



Government of Canada
Department of Communications

Gouvernement du Canada
Ministère des Communications

REPORT ON PREDICTING TELEVISION GHOSTING INTERFERENCE AND PICTURE QUALITY

PREPARED BY:

J. S. DADOURIAN
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MARCH, 1983

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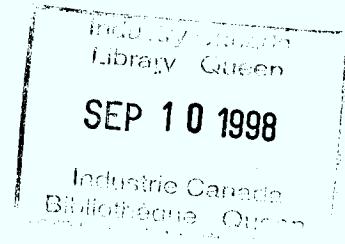
Telecommunication Regulatory Service



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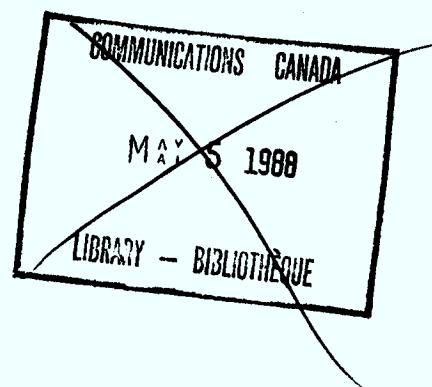


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SUMMARY

This report outlines a procedure to determine TV ghosting interference as derived from the study program titled "A Study Into Television and FM Radio Ghosting and Multipath Distortion" by E.W. Horrigan and Associates Ltd. The study was done for the Department under DSS Contract No. 36100-7-0615.

The study by E.W. Horrigan is contained in a two-volume report. The first volume dated September 1978 contains the results of the subjective effects of echoes on television picture quality and the relationship between ghost delay and ghost levels for levels of picture quality. The second volume, dated November 1978 contains the development of the ghost prediction method.

A computer program to predict TV ghost interference and to relate the levels to various grades of TV picture has been developed by the Department.

1. GENERAL

1.1 Purpose

The need for broadcasters to select a site that will provide an adequate signal level to the immediate and surrounding areas has on occasions resulted in the selection of a site located in close proximity to other antenna towers and metallic structures. In order to reduce ghost images, caused by multipath propagation, broadcasters are encouraged to choose transmitter sites to avoid such problems.

Ghost prediction methods now in use in selecting sites have not been realistic and practical. The prediction methods often ignore the effects of the shape of the pattern of the transmitting antenna, ground reflections and the finite length of the ghost structure thereby giving unrealistic results.

The purpose of this report is to provide a more accurate and practical method for predicting the severity of TV ghost interference.

1.2 Scope

1.2.1 Tower Cross-Section

The scattering cross-section for typical triangular towers is shown in Appendix B Figure 1. The results for the square section towers are expected to be substantially the same. Therefore the perimeter of the tower for all types of towers is used.

1.2.2 Frequency Range

The prediction method is valid for TV channels 2-13. Because lattice type structures are more transparent at UHF frequencies, a correction is necessary. Pending further study an approximate correction factor has been developed and may be applied for UHF cases, as described in Section 4.3.

2. DERIVATION OF THE GHOST LEVEL AND GHOST DELAY EQUATIONS

2.1 Definition of Parameters

The following parameters are used in deriving the basic ghost equations. The dimensions are shown in Appendices C and D:

- (w) Width of the face of the ghost tower in metres
- (s) number of tower sides  or 
- (f) radio frequency in MHz
- (h_t) transmitter centre of radiation above reference plane in metres
- (h_g) height of ghost tower above reference plane in metres
- (h_v) height of viewing antenna above/below reference in metres
- (d_g) distance from ghost tower to the transmitting tower in metres
- (d_v) distance from viewer to the transmitting tower in metres
- (d_g) distance from ghost tower to viewer in metres
- (d_d) direct distance from transmitter centre of radiation to point P on (h_g)
- (d_r) Distance from transmitter centre of radiation to point P on (h_g) via reference plane

- (P_i) incident power at point P on ghost tower
- (ϕ_{H_g}) azimuth to ghost tower in degrees
- (ϕ_{H_v}) azimuth to viewer in degrees
- (ϕ_{V_1}) depression angle to C/R of ghost tower (h_g) in degrees
- (ϕ_{V_2}) depression angle to reflection plane in degrees
- (ϕ_{V_3}) depression angle to viewer in degrees
- F ($\phi_{V_1}, \phi_{V_2}, \dots, \phi_{H_g}, \dots$) relative field at given azimuth or depression angle
- (ℓ) loop length in metres (w) x (s)
- (λ) wavelength in metres $\frac{300}{(f)}$
- $S(z)$ Fresnel integral = $1/2 - f(z) \cos((\pi/2)z^2) - g(z) \sin((\pi/2)z^2)$
- (P_t) = ERP
- (z) = $(\ell/\lambda + 0.5)$

— Note 1: For computational purposes the rational approximations* for $f(z)$ and $g(z)$ can be used to evaluate $S(z)$:

$$f(z) = \frac{1+0.926z}{2+1.792z+3.104z^2} + \xi(z)$$

$$g(z) = \frac{1}{2+4.142z+3.492z^2+6.67z^3} + \xi(z)$$

where $|\xi(z)| \leq 2 \times 10^{-3}$

* "Approximations for Calculating Fresnel Integrals",

C. Hastings, Approximation Newsletter, April 1956,

Note 10.

— Note 2: All dimensions are in metric units

2.2 Echo

An expression for echo delay (t_d) can be derived from the geometry of a triangle (see Appendix D. Figure 3) as follows:

$$t_d = 3.33 \left\{ d_s - d_v + d_g \right\} \times 10^{-3}$$

$$= 3.33 \left\{ d_s - d_v + [d_s^2 + d_v^2 - 2d_s d_v \cos(\phi_{H_g} - \phi_{H_v})]^{1/2} \right\} \times 10^{-3} \mu s$$

.....(1)

This relationship has been computed for various ghost situations and tabulated in Appendix I.

2.3 Derivation of Echo Magnitude

2.3.1 Assumptions

The basic equation for "echo" magnitude, given in most texts, is only true under the following conditions:

- a) when the transmitting and receiving antennas are isotropic radiators,
 - b) when the entire system is in a free-space environment,
 - c) when the tower in question is evenly illuminated and uniformly excited by a constant phase front.

The basic echo magnitude equation has been modified to take into consideration directional antennas, and unevenly illuminated structures.

The following are the factors:

- i) The effective scattering cross-section of the ghost tower derived in Section 2.3.4
- ii) the mean value of integral of incident power (P_i) derived in Section 2.3.6
- iii) the effective centre of radiation of ghost tower derived in Section 2.3.7
- iv) the transmitting antenna vertical pattern function derived in Section 2.3.8
- v) the transmitting antenna horizontal pattern function derived in Section 2.3.9.

2.3.2 Basic Echo Magnitude Equation

The ghost equation as outlined below is the basic free-space isotropic form which is later modified to conform to the restraints of a realistic environment.

- a) Power density at viewer's location: (w_d)

$$w_d = \frac{P_t}{4\pi(d_v)^2} \quad (\text{in units } \frac{\text{Watts}}{\text{m}^2})$$

- b) Power density at ghost tower location: (w_i)

$$w_i = \frac{P_t}{4\pi(d_s)^2} \quad (\text{in units } \frac{\text{Watts}}{\text{m}^2})$$

- c) Power density at viewer's location due to re-radiation from ghost tower: (W_g)

$$W_g = \frac{W_i \sigma}{4\pi(d_g)^2} \quad (\text{where } \sigma \text{ is the scattering cross-section})$$

$$= \frac{P_t \sigma}{4\pi(d_s)^2 \cdot 4\pi(d_g)^2}$$

- d) Basic ghost/signal ratio

$$\frac{W_g}{W_d} = \left[\frac{\sigma}{4\pi} \frac{d_v}{d_s d_g} \right]^2$$

given d_s and d_v , d_g can be computed as follows:

$$d_g = [d_s^2 + d_v^2 - 2d_s d_v \cos(\theta_{Hg} - \theta_{Hv})]^{1/2}$$

(d_g) can also be obtained from equation (1) as follows:

$$d_g = d_v - d_s + \left(\frac{\text{Delay } \mu\text{s}}{3.33 \times 10^{-3}} \right)$$

Therefore:

$$\frac{W_g}{W_d} = \sigma \frac{1}{4\pi} \left[\frac{d_v}{d_s (d_v - d_s + \frac{\mu\text{s}}{3.33 \times 10^{-3}})} \right]^2$$

Extracting the cross-section σ from this equation and defining the remainder in terms of λ^2 , the equation becomes the propagation factor related to Poynting's vector where the energy flow is expressed for convenience as follows:

$$\text{Power flow} = \int_S (E \times H) ds \quad (\text{in units } \frac{\text{Watts}}{\lambda^2})$$

Propagation factor: (p)

$$(p) = \frac{1}{4\pi} \left[\frac{d_v \lambda}{d_s (d_v - d_s + \frac{\mu s}{3.33 \times 10^{-3}})} \right]^2 \dots\dots\dots(2)$$

where (p) is also the area of the equivalent spherical surface in units of λ^2 .

2.3.3 Scattering Cross-Section Measurement

The measurement of the scattering cross-section for typical triangular section tower were made for loop sizes in the range of 0.5λ to 2.5λ . The results of these tests are listed below:

TABLE I

Loop Perimeter λ	Relative		Effective Area
	Dipole	Reflected Power Tower	per Unit λ Height
0.5	-86dB	-87dB	$0.36 \lambda^2$
1.0	-80dB	-75.5dB	$1.6 \lambda^2$
1.5	-86dB	-83.5dB	$1.0 \lambda^2$
2.0	-87dB	-79dB	$2.7 \lambda^2$
2.5	-88dB	-81dB	$2.3 \lambda^2$
Matched Dipole	reference	-5dB	

The measured cross-sections of the tower for unit wavelength height are shown in Appendix B, Figure 1, together with the general equation of the curve and of equivalent cylinder.

