NATIONAL RADIO ASTRONOMY OBSERVATORY

July 13, 1967

VLA SCIENTIFIC MEMORANDUM # 2

A SUMMARY OF COMPUTED BEAM PATTERNS FOR SINGLE ARRAYS

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Since the time is approaching when a decision about the VLA configuration must be made, it seemed appropriate to make available all of the beam patterns for single arrays which I have computed. Some of these have appeared already in the VLA Proposal; they are reproduced again here for the sake of completeness. The central section of each beam is shown, along with the associated transfer function and a tabular summary of the distribution of sidelobes. The characteristics of the arrays are given in Table I.

All of the arrays, with the exception of the circle illustrated in Figures 1 and 2, are equi-angular Wyes, rotated 4 or 5 degrees from a north-south line. There are equal numbers of elements on each arm, and the arms are of equal length. The beams have been computed directly from the transfer function, with a sampled cell having unit weight, independent of integration time, and an unsampled cell, or hole, having zero weight. A gaussian taper, decreasing 15 db to the edge, is used to suppress the diffraction lobes.

The outstanding features of these configurations are as follows:

Figures 1 - 2 (37 element circle): The beam has few sidelobes east and west, but has two arc-shaped sidelobes, of level -16 db, to the north and south, arising from the periodic holes along the V axis. In addition, there is a negative sidelobe of about -13 db near the main beam, produced in part by the diffraction pattern, and in part by the holes in the center of the transfer function.

Figures 3 - 6 (43 element Wye): The beam of the uniform Wye also has "arc" sidelobes (-13 db), displaced somewhat from the north-south direction, produced by the string of holes stretching towards the upper right in the transfer function. There is as well the strong negative sidelobe (-11 db) near the center, caused by the incomplete sampling for short spacings. Tapering of the element spacings along the arms corrects both of these problems for $\delta = +30°$, but degrades the performance near $\delta = 0°$.

Figures 7 - 11 (42 element Wye): The beam of this array is better than that of the uniform Wye, especially for $\delta = +30°$, where both the "arc" sidelobes and the negative central lobe have been reduced, to about -18 db. The beam for $\delta = 0°$ has many sidelobes in a north-south strip of length 20' and width 1', centered on the main beam. Beyond this strip the beam is excellent, with mean levels below -27 db. Again, tapering of the element spacing improves the performance at $\delta = +30°$, although by a smaller factor, and degrades the performance at $\delta = 0°$.

Figures 12 - 19 (36 element Wye, arm length 2100 m): This is the configuration recommended in the VLA Proposal. For $\delta = +30°$ the array has a low level of sidelobe (-20 db) uniformly over the entire field of view, with perhaps a trace of the "arc" sidelobe to the north and south. At $\delta = 0°$ the sidelobes are concentrated in a narrow north-south strip; outide this strip, the mean sidelobes level is below -25 db. The beam for southern declinations is good, since most of the holes appear at the edge of the transfer function, and merely broaden the beam.

Figures 20 - 22 (36 element Wye, arm length 2400 m): Originally, it was proposed that the VLA should have 24 kilometer arms, in order that the foreshortening for southern sources would not be too painful. However, these figures show that the beams for the northern declinations have higher sidelobes, by up to 2 db. Because of this, and the extra expense of 9 km of track, the arm length of 21 km was adopted.

Figures 23 - 33 (39 element Wye): Both the hole patterns in the transfer function and the sidelobe patterns of the synthesized beam are similar to those found for the 36 element configuration. The sidelobe levels are reduced, as was expected, by between 1 and 2 db.

Figure 34 presents a comparison of the peak and mean sidelobe levels for a number of Wye configurations. The definition of the zone number is found on any of the tabulations of sidelobe levels. All arrays are shown relative to the standard supplemented Wye of 36 elements and arm length 2100 m, with tracking $\pm$ 4 hours. The conclusions reached on the basis of percentage of holes in the transfer function are confirmed in this plot of sidelobe levels, i.e., that the longer arm length (2400 m) is not worthwhile; that a great improvement - up to 4 db - is achieved for all zones, in both peak and mean sidelobe levels by using the maximum tracking range available; and that although the 39 element array is better, the improvement is not great enough to justify the additional cost.

Figure 36 compares the "observed" sidelobe levels for Zone 5 with those computed from the statistical relations given in the VLA Proposal. The maximum sidelobes are generally much greater, by up to 4 db, than they would be were the holes distributed randomly. The observed mean sidelobes for δ = +30° are in good agreement with the predicted rms values; for δ = 0° and δ = 15°, the observed sidelobes are less than expected. This is because the hole distribution is not uniform - for δ = 0°, the sidelobes are confined to a narrow strip centered on the array beam, and for δ = 15° the holes act merely to broaden the beam.

That the sidelobe levels are sensitive to the manner in which the holes in the transfer function are distributed is shown by the large scatter of the points in Figure 35. For a given percentage of holes, the spread in sidelobe levels for different declinations and configurations may be as much as 6 db. For a given declination, the level varies with percentage of holes much as the theoretical relation would predict; presumably this is because the distribution of holes is similar, and only the percentage is changing. I conclude that the comparison of various configurations having the number of holes in the range 5 to 15 percent must be made from the beam studies.

In conclusion, let me repeat that the purpose of this report is to make available to the VLA group all of the beam plots which I have. There are about another 20, mainly of complementary arrays, available from N. C. Mathur. These give the performance of the VLA as it is now envisioned. I hope that this report will stimulate more discussion about the VLA configuration, particularly with reference to the following points:

(1) The present 36 element array has sidelobes which are lower than the limit set by the atmosphere, according to Blum. Is it worthwhile exploring arrays with fewer than 36 elements?

(2) The arrays with tapered spacing are much better than the arrays with uniform spacing for δ > 10°, say, but worse near the equator. Should we explore arrays with non-uniform spacings further? Note that there will be an increased number of stations.

(3) At some point we will have to define acceptable sidelobe levels and/or percentages of holes. If we adopt the atmospheric limit suggested by Blum, we may be able to get a satisfactory complementary array with only 18 elements. Are we ready now to make this decision?

TABLE I

Figure Numbers	Configuration	Percentage of holes	Relative Gain	Beamwidth (Seconds of arc)
1, 2	Circle, 37 elements $\delta = +30°$, $\pm 4^h$	7.7	297	9.6 x 10.6
3, 4	Uniform Wye, 43 els. $\delta = +30°$, $\pm 4^h$	12.8	284	9.2 x 9.6
5, 6	Tapered Wye, 43 els. $\delta = +30°$, $\pm 4^h$	3.5	420	10.4 x 10.4
7a, 8	Supp. Wye, 42 els. $\delta = +30°$, $\pm 4^h$	8.6	338	10.0 x 10.3
7b, 9	Supp. Wye, 42 els. $\delta = 0°$, $\pm 4^h$	10.3	355	9.6 x 10.7
10, 11	Tapered Wye, 42 els. $\delta = +30°$, $\pm 4^h$	6.0	417	10.5 x 10.6
12a, 13	Supp. Wye, 36 els, +30°, $\pm 4^h$, 2100m	14.1	319	10.1 x 10.4
12b, 14	Supp. Wye, 36 els, +30°, $\pm 6^h$, 2100m	6.7	414	10.2 x 10.5
15a, 16	Supp. Wye, 36 els, 0°, $\pm 4^h$, 2100m	21.2	330	9.4 x 11.3
15b, 17	Supp. Wye, 36 els, 0°, ± 5.3, 2100m	17.5	384	9.8 x 11.4
18, 19	Supp. Wye, 36 els, -15°, $\pm 4^h$, 2100m	22.2	324	10.9 x 12.3
20a, 21	Supp. Wye, 36 els, +30°, $\pm 4^h$, 2400m	15.4	293	9.8 x 10.4
20b, 22	Supp. Wye, 36 els, 0°, $\pm 4^h$, 2400m	22.9	307	9.3 x 11.1
23a, 24	Supp. Wye, 39 els, +30°, $\pm 4^h$, 2100m	10.1	346	10.1 x 10.3
23b, 25	Supp. Wye, 39 els, 0°, $\pm 4^h$, 2100m	15.9	360	9.6 x 10.9
26, 27	Supp. Wye, 39 els, -15°, $\pm 4^h$, 2100m	19.1	356	10.6 x 12.3
28a, 29	Supp. Wye, 39 els, +30°, $\pm 4^h$, 2400m	11.8	316	9.9 x 10.5
28b, 30	Supp. Wye, 39 els, -15°, $\pm 4^h$, 2400m	12.3	332	10.6 x 10.8
31a, 32	Supp. Wye, 39 els, 0°, $\pm 4^h$, 2400m	14.9	333	9.5 x 10.8
31b, 33	Supp. Wye, 39 els, 0°, $\pm 6^h$, 2400m	10.6	433	10.1 x 11.0

Proposed 8 - element Array

Parameters:

Nominal Operating Wavelength	0.1 m
Dish Size	130 ft = 39.624 m
Number of Dishes	8
Site Latitude	30.5° N

Rail Network: 9000 ft x 16000 ft cross as shown below

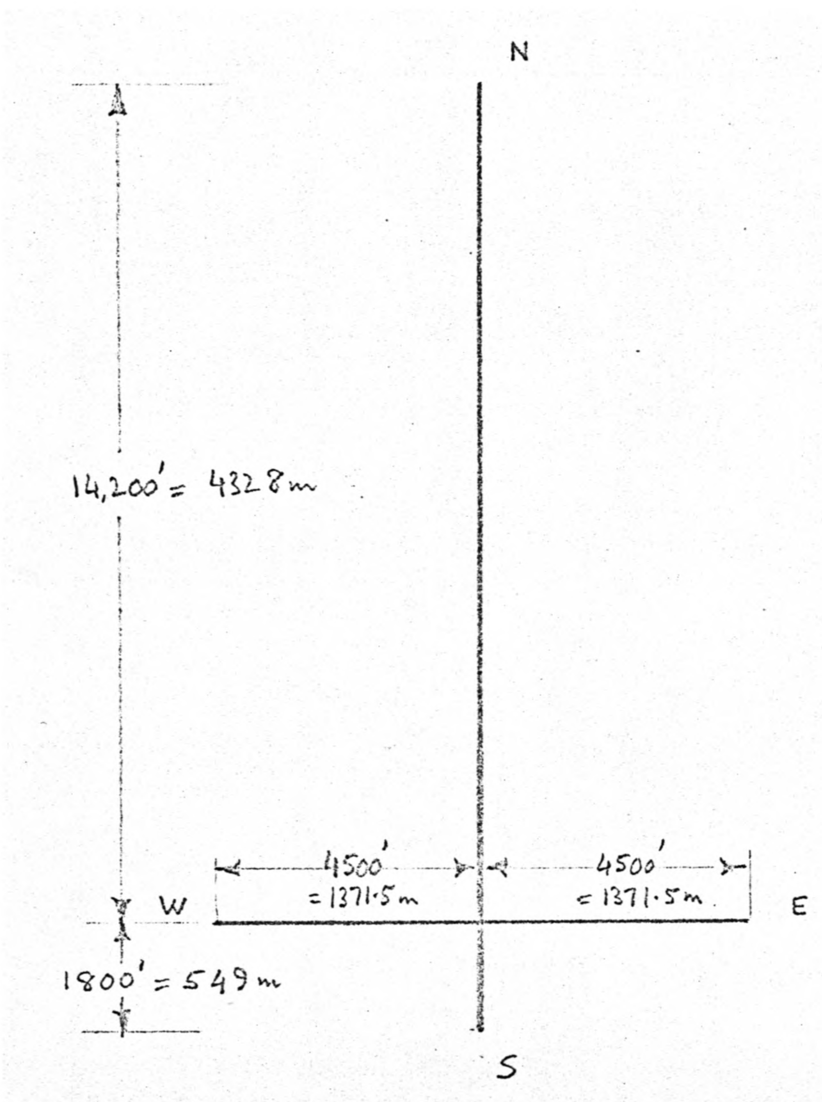
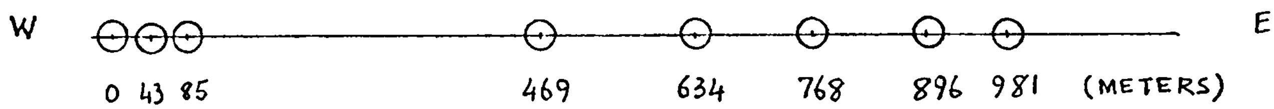


Figure 1



MODELS 140EW···

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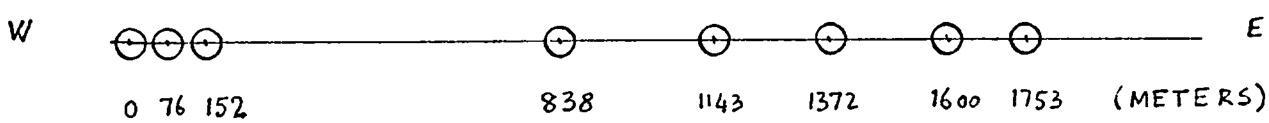
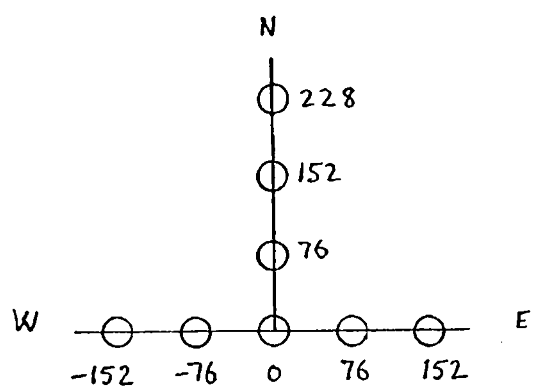


MODELS 250EW···

(b)



MODELS 250T-···

(c)

