ASSESSMENT OF ELECTROMAGNETIC INTERFERENCE EFFECTS OF THE ELLENVILLE WINDFARM

Final Report

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EXECUTIVE SUMMARY

The potential interference effects of 71 wind turbines (WTs) of the proposed Ellenville Windfarm on the performance of various electromagnetic systems operating in its vicinity have been assessed theoretically. Specific non-military systems considered are: three VOR (Very High-Frequency Omni Range) systems within 35 miles of the windfarm; four radio compasses within about 30 miles of the windfarm; seven microwave links: two earth stations (ES) receiving signals from geo-stationary satellites; one cable TV (CATV) Head-end receiving the desired TV signals and available commerical TV Channels operating at Cragsmore. In addition to these systems there may be some radar, navigational and other microwave systems associated with the U.S. Military Services in the region. Since it is understood that the military outfits prefer to do their own assessment, these military systems are excluded from the present assessment. AM and FM broadcast reception outside the windfarm should not be affected significantly; within the windfarms, the reception within a few rotor diameters of the individual WTs may experience some unacceptable interference effects. These systems have also been excluded from the detailed assessment.

The interference assessment has been carried out by assuming that the windfarm consists of vertical axis wind turbines (VAWTs), model F10 250, made by the Flo Wind Corporation. Windfarm interference effects to each of the systems named earlier have been assessed on the

basis of known criteria, and the assessment of such effects on specific systems are summarized below.

(i) <u>VOR Systems</u>

The VOR systems will not experience any unacceptable effects due to the windfarm.

(ii) <u>Radio Compasses</u>

The four radio compasses will not experience any significant interference produced by the windfarm.

(iii) <u>Microwave Links</u>

The performance of all of the microwave links except Links 6 and 8 will not experience any unacceptable effects due to the windfarm. Similar comments apply to the performance of the Links 6 and 8 provided that a few of the presently planned turbine sites are either modified (as recommended) or eliminated.

(iv) <u>Earth Stations</u>

The performance of the earth stations will not experience any unacceptable effects due to the windfarm.

(v) <u>Reception of CATV Head-End</u>

The television interference (TVI) effects produced would be insignificant on all of the TV Channels of interest.

(vi) <u>TV Reception at Cragsmore</u>

Even under the assumption of non-directional receiving antennas, it appears that no unacceptable TVI effects would be produced by the windfarm.

Acknowledgements

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1. Introduction

The present report is concerned with an assessment of the potential effects of interference produced by the proposed Ellenville Windfarm on the performance of various electromagnetic systems operating in its vicinity. The assessment is carried out theoretically, and the specific systems considered are: (i) VHF Omnidirectional Range or VOR navigational systems and radio compass systems, (ii) microwave links, (iii) Earth Stations (ES) receiving signals from geostationary satellites, (iv) television (TV) reception, and (v) Cable TV (CATV) Head-end installations for receiving the desired TV signals.

Undoubtedly, there are some AM- and FM-broadcast systems operating in the area. Reception of AM broadcast signals is usually vulnerable to various locally generated interference effects. The highest AM broadcast frequency being 1.6 MHz ($\lambda \simeq 188$ m), it is unlikely that the windfarm will produce any adverse effects unless the receiver is located within a few rotor diameters of a WT. The reception of FM broadcast signals would be even less vulnerable to such effects. For these reasons, these two systems have also been excluded from the present assessment.

The interference effects of concern arise because of the time varying multipath created by a rotating wind turbine (WT) blade [1]. The primary signal is generally reflected in an almost specular (mirror-like) manner off a blade to produce a secondary (interfering) signal. The strength of the latter is proportional to the equivalent scattering area (A_e) of the blade and decreases with increasing distance from the turbine; at any given distance it also increases with increasing frequency. If this secondary signal is sufficiently strong, it may combine with the primary signal at the receiver to produce unacceptable interference effects on the performance of the system under consideration. A key point is that because the reflection is specular, any given receiver will be affected only when the blade is suitably oriented. The nature and amount of the interference effects observed by the receiver depend on the nature of the electromagnetic system and its associated signal processing logic.

It should be pointed out that the observed interference caused by the assembly of WTs in the windfarm will generally be statistical in nature [2] depending on a number of parameters. However, we shall use non-statistical analyses to estimate the effects produced by the WTs, either singly or together, on each of the electromagnetic systems mentioned earlier. Our assessment will thus pertain to the maximum effects that may occur in a given case under worst conditions.

2. Background Information

Various information needed for the assessment are described in the present section.

2.1 Windfarm and Its Environment. The proposed windfarm (when fully established) will occupy a 1000 acre site approximately three miles southeast of Ellenville, NY and 30 miles west of Poughkeepsie, NY, as indicated on the road map section in Fig. 1. There is also a residential community (400 people) in Cragsmore located about three miles SE of the windfarm.

The proposed windfarm site superimposed on the topographical map of the area is shown in Fig. 2 where the hexagonal sections indicate

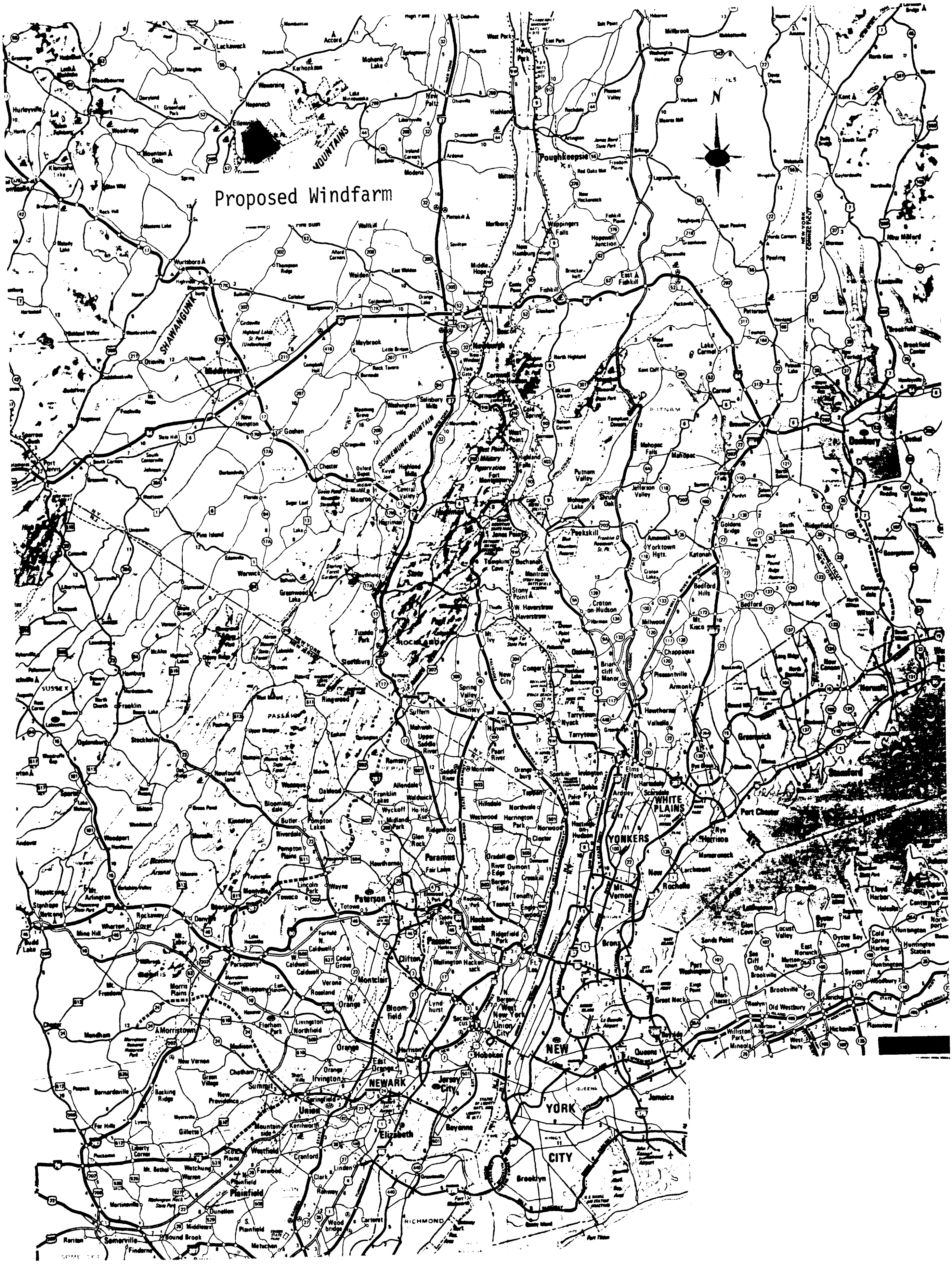

Fig. 1: Road map of the Ellenville area, showing the general location of the windfarm, indicated by   . (Scale: 1 inch = 10 miles).

