TELEVISION INTERFERENCE TESTS ON BLOCK ISLAND, RI

Technical Report No. 3

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14438-3-T = RL-2270

January 1980

Prepared for

Department of Energy
Wind Systems Branch
Division of Solar Energy

Work performed under Contract EY-76-S-02-2846.A004

NOTICE

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the assistance of our colleagues in the performance of this study, and we are particularly grateful to I. J. LaHaie and R. Ziemelis for their help with the data collection.

Completion of the interference tests on Block Island would not have been possible without the help of A. Birchenough of the NASA Lewis Research Center, and the excellent cooperation of F. Renz and H. Dupont of the Block Island Power Company.

ABSTRACT

Electromagnetic interference to television reception produced by the MOD-OA WT at Block Island has been studied by carrying out a number of on-site measurements at selected test sites and residential homes in the vicinity of the operating windmill. The commercial TV signals available on the island were used as the RF sources. Our measurements indicate that a properly oriented directional antenna having side and back lobes at least 15 dB down could provide interference-free reception at those homes 0.2 km or more from the WT that are in the backward interference region. At distances of less than 0.2 km it would be difficult, if not impossible, to avoid the interference even with the best antenna. In addition, there are also a number of homes which are up to 0.5 km from the WT and in the forward region, and for these the TVI problem would not be corrected by the use of good antennas. In this sense the installation of a CATV system is justified, particularly since the decision had to be made without benefit of the results obtained from the present study. The present measurements justify the provision of CATV service at all sites within 1 km of the WT, but the data do not substantiate the need at distances greater than 1 km. At these greater distances, any TVI could be avoided by the correct use of even a moderately good antenna.

Table of Contents

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1. INTRODUCTION

A large horizontal axis wind turbine (WT) or windmill has recently been installed on Block Island, which is about 20 km off the southern coast of mainland Rhode Island and 25 km east-northeast of Montauk Point, Long Island, New York. A portion of the U.S. Geological Survey map showing the location of the island with respect to the mainland is reproduced in Fig. 1. The present report is concerned with the possible impact of the WT on the reception of TV signals on Block Island.
To ascertain and estimate the TV interference (TVI) caused by the WT, a number of tests were performed over a period of two weeks during the month of October 1979. The tests were conducted by receiving commercially available TV signals at selected sites in the vicinity of the windmill. The following sections describe these on-site tests, and discuss the results obtained and their implications.

2. DESCRIPTION OF THE WT AND THE SITE

The experimental WT, designated as MOD-OA, is located on a knoll in New Meadow Hill Swamp in the eastern central portion of Block Island, as indicated on the map shown in Fig. 2. The island itself is 9.7 km long, and 5.6 km wide at its widest point. The WT site is 9.1 m above sea-level, and 6.1 to 7.6 m above the level of New Meadow Hill Swamp. The population of Block Island is about 500 year round, but increases to 5,000-10,000 [1] during the summer months.

A sketch of a MOD-OA series windmill similar to the one installed on Block Island is shown in Fig. 3 and the relevant specifications of the

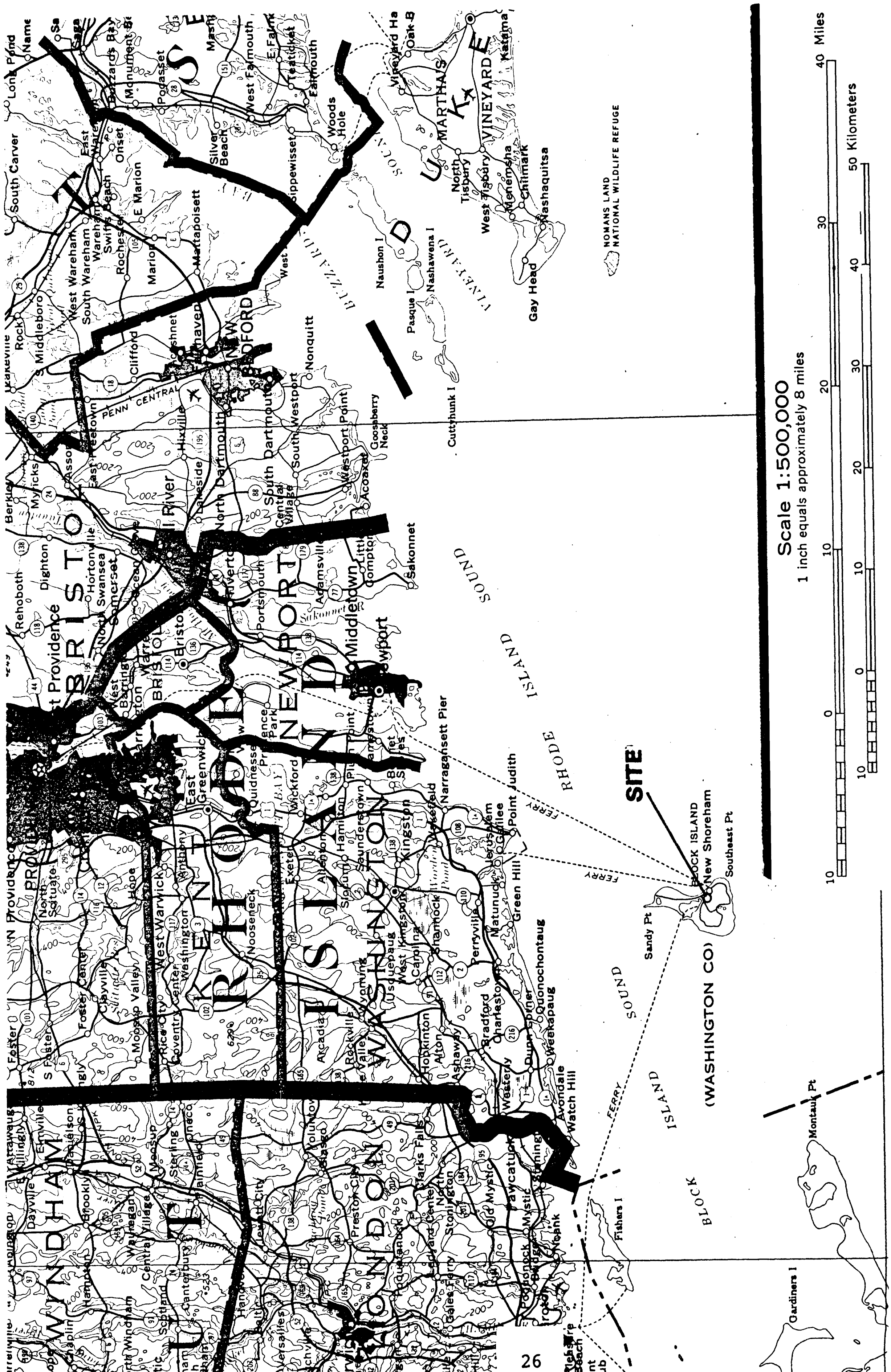

Figure 1. Map showing Block Island with respect to the mainland.

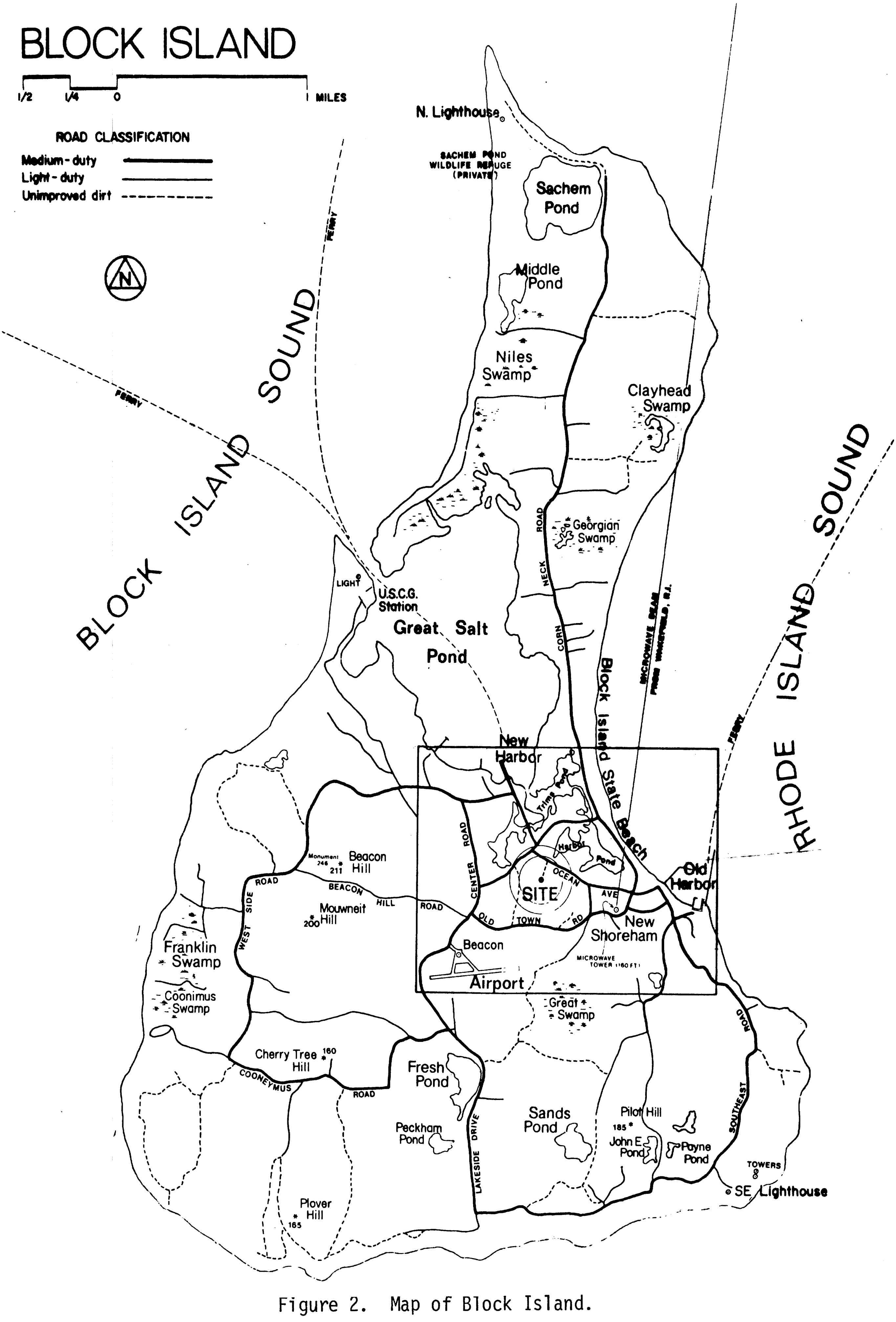

Figure 2. Map of Block Island.

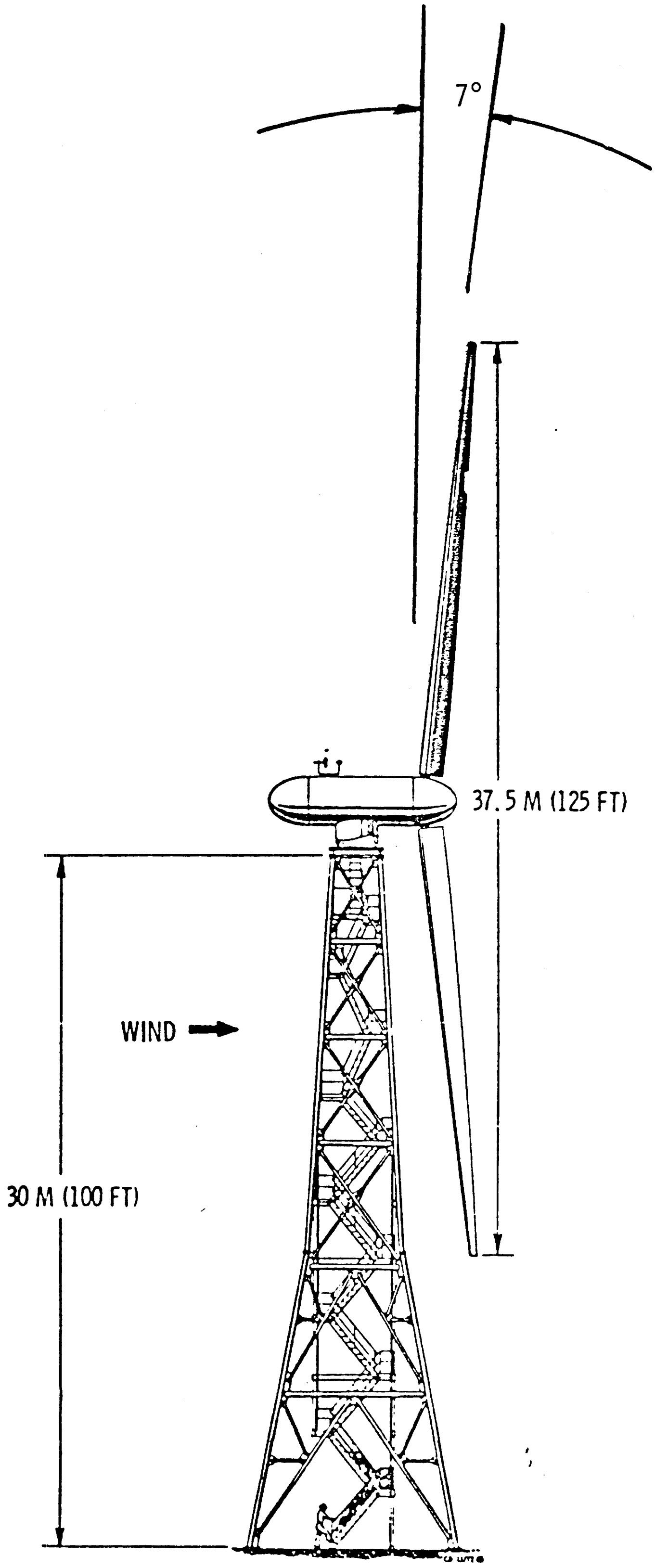

Figure 3. Sketch of a MOD-OA series wind turbine.

turbine are provided in Table 1. It is a large horizontal axis machine with a two-bladed propeller-type rotor and generator assembly mounted on a steel truss tower of height 30.5 m. The two metal blades are aerodynamically tapered with a total diameter of 38.1 m and a fixed coning angle of 7°; the total height of the machine is 50.3 m. The immediate vicinity of the WT site is shown in Fig. 4. There are no residences within 170 m of the site, and this is also the theoretical throw-distance in the event of the windmill blade failure [1]. It is appropriate to mention that the prevailing wind directions on Block Island are east and west.

The MOD-OA WT is integrated with the Block Island Power Company's power plant, and supplies electricity to the existing utility network. The electrical system of the machine consists of a 480 volt, 230 kw synchronous generator, an electrically operated generator breaker, an auxiliary station transformer, and a 480 to 2400 volt step-up transformer with a primary breaker. The generator and the system have adequate protection, instrumentation and controls; the generator is furnished with a brushless exciter, a solid-state voltage regulator, and automatic synchronization equipment [1].

The WT on Block Island generates a maximum of 200 kw AC power in winds of 31 to 55 km per hour. Above 55 km per hour, the blades are feathered and braked to stop the machine. During periods of low wind (13 to 16 km per hour), the blades are also feathered and the machine is shut down. In operation the windmill blades normally rotate at a speed ranging from 20 to 40 rpm depending on the prevailing wind speed.

Table 1

Specifications of the MOD-OA Wind Turbine on Block Island

Power	200 kilowatts, AC
Total Height	165 ft. (50.29 m)
Total Weight	91,000 lbs. (41.27 metric tons)
Tower:	
Type	steel truss
Height	100 feet (30.48 m)
Base	30 x 30 ft. (9.14 x 9.14 m)
Peak	7 x 7 ft. (2.13 x 2.13 m)
Weight (foundation excluded)	47,000 lbs. (21.32 metric tons)
Foundation	200 cu. yds. (152.91 cu. m) Concrete slab
Rotor:	
Number of blades	2
Type	aluminum
Rotor diameter	125 feet (38.10 m)
Swept area	12,265 sq. ft. (1139.46 sq. m)
Rotor weight	7,200 lbs. (3.26 metric tons)
Power System:	
Generator type	Synchronous AC
Rating	250 KVA
Power factor	0.8
Voltage	480 volt
Electromagnetic Scattering:	
Projected physical area of each blade	18.0 sq. m.
Equivalent scattering area of each blade	12.0 sq. m.

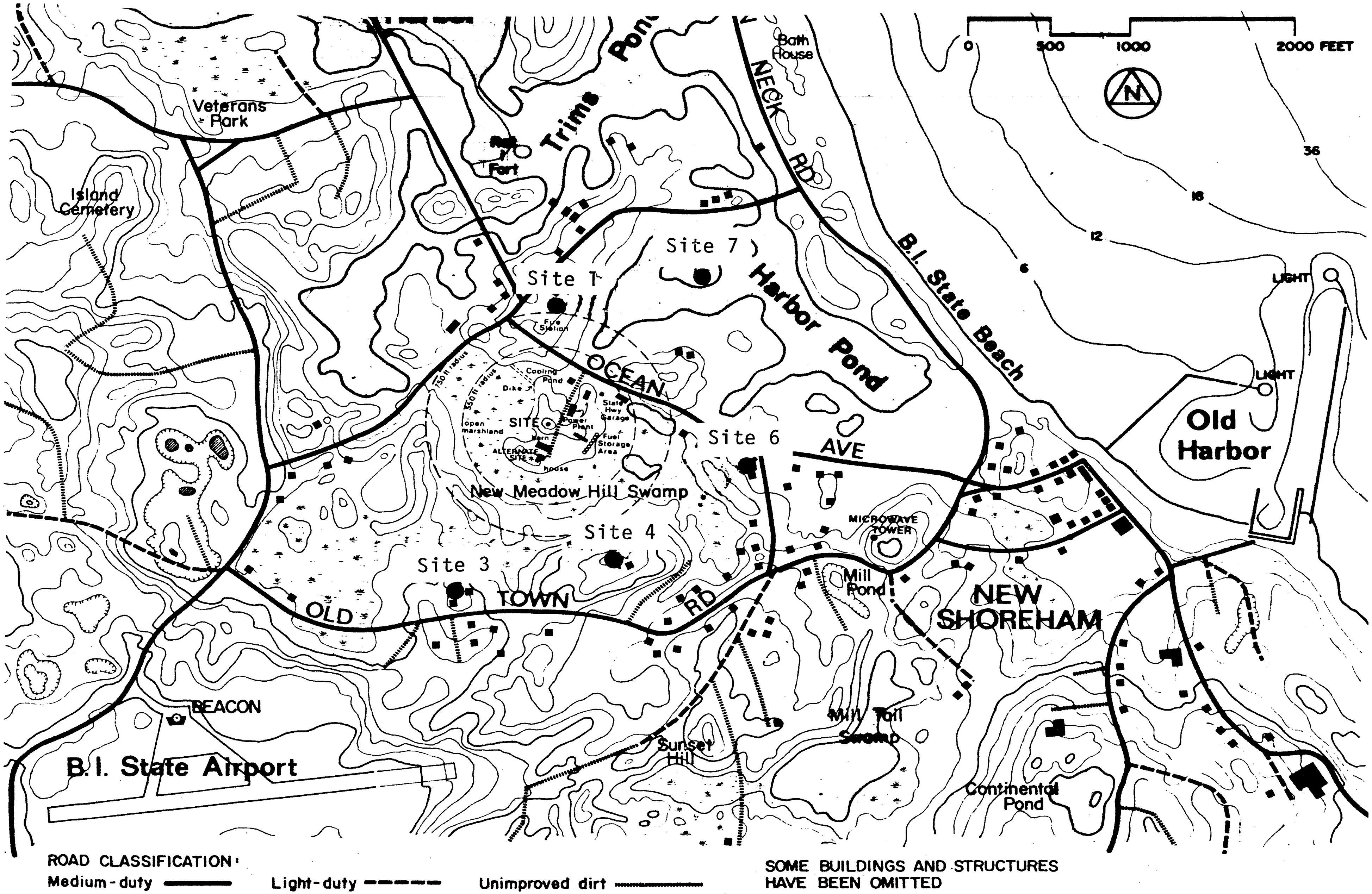

Figure 4. WT site vicinity map.

