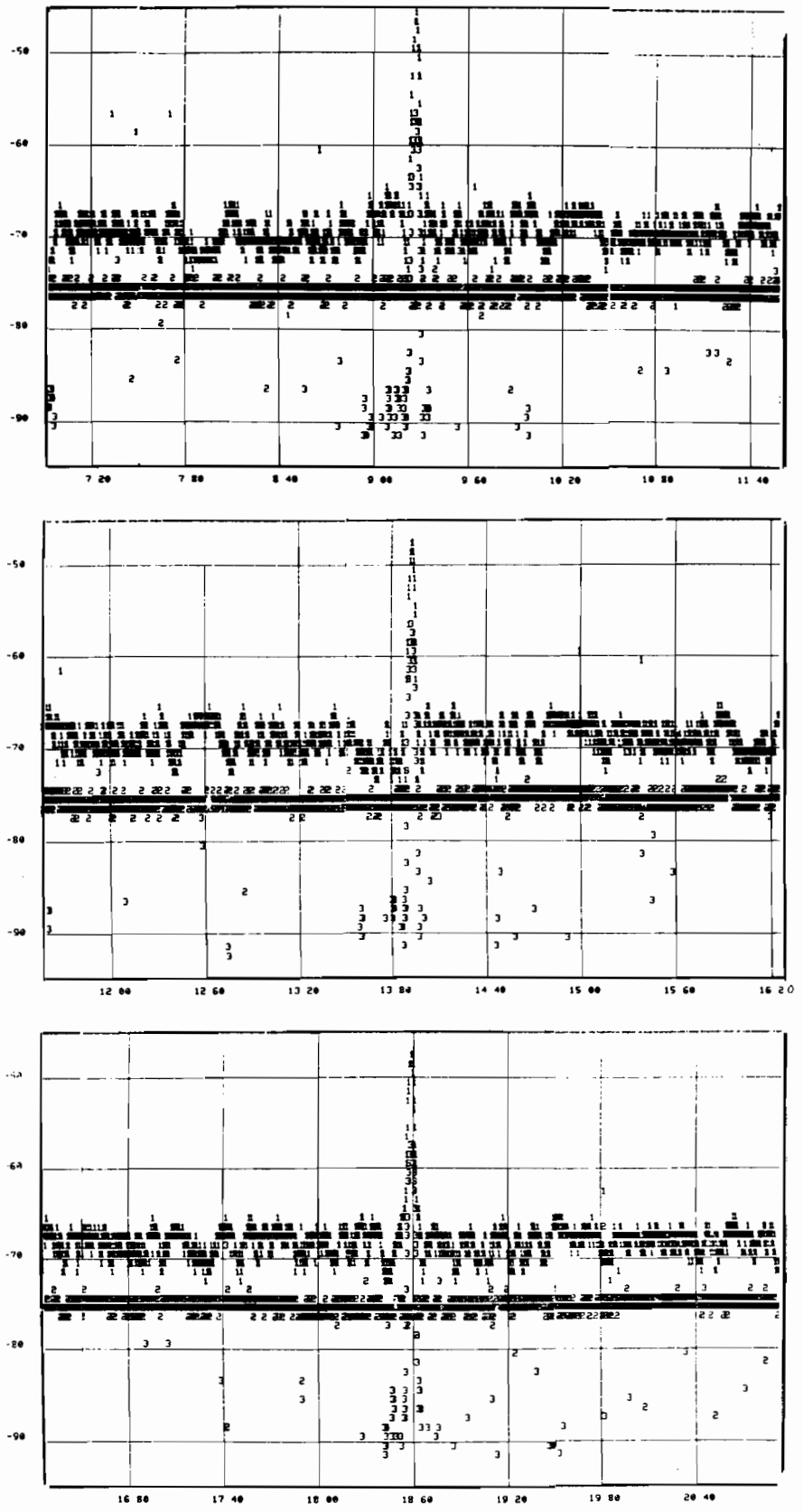


Fig. 3-3a. Antenna Pattern, Composite - Washington (ASR-7).

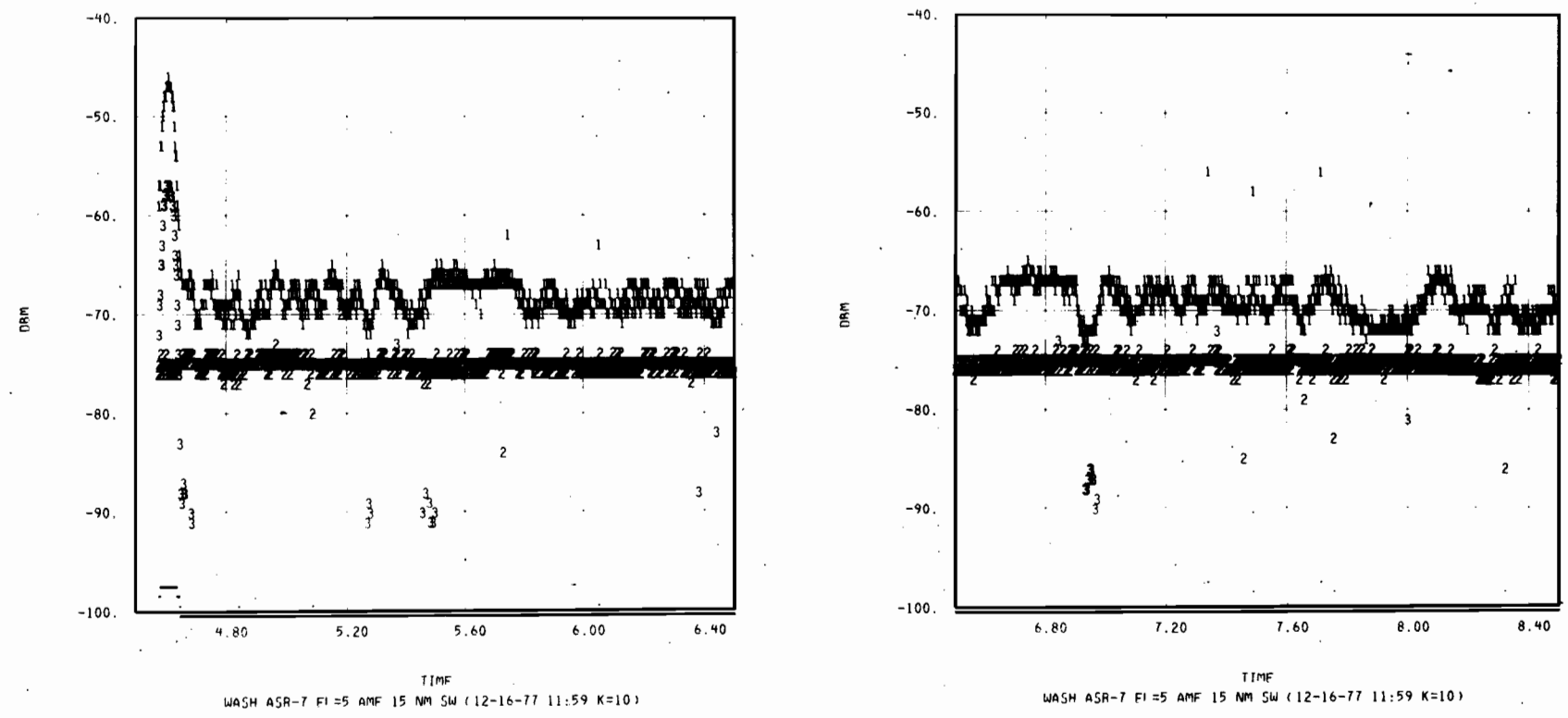
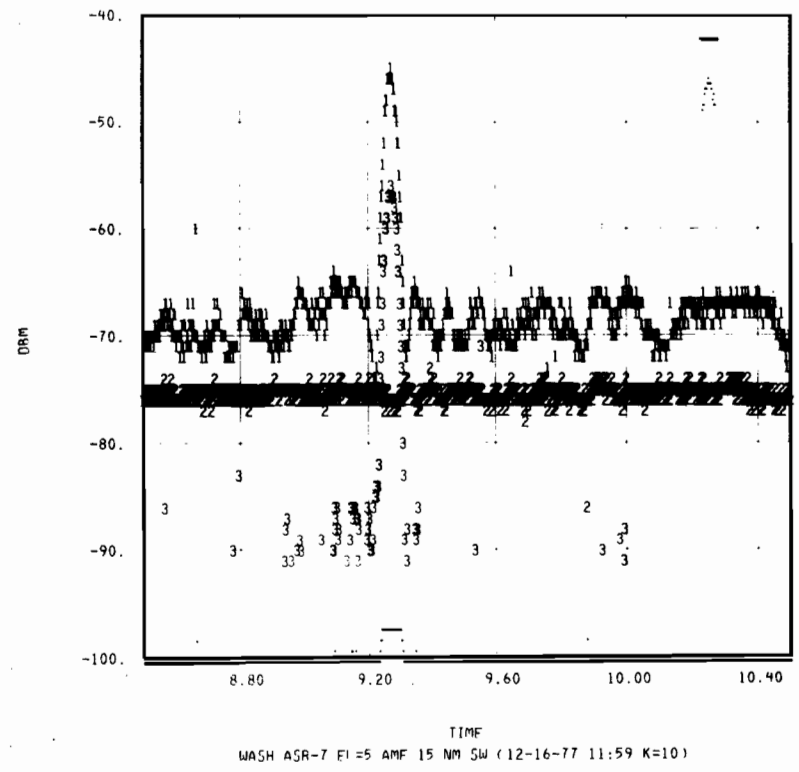


Fig. 3-3b. Antenna Pattern, Detail - Washington (ASR-7), 4.80-8.40 Secs.



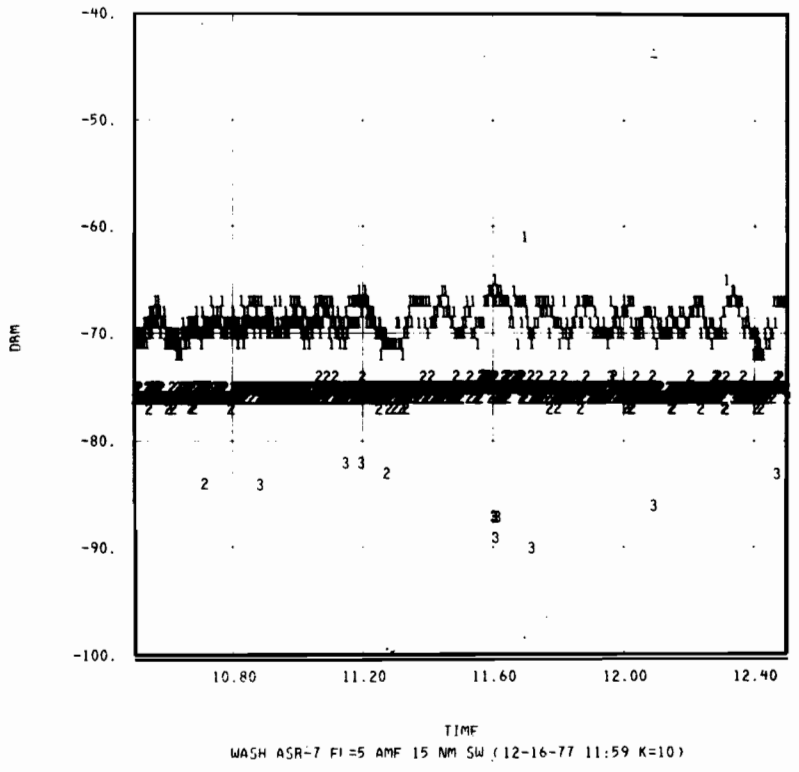


Fig. 3-3c. Antenna Pattern, Detail - Washington (ASR-7), 8.80-12.40 Secs.

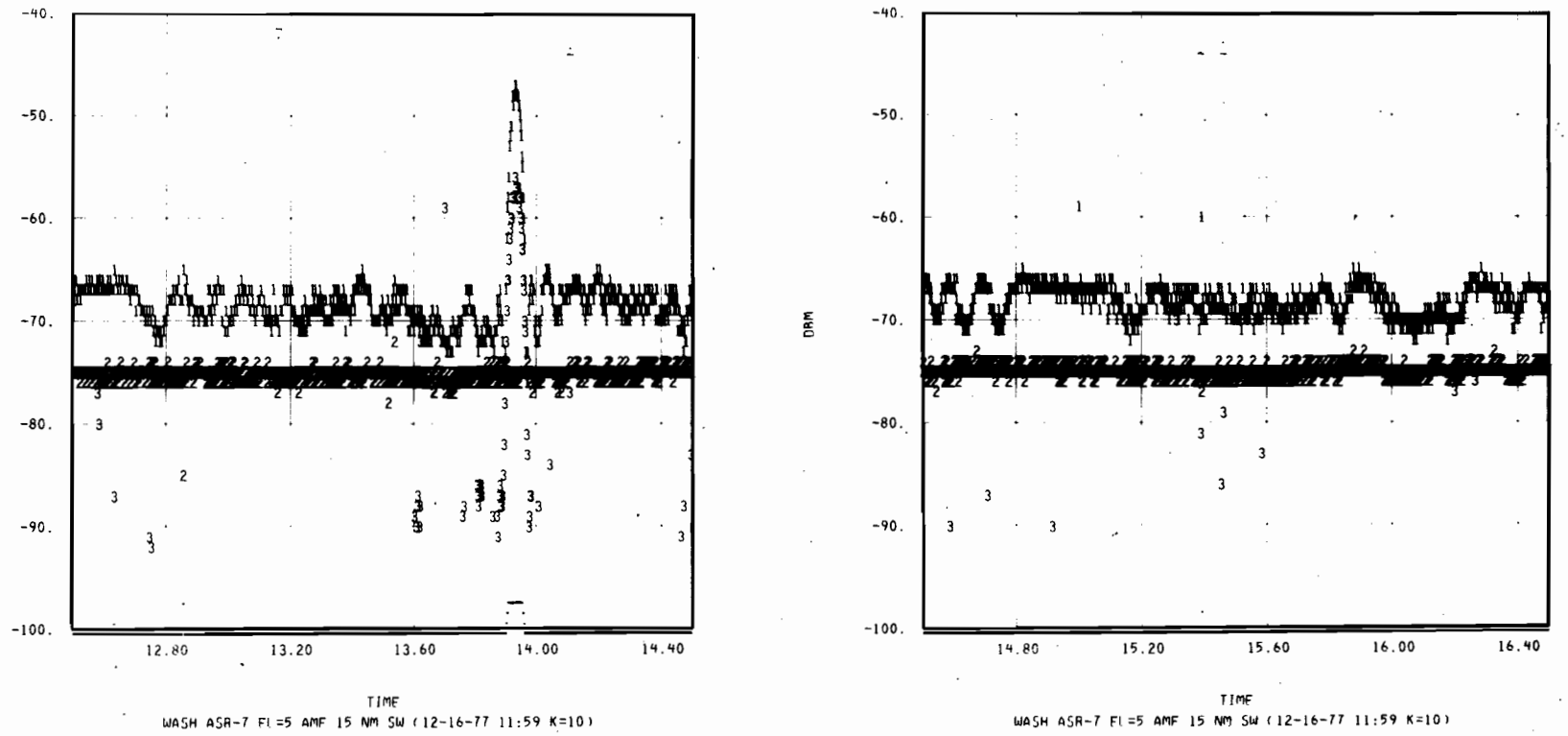
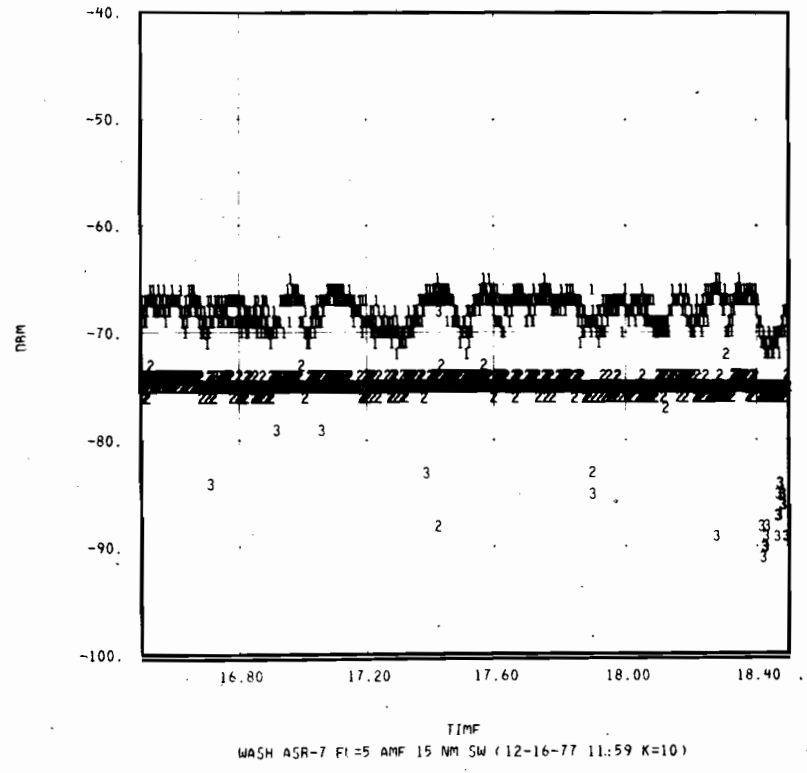


Fig. 3-3d. Antenna Pattern, Detail - Washington (ASR-7), 12.80-16.40 Secs.