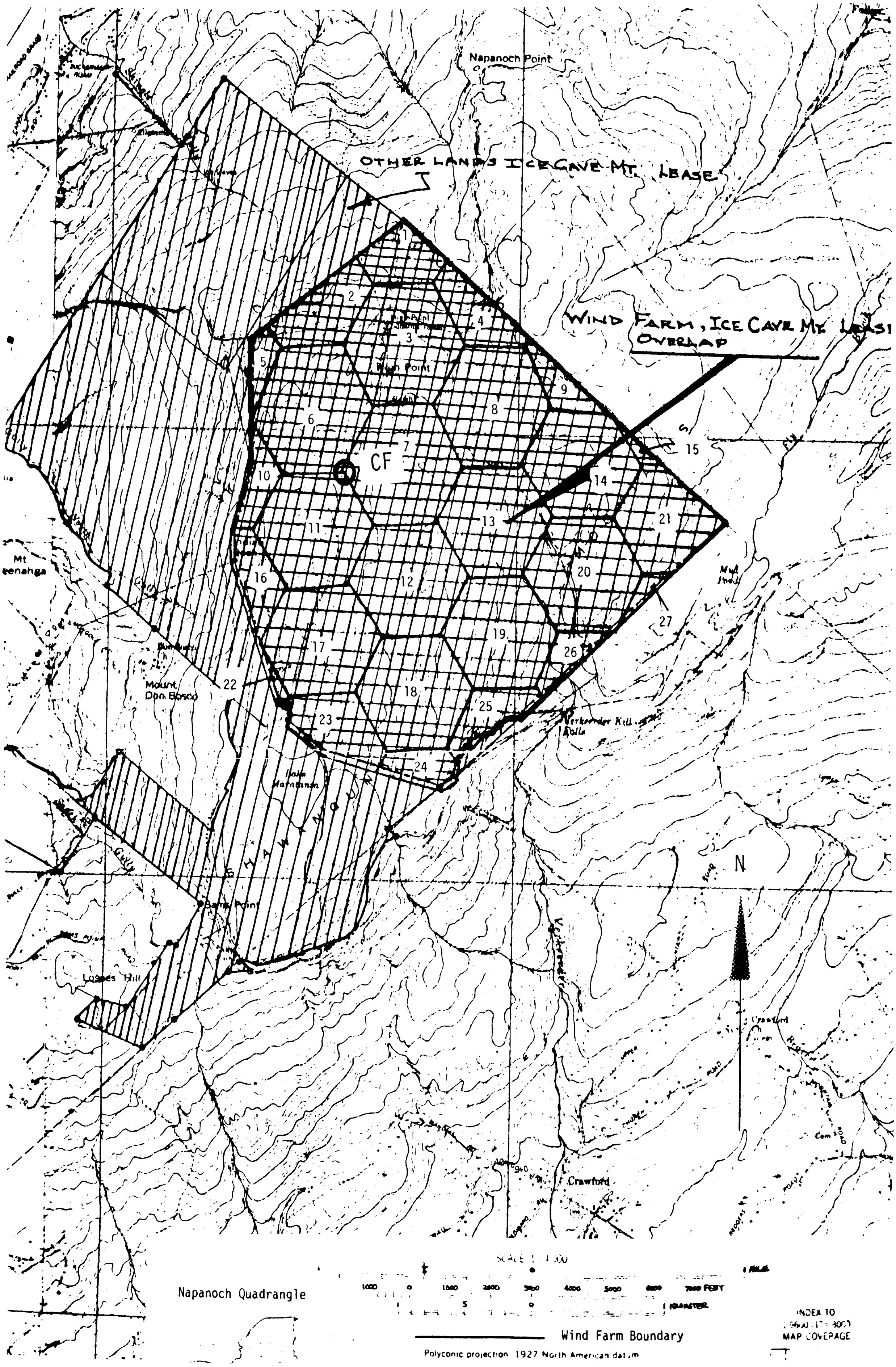

Fig. 2: Topographical map of the Ellenville Windfarm.

the regions where wind turbines (WTs) may be placed. The proposed site for the Phase I of the windfarm are the regions marked 6,7 and 11 in Fig. 2. As presently planned, during Phase I of the project 71 wind turbines will be deployed in a 300 acre area consisting of the regions indicated in Fig. 2; detailed deployment of the wind turbines for Phase I development is shown in Fig. 3 indicating the locations of 71 wind turbines. During the later phase of the project the number of WTs may be increased up to 170 deployed over a larger area. A more detailed version of the windfarm, showing the distribution of the presently planned 71 WTs, superimposed on a topographical map of the region is shown in Fig. 4 where again the hexagonal regions may contain WTs. For future reference we have indicated by CF the center of the Phase I windfarm of 71 WTs. The windfarm area is an unpopulated region with hills rising to about 2260 feet above sea level; the lowest elevation is about 2080 feet and the average is 2200 feet.

It is understood that the residents of Ellenville receive TV signals through cable TV (CATV) service; only the residents of Cragsmore do not use the cable TV service. About 9.0 miles southwest from the CF and outside the farm there is a tower (Head-end) containing antennas which receive available TV signals for a CATV service. The location of the CATV antenna tower (or Head-end) is shown in Fig. 4. The points marked ES in Fig. 4 represent the locations of two satellite earth stations to be discussed later. The directional radials originating from CF in Fig. 4 refer to the directions and distances of New York, Albany, Poughkeepsie and other cities where the transmitters of TV signals originating from those cities are located.

Planned Deployment of Wind Turbines for Phase One Development (Parcels 6, 7 and 11)

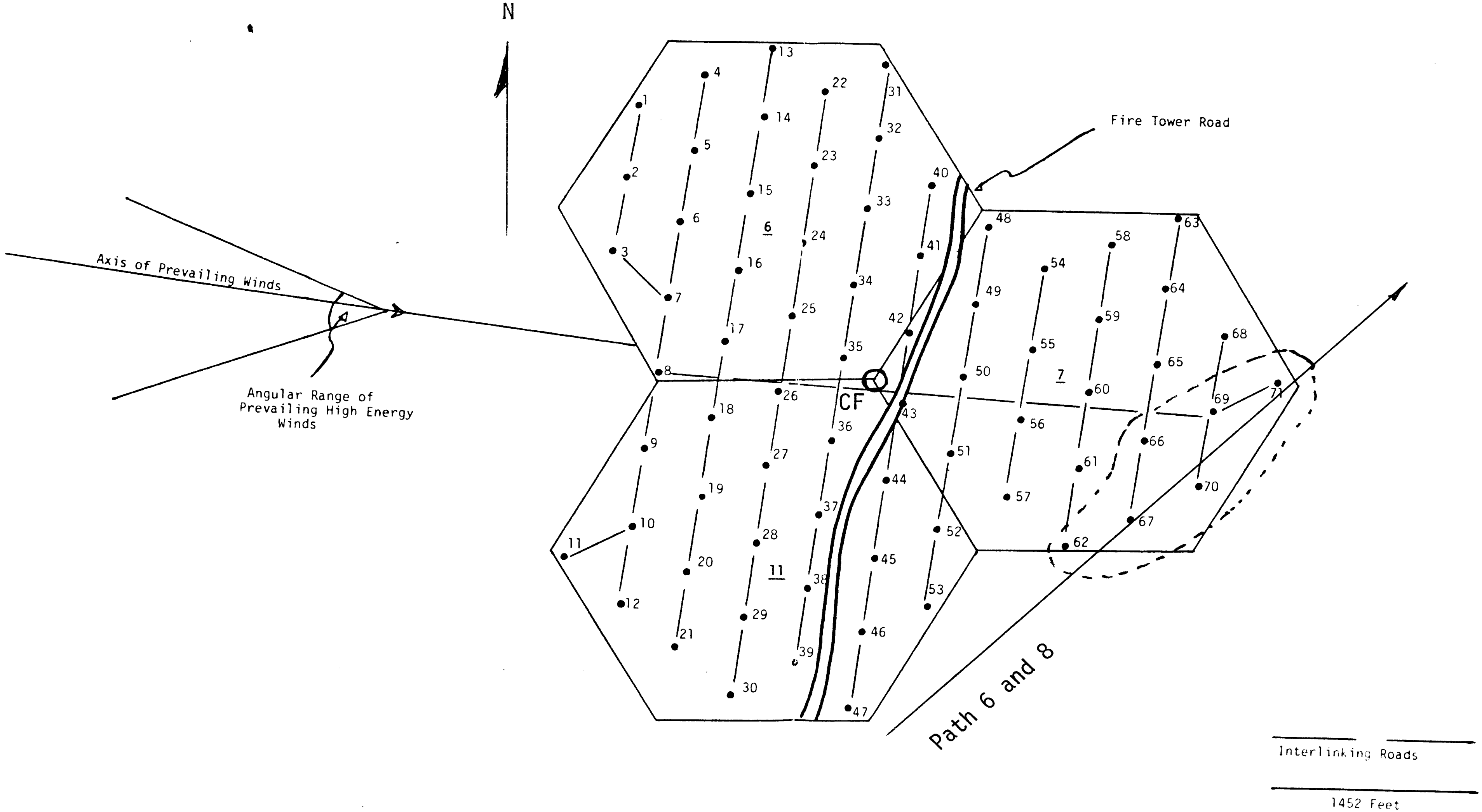

Fig. 3: Planned deployment of WTs for the Phase One development.