Figure 2

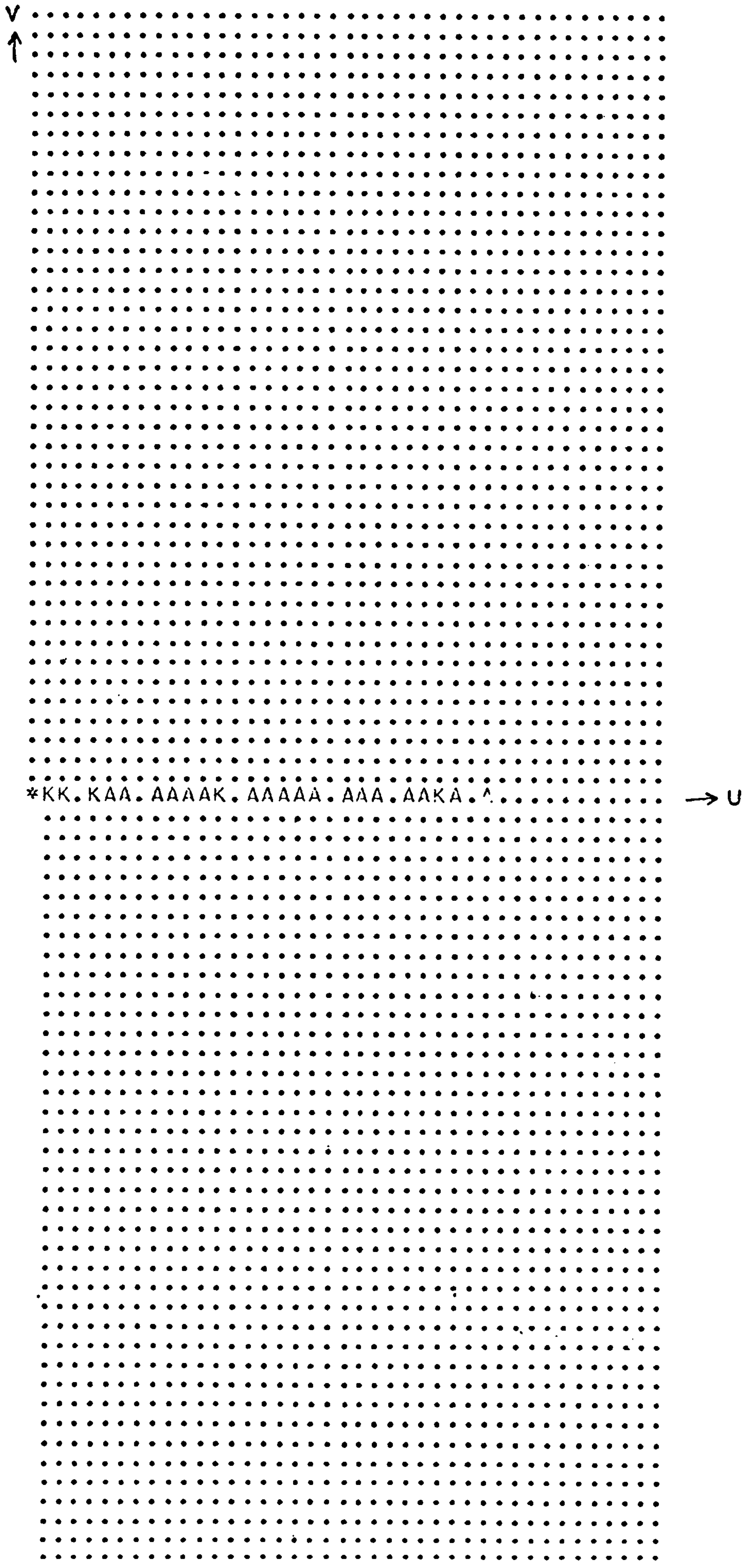
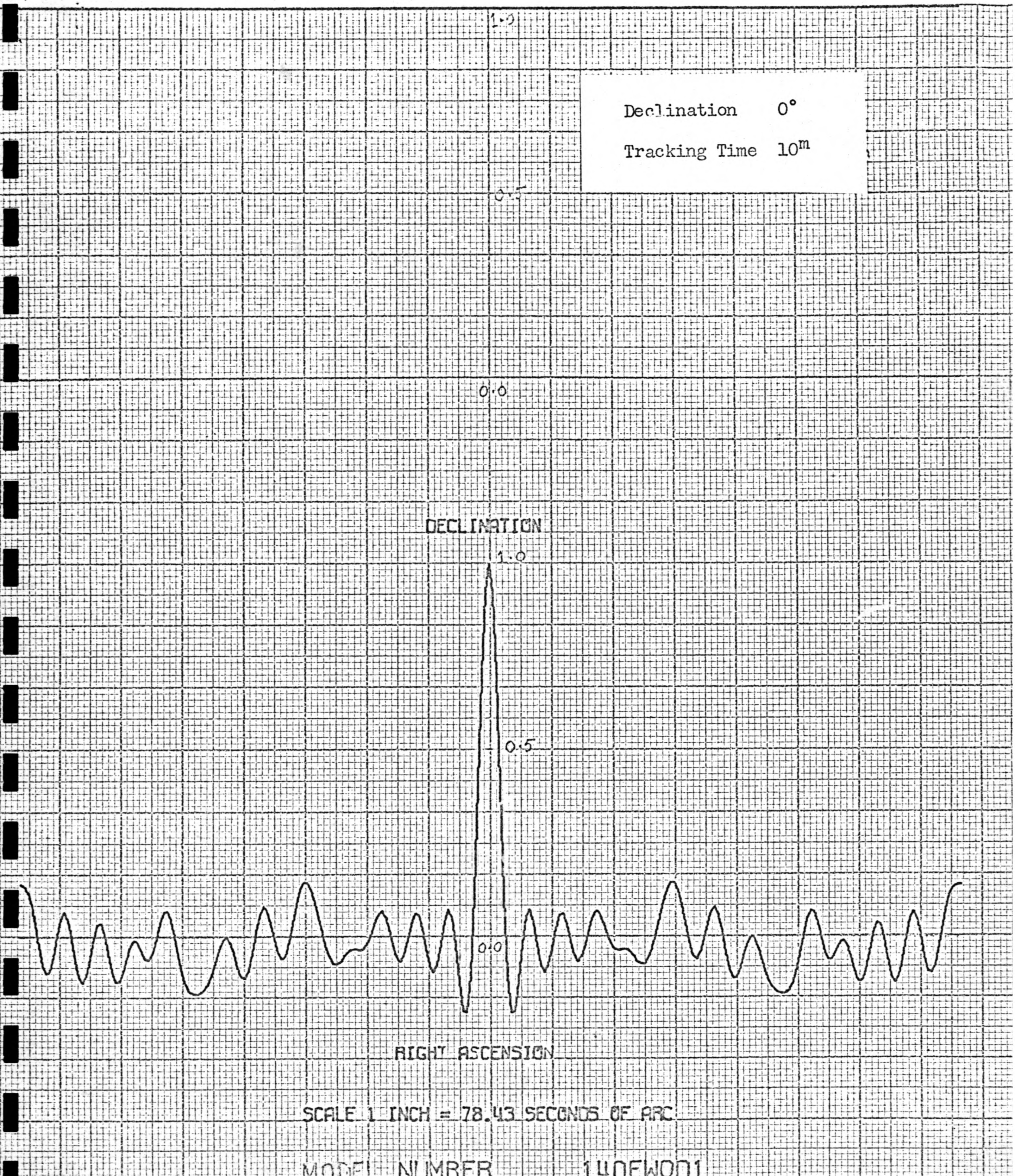


Figure 3(a)

MODEL 140EW001



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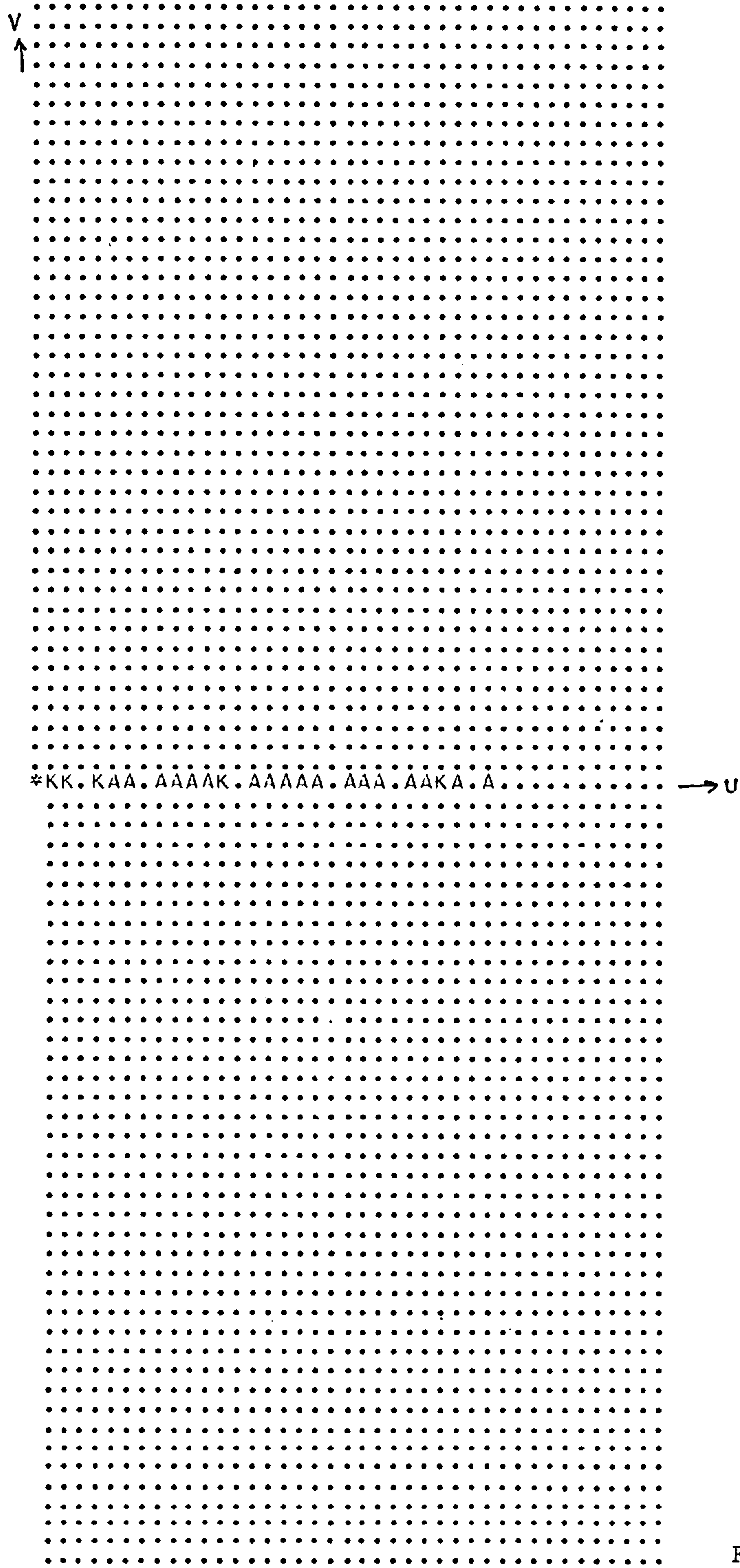
MODEL NUMBER 140EW001

Figure 3(b)



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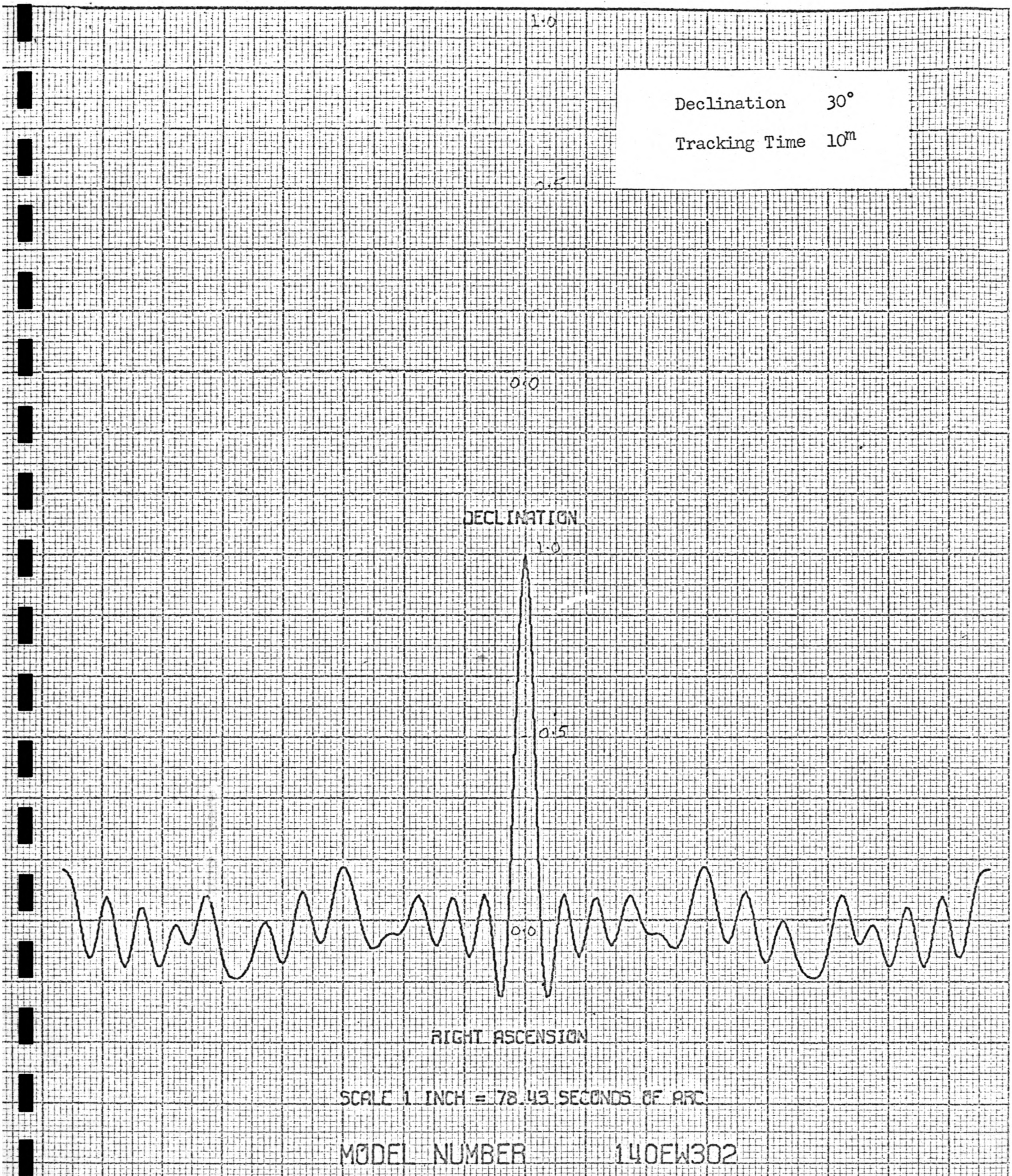
MODEL 140EW302



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MODEL NUMBER 140EW302

Figure 4(b)