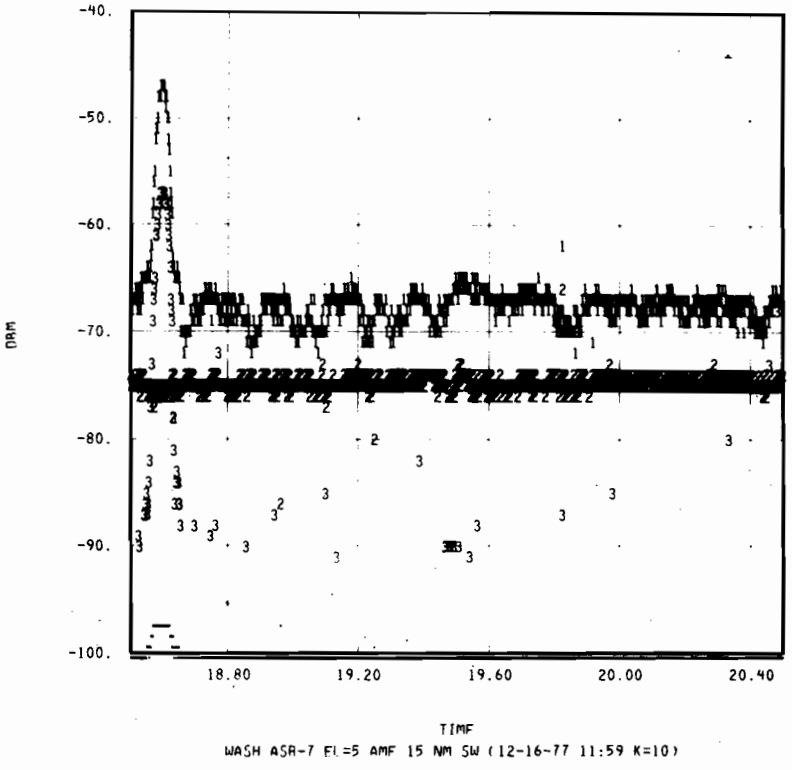


Fig. 3-3e. Antenna Pattern, Detail - Washington (ASR-7), 16.80-20.40 Secs.

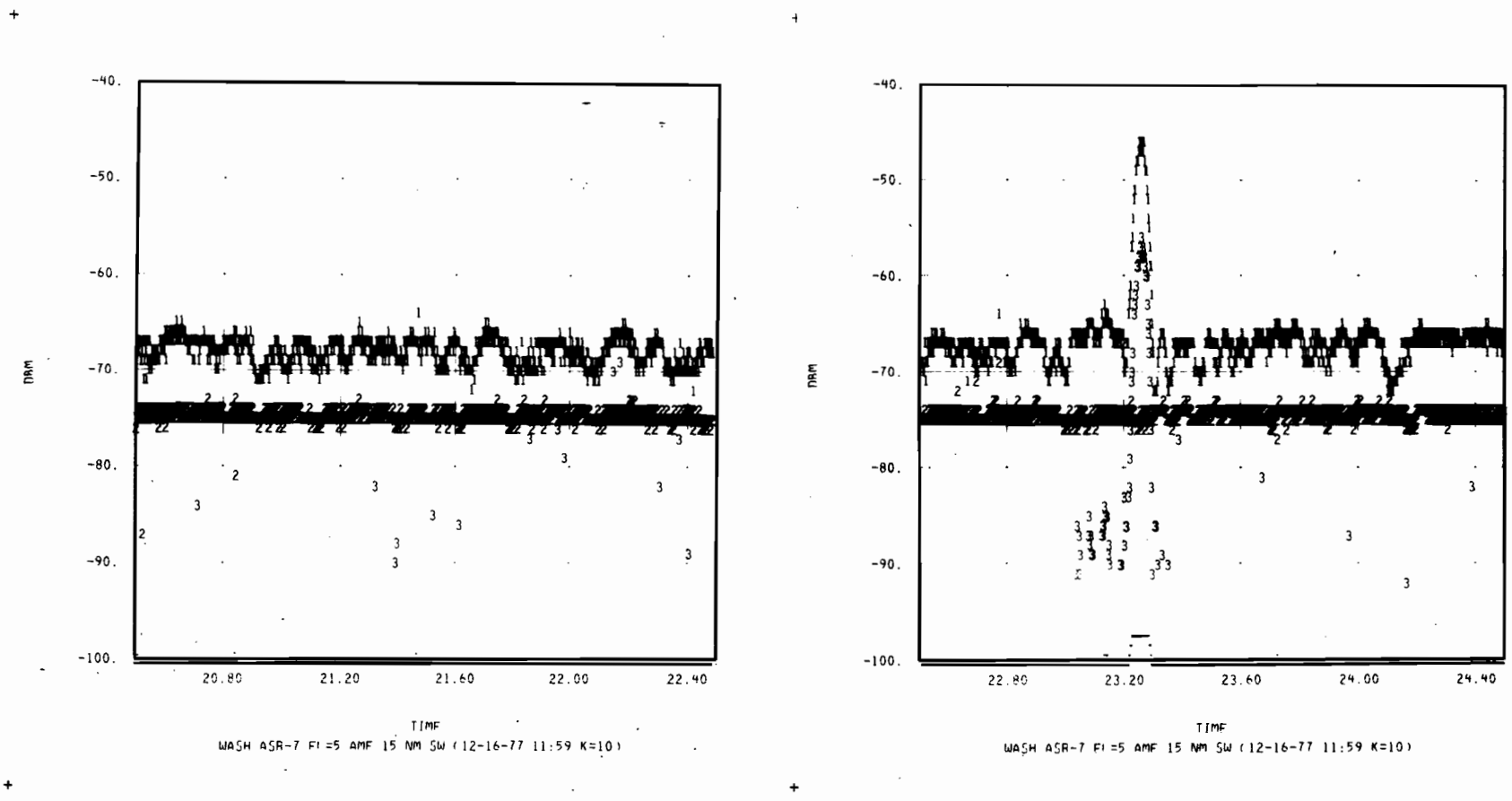


Fig. 3-3f. Antenna Pattern, Detail - Washington (ASR-7), 20.80-24.40 Secs.

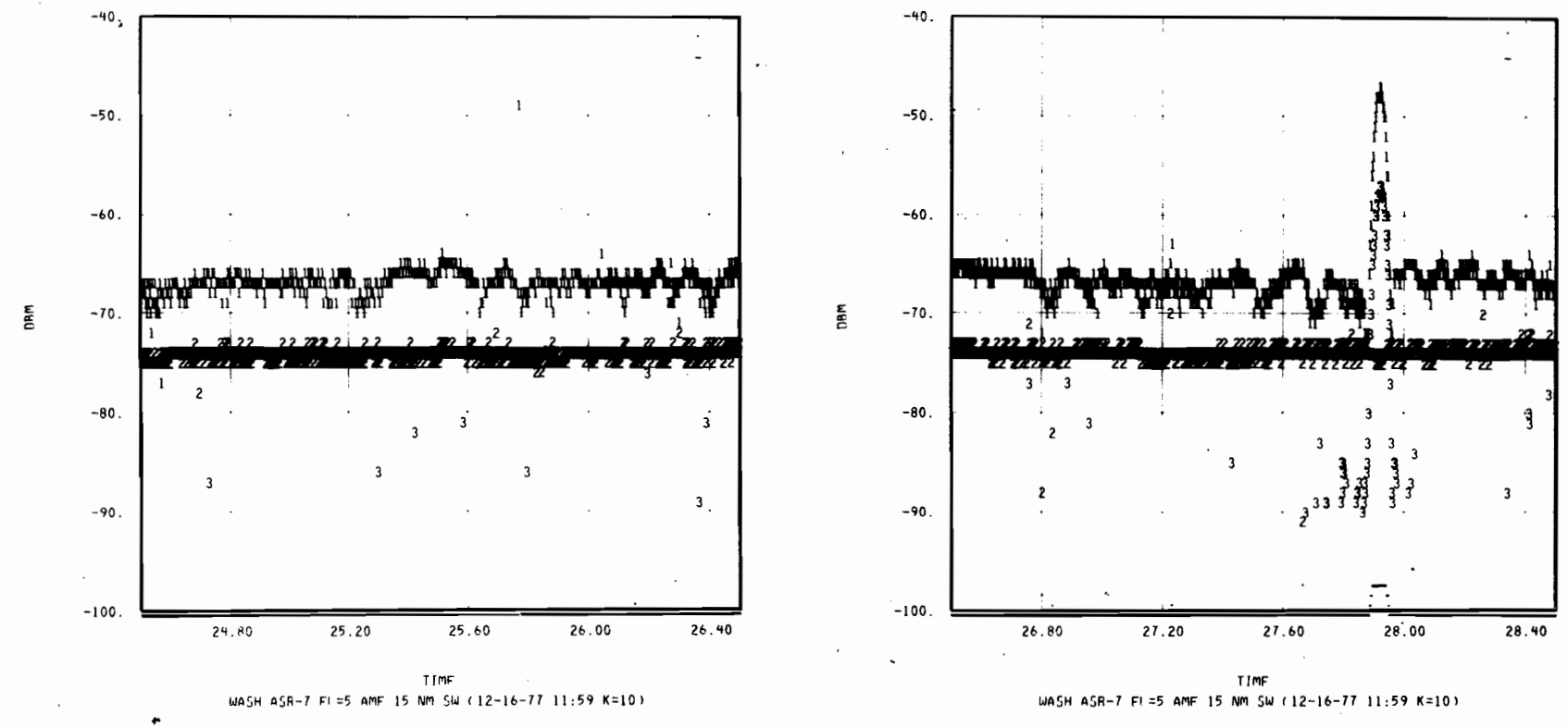


Fig. 3-3g. Antenna Pattern, Detail - Washington (ASR-7), 24.80-28.40 Secs.

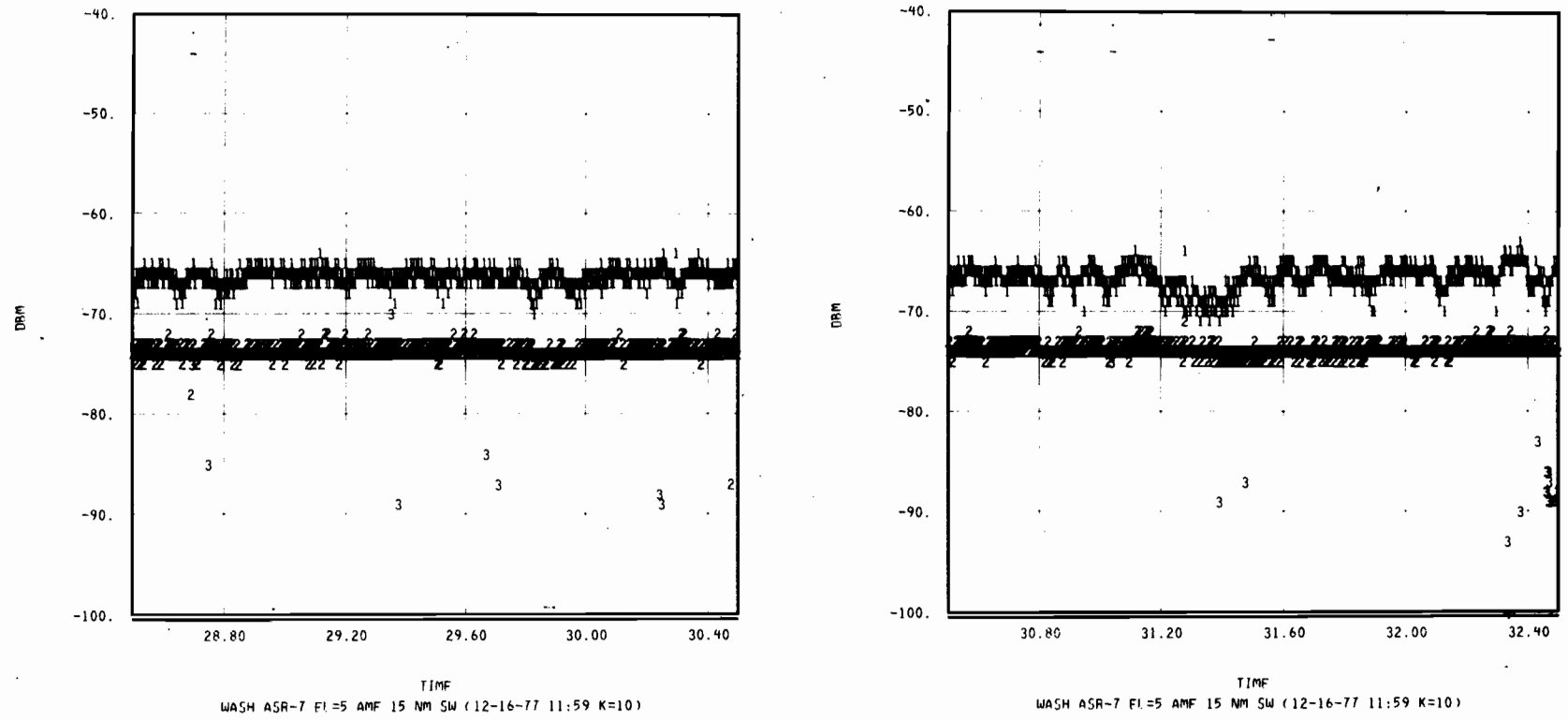


Fig. 3-3h. Antenna Pattern, Detail - Washington (ASR-7), 28.80-32.40 Secs.