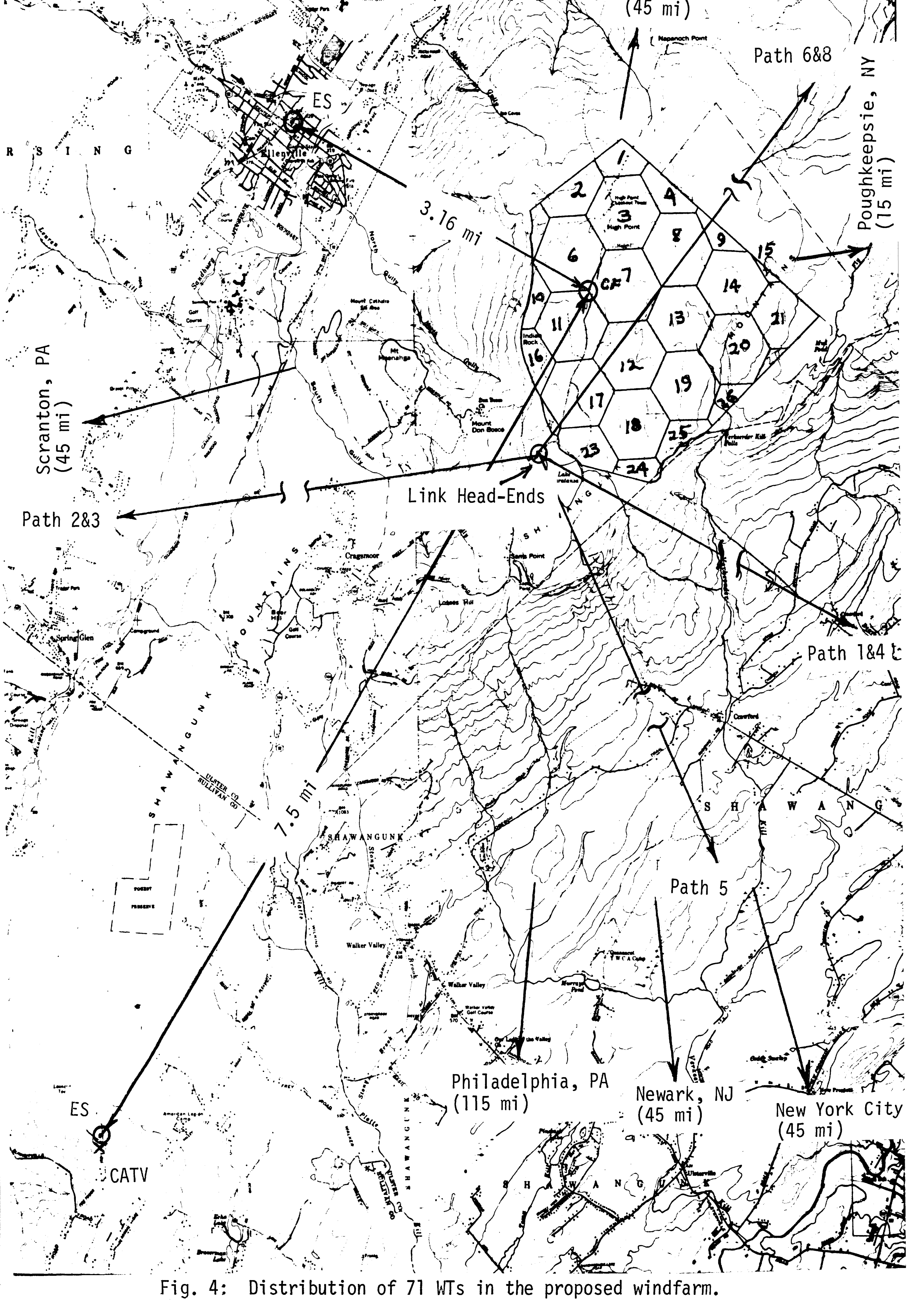

Fig. 4: Distribution of 71 WTs in the proposed windfarm.

2.2 TV Stations. It is believed that only a small community at Cragsmore (about three files from CF) directly receives the commercial TV signals available in the area; other communities in the region receive TV signals provided by a CATV organization whose Head-end is located at Wurtsboro. Table 2.1 lists the appropriate information about TV Channel signals received by the CATV system.

The terrain in the windfarm area is hilly, and all of the TV Channels may not be available for direct reception at all places. Also, due to shadowing and other effects, the ambient signal levels on some of the Channels may be very weak. This may be the case at Cragsmore.

2.3 VOR Station. Throughout the country the Federal Aviation Administration (FAA) maintains VHF Omni Range (VOR) [3] ground stations which provide navigation information to aircraft in flight. From FAA maps of VOR ground stations in the area, three VOR stations have been identified within about 35 miles of the windfarm. The relevant information about the three VOR stations is given in Table 2.2. The three VOR systems listed in Table 2.2 operate at slightly different frequencies. For computational purposes we shall assume that the operating frequency of each VOR is $f = 120$ MHz, with wavelength $\lambda = 2.5$ m.

2.4 Radio Compass. There exist four radio compasses in the region. The location of their transmitting antennas and other relevant information are given in Table 2.3.

2.5 Microwave Links. A number of microwave link paths used for point-to-point communication purposes criss-cross the windfarm area.

Table 2.1

TV Channel Signals Received by the CATV Head-end at Wurtsboro

(Distance = 7.5 miles from CF, elevation = 1470 ft, antenna tower height = 250 ft)

Station	TV Channel Number	TV Channel Video Freq. (MHz)	Origin (city)	Degrees from North
--	2	55.25	New York	154°
--	4	67.25	New York	154°
--	5	77.25	New York	154°
--	7	175.25	New York	154°
--	9	187.25	New York	154°
WPIX	11	199.25	New York	154°
	12	205.25	Poughkeepsie	75°
WNET	13	211.25	New York	154°
WTAF	17	488.25	Philadelphia	185°
WBRE			Scranton	257°
WDAN	22	519.25	Scranton	257°
WPWL	29	561.25	Philadelphia	185°
WNYE	31	573.25	New York	154°
WXTV	--		Patterson	169°
WNJU	--		Newark	158°
WNYL	--		New York	154°

Table 2.2

VOR Ground Stations Near the Windfarm

Designation	Frequency of Operation (MHz)	Direction from Windfarm	Distance from the Center of the windfarm (miles)
Pawling	112.2	East	34
Kingston	117.6	East	22
Huguenot	116.1	Southwest	27

Table 2.3

Radio Compasses Near the Windfarm

Location	Frequency (MHz)	Distance from the center of the windfarm (miles)	Direction
Meier	403	17.21	East
Neely	335	14.25	South
Otims	353	16.64	South
Monga	201	31.46	West

The points of origin or Head-ends of a number of such links are located near the windfarm (Fig. 4) and at a distance of about 1.15 miles from the center of the windfarm. Detailed technical information regarding the microwave links in the region was obtained from Spectrum Planning, Inc., of Richardson, TX, and is shown in Table 2.4 where the link paths are identified by numbers such as 6,8 etc. Using the data shown in Table 2.4 we have prepared a map indicating the microwave links in the windfarm region as shown in Fig. 5, where it can be seen that paths 6 and 8 are overhead and the rest have one Head-end in the windfarm area. From Fig. 5 it can be seen that the windfarm may have some impact only on the links 6 and 8. The WTs in the immediate vicinity of these two link paths may be identified in Fig. 4 and are identified in Fig. 3 as WT Nos. 62, 67, 66, 70, 69 and 71. As can be seen from Table 2.4 all links use slightly different frequency for reception and transmission and for convenience of calculation we shall assume that each link operates at a single average frequency for both.