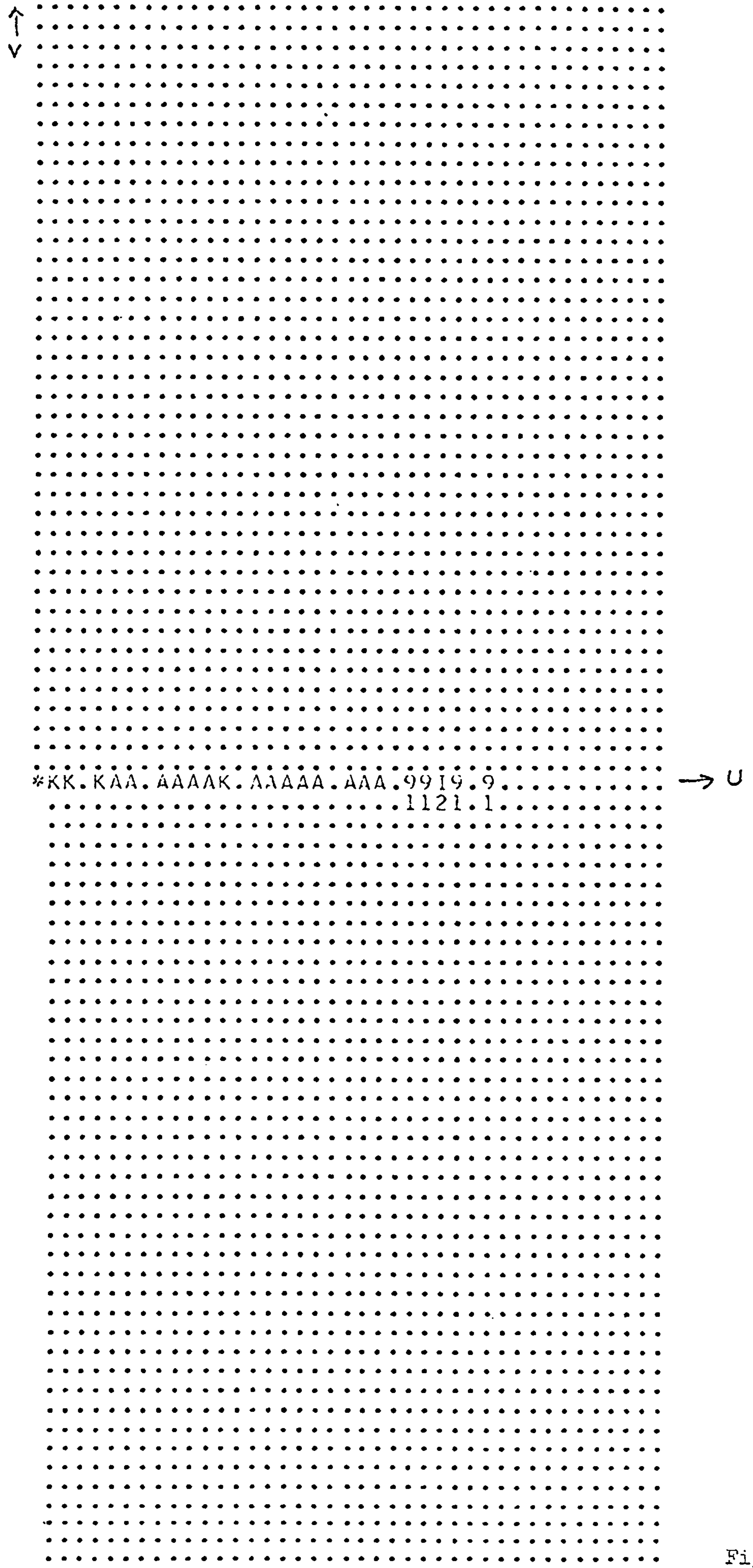
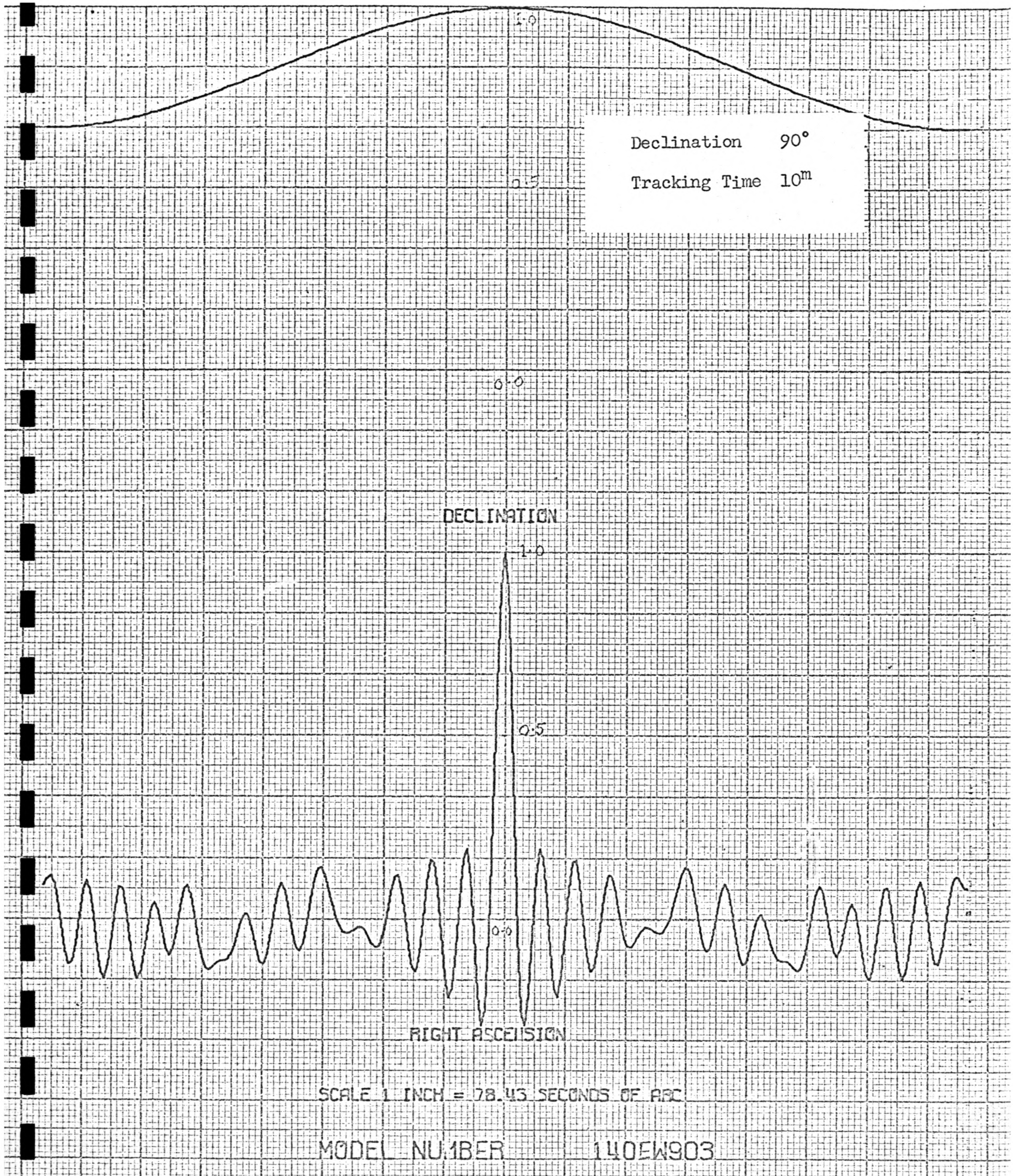


Figure 5(a)

MODEL 140EW903



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MODEL NUMBER 140EW903

Figure 5(b)

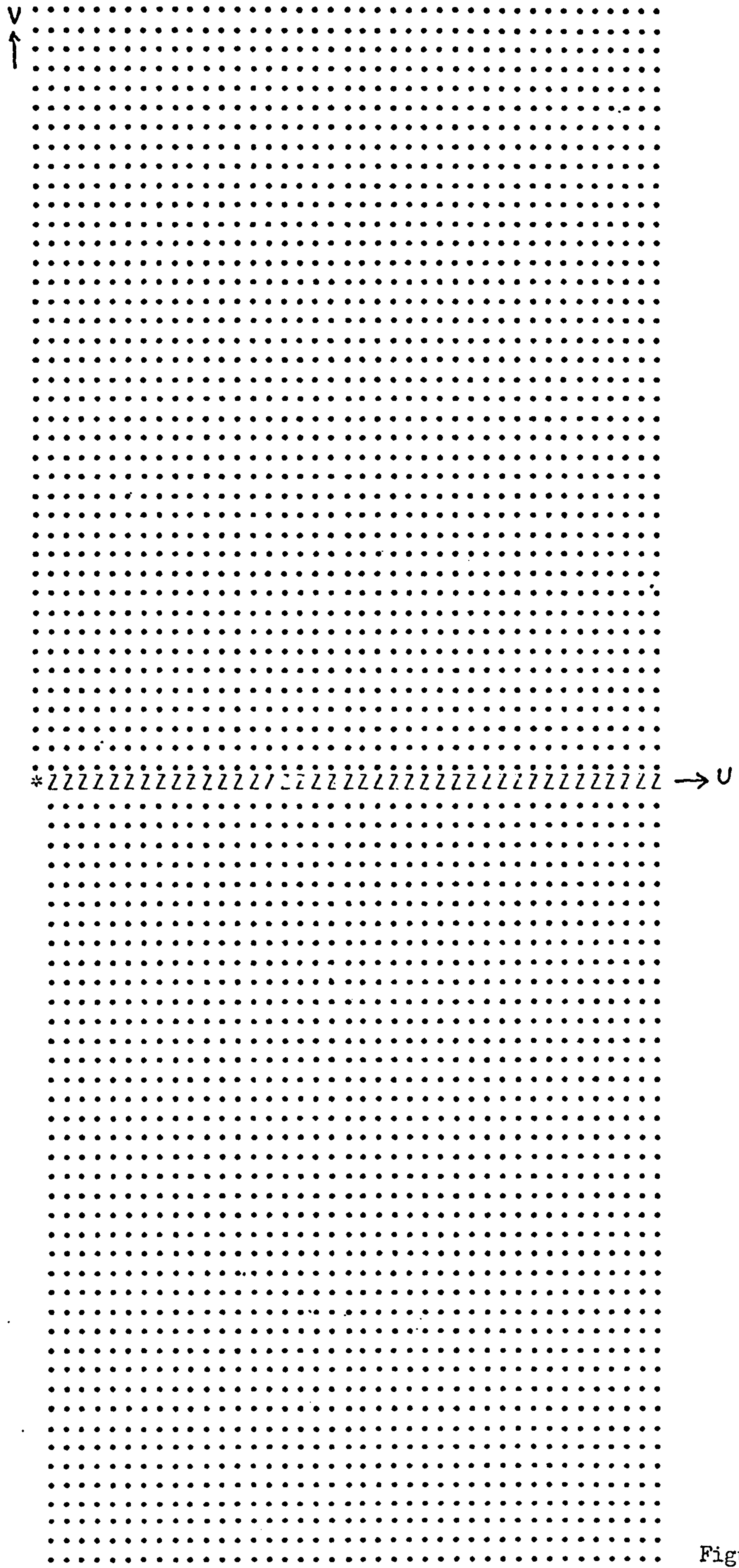
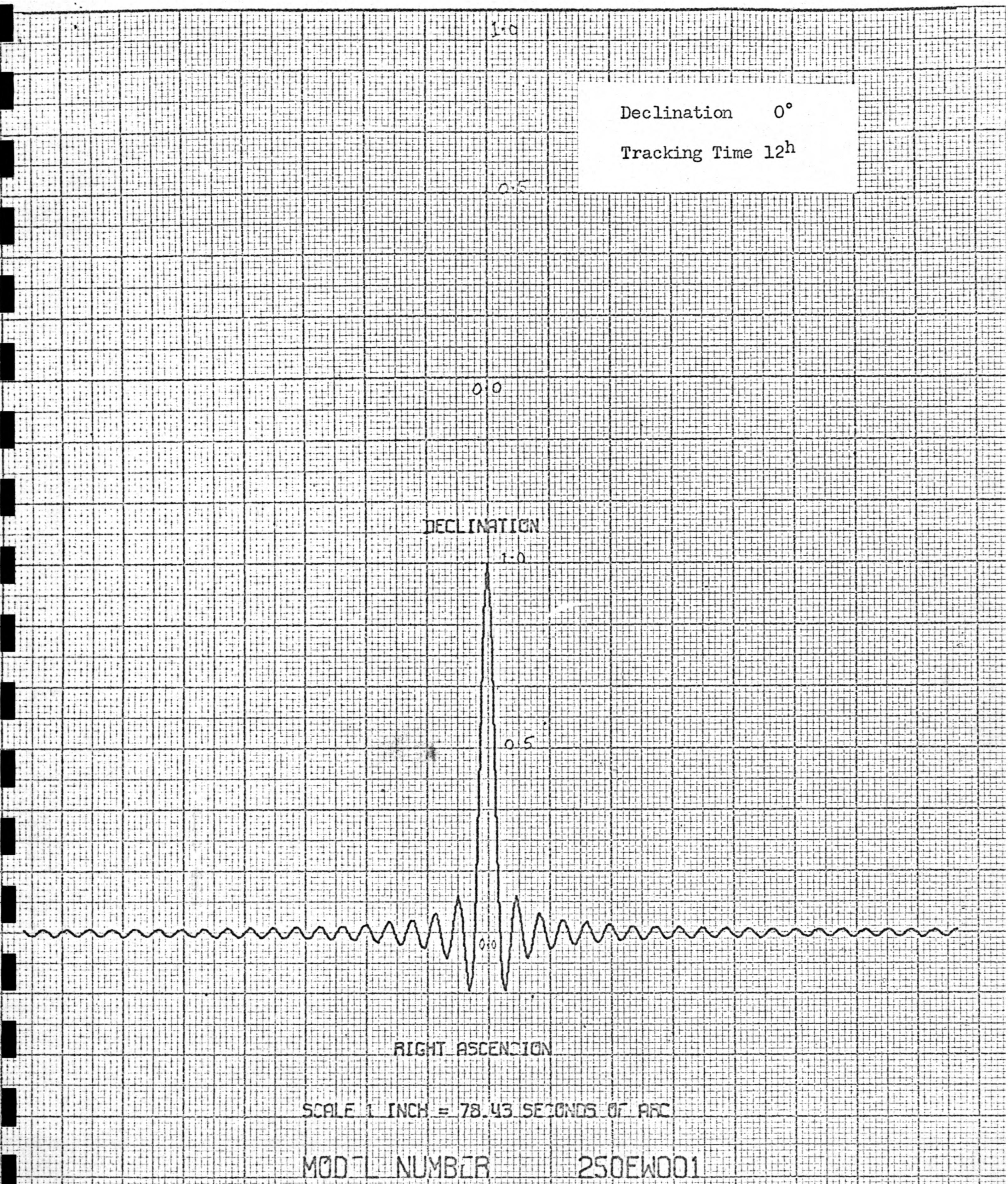