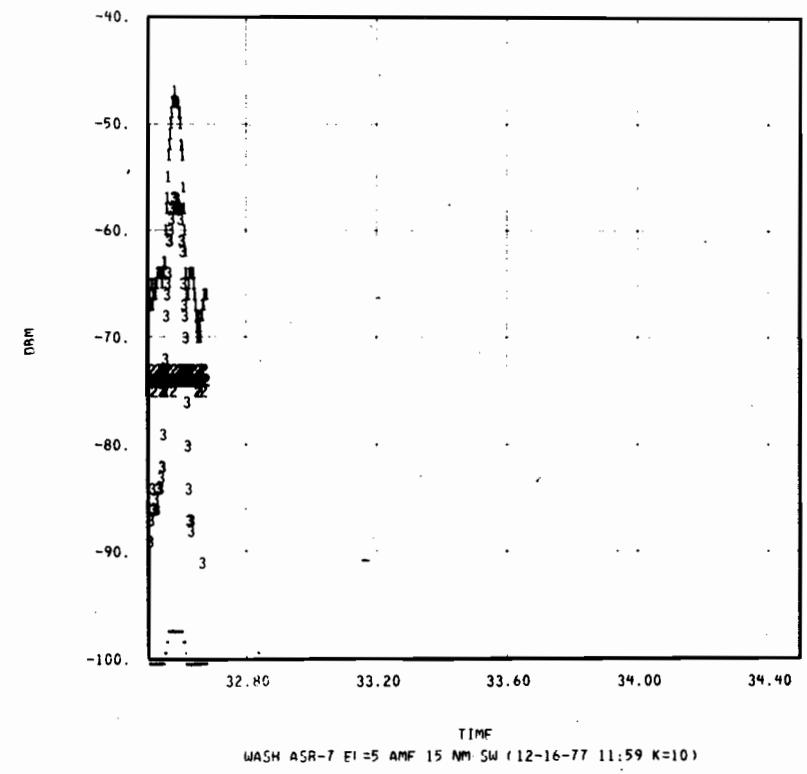


Fig. 3-3i. Antenna Pattern Detail - Washington (ASR-7), 32.80-34.40 Secs.

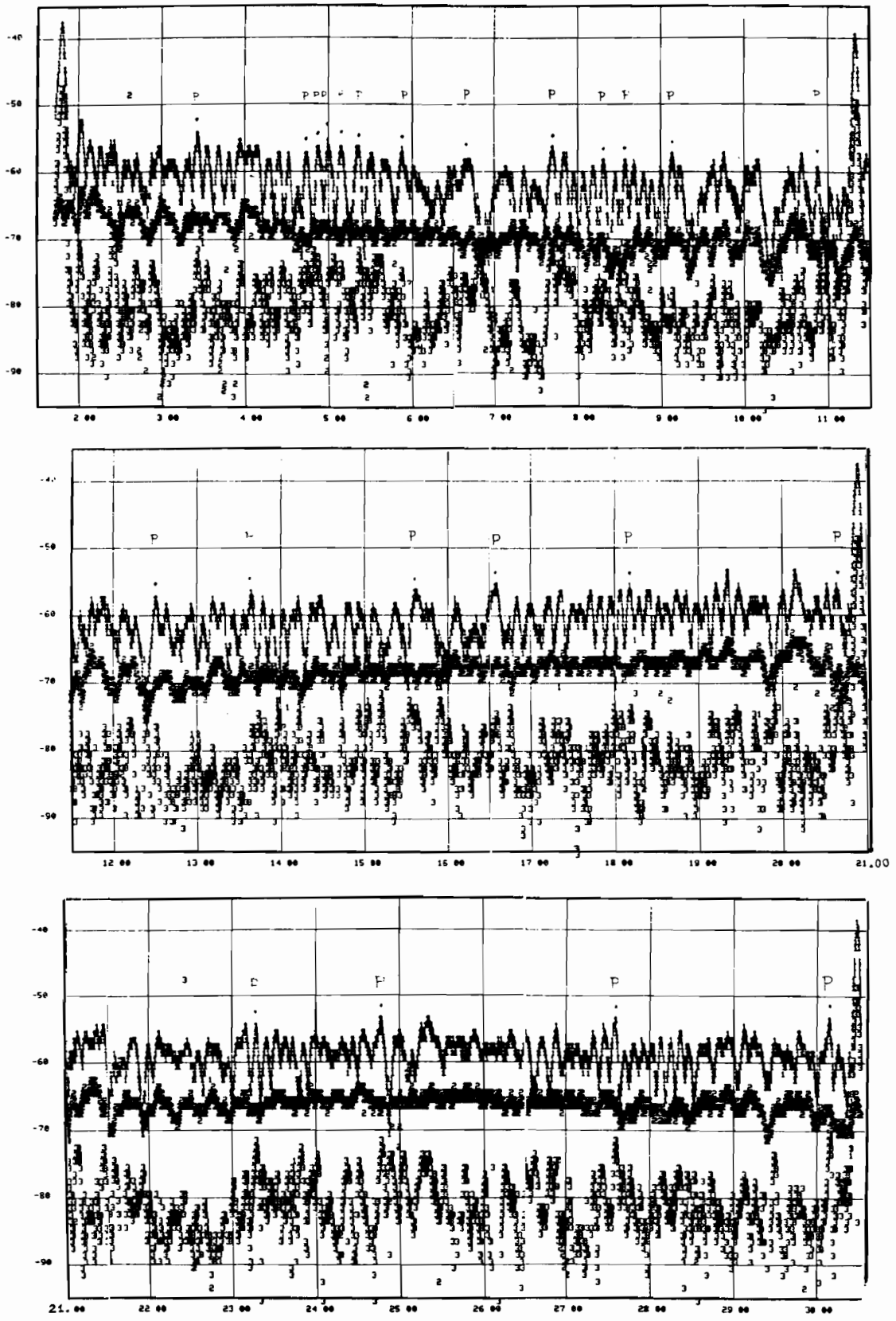


Fig. 3-4a. Antenna Pattern, Composite - JFK-NY (ARSR).

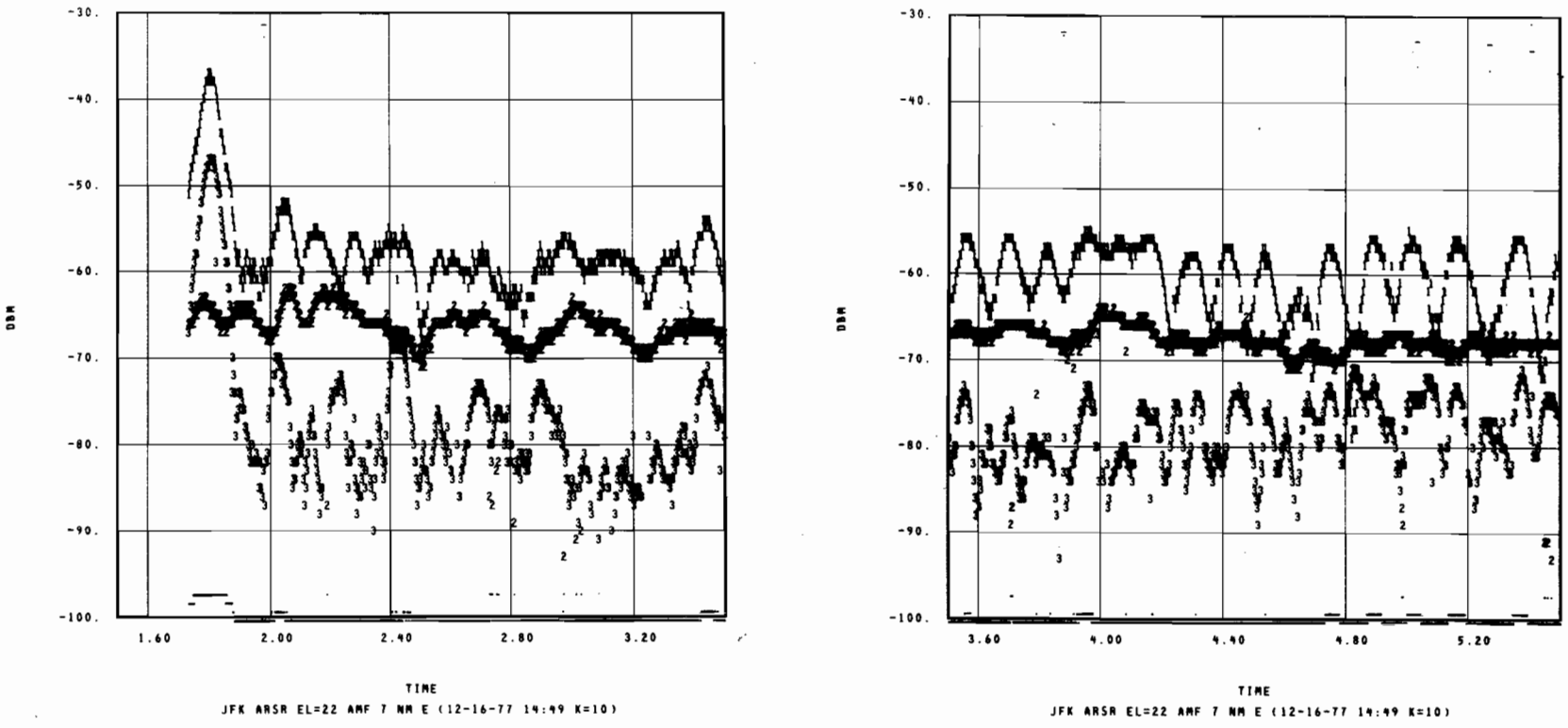


Fig. 3-4b. Antenna Pattern, Detail - JFK-NY (ARSR), 1.60-5.20 Secs.

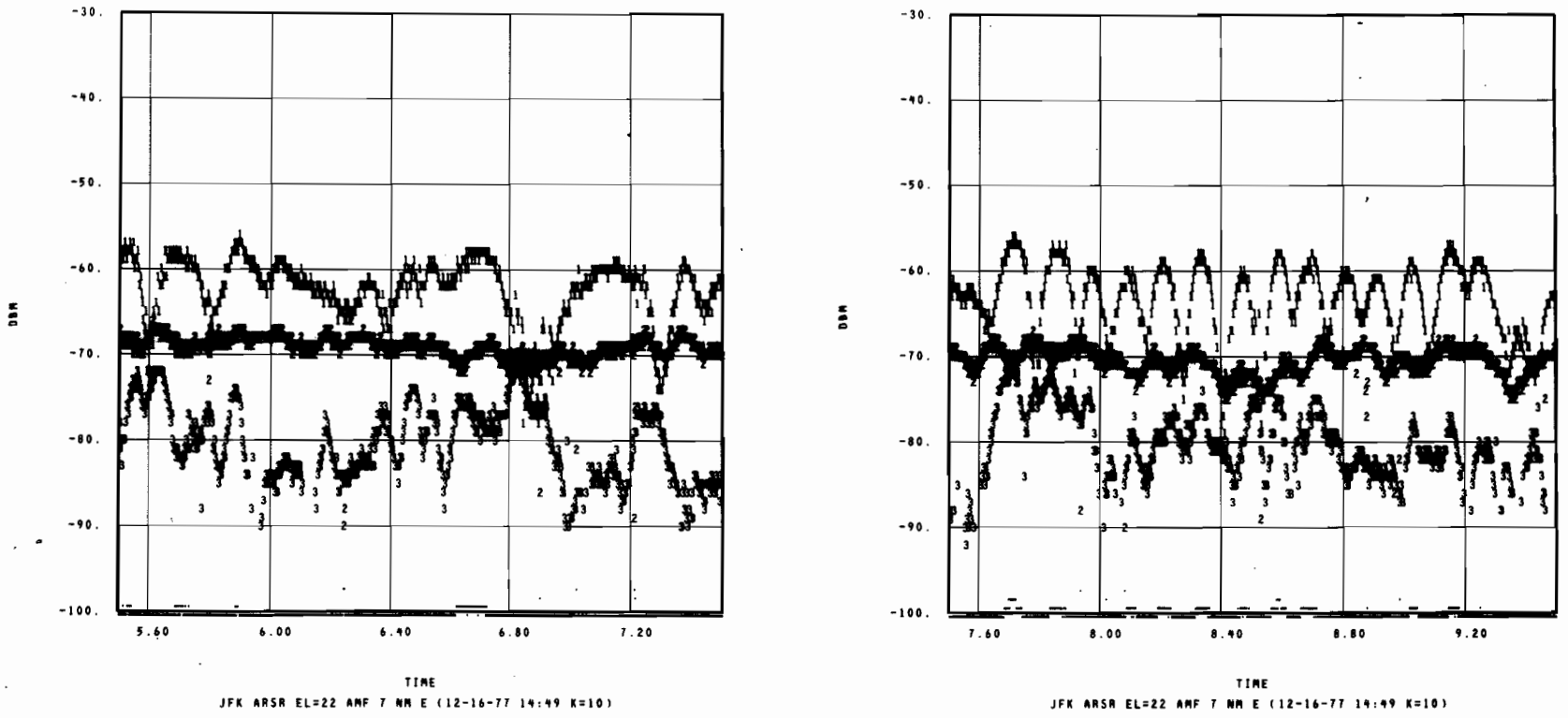
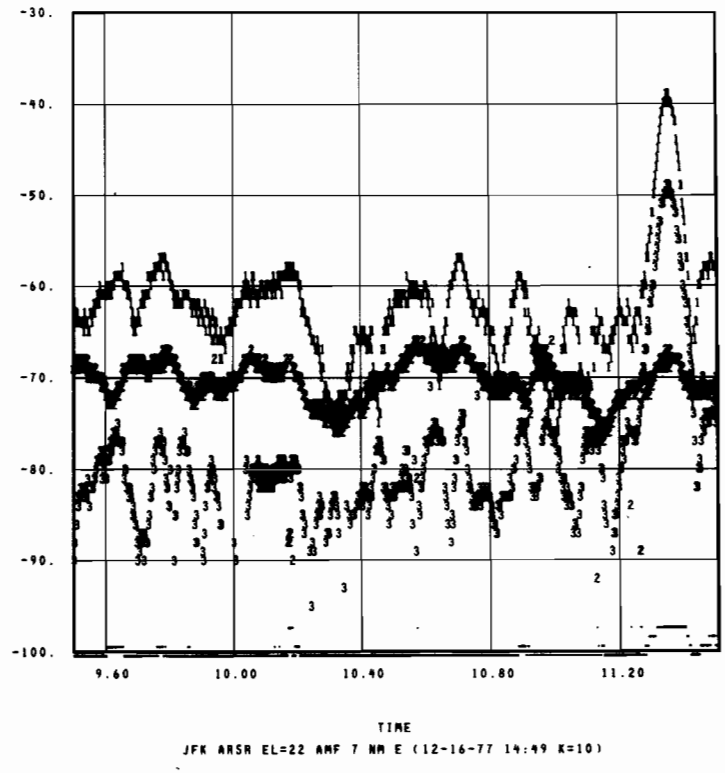


Fig. 3-4c. Antenna Pattern, Detail - JFK-NY (ARSR), 5.60-9.20 Secs.