3. TV INTERFERENCE PHENOMENA

For a better appreciation of the various tests and results to be discussed later, a general discussion of the TV interference phenomena near a windmill is given in the present section. In our previous investigations, the interference to TV reception caused by large horizontal axis windmills has been identified and quantified by comprehensive theoretical and experimental studies [2,3]. It has been found that the rotating blades of a windmill act as a time-varying multipath source to produce pulse amplitude modulation of the total signal received in the vicinity of the machine. For a receiving antenna so located and oriented as to pick up the specular or forward scattering off the rotating blades, this extraneous modulation, if sufficiently strong, can distort the video portion of a TV signal reproduction. At a given distance from the WT, the interference increases with increasing frequency and is therefore worst on the upper UHF TV Channels; it also decreases with increasing distance from the windmill, but in the worst case (and with a non-directional receiving antenna) can still produce objectionable video distortion at distances up to a few kilometers [4]. For ambient or primary signals above the noise level of the TV receiver, there is in general no significant dependence on the receiver used, and no audio distortion has been observed.

Generally, the nature of the interference depends on the location of the receiver with respect to the WT, the state and orientation of the blades, and the direction of arrival of the primary signal. When the windmill blades are stationary, the scattered signal may appear on the TV screen as a ghost whose position, or separation from the main picture, depends on the difference between the time delays suffered by the primary and scattered signals. A rotation of the blades then causes the ghost to fluctuate, and if the ghost is sufficiently strong, the resulting interference can be quite objectionable. In such cases, the received picture displays a horizontal jitter in synchronism with the blade rotation. As the interference increases, the entire (fuzzy) picture shows a pulsed brightening, and still stronger interference can disrupt the TV receiver's vertical sync, producing picture break-up. This type of interference occurs when the interfering signal reaches the receiver primarily as a result of specular scattering off the broad faces of the blades, and is called backward region interference. In the forward scattering region when the WT is almost in line between the TV transmitter and the receiver, there may be little or no difference in the times of arrival of the primary and scattered signals at the receiver, and the video interference then appears as an intensity (or brightness) fluctuation of the picture in synchronism with the blade rotation. This type of interference is termed forward region interference. In both cases, the amount of interference depends on the strength of the scattered signal relative to the primary one, and this decreases with increasing distance from the WT. Since each blade of the MOD-OA machine contributes individually, the resulting interference occurs at twice the rotation frequency of the blades.

The backward region interference shows no significant dependence on the ambient signal strength and appears to be independent of the receiver if the signal is well above the noise level of the receiver. Interference is observed only when a blade is positioned to direct the specularly reflected signal to the receiver. The azimuth and pitch angle of the blades are therefore key factors affecting the level of interference, and for any given transmitter and receiver locations, interference can occur only if the wind is such as to position the windmill appropriately. In the forward region, however, the interference does depend on the ambient signal strength, and a receiver located in a low signal level area is more vulnerable to this type of interference.

From laboratory simulation experiments [2,3] it has been established that the video distortion is still acceptable as long as the ratio of the scattered and primary field amplitudes at the receiver, i.e., the modulation index (m) of the total received signal, is such that $m < m_0 = 0.15$. For $m \geq m_0$ the resulting distortion is unacceptable. On the assumption that the WT blades are oriented to direct the maximum scattered signal to the receiver, the region where $m \geq m_0$ is defined as the interference zone of the windmill [3,4]. That portion of the zone produced by specular reflection off the blades is approximately a cardioid centered at the WT with its maximum pointing towards the TV transmitter. There is also a narrow lobe directed away from the transmitter resulting from forward scattering off the blades.

A method has been developed [4] to calculate the interference zone of a given WT for any TV Channel. A typical TV interference zone of a MOD-1 WT (having equivalent scattering area $A_e = 40\ m^2$) for TV Channel 52, with omnidirectional receiving antenna, is shown in Fig. 5 which indicates that the backward interference region is larger in area than the forward. Due to the nature of the approximations used to obtain Fig. 5, the maximum interference distance in the forward region appears larger than in the backward region; however, recent investigations [5] indicate that the former distance should be reduced by at

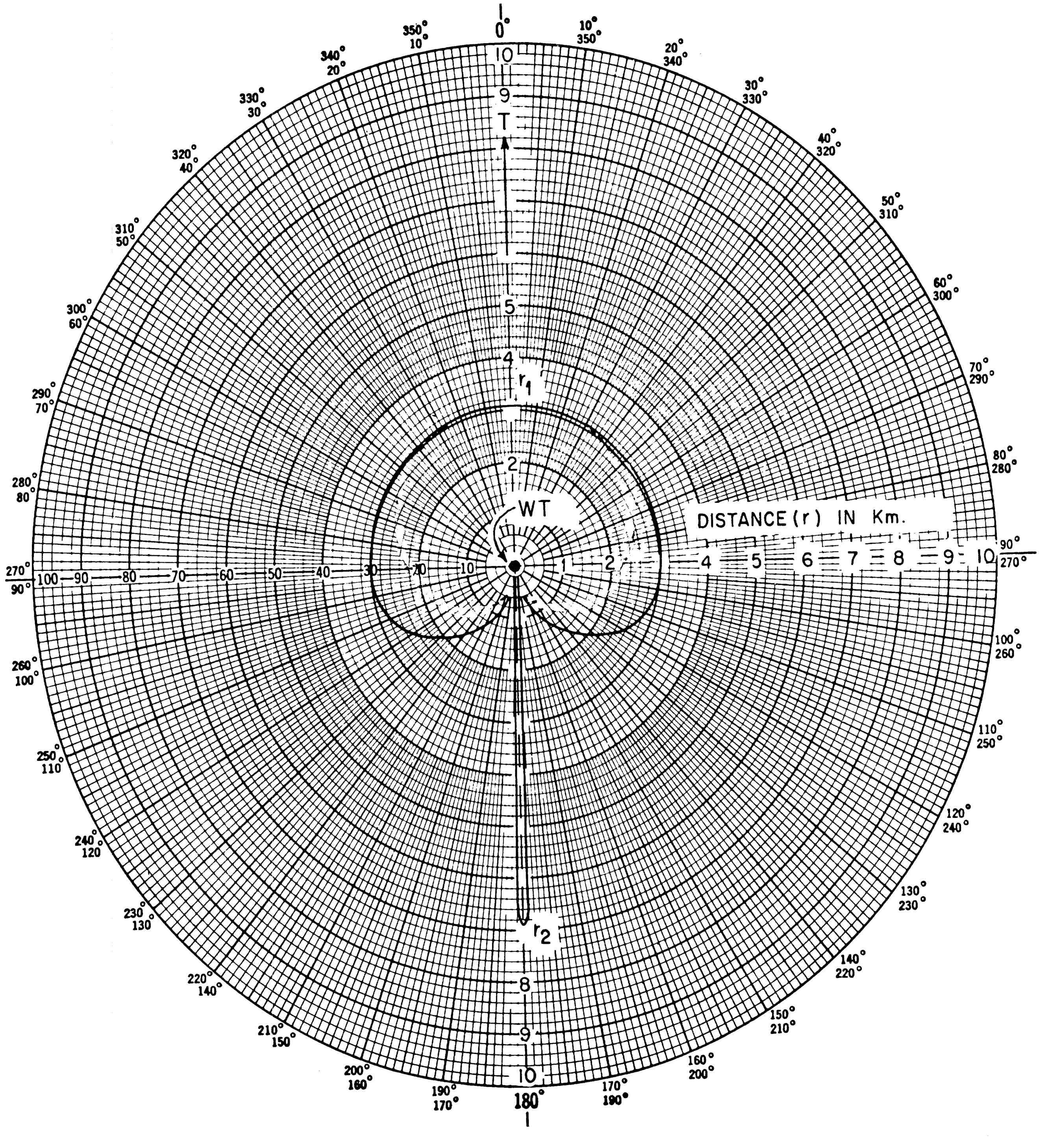

Figure 5. Calculated TV interference zone of a MOD-1 WT for TV Channel 52. Transmitter-to-WT distance = 120 km; receiving antenna omni-directional.

least a factor of two. From these results it can be seen that the backward interference region of a WT is of primary concern. It should be mentioned that the shapes of the interference zones are independent of the TV Channel numbers but their size increases with increasing TV Channel number. Finally, the fact that a receiver is located within the interference zone does not necessarily mean that it will experience TVI during the entire viewing time. A method has been developed [6] to estimate the percent viewing time during which unacceptable video distortion may occur by taking into account the relevant statistical parameters, e.g., wind speed, direction, etc. For example, the probability of observing no significant interference on Channel 53 on Block Island at a distance of only 0.5 km northwest of the WT is about 0.9 [6].

4. EXPERIMENTAL ARRANGEMENT AND DESCRIPTION OF MEASUREMENTS

The experimental set-up for performing the various tests is shown in Fig. 6 where only those components which are pertinent to the data collection have been included. With any given TV transmitter, a portion of the signal is scattered off the WT blades and this, together with the desired signal, was picked up by the receiving antenna and fed to a spectrum analyzer and a TV receiver. The receiving antenna, to be described later, was a commercially available directional antenna located at the test site at a convenient height above ground. The spectrum analyzer was tuned to the audio carrier frequency of the desired signal, and its vertical output was recorded on paper tape for later evaluation. This provided a recording of the total signal level received as a function of time, including any modulation produced by scattering from the windmill blades. The TV receiver

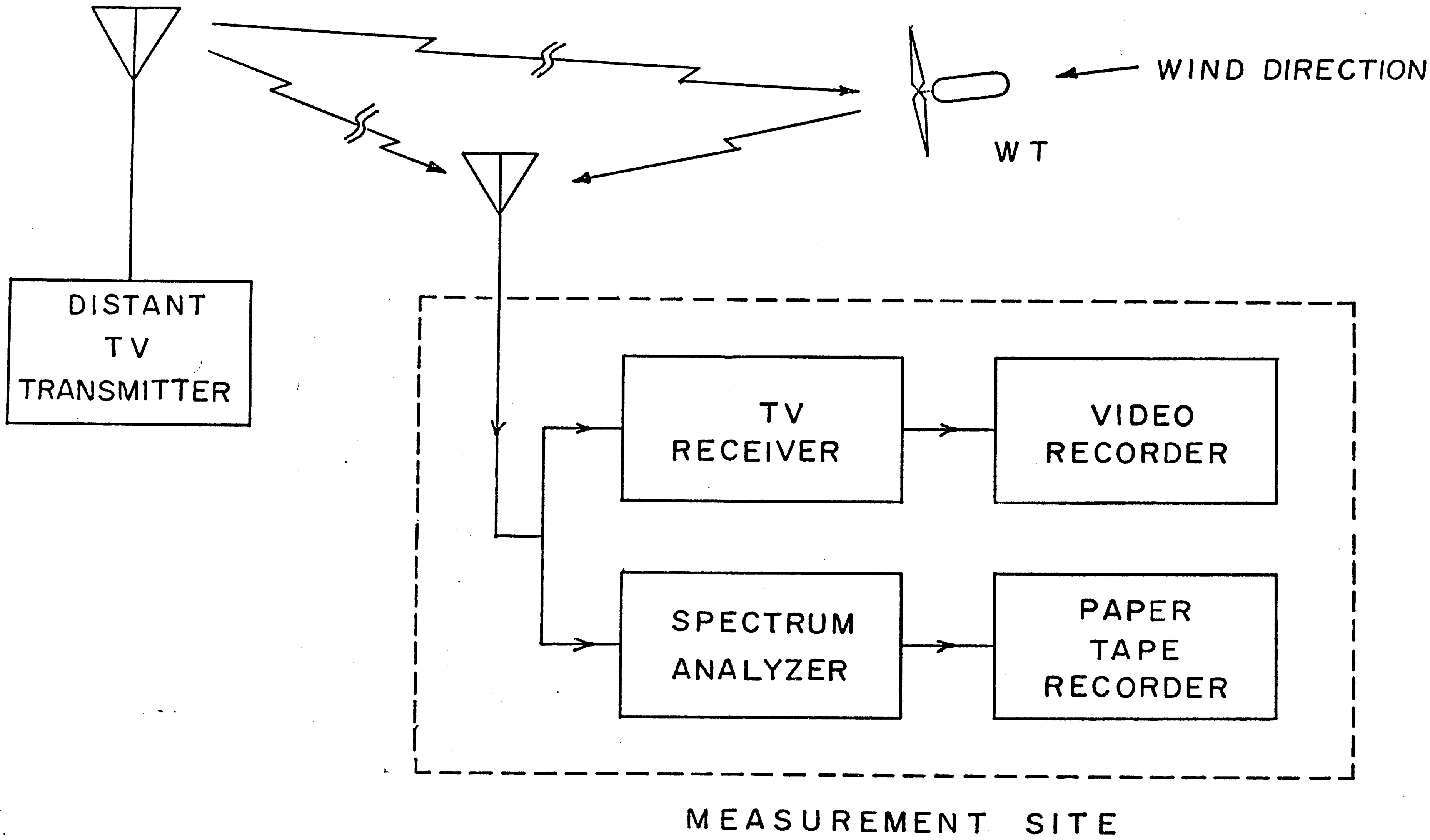

Figure 6. Schematic block diagram of a typical on-site measurement setup.

used was a 1976 Zenith model 17GC45 which has been rated superior for its rejection of interference [7]. The received TV program was observed to see if there was any video distortion. There was also provision to record the observed interference on the TV screen if so desired; this was accomplished with a TV camera in conjunction with a video recorder, not shown in Fig. 6. The test instruments were powered from the commercially available 60 Hz power supply.

At a test site, the above set-up was used to conduct some or all of the following types of measurement:

(i) Field Strength: The strength of the available signal was measured by pointing the main beam of the receiving antenna towards the TV transmitter so that a maximum output was obtained from the spectrum analyzer which then yielded the field strength in dBm (dB above a milliwatt).

(ii) Antenna Response in Test Environment: For a given TV signal, the output of the spectrum analyzer was obtained as a function of the antenna beam pointing direction with the WT blades rotating and without. The results obtained from these measurements contained substantial information, and were used to judge the following: (a) the horizontal plane pattern of the antenna in the actual test environment, (b) the effect of the windmill and/or its blade rotation on the received signal and (c) an estimate of the amount of signal modulation caused by the blade rotation.

(iii) Static Scattering: With the blades locked in a desired position and the WT yawing in azimuth through 360°, the TV signal scattered by the windmill was measured with the antenna pointing at the WT. These measurements gave the maximum blade-scattered signal that could be received at a given site and for a given TV Channel.

(iv) TV Interference (TVI): The TVI measurements were conducted with the antenna beam positioned to receive the desired TV signal. With the windmill blades rotating, the spectrum analyzer output was recorded as a function of time, and, at the same time, the received picture on the TV screen was observed for video distortion.

As mentioned earlier, the signal scattered by a rotating blade combines with the direct signal to produce an amplitude modulated signal at the inputs to the spectrum analyzer and the TV receiver. Thus, as a function of time, the output of the spectrum analyzer varies above and below the ambient signal level, and it is conventional to quote the total variation (Δ) of the received signal amplitude in dB from which the amplitude modulation index (m) can be obtained. For future reference, the relationship between the percent modulation (m x 100) and the total dB variation of the received signal level is plotted in Fig. 7. Usually, a total signal variation greater than or equal to 2.6 dB ($m \geq 0.15$) causes unacceptable video distortion for backward region interference [2,3]; however, it should be mentioned that barely visible but acceptable distortion may occur even for $\Delta < \Delta_0 = 2.6$ dB. For forward region interference, the corresponding value of Δ_0 is larger, and can be as large as 6.5 dB ($m \simeq 0.35$) [6] for ambient signals of the order of -60 dBm but smaller for weaker ambient signals.

During the TVI measurements, the observed picture distortion was video recorded whenever this was thought to be desirable.

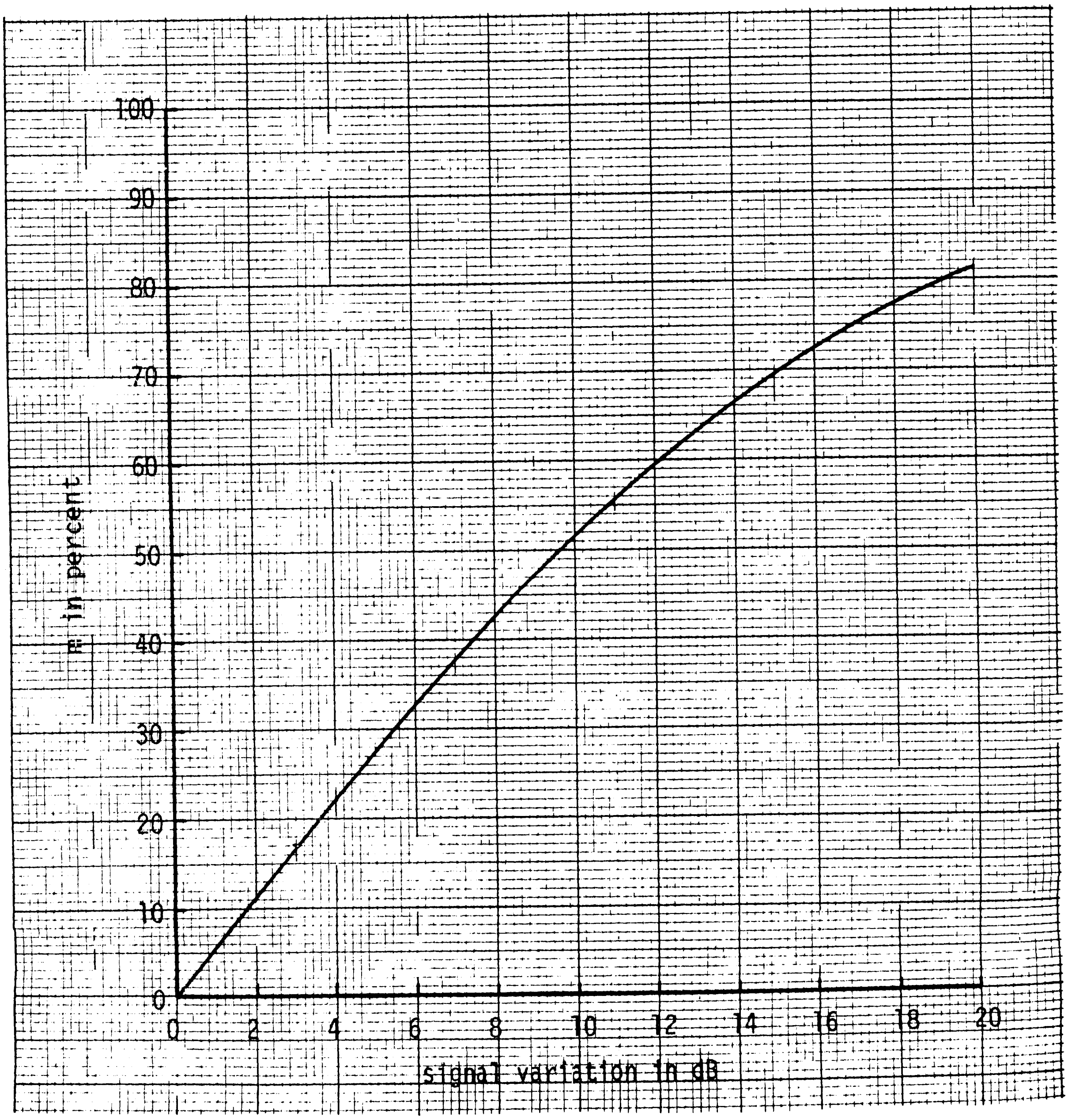

Figure 7. Percent modulation as a function of the total dB variation of the observed signal.