The cross-section for cylindrical structures have been defined in terms of loop circumference expressed in wavelength units and merged with the tower section equation.

2.3.4 Scattering Cross-Sections Equation

The measured scattering cross-sections (σ_t) of one wavelength high triangular tower section as listed in Section 2.3.3 have been fitted to a suitable equation over the loop peripheral range of 0.5λ to 3.0λ .

The measured triangular tower cross-section has the form of a modified Fresnel Integral over the loop peripheral range of 0.5λ to 3.0λ .

$$\sigma_t = f\left(\frac{hs}{\lambda}\right) f\left(\frac{\rho}{\lambda}\right) f(S(z)) \quad \text{Where: } S(z) = \int_0^z \sin\left(\frac{\pi}{2} t^2\right) dt$$

A working equation was generated using this format which adequately describes the measured results over the loop range 0.5λ to 3.0λ .

$$\sigma_t = \frac{1}{1.2} \left(\frac{\pi}{2} \frac{hs}{\lambda}\right)^2 \cdot \left[\frac{\rho}{\lambda} \left(1 - e^{-\left(\frac{2\rho}{\lambda}\right)^2}\right) S(z) \right]$$

where $(z) = \left(\frac{\rho}{\lambda} + 0.5\right)$

Using the relationship between the Fresnel Integral and its auxiliary functions $f(z)$ and $g(z)$, the Fresnel Integral $S(z)$ can be expressed as:

$$S(z) = \frac{1}{2} - f(z) \cos\left(\frac{\pi z^2}{2}\right) - g(z) \sin\left(\frac{\pi z^2}{2}\right)$$

For computational purposes the rational approximations* for $f(z)$ and $g(z)$ can be used to evaluate $S(z)$:

$$f(z) = \frac{1 + 0.926z}{2 + 1.792z + 3.104z^2} + \xi(z)$$

$$g(z) = \frac{1}{2 + 4.142z + 3.492z^2 + 6.67z^3} + \xi(z)$$

where $|\xi(z)| \leq 2 \times 10^{-3}$

* "Approximations for Calculating Fresnel Integrals",
C. Hastings, Approximation Newsletter,
April 1956, Note 10.

$$\sigma_t = \left\{ \frac{1}{1.2} \cdot \left(\frac{\pi}{2} \frac{h_s}{\lambda} \right)^2 \cdot \left[\frac{\ell}{\lambda}^{(1-e^{-\left(\frac{2\ell}{\lambda}\right)^2}} \cdot (1/2 - f(z) \cos(\frac{\pi}{2} z^2) - g(z) \sin(\frac{\pi}{2} z^2)) \right] \right\} \dots \quad (3)$$

The scattering cross-section of a right cylinder (σ_{cyl}) is defined as:

$$\sigma_{cyl} = 2\pi \frac{a}{\lambda} L^2$$

where L = height of cylinder
 a = radius of cylinder

$$\text{let } \frac{2\pi a}{\lambda} = \frac{l}{\lambda}$$

and let $L = \frac{h_s}{\lambda}$

If $\frac{\ell}{\lambda} \leq 3.0$ use(3)

If $\frac{t}{\lambda} > 3.0$ use(3A)

2.3.5 Incident Power on Ghost Tower

In the basic ghost magnitude equation the assumption was made that the entire system was in a free-space isotropic environment. This situation does not generally exist in practice and therefore the incident power cannot be expressed as:

$$P_i = \frac{P_t}{4\pi(d_s)^2}$$

Consider the situation which will usually exist in a ghosting problem: The two towers are of finite height above a common reference plane separated by a distance which is in the range $h_s \leq d_s \leq 50h_s$. In this range the effects of ground reflection cannot be ignored and it is necessary to define the incident power function and its mean value integral.

From the geometry of Figure 4 in Appendix D, it can be shown that the incident power P_i at any point on h_s can be expressed by a modification of the cosine law:

$$P_i = [F(\theta v_1)]^2 + [F(\theta v_2)]^2 - 2F(\theta v_1)F(\theta v_2)\cos \frac{2\pi}{\lambda} \left\{ [d_s^2 + (ht-hs)^2]^{1/2} - [d_s^2 + (ht+hs)^2]^{1/2} \right\}$$

where $\theta v_1 = \tan^{-1} \left(\frac{ht-hs}{d_s} \right)$

$$\text{where } \theta v_2 = \tan^{-1} \left(\frac{ht+hs}{d_s} \right)$$

To facilitate manipulation and computation let:

$$P_i = (F_1)^2 + (F_2)^2 - 2F_1F_2 \cos (\chi)$$

$$\text{where } \chi = \frac{2\pi}{\lambda} \left\{ [d_s^2 + (ht-hs)^2]^{1/2} - [d_s^2 + (ht+hs)^2]^{1/2} \right\}$$

$$\text{let } \frac{(hs)^2 + (ht)^2}{(d_s)^2} = a$$

$$\frac{2(hs)(ht)}{(d_s)^2} = b$$

Radio Frequency = (f)MHz

$$\chi = 1.2(f)d_g \left[(1+a-b)^{1/2} - (1+a+b)^{1/2} \right]$$

2.3.6 Mean Value Integral of Incident Power (P_i)

The total effective power averaged over the ghost tower equated to that of an evenly illuminated structure will provide a modifying factor for use with the basic ghost magnitude equation. This will relate the original free-space equation to a practical environment.

If the incident power function P_i is related to (x) instead of (hs) the mean value integral (k) becomes:

$$k = \frac{\int_0^x p_i d\chi}{x} \dots \dots \dots \quad (4)$$

This function can be adequately derived by Simpson's Rule using a modest number of intervals of (X) because the relationship between (h_s) and (X) is not significant in defining the ratio (k).

2.3.7 Centre of Radiation of Ghost Tower

The effective centre of radiation on the ghost tower (h_g) can be likened to the 1st moment centroid of area of the integral of P_i in the plane normal to the reference surface.

$$\bar{h}_s = \frac{\int_0^{h_s} h \, dA}{A}$$

With a view to the simplification of this factor several forms of illumination distribution have been examined and the likely range of the ratio ($\frac{h_s}{h_s}$) will be between 0.5 and 1.0. Therefore, a value of 0.75 will be used to compute incident power over the ghost tower.

However, the linear height/gain function $(\frac{h_s}{h_t})^2$ referred to the viewing location applies only where the air path and ground reflected components of both ghost signal and direct signal are substantially out of phase. Where first Fresnel zone clearance exists the factor $(\frac{h_s}{h_t})^2$ should be equated to one (1) for realistic ghost computations.

Approximate solution for 1st 'Fresnel' zone clearance:

(f) $\frac{h_t - h_v}{d_v} \leq 75$ Linear Height/Gain use (5)

(f) $\frac{h_t - h_v}{d_v} > 75$ Free space Path use (5A)

where h_t = Tx height

h_v = Viewer height

d_v = Viewer distance

(f) = frequency in MHz

2.3.8 The Transmitting Antenna Vertical Pattern Function

The factor allows for the non-isotropic vertical pattern of a practical transmitting antenna. It provides a ratio of the relative vertical pattern power on the centre of radiation of the ghost tower to that at the viewer's location by inputting the relative vertical field at two computed angles. The factor P_v is computed as follows:

$$\text{let } \theta v_1 = \tan^{-1} \left(\frac{h_t - \bar{h}_s}{d_s} \right)$$

$$\theta v_3 = \tan^{-1} \left(\frac{h_t - h_v}{d_v} \right)$$

2.3.9 The Transmitting Antenna Horizontal Pattern Function

This factor allows for the non-isotropic horizontal pattern of the transmitting antenna in a similar manner to that used for the vertical pattern in Section 2.3.8 above.

The pattern factor relative power function P_h is derived below:

where θH_g = azimuth of ghost tower

θ_{H_v} = azimuth of viewer

2.3.10 Complete Echo Magnitude Equation

Combining all the factors derived in Section 2.3, the basic echo magnitude equation is modified as follows:

$$\text{Ghost dB} = G = 10 \log_{10} \left\{ \frac{1}{4\pi} \cdot \frac{d_v \lambda^2}{d_s d_g} \cdot (\sigma_t \text{ or } \sigma_{cyl}) \cdot \left(\frac{\int_0^X P_i dx}{X} \right) \cdot \left(\frac{\bar{h}_s}{h_t} \right)^2 \cdot \left[\frac{F(\phi V_1)^2}{F(\phi V_3)} \right] \cdot \left[\frac{F(\phi H_g)}{F(\phi H_v)} \right] \right\}$$

= 10 log₁₀ { Eq (2) x (3 or 3A) x (4) x (5 or 5A) x (6) x (7) } (8)

This equation is capable of predicting a maximum value of "ghost" magnitude and can be used to evaluate the limits of proximity of structures adjacent to television radiators.

3. PICTURE QUALITY

3.1 Impairment Scale

The system of grading established for the impairment scale, indicates the degree of impairment in a television picture, relative to any single performance parameter and is designated as follows:

<u>Impairment Grade</u>	<u>Impairment</u>
5	Imperceptible (Excellent)
4	Perceptible but not annoying (Good)
3	Somewhat annoying (Fair)
2	Severely annoying (Poor)
1	Unusable (Bad)

3.2 Relationship between Picture Quality, and Echo Delay and Magnitude

The severity of a ghost image or interference reflection due to multipath effect is a function of the time displacement (t_d in μs) between the direct and the reflected wave and the magnitude of the reflected wave compared to the direct wave (G in dB). For a particular grade of picture the shorter the time delay, the larger the permitted reflected wave. Subjective tests have shown a relationship between the two and the graph in the Appendix E shows this function for various TV impairment grades. Using the linear regressions technique, the relationship could be expressed as follows for a typical viewing population sample:

Impairment Grade

$$N = 6 - \left[0.143(G) \exp\left(-\frac{0.637}{t_d}\right) - 6.65 \exp\left(-\frac{0.475}{t_d}\right) \right] \dots\dots\dots(9)$$

4.