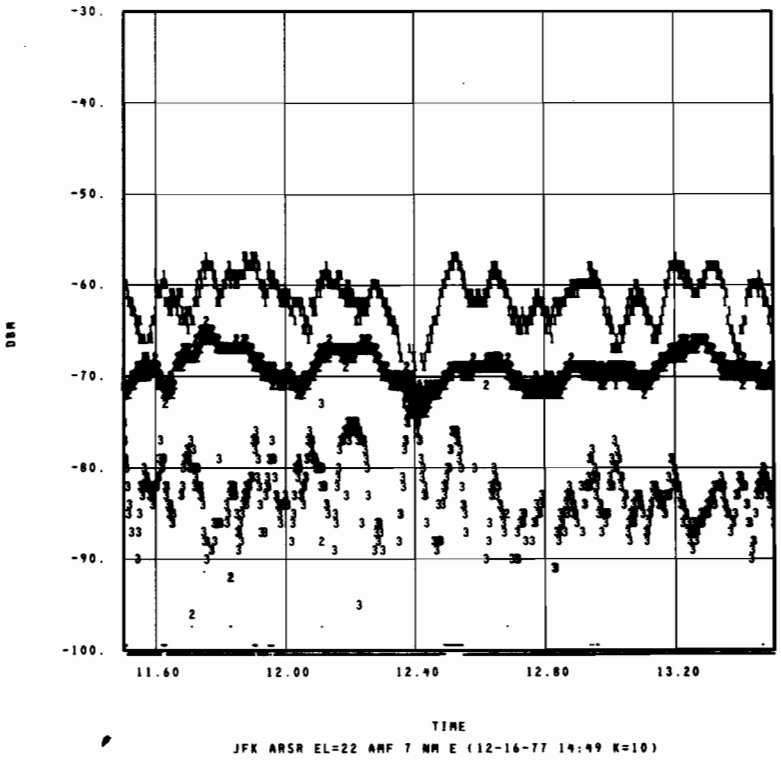


Fig. 3-4d. Antenna Pattern, Detail - JFK-NY (ARSR), 9.60-13.20 Secs.

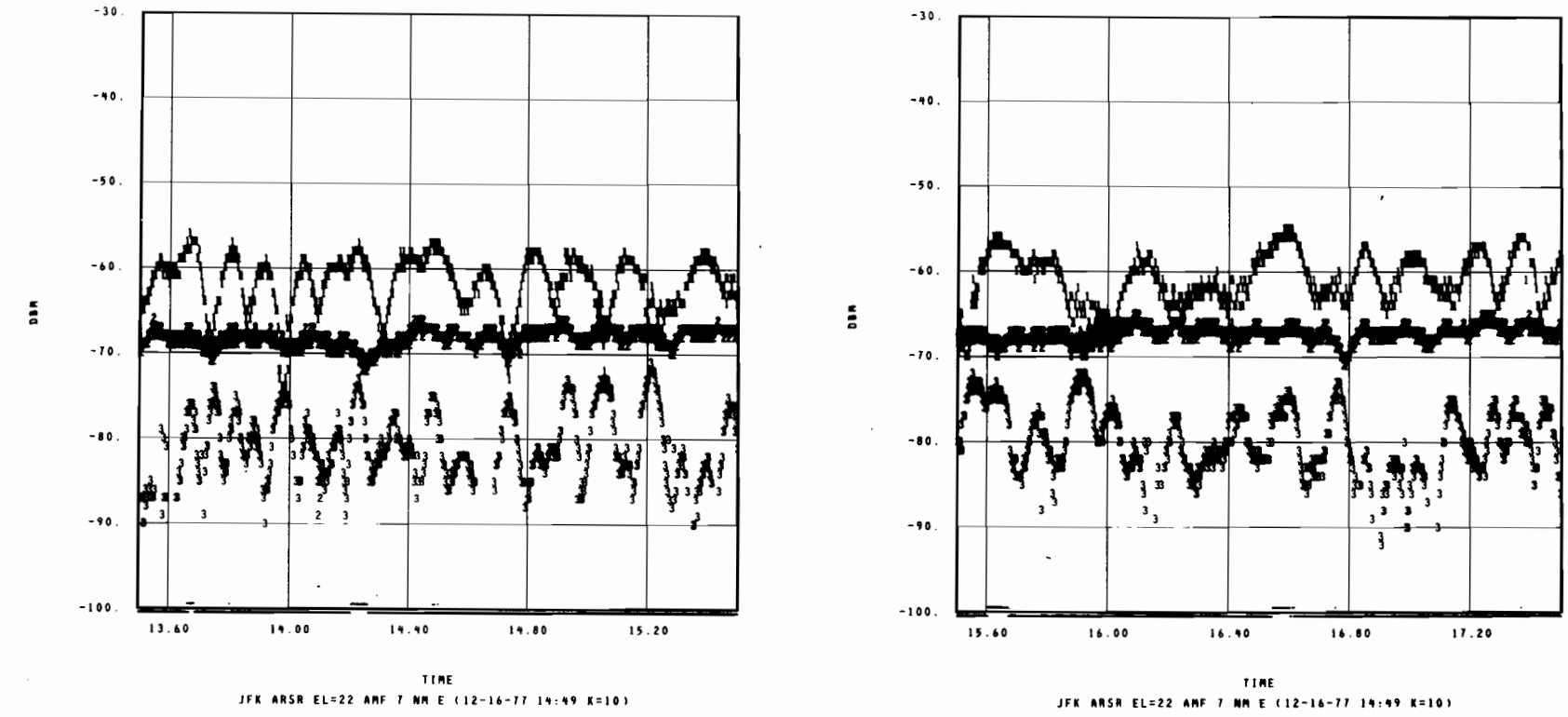


Fig. 3-4e. Antenna Pattern, Detail - JFK-NY (ARSR), 13.60-17.20 Secs.

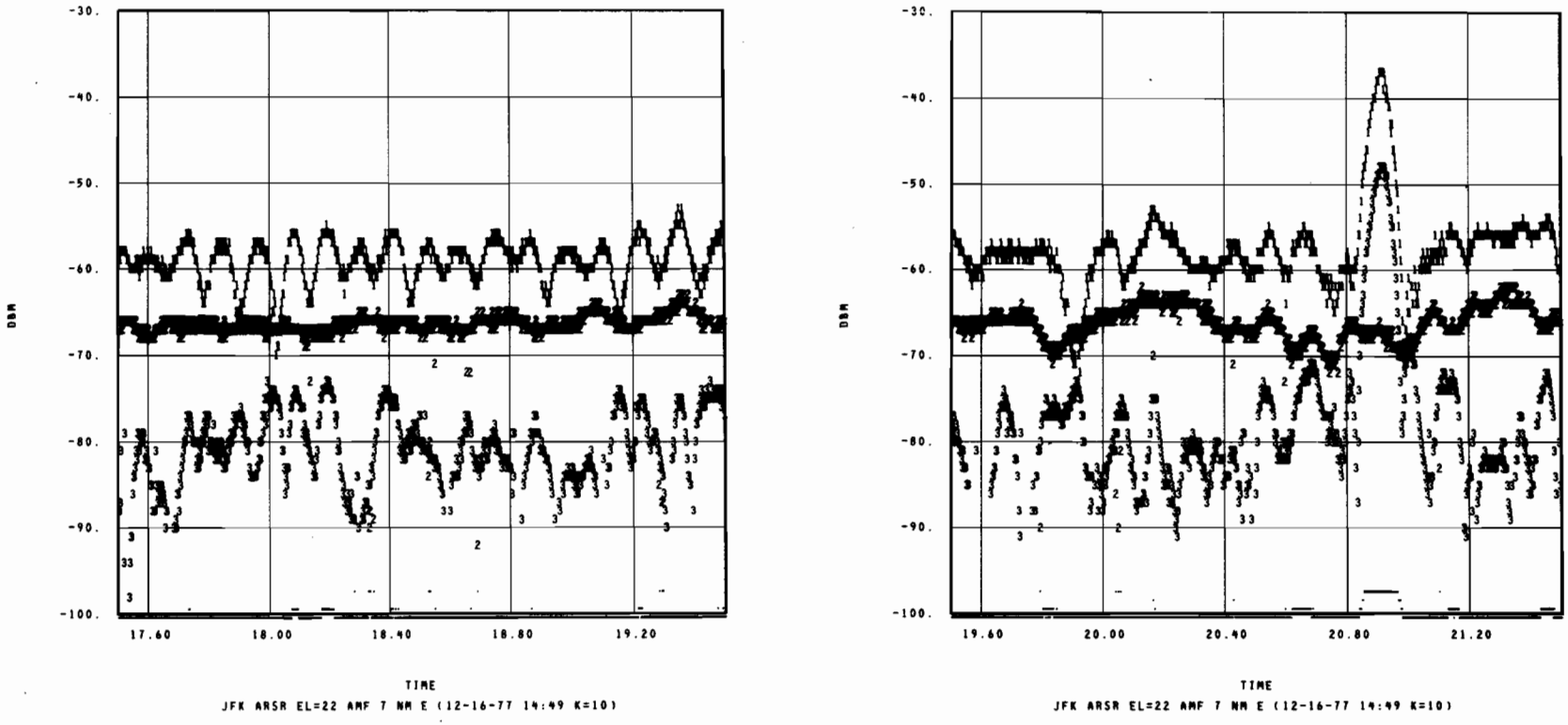


Fig. 3-4f. Antenna Pattern, Detail - JFK-NY (ARSR), 17.60-21.20 Secs.

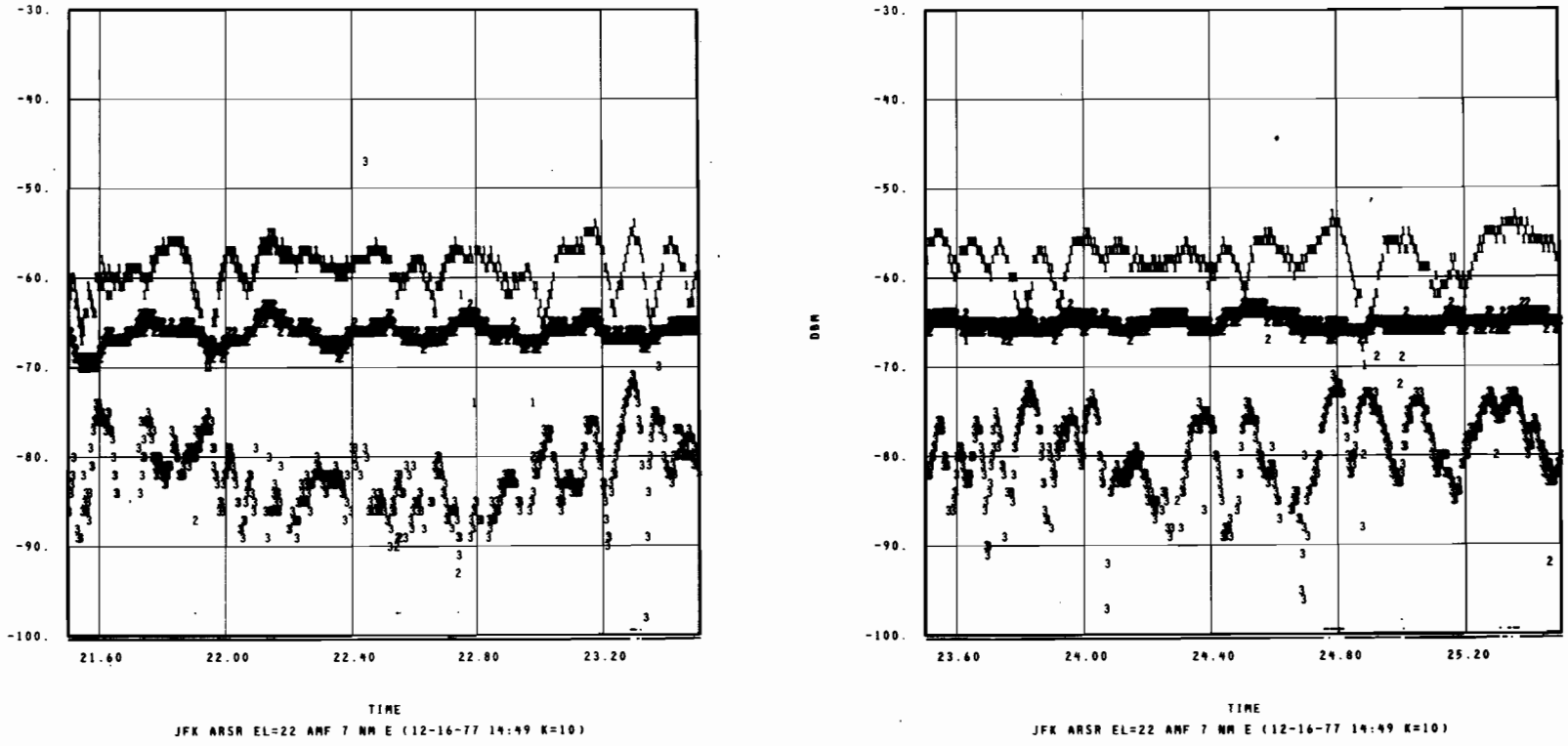


Fig. 3-4g. Antenna Pattern, Detail - JFK-NY (ARSR), 21.60-25.20 Secs.

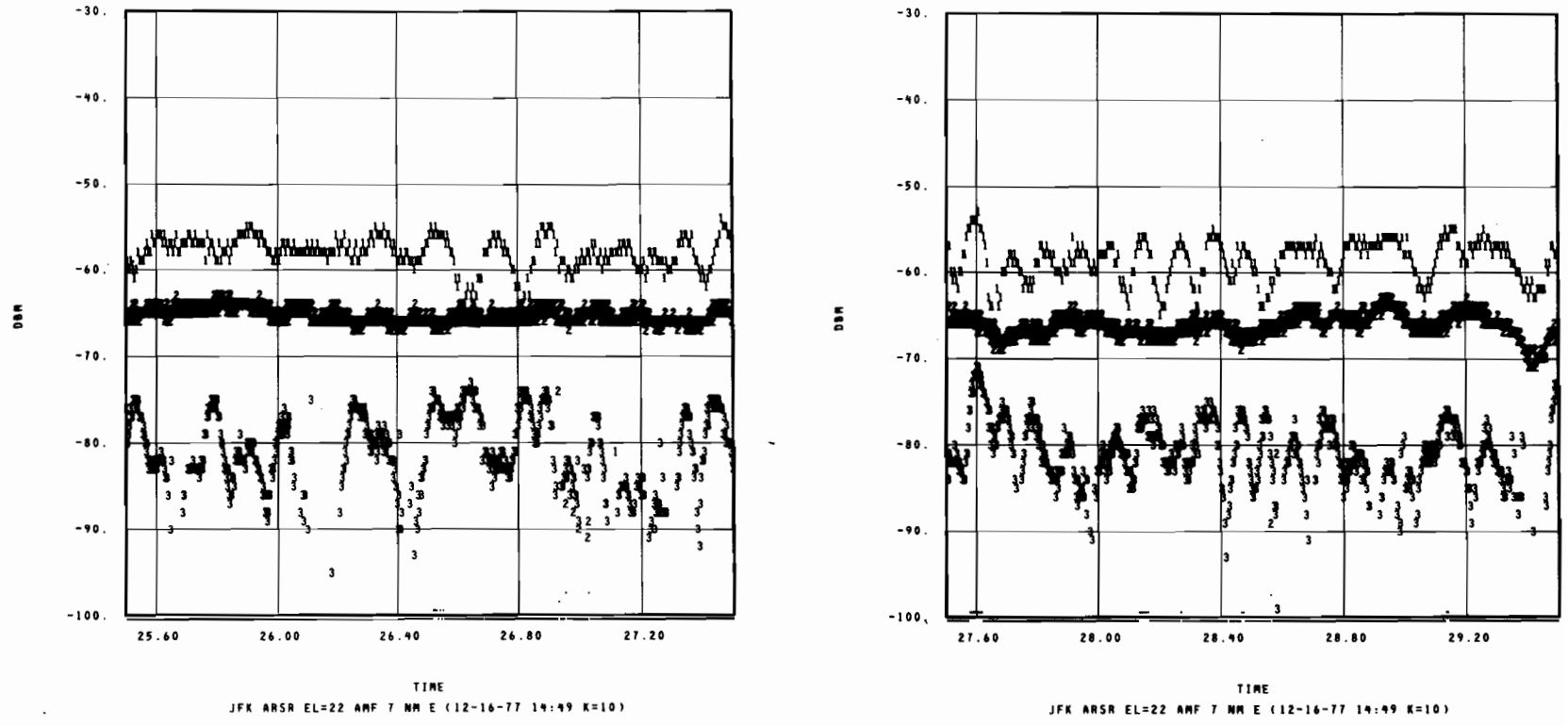


Fig. 3-4h. Antenna Pattern, Detail - JFK-NY (ARSR), 25.60-29.20 Secs.