In a few instances, TVI measurements were also carried out by pointing the antenna beam at the rotating WT. This was done to simulate the worst possible situation of a directional antenna wrongly oriented, and the interference in such cases was generally quite high.

(v) Threshold TVI: In addition to the experiments described in (iv), some measurements of the threshold (maximum acceptable) level of interference on a given TV Channel were performed as follows. With the blades rotating, data were collected in a manner similar to that described in (iv) but with the antenna oriented so that the maximum acceptable video distortion was observed on the TV screen. These results were obtained primarily for comparison with those of a previous study [2].

5. THE RECEIVING ANTENNA CHARACTERISTICS

For our measurements we used a commercially available log-periodic antenna manufactured by Channel Master and designed to cover the entire band of TV frequencies. The input impedance of the antenna is about 150 Ω at the midband frequencies, and the antenna has nominal gain (with respect to isotropic) of 7 dB and 4 dB in the VHF and UHF bands, respectively.

Using our laboratory's 46 m outside antenna pattern range, the horizontal plane radiation pattern of the above antenna was measured at all of the television frequencies. It was found that the pattern of the antenna varies significantly over the TV Channel frequencies. However, the antenna gain remains fairly constant over each of the lower VHF (Channels 2-6), upper VHF (Channels 8-13) and UHF (Channels 14-83) bands of frequencies. Measured patterns at TV Channel frequencies selected in the three bands are shown in Figs. 8(a)-(d). Note that typically the antenna has a side-lobe level (including the back lobe) of about -10 dB.

It is worth mentioning that the performance of an antenna is usually affected by its environment, and for this reason we also carried out pattern measurements under the actual test conditions as described in Section 4.

6. TEST SITES

Measurements were made at a number of test sites in the vicinity of the WT as indicated in Fig. 4. The actual location of each test site with respect to the windmill is shown in Fig. 9. At test site 1 it is planned to install the antenna assembly ('head end') of a cable TV (CATV) system for receiving the TV signals available on Block Island and subsequently cabling them to the local people. Since a knowledge of the WT-generated interference at this site is particularly important, a major portion of our investigation was conducted here.

Site 3 is located behind the funeral home. Sites 4 and 6 are located at two residential homes, those of the Lewis and Rose families.

Some initial tests were also carried out at another home, marked as site 7 in Fig. 4, but since no detailed TVI tests were made here, it is not shown in Fig. 9.

7. AVAILABLE TV SIGNALS

A number of commercial TV signals are available for reception on Block Island. The directions of arrival of these signals with respect to the WT are shown in Fig. 10 where we have also indicated the approximate

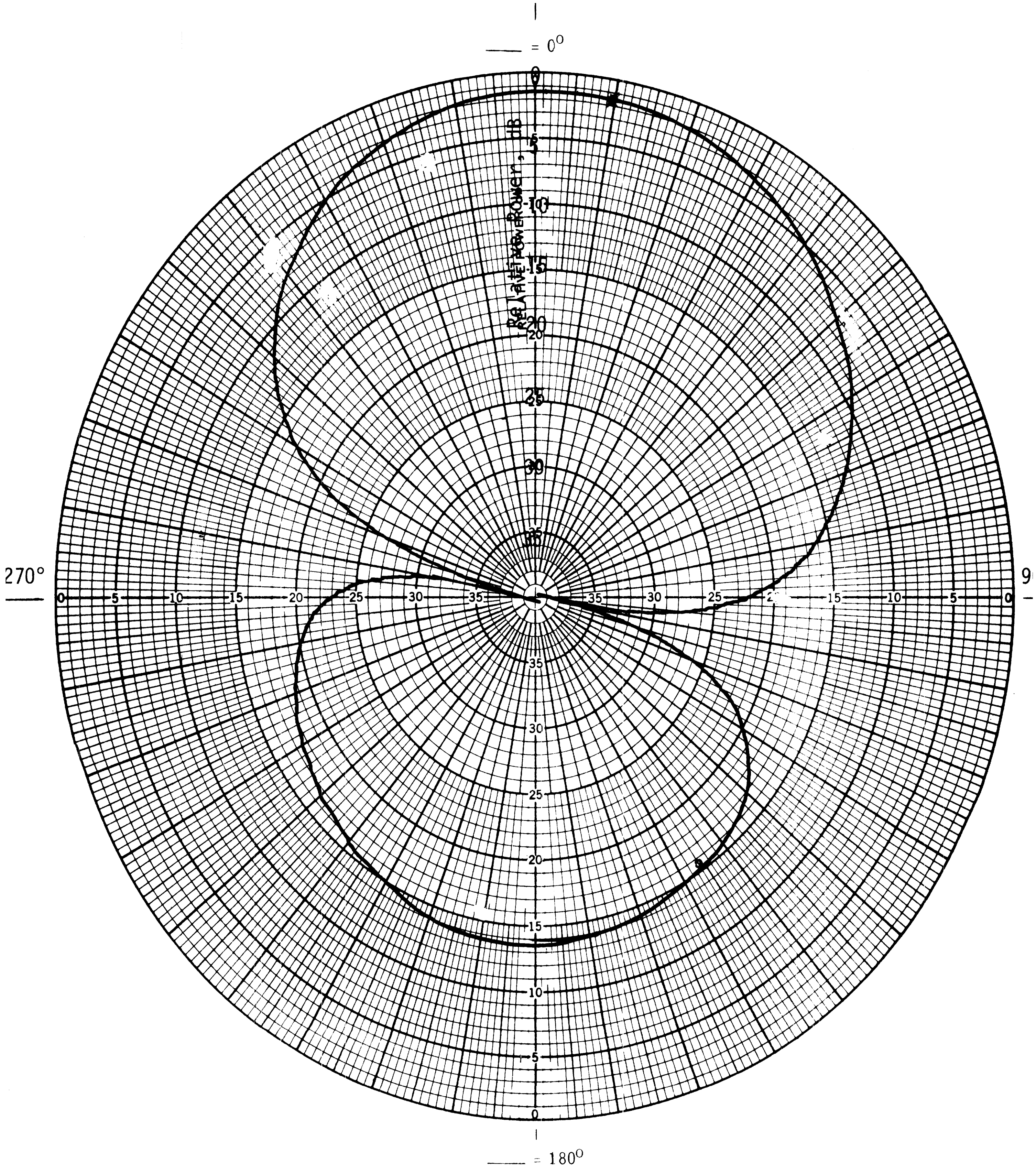

Figure 8. Measured horizontal plane pattern of the commercially available TV antenna used as the test antenna.
(a) f = 82.8 MHz ∿ Channel 6

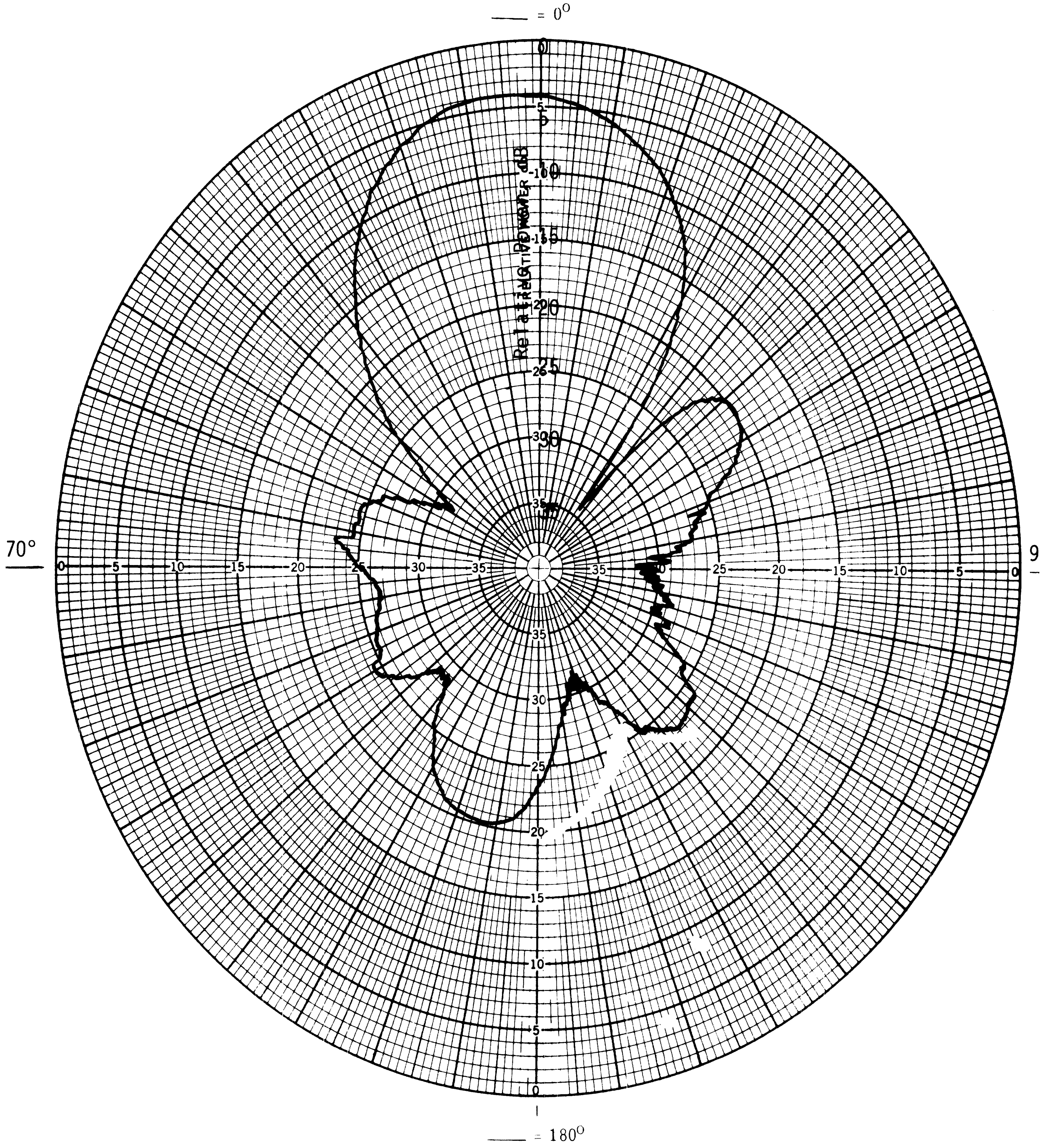

Figure 8. Measured horizontal plane pattern of the commercially available TV antenna used as the test antenna.
(b) f = 193.6 MHz ∿ Channel 10

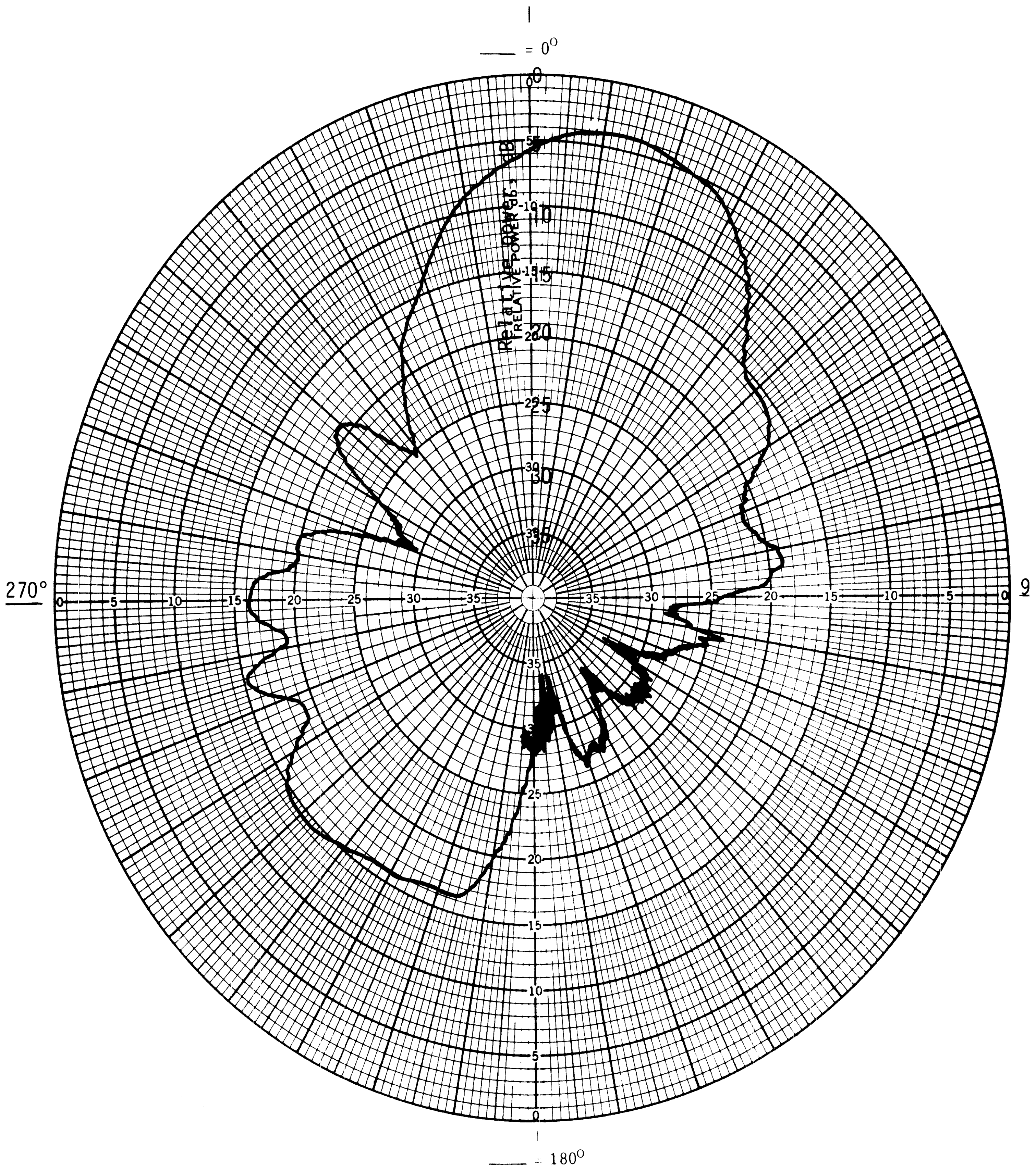

Figure 8. Measured horizontal plane pattern of the commercially available TV antenna used as the test antenna. (c) f = 604 MHz ∿ Channel 36

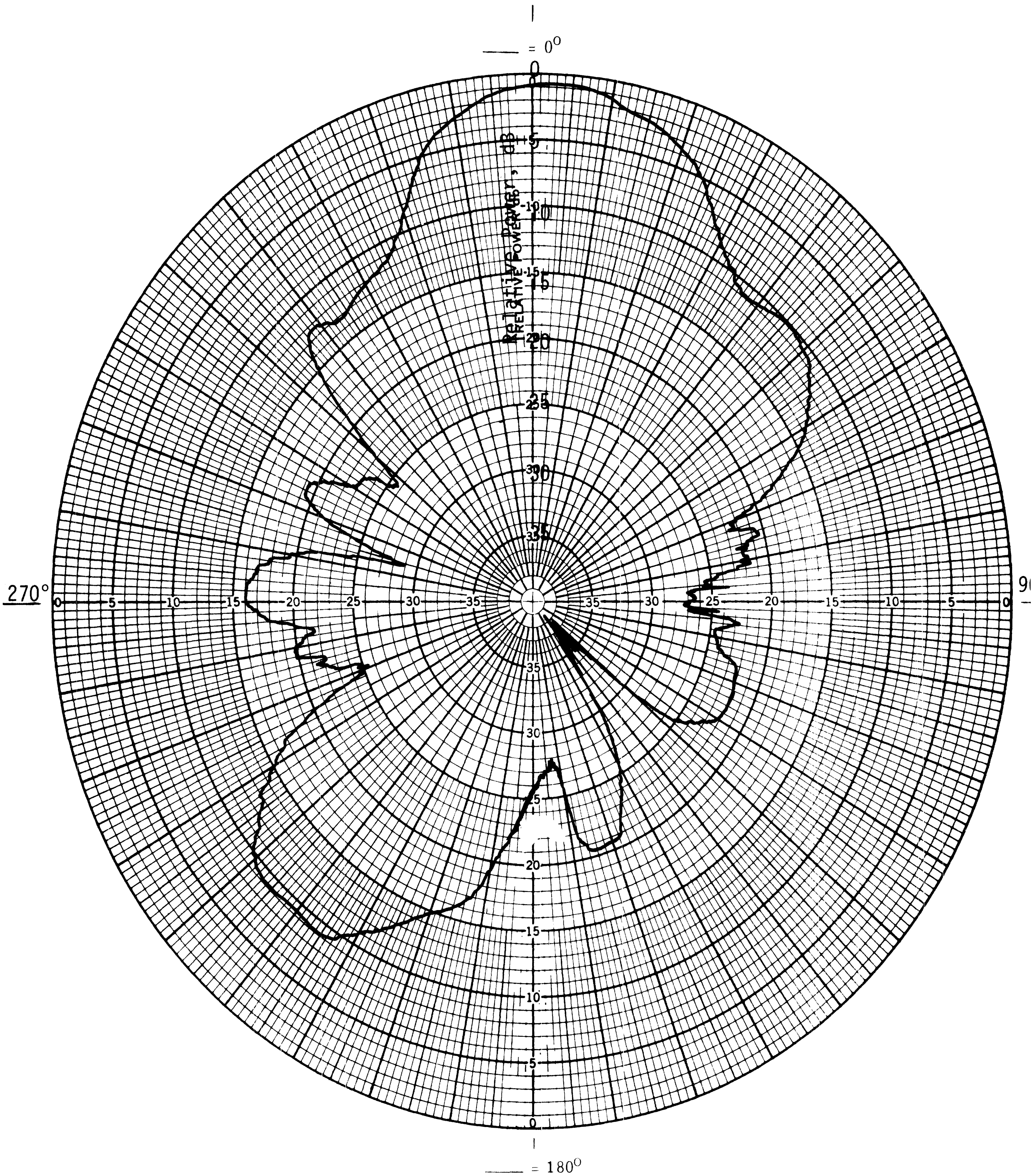

Figure 8. Measured horizontal plane pattern of the commercially available TV antenna used as the test antenna.
(d) f = 699 MHz ∿ Channel 52

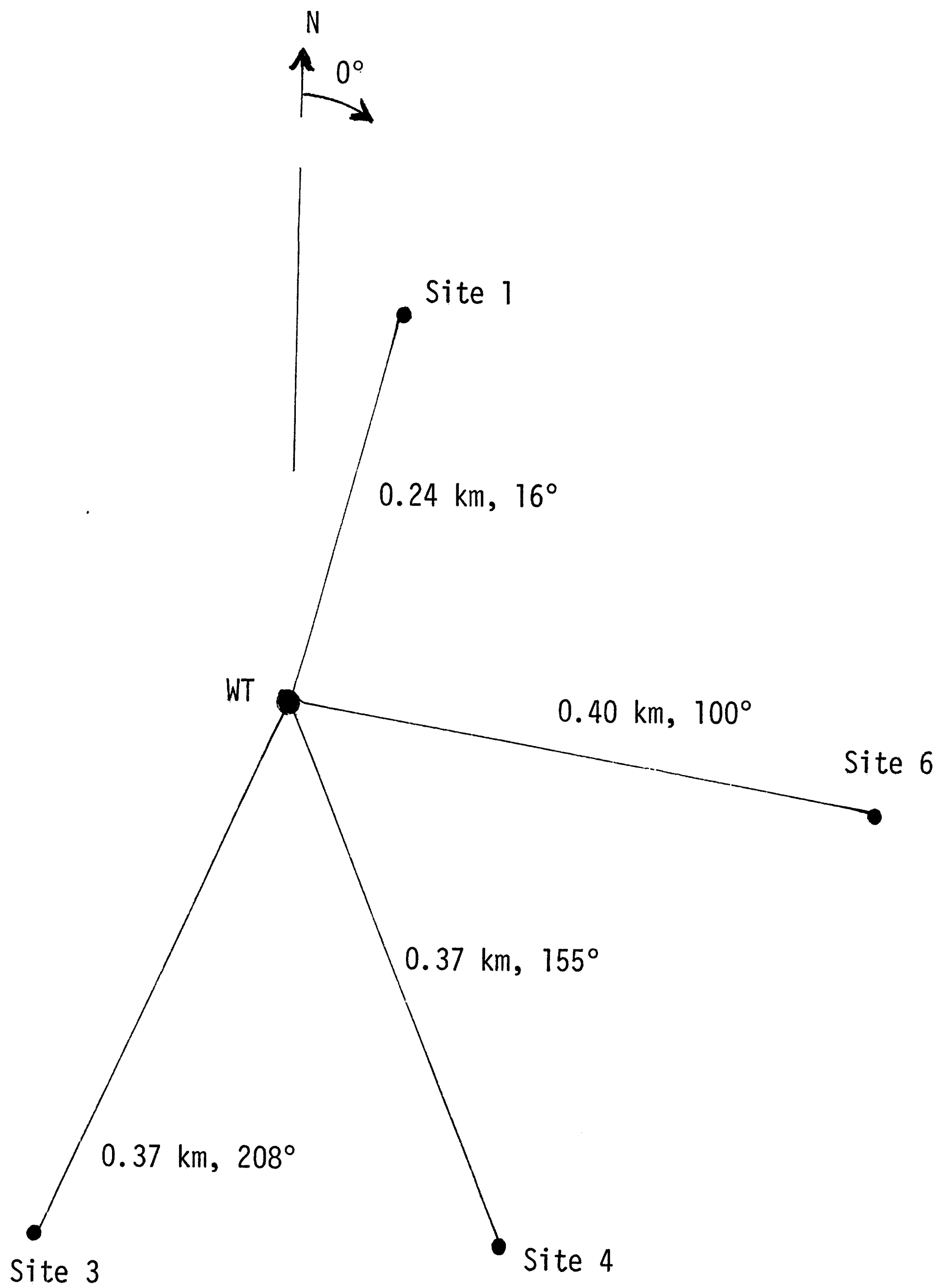

Figure 9. Test sites with respect to the WT.