COMPUTATION OF TELEVISION GHOSTING

4.1

The Software Package

A computational package in fortran language, developed in the Department performs the following functions

- a) computes and records the echo delay in microseconds (Eq. 1).
- b) computes and selects the measured tower or equivalent cylinder cross-section dependent upon loop size.

- c) computes incident power on ghost tower based on ground reflection, transmitting antenna vertical pattern, ghost tower height and separation.
- d) computes mean value integral of incident radiation on ghost tower.
- e) computes centre of radiation of ghost tower.
- f) computes propagation co-efficient based on three paths (d_s , d_v , & d_g).
- g) computes transmitter to viewer path clearance and selects path treatment.
- h) computes T_x antenna horizontal pattern co-efficient.
- i) computes T_x antenna vertical pattern co-efficient.
- j) computes and records echo amplitude in dB (Eq. 8).
- k) computes and records "Typical Viewer" grade of TV service (Eq. 9).

The listing of the program together with typical example of program execution is given in Appendix A.

4.2 Approximate Solution

A rough approximation of the ghost situation can be obtained without the use of the software program, for preliminary planning purposes only, by the following method:

Define the various parameters as described in section 2.

- a) Calculate delay using Eq. (1)
- b) Calculate propagation factor from Eq. (2)
- c) Obtain $\frac{\sigma_t}{\lambda^2}$ or $\frac{\sigma_{cyl}}{\lambda^2}$ factor from Figure No. 1 of the Appendix B

d) Multiply c) by $\frac{(hs)^2}{\lambda^2}$ to obtain either σ_{cyl} or σ_t as required

- Eq. (3) or Eq. (3A)

e) Obtain rough approximation to Eq. (4) by a second order approximation outlined below:

i) compute the relative field at $\phi V_1 = F(\phi V_1)$ where ϕV_1 is defined as follows: $\phi V_1 = \tan^{-1} \left(\frac{ht-hs}{ds} \right)$

ii) Eq. (4) $\left[\frac{F(\phi V_1)}{2} \right]^2$

f) Compute qualifying equations and obtain Eq. (5) or (5A) as required

g) Compute Eq. (6)

h) Compute Eq. (7)

i) Obtain Ghost in dB as follows:

$$\text{Ghost dB} = 10 \log_{10} \left\{ (\text{Eq. (2)} \times (\text{3 or 3A}) \times (\text{4}) \times (\text{5 or 5A}) \times (\text{6}) \times (\text{7})) \right\}$$

Next obtain TV Grade No. from Figure 5 of Appendix E using a) and

i) above.

This method only provides an approximate solution and may be in error by ± 10 dB, dependent upon complexity of the situation.

4.3

Television Ghost Prediction

(Correction factor for UHF Band)

a) for the VHF Bands where $\frac{l}{\lambda} \leq 3$ (where l = tower width times number of sides to tower), the ghost tower can be treated as a solid surface even when using a typical lattice type structure. In these cases the ghost amplitude and delay will be calculated by the methods given above.

b) For UHF situations or where $\frac{l}{\lambda} > 3$, the lattice type structure cannot be equated to an equivalent solid cylinder because much of the incident energy can flow through the structure unimpeded. A correction factor, based on theoretical study of lattice transparency relative to a solid equivalent cylinder, has been developed for situations where $\frac{l}{\lambda} > 3$ pending further study to produce a general prediction formula covering both VHF and UHF Ghosting situations. The Example III in Sections 5.1 illustrates the use of the tentative correction curve (Figure 6 of Appendix F) and the related dotted curve (Figure 1 of Appendix B). In this case the corrected 'Ghost' amplitude and the original delay values computed from the software program should be applied to Figure No. 5 of Appendix E to obtain the new Impairment Grade.

5. TYPICAL EXAMPLES OF COMPUTATIONS AND COMPARISONS WITH MEASURED GHOST

5.1 Typical Examples of Computations

Typical examples of TV signal ghost interference computations for various ghost situations are given below:

TABLE II

#	<u>Program Input</u>		<u>Example I</u>	<u>Example II</u>	<u>Example III</u>
1	Width of ghost tower (W)	m	1.52	1.52	0.61
2	Number of tower sides (S)		3	3	3
3	TV Channel frequency (f)	MHz	61.25	77.25	579.25**
4	Height of T_x tower above ref. (h_t)	m	130.2	200	56
5	Distance of ghost tower (d_g)	m	555	910	147.8
6	Height of ghost tower above ref. (h_g)	m	97	53	19.8
7	Distance to viewer (d_v)	m	4060	720	1127
8	Height of viewer above/below ref. (h_v)	m	-70	-285	-67
9	Azimuth of ghost tower (ϕ_{H_g})	Deg.	280	50.6	325
10	Azimuth of viewer (ϕ_{H_v})	Deg.	90	35	37
11	Relative Horizontal Field $F(\phi_{H_g})$		0.63	1.0	0.96
12	Relative Horizontal Field $F(\phi_{H_v})$		0.3	1.0	0.95
13	Relative Vertical Field $F(\phi_{V_1})$ at C/R		0.5	0.65	0.12
14	Relative Vertical Field $F(\phi_{V_2})$		0.05	0.28	0.2
15	Relative Vertical Field $F(\phi_{V_3})$ at C/R		0.65	0.21	0.7
16	Lower limit of Integration* (Normally 0.0)	0.0		0.0	0.0
	(Incident Power on ghost tower)				

#	<u>Program Output</u>		<u>Example I</u>	<u>Example II</u>	<u>Example III</u>
1	Ghost dB		-32.28	-20.97	-50.83 **
2	Ghost Delay μ s		3.67	1.60	0.37
3	TV Picture Grade		4.04	3.08	>5.00**

* Lower Limit of Integration:

If the reference plane is drawn in accordance with the elevation situations shown in Figure 2 of Appendix C, the lower limit of integration of incident power on ghost tower will be zero. However, if an unusual situation exists and the reference plane does not intercept the ghost tower base because of topographical features etc., an appropriate lower limit of integration value should be used.

** Correction factor for UHF Band:

$$f = 579.25 \text{MHz} ; \lambda = \frac{300}{(f)} = \frac{300}{579.25} = 0.52 \text{ metres}$$

$$l = w \times s = 3 \times 0.61 = 1.8 \text{ metres} ; \therefore \frac{l}{\lambda} = \frac{1.8}{0.52} = 3.5$$

- Correction factor relative to the Equivalent Cylinder Curve = 2.5 dB
(see Figure 6 of Appendix F)
- Corrected ghost amplitude = $-50.83 - 2.5 = -53.33$ dB
- TV Picture grade > 5.0
(see Figure 5 of Appendix E)

5.2 Comparisons with Measured Ghosts

The ghost measurements at a particular viewing site for various ghost tower heights in Example I of Table II are tabulated below:

TABLE III

Ghost Tower Height (m)				
	97	108	135	182
Measured Ghost dB	-32.2	-25.6	-19.7	-18.8
Calculated Ghost dB	-32.28	-31.13	-22.42	-17.36

The following conclusions could be drawn from the results given in the above table.

- a) The differences in the measured and calculated ghost magnitude values are well within the range of experimental error.
- b) The reduction of the centre of radiation of ghost tower from 182m to 97m, would result in the reduction in ghost amplitude of about 14dB.
(see Figure 7 of Appendix G)