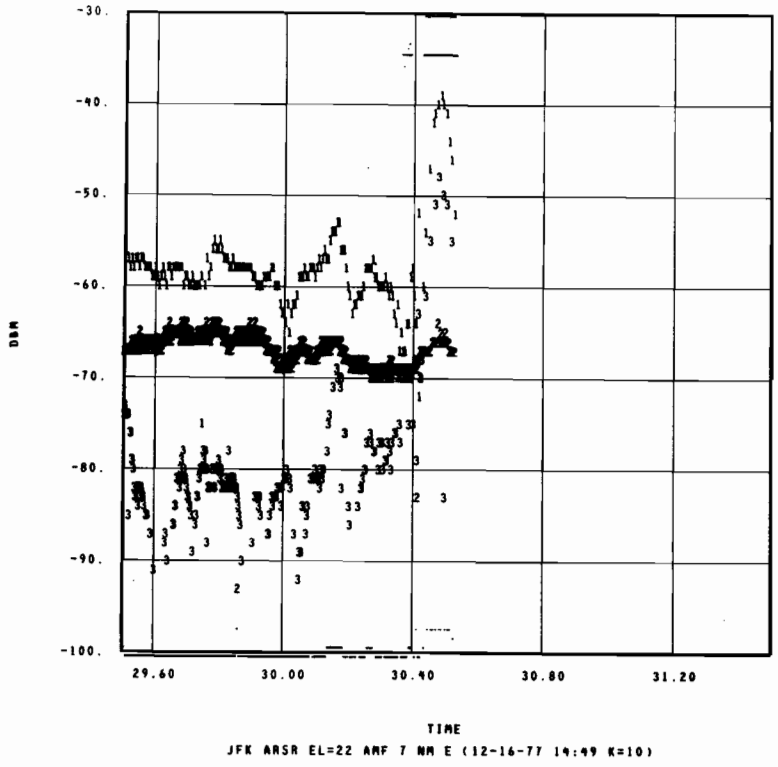


Fig. 3-4i. Antenna Pattern, Detail - JFK-NY (ARSR), 29.60-31.20 Secs.

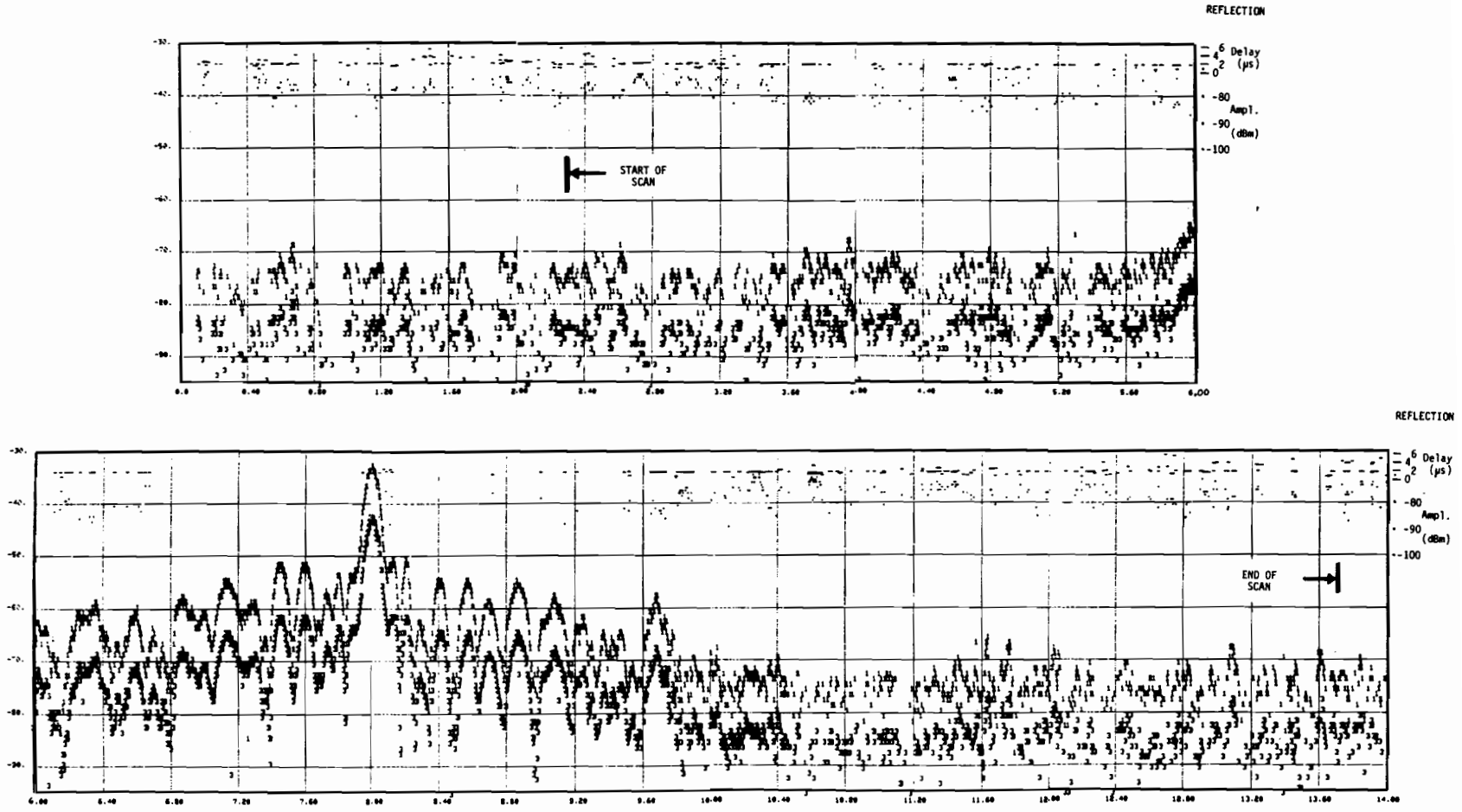


Fig. 3-5a. Antenna Pattern, Composite - Montauk Point (Air Force).

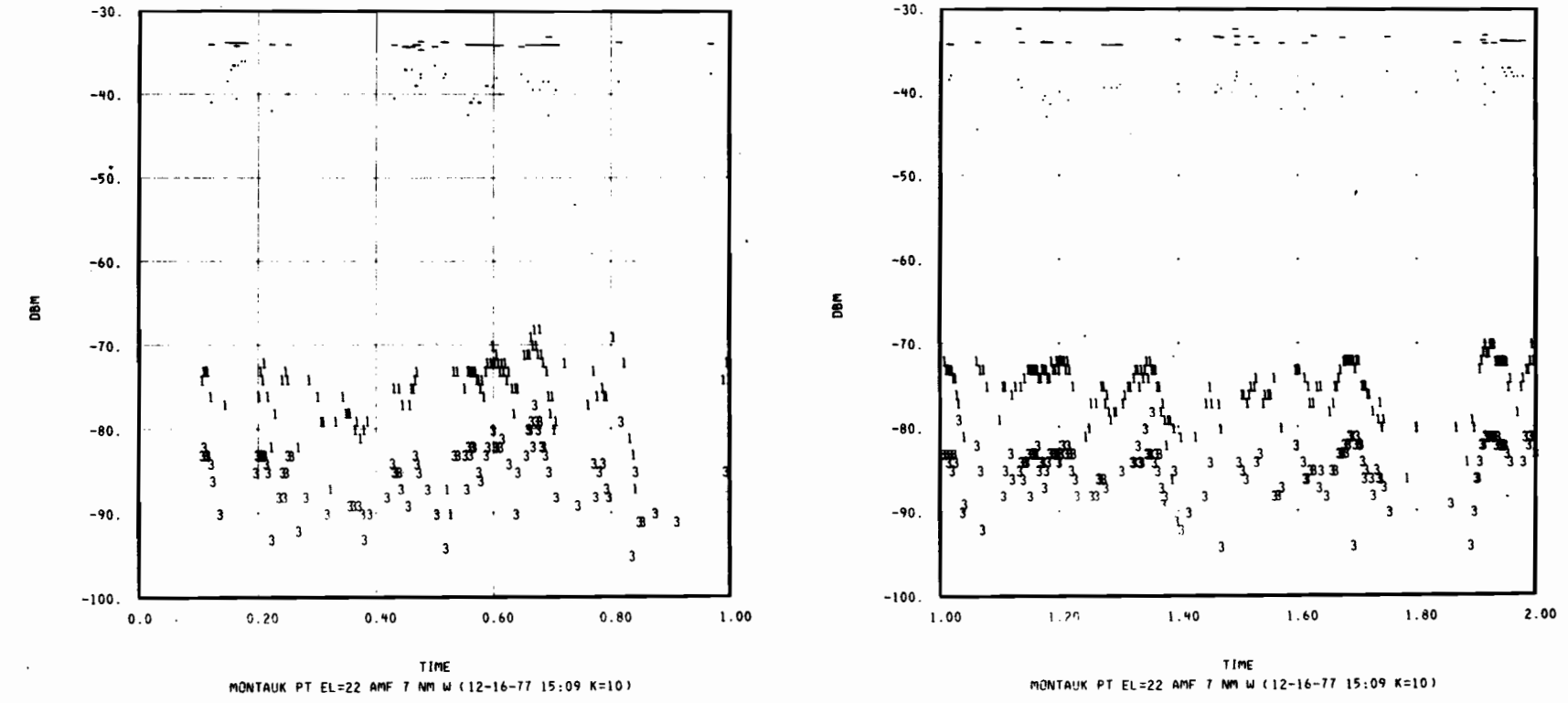


Fig. 3-5b. Antenna Pattern, Detail - Montauk Point, 0.0-2.00 Secs.

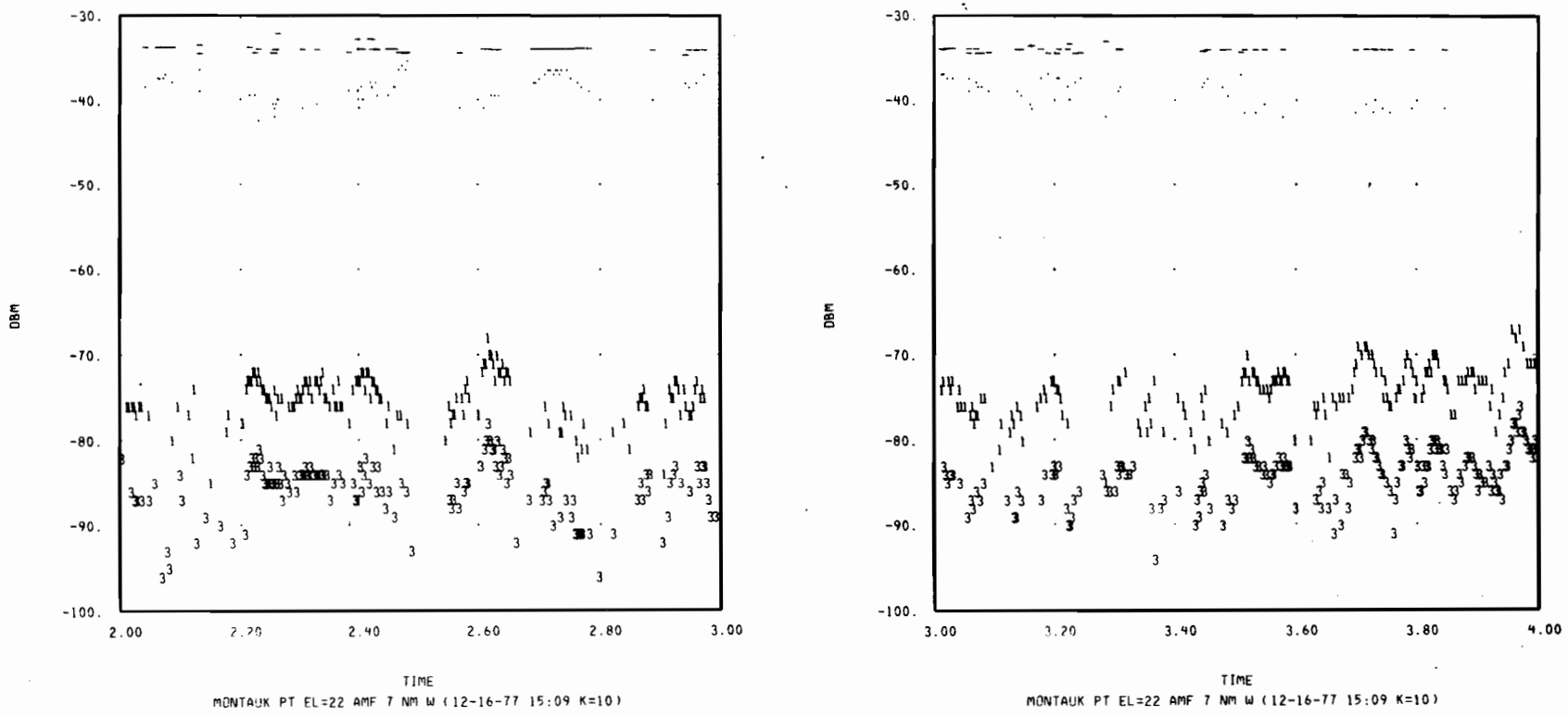


Fig. 3-5c. Antenna Pattern, Detail - Montauk Point, 2.00-4.00 Secs.