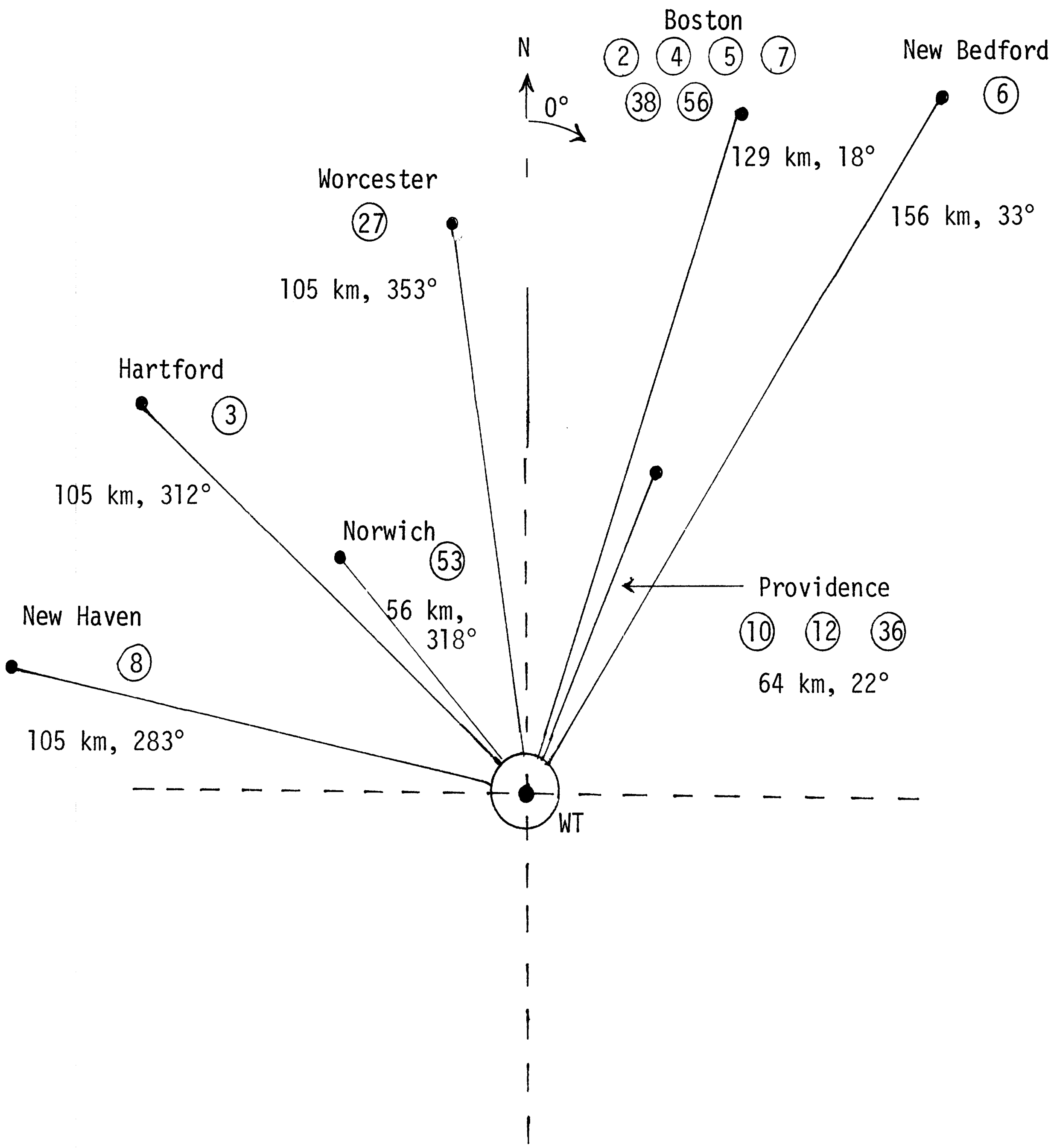

Figure 10. Location of the available TV signal transmitters with respect to the WT. Circled numbers indicate TV Channel numbers.

distances to the transmitters and their locations. The circled numbers are the TV Channel numbers. Figures 9 and 10 can be used to determine whether a test site is in the backward or forward part of the WT interference zone for a given TV signal.

While some individual antennas can receive all nine VHF and five UHF TV Channels shown in Fig. 10, the reception quality is generally poor on Block Island [1]. In fact, the entire island is in either the fringe or deep shadow reception area for all of the available TV Channels [Note: with transmitting and receiving antenna heights of 300 m and 10 m, respectively, the distance to the radio horizon is about 73 km].

Because of the low field strengths on the island, the height of the receiving antenna used has a significant effect on the signal strength and, hence, on the quality of the received picture. The typical height of a TV antenna mounted on the roof of a home is 10 m, and this is much smaller than the height of the WT blades. The blades are therefore exposed to a stronger field than the home-owner's antenna, and this could lead to a WT-scattered field of the same order as the primary signal, resulting in unacceptable video distortion at that site. The possibility of this occurring was indicated by early theoretical calculations [1], and was the reason for the decision to install a CATV system to ensure interference-free TV reception on the island.

8. SITE 1 RESULTS

8.1 Field Strength

The field strengths of the available TV signals were measured with receiving antenna heights of 4.6 and 12.2 m above ground. The latter height was used to correspond to the height of the proposed CATV system antennas. The results are shown in Table 2, and in the cases where no value is given the received field strength was too low (below the noise level of the spectrum analyzer) to allow a meaningful reading to be obtained. The results show that the field strengths do increase with height on all Channels, but except for Channel 6, the fields are generally weak. For all of the subsequent measurements the antenna height used was 4.6 m.

8.2 Antenna Response

The received field strengths on Channel 6 as functions of the antenna rotation, obtained with and without the WT blades rotating, are given in Figs. 11(a) and 11(b) respectively. Comparison of these patterns, in particular Fig. 11(b), with the corresponding laboratory pattern Fig. 8(a) shows that the test environment has reduced the depth of one of the nulls in the pattern. This is attributed to the particular location of a building at site 1 with respect to the direction of arrival of the Channel 6 signals.

The effects of the WT blade rotation on the antenna response are clearly evident in Fig. 11. With the antenna beam pointing in the direction of the Channel 6 transmitter, the WT blades produce about 0.4 dB variation in the received signal (Fig. 11(a)), but with the antenna beam directed towards the WT, a significantly larger variation ($\sim$8 dB) occurs.

Table 2

Field Strengths of Available TV Signals at Site 1

TV Channel No.	Audio Carrier Frequency (MHz)	Distance of the Transmitter from WT (km)	Field Strength (dBm)	
			Antenna Ht. (4.6 m)	Antenna Ht. (12.2 m)
2	59.75	129	-84	-80
3	65.75	105	--	-80
4	71.75	129	-82	-75
5	81.75	129	-86	-83
6	87.75	156	-52	-47
7	179.75	129	-81	-82
8	185.75	105	-88	-80
10	197.75	64	-66	-60
12	209.75	64	-66	-60
27	553.75	105	--	-87
36	607.75	64	-90	-82
38	619.75	129	--	-86
53	709.75	56	-62	-63
56	727.75	129	--	-88

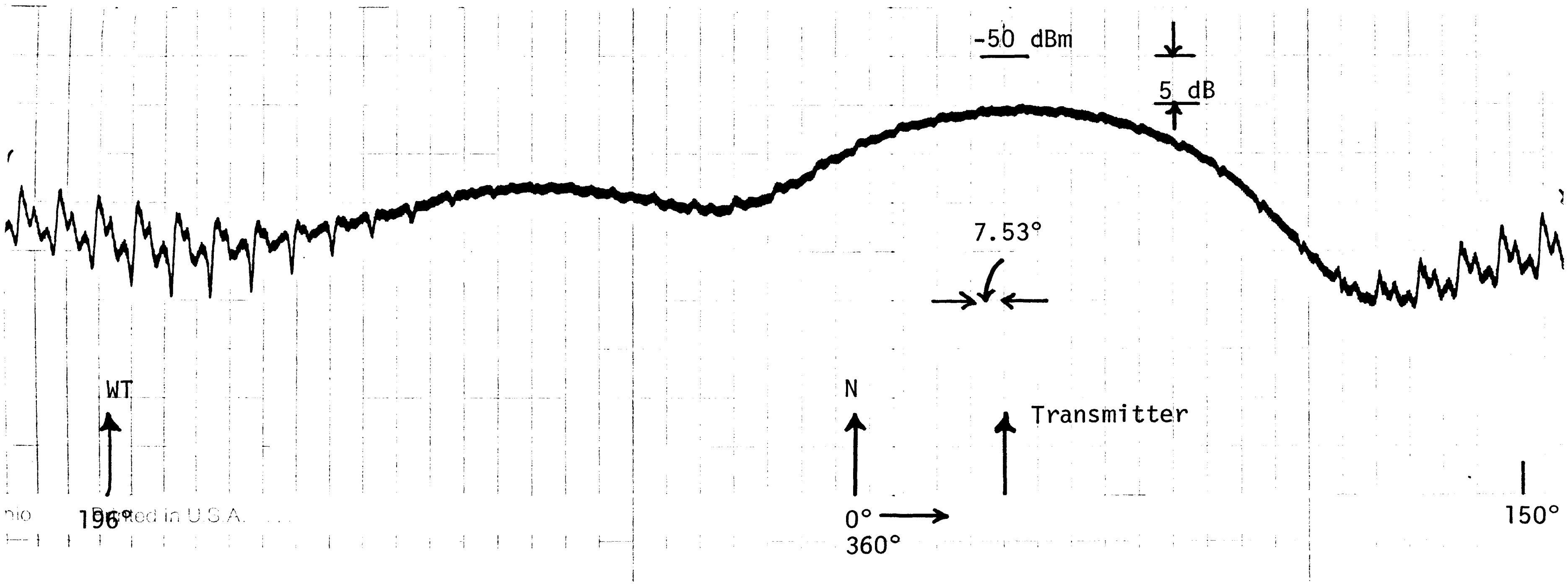

Figure 11(a). Strength of TV Channel 6 signal received at site 1 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height = 4.6 m; WT blades rotating.

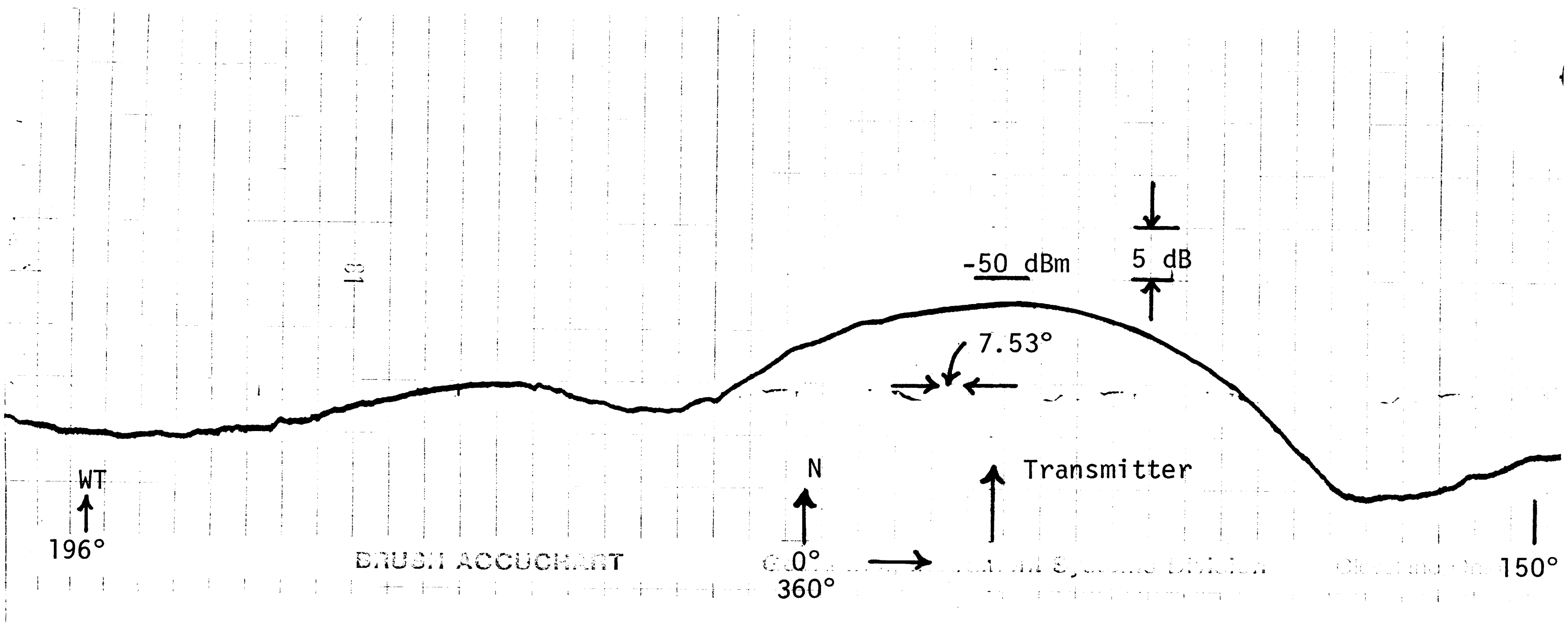

Figure 11(b). Strength of TV Channel 6 signal received at site 1 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height = 4.6 m; WT blades stationary.

Analogous results for TV Channels 10, 12 and 53 are shown in Figs. 12, 13 and 14, respectively. In all three cases, no appreciable signal modulation due to the WT blade rotation was observed when the antenna beam was pointed towards the TV transmitter.

8.3 Static Scattering

With the blades locked in an almost vertical position and the WT yawing in azimuth, the total received signal on Channel 6 as a function of time with the antenna main beam pointed at the WT is shown in Fig. 15. The scattered signals produced by the two blades can be clearly seen in Fig. 15, which indicates that the maximum scattered field amplitude is about 2 dB.

No appreciable scattering was observed with other TV Channels and, hence, those results are not presented.

8.4 Television Interference (TVI)

The total received signal as a function of time with the antenna beam pointed in the direction of the TV Channel 6 transmitter and the WT blades rotating at 40 rpm is shown in Fig. 16. The modulation pulses due to the blade rotation occur at 0.75 sec. intervals, i.e., at half the rotation period of the blades. The total signal variation caused by these pulses is about 0.6 dB ($m = 0.03$), and this produced a barely visible amount of video distortion of the received picture. Although this distortion was judged to be acceptable for ordinary viewing, it may not be acceptable for CATV transmission purposes.

Similar results obtained on Channel 6 but with the antenna beam pointed towards the operating WT are shown in Fig. 17 where the expanded

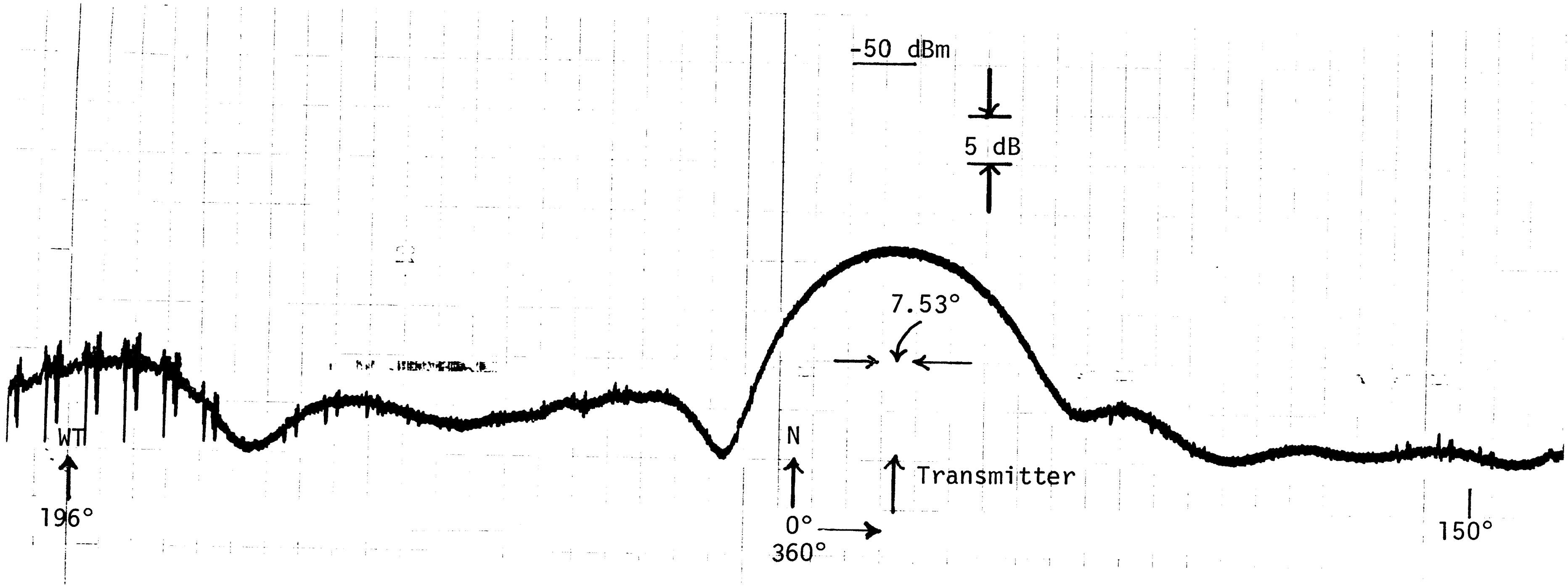

Figure 12(a). Strength of TV Channel 10 signal received at site 1 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height = 4.6 m; WT blades rotating.