5.3

Distance (ds) Characteristic

The ghost ratios for various distances (ds) between the ghost tower and transmitter at the particular azimuth to ghost tower in Example I of Table II were computed and are plotted as shown in Figure 8 of Appendix H. The results show that the value of reflection field attenuates in approximate proportion to the distance (ds).

```

1.000 C----- HORRIGAN GHOST CALCULATION PROGRAM FOR TV-FM.
2.000 C----- THIS PROGRAM IS A DIRECT COPY OF A BASIC PROGRAM DEVELOPED
3.000 C----- BY M. VARCOE OF THE AM SECTION. MINIMAL EFFORT HAS BEEN USED
4.000 C----- TO MAKE THIS VERSION ELEGANT. BUT IT WORKS!!!!
5.000 C----- IMPLICIT REAL(A-Z)
6.000 C----- FTRTFREE66555
7.000 C----- INTEGER I,N0,J1
8.000 C----- DIMENSION U(10),G(10)
9.000 C----- R=57.29577958
10.000 C----- DATA (U(I),Q(I),I=1,5)
11.000 C----- * / 744371695E-10,147762112E-9,216697697E-9,134633360E-9,
12.000 C----- 339704784E-9,109543181E-9,432531683E-9,747256746E-10,
13.000 C----- 486953264E-9,333356722E-10/
14.000 C----- 16 OUTPUT(102)*INPUT WIDTH OF GHOST TOWER*
15.000 C----- 18 INPUT(101) W
16.000 C----- 20 OUTPUT(102)*INPUT NUMBER OF TOWER SIDES*
17.000 C----- 25 INPUT(101) S
18.000 C----- 30 OUTPUT(102)*INPUT TV OR EM FREQUENCY IN MHZ*
19.000 C----- 35 INPUT(101) F
20.000 C----- 40 A1=W*S*F
21.000 C----- 45 A2=A1/300.0
22.000 C----- 50 BE=A2+0.5
23.000 C----- 55 OUTPUT(102)*INPUT HEIGHT OF TRANSMITTER TOWER ABOVE REF. PLANE*
24.000 C----- 60 INPUT(101) H1
25.000 C----- 65 OUTPUT(102)*INPUT DISTANCE TO GHOST TOWER*
26.000 C----- 70 INPUT(101) D1
27.000 C----- 75 OUTPUT(102)*INPUT HEIGHT OF GHOST TOWER ABOVE REFERENCE*
28.000 C----- 80 INPUT(101) H2
29.000 C----- 85 C=(F*H2)/300.0
30.000 C----- 90 E=H2-3.0/4.0
31.000 C----- 95 OUTPUT(102)*INPUT DISTANCE TO VIEWER (ENTER 0.0 TO STOP)
32.000 C----- 100 INPUT(101) D2:IF(D2.EQ.0.0)STOP
33.000 C----- 105 OUTPUT(102)*INPUT HEIGHT OF VIEWER ABOVE/BELLOW REF.-
34.000 C----- 110 INPUT(101) H3
35.000 C----- 115 OUTPUT(102)*INPUT AZIMUTH GHOST TOWER DEG. (0HG)*
36.000 C----- 120 INPUT(101) T1
37.000 C----- 125 OUTPUT(102)*INPUT AZIMUTH VIEWER DEG. (0HV)*
38.000 C----- 130 INPUT(101) T2
39.000 C----- 132 A3=COS((T1-T2)/P)+2.0*D1*D2-D1**2-D2**2
40.000 C----- 134 A4=A3**2
41.000 C----- 136 A5=SQRT(A4)
42.000 C----- 138 A6=SQRT(A5)
43.000 C----- 140 G=(A6-D2+D1)/300.0
44.000 C----- 141 WRITE(102,141)
45.000 C----- 141 FORMAT(*INPUT PFLATTE HORIZ. FIELD AT GHOST TOWER AZI.*)
46.000 C----- +*(0HG)*
47.000 C----- 145 INPUT(101) F2
48.000 C----- 150 OUTPUT(102)*INPUT RELATIVE HOR. FIELD AT AZI. VIEWER (0HV)*
49.000 C----- 155 INPUT(101) F3
50.000 C----- 160 J=(F2/F3)**2
51.000 C----- 165 K=P*ATAN((H1-E)/D1)
52.000 C----- 170 OUTPUT(102)*VERT. DEPRESSION ANGLE GHOST TOWER FROM*,
53.000 C----- * FROM TRANSMITTER (0V1)=*,K
54.000 C----- 175 OUTPUT(102)*INPUT RELATIVE VERT. FIELD AT 0V1*
55.000 C----- 180 INPUT(101) F4
56.000 C----- 185 L=P*ATAN((H1+E)/D1)
57.000 C----- 190 OUTPUT(102)*VERT. DEPRESS. ANGLE TO REFLECTION PLANE(0V2)=*,L
58.000 C----- 195 OUTPUT(102)*INPUT RELATIVE FIELD AT 0V2*

```

Listing of the Software Package in FORTRAN

APPENDIX A

SHORRIGAN 3 MAR 83 GPP0070 COPY FOR PROGRAMMER
 59 - 59.000 200 INPUT(101) F5
 60 - 60.000 205 M=P*ATAN((H1-H3)/D2)
 61 - 61.000 210 OUTPUT(102)*VEPTICAL DEPRFSSION ANGLE TO VIEWER DV3=°,M
 62 - 62.000 215 OUTPUT(102)*INPUT VERTICAL FIELD AT DV3°
 63 - 63.000 220 INPUT(101) F6
 64 - 64.000 225 N2=(F4/F6)**2
 65 - 65.000 230 D3=D1**2
 66 - 66.000 235 P1=(H1**2+H2**2)/D3
 67 - 67.000 240 Q0=(2.0*H1+H2)/D3
 68 - 68.000 245 R=SQRT(1.0+P1-Q0)
 69 - 69.000 250 S=1.2*F*D1*(SQRT(1.0+P1+Q0)-R)
 70 - 70.000 255 N0=0
 71 - 71.000 267 J1=0
 72 - 72.000 300 X1=LOG(99.0)
 73 - 73.000 310 Y1=F4**2+F5**2-2.0+F4+F5+COS(X1/P)
 74 - 74.000 340 IF (J1.EQ.1) GOTO 475
 75 - 75.000 345 IF (J1.EQ.2) GOTO 495
 76 - 76.000 350 IF (N0.EQ.1) GOTO 410
 77 - 77.000 360 OUTPUT(102)*INPUT LOWER LIMIT OF INTEGRAL (NORMALLY 0.0)*
 78 - 78.000 370 INPUT(101) A0
 79 - 79.000 375 B0=S
 80 - 80.000 380 N0=2
 81 - 81.000 385 A=A0
 82 - 82.000 390 IF (N0.EQ.1) GOTO 425
 83 - 83.000 395 Z0=B0.0
 84 - 84.000 400 D=(B0-A0)/N0
 85 - 85.000 405 B1=A
 86 - 86.000 410 B1=B1+D
 87 - 87.000 415 IF (B1.LE.B0) GOTO 430
 88 - 88.000 420 IF (Z0.GT.0) GOTO 530
 89 - 89.000 425 B1=B0
 90 - 90.000 430 C1=0.5*(B1+A)
 91 - 91.000 435 C2=B1-A
 92 - 92.000 440 S1=0
 93 - 93.000 445 I=0
 94 - 94.000 450 I=I+1
 95 - 95.000 455 W1=C2+U(I)
 96 - 96.000 460 X1=C1+W1
 97 - 97.000 465 J1=1
 98 - 98.000 470 GOTO 310
 99 - 99.000 475 S1=S1+Q(I)*Y1
 100 - 100.000 480 X1=C1-W1
 101 - 101.000 485 J1=2
 102 - 102.000 490 GOTO 310
 103 - 103.000 495 S1=S1+Q(I)*Y1
 104 - 104.000 500 IF (I.LT.5) GOTO 450
 105 - 105.000 505 IF (N0.EQ.1) GOTO 525
 106 - 106.000 510 Z0=Z0+S1*C2
 107 - 107.000 515 A=51
 108 - 108.000 520 GOTO 410
 109 - 109.000 525 Z0=S1*C2
 110 - 110.000 530 OUTPUT(102)*
 111 - 111.000 540 R1=Z0/S
 112 - 112.000 550 T=(B+0.926+1.0)/(B**2*3.104+2.0+(B+1.792))
 113 - 113.000 555 UU=1.0/(B**2*6.67+B**2*3.492+B**4*1.42+2.0)
 114 - 114.000 560 V=UU*SIN((B**2*90.0)/P)
 115 - 115.000 565 W=T*COS((B**2*90.0)/P)
 116 - 116.000 570 X=2.05*(0.5-V-W)
 117 - 117.000 575 Y=A2*C**2

118 -	118.000	580	Z1=1.0
119 -	119.000	585	Z2=Z1*C**2*X*A2
120 -	120.000	590	Z3=(300.0*D2/(F+D1*(G+1000.0/3.0+D2-D1)))**2/4.0/3.1415926
121 -	121.000	600	IF (A2.GT.2.25) GOTO 610
122 -	122.000	605	Y=Z2
123 -	123.000	610	P2=Y+Z3*R1*N2*J
124 -	124.000	615	QQ=(E/H1)**2
125 -	125.000	620	T2=(F+H1)/D2
126 -	126.000	625	IF (T2.LT.7.5) GOTO 630
127 -	127.000	627	QQ=1.0
128 -	128.000	630	R2=10.0*LOG(P2*QQ)/LOG(10.0)
129 -	129.000	632	OUTPUT(102)*GHOST DB=*,R2
130 -	130.000	635	OUTPUT(102)*GHOST DELAY MICROSECONDS=*,G
131 -	131.000	640	UU=R2*(0.143)*(EXP(-0.637/G))
132 -	132.000	645	X=6.0-(UU+6.65*(EXP(-0.475/G)))
133 -	133.000	650	IF (X.LT.5.0) GOTO 660
134 -	134.000	655	X=5.0
135 -	135.000	660	OUTPUT(102)*TV IMPAIRMENT GRADE=*,X
136 -	136.000	665	V=141.4*(SIN((G+1.8)/P))
137 -	137.000	670	V1=V*EXP(R2/20.0*LOG(10.0))
138 -	138.000	675	OUTPUT(102)*FM DISTORTION=*,V1
139 -	139.000	677	OUTPUT(102)* :
140 -	140.000	678	OUTPUT(102)* :
141 -	141.000	680	GOTO 95
142 -	142.000	850	END

A TYPICAL EXAMPLE OF PROGRAM EXECUTION

XHORRIGAM.0060040
INPUT WIDTH OF GHOST TOWER
71.52
INPUT NUMBER OF TOWER SIDES
73
INPUT TU OR FM FREQUENCY IN MHZ
761.25
INPUT HEIGHT OF TRANSMITTER TOWER ABOVE REF. PLANE
7130.2
INPUT DISTANCE TO GHOST TOWER
7555
INPUT HEIGHT OF GHOST TOWER ABOVE REFERENCE
7137
INPUT DISTANCE TO VIEWER (ENTER 0.0 TO STOP)
74060
INPUT HEIGHT OF VIEWER ABOVE/BELOW REF.
7-70
INPUT AZIMUTH GHOST TOWER DEG. (0HG)
7280
INPUT AZIMUTH VIEWER DEG. (0HU)
790
INPUT RELATIVE HORIZ. FIELD AT GHOST TOWER AZI. (0HG)
70.63
INPUT RELATIVE HOR. FIELD AT AZI. VIEWER (0HU)
70.3
VERT. DEPRESSION ANGLE GHOST TOWER FROM
FROM TRANSMITTER (0U1)=
K = 2.83151
INPUT RELATIVE VERT. FIELD AT 0U1
70.65
VERT. DEPRESS. ANGLE TO REFLECTION PLANE(0U2)=
L = 22.7692
INPUT RELATIVE FIELD AT 0U2
76.05
VERTICAL DEPRESSION ANGLE TO VIEWER 0U3=
M = 2.82299
INPUT VERTICAL FIELD AT 0U3
70.65
INPUT LOWER LIMIT OF INTEGRAL (NORMALLY 0.0)
?