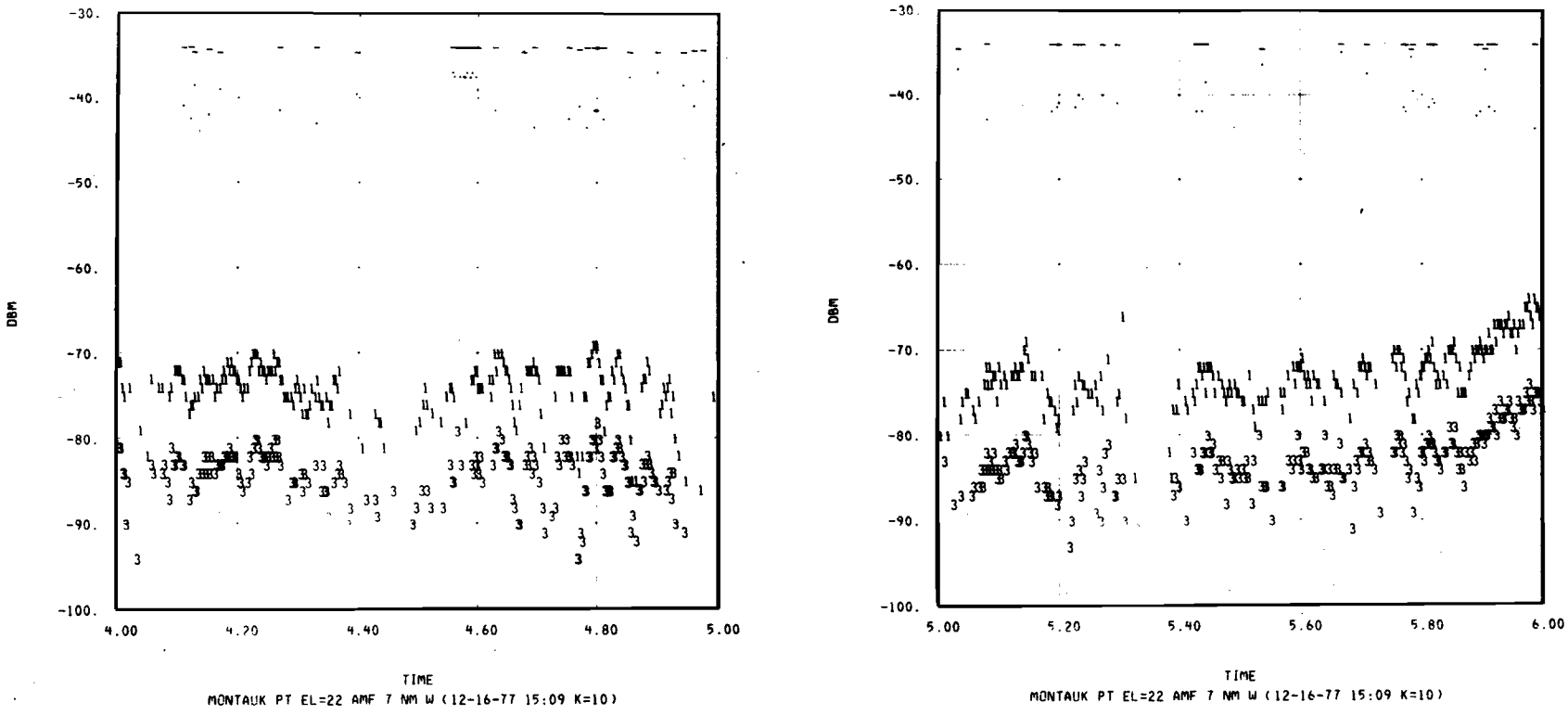
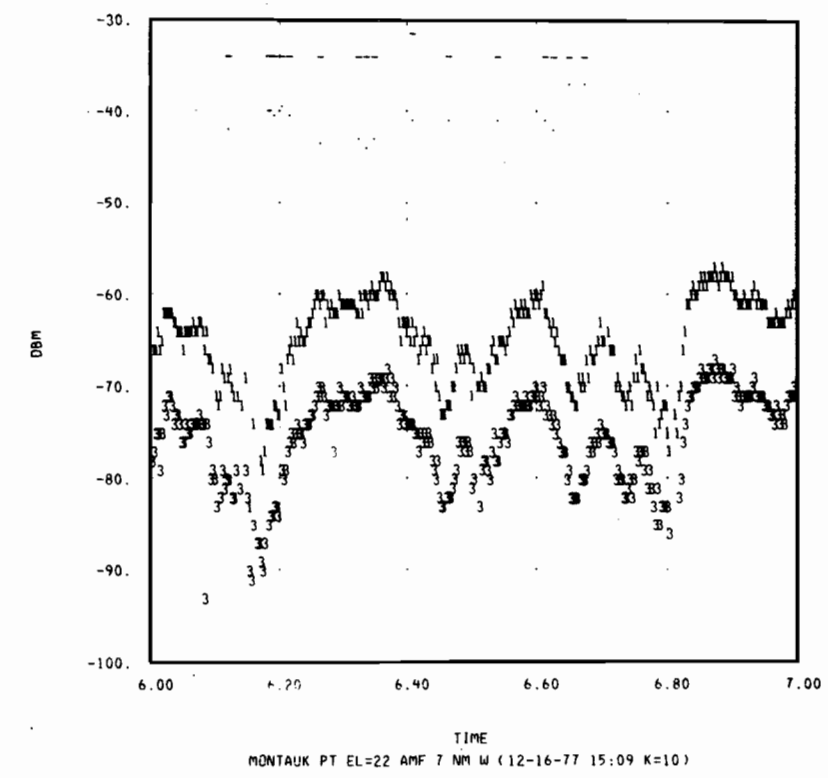


Fig. 3-5d. Antenna Pattern, Detail - Montauk Point, 4.00-6.00 Secs.



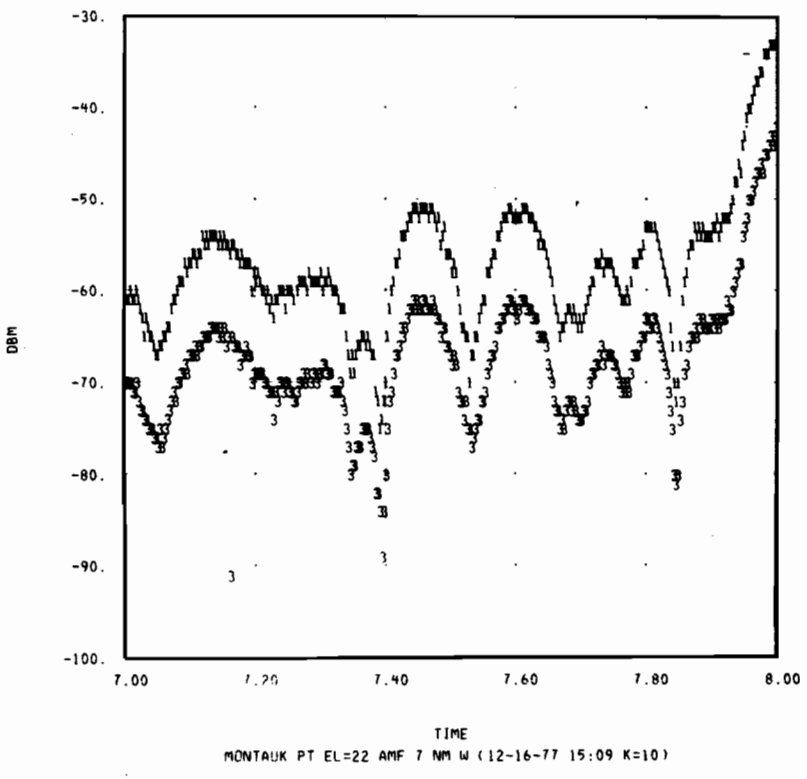


Fig. 3-5e. Antenna Pattern, Detail - Montauk Point, 6.00-8.00 Secs.

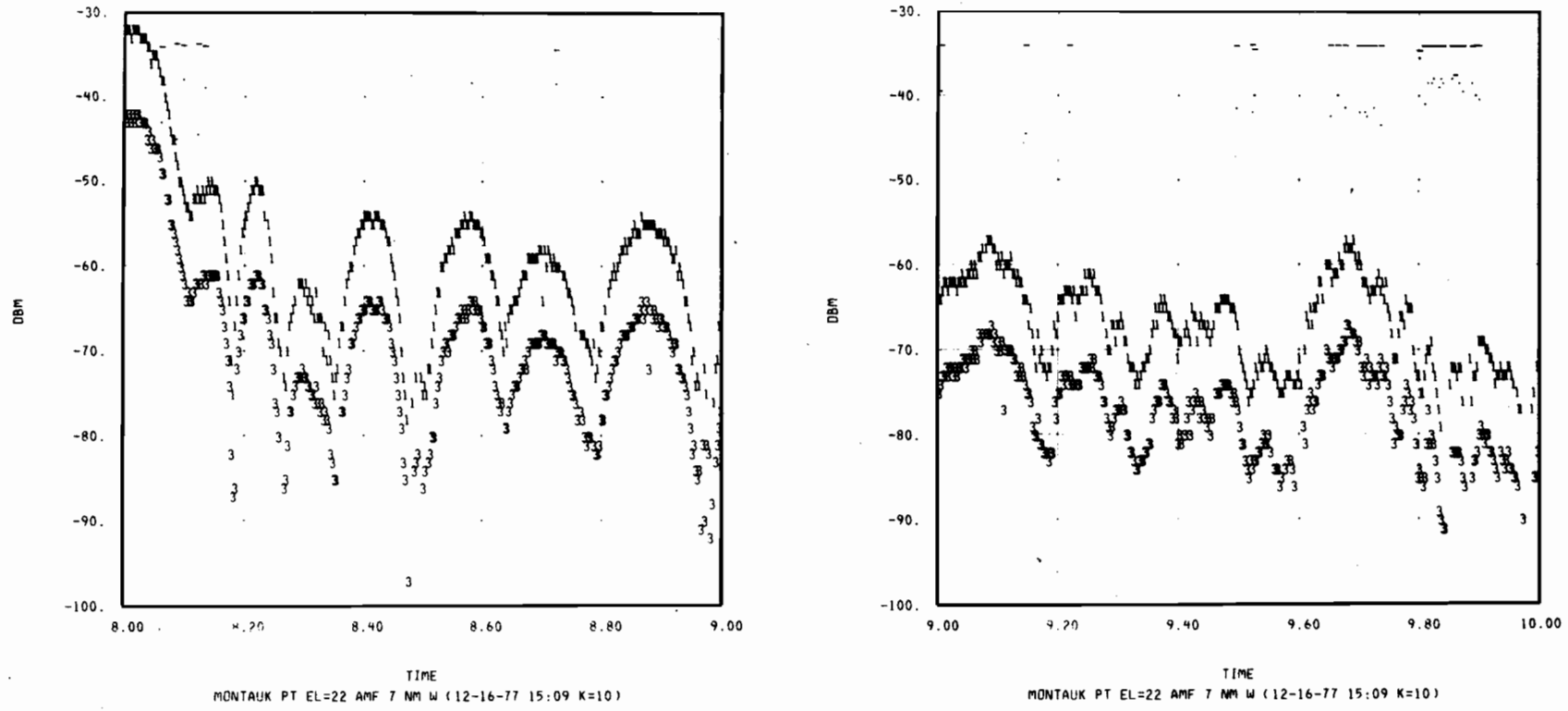


Fig. 3-5f. Antenna Pattern, Detail - Montauk Point, 8.00-10.00 Secs.

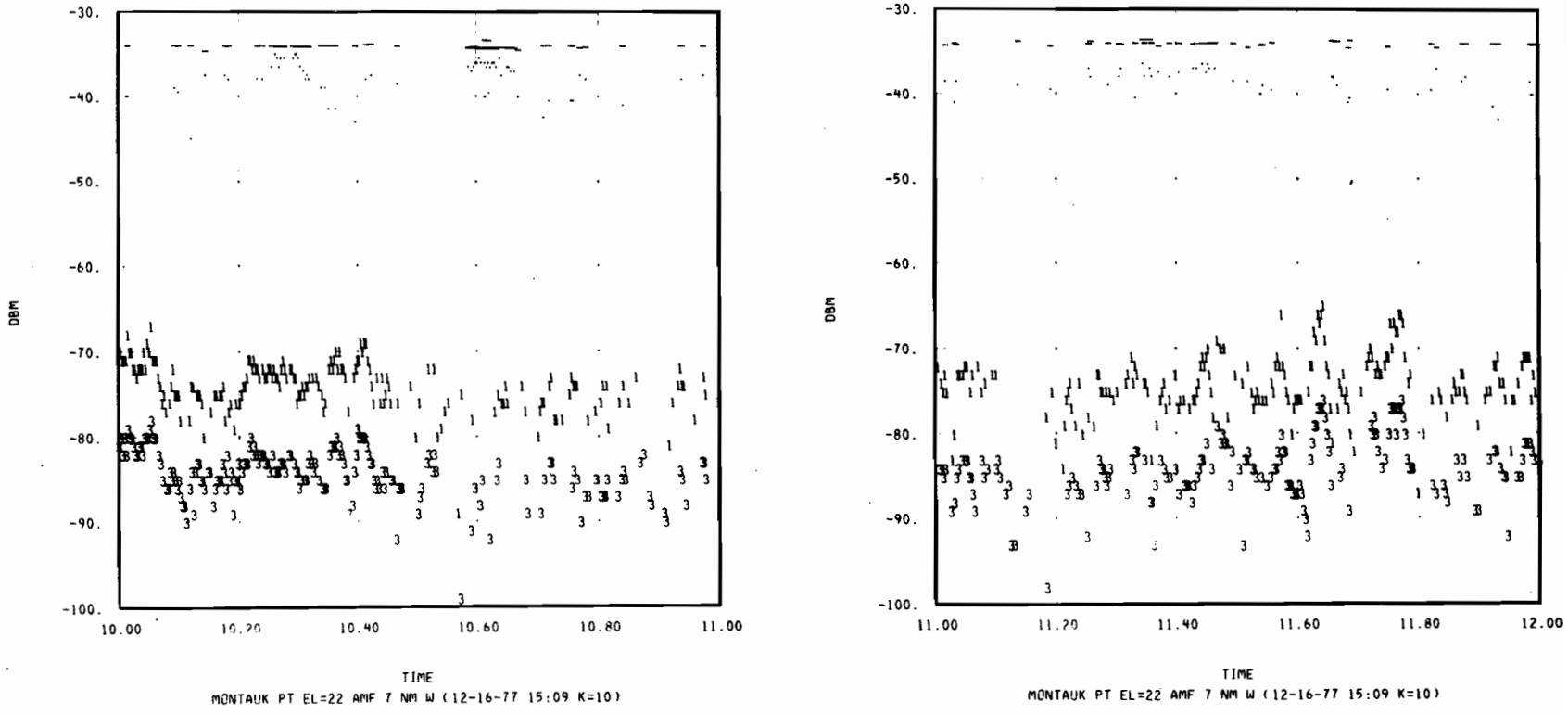
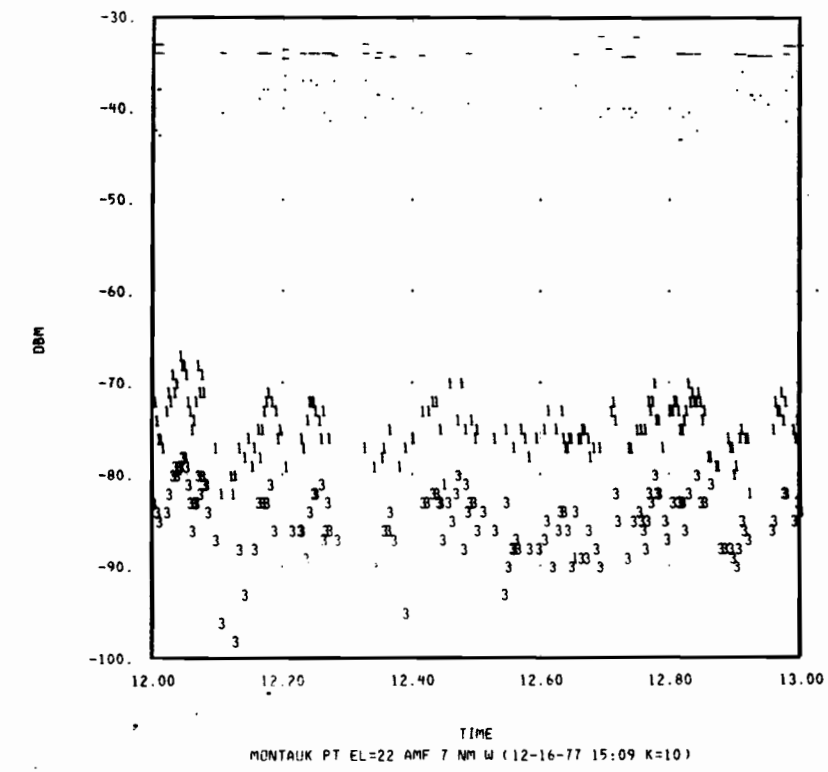


Fig. 3-5g. Antenna Pattern, Detail - Montauk Point, 10.00-12.00 Secs.