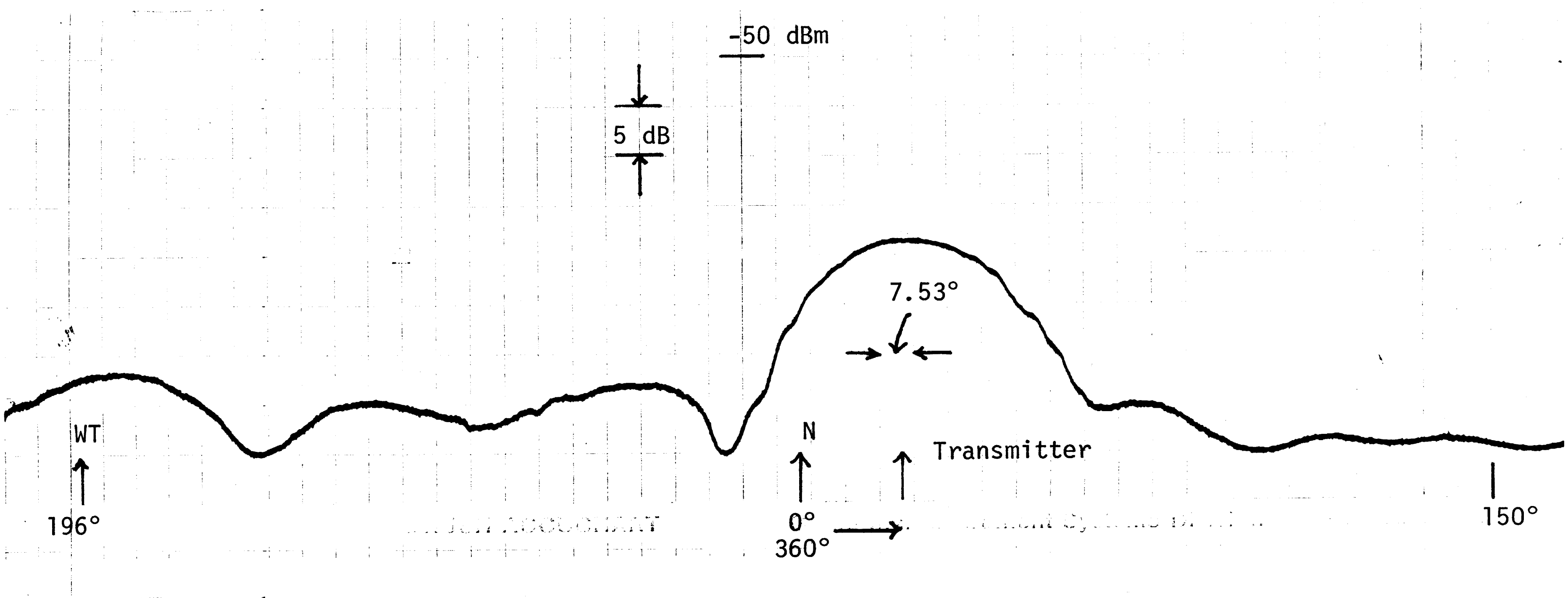

Figure 12(b). Strength of TV Channel 10 signal received site 1 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height = 4.6 m; WT blades stationary.

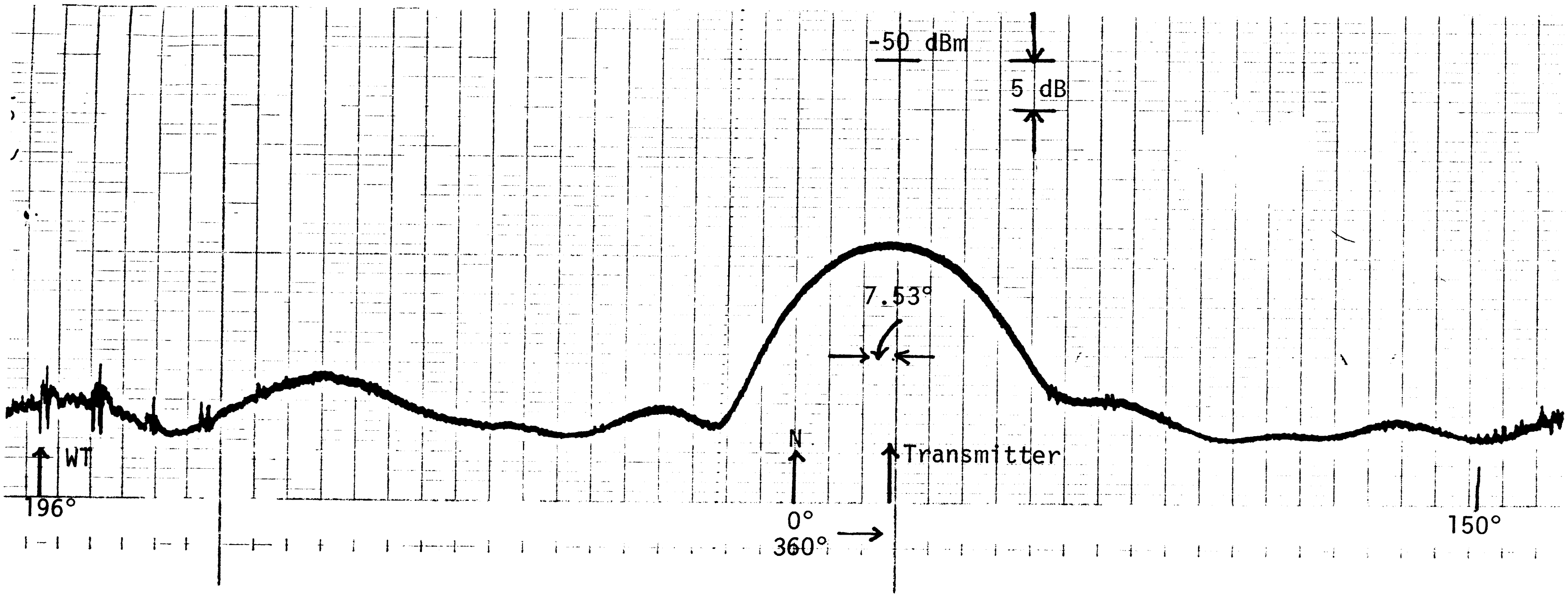

Figure 13(a). Strength of TV Channel 12 signal received at site 1 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height 4.6 m; WT blades rotating.

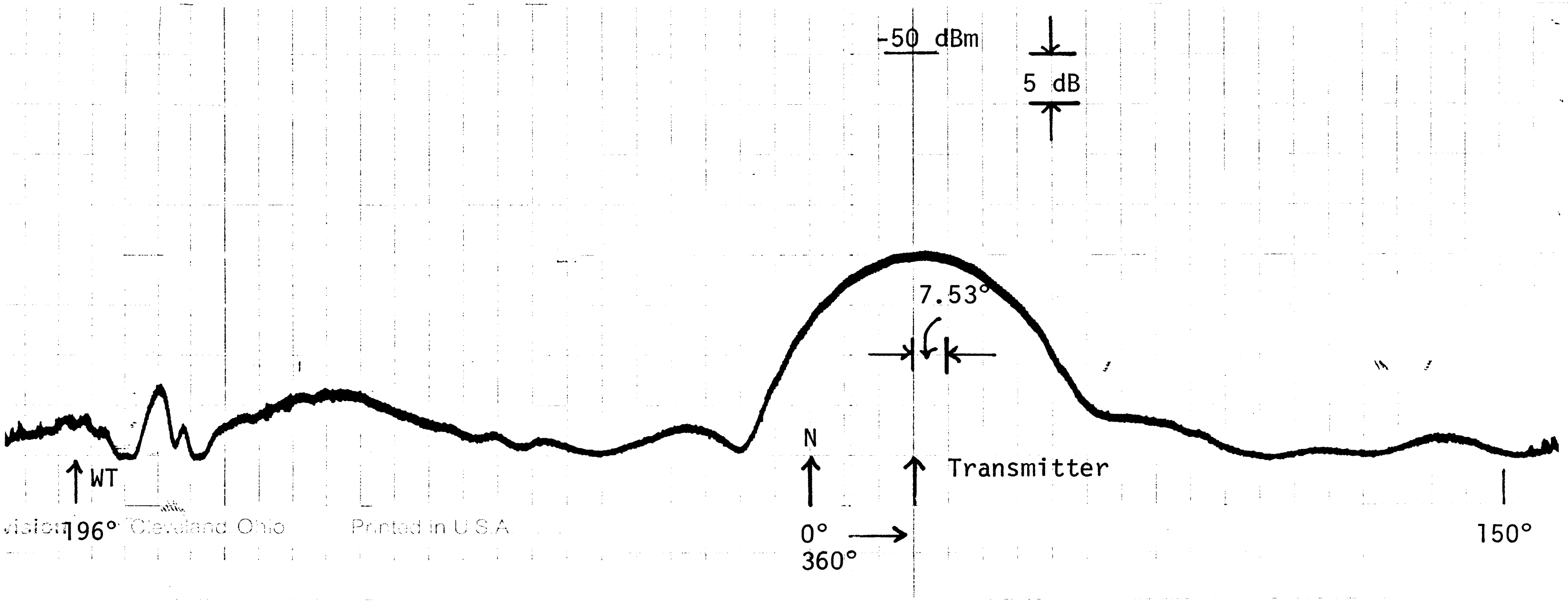

Figure 13(b). Strength of TV Channel 12 signal received at site 1 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height 4.6 m; WT blades stationary.

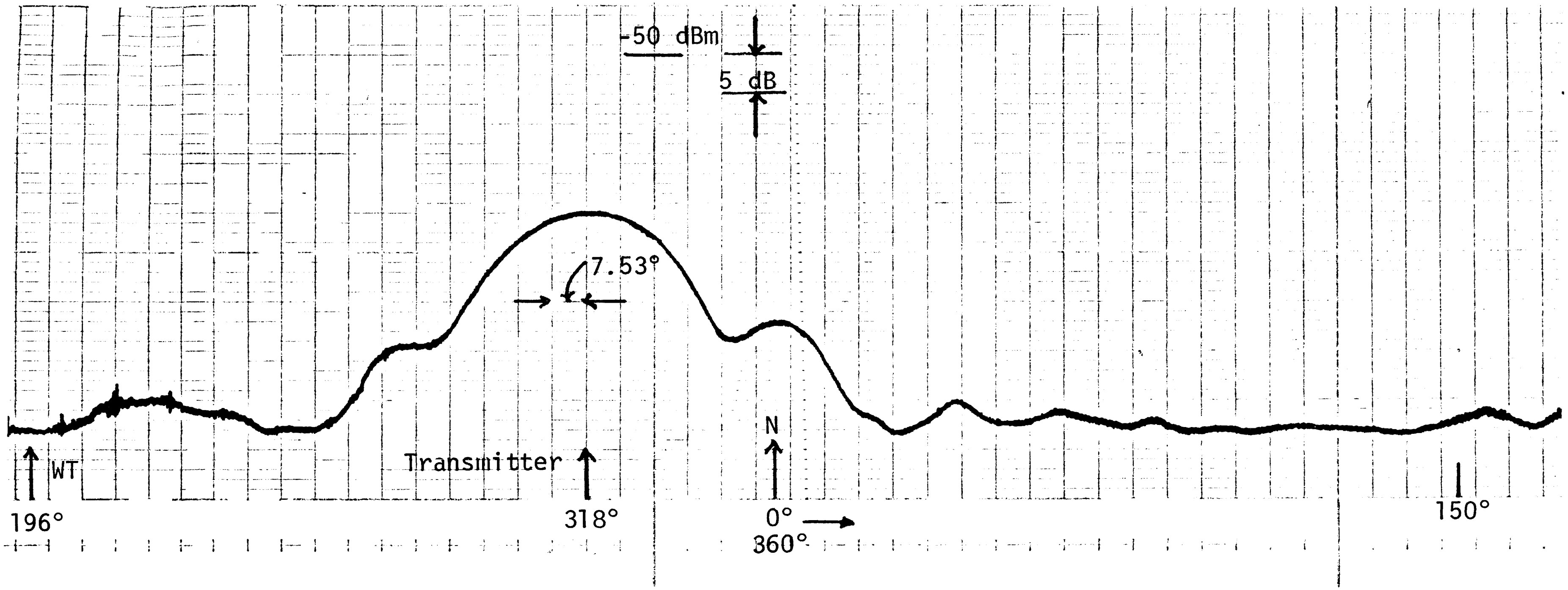

Figure 14(a). Strength of TV Channel 53 signal received at site 1 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height 4.6 m; WT blades rotating.

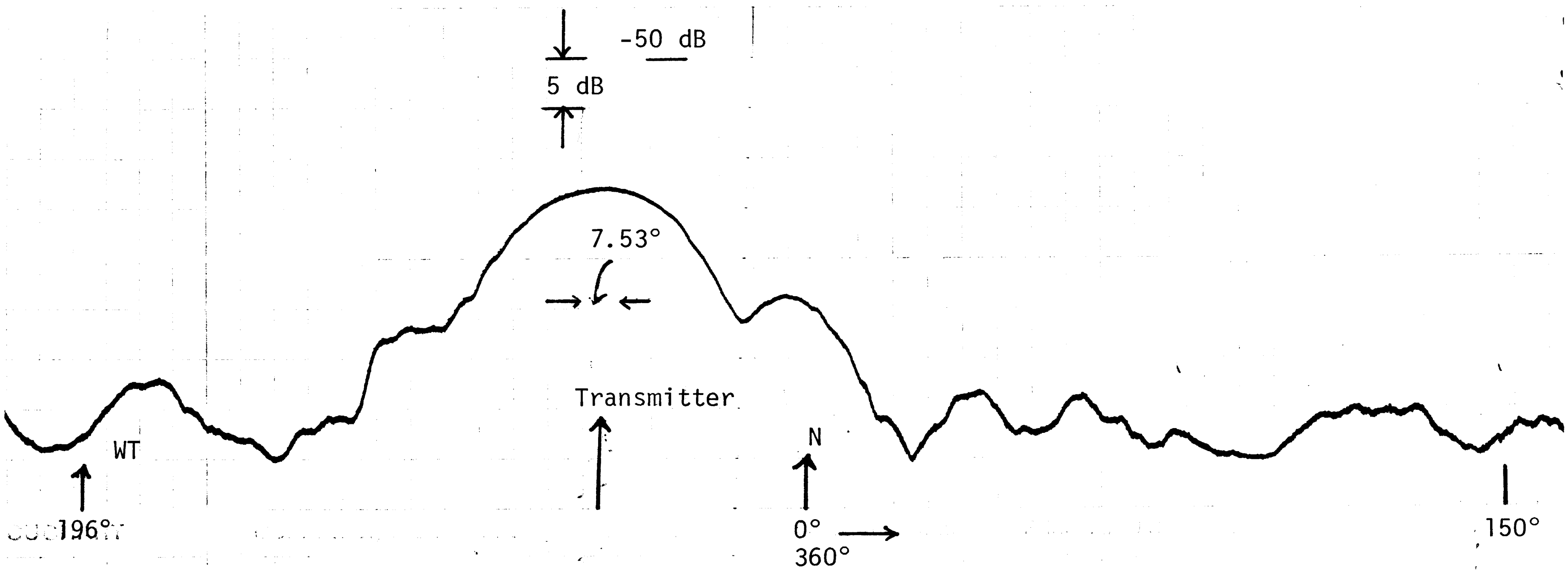

Figure 14(b). Strength of TV Channel 53 signal received at site 1 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height 4.6 m; WT blades stationary.

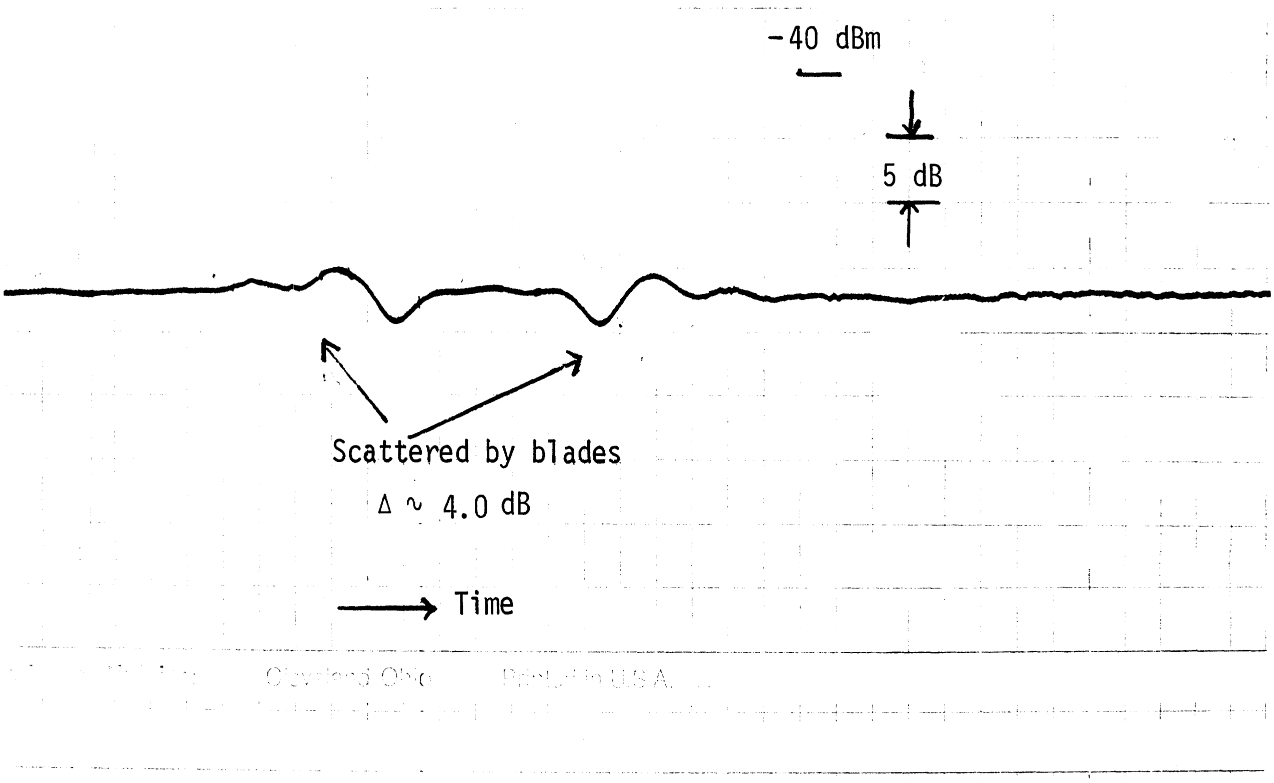

Figure 15. Received Channel 6 signal vs. time obtained at site 1 with the blades stationary and the WT yawing in azimuth. Antenna height = 4.6 m. Antenna main beam pointed at the WT.