GHOST DB=
R2 = -22.4263
GHOST DELAY MICROSECONDS=
G = 3.67523
TU GRADE=
X = 2.85287
FM DISTORTION=
U1 = 1.23198

INPUT DISTANCE TO VIEWER (ENTER 0.0 TO STOP)

FIGURE I

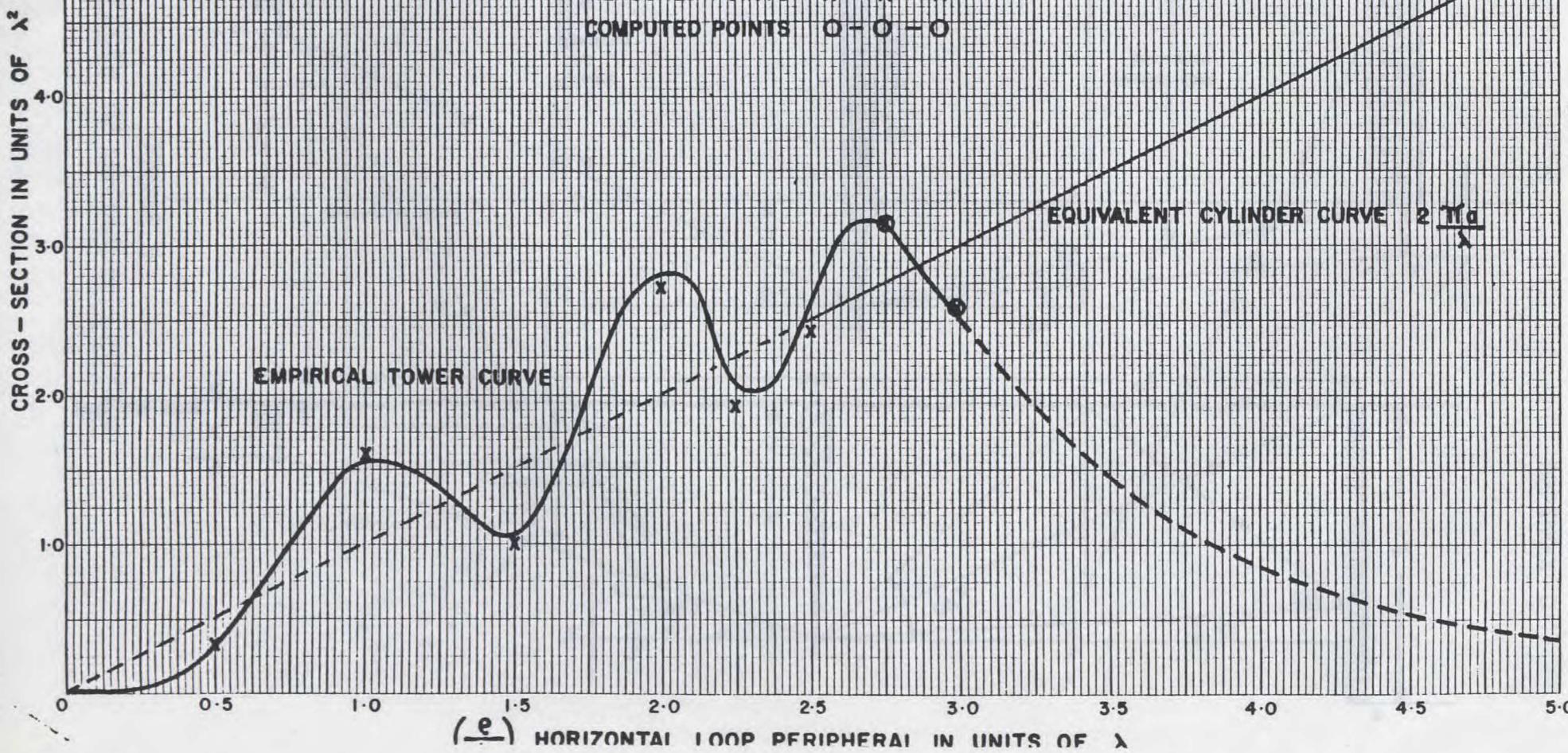
SCATTERING CROSS-SECTIONSTRIANGULAR LATTICE TOWER AND EQUIVALENT
CYLINDER FOR HORIZONTAL POLARIZATIONAREAS IN UNITS OF λ^2 FOR UNIT X HEIGHT