Figure 6(a

MODEL 250EW001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MODEL NUMBER 250EW001

Figure 6(b)

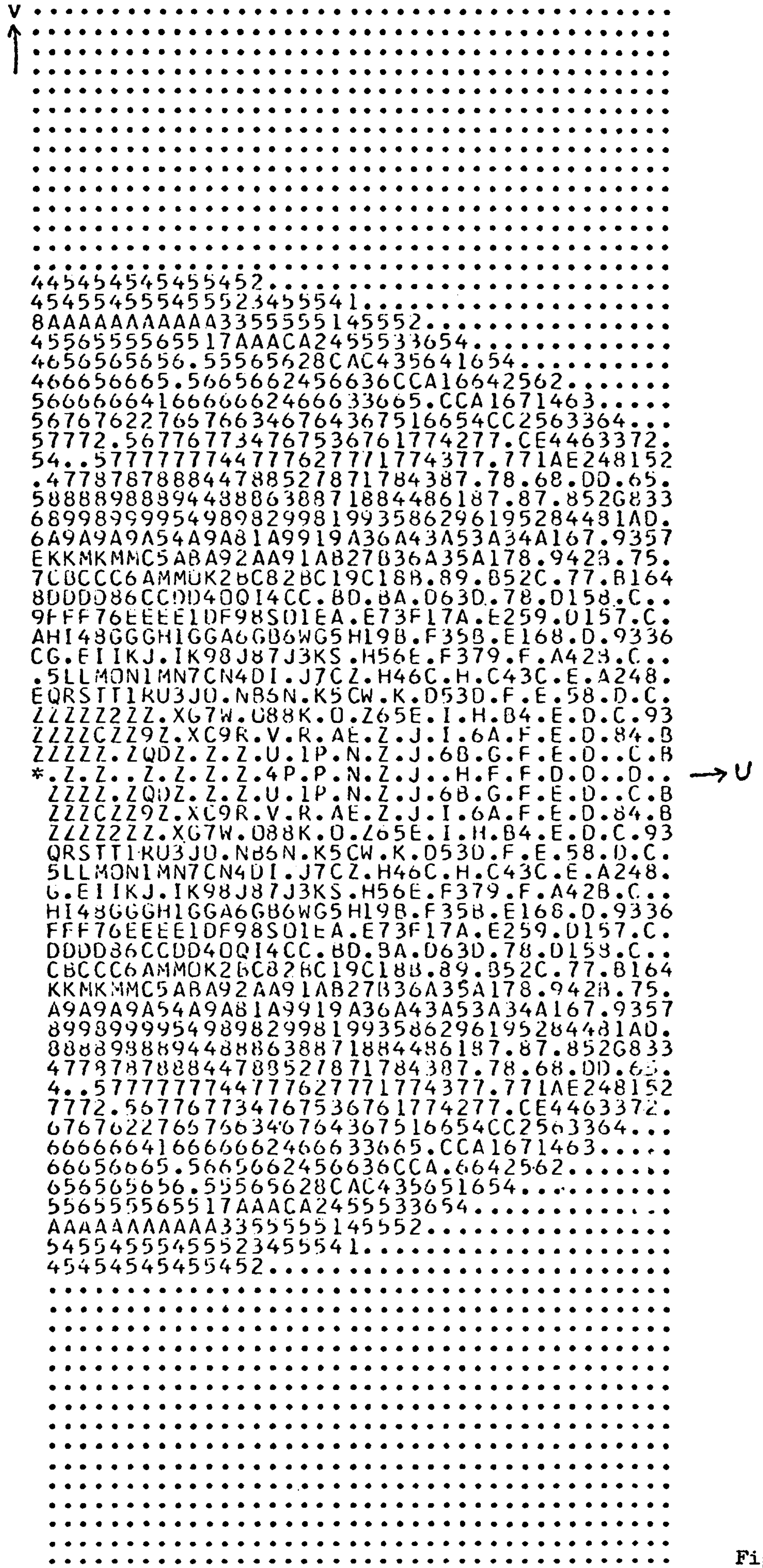
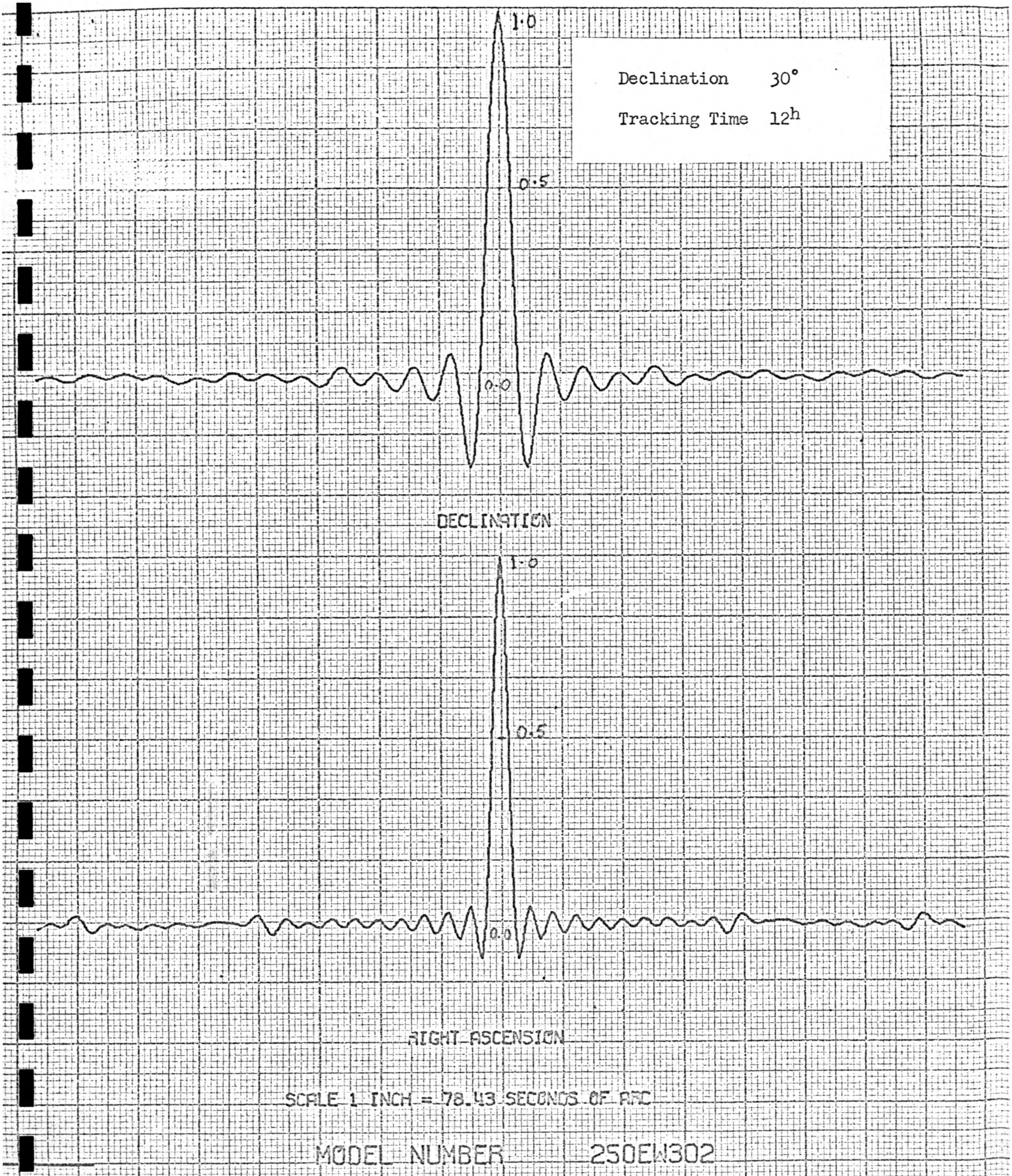


Figure 7(a)

MODEL 250EW302



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DECLINATION
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RIGHT ASCENSION
SCALE 1 INCH = 78.43 SECONDS OF ARC
MODEL NUMBER 250EW302

Figure 7(b)

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Figure 8(a)

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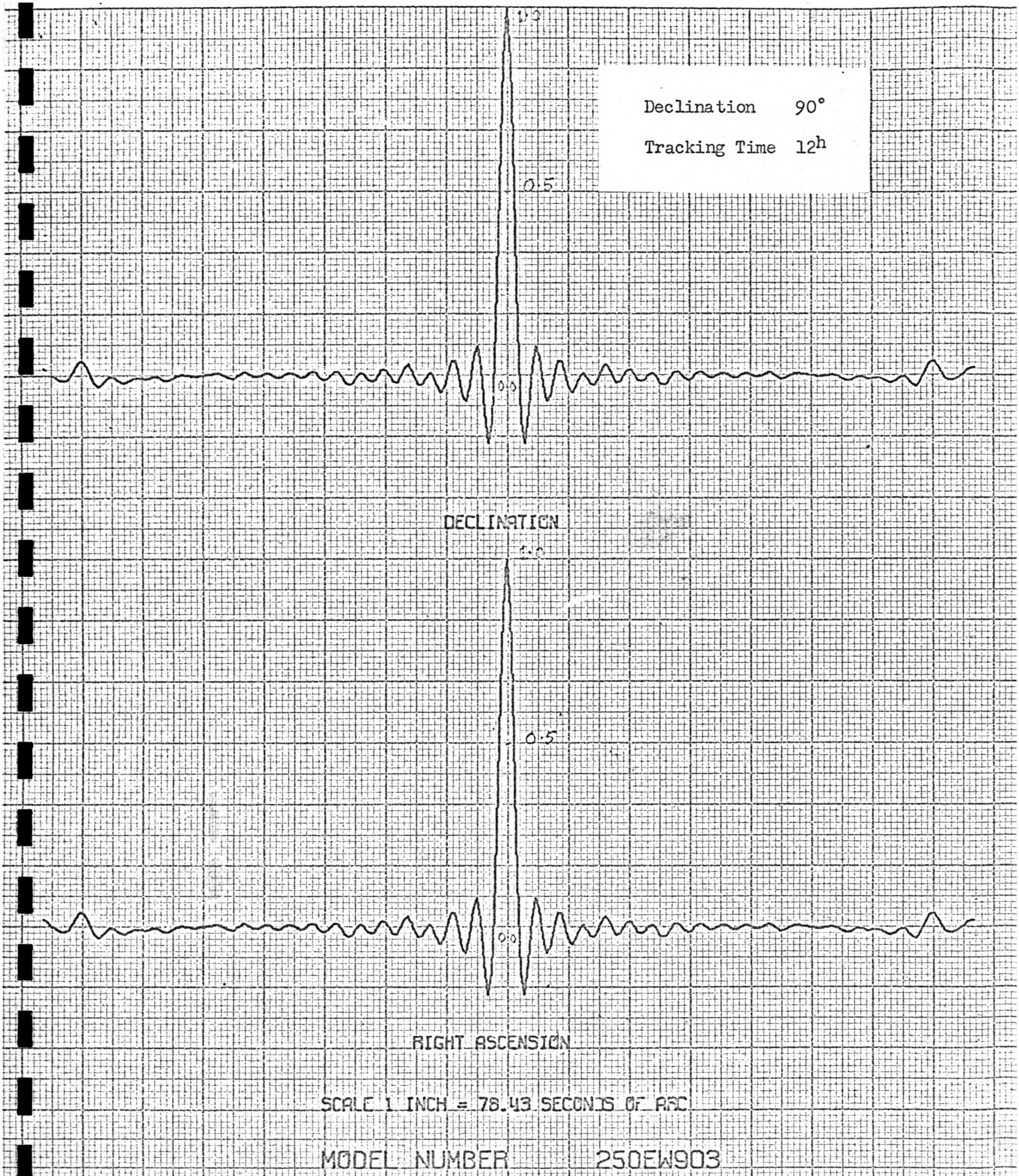
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MODEL NUMBER 250EW903

Figure 8(b)

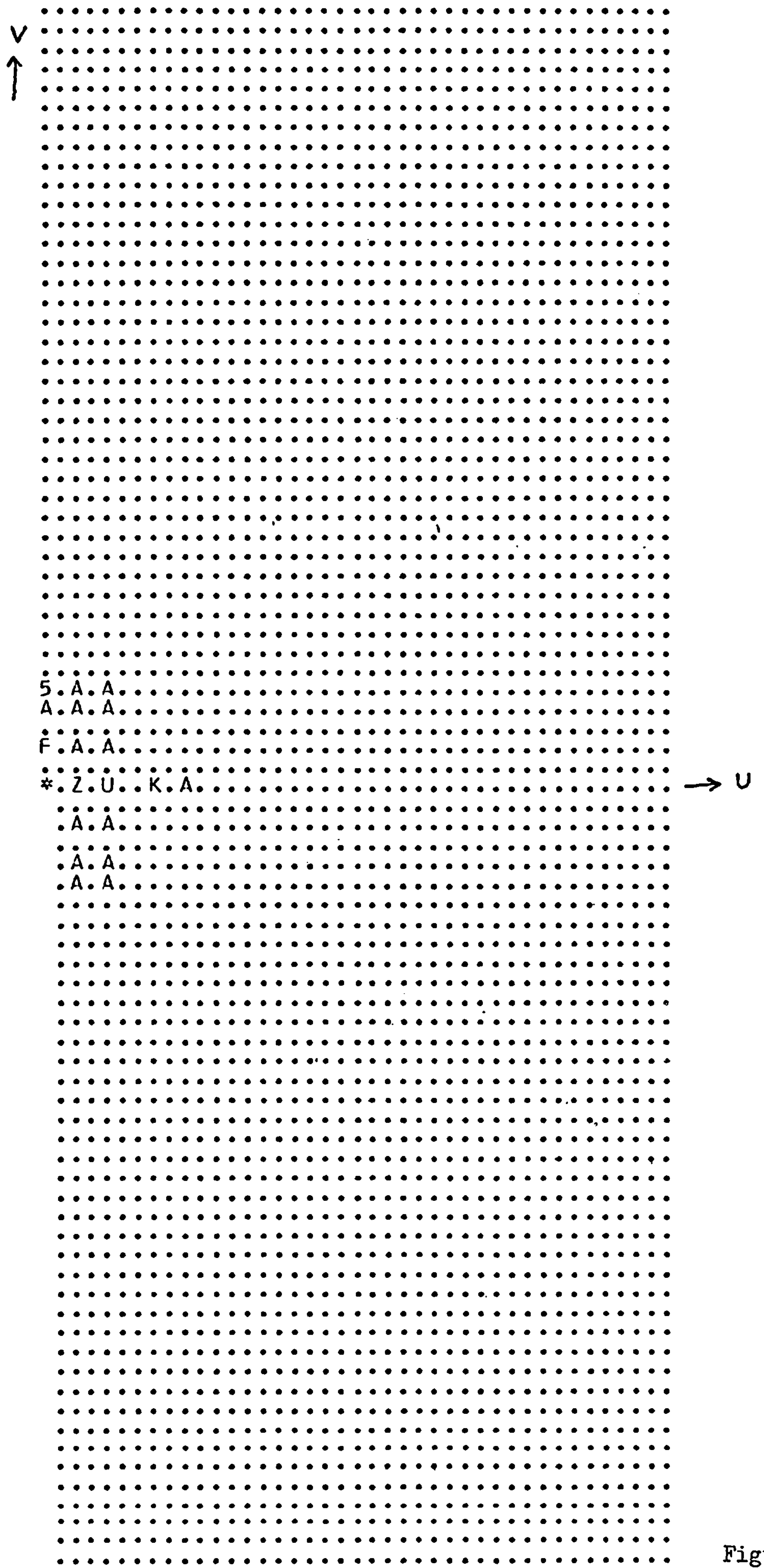

Figure 9(a)