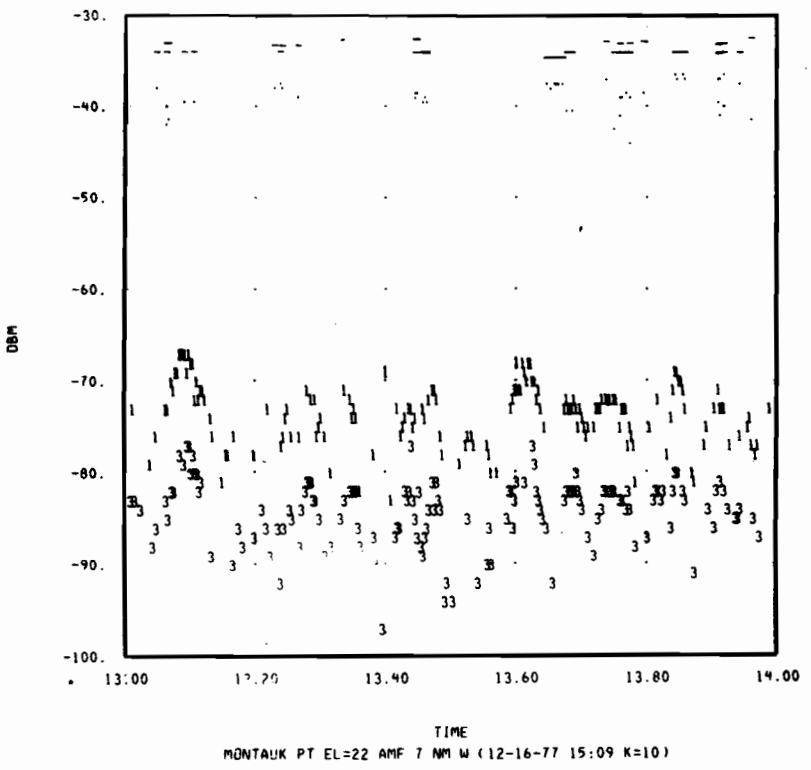


Fig. 3-5h. Antenna Pattern, Detail - Montauk Point, 12.00-14.00 Secs.

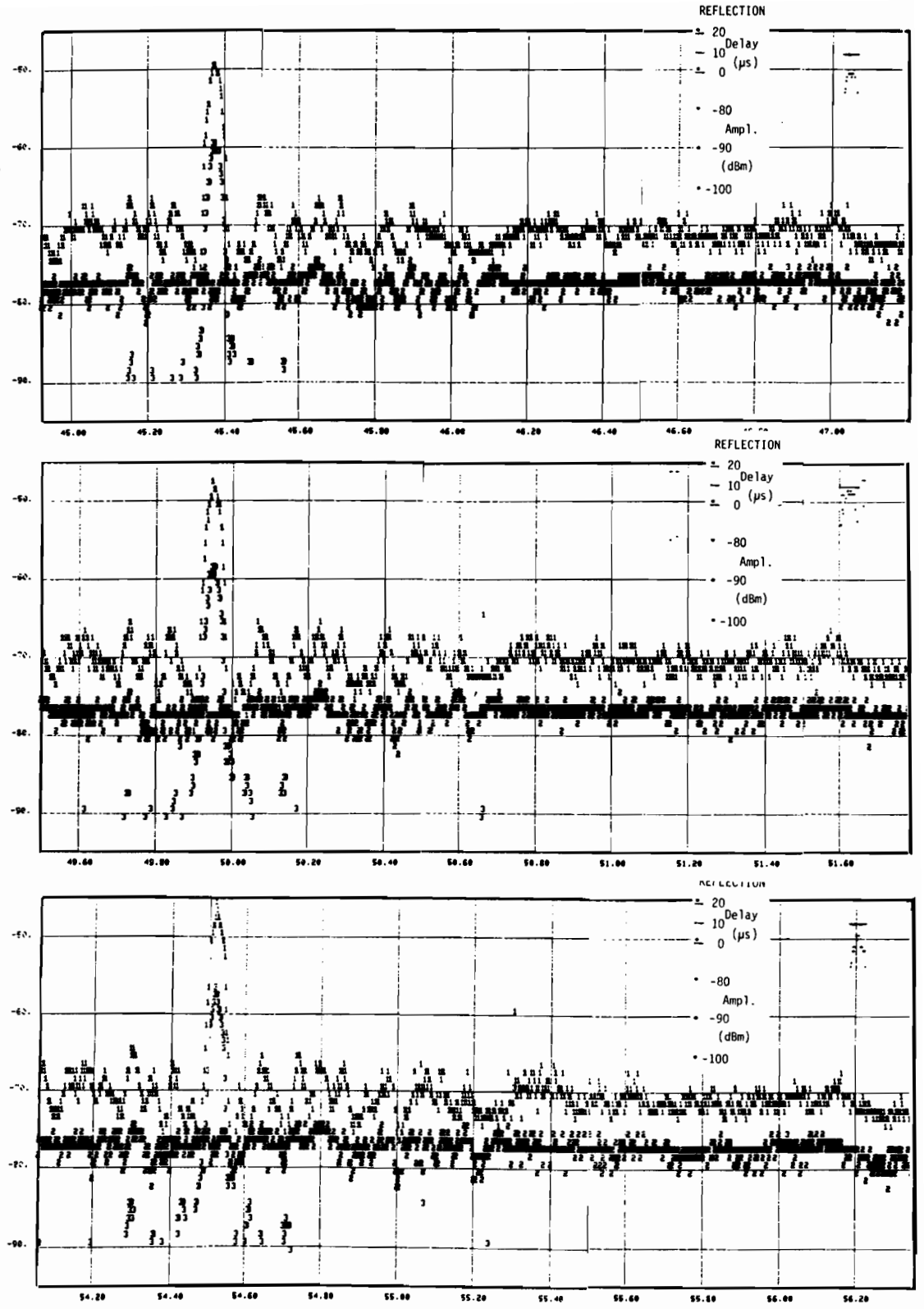


Fig. 3-6a. Antenna Pattern, Composite - Logan (ASR-7).

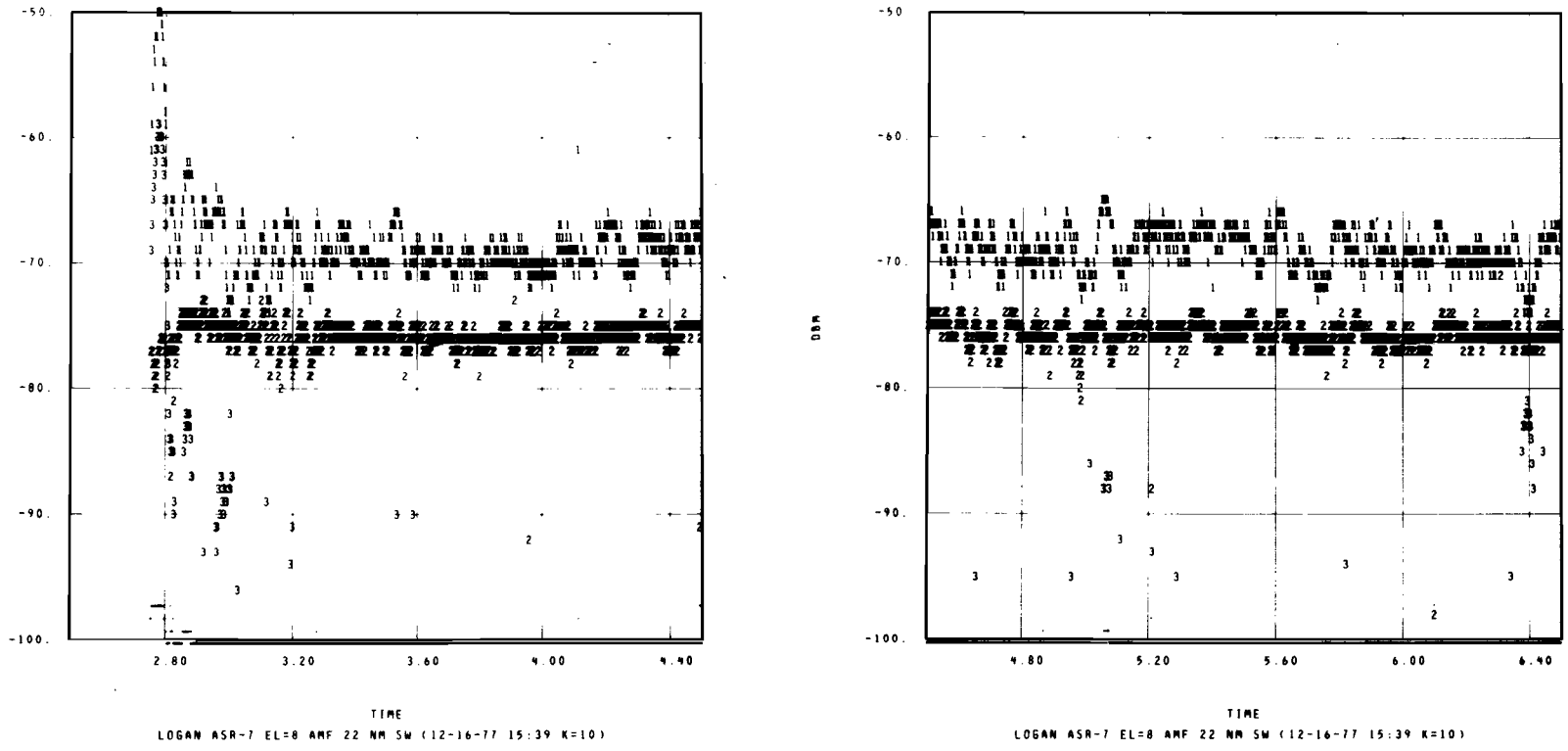
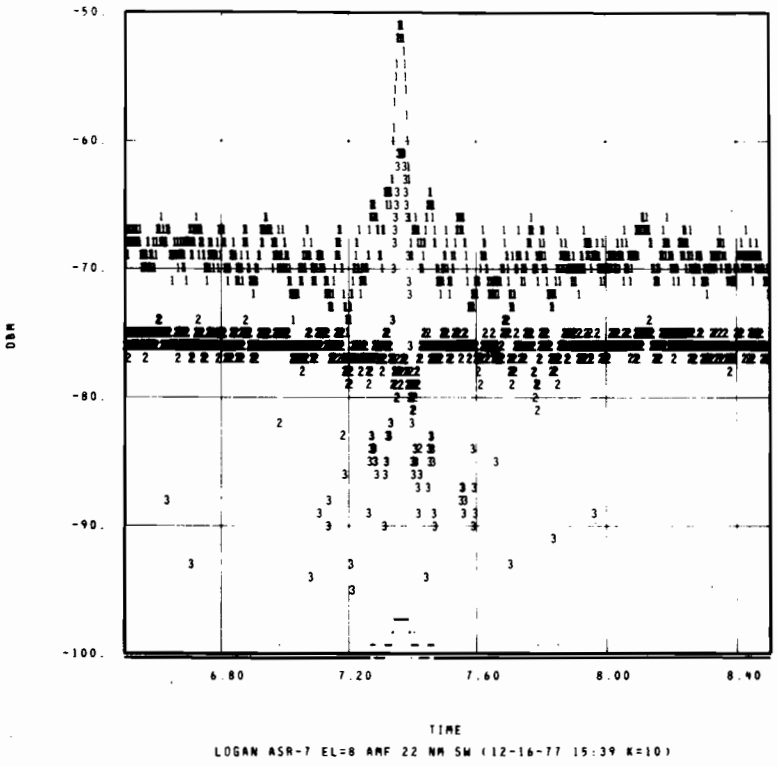


Fig. 3-6b. Antenna Pattern, Detail - Logan (ASR-7), 2.80-6.40 Secs.



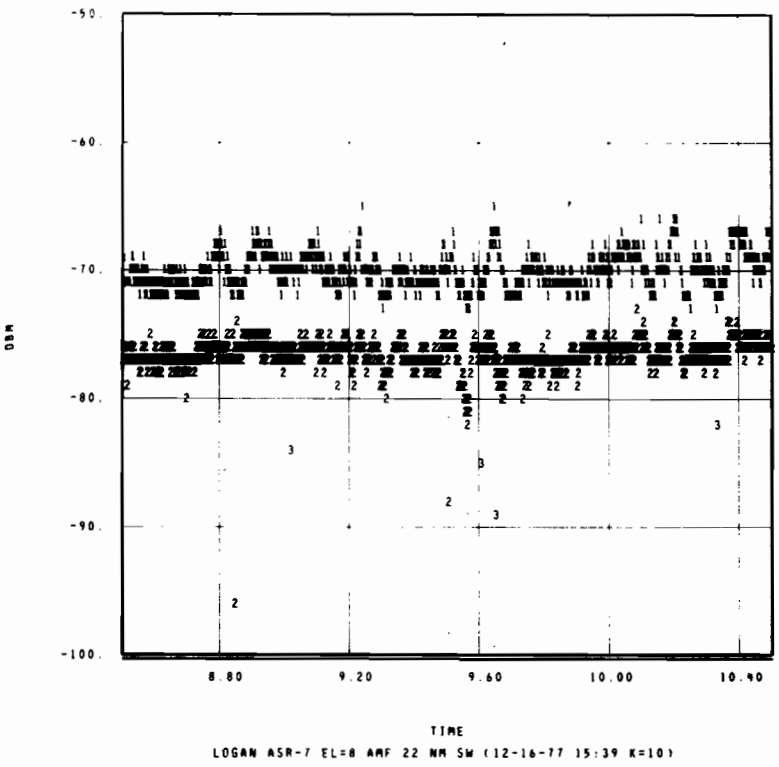


Fig. 3-6c. Antenna Pattern, Detail - Logan (ASR-7), 6.80-10.40 Secs.