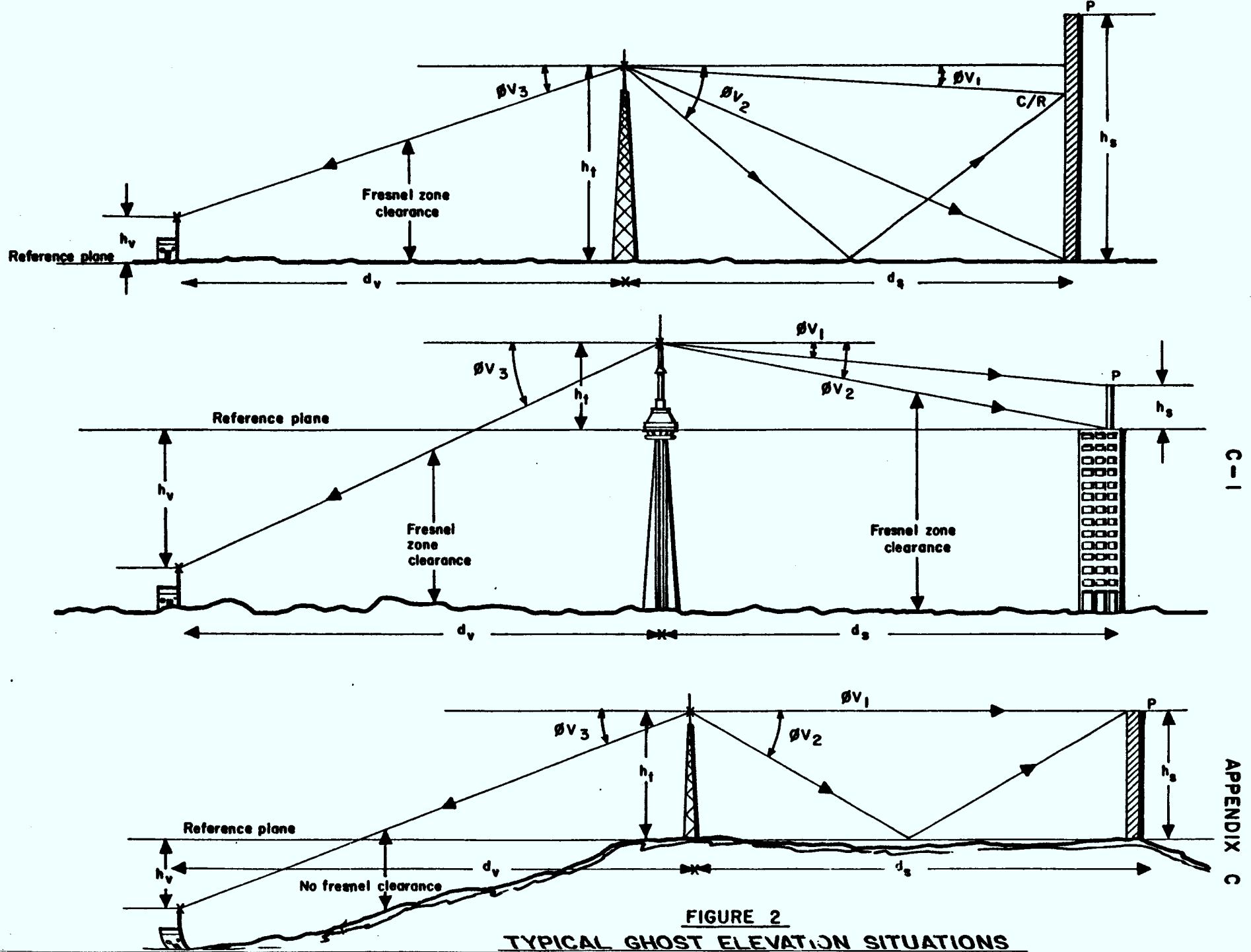
MEASURED POINTS X - X - X

COMPUTED POINTS O - O - O

B - I

APPENDIX B





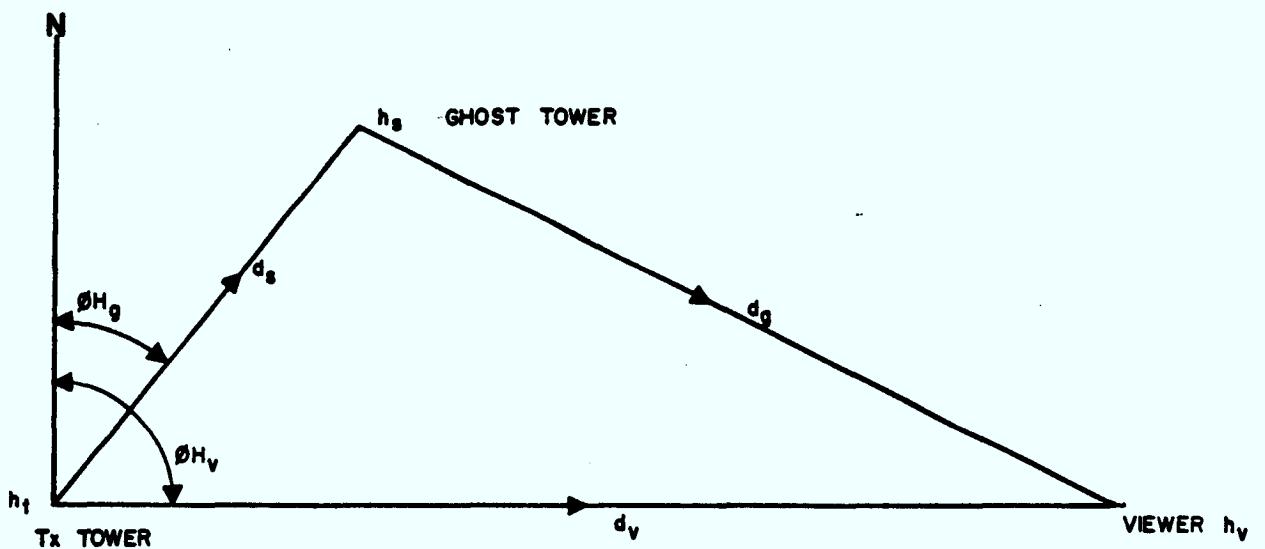


FIGURE 3
TYPICAL GHOST AZIMUTH SITUATION

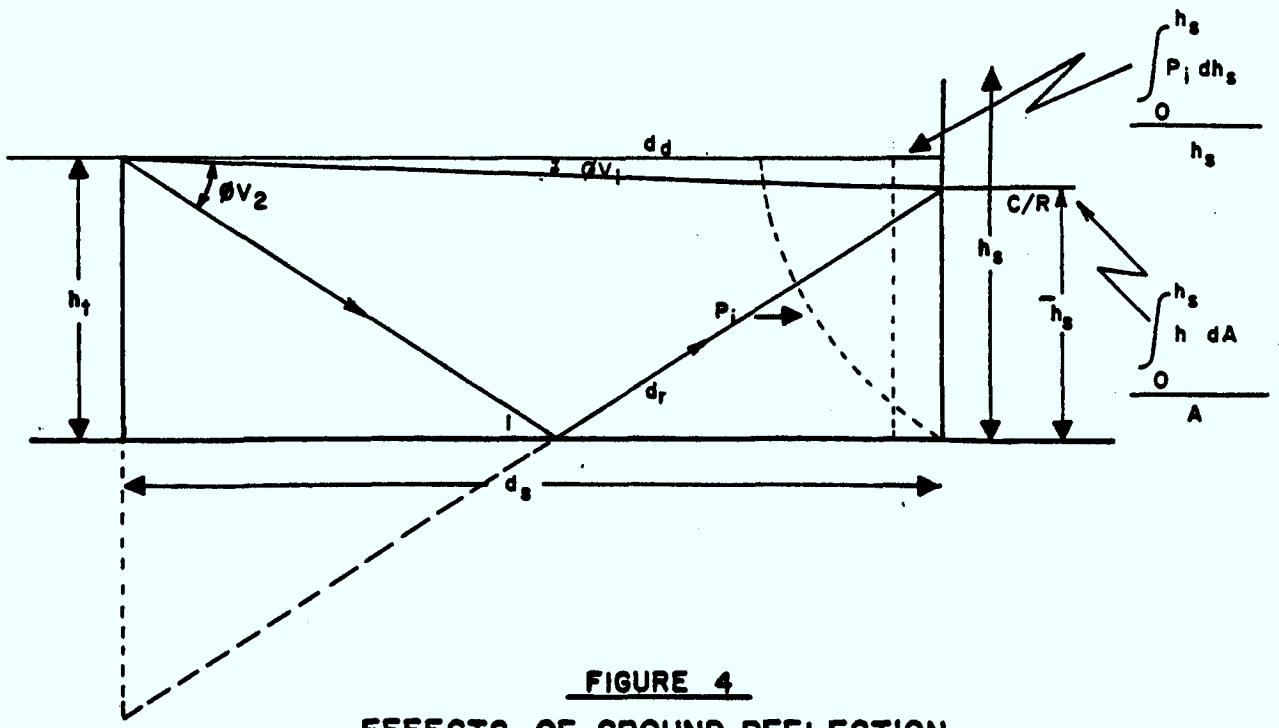


FIGURE 4
EFFECTS OF GROUND REFLECTION

FIGURE 5

TELEVISION GHOST INVESTIGATION
GHOST DELAY versus GHOST LEVEL
FOR GIVEN PICTURE GRADE
BASED ON TYPICAL VIEWER POPULATION SAMPLE