MODEL 250T-001

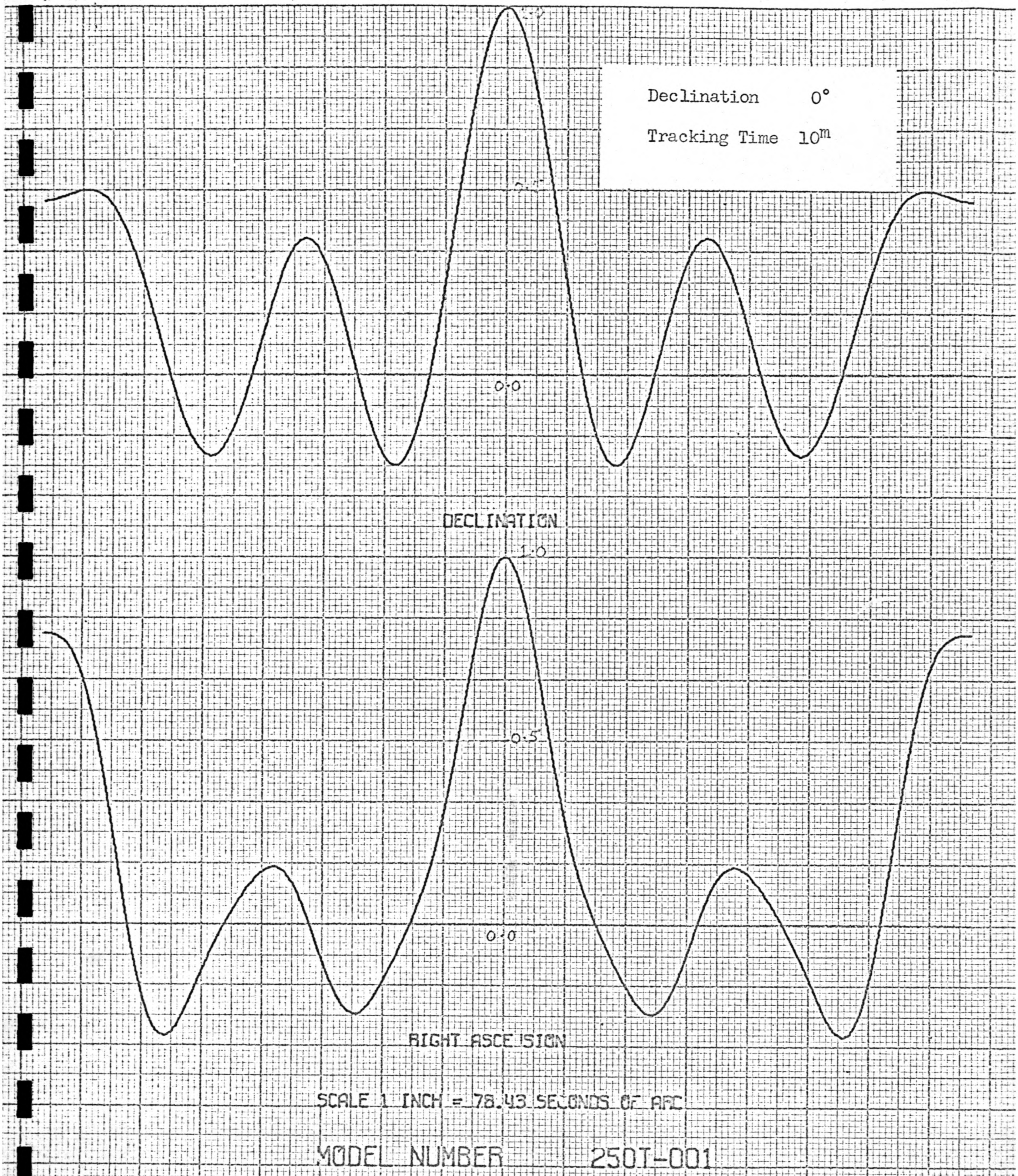
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Figure 9(b)

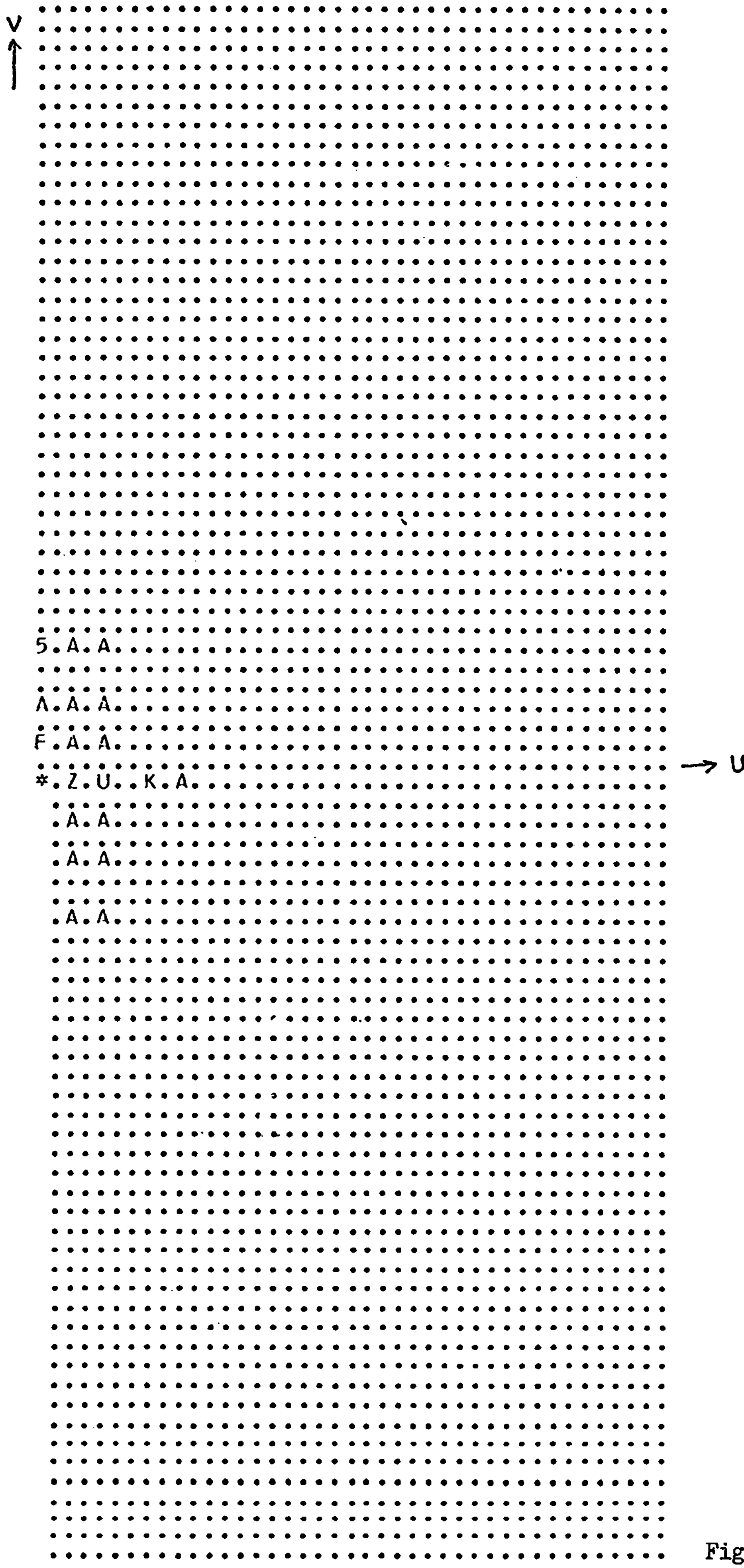
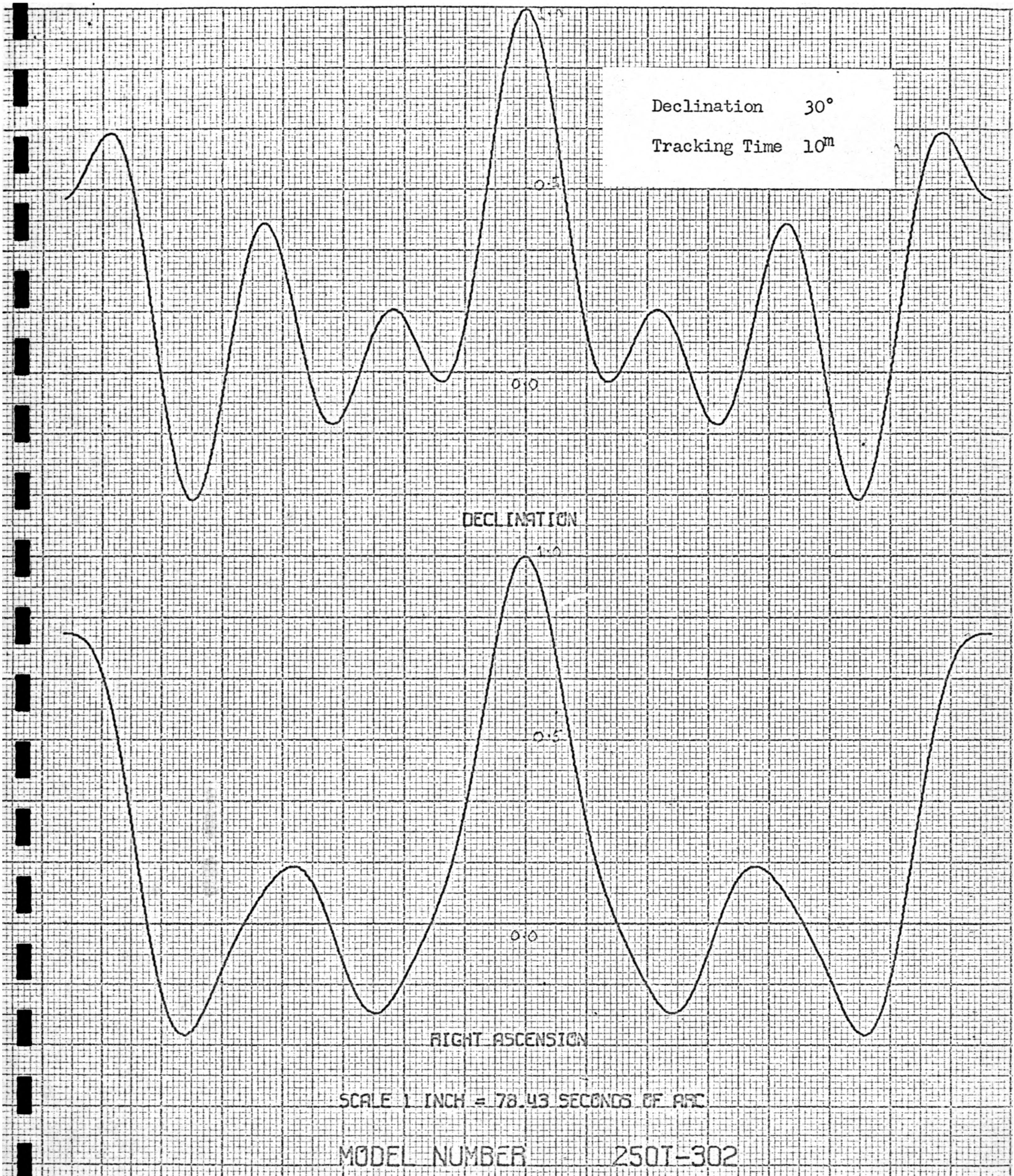


Figure 10(a)

MODEL 250T-302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MODEL NUMBER 250T-302

Figure 10(b)

