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TILTING ANTENNAS TO REDUCE LINE-OF-SIGHT MICROWAVE LINK FADING

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FINAL REPORT

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16. Abstract

Tilting the antennas up to obtain 2 dB loss (for each antenna) over maximum gain during steady signal conditions is shown to reduce fading over this particular path. The technique should also work on other paths where sufficient angular separation between the direct and reflected rays exists, and where antennas with sufficiently "sharp" main beams are used.

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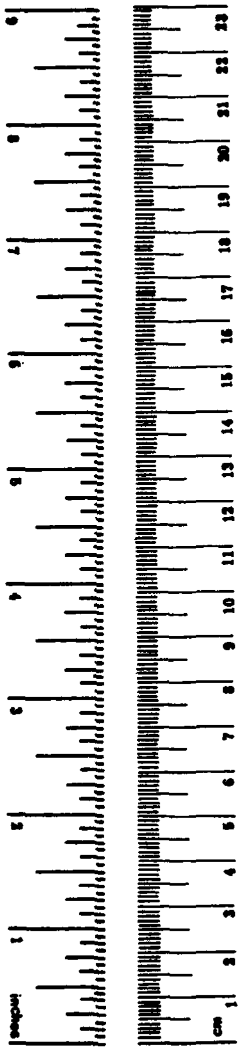
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

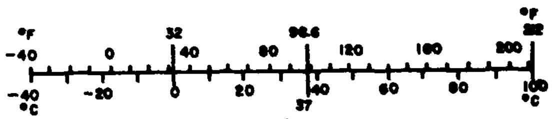
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



CONTENTS

TILTING ANTENNAS TO REDUCE LINE-OF-SIGHT MICROWAVE LINK FADING

W. J. Hartman and D. Smith*

SUMMARY

Tilting the antennas up to obtain 2 dB loss (for each antenna) over maximum gain during steady signal conditions is shown to reduce fading over this particular path. The technique should also work on other paths where sufficient angular separation between the direct and reflected rays exists, and where antennas with sufficiently "sharp" main beams are used.

INTRODUCTION

Many line-of-sight paths exhibit fading caused by ground reflections that interfere with the signal over the direct path. The regions where the ground reflections occur are determined by the path geometry, the orientation of the terrain and the refractive index structure. Consequently, it is sometimes possible to control this interference through the judicious use of antenna heights and antenna patterns which limit the amount of energy illuminating the regions where reflections occur.

This paper presents some experimental results obtained over an FAA Radar Microwave Link (RML) between Fowler and

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Boone, Colorado, where tilting the antennas upward was used to limit the power directed toward the ground reflection points.

Some supporting theoretical results are also given. Although these are not precise, they do give guidelines for applying the technique to other paths.

PATH AND EQUIPMENT DESCRIPTION

The microwave link between Fowler and Boone is 50 km long and crosses the Arkansas River valley at midpath at about 151 m above the river. Ground elevation at Boone is 130 m higher than at the Fowler site. The terrain along the radio path is mostly rolling grassland with some cultivated dryland crops, except that the flat ground near the river is irrigated. There are few trees along the path except near the river, which at this point is a shallow, meandering stream 9 to 12 m wide. The lower portion of figure 1 shows the path profile.

The transmit antenna is a roof mounted parabolic dish 1.5 m (5 ft) in diameter, see figure 2, and the two receive antennas are roof mounted 1.2 m (4-ft) parabolic dishes (see Fig. 3) spaced horizontally 1.37 m between centers. The centers of the antennas are 4.8 m above the local terrain. One of the two receive antennas was tilted upward so that 2 dB of loss was observed during the portion of day when the atmosphere was well mixed, while the second antenna was aligned for maximum gain during this period. The nominal signal level during these periods was approximately -50 dBm for the untilted antennas. The transmit antenna was aligned for maximum gain during one part of the tests and tilted upward to achieve 2 dB loss from maximum during a second part of the test.

In reference to figure 4, each receiver consisted of a solid-state balanced mixer and preamplifier combination. The local oscillator source was a cavity-stabilized transistor oscillator with a stability of ±5.0 MHz operating 70 MHz below the incoming received RF signal of 8110 MHz. The 70 MHz IF output of the preamplifier was fed to a 70 MHz log-linear amplifier which has an output voltage proportioned to the log of the received RF signal level. The output of the log-linear amplifier is conditioned in an operational amplifier to provide DC offset and gain control. The output of the operational amplifier was then recorded on a strip chart recorder and on magnetic tape.

The FM magnetic tape recorder operated at 15/32 inch per second. The center frequency at this speed was 843 Hz (IRIG standard for double bandwidth recording) and could be deviated ±40% with a ±1.35 V DC signal.

The system was calibrated from receiver input through the magnetic tape system by substitution techniques using an SHF signal generator operating at the same frequency as the transmitter. A power meter was used to set the proper power level of the signal generator. The receivers were calibrated from -45 dBm to -100 dBm equivalent RF received signal level. A frequency counter was used to count the FM recorder frequency deviation. Each recorder was calibrated at the beginning and end of each magnetic tape.

The AGC voltages on two FAA receivers were also monitored and recorded. In order to prevent the recording equipment from loading the receiver AGC output, the signals were passed through a unity gain isolation amplifier before they were recorded.

A comparison of the AGC calibrations for the FAA receiver and the ITS receiver are shown in figure 5. The receiving equipment was installed in one rack and the recording and calibration equipment was placed on a moveable cart. (See Fig. 6.)

RESULTS

Preliminary data with both receive antennas aligned for maximum gain showed the fading on the two receiver systems to be nearly identical. Consequently it was not necessary to obtain data for both combinations of tilted and untilted antennas, and the same antenna remained tilted the same throughout the tests.

Chart recordings were made continuously from July 19 through August 22, 1974. Magnetic tape recordings were made for 8 hours each day, except for two 5-day periods, July 26 - July 30 and August 12 - August 16, when 24 hours per day were recorded. Due to the perversities of nature several periods of fading occurred when the tape recorder was off. One period of recording extending from approximately 1200 August 1 to 0900 August 2, is shown in figure 7. On the average for the entire period of the tests, approximately 18 hours per day were free from any fading greater than 5 dB, and approximately 3 hours per day showed some fading exceeding 20 dB. For steady signal conditions, the levels ranged between -50 dBm and -55 dBm. The period for testing was chosen because previous experiments indicated a high probability of fading during the night throughout July and August.

The data recorded on the chart were scanned to determine periods of fading and these were further edited to eliminate those periods containing switching transients. The remaining data consist of 13 periods of one to four hours duration with the transmitter untilted (U) ending August 11, and 11 periods with the transmitter tilted (T), ending August 16. For the 13

U sample periods, two exhibit deeper fading for the tilted receive antenna than for the untilted antenna. For the 11 T samples none shows deeper fading for the tilted receive antenna than for the untilted antenna. On the other hand, 9 U samples and 8 T samples show significantly less fading for the tilted antenna than the untilted.

The cumulative distributions for each of these 24 samples are shown in figures 8 through 31, figures 19 et seq. being those in which transmitter antenna is tilted. Note that the tilted system has an inherent 2 dB greater loss than the untilted system. Figures 14, 15, 16, 18, 19, 21, 24, 25, and 30 also show the corresponding strip chart recordings which illustrate some of the types of fading encountered.

The data clearly show that the amount of time the signal is in a deep fade is much less for the tilted antenna than for the untilted antenna.

The distributions cover the periods indicated in the figures and consequently the percent of time does not correspond to the same amount of time from one figure to the next. Since the deep fading is of greatest concern, table 1 was prepared to show the amount of time the signal was below -75 dBm and -85 dBm for the periods analyzed.

BACKGROUND AND HEURISTIC

In order for the tilting technique described here to reduce fading, it is sufficient (1) to assume that the fading is caused by the interference between the direct path component and one (or more) component which is reflected (scattered) from below the direct path, and (2) to use an antenna with an appropriate pattern.

Table 1.

Figure Number	Total Minutes	Time That the Signal Was Less Than -80 dBm Untilted	-80 dBm Tilted	-75 dBm Untilted	-75 dBm Tilted
8	200	0	0	.40	1.0
9	102	0	0	.30	0
10	107	0	0	0	0
11	120	0	0	.72	0
12	68	0	0	0	0
13	124	0	0	.37	0
14	130	.46	0	1.56	0
15	145	.15	1.01	.73	2.76
16	205	3.79	0	9.64	0
17	102	0	.20	.31	1.38
18	54	.40	0	.97	0
19	95	.47	0	1.42	0
20	78	.94	0	1.95	0
21	120	1.20	0	6.60	0
22	47	1.32	0	2.82	0
23	214	0	0	4.70	0
24	217	.54	0	4.12	0
25	217	0	0	1.19	0
26	198	.12	0	.59	.06
27	82	.33	.25	.98	.70
28	109	1.20	0	6.30	0
29	107	0	0	0	0
30	107	0	0	.43	.21
31	214	0	0	.64	0
Total	52.7 (hours)	10.92 (min)	1.46 (min)	46.74 (min)	6.11 (min)

We now focus attention on the ground reflections for two reasons: (1) The angles between the direct and ground reflected rays are larger than the angles between the direct and atmospherically reflected rays, when the reflection points are at the same distance along the path, and (2) these angles can be easily determined for the ground reflection points, whereas even the location and orientation of atmospheric layers is difficult to determine.

If we examine the ground reflections, we find that the points where reflections occur are determined by the slope and elevation of the ground and the refractive gradient of the atmosphere. Calculations of the locations of reflection points for different values of N, and the rooftop antennas used in this experiment were made and are shown in the upper portion of figure 1. Additional calculations for different antenna heights were done previously and the combination of antenna heights which gave the fewest number of possible reflection points was chosen as one of several in a prior experiment (Skerjanec and Samson 1972). Of all the antenna heights tested, this chosen height produced the least fading, indicating, although not proving, that ground reflections were significant. Thus, from this previous work, there was a basis for believing that tilting the antenna would reduce fading.

Turning our attention to antenna patterns, we will use the 4 ft dish for our example. The theoretical antenna pattern for this antenna is shown in figure 32. The salient feature here is illustrated by the following: If the direct path is centered at the maximum gain (0 dB), it is necessary to go off axis 0.6° to obtain 1 dB loss. If the direct path is centered at the 1 dB point, an additional 1 dB loss is obtained at an off axis angle change of 0.24°. Similarly to go from 2 dB to 3 dB requires only 0.12°. This (0.12°) represents a height difference between the direct path and the reflection point of 52 m at midpath (for this geometry) to obtain at least 1 dB difference, whereas 0.6° corresponds to a height difference of 262 m. If the reflected path is down 1 dB from the direct path, the maximum fade depth which can occur is 19.2 dB for a two path model.

CONCLUSIONS

On line-of-sight paths multipath components which originate below the direct path are usually present, even though their magnitude may be small. When the direct path is attenuated (e.g., by atmospheric induced diffraction effects) the magnitudes of the off-path components relative to the direct path may become large enough to produce deep fading. In figure 7, this effect is clearly indicated, with power fading occurring on both signals between the points A and B, and the additional multipath fading occuring between points B and C. The reduction of the multipath component by antenna tilting reduces the depth of fades. It is clear that tilting the antenna will have little or no effect on the diffraction type fading. Thus, for paths which exhibit the characteristic described above (i.e., power fading of the direct signal to a level which induces multipath fading), tilting the antennas upward should provide some protection against the deeper multipath fading.

ACKNOWLEDGMENT

G. A Hufford kindly supplied figure 1.

REFERENCE

Skerjanec, R. E., and C. A. Samson (1972) Microwave link performance measurements at 8 and 14 GHz, Report No. FAA-RD-72-115 prepared for the Department of Transportation, Federal Aviation Administration, Systems Research & Development Service, Washington DC 20591.

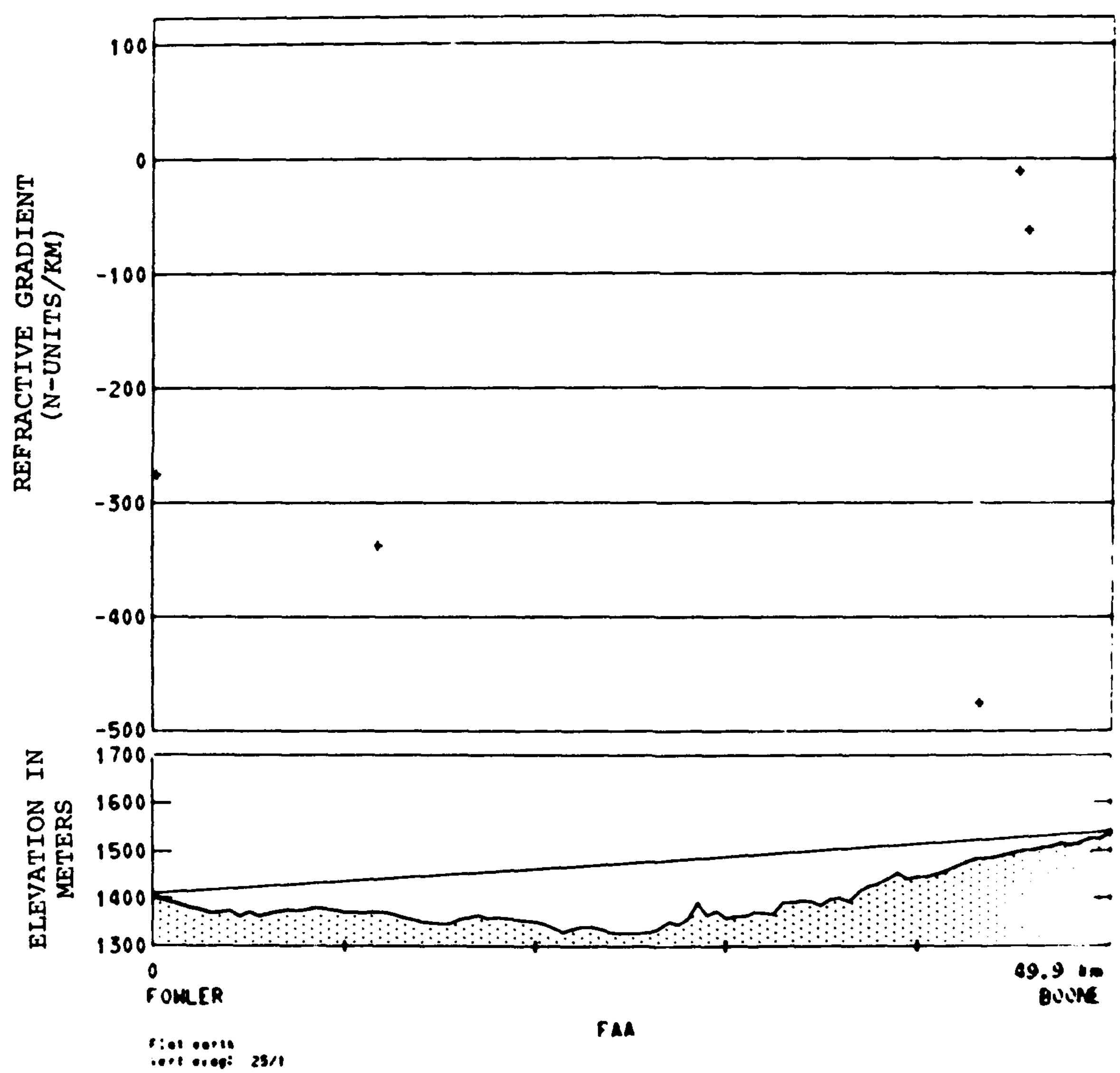

Figure 1. Path profile and location along the path of possible reflecting points for different refractive gradients, ΔN.