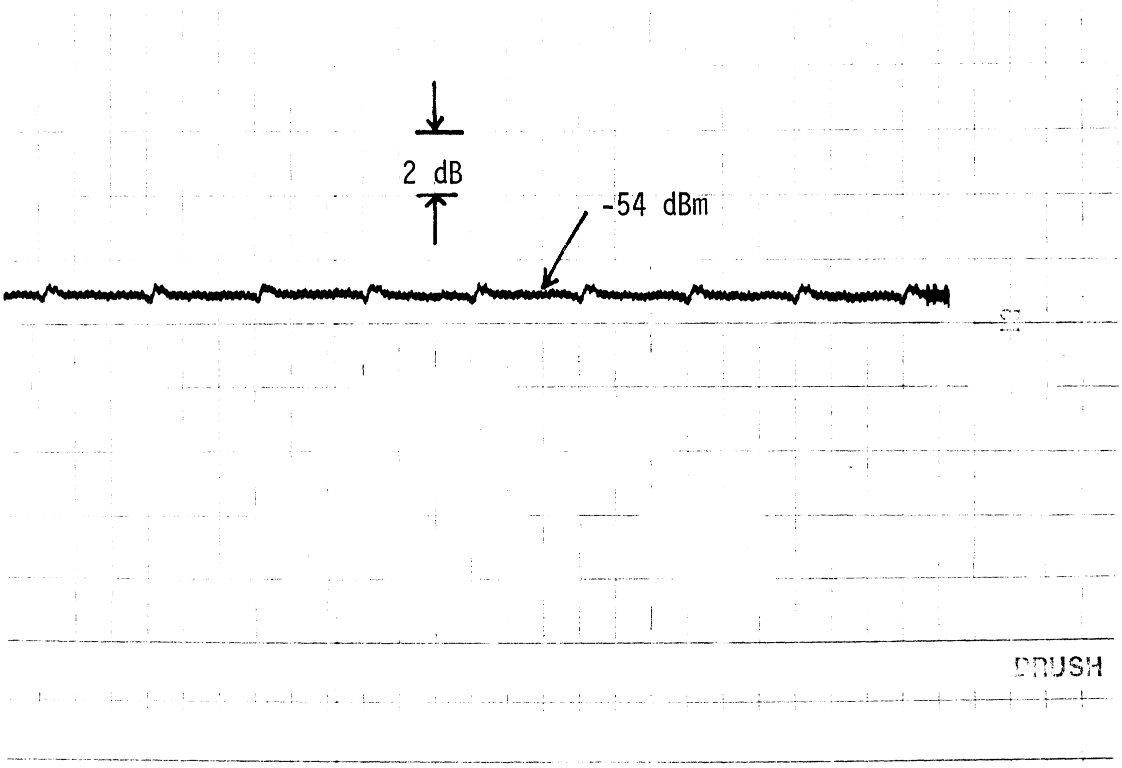

Figure 16. Channel 6 signal as a function of time received at site 1 with the antenna main beam pointed at the distant transmitter. Blade rotation frequency = 40 rpm; WT-to-receiver distance = 0.24 km.

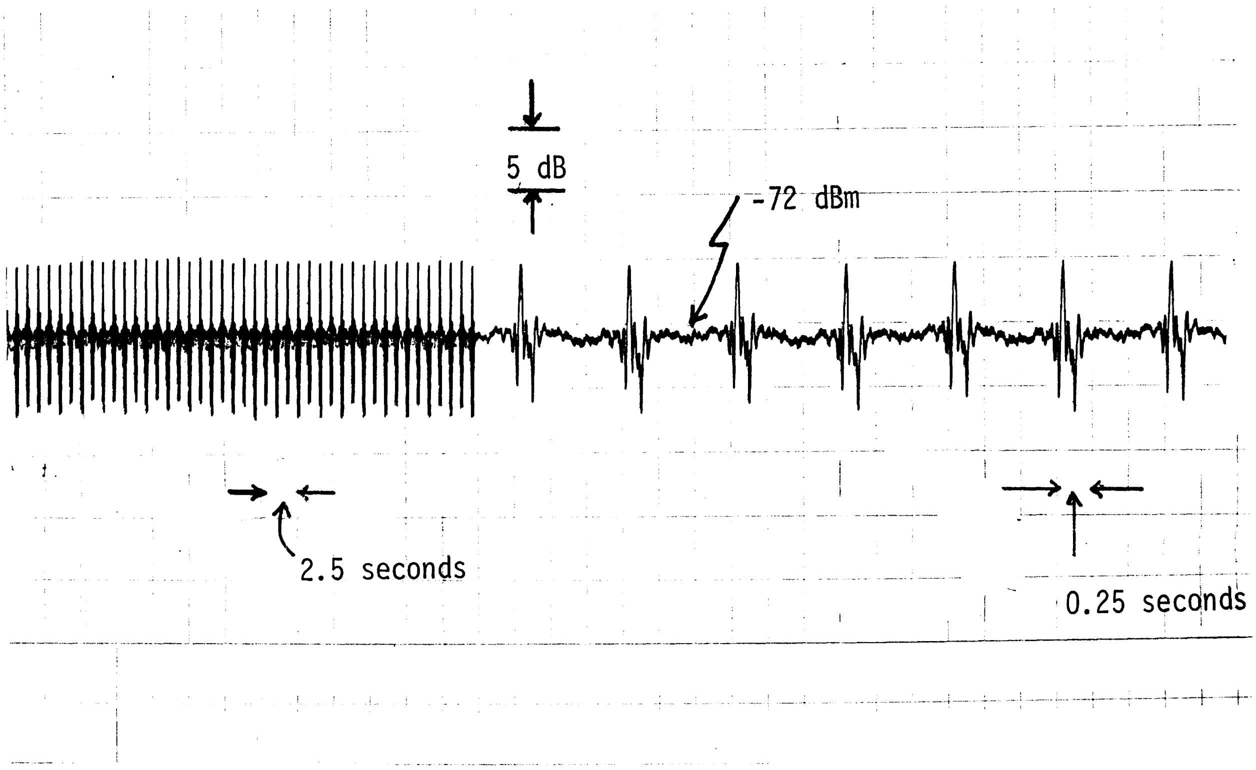

Figure 17. Channel 6 signal as a function of time received at site 1 with the antenna main beam pointed at the WT. Blade rotation frequency = 40 rpm; WT-to-receiver distance = 0.24 km.

time scale results are given so that the modulation waveform of the received signal may be judged. In this case it was found that the modulation produced by the blade rotation was quite strong and caused about 12 dB (m = 0.59) total variation of the received signal (compare with Fig. 16). With such a large extraneous modulation, very strong (and naturally unacceptable!) video distortion of the received picture was observed. The results given in Figs. 16 and 17 are quite similar to those obtained in our previous studies reported elsewhere [2,3].

Signals received on Channels 10 and 53 contained insignificant amounts of modulation and, consequently, no interference was observed in the received pictures for these Channels. Typical results are shown in Figs. 18 and 19. Although it is possible that TVI would be observed on these Channels if the antenna beam were pointed away from the appropriate transmitter, no tests were conducted to investigate this.

Since detectable TVI effects were observed on Channel 6, and since these effects were judged unacceptable for the proposed CATV system, further tests were conducted on Channel 6 to determine the specifications which the receiving antenna must have to make the interference insignificant. The results shown in Fig. 16 were obtained with the antenna oriented such that the direct and WT-scattered signals were received via the main-beam maximum and the back lobe of the antenna, respectively. By slightly rotating the antenna, it was possible to control the received strength of the scattered signal relative to the direct. In this manner, it was established that no TVI effects would be observed if the scattered signal is about 15 dB below the direct one. Based on this finding, it is argued that with a properly directed receiving antenna having a side and back lobe ratio of -15 dB or better, no TVI effects will be observed on Channel 6.

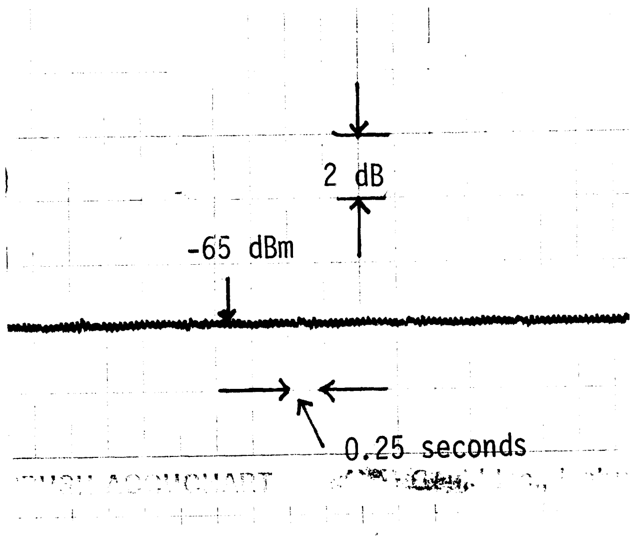

Figure 18. Channel 10 signal as a function of time received at site 1 with the antenna mainbeam pointed at the distant transmitter. Blade rotation frequency = 40 rpm. WT-to-receiver distance = 0.24 km.

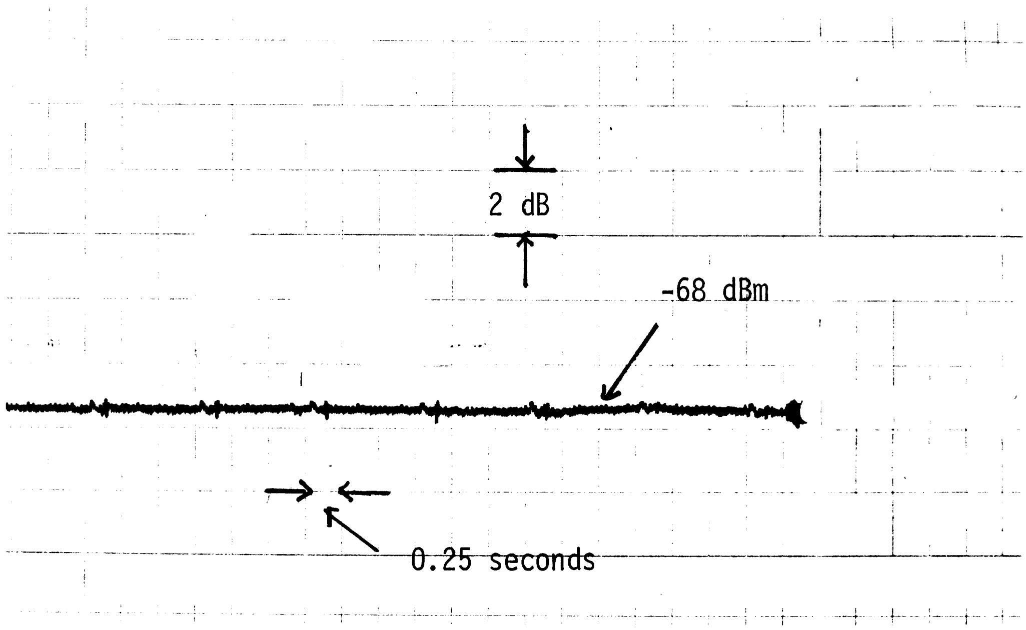

Figure 19. Channel 53 signal as a function of time received at site 1 with the antenna mainbeam pointed at the distant transmitter. Blade rotation frequency = 40 rpm. WT-to-receiver distance = 0.24 km.

8.5 Threshold TVI

The total signals as functions of time received under threshold TVI conditions on four different TV Channels are shown in Figs. 20(a)-(d). As expected, the occurrence and degree of interference depended on the antenna beam direction, the WT pointing direction and the blade pitch angle.

With the antenna oriented so that the video distortion due to the WT blade rotation was at the threshold level, the corresponding total signal variation Δ_0 obtained from Fig. 20 ranged from 2.5 to 3.5 dB for Channels 6, 10 and 12, but was comparable to 7 dB for Channel 53.

In our previously reported [2] laboratory studies the threshold signal variation was set at Δ_0 = 2.6 dB. In view of the low ambient signal levels on Block Island, the values of Δ_0 found for Channels 6, 10 and 12 are in good agreement with the laboratory value. With Channel 53, however, the signal was very low and the picture quality so very poor that it was almost impossible to distinguish the systematic interference due to the WT from the random fluctuations of the 'snow', and this undoubtedly accounts for the anomalous value of Δ_0 found for this Channel. The observed picture distortion on Channels 6 and 10 was recorded on video tape for permanent record.

9. SITE 3 RESULTS

9.1 Field Strength

The field strengths of the available TV signals were measured with the receiving antenna located 4.6 m above the ground. The results are shown in Table 3, where the analogous results for site 1 are also shown for comparison.

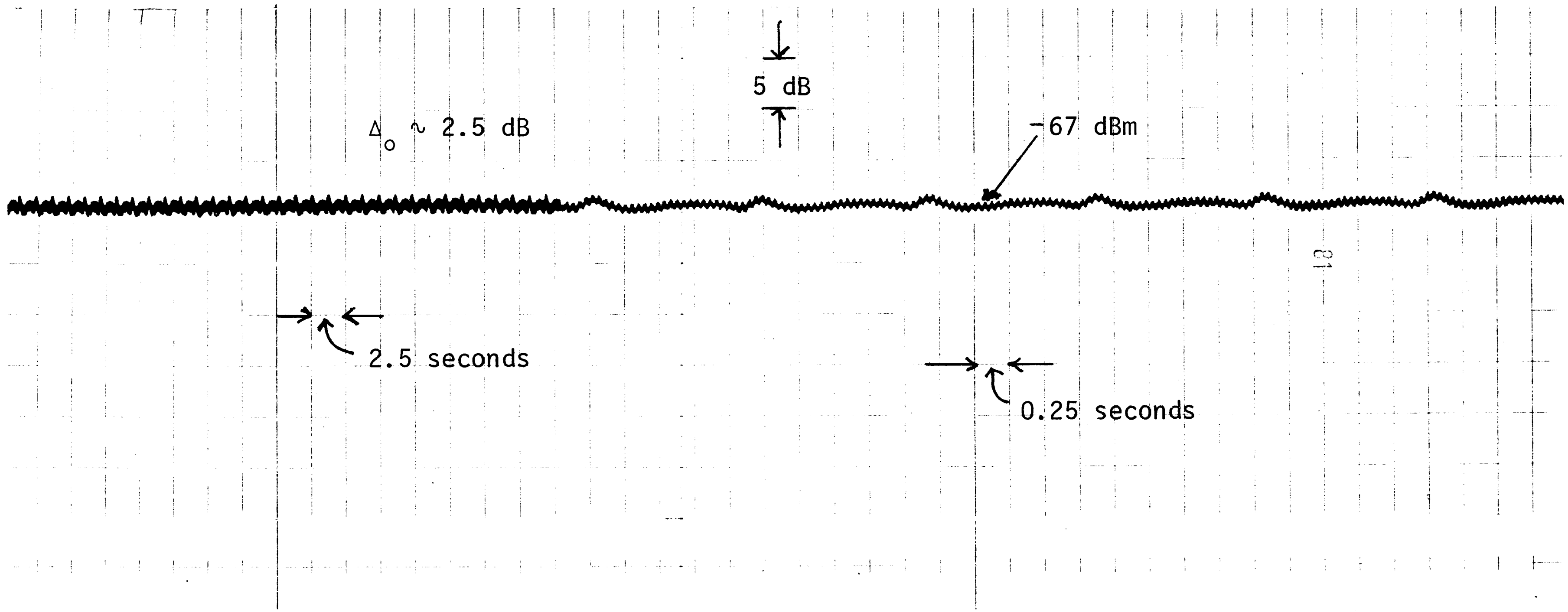

Figure 20(a). Received Channel 6 signal vs. time producing threshold interference at site 1. Blade rotation frequency ~ 30 rpm; WT-to-receiver distance = 0.24 km.

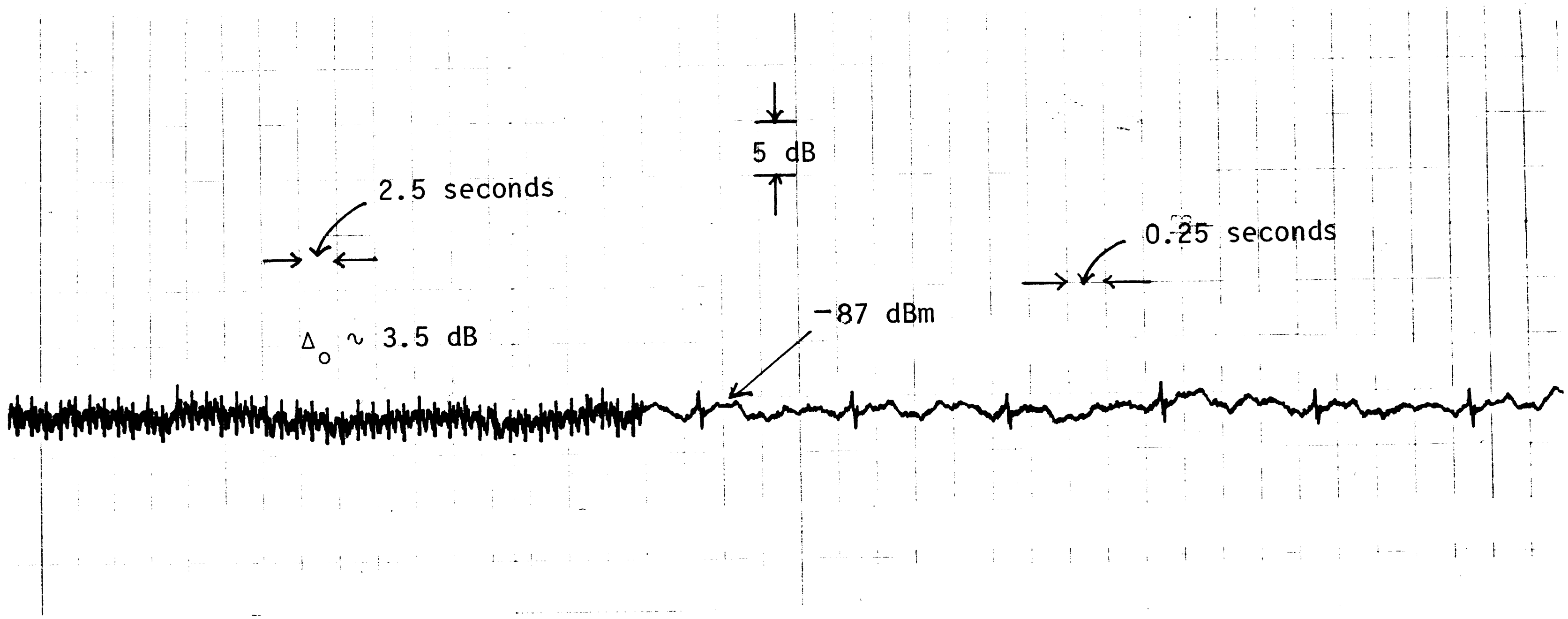

Figure 20(b). Received Channel 10 signal vs. time producing threshold interference at site 1. Blade rotation frequency = 30 rpm; WT-to-receiver distance = 0.24 km.

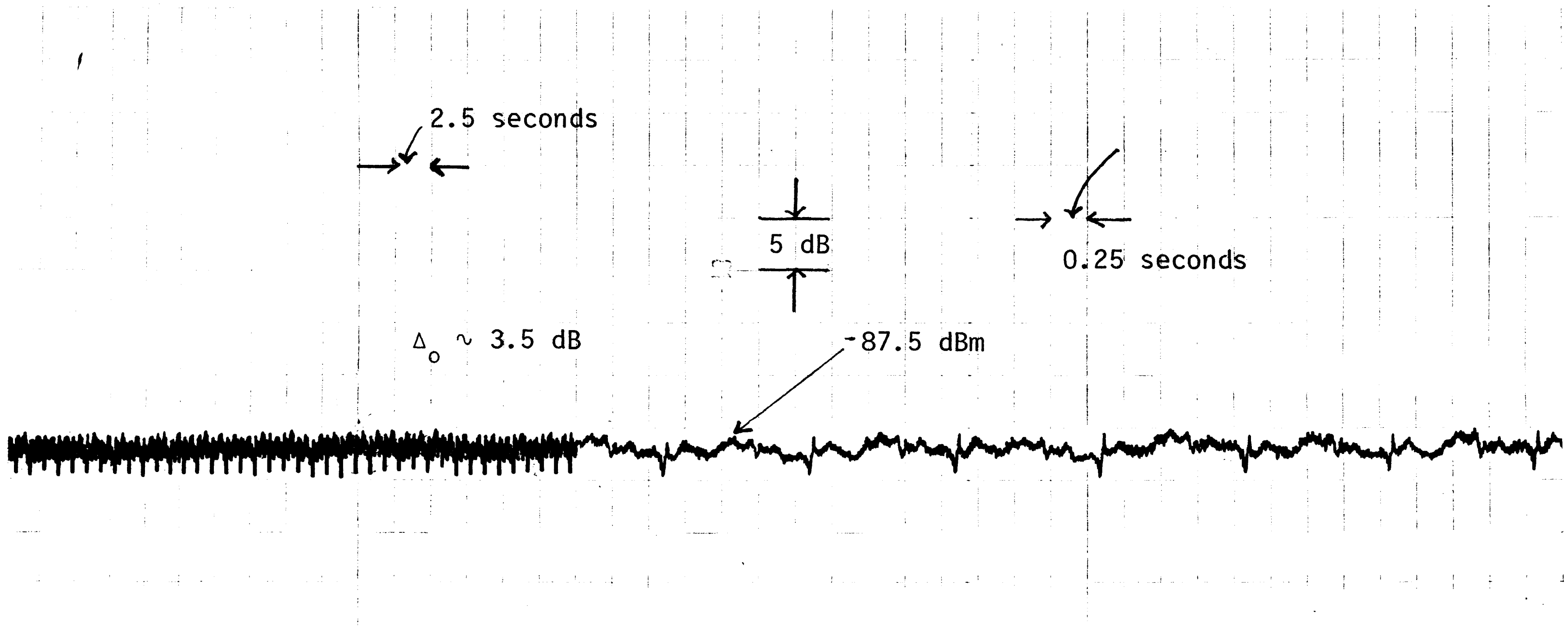

Figure 20(c). Received Channel 12 signal vs. time producing threshold interference at site 1. Blade rotation frequency = 30 rpm; WT-to-receiver distance = 0.24 km.