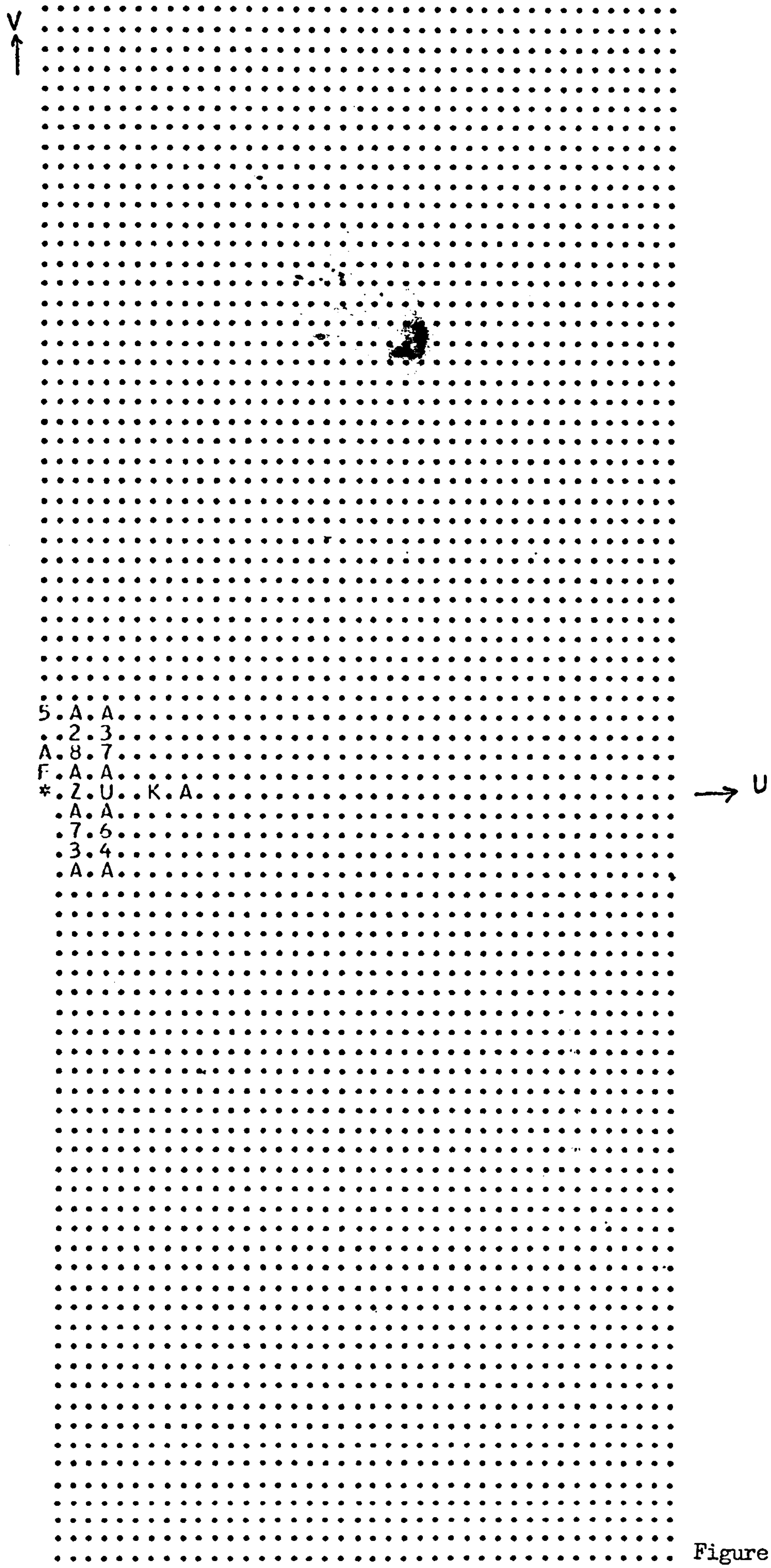
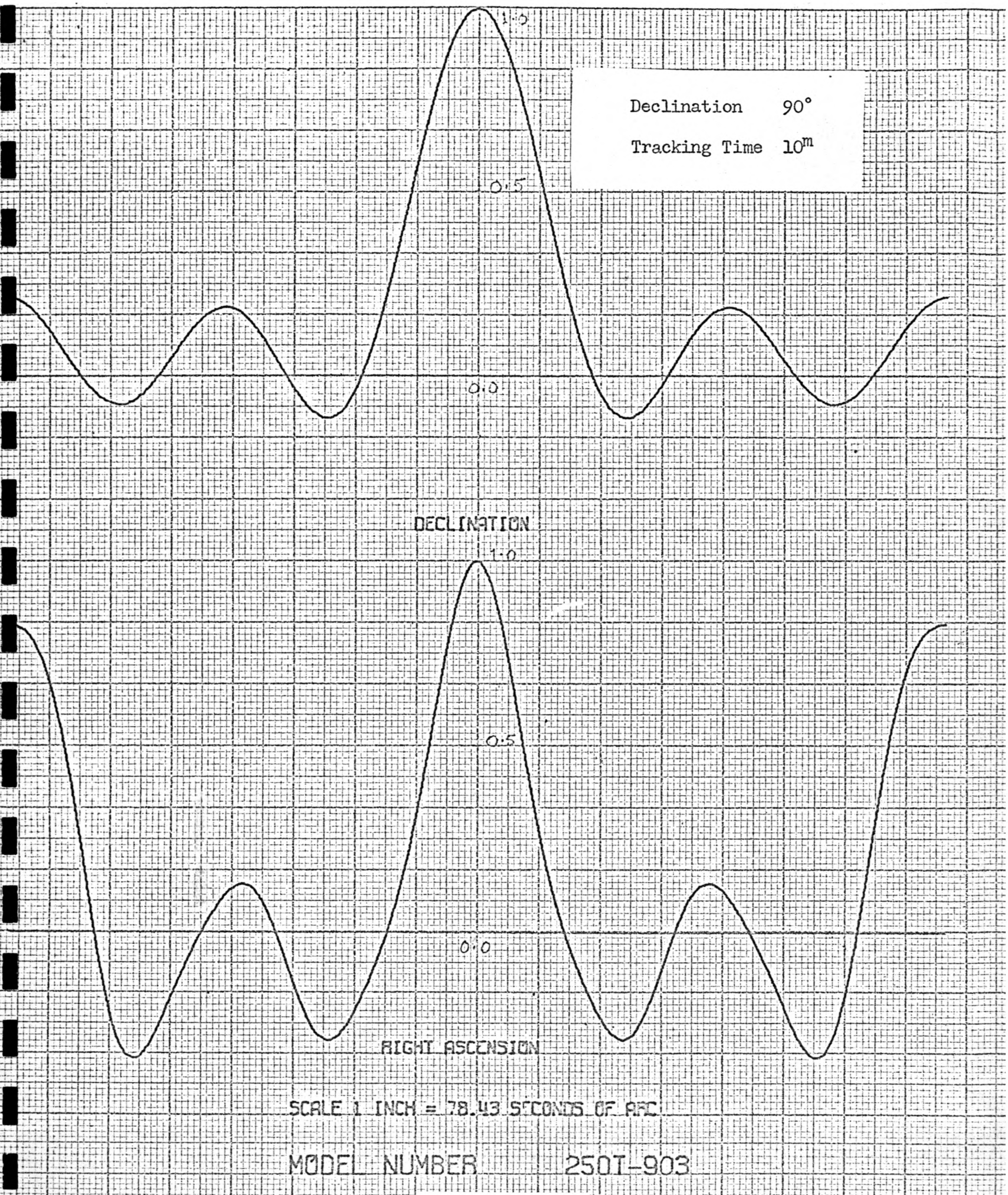


Figure 11(a

MODEL 250T-903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Declination 90°
Tracking Time 10m
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SCALE 1 INCH = 78.43 SECONDS OF ARC
MODEL NUMBER 250T-903

Figure 11(b)

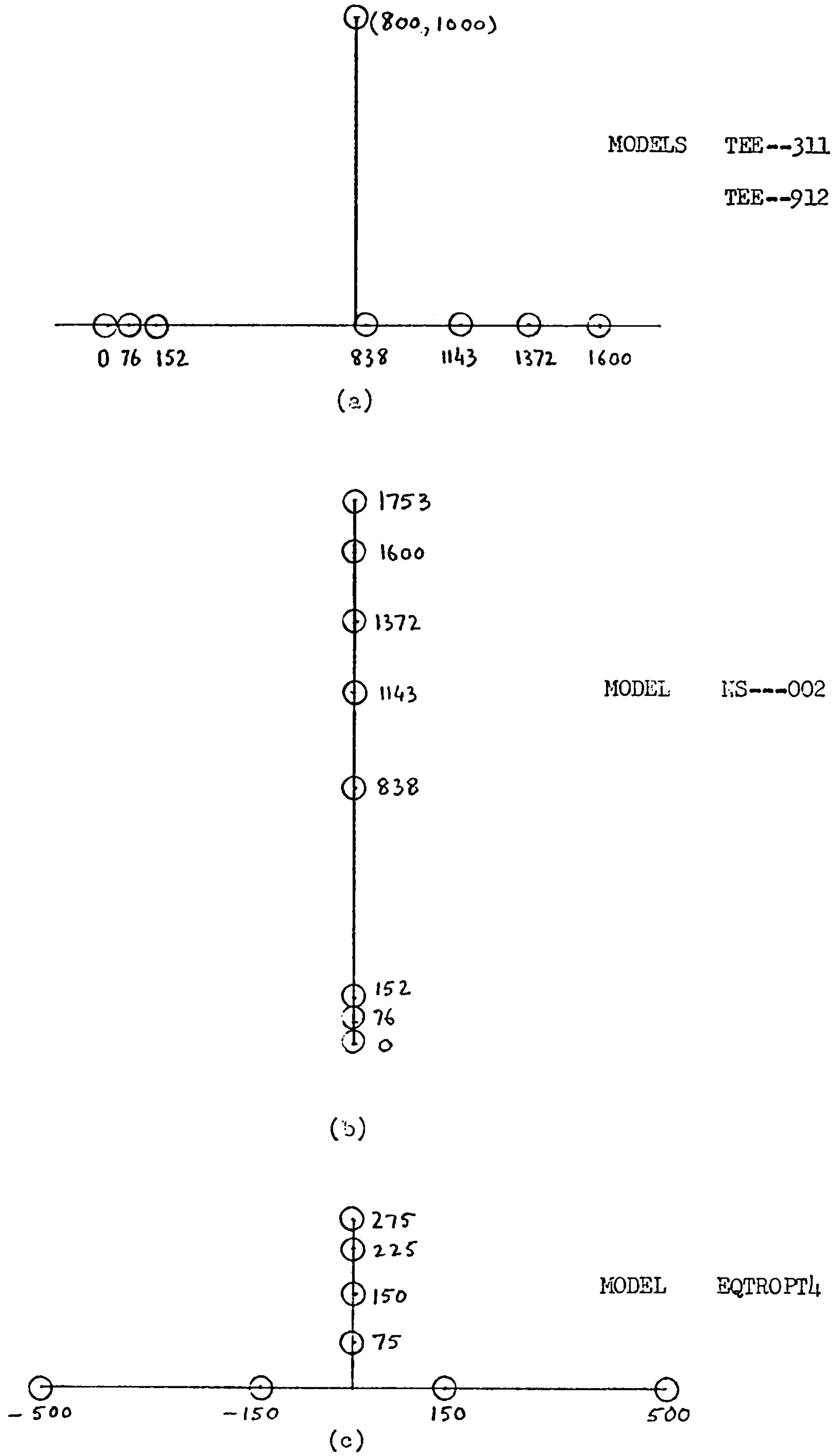
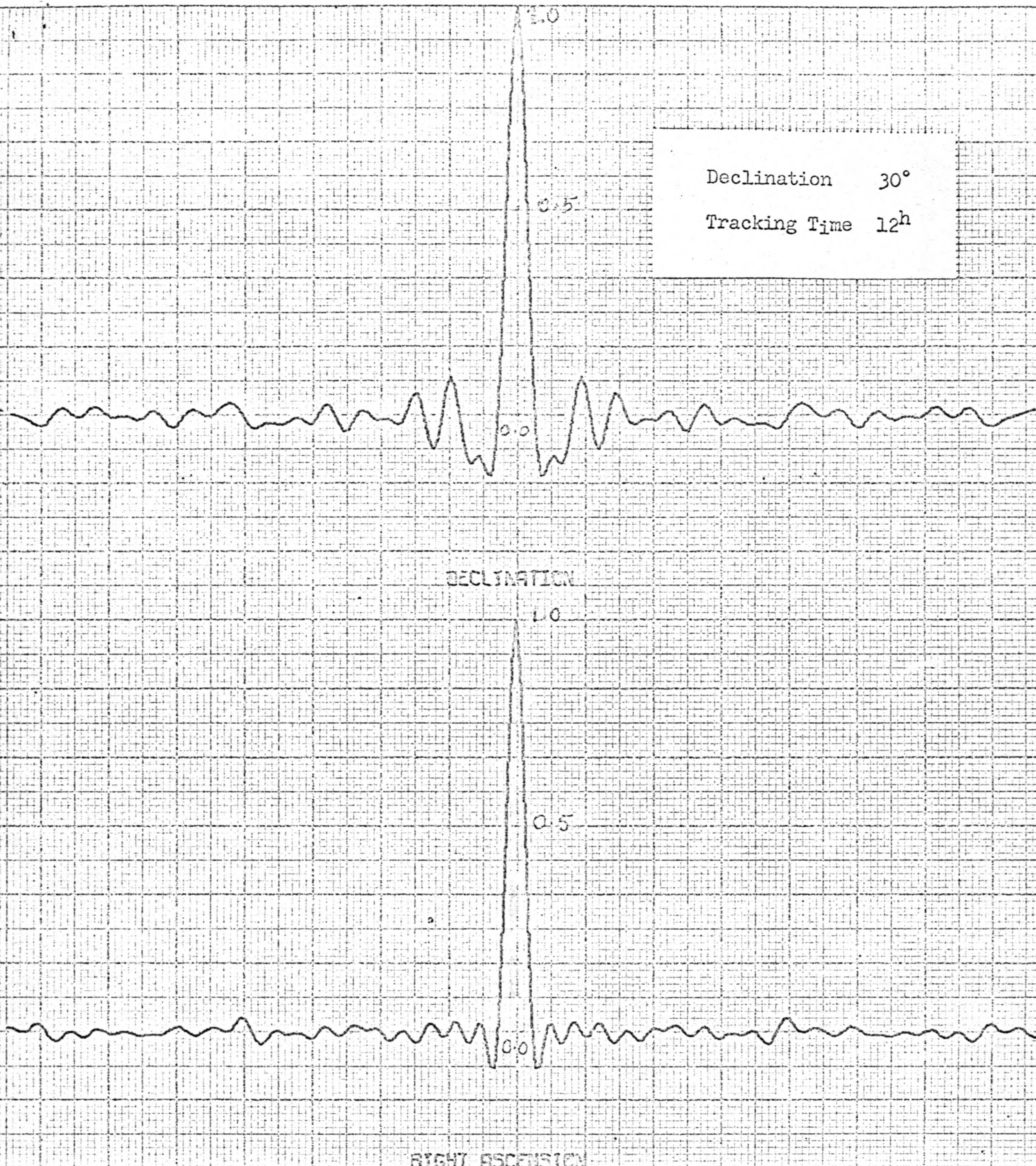

(800, 1000)
MODELS TEE--311
TEE--912
0 76 152
838
1143
1372
1600
(a)
1753
1600
1372
1143
838
152
76
0
MODEL NS---002
(b)
275
225
150
75
MODEL EQTROPT4
-500
-150
150
500
(c)