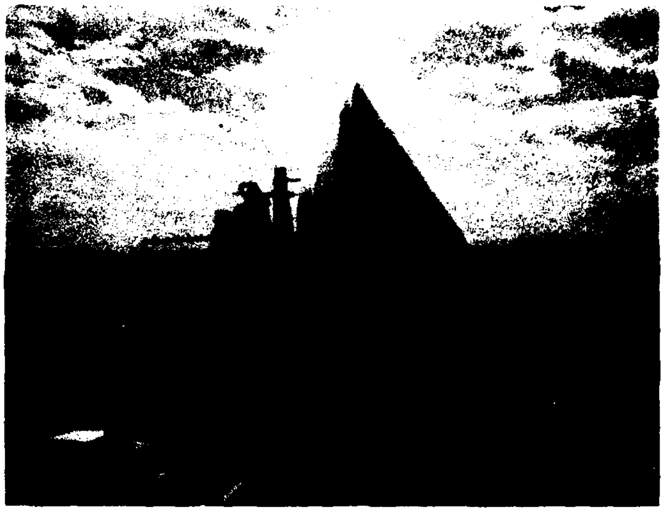

Figure 2. Transmit antenna at Fowler site.

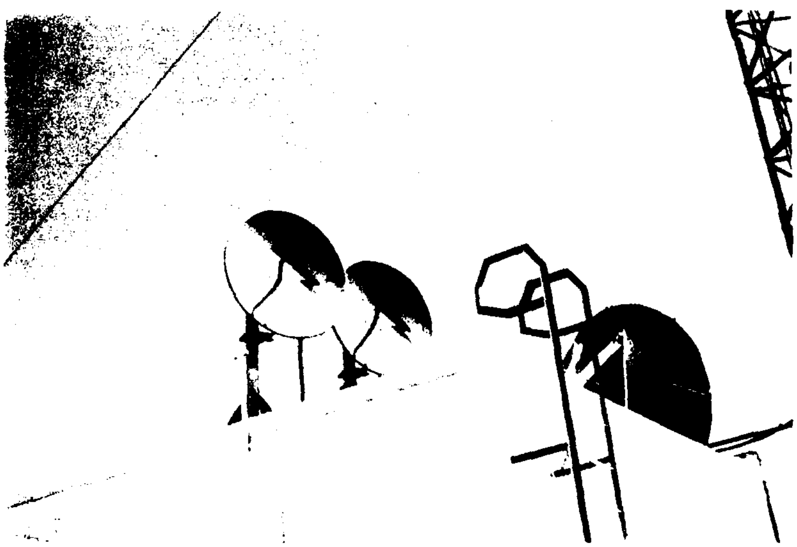

Figure 3. Receive antennas at Boone site.

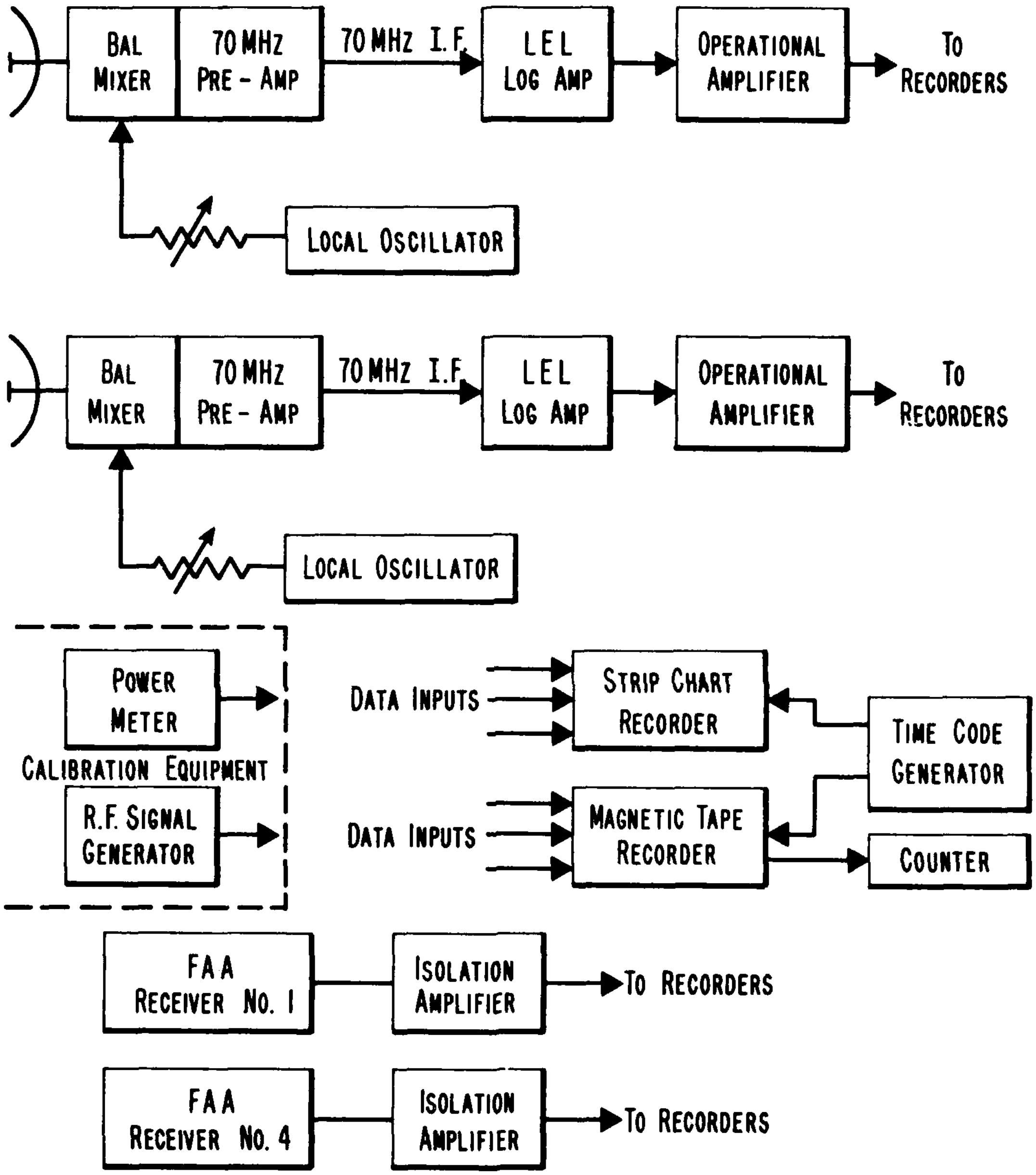

Figure 4. Block diagram of equipment used in the experiment.

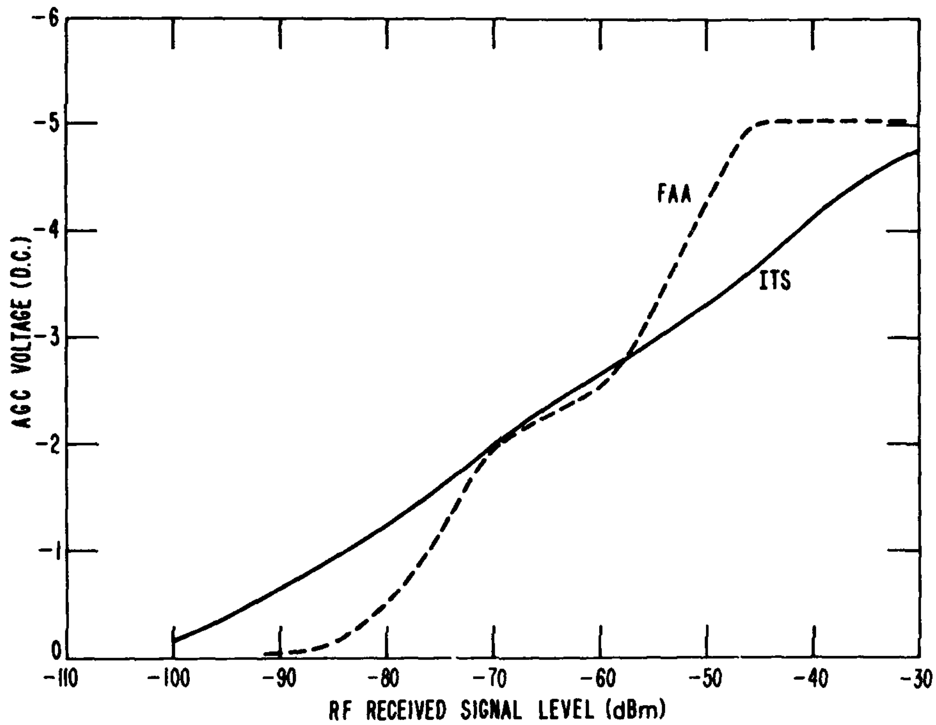

Figure 5. A comparison of AGC curves for the ITS receivers and the FAA receivers.

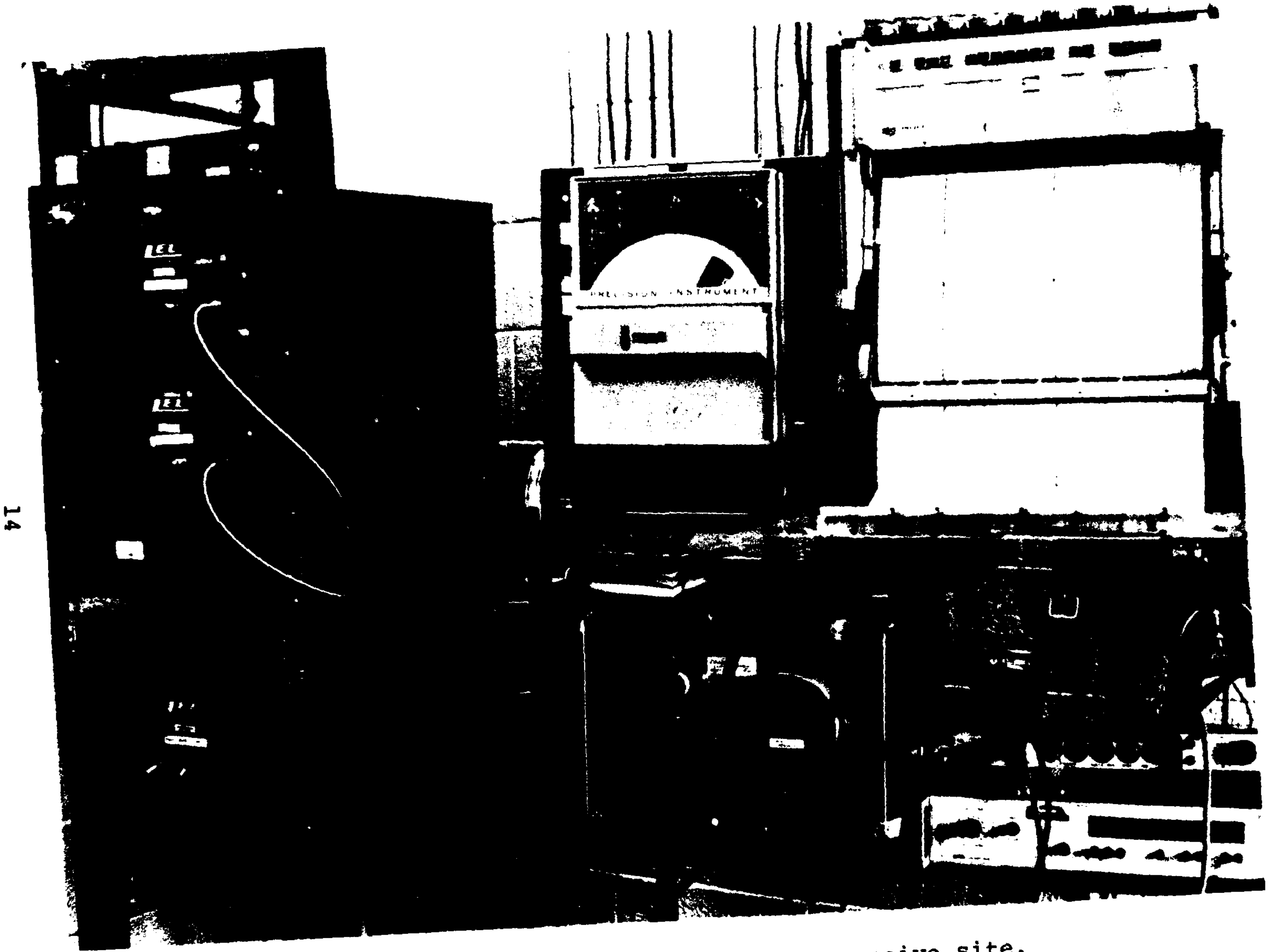

Figure 6. Equipment in use at the receive site.

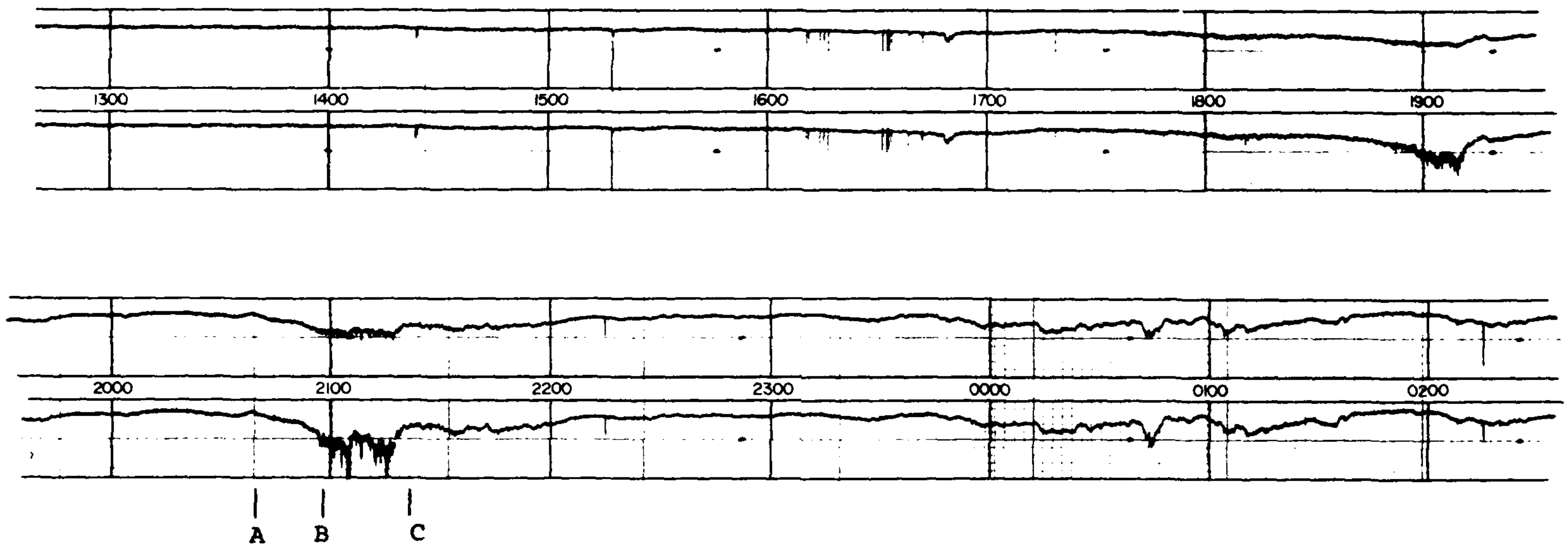

Figure 7. Strip chart recording of received signal, 1300 August 1, to 0900 August 2. The upper trace on the chart shows the received signal level from the tilted receiving antenna.