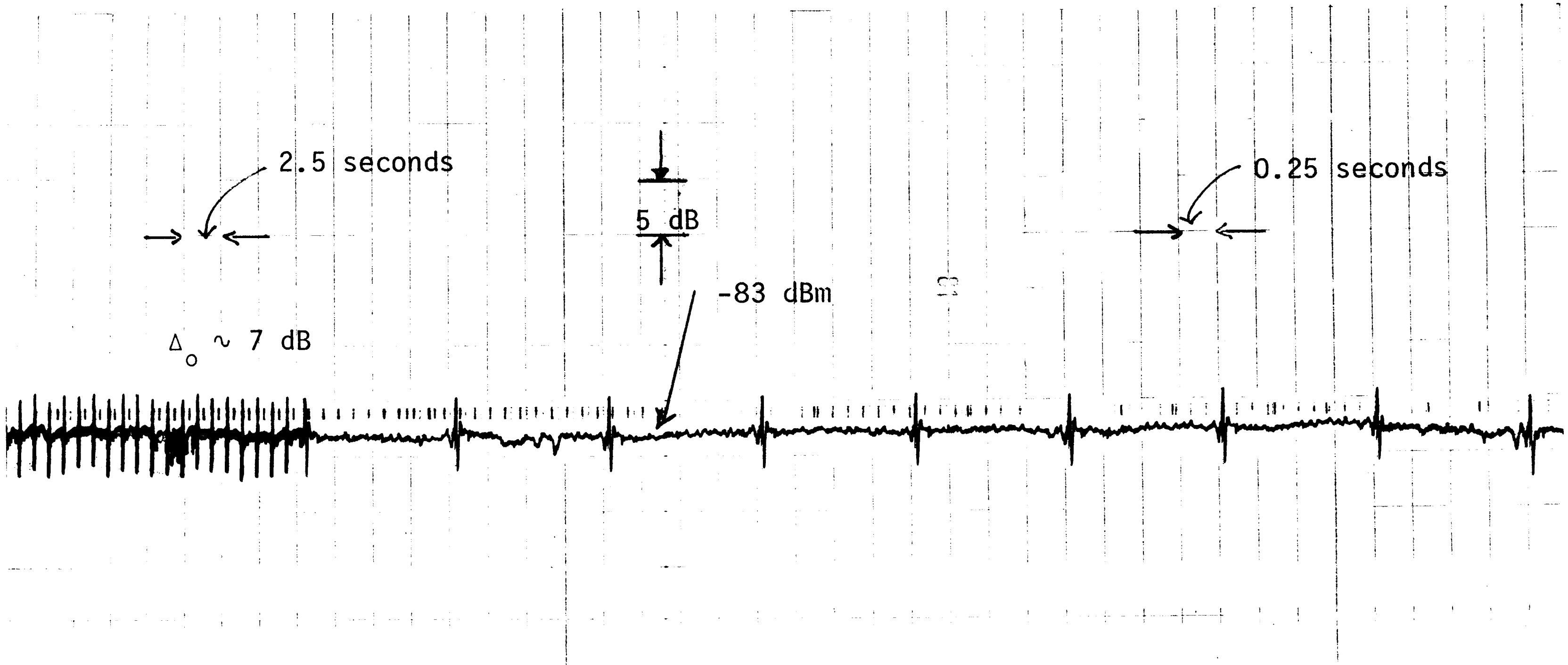

Figure 20(d). Received Channel 53 signal vs. time producing threshold interference at site 1. Blade rotation frequency = 30 rpm; WT-to-receiver distance = 0.24 km.

Table 3

Field Strengths of Available TV Signals at Sites 3 and 1

(Antenna Height = 4.6 m)

TV Channel No.	Audio Carrier Frequency (MHz)	Distance of the TV Transmitter from WT (km)	Field Strength (dBm)	
			Site 3	Site 1
2	59.75	129	-77	-87
3	65.75	105	-85	--
4	71.75	129	-78	-85
5	81.75	129	-86	-89
6	87.75	156	-49	-55
7	179.75	129	--	-88
8	185.75	105	-86	-88
10	197.75	64	-69	-69
12	209.75	64	-70	-70
27	553.75	105	--	--
36	607.75	64	--	-74
38	619.75	129	--	--
53	709.75	56	-79	-64
56	727.75	129	--	--

The generally larger signal strengths at site 3 may be due to the greater height of this site above sea level.

9.2 Antenna Response

The received field strengths on Channels 6, 10 and 12 as functions of the antenna rotation with the WT blades rotating are given in Figs. 21(a)-(c). Comparison of Fig. 21(a) with the corresponding Channel 6 results at site 1 (Fig. 11(a)), shows that the results in the pattern are now well formed since there was no building nearby to produce reflections. Except for the modulation pulses, the results in Fig. 21(a)-(c) are also similar to the laboratory-measured patterns in Fig. 8.

Observe that at this site the WT blade rotation produces only an insignificant amount of modulation of the received signal.

9.3 Television Interference

Site 3 was suitable for forward region interference measurements (see Figs. 8 and 9), i.e., the antenna received the direct and scattered signals from approximately the same direction. Figures 22(a)-(c) show the relevant portions of the total received signals as functions of time for selected TV Channels. The modulation pulses are visible in all the results, but the pulse amplitudes were not strong enough to produce any significant distortion of the TV picture. Due to the inaccessibility of this area around the WT, it was not possible to move closer in to quantify the forward region type of interference.

10. SITE 4 RESULTS

10.1 Antenna Response

The received field strengths on Channels 6 and 53 as functions of the antenna rotation with the WT blades rotating are shown in Figs. 23(a)-(b) where the approximate directions of the antenna for which reception could be vulnerable to TVI effects are indicated.

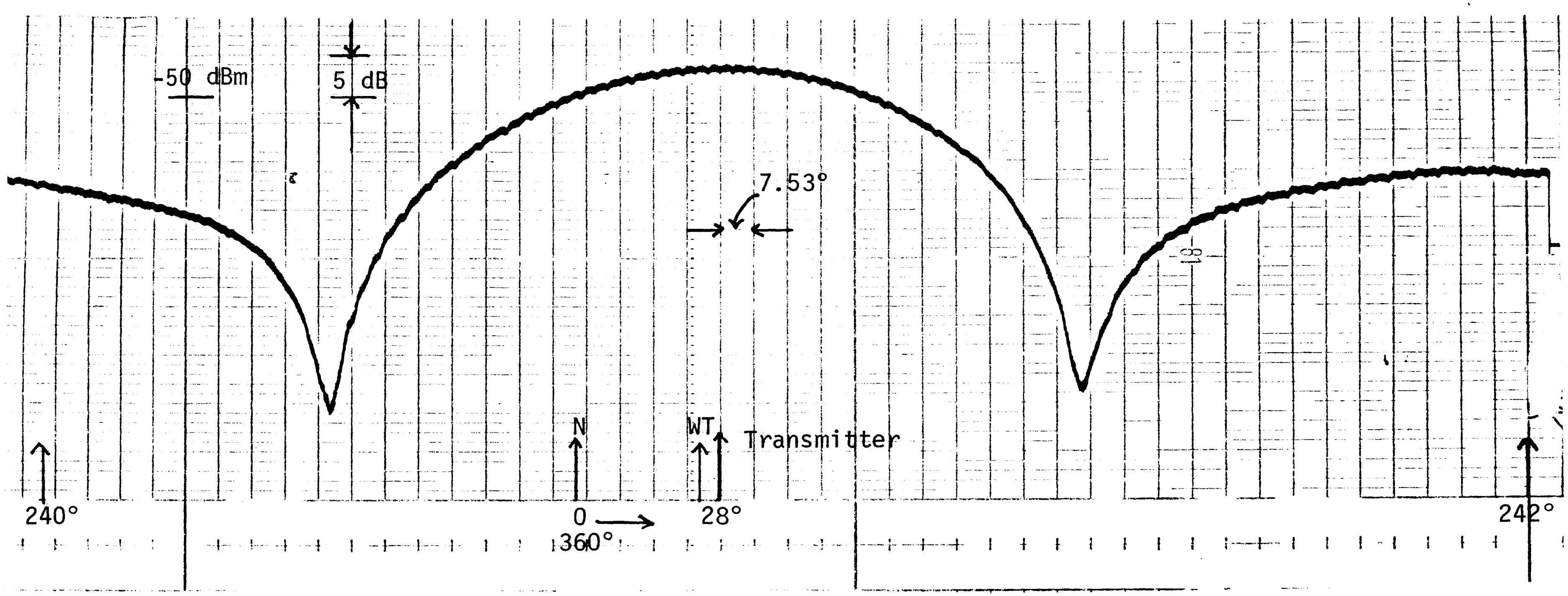

Figure 21(a). Strength of TV Channel 6 signal received at site 3 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height = 4.6 m; WT blades rotating.

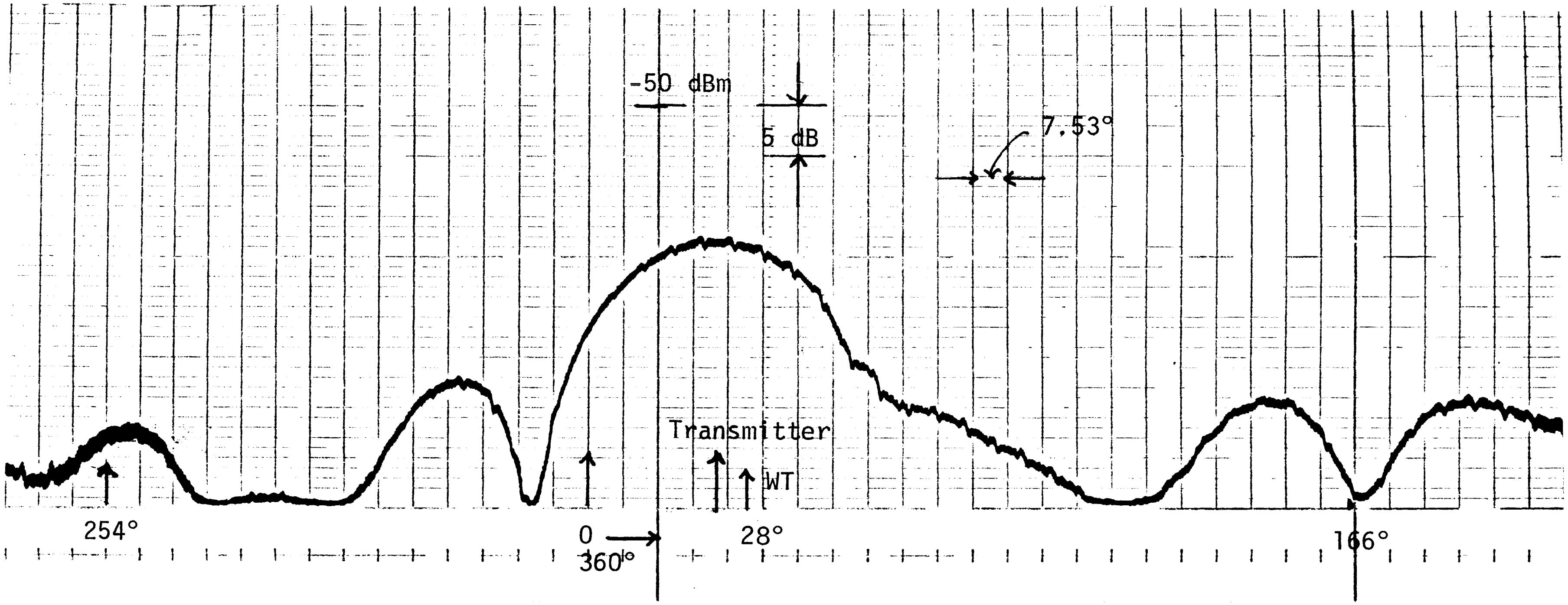

Figure 21(b). Strength of TV Channel 10 signal received at site 3 vs. antenna rotation angle (or time: 1 division = 1 second). Antenna height = 4.6 m; WT blades rotating.

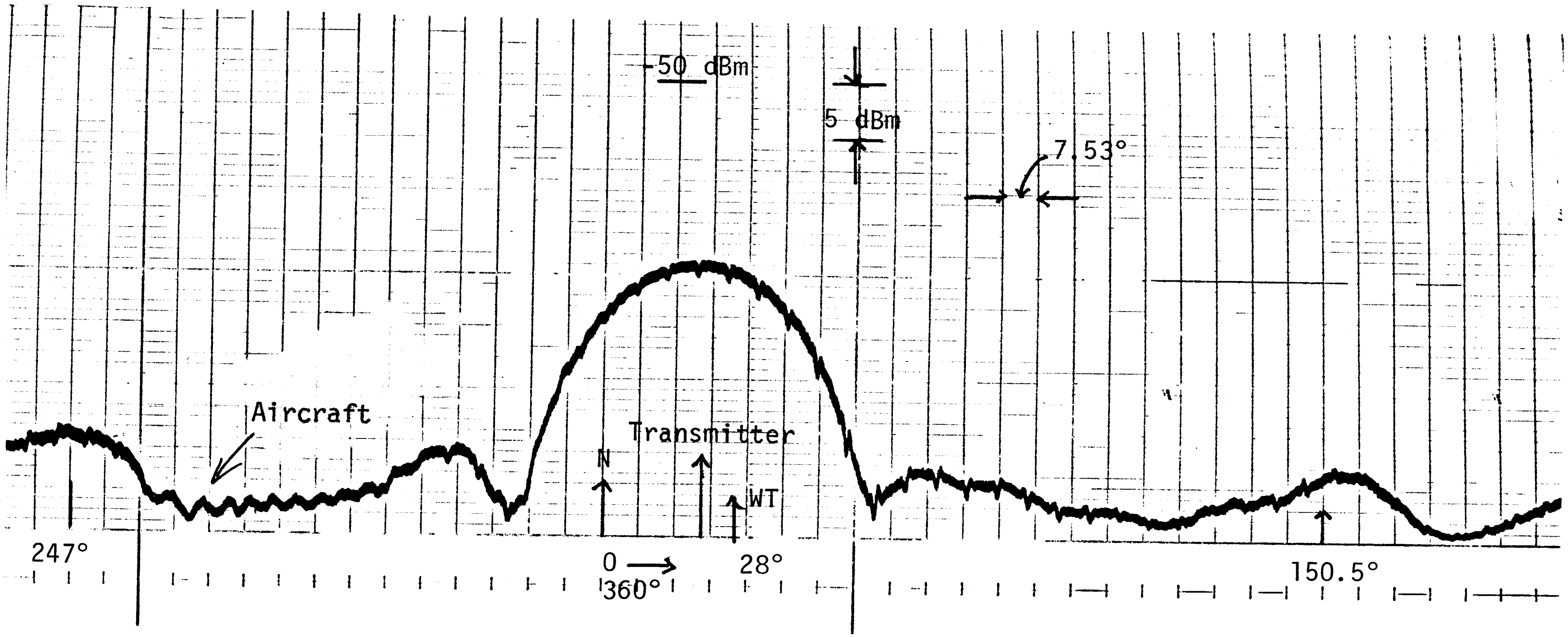

Figure 21(c). Strength of TV Channel 12 signal received at site 3 vs. antenna rotation angle (or time: 1 division = 1 second). Antenna height = 4.6 m; WT blades rotating.

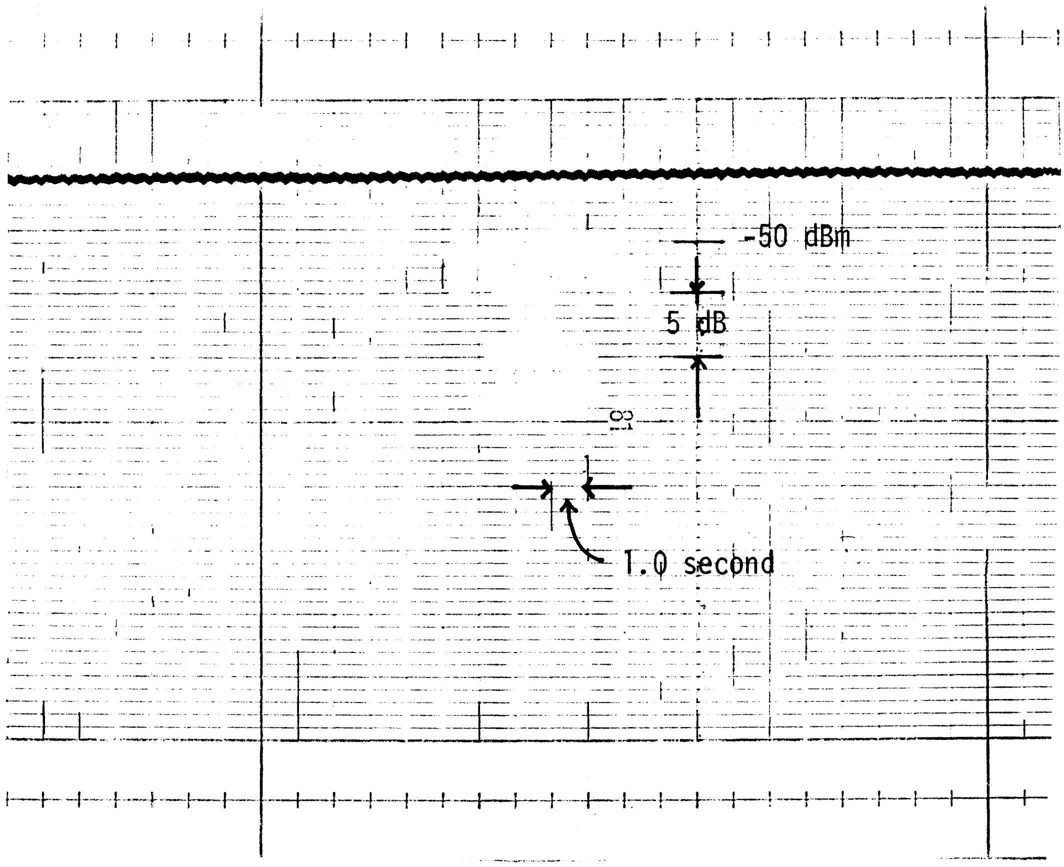

Figure 22(a). TV Channel 6 signal vs. time received at site 3 with antenna mainbeam pointed at the distant transmitter. Blade rotation frequency ∿30 rpm; WT-to-receiver distance = 0.37 km.