Figure 12

Figure 13(a)

MODEL TEE--311



SCALE 1 INCH = 70.43 SECONDS OF ARC

MODEL NUMBER TEE--311

Figure 13(b)

V ↑

```
.26656........6...13..4.................
......56665...663..362..54..............
56651.....1666...364..46..261...........
....566675....664..263..64..62..........
.........16761..274..371.26..43.........
56767b765....574..273..54..72.35........
.........27671..365..371.37..53.25......
57777772....675..274..64..71.44.25......
.......57771..276..372.37..63.34.25.....
5877871....685..184..64..72.44.34.25....
......7788...286..381.37..63.35.34.33...
58886.....885..284..75.181.53.34.43.42..
8HGGIPOI81..387..481.37..72.53.43.52.61..
588....8GQJ7..186..75.19..63.53.61.7..6..
..1989991.5KQ8..391.47..82.62.62.7..6.24.
4A999...898..JP6..85.28..72.71.7..7.24.5.
6A9A9KIA7.1A9.20H2.47.19..8..8..7.34.6..4
5AAAAA4ADJA1.A7.D05.38.19..9.17.34.51.6..
EKKMKI6AB5BJA13B24P9.29.18.17.34.61.7.42.
.....4MMK6B6BH7.95.OC.28.27.35.62.7.33.6.
7CBC8...2M05C6GD.67.LC.37.45.71.7.33.6.33
6CDCGECB...OGA7BG257.P8.45.71.8.34.7.24.1
.....ADEED1.8Q7B8G357.P5.81.8.34.7.24.6..
.........BEE9..UAD7H265402.9.44.8.25.7.33.
GJEFE9....DDF..KCC8G.92CH.36.8.16.6.24.6.
.AFFFMFF...6EF3.KABBC.A.06.8.26.7.34.6.6.
......GHJB..1GD3.077H6372P.17.8.25.7.6..6
AHIII...EII..1GF..QA6I.A.J8.8.25.7.51.6..
.....IK3.5IJ2.1EF.8GBBB19.Q.35.8.61.6.6..
........HE.2JJ..6D9.066I29.K7.8.61.7.7.6..
.........8I.2II..EE1.OBBA285J.8..7.6.6.15.
EQR1.....5I.5IB..ED.M65J.9.Q1.8.7.7.15.6.
...RT6....8E.EK..BE.2KBD781G8.8.7.25.7.6.
ZZ...PI....H3.GF..EB.MAA9.98I.7.43.6.6.6.
.AZZJ.HI....K.GF..CC.M64J.9.0.71.7.7.6.6.
....ZZ.P6...I..M9.AF.4IAJ.8.P..7.7.6.6..6
RZZD.ZJ.T....I.FE..G8.KAA89.I6.8.7.7.51.5
...ZD.Z.R1...I.FF..CC.MAAA9.G8.7.7.6..6.6
ZZZ.Z.Z..R...I.FE..CB.KA9917G8.7.7.7..6.6
..Z.Z.AZ.Q...H.AK..CC.KAA9.9H8.8.7.6..6.2
*.Z.Z..Z.P...H..T..CB.MA99.9G7.7.7.7..7..   → U
 .Z.Z.AZ.Q...H.AJ..CC.KAAA.8H8.8.7.6..6.2
 ZZ.Z.Z..R...I.FE..DB.KA9918G8.7.7.7..6.6
 ..ZD.Z.R1...I.FF..CC.MAA99.G8.7.7.6..6.6
 ZZD.ZJ.T....I.FE..G8.KA998.I6.8.7.7.51.5
 ...ZZ.P6...I..M9.AE.4IAK.9.P..7.7.6.6..6
 AZZJ.HI....K.GF..DC.M64I.9.0.71.7.7.6.6.
 Z...PI....H3.HF..EB.MAAA.98I.7.43.6.6.6.
 ..RT6....8E.EJ..BE.2KBD781G8.8.7.25.7.6.
 QR1.....5I.5IB..ED.M65J.9.Q1.8.7.7.15.6.
 ........8I.2II..DE1.OBBA185J.8..7.6.6.15.
 .......HE.2JJ..6D9.056J1A.K7.8.61.7.7.6..
 ....IK3.5IJ2.1EF.8GCBA.9.Q.35.8.61.6.6..
 HIII...EII..1GF..QA6H1A.J8.8.25.7.51.6..
 .....GGKB..1GD3.077G7372P.17.8.25.7.6..6
 AFFFMFF...6EF3.KABBD.B.06.8.26.7.34.6.6.
 JEFE9....DDF..KCC8G.92CH.36.8.16.6.24.6.
 ........BEE9..OAC7G265402.9.44.8.25.7.33.
 ....ACEED1.8Q7B8H357.P5.81.8.34.7.24.6..
 CCCGFCB...OGA7BH257.09.45.71.8.34.7.24.1
 CBC8...2M06B6HC.67.LC.37.45.71.7.33.6.33
 ....4MMK6B6BI6.A5.OC.28.27.35.62.7.33.6.
 KKMKI6AB5BIB.3A24P9.29.18.17.34.61.7.42.
 AAAAA4ADJA21A7.D05.38.19..9.17.34.51.6..
 A9AAJJ97.299.20H2.47.19..8..8..7.34.6..4
 99A8...898..JP6..85.28..72.71.7..7.24.5.
 .1998991.5KQ8..391.47..82.62.62.7..6.24.
 97....8GQJ7..186..75.19..63.53.61.7..6..
 HGGIPOI81..387..481.37..72.53.43.52.61..
 8886.....885..284..75.181.53.34.33.42...
 .....7788...286..381.37..63.35.35.33....
 877371....685..184..64..72.44.34.25.....
 .......47771..276..372.37..63.34.25......
 7777773....675..274..64..71.44.25.......
 ........27671..365..371.37..53.25........
 67576765....574..273..54..72.35.........
 .........16761..274..371.26..43.........
 ...566675....664..263..64..62...........
 6661.....1666...364..46..261............
 .....66665....663..362..54..............
 26656.........6....13...4...................
```

Figure 14(a)

MODEL TEE--912

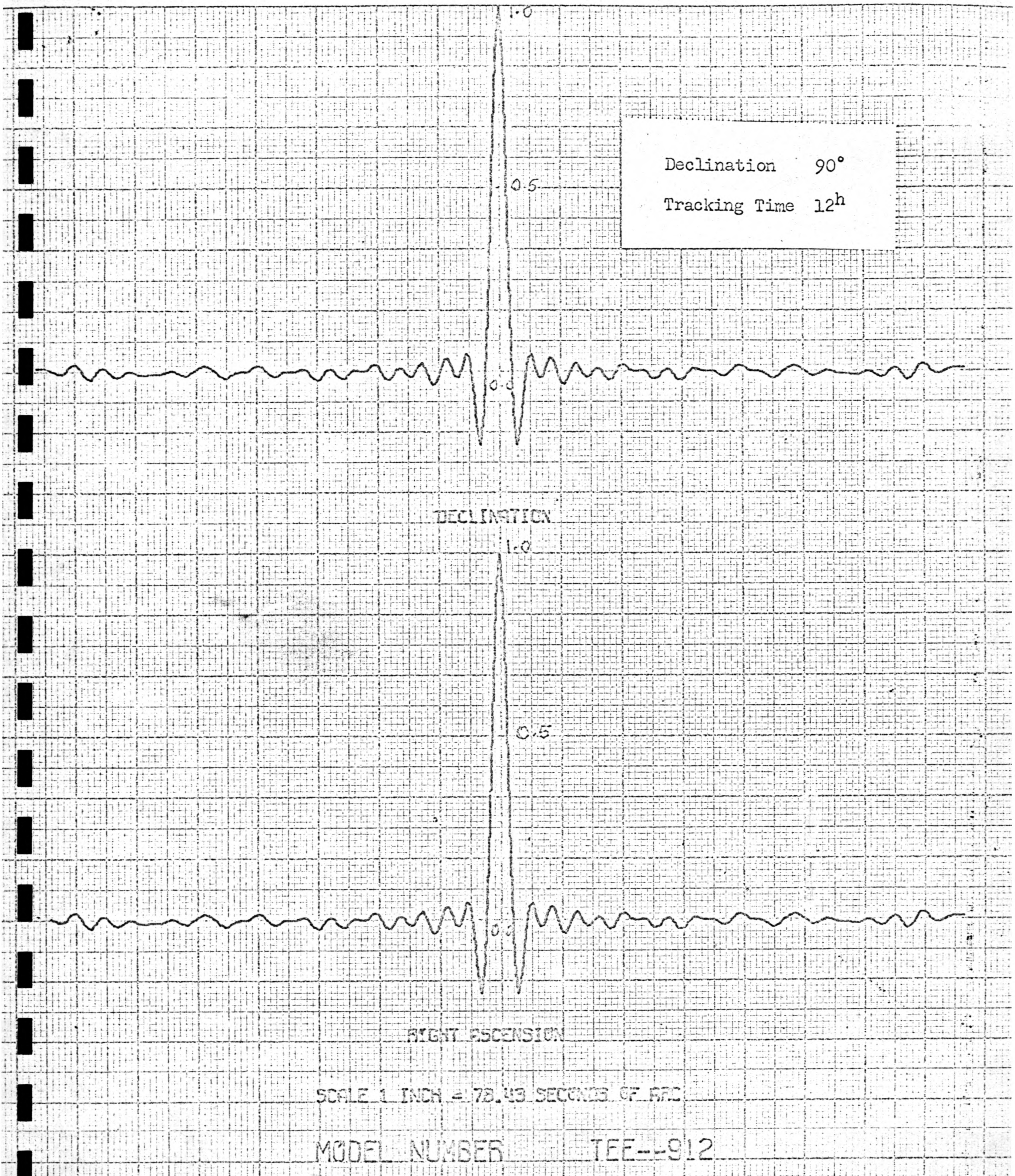

Declination 90°
Tracking Time 12h
1.0
0.5
0.0
DECLINATION
1.0
0.5
0.0
RIGHT ASCENSION
SCALE 1 INCH = 78.43 SECONDS OF ARC
MODEL NUMBER TEE--912

Figure 14(b)

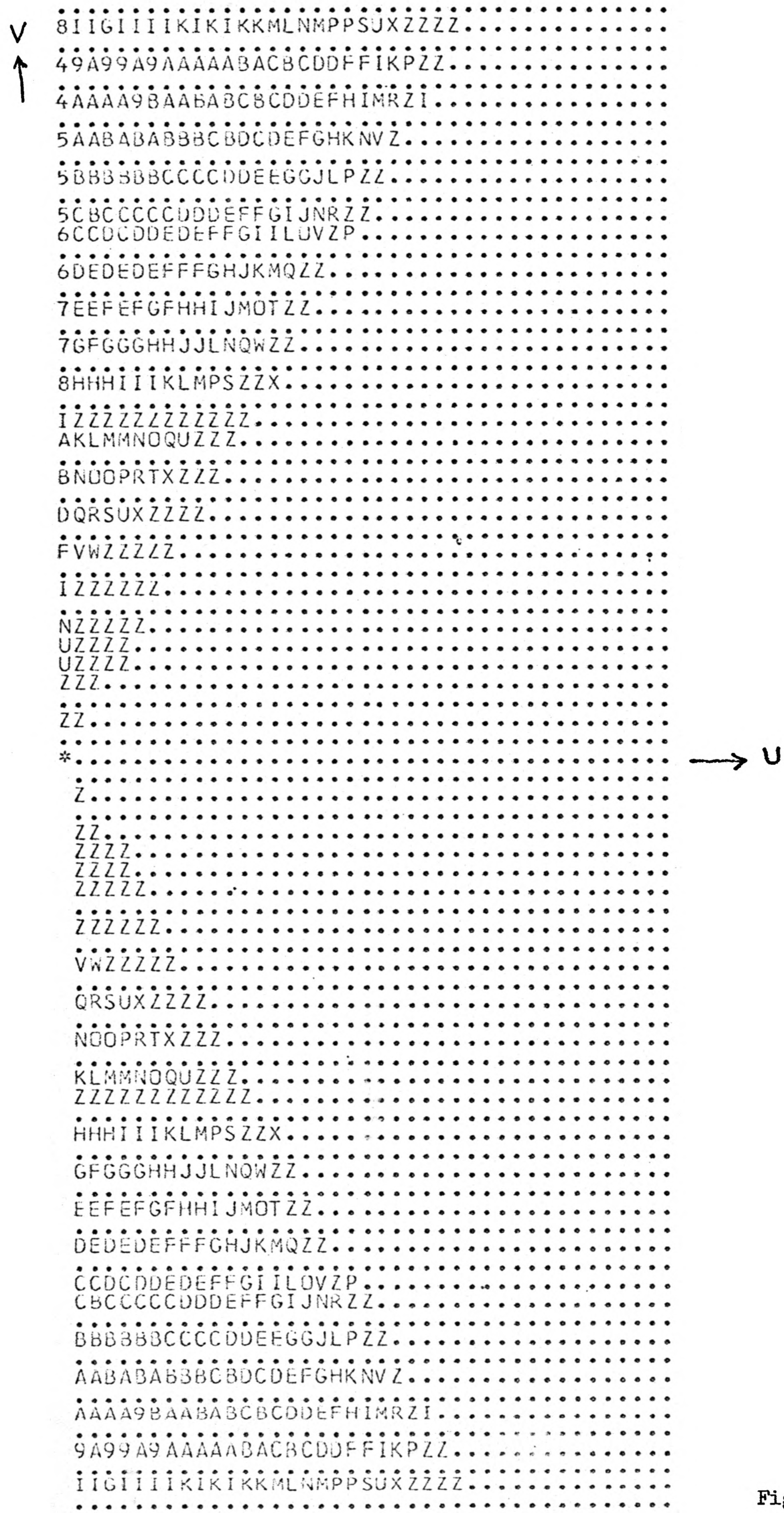


Figure 15(a)