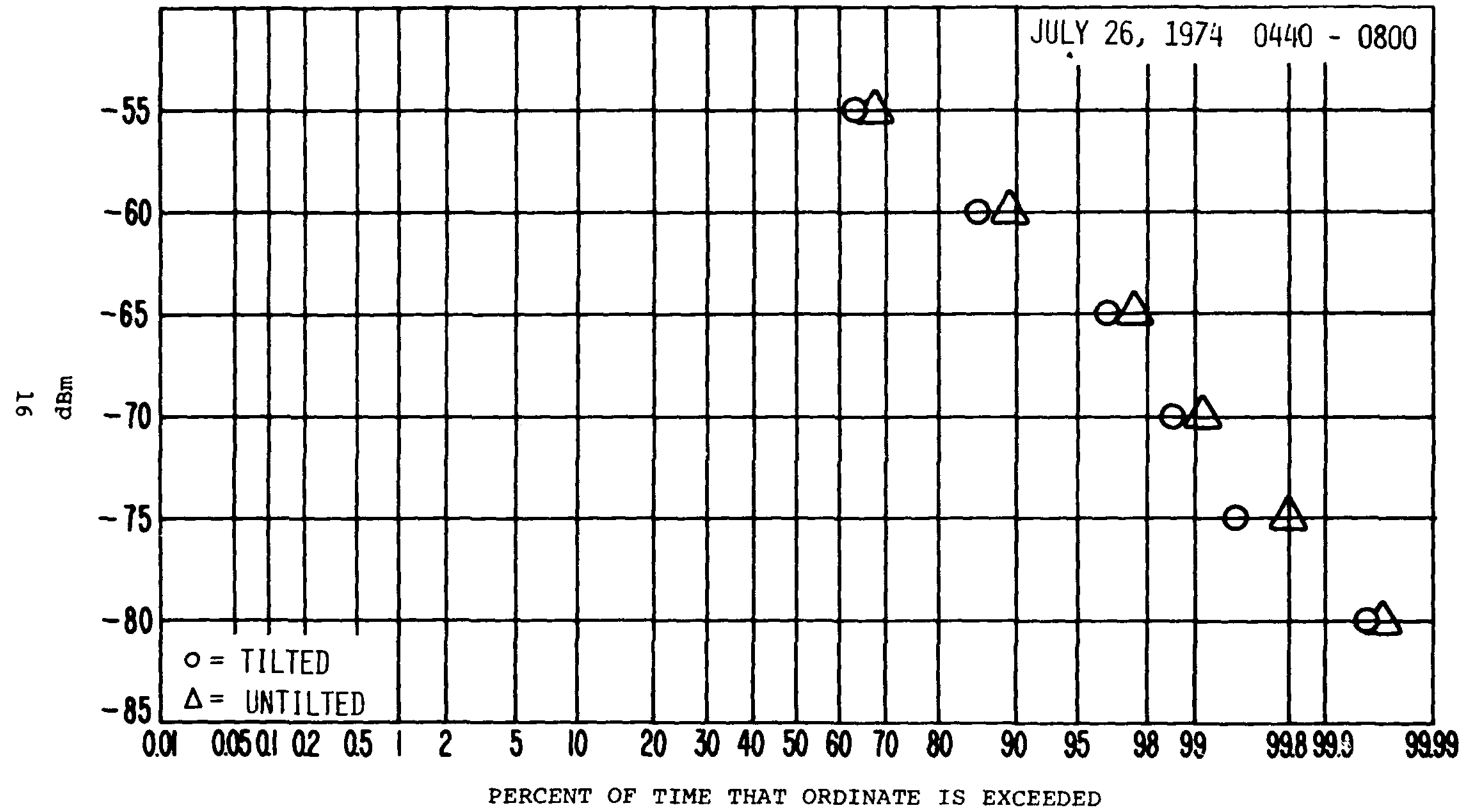

Figure 8. Cumulative distributions of signal level for the time period indicated.

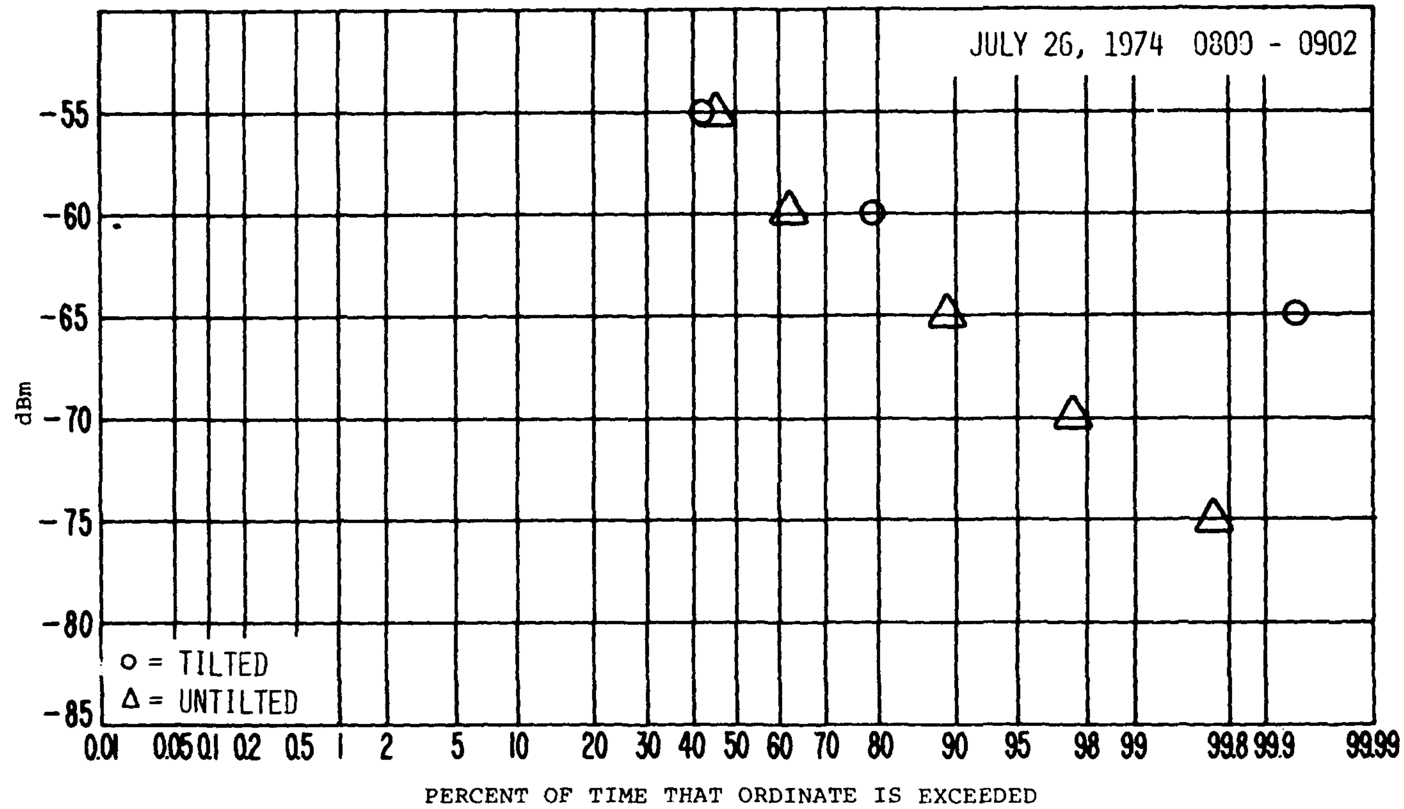

Figure 9. Cumulative distributions of signal level for the time period indicated.

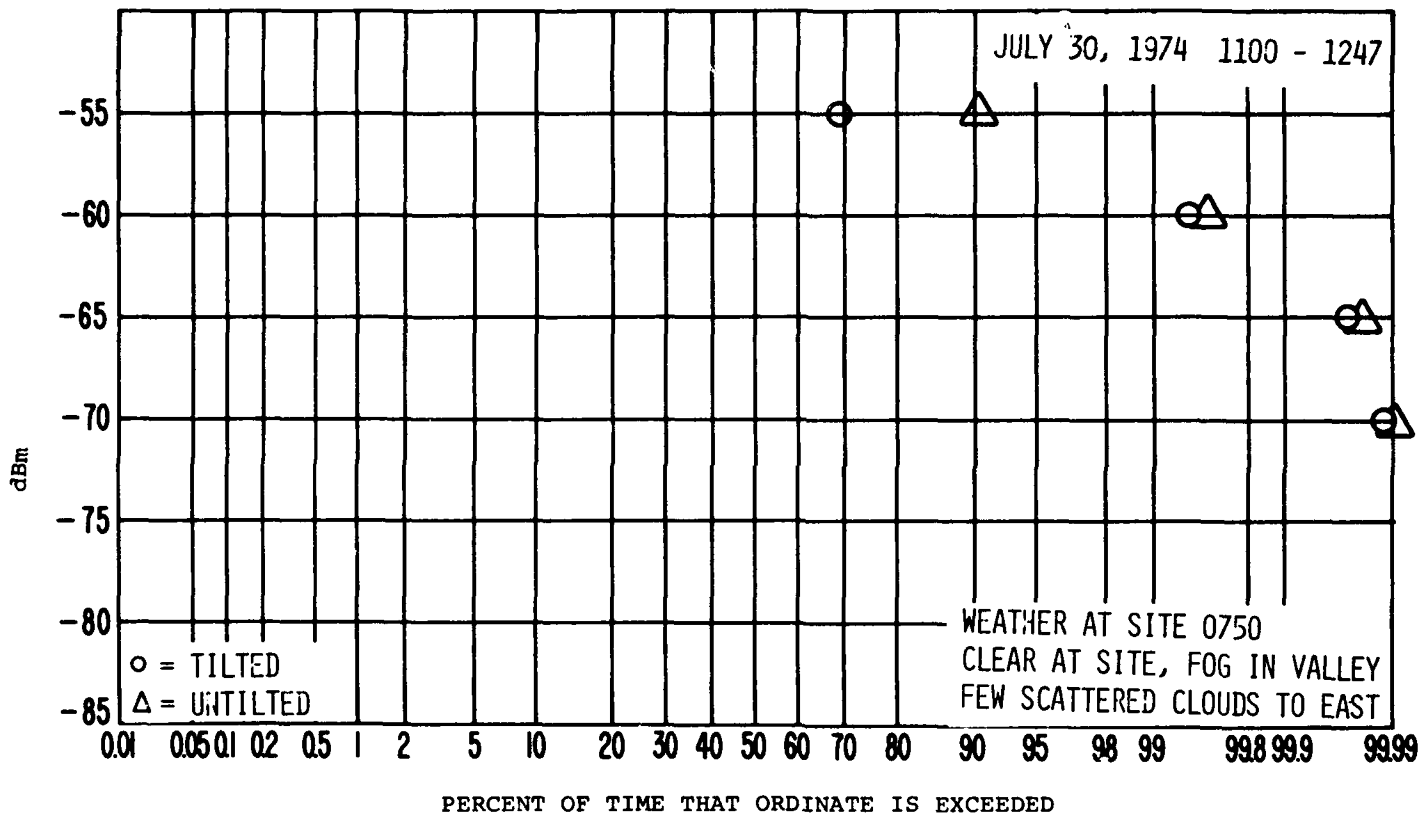

Figure 10. Cumulative distributions of signal level for the time period indicated.

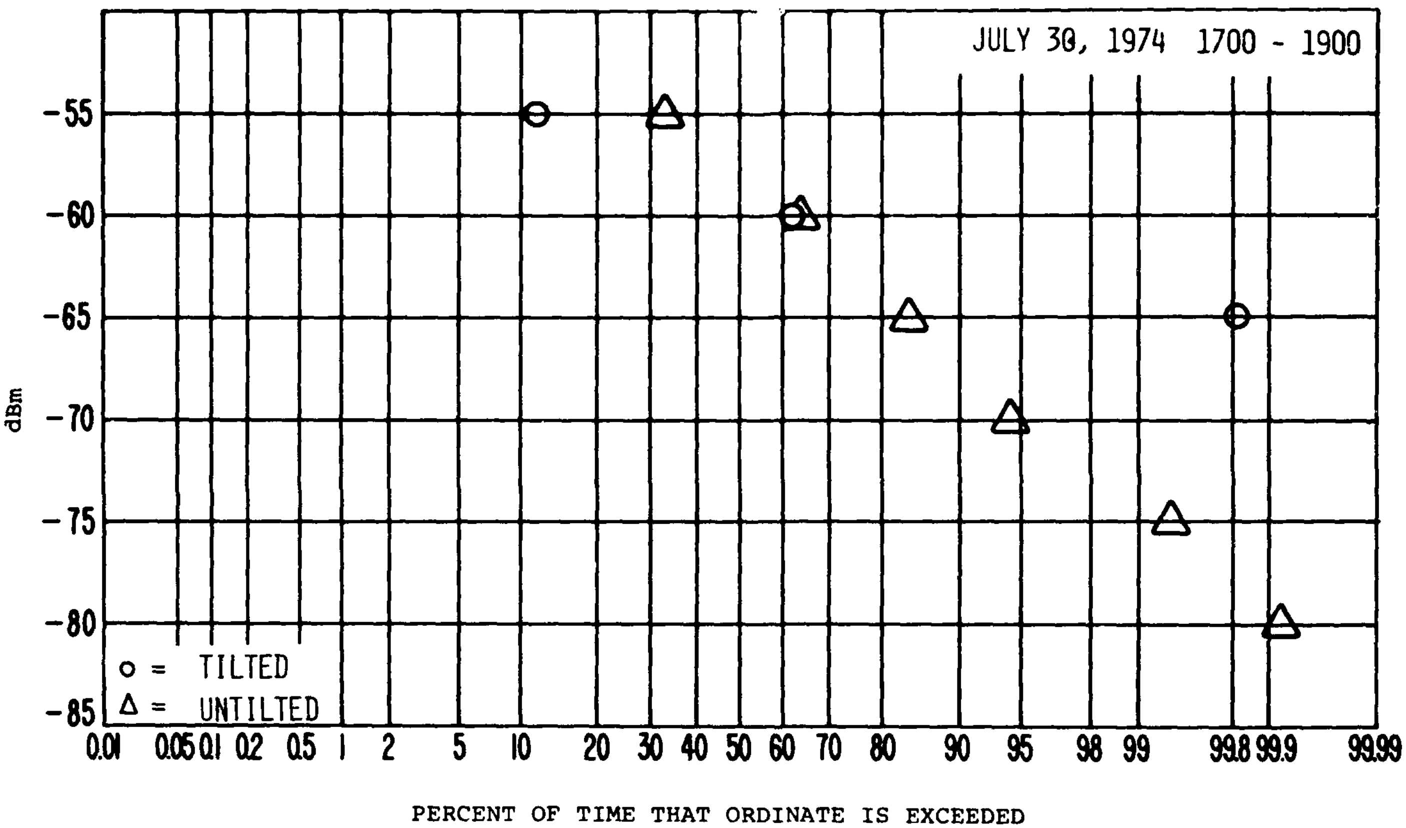

Figure 11. Cumulative distributions of signal level for the time period indicated.