2.6 Earth Stations. Two earth stations (ES) communicating with geo-stationary satellites are located in the vicinity of the windfarm and are shown as ES in Fig. 5. Each of the earth stations is equipped with large parabolic dish antennas (10 m and/or 15 m in diameter) which are commonly directed at the desired stationary satellite located above the equator. The present two earth station antennas would be generally directed towards the southerly direction, and their antenna beams would not cross the windfarm area.

2.7 Wind Turbines. It is understood that the wind turbine constituting the windfarm will belong to a class of vertical axis wind turbines (VAWTs) manufactured by the Flo Wind Corporation.

Table 2.4

Microwave Links in the Vicinity of the Windfarm

Path 1: Common Carrier Microwave

CALL SIGN & OWNER	WCG284 NYTEL	KYN59 NYTEL
STATE & LOCATION	NY, WALDEN	NY, ELLENVILLE
ELEVATION	516 FT	2274 FT
LATITUDE	41-35-59 N	41-41- 1 N
LONGITUDE	74- 7-48 W	74-21-24 W
AZIMUTH & DISTANCE	296.34 DEG 13.09 MI	116.18 DEG 21.06 KM
TRANSMIT ANT TYPE	USR10P-3J107	USR10P-3J107
FCC DESIG & MANFAC	G13700 GABRIEL	G13700 GABRIEL
ANT GAIN & HEIGHT	47.9 DBI 60 FT	47.9 DBI 62 FT
RECEIVE ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
DIVERSITY ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
EQUIPMENT MANUFAC	NIPPON ELECTRIC	NIPPON ELECTRIC
MANUFACTURERS TYPE	TRP11GD672-101A	TRP11GD672-101A
EMISSION DESIGNATION	40000F9Y	40000F9Y
FCC DESIG & STABILITY	2PT201 .00500	2PT201 .00500
XMIT POWER & LINE LOSS	29.0 DBM 0 DB	29.0 DBM 0 DB
RECV SIGNAL LEVEL	-15.1 DBM	-15.1 DBM
TRAFFIC TYPE	672 DIGITAL	672 DIGITAL
TRANSMIT FREQS	10755.0B 10715.0U 10375.0G 11115.0B 10795.0B 11035.0B	11405.0B 11645.0U 11325.0G 11565.0B 11245.0U 11485.0B

Path 2

CALL SIGN & OWNER	WCG285 NYTEL	KYN59 NYTEL
STATE & LOCATION	NY, MONTICELLO	NY, ELLENVILLE
ELEVATION	1543 FT	2274 FT
LATITUDE	41-39-14 N	41-41- 1 N
LONGITUDE	74-41-10 W	74-21-24 W
AZIMUTH & DISTANCE	83.03 DEG 17.17 MI	263.25 DEG 27.63 KM
TRANSMIT ANT TYPE	USR12P-3J107	USR10P-3J107
FCC DESIG & MANFAC	G16900 GABRIEL	G13700 GABRIEL
ANT GAIN & HEIGHT	49.5 DBI 60 FT	47.9 DBI 62 FT
RECEIVE ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
DIVERSITY ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
EQUIPMENT MANUFAC	NIPPON ELECTRIC	NIPPON ELECTRIC
MANUFACTURERS TYPE	TRP11GD672-101A	TRP11GD672-101A
EMISSION DESIGNATION	40000F9Y	40000F9Y
FCC DESIG & STABILITY	2PT201 .00500	2PT201 .00500
XMIT POWER & LINE LOSS	29.0 DBM 0 DB	29.0 DBM 0 DB
RECV SIGNAL LEVEL	-15.9 DBM	-15.9 DBM
TRAFFIC TYPE	672 DIGITAL	672 DIGITAL
TRANSMIT FREQS	10955.0G 10715.0B 10375.0G 11115.0U 10795.0U 11035.0B	11405.0G 11645.0B 11325.0G 11565.0U 11245.0U 11485.0B

Path 3

CALL SIGN & OWNER	WCG285 NYTEL	KYN59 NYTEL
STATE & LOCATION	NY, MONTICELLO	NY, ELLENVILLE
ELEVATION	1543 FT	2274 FT
LATITUDE	41-39-14 N	41-41- 1 N
LONGITUDE	74-41-10 W	74-21-24 W
AZIMUTH & DISTANCE	83.03 DEG 17.17 MI	263.25 DEG 27.63 KM
TRANSMIT ANT TYPE	USR12P-3J107	USR10P-3J107
FCC DESIG & MANFAC	G16900 GABRIEL	G13700 GABRIEL
ANT GAIN & HEIGHT	47.5 DBI 57 FT	47.9 DBI 62 FT
RECEIVE ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
DIVERSITY ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
EQUIPMENT MANUFAC	NIPPON ELECTRIC	NIPPON ELECTRIC
MANUFACTURERS TYPE	TRP11GD672-101A	TRP11GD672-101A
EMISSION DESIGNATION	40000F9Y	40000F9Y
FCC DESIG & STABILITY	2PT201 .00500	2PT201 .00500
XMIT POWER & LINE LOSS	31.0 DBM 0 DB	31.0 DBM 0 DB
RECV SIGNAL LEVEL	-13.9 DBM	-13.9 DBM
TRAFFIC TYPE	96 DIGITAL	96 DIGITAL
TRANSMIT FREQS 10955.0V	10875.0V 10775.0H	11405.0V 11325.0V 11245.0H

Path 4

CALL SIGN & OWNER	KYN59 NYTEL	WCG284 NYTEL
STATE & LOCATION	NY, ELLENVILLE	NY, WALDEN
ELEVATION	2274 FT	516 FT
LATITUDE	41-41- 1 N	41-35-59 N
LONGITUDE	74-21-24 W	74- 7-48 W
AZIMUTH & DISTANCE	116.18 DEG 13.09 MI	296.34 DEG 21.06 KM
TRANSMIT ANT TYPE	USR10P-3J107	USR10P-3J107
FCC DESIG & MANFAC	G13700 GABRIEL	G13700 GABRIEL
ANT GAIN & HEIGHT	47.9 DBI 62 FT	47.9 DBI 60 FT
RECEIVE ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
DIVERSITY ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
EQUIPMENT MANUFAC	NIPPON ELECTRIC	NIPPON ELECTRIC
MANUFACTURERS TYPE	TRP11GD672-101A	TRP11GD672-101A
EMISSION DESIGNATION	40000F9Y	40000F9Y
FCC DESIG & STABILITY	2PT201 .00500	2PT201 .00500
XMIT POWER & LINE LOSS	31.0 DBM 0 DB	31.0 DBM 0 DB
RECV SIGNAL LEVEL	-13.1 DBM	-13.1 DBM
TRAFFIC TYPE	96 DIGITAL	96 DIGITAL
TRANSMIT FREQS 11605.0V	11525.0V 11285.0H	11155.0V 11075.0V 10835.0H

Path 5

CALL SIGN & OWNER	KEA63 ATTNEA	KEG62 ATTNEA
STATE & LOCATION	NY, JACKIE JONS	NY, ELLENVILLE
ELEVATION	1226 FT	2270 FT
LATITUDE	41-13-27 N	41-41- 1 N
LONGITUDE	74- 4-11 W	74-21-24 W
AZIMUTH & DISTANCE	334.93 DEG 35.03 MI	154.74 DEG 56.38 KM
TRANSMIT ANT TYPE	KS15676	KS15676
FCC DESIG & MANFAC	B43000 WE	B43000 WE
ANT GAIN & HEIGHT	39.4 DBI 217 FT	39.4 DBI 83 FT
RECEIVE ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
DIVERSITY ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
EQUIPMENT MANUFAC	WESTERN ELECTRIC	WESTERN ELECTRIC
MANUFACTURERS TYPE	TD-2	TD-2
EMISSION DESIGNATION	20000F9	20000F9
FCC DESIG & STABILITY	2PYY01 .00500	2PYY01 .00500
XMIT POWER & LINE LOSS	33.0 DBM 0 DB	33.0 DBM 0 DB
RECV SIGNAL LEVEL	-27.6 DBM	-27.6 DBM
TRAFFIC TYPE	1200 CHANNEL MSG	1200 CHANNEL MSG
TRANSMIT FREQS	3730.0V 3810.0V 3890.0V 3970.0V 4050.0V 4130.0V	3770.0V 3850.0V 3930.0V 4010.0V 4090.0V 4170.0V