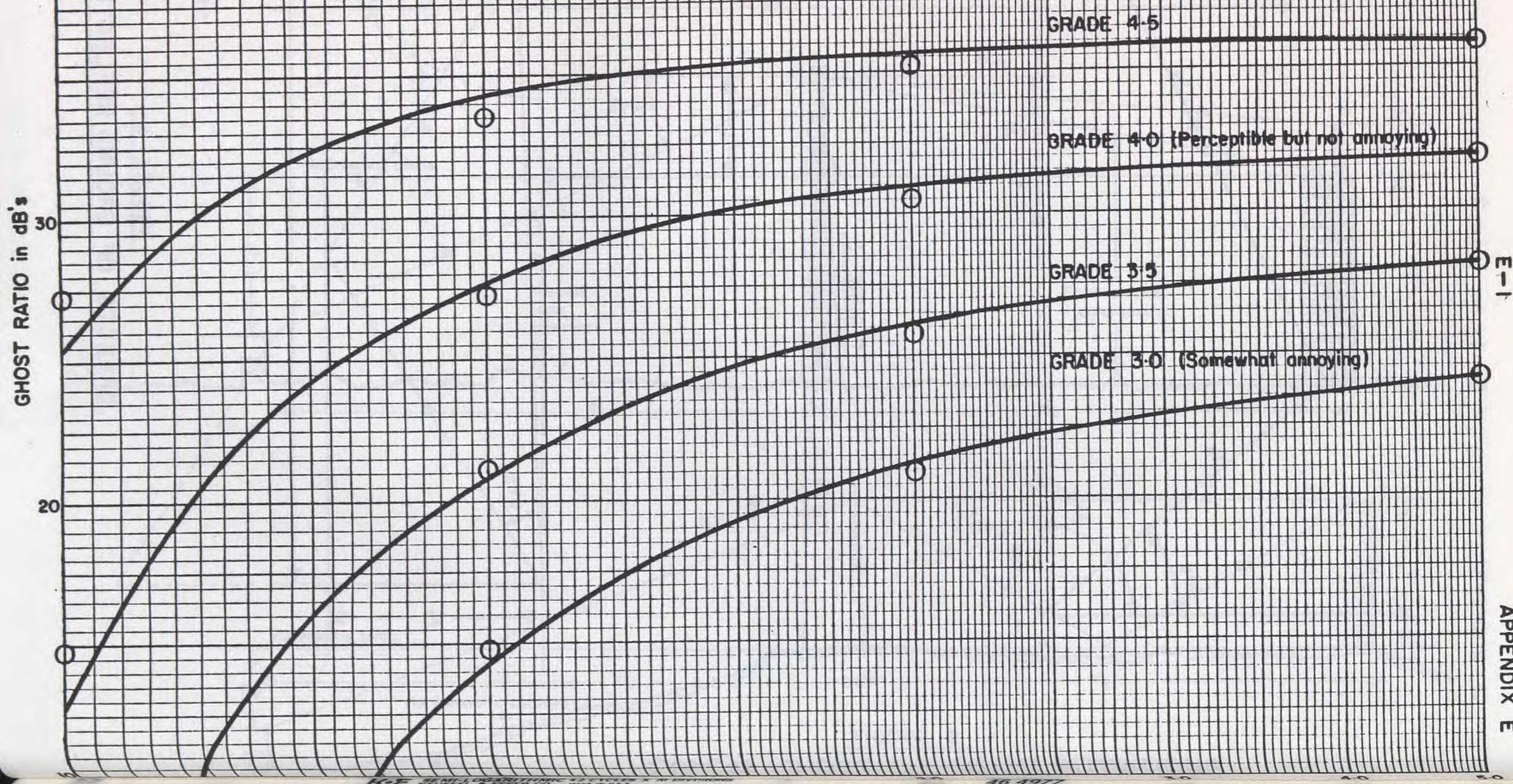


FIGURE 6

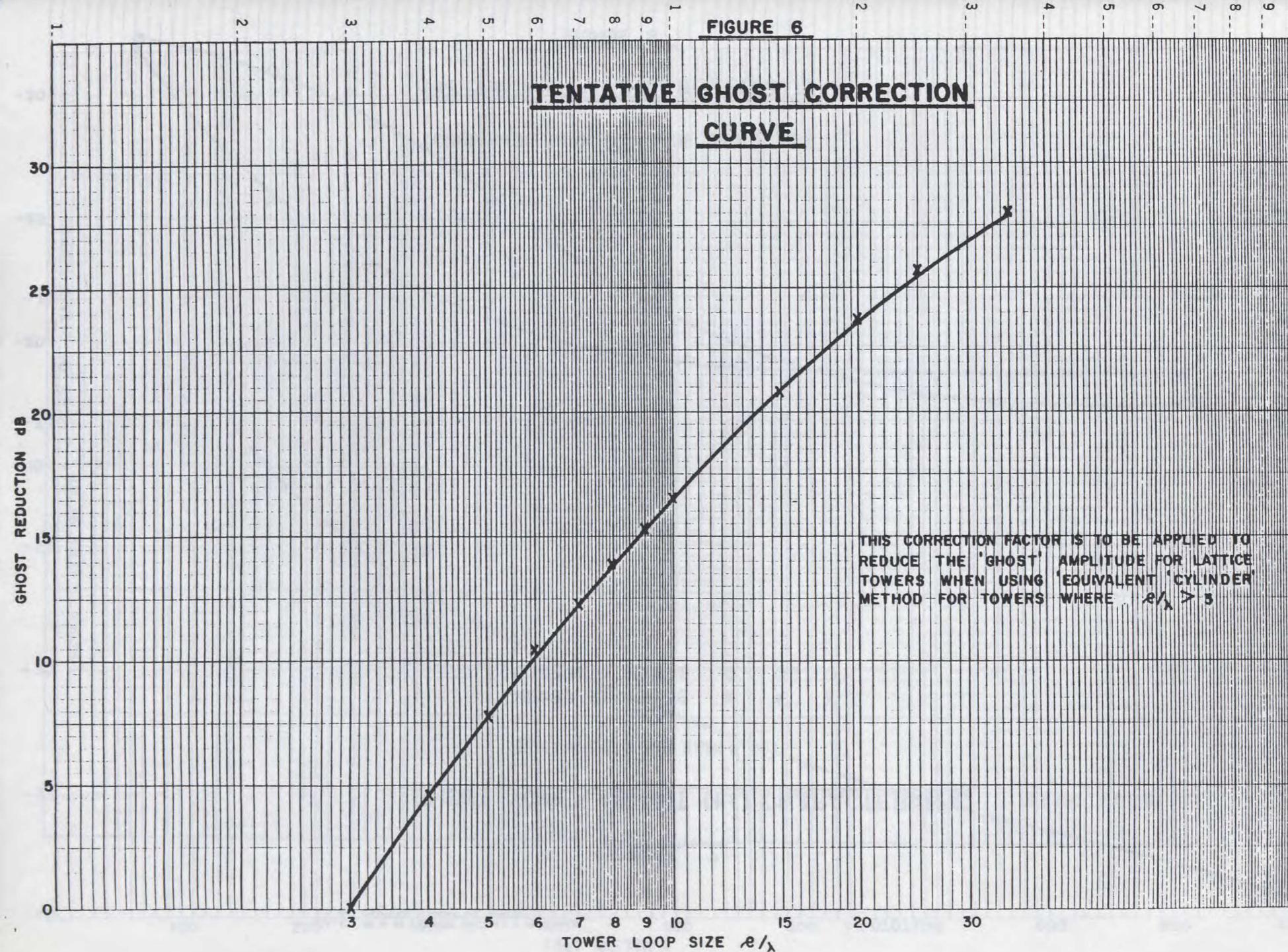
**TENTATIVE GHOST CORRECTION
CURVE**

FIGURE 7

GHOST TOWER HEIGHT (h_s) CHARACTERISTIC

(EXAMPLE I OF TABLE II)

MEASURED POINTS X X X
COMPUTED POINTS O O O

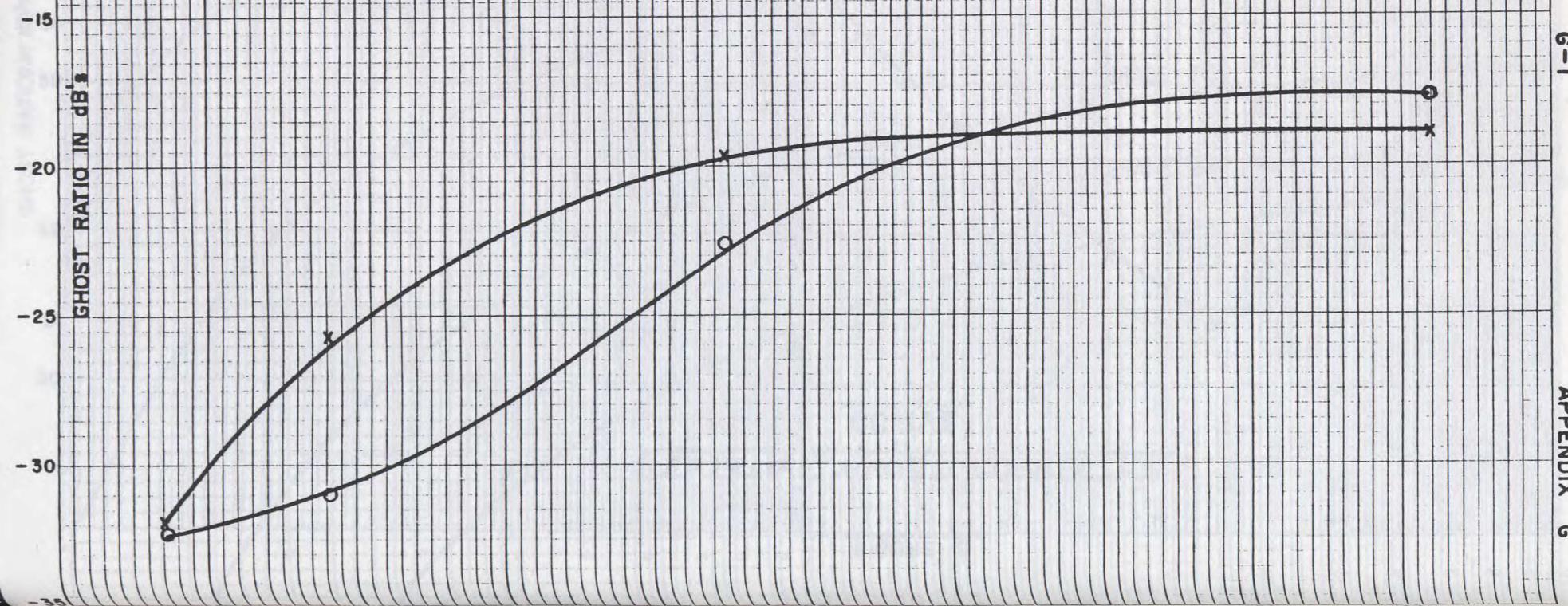
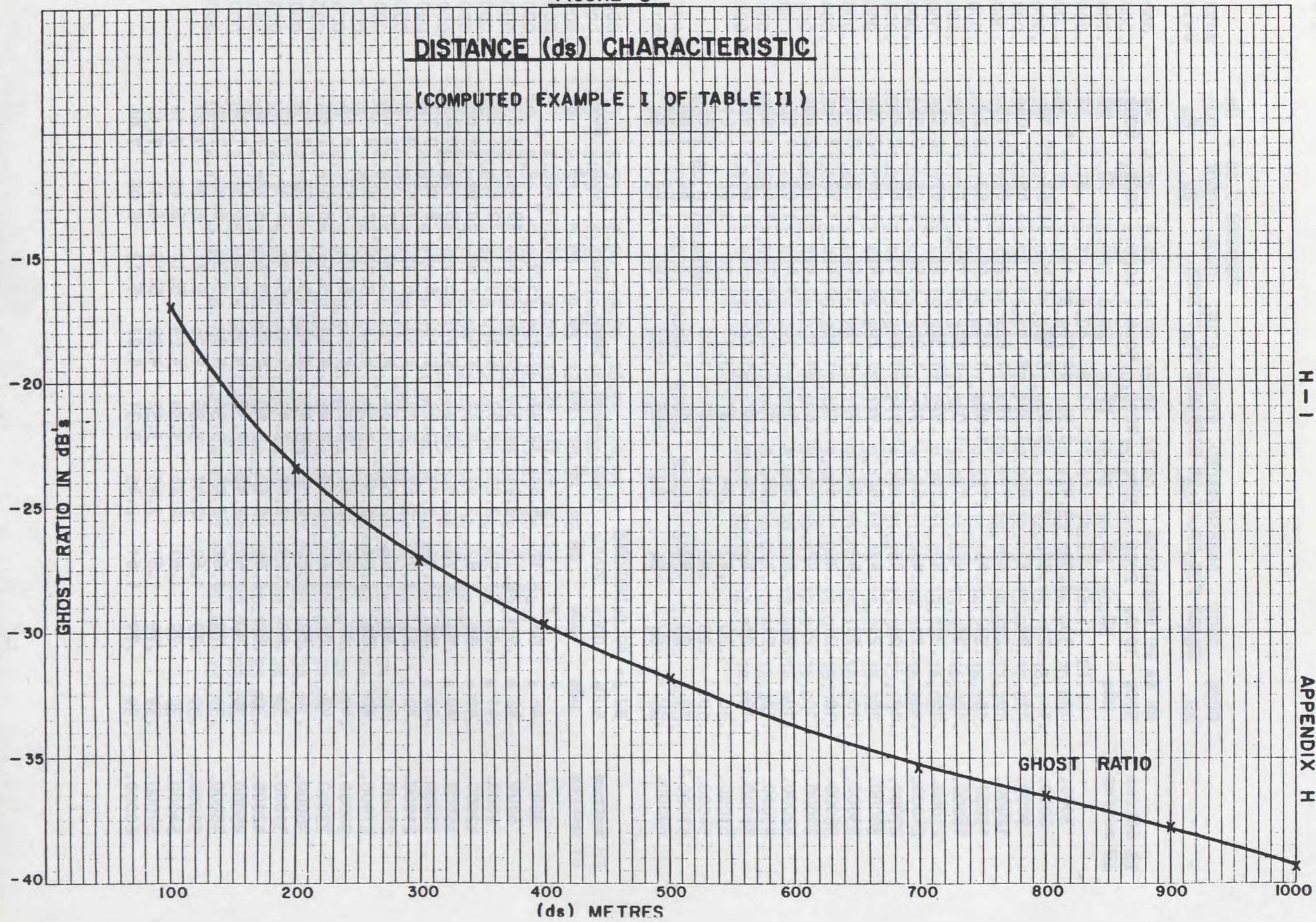