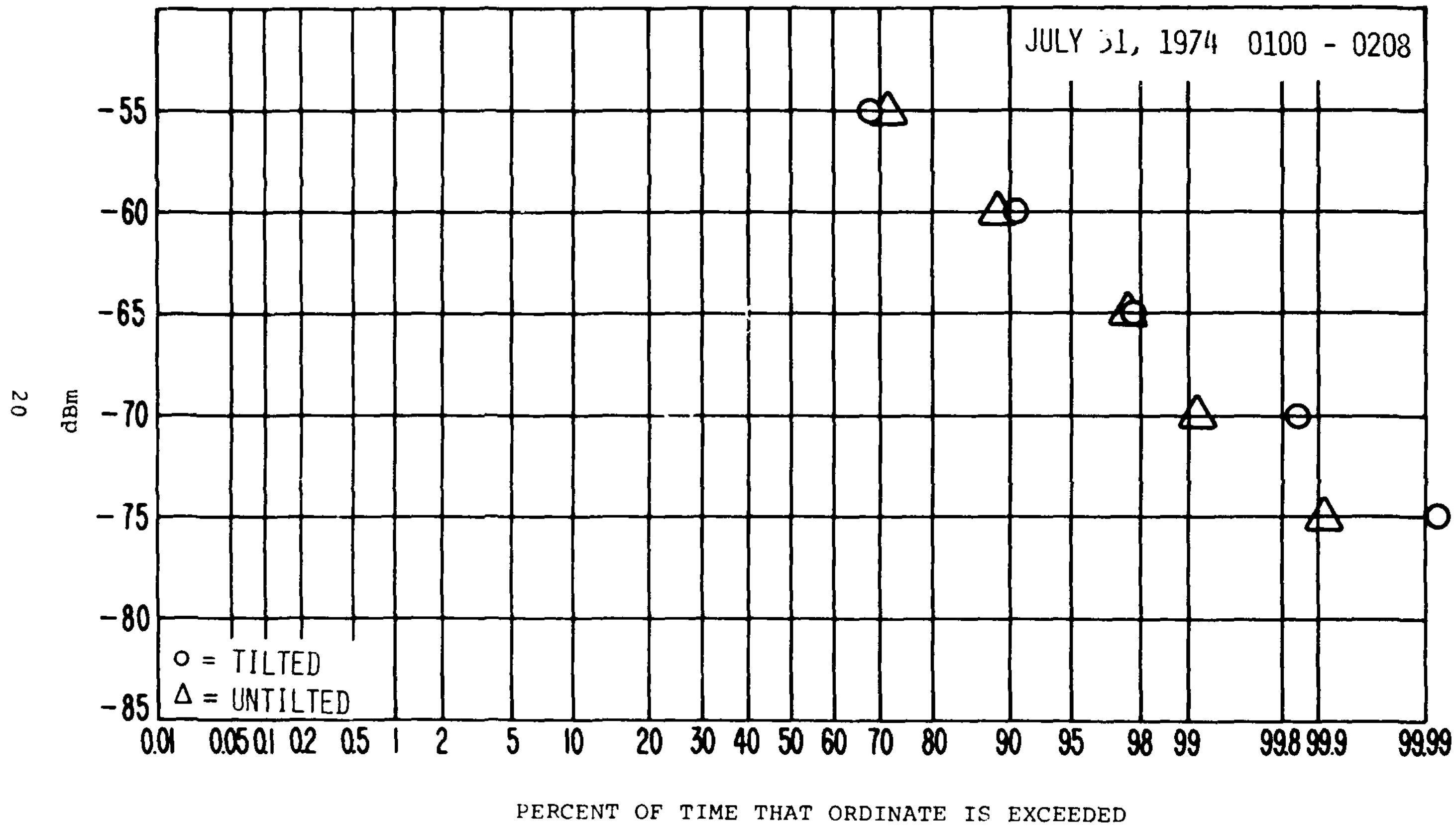

Figure 12. Cumulative distributions of signal level for the time period indicated.

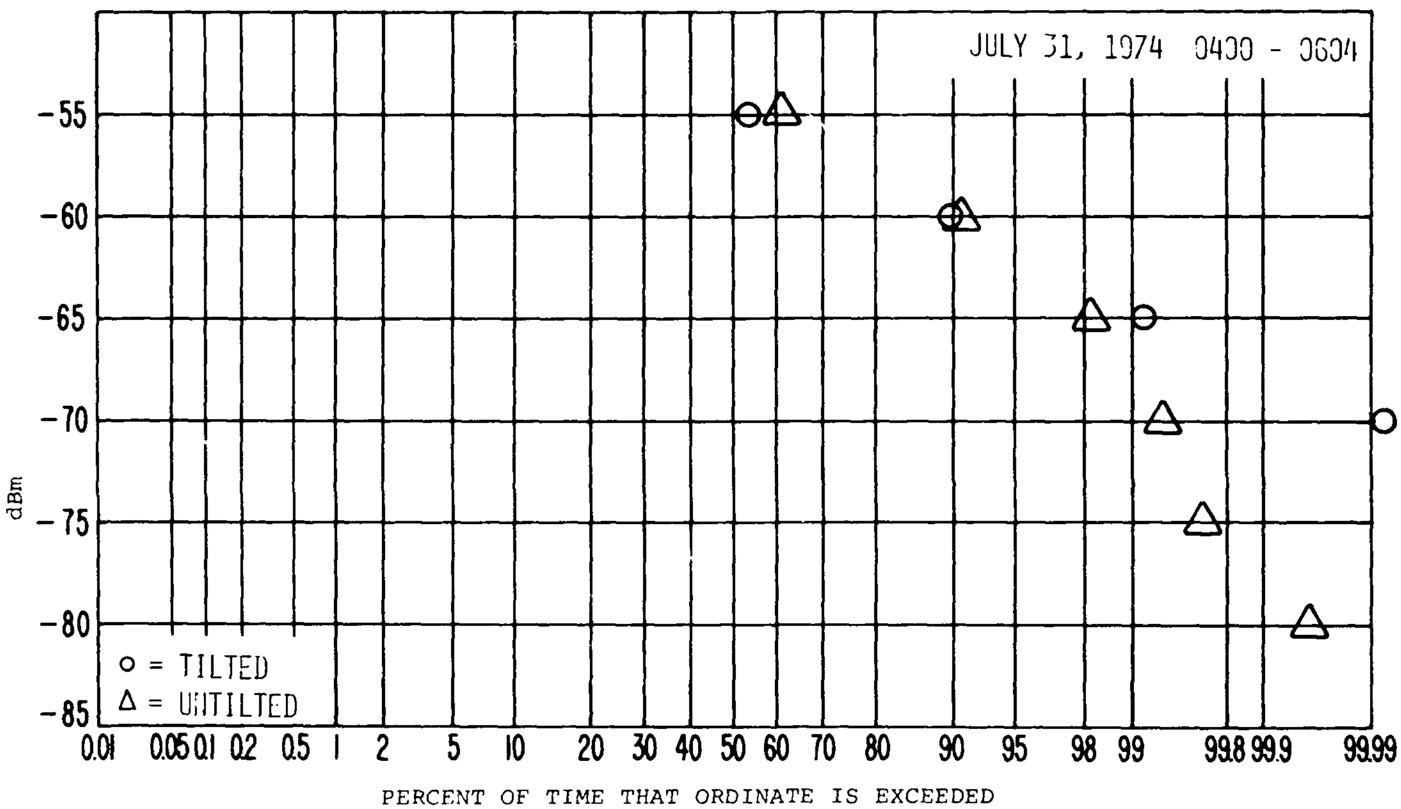

Figure 13. Cumulative distributions of signal level for the time period indicated.

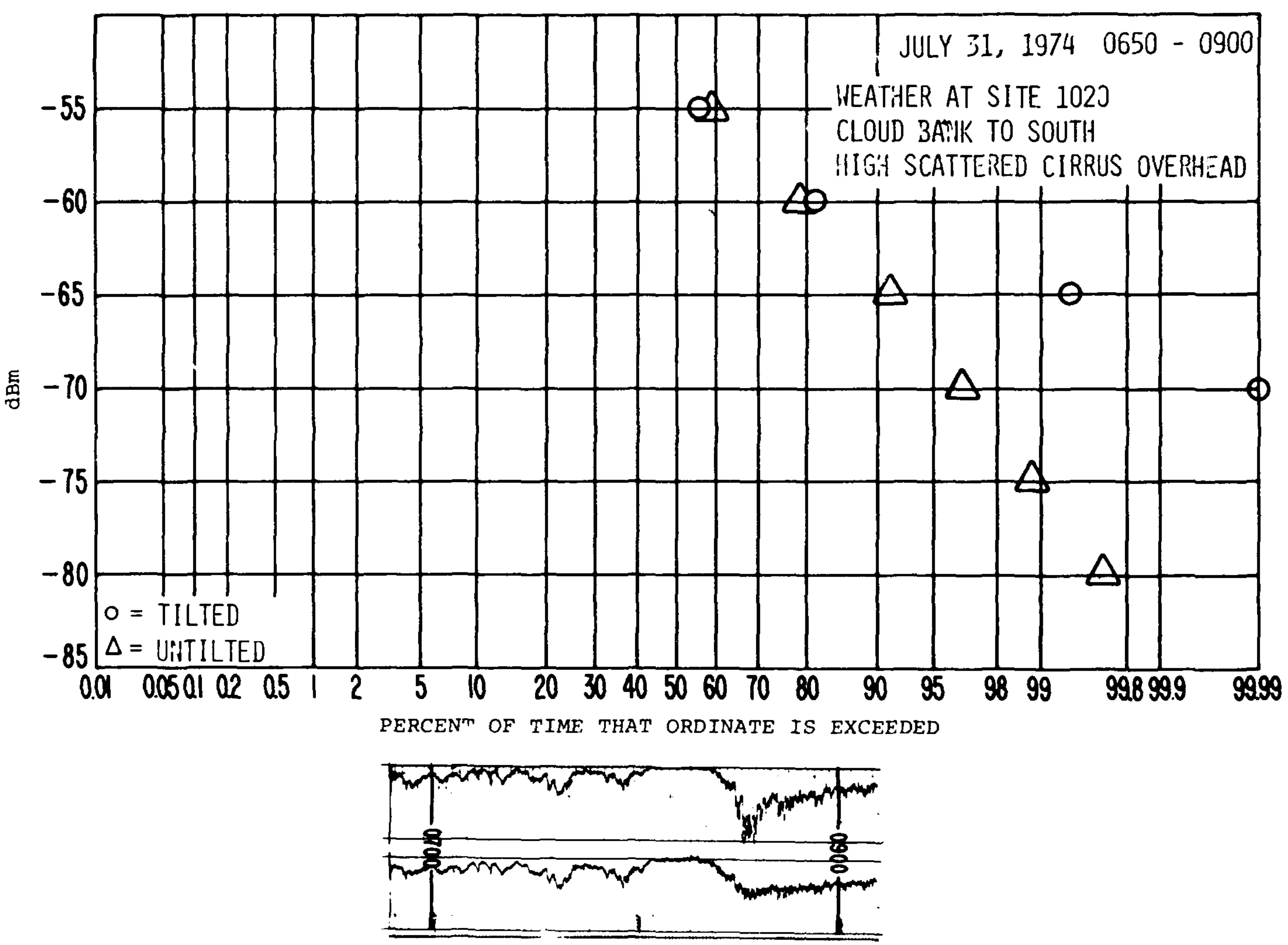

Figure 14. Cumulative distributions of signal level for the time period indicated and corresponding signal level recordings. The upper recording is for the untilted antenna.

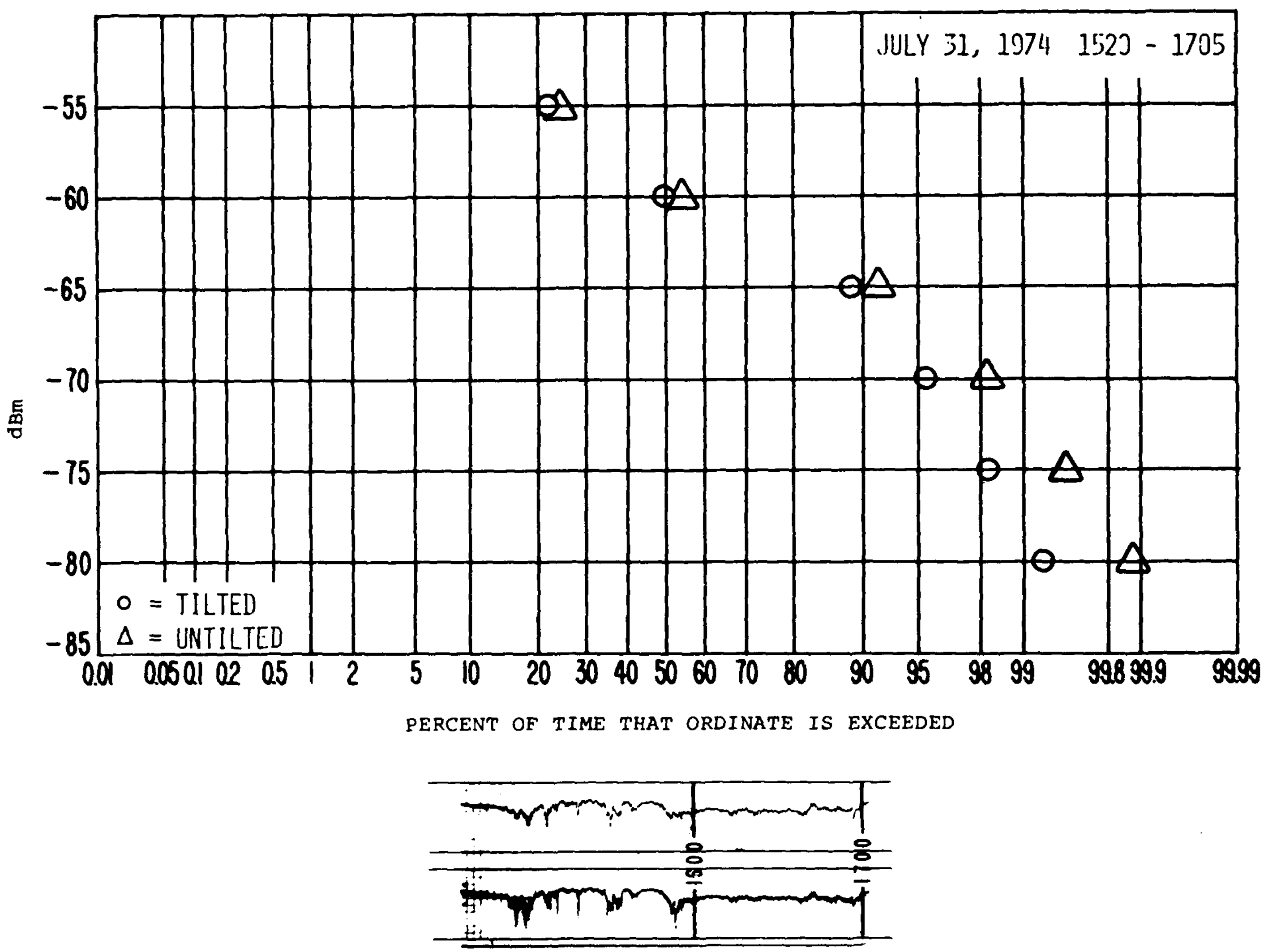

Figure 15. Cumulative distributions of signal level for the time period indicated and corresponding signal level recordings. The upper recording is for the untilted antenna.