Path 6

CALL SIGN & OWNER	KEE58 ATTNEA	KEG62 ATTNEA
STATE & LOCATION	NY, HALIHAN HILL	NY, ELLENVILLE
ELEVATION	524 FT	2270 FT
LATITUDE	41-59-20 N	41-41- 1 N
LONGITUDE	74- 1- 8 W	74-21-24 W
AZIMUTH & DISTANCE	219.72 DEG 27.35 MI	39.49 DEG 44.01 KM
TRANSMIT ANT TYPE	KS15676	KS15676
FCC DESIG & MANFAC	B43000 WE	B43000 WE
ANT GAIN & HEIGHT	39.4 DBI 108 FT	39.4 DBI 83 FT
RECEIVE ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
DIVERSITY ANT TYPE		
FCC DESIG & MANFAC		
ANT GAIN & HEIGHT		
EQUIPMENT MANUFAC	WESTERN ELECTRIC	WESTERN ELECTRIC
MANUFACTURERS TYPE	TD-2	TD-2
EMISSION DESIGNATION	20000F9	20000F9
FCC DESIG & STABILITY	2PYY01 .00500	2PYY01 .00500
XMIT POWER & LINE LOSS	37.0 DBM 0 DB	37.0 DBM 0 DB
RECV SIGNAL LEVEL	-21.5 DBM	-21.5 DBM
TRAFFIC TYPE	1500 CHANNEL MSG	1500 CHANNEL MSG
TRANSMIT FREQS	3710.0H 3790.0H 3870.0H 3950.0H 4030.0H 4110.0H	3750.0H 3830.0H 3910.0H 3990.0H 4070.0H 4150.0H

Path 8

CALL SIGN & OWNER	KEM47	NYTEL	KYN59	NYTEL
STATE & LOCATION	NY, HALIHAN HILL		NY, ELLENVILLE	
ELEVATION	520 FT		2274 FT	
LATITUDE	41-59-22 N		41-41- 1 N	
LONGITUDE	74- 1- 6 W		74-21-24 W	
AZIMUTH & DISTANCE	219.72 DEG	27.39 MI	39.49 DEG	44.09 KM
TRANSMIT ANT TYPE	KS-15676		KS-15676	
FCC DESIG & MANFAC	B63100	WE	B63100	WE
ANT GAIN & HEIGHT	43.0 DBI	108 FT	43.0 DBI	83 FT
RECEIVE ANT TYPE				
FCC DESIG & MANFAC				
ANT GAIN & HEIGHT				
DIVERSITY ANT TYPE				
FCC DESIG & MANFAC				
ANT GAIN & HEIGHT				
EQUIPMENT MANUFAC	RAYTHEON		RAYTHEON	
MANUFACTURERS TYPE	KTR-3A		KTR-3A	
EMISSION DESIGNATION	30000F9		30000F9	
FCC DESIG & STABILITY	2JYE03	.00200	2JYE03	.00200
XMIT POWER & LINE LOSS	40.0 DBM	0 DB	40.0 DBM	0 DB
RECV SIGNAL LEVEL	-15.2 DBM		-15.2 DBM	
TRAFFIC TYPE	VIDEO		VIDEO	
TRANSMIT FREQS 6226.9H			6063.8H	

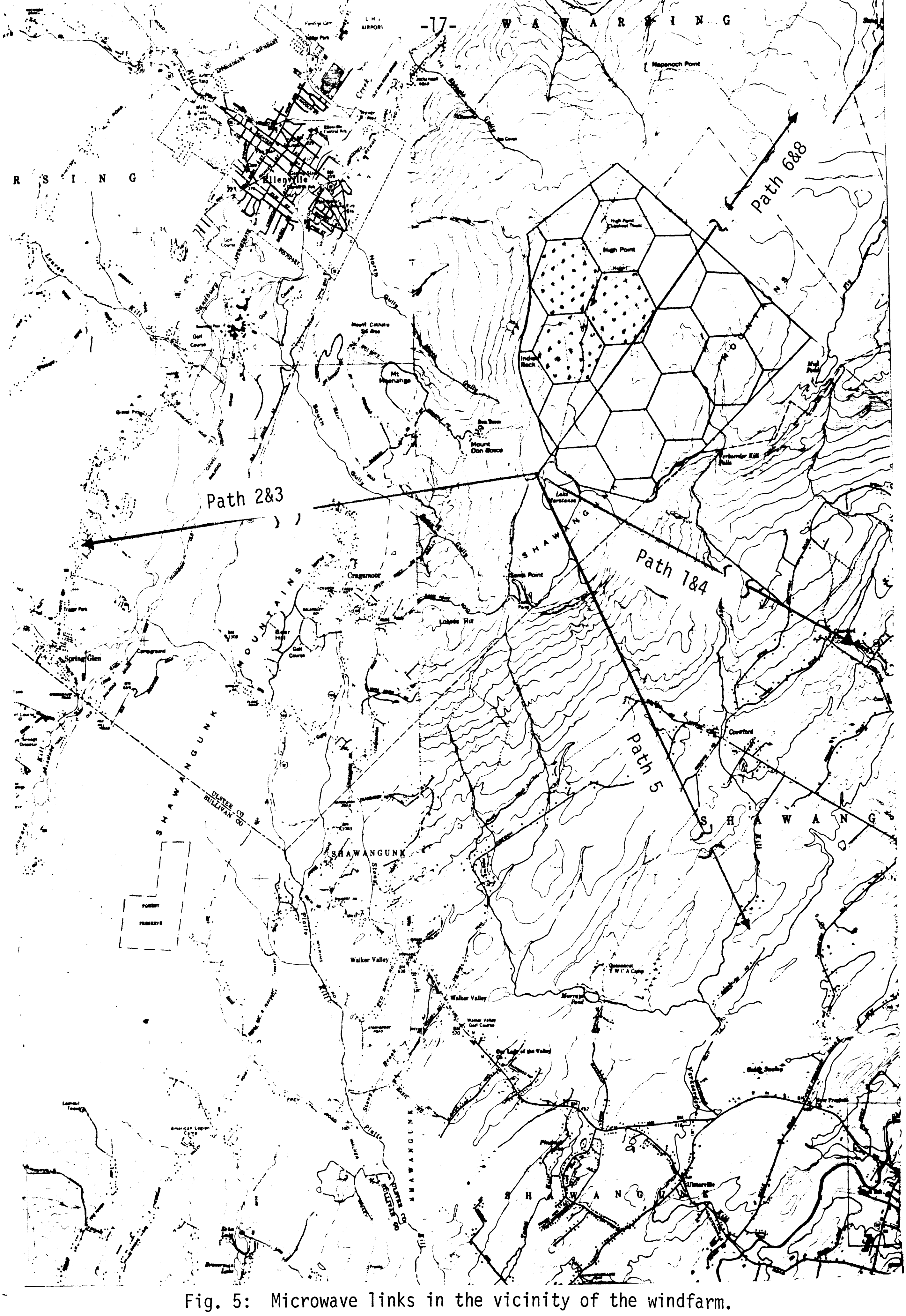

Fig. 5: Microwave links in the vicinity of the windfarm.

Specific models considered are Flo 170, Flo 250 and Flo 500, and it is believed that the Phase I windfarm will consist of Flo 250 WTs. Relevant information about all three WTs needed for their electromagnetic interference assessment is given in Table 2.5. The blades are made of aluminum and the turbine rpm is 53.

The most important parameter needed for the assessment of the electromagnetic interference caused by a wind turbine is the equivalent scattering area (A_e) of its blade [4]. For the present WTs the appropriate A_e will be obtained by using the following [4]:

$$A_e = w\sqrt{D\lambda} \tag{1}$$

where w = blade width,

D = rotor diameter and

λ = wavelength.

For Flo 250, w = 0.61 m, D = 17.1 m and we obtain

$$A_e = 2.52\sqrt{\lambda} \quad m^2 \tag{2}$$

We shall use Eq. (2) for the assessment of interference to all systems caused by the Flo 250 WTs.

3. Interference Assessment Procedure

The interference assessment which has been carried out is analytical and, in the case of those systems which are impacted, quantitative. The procedures used are based on the analyses and

Table 2.5

Relevant Information about the Three Vertical Axis Wind Turbines

WT Type	Blade Width (m)	Rotor Dia. (m)	Rotor Ht. (m)	Ground Clearance (m)	Overall Ht. (m)
Flo 170 (170 kW)	0.61	17.1	22.9	5.1	28
Flo 250 (250 kW)	0.61	17.1	22.9	5.1	28
Flo 500 (500 kW)	0.61?	25.0	37.5	5.1	42.6

techniques developed by the Radiation Laboratory during our previous studies of electromagnetic interference produced by WTs, the details of which may be found in [1,5-7]. In the present section we merely quote the basic criteria used to judge the acceptability (or unacceptability) of the interference effects produced in a given situation, and these same criteria are also used to judge the acceptability (or unacceptability) of a particular WT at a given site.