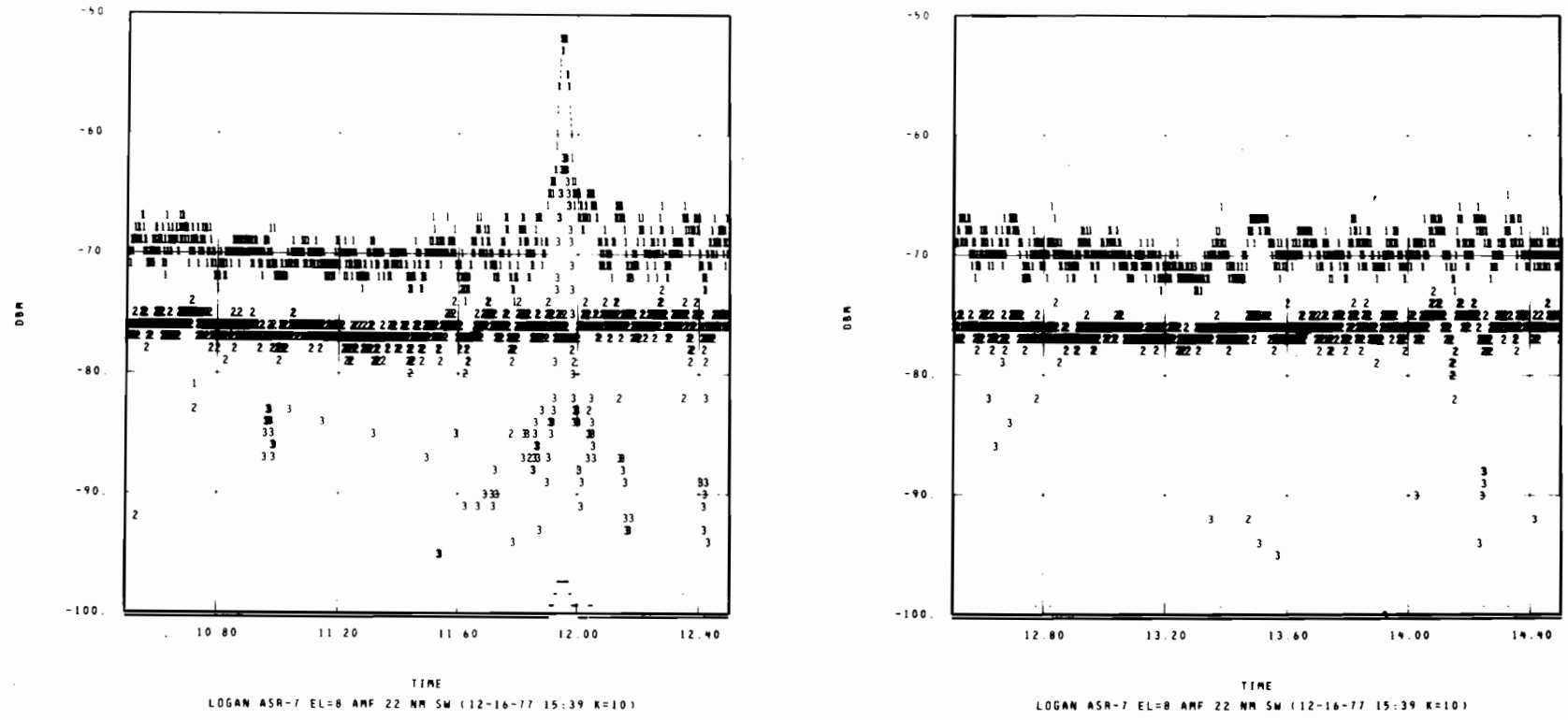


Fig. 3-6d. Antenna Pattern, Detail - Logan (ASR-7), 10.80-14.40 Secs.

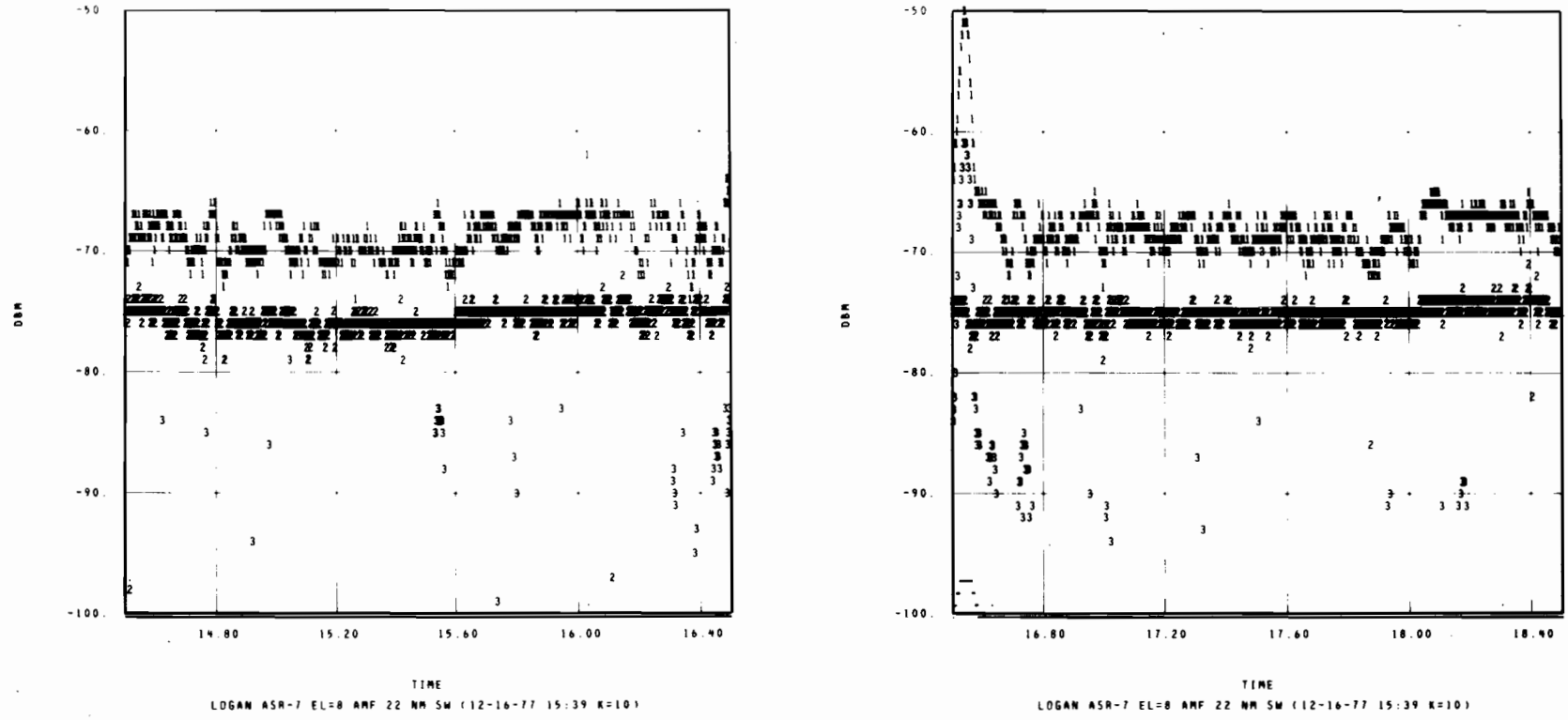


Fig. 3-6e. Antenna Pattern, Detail - Logan (ASR-7), 14.80-18.40 Secs.

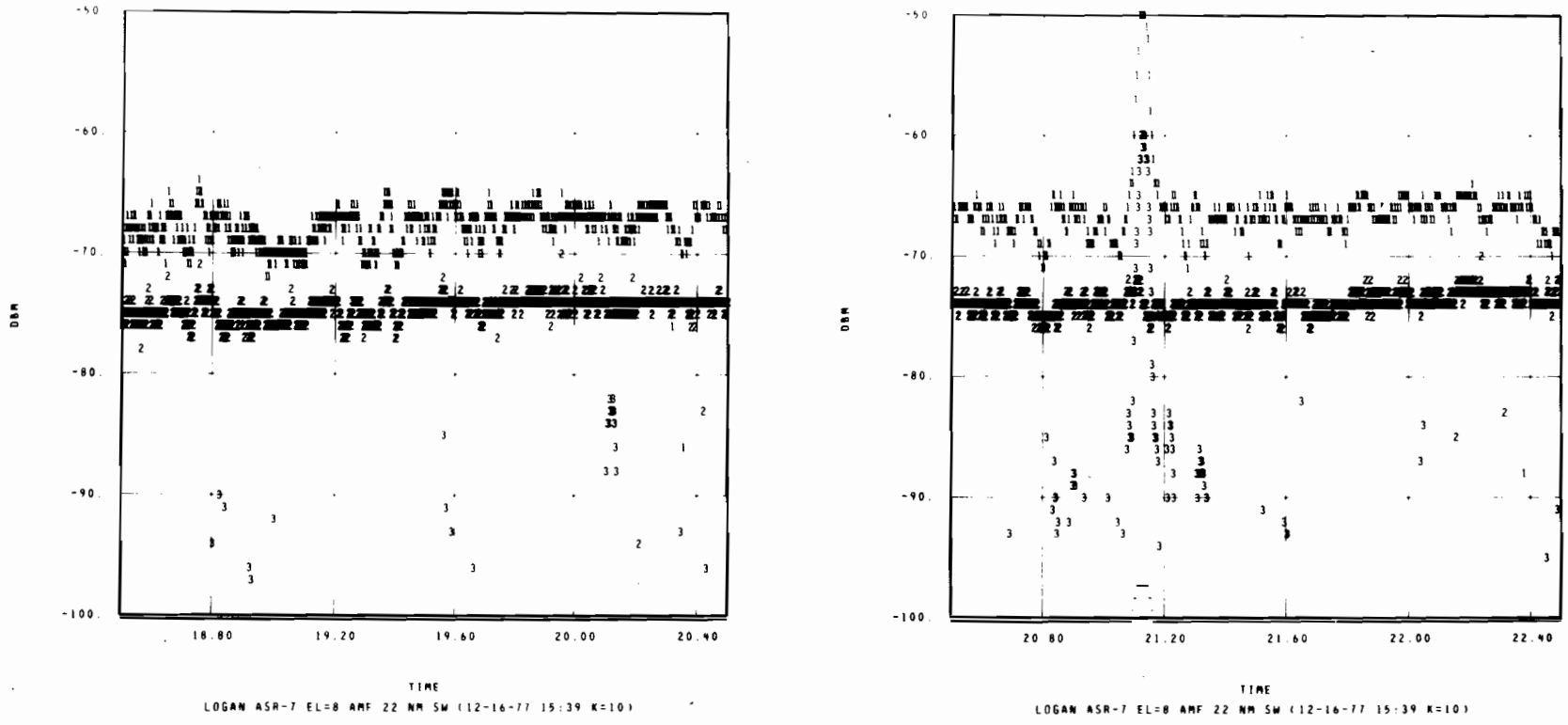


Fig. 3-6f. Antenna Pattern, Detail - Logan (ASR-7), 18.80-22.40 Secs.

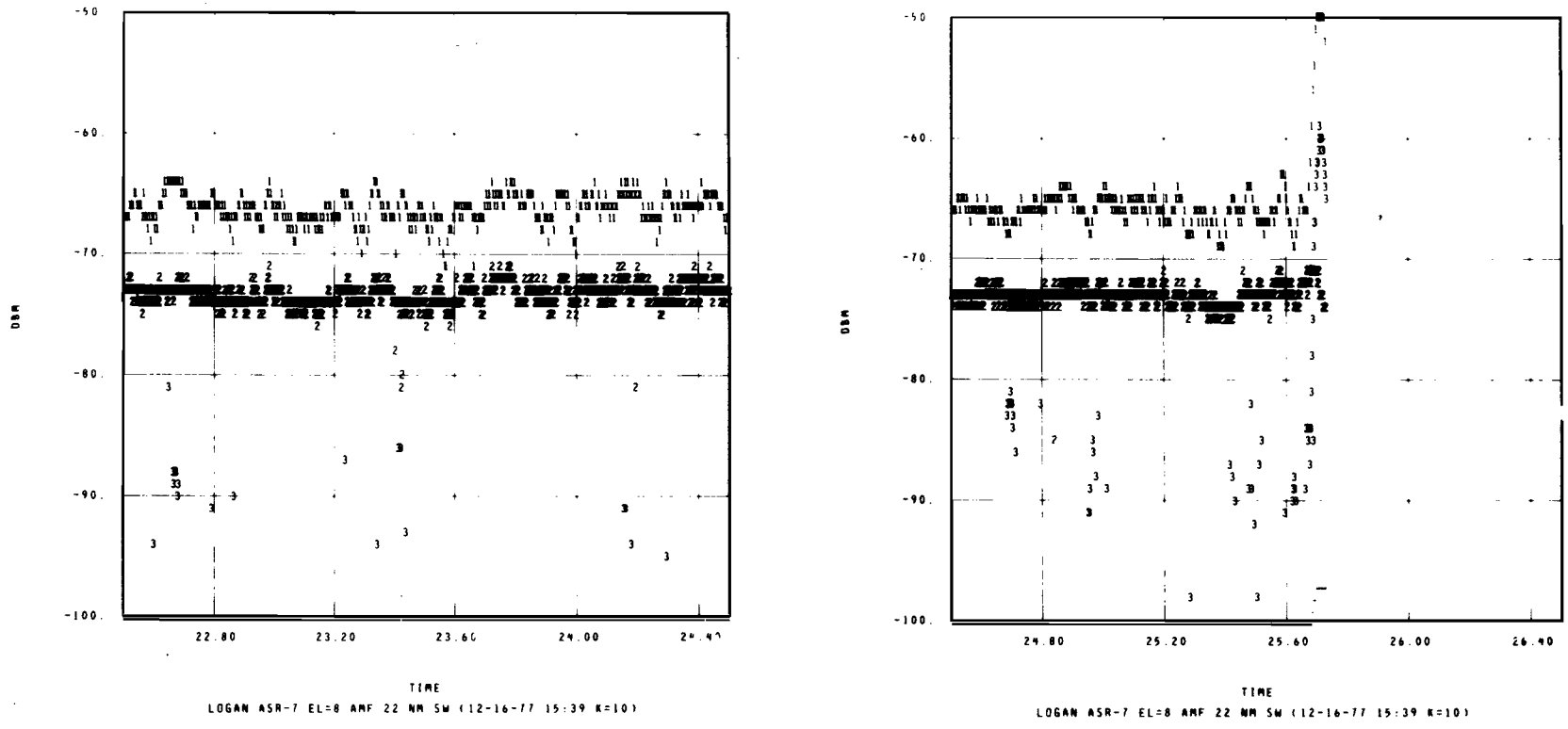


Fig. 3-6g. Antenna Pattern, Detail - Logan (ASR-7), 22.80-26.40 Secs.

4.0 SUMMARY

Based on the measurements recorded at 24 locations from Boston to Washington, characteristics of the population of interrogators detected may be summarized as follows:

Number of interrogators		
detected	68	
identified	46	
not identified	22	
employing staggered PRI		
2-pulse	1	
3-pulse	2	
5-pulse	13	
8-pulse	3	
9-pulse	1	
40-pulse	3	
Range of average PRF	202.2-445.3	per sec
Range of antenna scan intervals for		
terminal interrogators	3.92-4.69	sec
enroute interrogators	10-12	sec
Most frequent interlace mode for		
terminal interrogators	AAC	
enroute interrogators	2ACA	
Number of interrogators transmitting Mode 4	2	

Antenna patterns for fourteen of the 68 interrogators detected, derived from the same in-flight data, show:

a) Mild sidelobe punch-through is prevalent, and hard sidelobe punch-through (> 9 dB) occurs for a few interrogators.

b) Appreciable (up to 10 dB) changes in sidelobe levels occur frequently over a period of a few antenna scans as a result of the motion of the measuring aircraft.