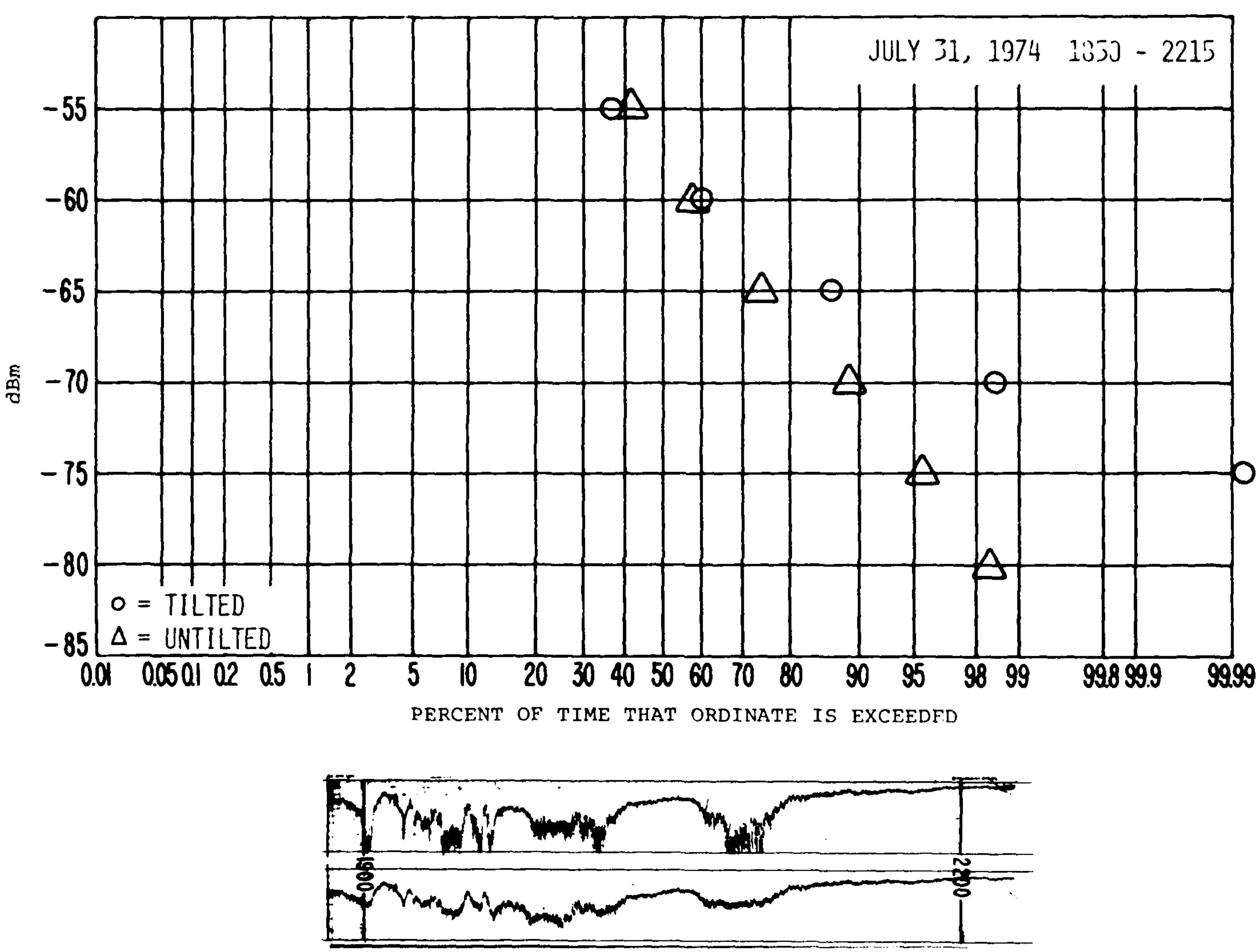

Figure 16. Cumulative distributions of signal level for the time period indicated and corresponding signal level recordings. The upper recording is for the untilted antenna.

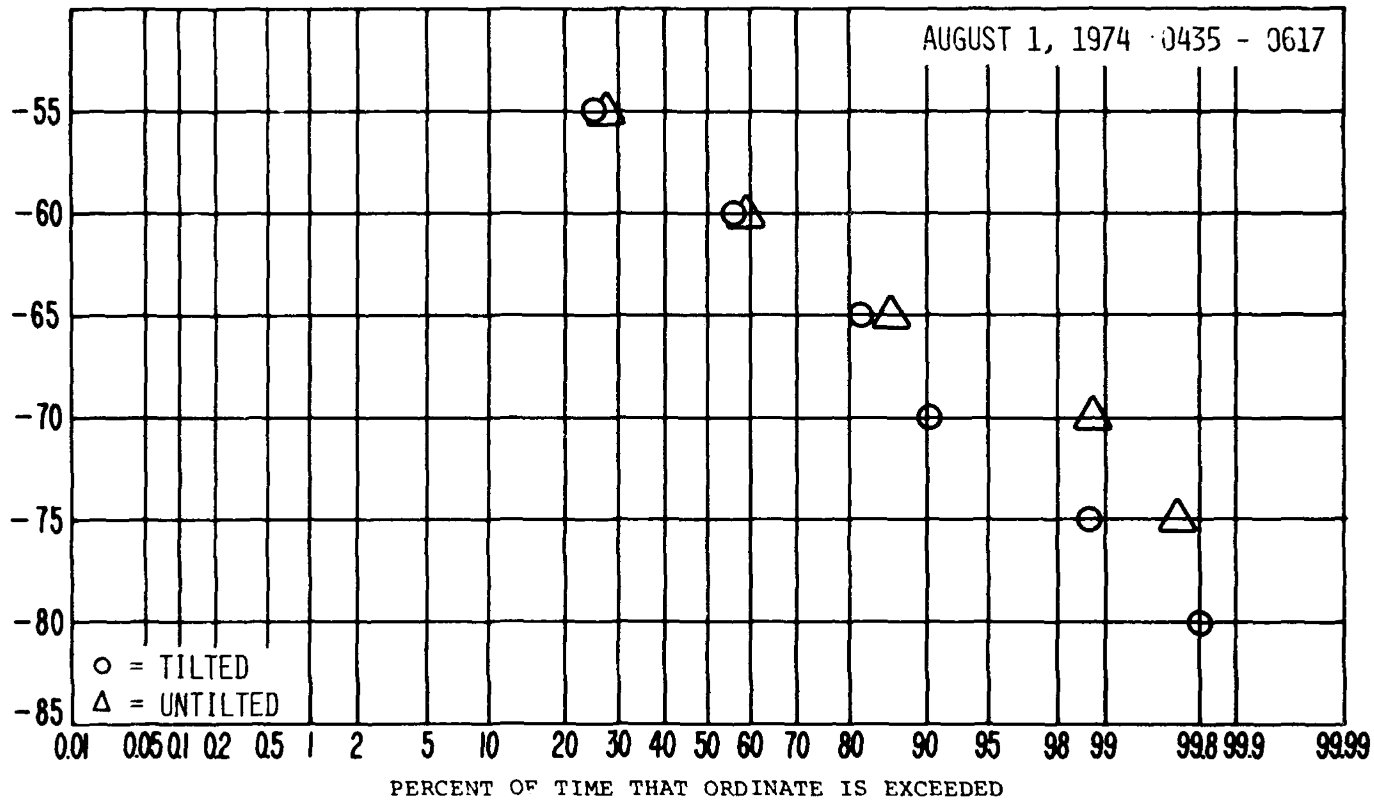

Figure 17. Cumulative distributions of signal level for the time period indicated.

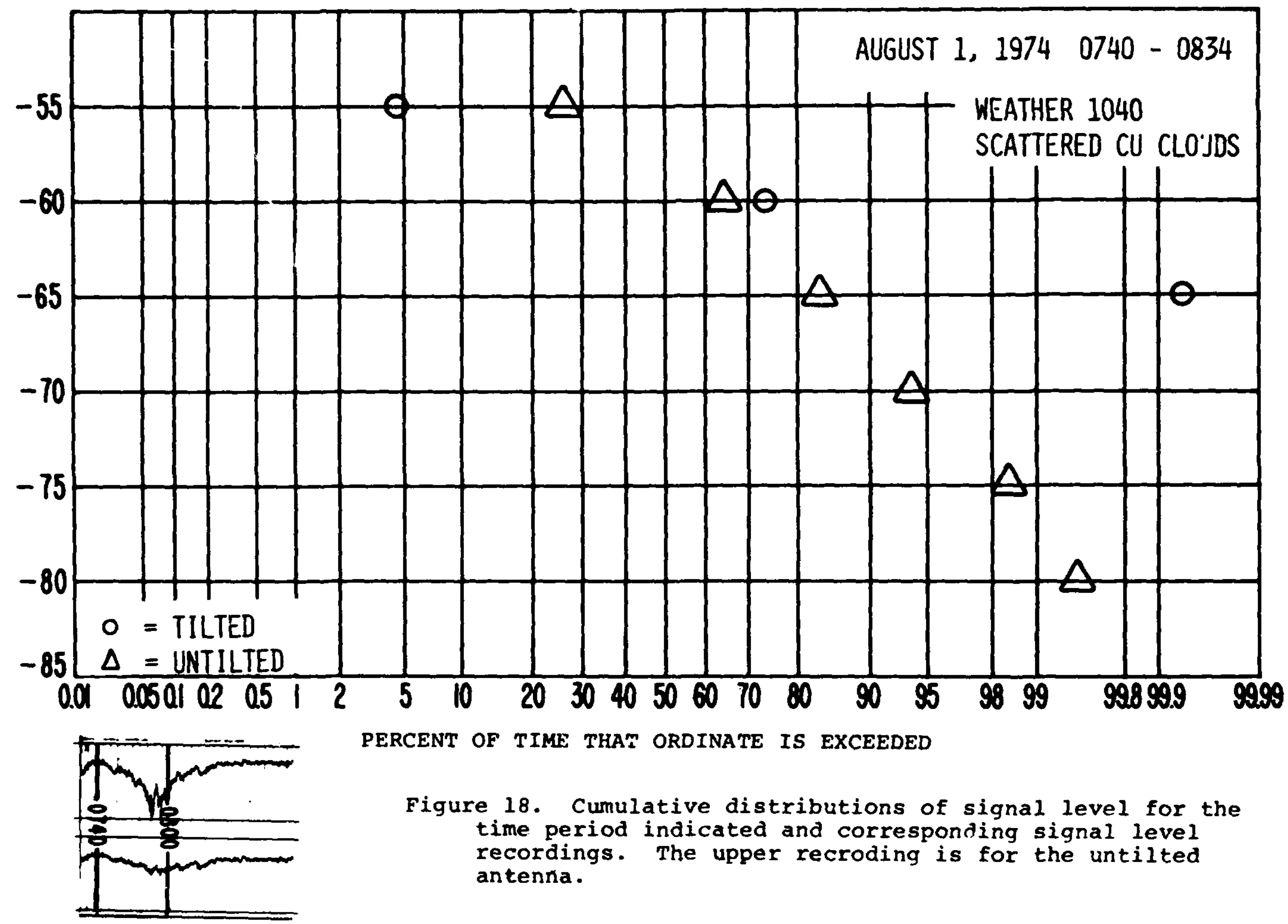

Figure 18. Cumulative distributions of signal level for the time period indicated and corresponding signal level recordings. The upper recroding is for the untilted antenna.

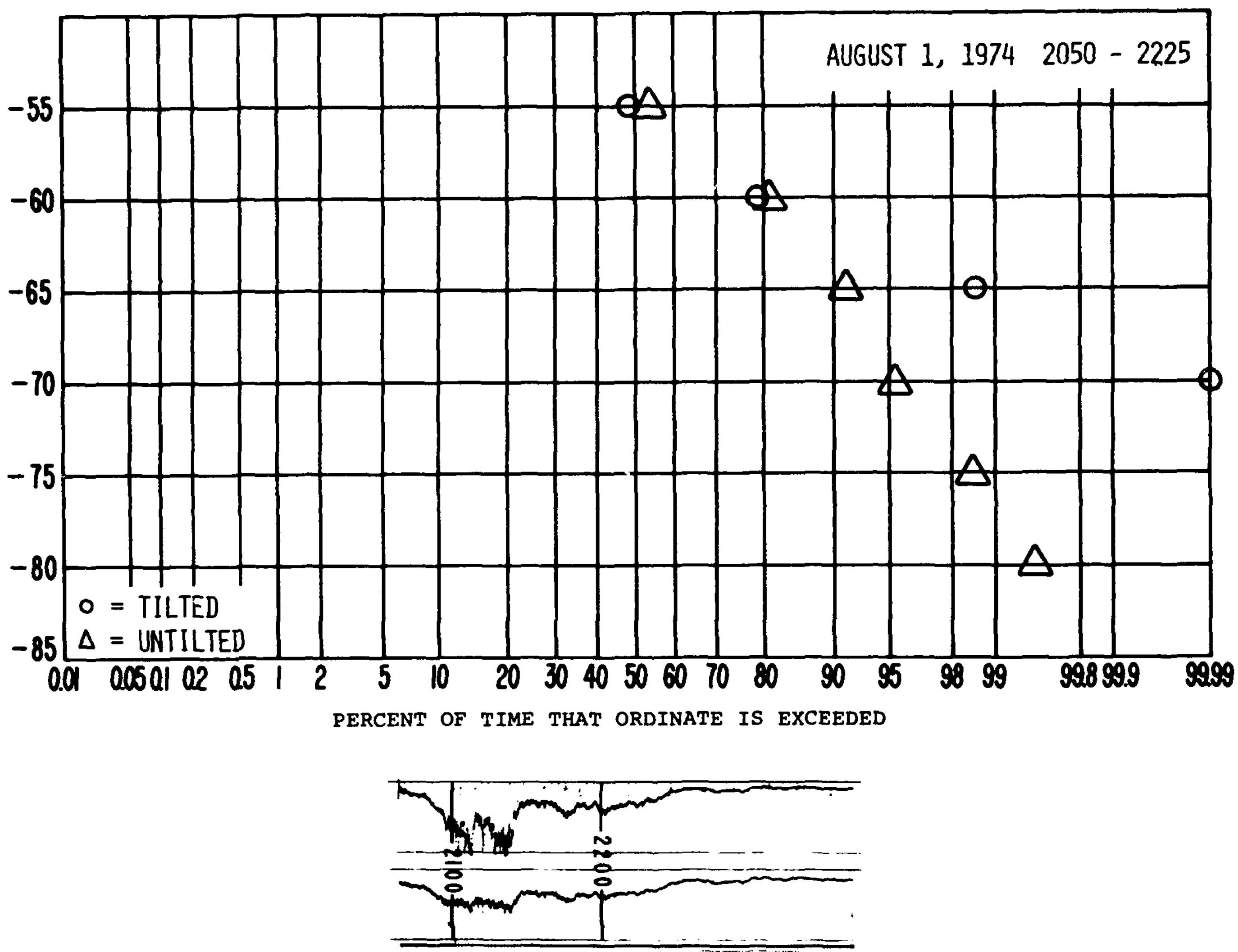

Figure 19. Cumulative distributions of signal level for the time period indicated and corresponding signal level recordings. The upper recording is for the untilted antenna.