The basic parameter that is used to judge the effect of WT-produced interference on an electromagnetic system is

$$\Gamma = \frac{\text{amplitude of the interference signal caused by one WT}}{\text{amplitude of the desired (direct) signal}} , \tag{3}$$

where the fields are computed at the receiver of the system under consideration. As mentioned in the Introduction, the interference signal is produced by scattering off the WT blade(s), and in general

$$\Gamma = \frac{E_B}{E_R} \frac{A_e}{\lambda d} , \tag{4}$$

where E_B,E_R are the amplitudes of the ambient electric fields at the WT and the receivers, respectively,

λ is the operating wavelength and

d is the distance between the WT and the receiver.

Γ also depends in a rather complicated manner on the ambient signal strengths at the WT and receiver locations, and on the receiving antenna characteristics [1,4]. In our previous studies we developed approximate expressions for Γ under various situations. In the absence of specific information about E_B and E_R we shall make appropriate approximations in individual cases. Assuming that the interference effects produced by the individual machines are additive in power, the total effect produced by N WTs is then judged by the parameter Γ_T:

$$\Gamma_T = \sum_{n=1}^{N} \left(\Gamma_n^2\right)^{1/2} ,$$

where Γ_n is that produced by the nth WT. In many cases we shall assume $\Gamma_1 = \Gamma_2 .. = \Gamma_N = \Gamma$, and use

$$\Gamma_T = \sqrt{N}\,\Gamma \quad . \tag{5}$$

In some cases only the machine(s) closest to the receiver cause most of the problem, but in other cases there can be many machines which contribute significantly to the total effect. The actual criteria (including the values of Γ_T or Γ) which are used to judge the interference effects depend on the electromagnetic system under consideration, and are discussed in the following sections.

3.1 Interference to VOR and Radio Compass. In the vicinity of a VOR ground station the FAA prohibits [3] the existence of any tall scattering object which makes an angle of more than 1.5° (for metal objects) and 2.5° (for wooden or non-metallic objects) at the phase center of the VOR antenna. It is also recommended that the amplitudes of any reflected or scattered interfering signal relative to that of the desired signal at the receiver not exceed 20 percent. We shall use the following acceptability criterion for assessing the effect of interference on VOR performance:

$$\Gamma_T \text{ (or } \Gamma) \leq 0.2 \text{ (or } -14 \text{ dB)} \quad . \qquad (6)$$

In the absence of more detailed information about the radio compasses in the region, we shall use the acceptability criterion for such systems in the same manner (i.e., Eq. 8) as that for earth stations discussed in Section 3.3.

3.2 Interference to Microwave Link. The satisfactory performance of a microwave link system requires that there be adequate clearance between the link path, i.e., the optical line-of-sight transmission path between the two link antennas, and any nearby scattering objects. It is often required [8] that all scattering objects lie outside the first few Fresnel zones as shown in Fig. 6 and in the present case we shall use the acceptability criterion

$$H \geq 3H_1 \quad . \qquad (7)$$

The parameter H_1 is obtained from a knowledge of d, d_1 and the operating wavelength.

In addition to using the criterion given by Eq. (7), in some cases we have also calculated Γ_T (or Γ) to estimate the magnitude of the scattered (or interfering) signal relative to the desired one.

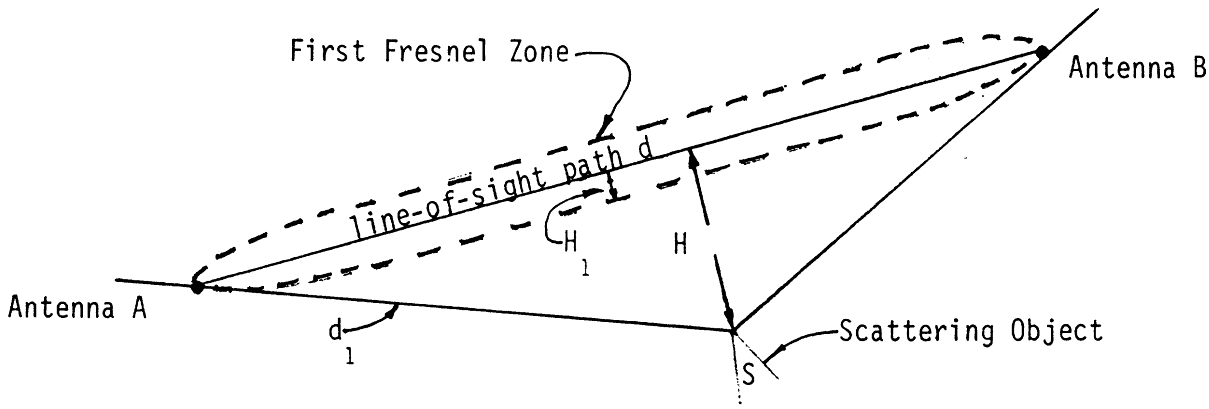

Fig. 6: Diagram showing a scattering object outside the first Fresnel zone of the link antennas.

H_1 = first Fresnel zone distance and

H = the clearance of S from the link path.

3.3 Interference to Earth Stations. Interference to an earth station (ES) communicating with a geo-stationary satellite has been assessed by using the Fresnel distance criterion, given by Eq. (7), used for the microwave links. We have also used the acceptability criterion

$$\Gamma_T \leq 0.01 \text{ (-40 dB)} \quad (8)$$

to estimate the level of interference signal at the earth station.

3.4 Interference to Television Reception. WT interference effects to TV reception generally appear in the form of video distortion occurring at twice the rotation frequency of the blade. The dominant parameter determining the interference by a WT is the equivalent scattering area of its blade. However, at a certain distance from the WT the maximum video distortion observed depends on the state of the WT blade (i.e., pitch, plane of rotation, etc.), the ambient signal strengths at the WT and the receiver, the characteristics of the receiving antenna, and on whether the receiver is located in the forward or backward region of the WT. In the backward region the directional property of the receiving antenna may be used to discriminate against the interference effects but in the forward region this cannot be done and hence the effects may be more severe.

When the blades are stationary the scattered field may appear on the TV screen as a ghost whose position (i.e., separation from the direct picture) depends on the difference between the time delays suffered by the direct 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 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 larger interference can disrupt the TV receiver's vertical sync, causing the picture to roll over ('slip') or even break up. This type of interference occurs when the interfering signal reaches the receiver as a result of scattering, primarily specular, off the broad face of a blade, and is called the backward region interference. As the angle between the WT-transmitter and WT-receiver directions increases, the separation of the ghost decreases, and a somewhat greater interference is now required to produce the same amount of distortion. In the forward scattering region, when the WT is almost in line between the transmitter and the receiver, there is virtually no difference in the times of arrival of the primary and secondary signals. The ghost is then superimposed on the undistorted picture and the video interference appears as an intensity (brightness) fluctuation of the picture in synchronism with the blade rotation. In all cases, the amount of interference depends on the strength of the scattered signal relative to the primary signal at the receiver, i.e., on the modulation index of the total received signal, and the modulation threshold is defined to be the largest value of the modulation index for which the distortion is still judged to be acceptable.

It can be shown [1,2,5,6] that in the case of television interference (TVI) caused by WTs, the parameter Γ_T (or Γ), defined earlier, can be interpreted as the amplitude modulation index m_T (or m) suffered by the received signal due to the scattering by the rotating WT blades. Judgement of TVI effects or the video distortion observed is made on the basis of m_T (or m).

In the backward region for all levels of ambient signals, and in the forward region where the ambient signal is weak, interference effects are judged to be acceptable if

$$m_T \text{ (or m)} \leq 0.15 \quad (\sim -17 \text{ dB}) \quad . \tag{9}$$

For a receiver in the forward region where the ambient signal is strong, the corresponding criterion is

$$m_T \text{ (or m)} \leq 0.35 \quad (\sim -9 \text{ dB}) \quad . \tag{10}$$

The above criteria are based on the subjective assumption [4] that the resultant video distortion is acceptable. For satisfactory performance of a CATV Head-end the requirement on the interfering signal is more severe [9] and we shall assume the following acceptability criterion:

$$m_T \text{ (or m)} \leq 0.05 \quad (-26 \text{ dB}) \quad . \tag{11}$$

4. Assessment of Interference

The windfarm interference effects on various systems are quantitatively estimated in the present section. The assessment includes the effects of 71 Flo 250 WTs which are presently planned to be installed in the windfarm. Where appropriate, information is also supplied for the effects produced by the windfarm consisting of 170 such WTs.

4.1 Interference to VOR. The interference signal ratio Γ_T at the VOR receiver, produced by the windfarm, has been calculated for the VOR systems identified in Table 2.2. Detailed calculations of Γ_T for specific cases are discussed in Appendix 1.

Γ_T values for the Kingston VOR system obtained for windfarms of 71 and 170 WTs are shown in Table 4.1 which indicates that for both cases the windfarm produces $\Gamma_T < -14$ dB, i.e., any interference effects produced would be insignificant. The other VOR ground stations being farther away from the windfarm (see Table 2.2), it is unlikely that their performance would be adversely affected by the windfarm.