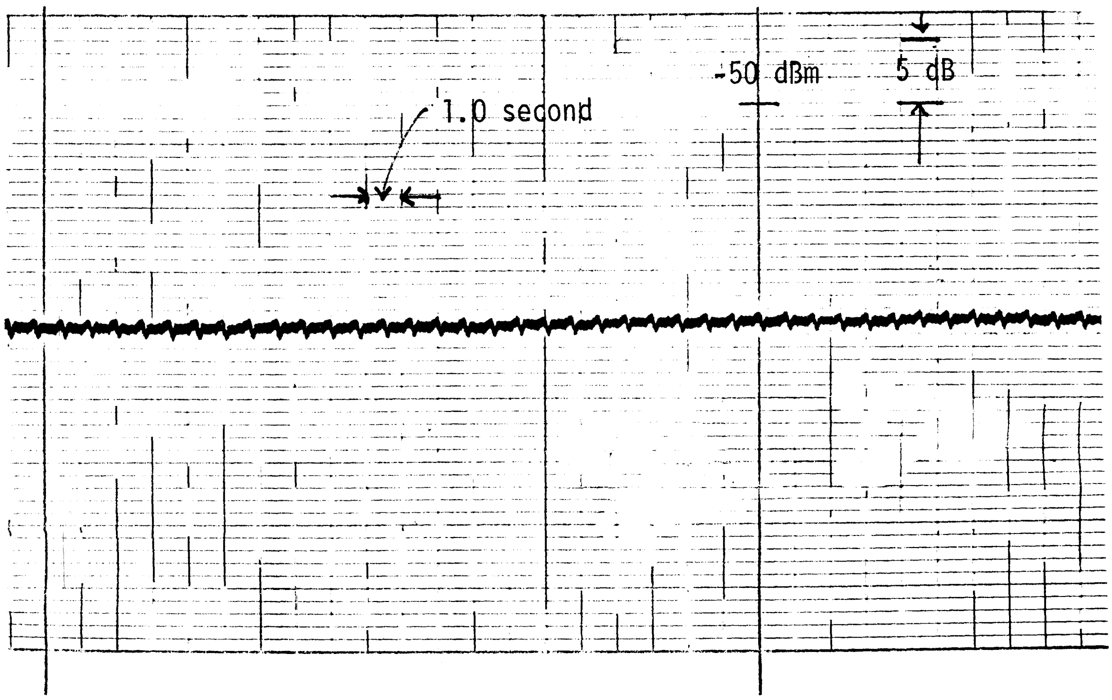

Figure 22(b). TV Channel 10 signal vs. time received at site 3 with the antenna mainbeam pointed at the distant transmitter. Blade rotation frequency = 30 rpm; WT-to-receiver distance = 0.37 km.

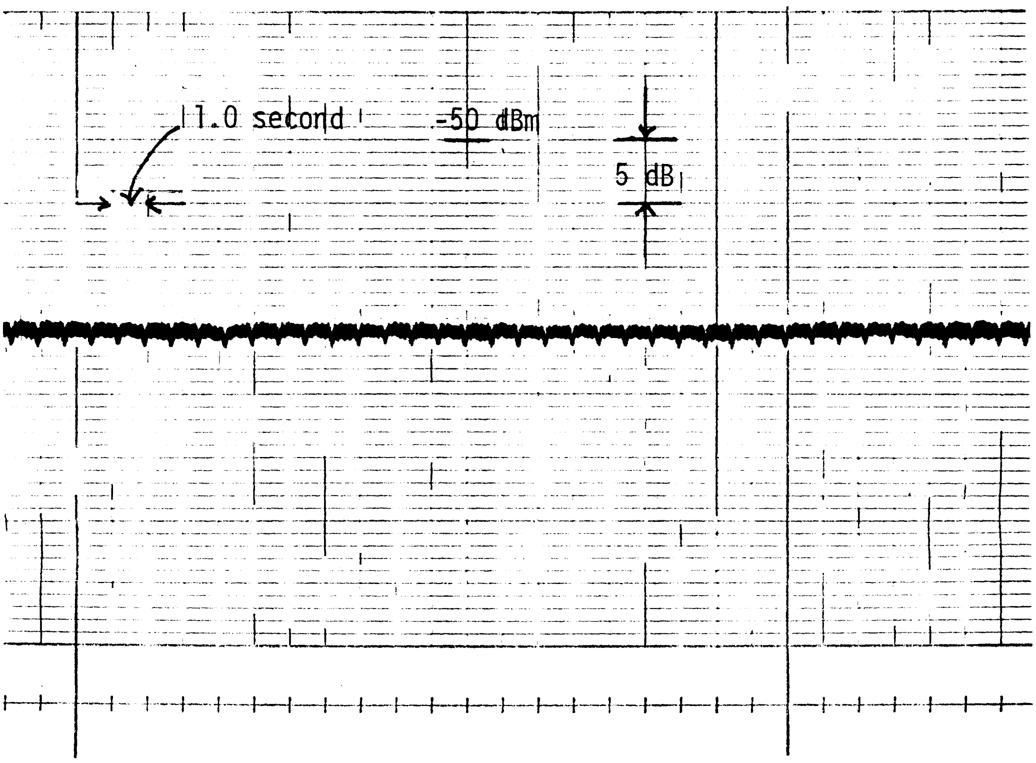

Figure 22(c). TV Channel 12 signal vs. time received at site 3 with the antenna mainbeam pointed at the distant transmitter. Blade rotation frequency = 30 rpm; WT-to-receiver distance = 0.37 km.

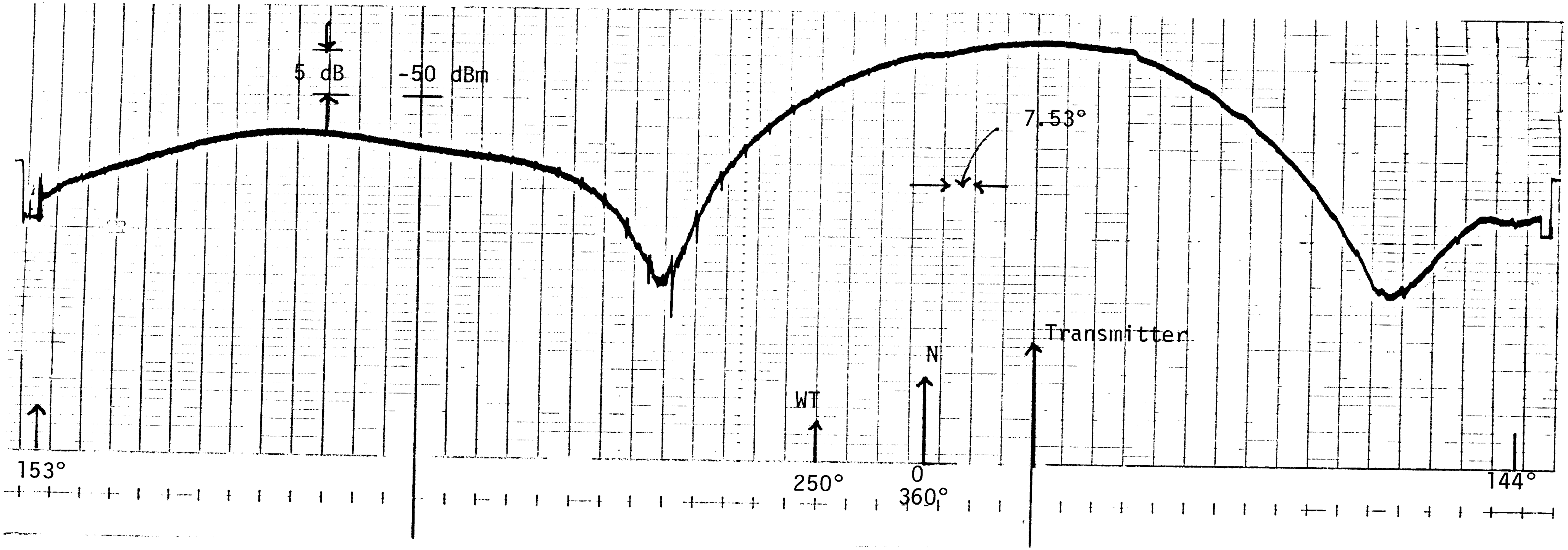

Figure 23(a). Strength of TV Channel 6 signal received at site 4 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height = 4.6 m; WT blades rotating.

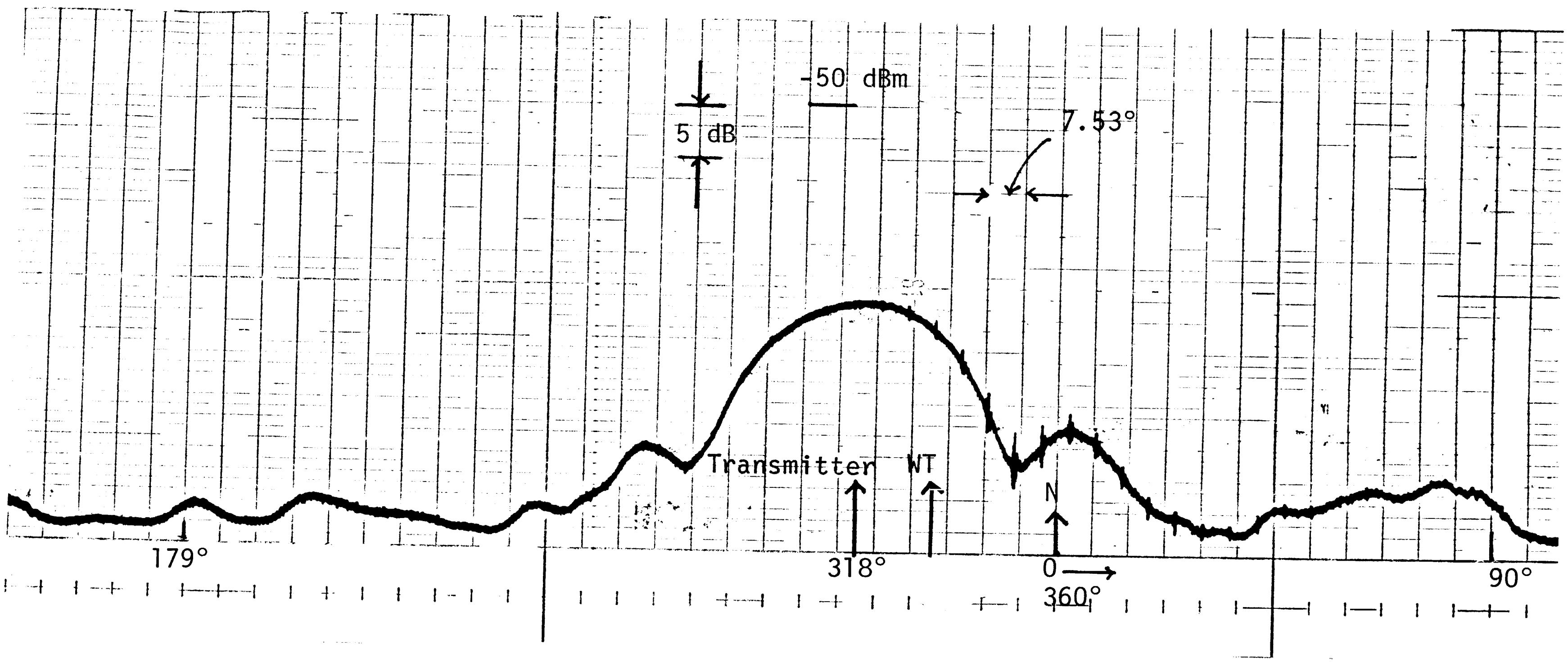

Figure 23(b) Strength of TV Channel 53 signal received at site 4 vs. antenna rotation angle in degrees (or time: 1 division = 1 second). Antenna height = 4.6 m; WT blades rotating.

10.2 Television Interference

For normal viewing of Channel 6 at this site, the antenna should be pointed towards the transmitter. Under this condition, no observable TVI was obtained, as can be seen from Fig. 23(a).

With the antenna pointed towards the operating WT, the received signal as a function of time on Channel 53 is shown in Fig. 24, which indicates that the modulation pulses are of order 2 dB. Even with this orientation, however, no appreciable TV interference was observed.

11. RESIDENTIAL HOME RESULTS

11.1 Site 7

During the initial part of our study, a home was selected at site 7 (see Fig. 4), about 0.4 km away from the WT. The owner was using a 'rabbit-ears' type of indoor antenna and, consequently, the received picture was very snowy, indicative of an extremely low signal level. It was observed that with the windmill blades rotating, video distortion due to the WT occurred on all of the available TV Channels, and that generally the interference synchronized with the vertical position of the blades.

11.2 Home at Site 4

With our receiving antenna oriented to receive the desired signal, the total received signal as a function of time was recorded and the TV picture observed on the owner's RCA XL-100 set with TV Channels 6, 10, 12 and 36. We saw no detectable modulation pulses in the spectrum analyzer output, and no detectable distortion of the received pictures.

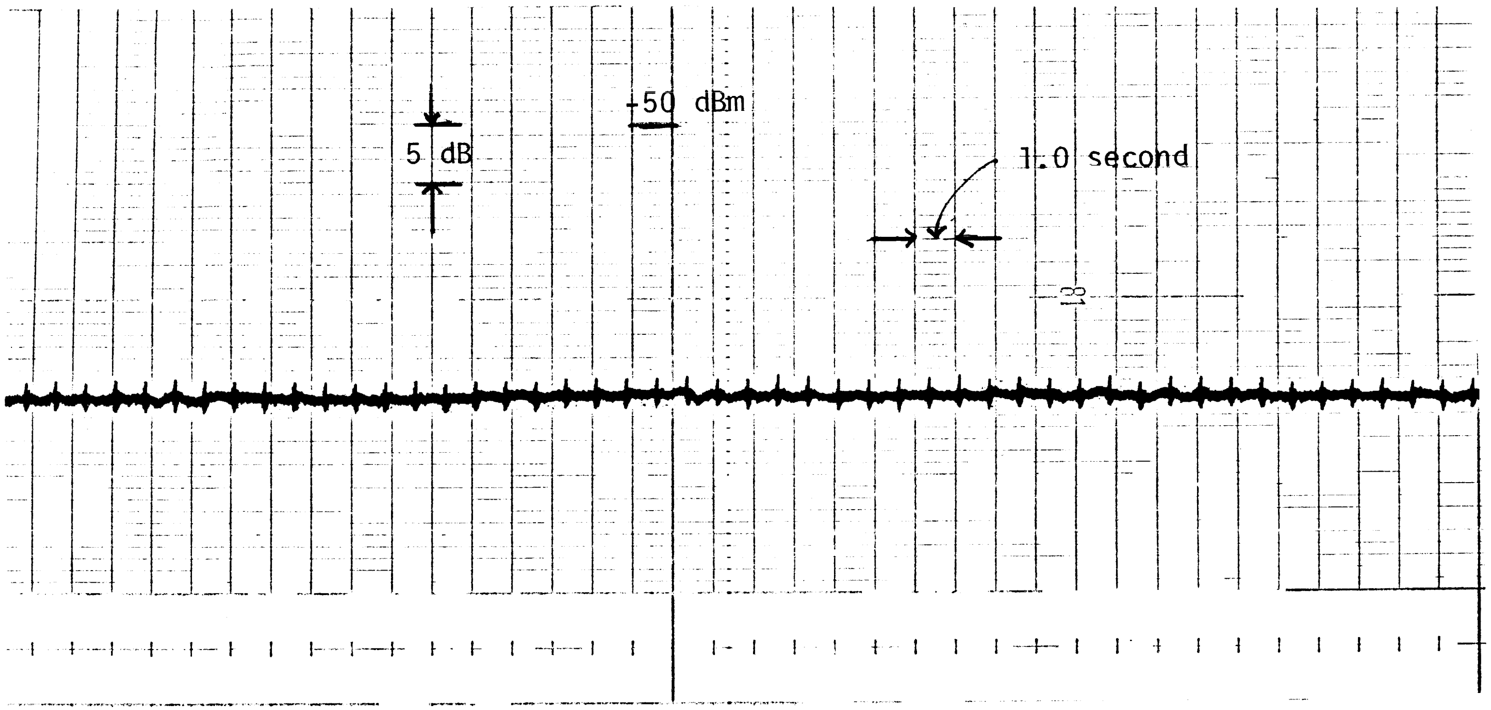

Figure 24. Received TV Channel 53 signal vs. time obtained at site 4 with the antenna pointing toward the WT. Blade rotation frequency $\sim$30 rpm; WT-to-receiver distance = 0.37 km.

11.3 Home at Site 6

Interference tests were conducted on Channels 30 and 53 using the homeowner's TV set model RCA XL-100 with an outdoor bow-tie type of UHF antenna. For both Channels the received signal strength was weak (-85 to -88 dBm). The signal variations of the spectrum analyzer output were about 3 dB, and these produced a fairly strong distortion of the received picture. Due to lack of time, no further measurements were conducted at this home.

12. GENERAL DISCUSSION OF MEASUREMENTS AND RESULTS

Electromagnetic interference to television reception caused by the MOD-OA WT at Block Island has been studied by carrying out a number of on-site measurements at selected test sites and residential homes in the vicinity of the operating windmill. The commercial TV signals available on the island were used as the RF sources. On many occasions during the test program, either the windmill was not in operation due to the lack of a favorable wind or its mode of operation could not be controlled in a manner required by the specific tests. As a result, it was not possible to collect complete (or exhaustive) data during the span of the program. In spite of this, the test measurements provided valuable TVI data. The main findings from the measurements may be summarized as follows:

(i) Block Island is a poor reception area for all of the available TV signals. The ambient signals are weak, and the received picture is generally snowy and of poor quality.

(ii) Using a home-owner's "rabbit-ears" type of antenna, unacceptable interference has been observed on all TV Channels at a home located about 0.4 km from the WT.

With a moderately good receiving antenna having a front-to-back ratio of about 10 dB, unacceptable interference have been observed on Channel 6 at a site 0.24 km from the WT in the backward part of the interference zone. At this site it was also found that the observed interference could be made insignificant by using an antenna whose side and back lobes are $\geq$ 15 dB down; with this antenna no objectionable backward region interference would occur at distances $\gtrsim$ 0.24 km.

At another home 0.37 km from the WT and located in the forward region of interference, unacceptable interference has been observed on Channels 30 and 53 when using the home-owner's "bow-tie" outdoor UHF antenna.

(iii) Using an antenna having 10 dB front-to-back ratio and located 4.6 m above ground, unacceptable interference has been observed at the proposed CATV site located 0.24 km from the windmill. However, detailed measurements showed that the site would be acceptable for a CATV antenna installation provided the antenna system has side and back lobe levels which are at least 15 dB down. It is doubtful if any site closer to the WT would be acceptable, and it is preferable to have the site further away.

Overall, the above results are consistent with those of our previous studies [2,3].

13. CONCLUSIONS

With a poor antenna (such as "rabbit ears") or a good directional antenna incorrectly oriented, the interference on some TV Channels could extend to 1 km and more from the WT. There are a number of homes located within 0.5 km of the WT and some as close as 0.2 km. Most are in the backward portion of the interference zone, but within 1 km of the WT there are many homes whose TV reception could be adversely affected.

Our measurements indicate that a properly oriented directional antenna having side and back lobes at least 15 dB down could provide interference-free reception at those homes 0.2 km or more from the WT that are in the backward region. At distances less than 0.2 km it would be difficult, if not impossible, to avoid the interference even with the best antenna. In addition, there is also a handful of homes which are up to 0.5 km from the WT and in the forward region, and for these the TVI problem would not be corrected by the use of a good antenna.

In this sense, therefore, the installation of a CATV system is justified, particularly since the decision had to be made without benefit of the above results, and even prior to the pertinent results obtained from our earlier studies [2,3,4]. The present tests justify the provision of CATV service at all sites within about 1 km of the WT, but the data do not substantiate the need at distances greater than 1 km. At these greater distances, any TVI could be avoided by the correct use of even a moderately good antenna.

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