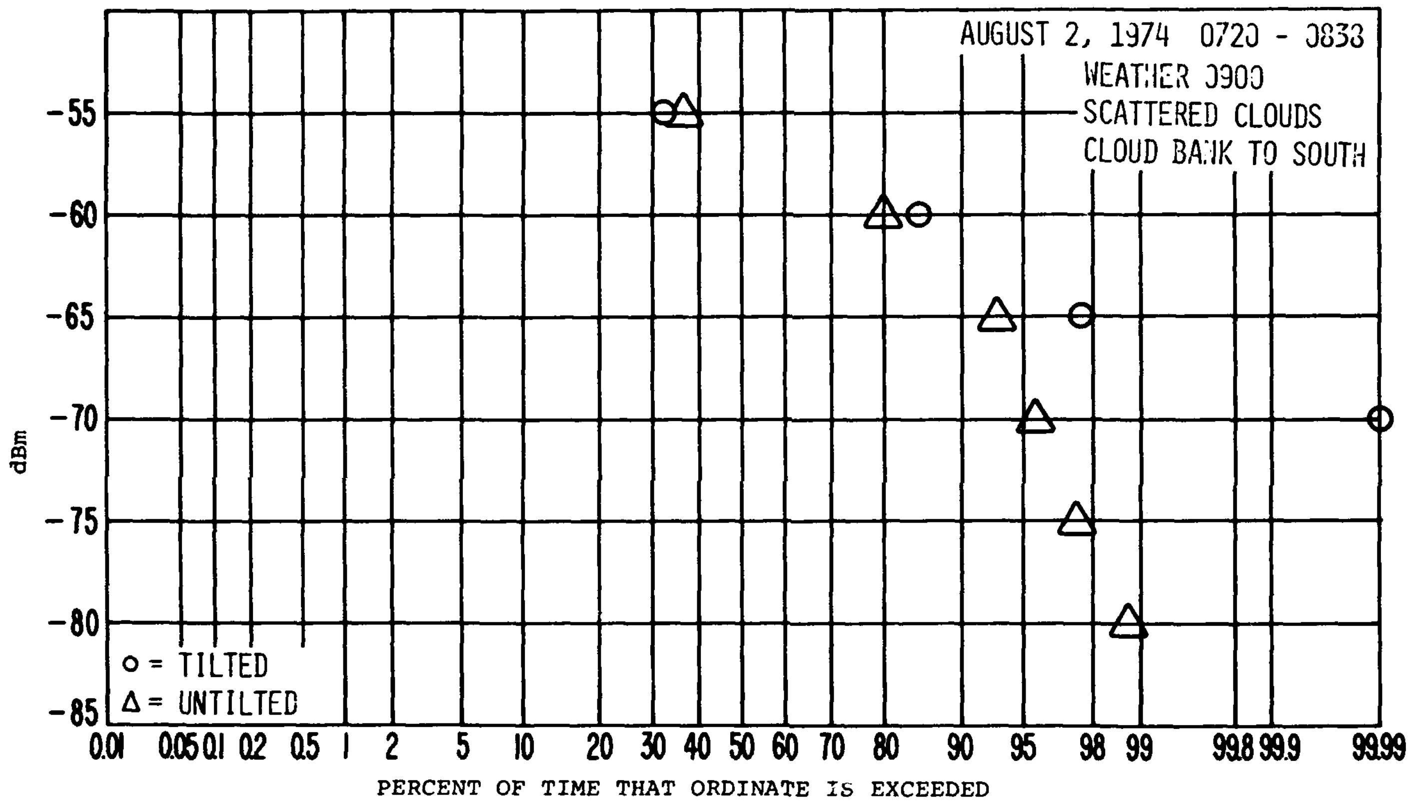

Figure 20. Cumulative distributions of signal level for the time period indicated

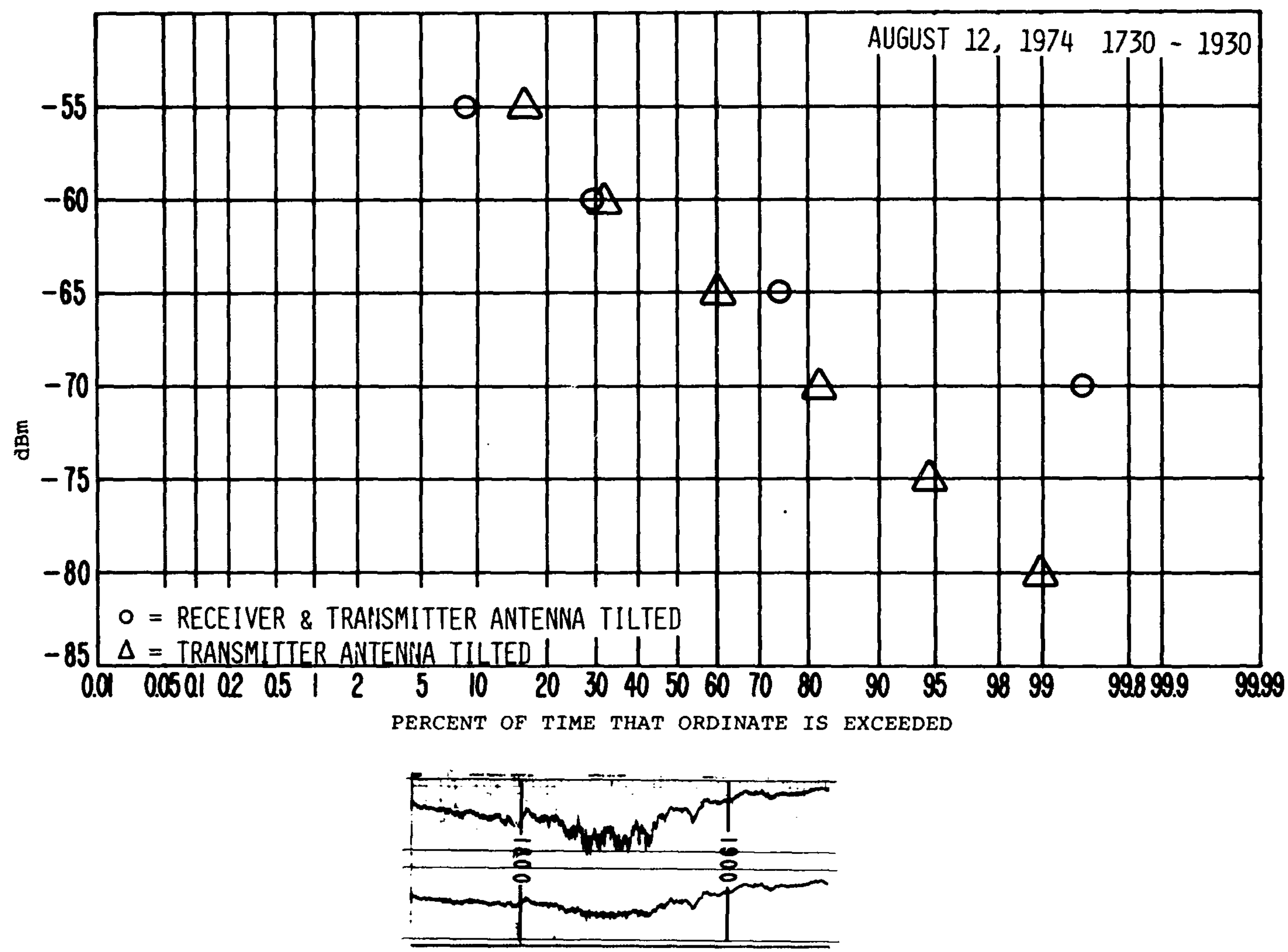

Figure 21. Cumulative distributions of signal level for the time period indicated and corresponding signal level recordings. The upper recording is for the untilted antenna.

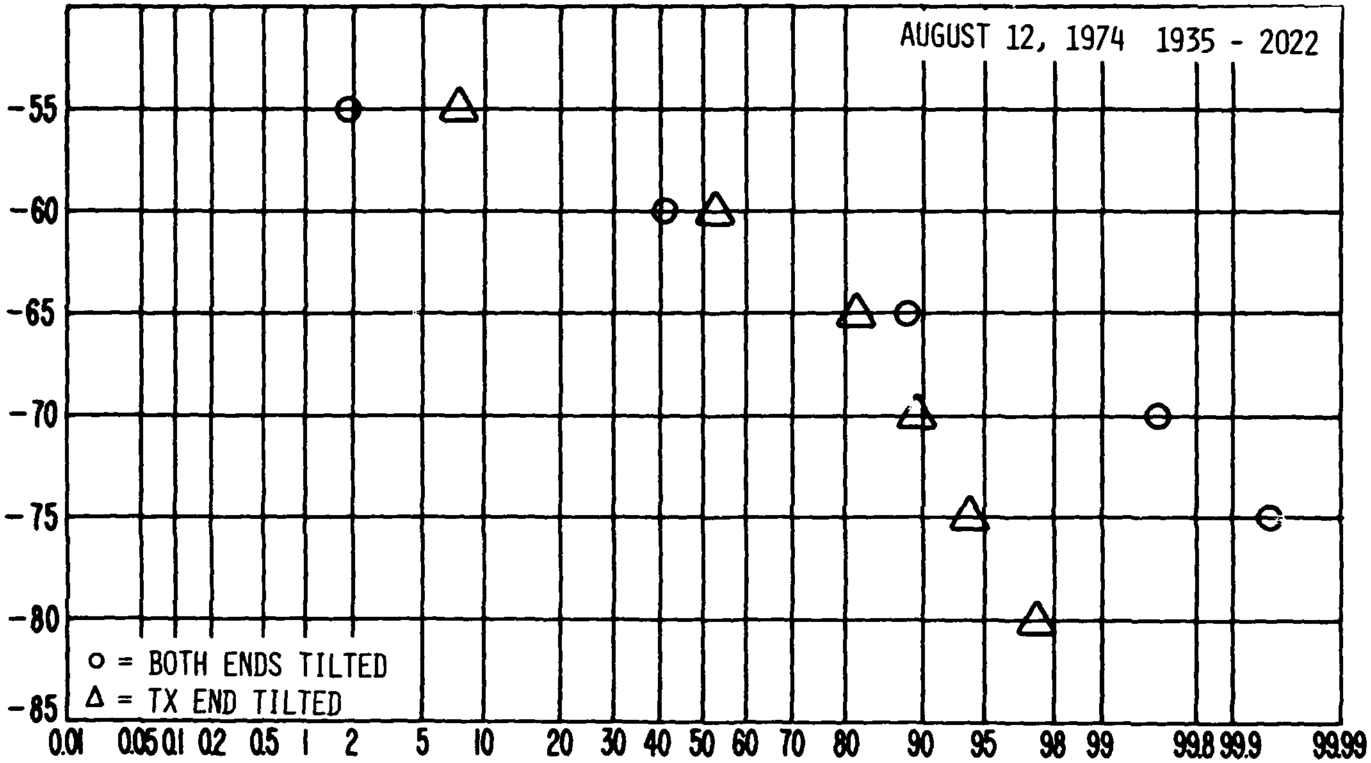

Figure 22. Cumulative distributions of signal level for the time period indicated.

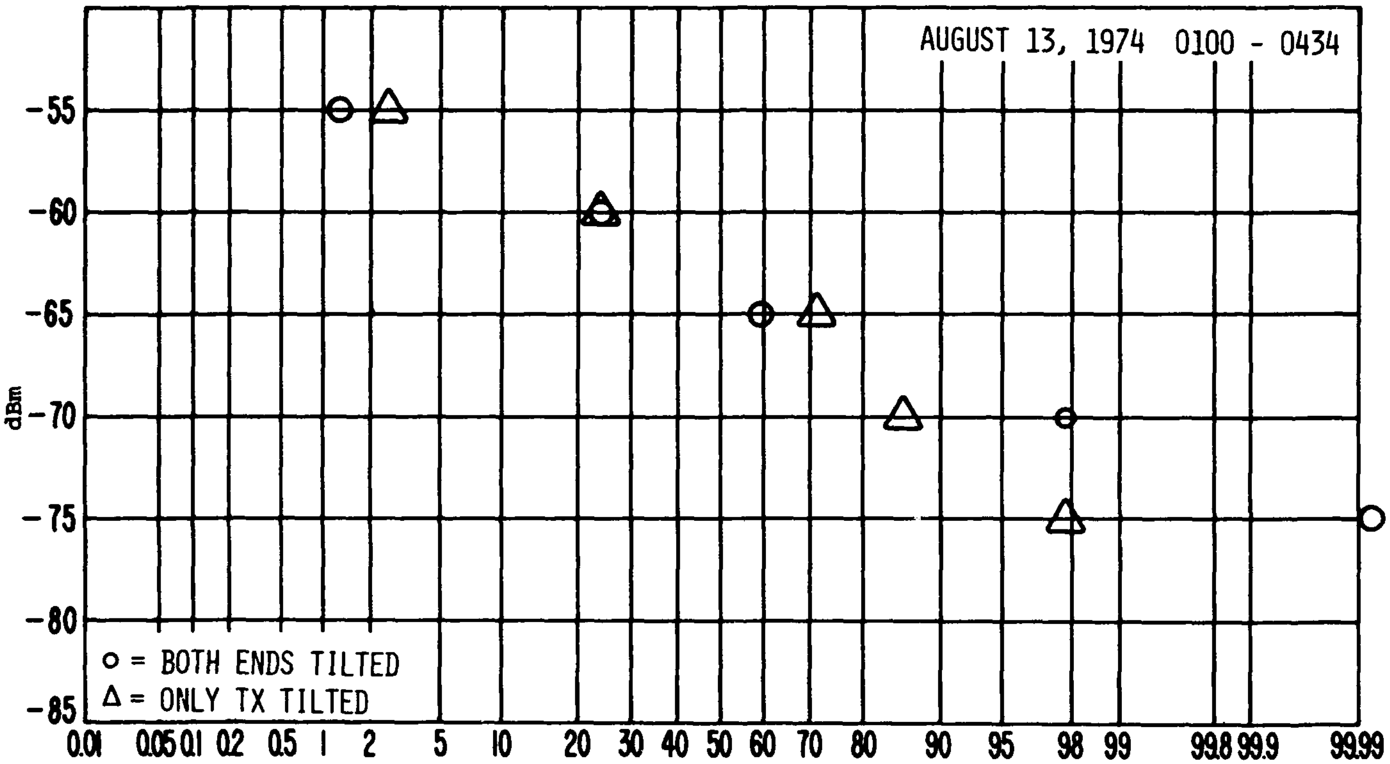

Figure 23. Cumulative distributions of signal level for the time period indicated.