4.2 Interference to Radio Compasses. With the information given in Table 2.3 and using Eqs. (2) and (4) and assuming $E_T = E_R$ we have calculated the appropriate Γ_1 and Γ_T values for the four radio compasses under consideration. The results are shown in Table 4.2. In all cases, the Γ_T values are found to be less than -40 dB.

4.3 Interference to Microwave Links. Assessment of interference to the microwave links in the vicinity of the windfarm has been carried out on the basis of Fresnel distance criterion mentioned in Section 3.2. Details of actual calculations required for sample assessment are described in Appendix II. Among the many microwave links originating from Head-ends located near the windfarm only paths 6 and 8 pass over the windfarm (see Figs. 4 and 5). In Appendix II

Table 4.1

Γ_T at a VOR Receiver Produced by the Windfarm

	Γ_T in dB, cuased by the windfarm of	
	71 Flo 250 WTs	170 Flo 250 WTs
Kingston VOR	-62 dB	-58 dB

Table 4.2

Values for the Radio Compasses

	Γ_T (dB)	
Station	71 Flo 250 WTs	170 Flo 250 WTs
Meier	-55	-51
Neely	-54	-50
Otims	-55	-51
Monga	-63	-59

we have investigated the interference effects on Path 6 only; the Path 8 link operates on a higher frequency, and being oriented similar to Path 6, it is argued that the Path 6 assessment will apply to this case also. Table 4.3 lists the assessment parameters of the offending WT sites for Link Path 6. Under the criterion Δr or $\Delta H \leq 3H_1$, turbines 67, 70, 69 and 71 are unacceptable at their present locations. They will be acceptable provided they are displaced from their present locations in a manner given in Table II.2. Under this condition, all other links would be unaffected by the windfarm.

4.4 Interference to Earth Stations. As shown in Fig. 4 there exists one earth station at Ellenville at a distance of 3.16 miles (5.08 km) and at Wurtsboro at a distance of 7.5 miles (12.03 km) from the center of the windfarm. We shall assume that the earth station uses a 30 ft (10 m) diameter parabolic dish antenna at f = 4.0 GHz, i.e., λ = 0.246 ft (0.075 m); at this frequency the antenna typically has a beam width of approximately 0.5 degrees and side lobe level of about -25 dB. If the interference effects are acceptable for this antenna, they would also be acceptable for a larger (49 ft or 15 m) antenna used by earth stations. We shall show the assessment for the Ellenville ES.

Sample calculation:

$f = 4.0$ GHz, $\lambda = 0.075$ m , $d = 5.08$ km

$A_e = 2.52 \sqrt{\lambda} = 0.690$ m ^{2}

$\Gamma_1 = 2A_e/\lambda_d = 3.62 \times 10^{-3}$

Γ_T for 71 machines = 3.05×10^{-2} (-30.3 dB)

Γ_T for 170 machines = 4.173×10^{-2} (-26.5 dB)

Assuming antenna discrimination of -25 dB we obtain

Table 4.3

Assessment Parameters for Offending WT Sites for Flo 250 WT: Link Path 6

Site No.	Δr (ft)	ΔH (ft)	$3H_1$ (ft)
62	372	35	116
67	105	60	120
66	372	56	124
70	105	74	124
69	105	69	127
71	0	94	130

Γ_T for 71 machines = -55.3 dB

Γ_T for 170 machines = -51.5 dB

In both cases, Γ_T is less than -40 dB; therefore the windfarm would not produce unacceptable interference to the Ellenville ES. The Wurtsboro ES, being farther away from the CF, would not be affected by the windfarm.

4.5 Television Interference (TVI) Effects at the CATV Head-End. A CATV Head-end, identified as CATV in Fig. 4, is located at Wurtsboro (elevation 1470 ft) and is at a distance of 7.5 miles (12.03 km) from the center of the farm. The antenna tower height being 250 ft, the elevation of all CATV antennas is 1720 ft. It is assumed that the CATV Head-end received all TV signals listed in Table 2.1. During reception of signals from the stations listed in Table 2.1, it may be assumed that the entire windfarm is located in the backward region. We shall therefore determine the interference signals assuming all WT sites to be in the backward region.

In the present case, it is reasonable to assume that the ambient TV signals at the CATV Head-end and at the WT sites are of the same order of magnitude, i.e., $E_B/E_R = 1$. For the purpose of calculation of m_T it is assumed that the CATV antenna beam is directed to recieve maximum signals from the desired direction, and that the side and/or back lobe level of the antenna is at least -20 dB.

Wn shall perform the assessment for TV Channels 2 ($\lambda \simeq 6$ m), 22 ($\lambda \simeq 0.5$ m) and 31 ($\lambda \simeq 0.52$ m). A sample calculation for Channel 2 is given below:

$f = 55.25$ MHz , $\lambda \simeq 6$ m , $d \simeq 12.03$ km

$A_e = 2.52 \sqrt{\lambda} = 6.17\ m^2$ (assuming the receiving antenna to be isotropic),

$m = \Gamma = 2A_e/\lambda d = 1.71 \times 10^{-4}$

m_T for 71 Flo 250 WTs

$= \sqrt{71}\ m = 1.44 \times 10^{-3}$ (-56.8 dB)

m_T for 170 Flo 250 WTs

$= \sqrt{170}\ m = 2.23 \times 10^{-3}$ (-53.0 dB)

With -20 dB discrimination provided by the receiving antenna m_T values for 71 and 170 machines are -76.8 and -73.0 dB, respectively. Calculated m_T values for Channels 2, 22 and 31 applicable to the windfarm of 71 and 170 WTs are shown in Table 4.4.

Under the assumption that acceptable TVI effects would occur for $m_T \geq -26$ dB, the results of Table 4.4 indicate that the interference effects produced by the windfarm on the performance of the CATV Head-end would be insignificant for the Channels 2, 22, 31 and for all other Channels listed in Table 2.1.

4.5 Interference to TV Reception at Cragsmore. It is understood that the residents at Cragsmore (elevation about 1800 ft), distant 4.88 km from the center of the windfarm, receive TV signals without the help from the CATV service. In the absence of detailed knowledge of the ambient signals on the desired Channels available in the area, we shall assume that $E_B = E_R$ and obtain an estimate of the m_T values under the worst possible conditions, i.e., the receiving antenna is isotropic. Table 4.5 shows the m_T values caused by the windfarm of 71 and 170 Flo 250 WTs for two typical Channels.

Table 4.4

m_T Values for TVI Effects at the CATV Head-End Due to a Windfarm of Flo 250 WTs. (Antenna sidelobe = -20 dB)

	m_T (dB)	
TV Channel No.	71 WTs	170 WTs
2	-76.8	-73.0
22	-66.6	-62.9
31	-66.2	-62.5

Note: TVI effects acceptable if $m_T \leq -26$ dB.

Table 4.5

m_T Values for TVI Effects at Cragsmore Caused by the Windfarm of Flo 250 WTs. (Receiving antenna isotropic)

TV Channel No.	m_T (dB)	
	71 WTs	170 WTs
2	-49	-45
22	-39	-35

The results given in Table 4.5 when compared with the acceptability criteria given by Eqs. (9) or (10) indicate that the TVI effects at Cragsmore would be insignificant for the TV Channels 2 and 22; hence it is concluded that they would also be insignificant for all the other Channels listed in Table 2.1, assuming that they are also available in the area.

5. Conclusions

The fundamental parameter required to estimate the electromagnetic interference effects of a WT is the equivalent scattering area of its blade. To the best of our knowledge, such information about the candidate WTs (i.e., Flo 170, 250 and 500) for the Ellenville Windfarm is not yet precisely known. We have obtained, only approximately, the required information by applying extrapolation laws to our present knowledge of the scattering area of the 17-m Darrieus developed by the Sandia Laboratories. Since the VAWTs developed by the Flo Wind Corporation are similar to the Darrieus, it is believed that the estimate of the scattering area used for the present assessment is valid.

The TVI effects at a receiving site also depend quite strongly on the ratio of ambient signal strengths at the receiving and WT sites. In a rugged terrain like the Ellenville Windfarm it is difficult to determine these signal strengths theoretically. Although we have made approximations to these parameters based on our experience, the actual signal ratios may be different (this may be so, particularly for the assessment of TV reception at Cragsmore). For more precise TVI assessment, the desired ambient signal strengths should be measured at the receiving and WT sites.