MODEL NS---002

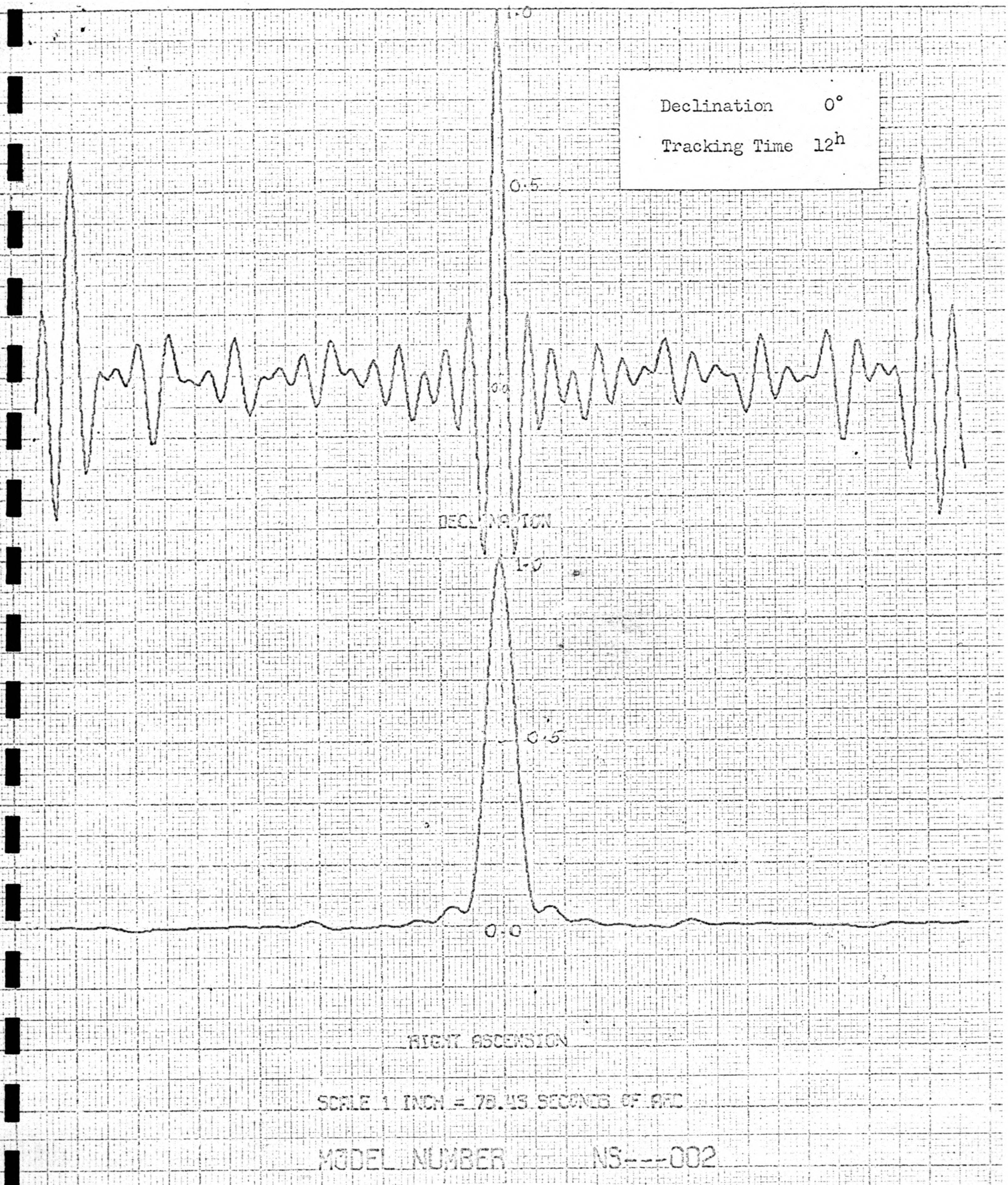

Declination 0°
Tracking Time 12h
1.0
0.5
0.0
DECLINATION
1.0
0.5
0.0
RIGHT ASCENSION
SCALE 1 INCH = 78.43 SECONDS OF ARC
MODEL NUMBER NS---002

Figure 15(b)

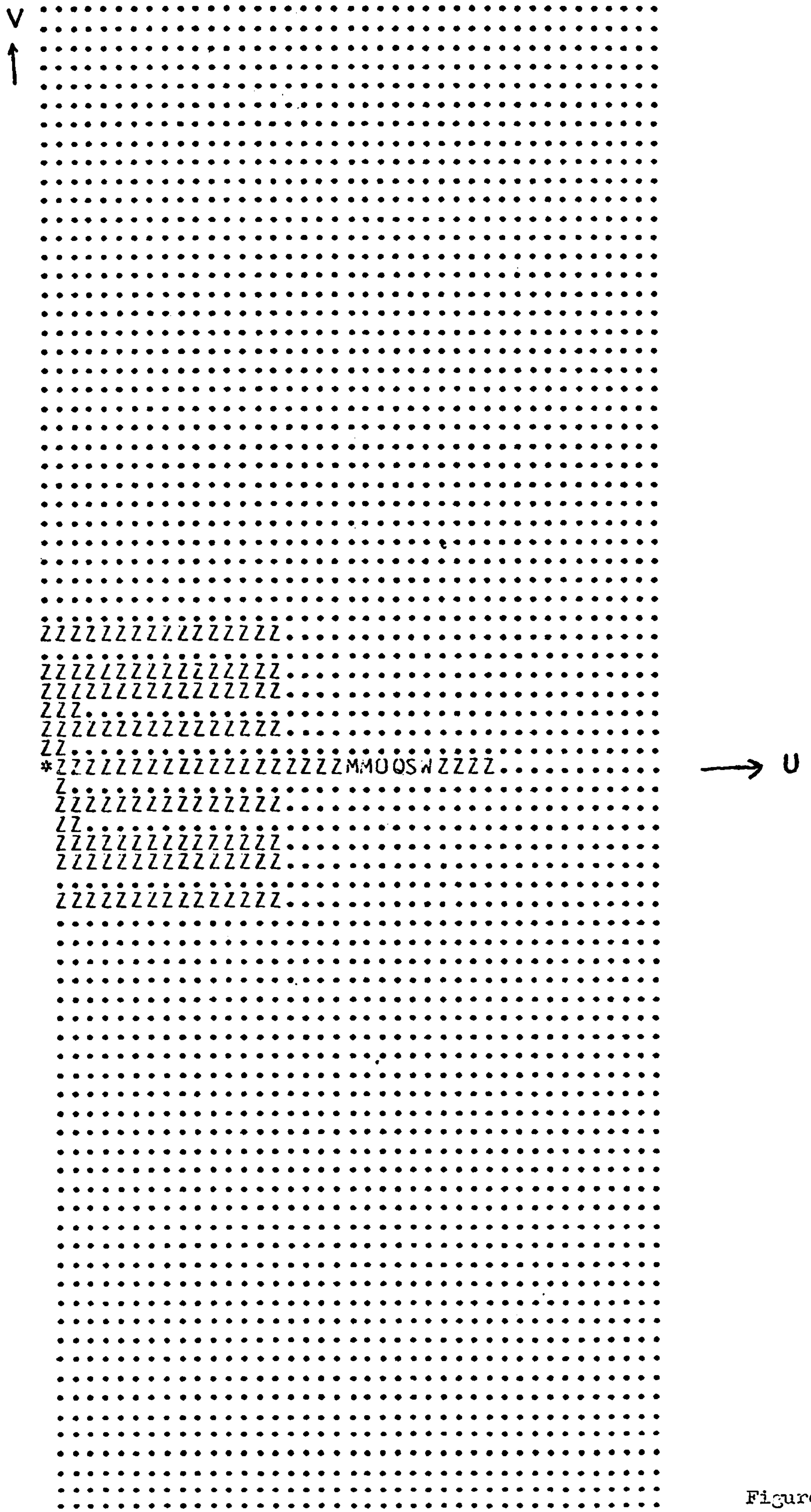


Figure 16(a)

MODEL EQTROPT4

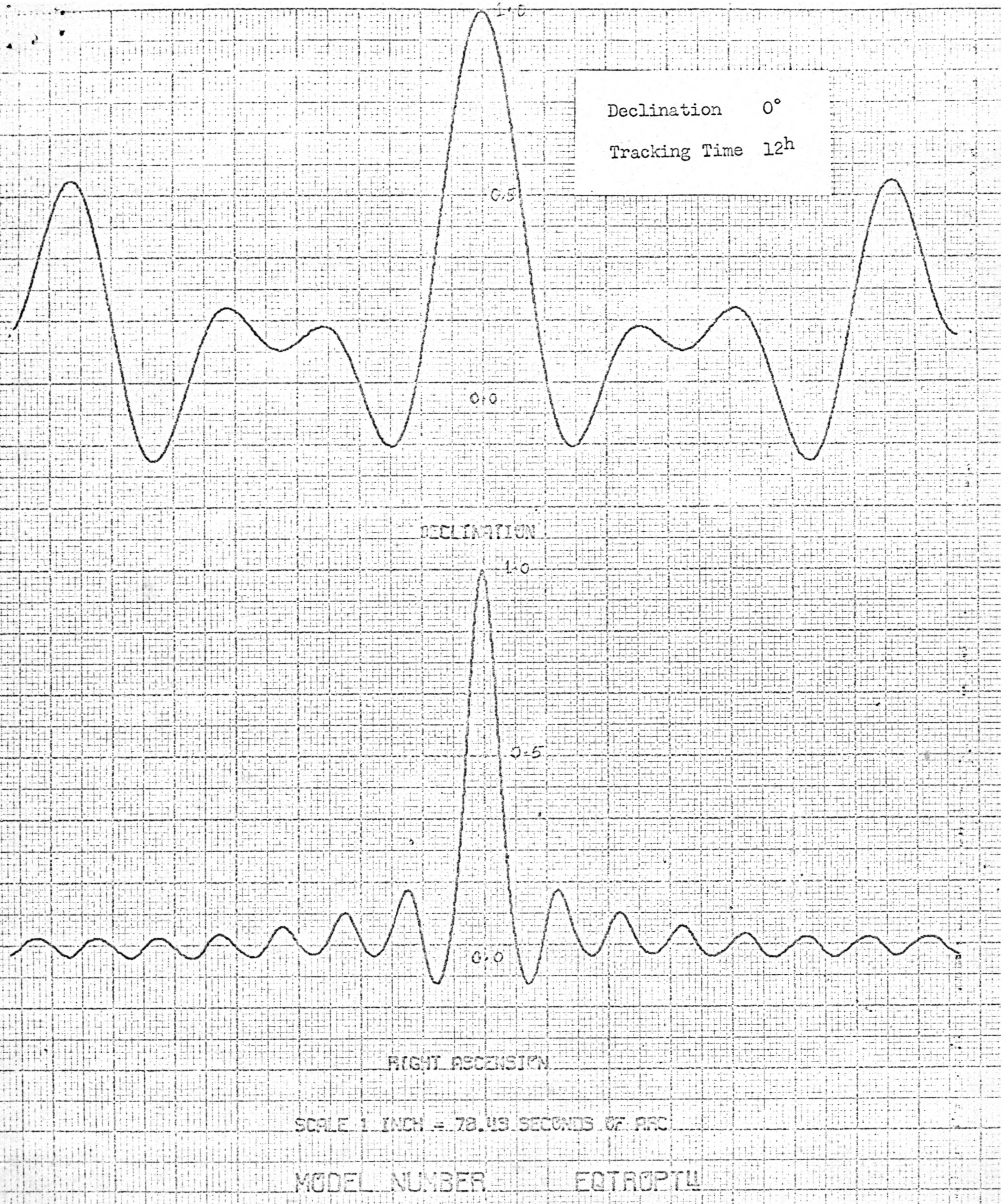

1.0
0.5
0.0
Declination 0°
Tracking Time 12h
DECLINATION
1.0
0.5
0.0
RIGHT ASCENSION
SCALE 1 INCH = 78.43 SECONDS OF ARC
MODEL NUMBER EQTROPT4

Figure 16(b)

Table I

Performance of the Proposed 8-element Array

Model No.	Decli-nation	Tracking Time	Holes (%)	Half Power Beamwidth (R.A. x Decl)	Maximum Sidelobe Level *					RMS Sidelobe Level				
					Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
140EW001	0°	10^m	99.11	11.8 x Fan	- 0.0	- 0.0	- 0.0	- 0.0	- 0.0	- 5.1	- 7.7	- 9.9	-10.8	-11.0
140EW302	30°	10^m	99.11	11.8 x Fan	- 0.0	- 0.0	- 0.0	- 0.0	- 0.0	- 5.1	- 7.7	- 9.9	-10.8	-11.0
140EW903	90°	10^m	98.92	11.8 x Fan	- 0.0	- 0.0	- 0.1	- 0.2	- 0.6	- 5.1	- 6.6	- 8.5	-10.5	-11.5
250EW001	0°	12^h	98.41	9.4 x Fan	- 0.0	- 0.0	- 0.0	- 0.0	- 0.0	- 6.5	- 9.0	-11.5	-14.0	-16.4
250EW302	30°	12^h	38.49	11.0 x 14.1	- 5.9	- 6.8	-11.5	-15.2	-15.6	-12.7	-17.5	-20.9	-23.5	-23.6
250EW903	90°	12^h	43.29	9.4 x 9.4	- 7.3	-11.6	-13.3	-15.6	-11.6	-14.4	-19.8	-22.8	-24.2	-21.0
250T-001	0°	10^m	99.26	60.4 x 60.4	- 0.4	- 1.3	- 4.9	- 4.3	- 1.0	- 1.1	- 4.3	- 9.5	-11.2	- 9.9
250T-302	30°	10^m	99.26	60.4 x 48.6	- 0.5	- 1.5	- 5.6	- 6.0	- 1.0	- 1.3	- 5.3	-11.7	-11.7	- 9.7
250T-903	90°	10^m	99.11	60.4 x 85.5	- 0.2	- 0.7	- 2.6	- 5.3	- 0.8	- 0.8	- 3.0	-10.2	-11.6	-11.2
TEE--311	30°	12^h	38.76	11.0 x 13.3	- 8.3	- 9.3	-10.4	-13.0	-14.5	-11.9	-16.3	-18.7	-20.6	-22.3
TEE--912	90°	12^h	37.95	8.6 x 8.6	- 6.9	-13.1	-14.6	-15.2	-13.1	-13.9	-18.2	-20.6	-21.7	-21.0
NS---002	0°	12^h	78.96	20.4 x 7.8	- 3.5	- 7.9	- 9.1	-10.1	- 2.3	- 8.4	-13.3	-16.9	-21.6	-21.5
EQTROPT4	0°	12^h	93.73	22.7 x 48.6	- 0.6	- 2.1	- 6.9	- 7.5	- 2.6	- 4.6	-11.0	-13.0	-18.2	-18.2

* The Field of View (10' x 10') is divided into 5 zones. The zones are square annuli lying at the following distances from the center of the main beam: Zone 1 10".9 - 20".5, Zone 2 20".5 - 40", Zone 3 40" - 77".5, Zone 4 77".5 - 155", Zone 5 155" - 300".