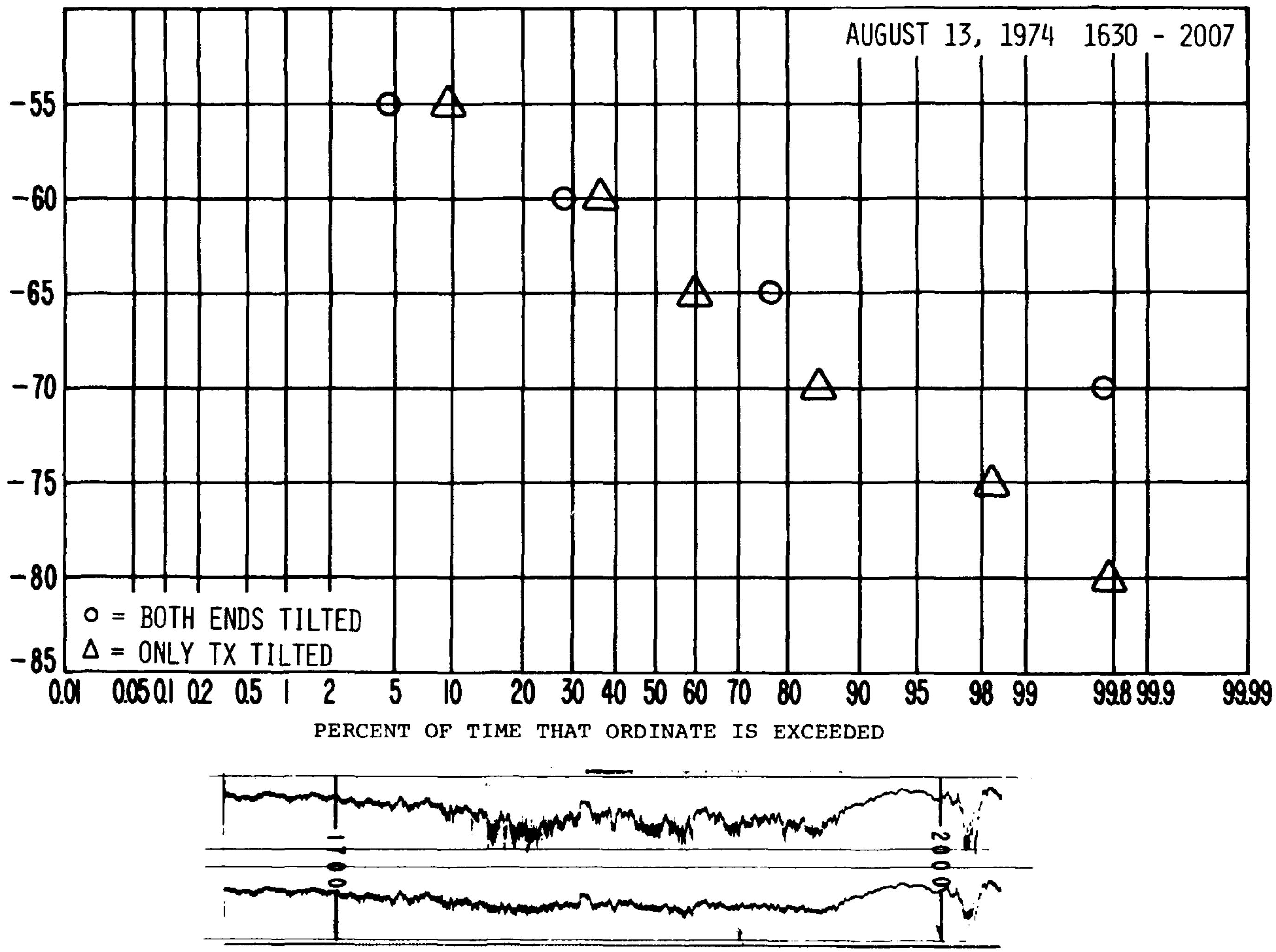

Figure 24. Cumulative distributions of signal level for the time period indicated and corresponding signal level recordings. The upper recording is for the untilted antenna.

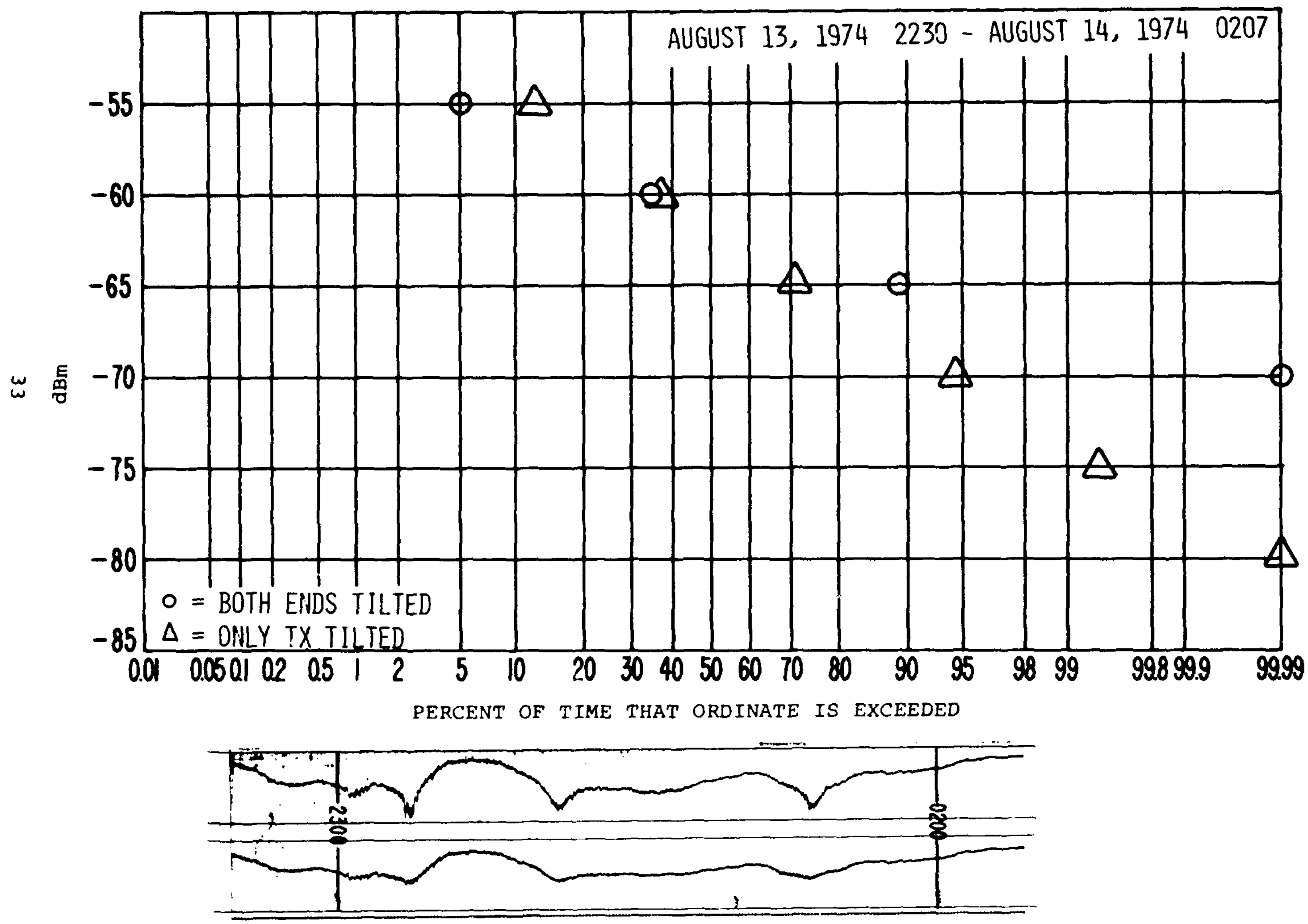

Figure 25. Cumulative distributions of signal level for the time period indicated and corresponding signal level recordings. The upper recording is for the untilted antenna.

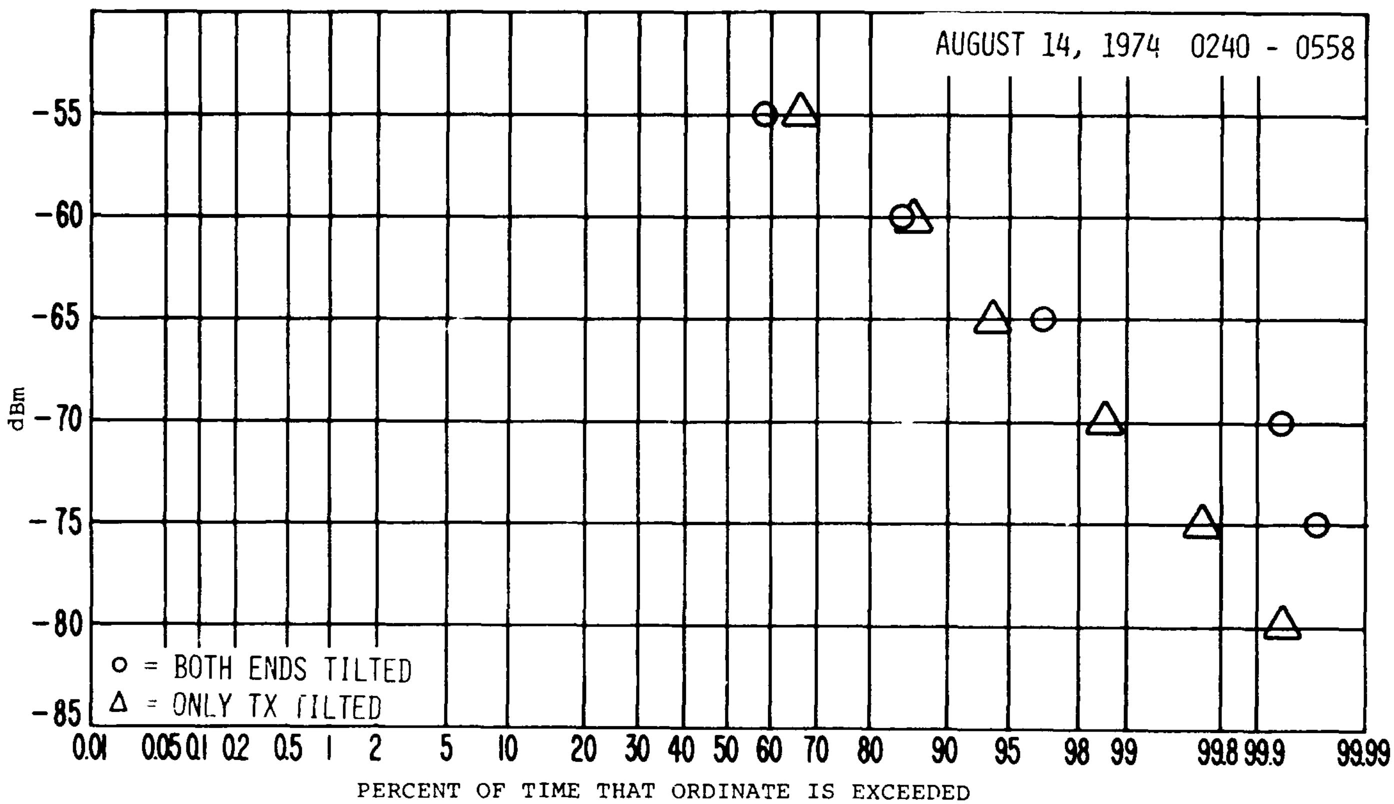

Figure 26. Cumulative distributions of signal level for the time period indicated.

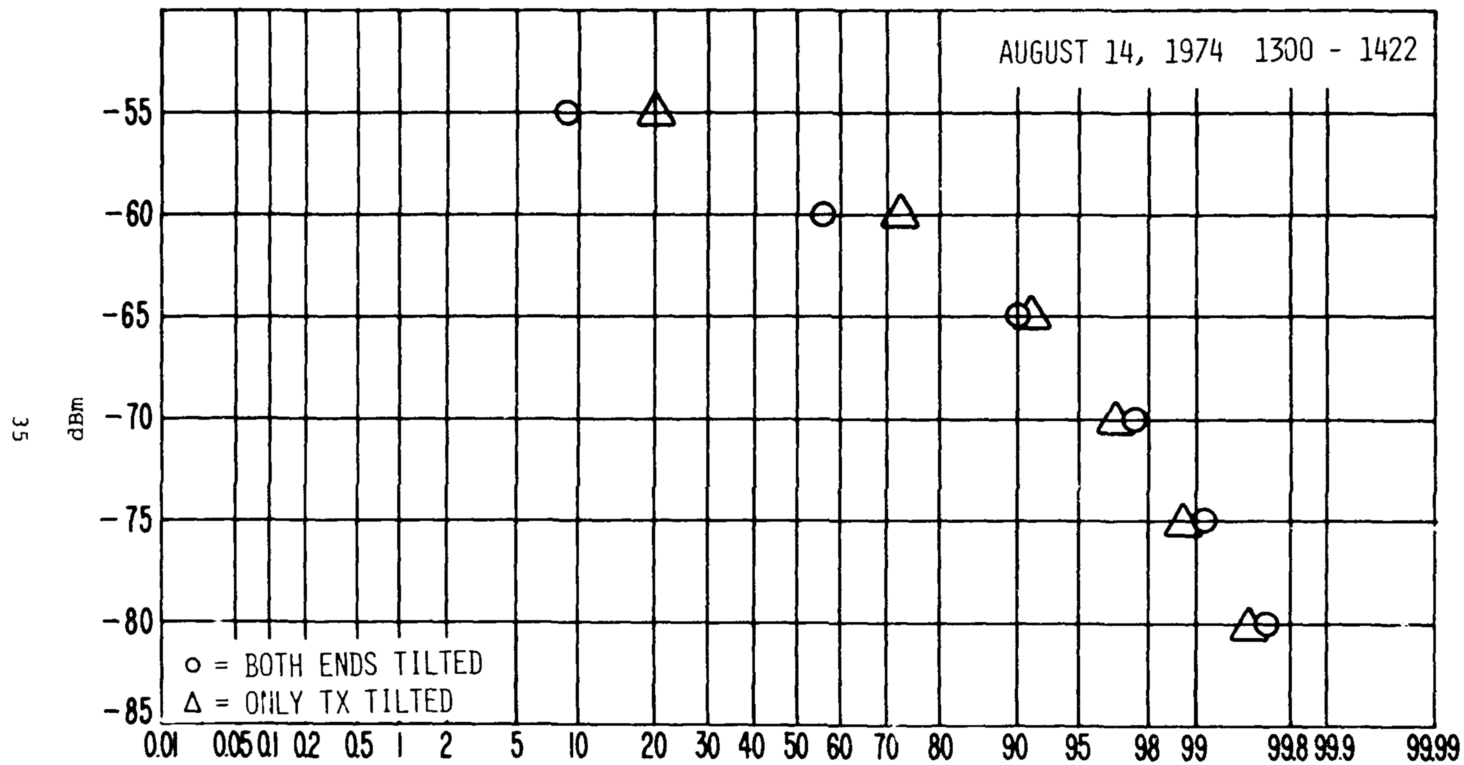

Figure 27. Cumulative distributions of signal level for the time period indicated.