APPENDIX I. CALCULATION OF Γ_T FOR ASSESSMENT OF VOR INTERFERENCE

It is assumed that the WTs of the farm may cause interference only if they are visible from the antenna of the VOR ground station, i.e., when the antenna and the WT(s) are within the radio line-of-sight distance. The radio line-of-sight distance (d_H) between two points at heights h_1 and h_2 above a smooth spherical earth is

$$d_H = \sqrt{2}\,(\sqrt{h_1} + \sqrt{h_2}) \quad , \qquad \text{(I.1)}$$

where d_H is expressed in miles and h_1, h_2 are in feet. Identifying h_1 as the VOR antenna height and h_2 as the WT height and assuming smooth terrain between the VOR station and the WT, Eq. (I.1) can be used to determine whether the WTs in the farm would be visible from the VOR antenna.

For example, in the case of Kingston VOR station $h_1 = 2200 + 92 = 2292$ ft. Let the average height above the sea level of a WT in the farm be $h_2 = 2292$ ft. Thus, from Eq. (I.1)

$$d_H \simeq 73 \text{ miles (118 km)} \quad .$$

Under the assumption that the terrain between the Kingston VOR station (about 22 miles from the windfarm) and the windfarm is smooth, it appears that all the WTs in the farm would be visible from the VOR station.

Calculations for the Kingston VOR: Γ_T for the Flow 250 WTs are obtained as follows:

Kingston VOR: distance from the center of the windfarm d = 21.7 miles = 34.94 km.

f = 120 MHz, λ = 2.5 m

$$A_e = 2.52\sqrt{\lambda}\ m^2$$

for one WT at a distance of 34.94 km

$$\Gamma \simeq \frac{2A_e}{\lambda d} = 9.14 \times 10^{-5}\ (-81\ dB)$$

for 71 machines

$$\Gamma_T = \sqrt{71}\,\Gamma = 77.02 \times 10^{-5}\ (-62\ dB)$$

for 170 machines

$$\Gamma_T = \sqrt{170}\,\Gamma = 119.17 \times 10^{-5}\ (-58\ dB) \quad .$$

Other VORs are located at distances larger than that of the Kingston VOR (i.e., d > 21.7 miles), hence the Γ_T values for these stations would be less than the values obtained above.

APPENDIX II. ASSESSMENT OF INTERFERENCE TO MICROWAVE LINKS

We shall illustrate the assessment of windfarm interference to microwave links by describing the calculation procedure followed in a typical case. For a given WT site of elevation H_s, located at a horizontal distance $\Delta r'$ from the link path of elevation h_ℓ at the location of the WT, we define the following two parameters:

horizontal clearance $\Delta r = \Delta r' - D/2$,

vertical clearance $\Delta H = h_\ell - h_T$,

where D = the rotor diameter of the WT and

$h_T = H_s + h_{WT} + D/2$, H_{WT} being the total height of the WT.

The acceptability criterion for the site, based on the considerations of Fresnel distance (Section 3.2), is now

$$|\Delta H| \text{ or } |\Delta r| \geq 3H_1 \qquad \text{(II.1)}$$

where

$$H_1 = \frac{\left[\lambda(d - d_1)d_1\right]^{1/2}}{d} , \qquad \text{(II.2)}$$

λ being the wavelength and d, d_1 as explained in Fig. 8.

Figures 4 and 5 show the microwave link paths superposed on the windfarm. For each link the offending sites (generally for $\Delta r < 3H_1$) are identified, and the corresponding ΔH, Δr and H_1 are calculated for a given WT by using (II.1) and (II.2)

Sample Calculations for Path 6

From the data given in Table 2.4 we prepare the elevation diagram, shown in Fig. II.1, for the link Path 6 whose one Head-end (antenna No. 1) is located near the windfarm. It is assumed that $f = 4.0$ GHz, $\lambda = 0.246$ ft, with Flow 250 WT ($h_{WT} = 92$ ft, $D/2 = 28.5$ ft) at each of the offending sites (numbered according to the WT number) near Path 6, and the various parameters required for the calculation of ΔH and Δr are now obtained by using Figs. 4.5 and II.1. The results are shown in Table II.1. According to the criterion given by Eq. (II.2), of the sites considered in Table II.1, only sites 62 and 66 are acceptable. To make the other sites acceptable according to the present cirterion the respective WTs should be displaced from their present location in a manner given in Table II.2.

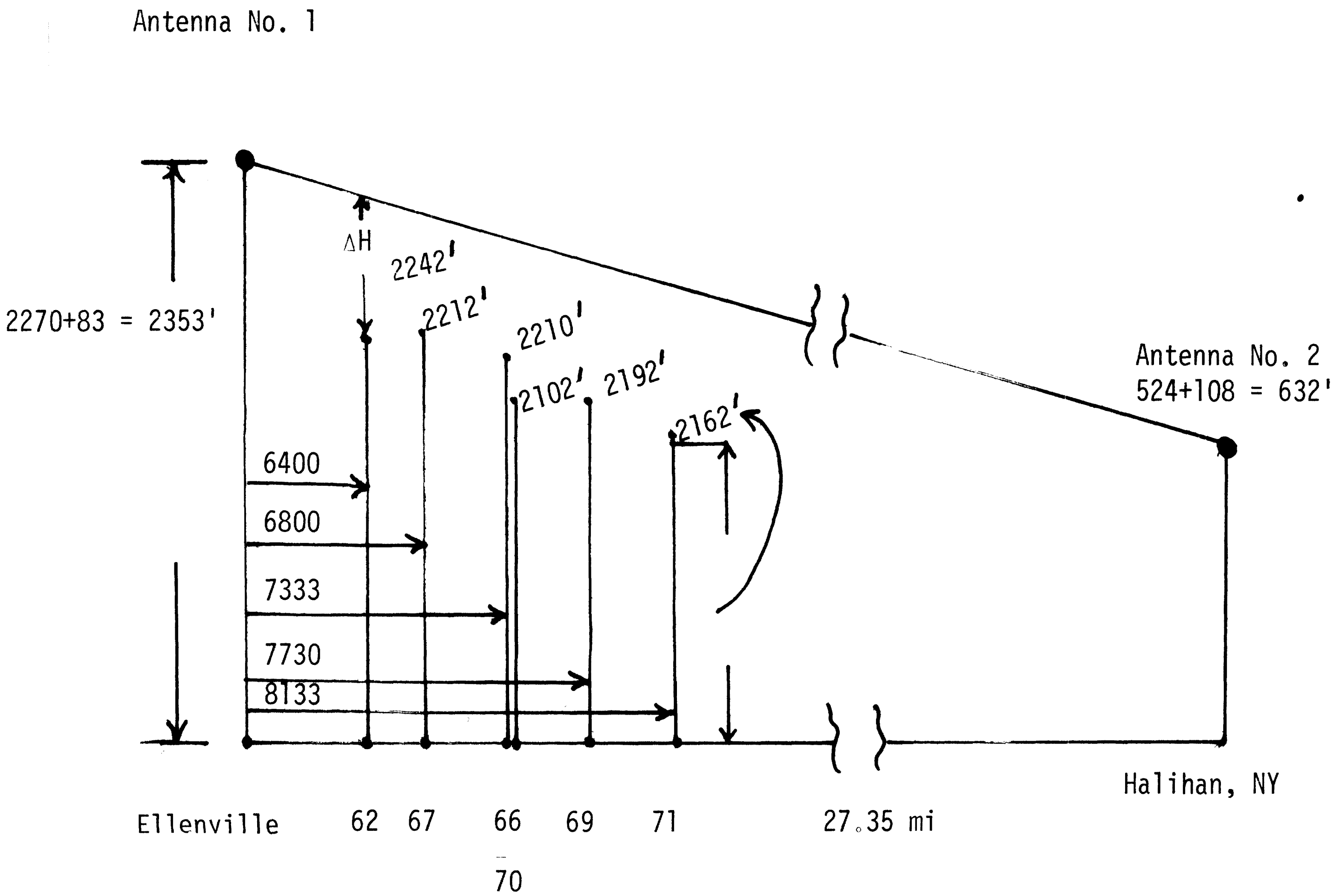

Fig. II.1 Elevation Diagrams for Link Path 6.

Table II.1

Flo 250 Windfarm Interference Assessment Parameters for Link Path 6

(d = 27.35 miles, f = 4.0 GHz)

Site No.	$\Delta r'$ (ft)	Δr (ft)	ΔH (ft)	d_1 (ft)	$3H_1$ (ft)
62	400	371.5	35	6400	116
67	133	104.5	60	6800	120
66	400	371.5	56	7333	124
70	133	104.5	74	7333	124
69	133	104.5	69	7730	127
71	0	0	94	8133	130

Table II.2

Required Displacement of WTs for Acceptability

WT No.	Displace amount (ft)	direction
67	25	West
70	20	East
69	25	West
71	130	East or West

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