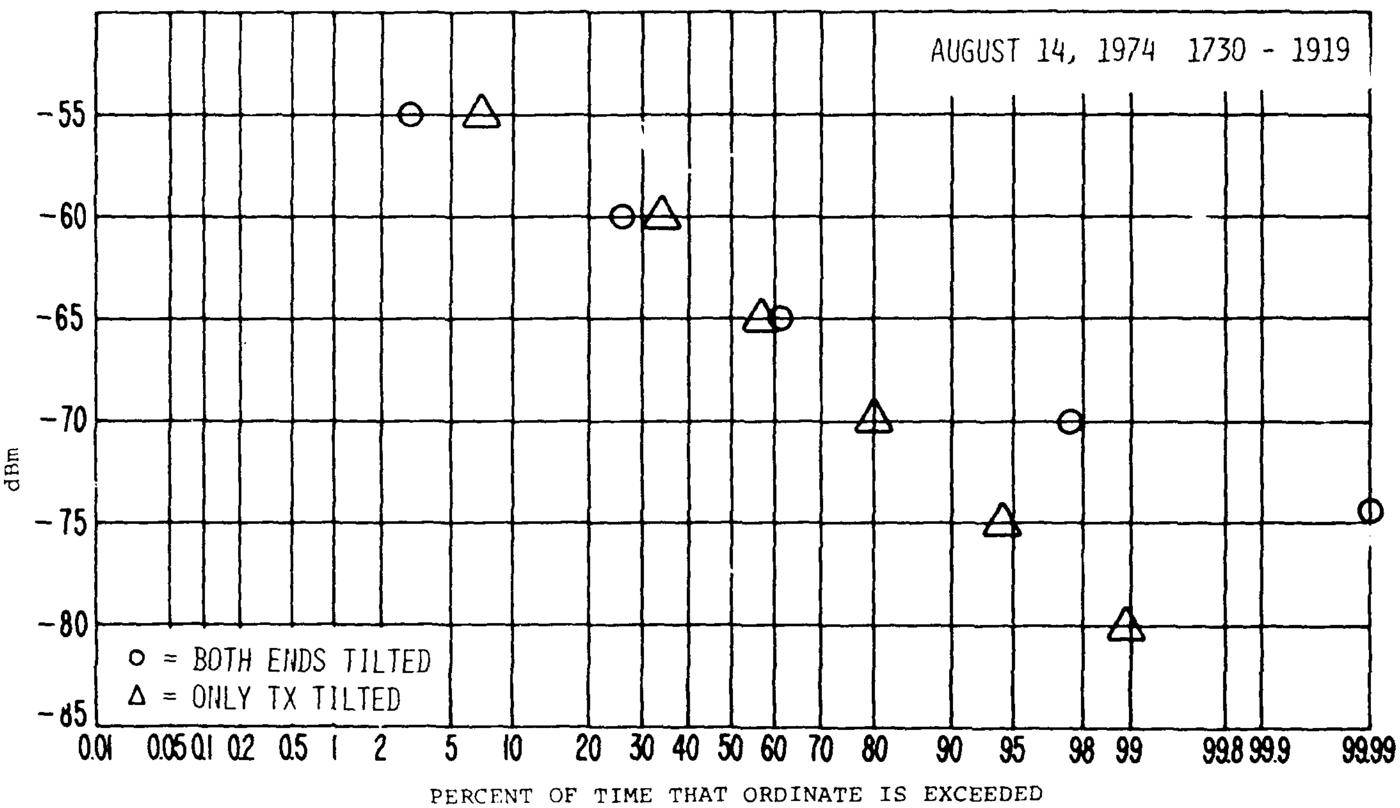

Figure 28. Cumulative distributions of signal level for the time period indicated.

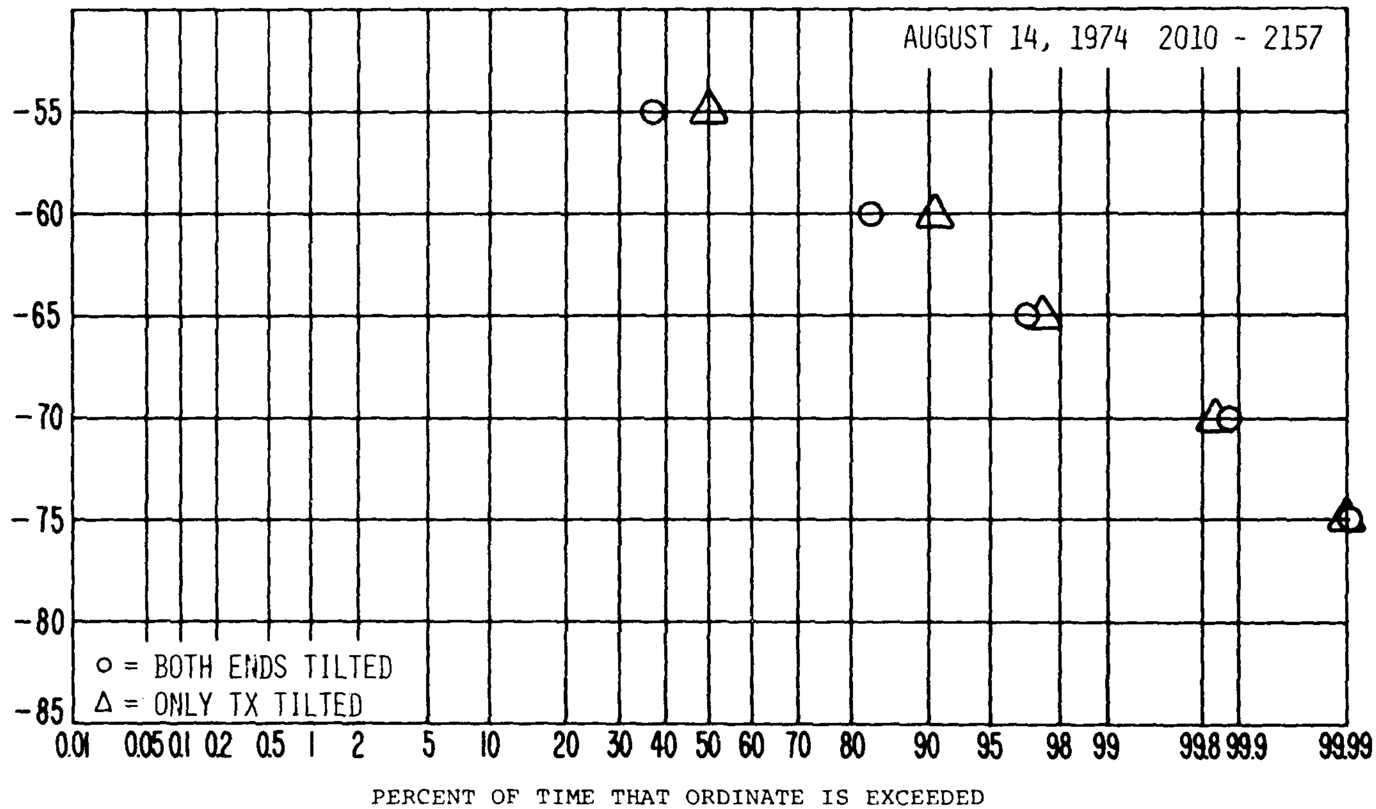

Figure 29. Cumulative distributions of signal level for the time period indicated.

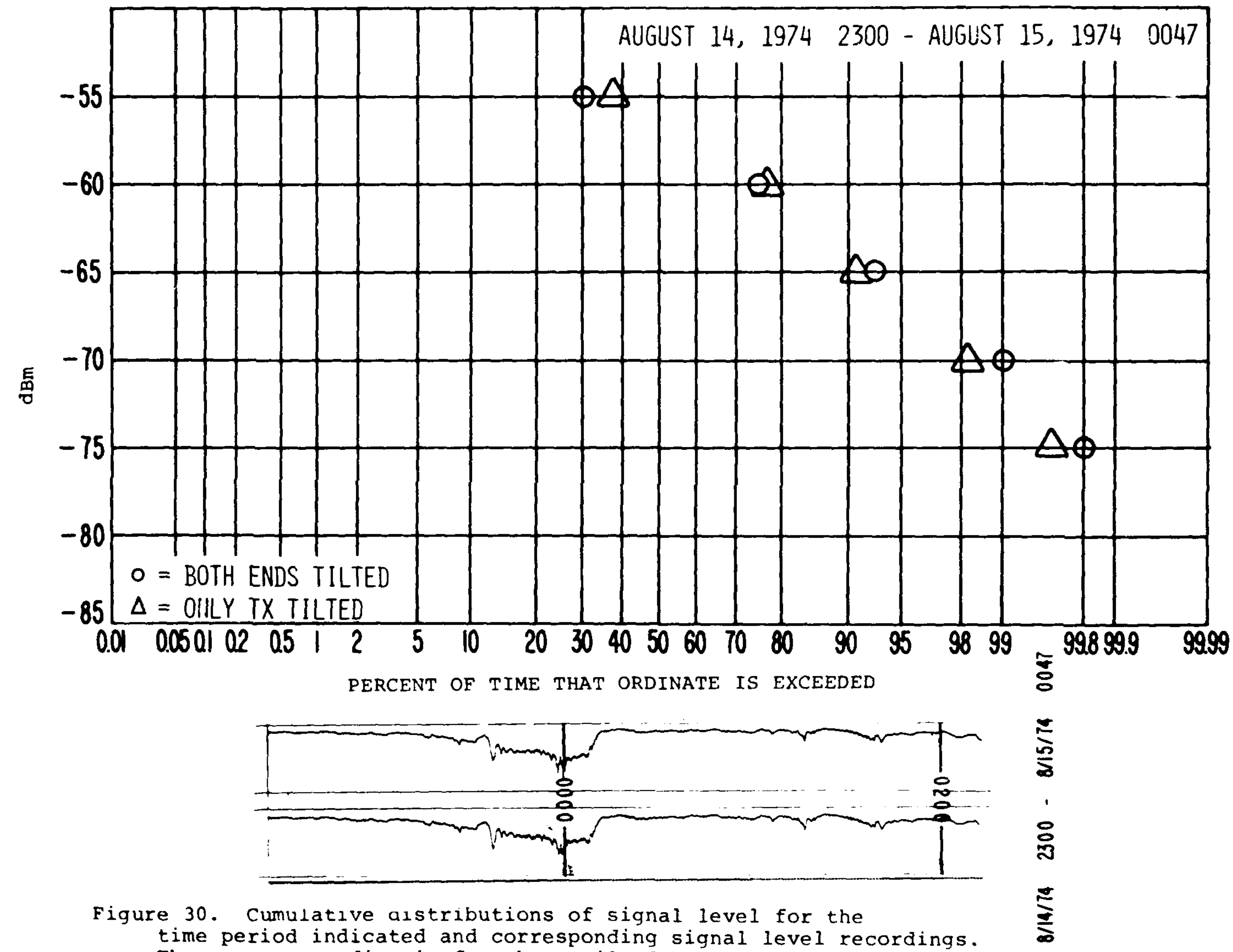

Figure 30. Cumulative distributions of signal level for the time period indicated and corresponding signal level recordings. The upper recording is for the untilted antenna.

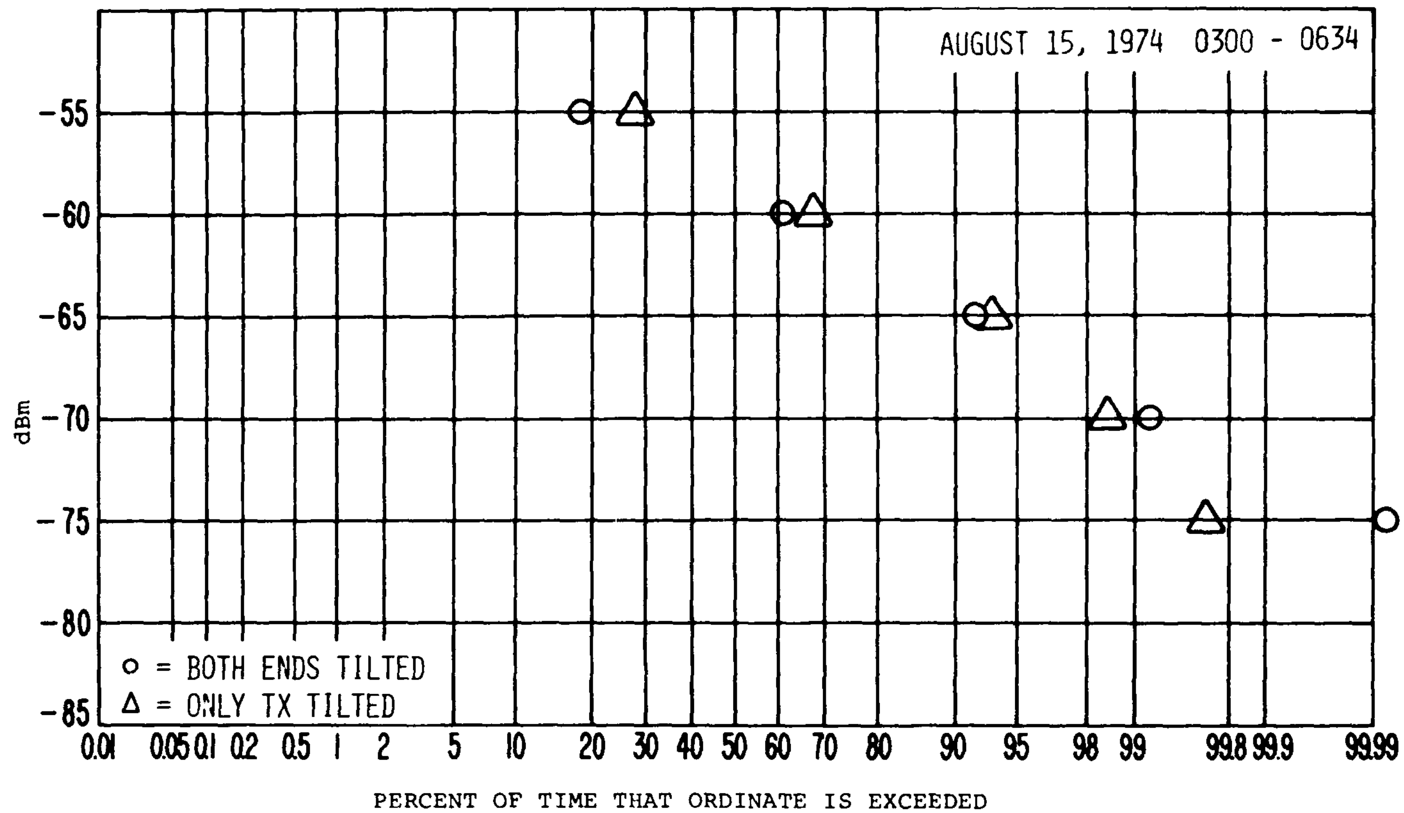

Figure 31. Cumulative distributions of signal level for the time period indicated.

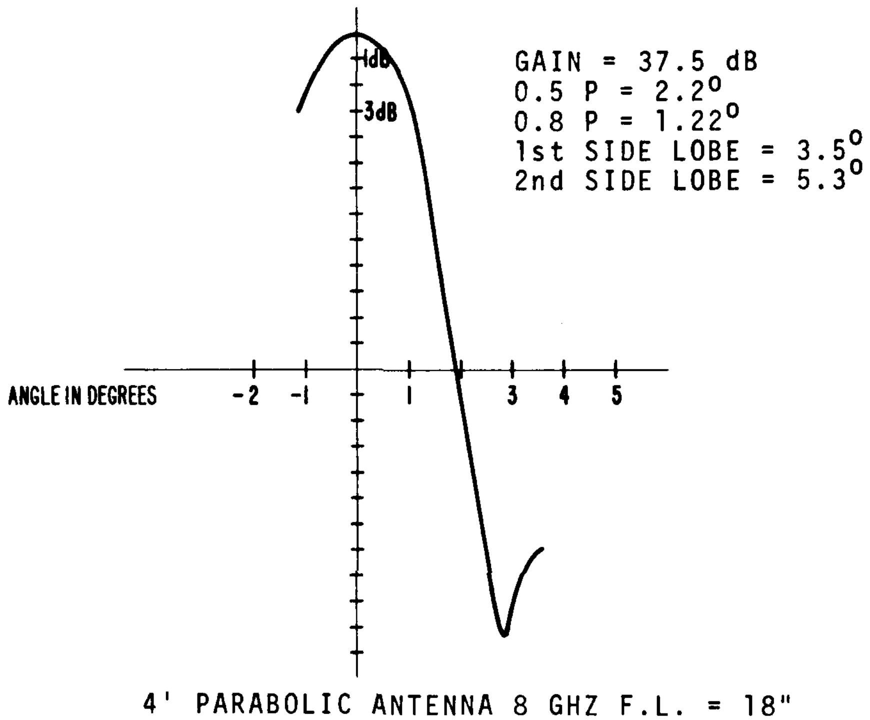

Figure 32. Theoretical antenna pattern for the 1.5 m (4 ft) dish at 8 GHz. Focal length is 45 cm (18 in).