FIGURE 8

DISTANCE (ds) CHARACTERISTIC

(COMPUTED EXAMPLE I OF TABLE II)



APPENDIX NO. I
TABLE FOR DELAY VS DISTANCE TO VIEWER

$\theta_H = 20.0$ DEGREES

DS metres DV metres	$\theta_H = 20.0$ DEGREES									
	500. μs	1000. μs	2000. μs	3000. μs	4000. μs	5000. μs	6000. μs	7000. μs	8000. μs	
3000.	.12	.30	1.04	3.47	8.55	14.70	21.14	*	*	
6000.	.11	.24	.59	1.14	2.09	3.83	6.95	11.54	17.10	
9000.	.11	.23	.51	.89	1.39	2.10	3.13	4.69	7.04	
12000.	.10	.22	.48	.79	1.18	1.66	2.28	3.09	4.17	
15000.	.10	.21	.46	.75	1.08	1.48	1.95	2.52	3.22	
18000.	.10	.21	.45	.72	1.02	1.37	1.77	2.23	2.78	
21000.	.10	.21	.44	.70	.98	1.30	1.66	2.07	2.52	
24000.	.10	.21	.44	.69	.96	1.26	1.59	1.95	2.36	
27000.	.10	.21	.43	.68	.94	1.22	1.53	1.87	2.25	
30000.	.10	.21	.43	.67	.92	1.20	1.49	1.81	2.16	
33000.	.10	.21	.43	.66	.91	1.18	1.46	1.77	2.10	
36000.	.10	.21	.42	.66	.90	1.16	1.44	1.73	2.05	
39000.	.10	.21	.42	.65	.89	1.15	1.42	1.70	2.00	
42000.	.10	.21	.42	.65	.89	1.14	1.40	1.68	1.97	
45000.	.10	.21	.42	.64	.88	1.13	1.38	1.66	1.94	
48000.	.10	.21	.42	.64	.87	1.12	1.37	1.64	1.92	
51000.	.10	.20	.42	.64	.87	1.11	1.36	1.62	1.89	
54000.	.10	.20	.42	.64	.87	1.10	1.35	1.61	1.88	
57000.	.10	.20	.42	.64	.86	1.10	1.34	1.60	1.86	
60000.	.10	.20	.42	.63	.86	1.09	1.34	1.59	1.85	

$\theta_H = 40.0$ DEGREES

DS metres DV metres	$\theta_H = 40.0$ DEGREES									
	500. μs	1000. μs	2000. μs	3000. μs	4000. μs	5000. μs	6000. μs	7000. μs	8000. μs	
3000.	.46	1.08	3.17	6.84	11.91	17.73	23.91	*	*	
6000.	.42	.91	2.16	3.91	6.34	9.59	13.68	18.48	23.81	
9000.	.41	.86	1.93	3.25	4.90	6.96	9.51	12.62	16.30	
12000.	.40	.84	1.82	2.97	4.33	5.93	7.83	10.06	12.68	
15000.	.40	.83	1.76	2.82	4.03	5.41	6.99	8.79	10.85	
18000.	.40	.82	1.73	2.73	3.85	5.10	6.49	8.05	9.79	
21000.	.40	.81	1.70	2.67	3.73	4.89	6.17	7.57	9.12	
24000.	.40	.81	1.68	2.62	3.64	4.75	5.94	7.24	8.66	
27000.	.40	.81	1.67	2.59	3.58	4.64	5.78	7.00	8.32	
30000.	.40	.80	1.66	2.56	3.53	4.55	5.65	6.82	8.06	
33000.	.40	.80	1.65	2.54	3.49	4.49	5.55	6.67	7.86	
36000.	.39	.80	1.64	2.52	3.45	4.43	5.47	6.55	7.70	
39000.	.39	.80	1.63	2.51	3.43	4.39	5.40	6.46	7.57	
42000.	.39	.80	1.63	2.50	3.40	4.35	5.34	6.38	7.46	
45000.	.39	.80	1.62	2.48	3.38	4.32	5.29	6.31	7.37	
48000.	.39	.79	1.62	2.48	3.36	4.29	5.25	6.25	7.29	
51000.	.39	.79	1.62	2.47	3.35	4.26	5.21	6.20	7.22	
54000.	.39	.79	1.61	2.46	3.34	4.24	5.18	6.15	7.16	
57000.	.39	.79	1.61	2.45	3.32	4.22	5.15	6.11	7.10	
60000.	.39	.79	1.61	2.45	3.31	4.21	5.13	6.08	7.06	

$\theta H = 60.0$ DEGREES

DS metres DV metres	500. μ S	1000. μ S	2000. μ S	3000. μ S	4000. μ S	5000. μ S	6000. μ S	7000. μ S	8000. μ S
3000.	.95	2.15	5.49	10.00	15.35	21.20	*	*	*
6000.	.89	1.89	4.30	7.32	10.97	15.23	20.00	*	*
9000.	.87	1.81	3.95	6.46	9.37	12.70	16.46	20.62	*
12000.	.86	1.78	3.79	6.06	8.61	11.47	14.64	18.13	21.94
15000.	.85	1.75	3.69	5.83	8.18	10.76	13.59	16.67	20.00
18000.	.85	1.74	3.63	5.68	7.90	10.31	12.92	15.72	18.73
21000.	.85	1.73	3.58	5.57	7.71	10.00	12.45	15.07	17.86
24000.	.85	1.72	3.55	5.50	7.57	9.77	12.11	14.59	17.22
27000.	.84	1.71	3.53	5.44	7.46	9.60	11.85	14.23	16.74
30000.	.84	1.71	3.51	5.39	7.38	9.46	11.65	13.95	16.36
33000.	.84	1.71	3.49	5.36	7.31	9.35	11.49	13.72	16.05
36000.	.84	1.70	3.48	5.33	7.25	9.26	11.36	13.54	15.80
39000.	.84	1.70	3.46	5.30	7.21	9.19	11.24	13.38	15.60
42000.	.84	1.70	3.46	5.28	7.17	9.12	11.15	13.25	15.42
45000.	.84	1.69	3.45	5.26	7.13	9.07	11.07	13.13	15.27
48000.	.84	1.69	3.44	5.24	7.10	9.02	11.00	13.04	15.14
51000.	.84	1.69	3.43	5.23	7.07	8.98	10.93	12.95	15.03
54000.	.84	1.69	3.43	5.21	7.05	8.94	10.88	12.88	14.93
57000.	.84	1.69	3.42	5.20	7.03	8.91	10.83	12.81	14.84
60000.	.84	1.69	3.42	5.19	7.01	8.88	10.79	12.75	14.76

 $\theta H = 80.0$ DEGREES

DS metres DV metres	500. μ S	1000. μ S	2000. μ S	3000. μ S	4000. μ S	5000. μ S	6000. μ S	7000. μ S	8000. μ S
3000.	1.51	3.31	7.68	12.86	18.55	24.55	*	*	*
6000.	1.45	3.03	6.62	10.75	15.36	20.37	*	*	*
9000.	1.42	2.94	6.25	9.93	13.97	18.35	23.04	*	*
12000.	1.41	2.89	6.06	9.51	13.24	17.24	21.50	*	*
15000.	1.40	2.86	5.95	9.26	12.79	16.55	20.52	24.71	*
18000.	1.40	2.85	5.87	9.09	12.49	16.08	19.86	23.82	*
21000.	1.40	2.83	5.82	8.97	12.28	15.75	19.38	23.17	*
24000.	1.39	2.82	5.78	8.88	12.12	15.50	19.02	22.68	*
27000.	1.39	2.81	5.75	8.81	12.00	15.31	18.74	22.30	*
30000.	1.39	2.81	5.73	8.76	11.90	15.15	18.52	21.99	*
33000.	1.39	2.80	5.71	8.71	11.82	15.02	18.33	21.74	*
36000.	1.39	2.80	5.69	8.67	11.75	14.92	18.18	21.54	24.99
39000.	1.39	2.80	5.68	8.64	11.69	14.83	18.05	21.36	24.76
42000.	1.39	2.79	5.66	8.61	11.64	14.75	17.94	21.21	24.56
45000.	1.39	2.79	5.65	8.59	11.60	14.69	17.84	21.08	24.39
48000.	1.39	2.79	5.64	8.57	11.56	14.63	17.76	20.97	24.24
51000.	1.39	2.79	5.64	8.55	11.53	14.58	17.69	20.86	24.11
54000.	1.38	2.78	5.63	8.54	11.50	14.53	17.62	20.78	23.99
57000.	1.38	2.78	5.62	8.52	11.48	14.49	17.56	20.70	23.89
60000.	1.38	2.78	5.62	8.51	11.45	14.45	17.51	20.62	23.79

		$\theta H = 100.0$ DEGREES								
DS metres	DV metres	500. μS	1000. μS	2000. μS	3000. μS	4000. μS	5000. μS	6000. μS	7000. μS	8000. μS
3000.	2.09	4.41	9.61	15.32	21.34	*	*	*	*	*
6000.	2.02	4.17	8.82	13.86	19.23	24.84	*	*	*	*
9000.	2.00	4.09	8.51	13.23	18.21	23.43	*	*	*	*
12000.	1.99	4.04	8.34	12.88	17.64	22.59	*	*	*	*
15000.	1.98	4.02	8.24	12.67	17.27	22.05	*	*	*	*
18000.	1.98	4.00	8.18	12.52	17.02	21.67	*	*	*	*
21000.	1.98	3.99	8.13	12.41	16.83	21.39	*	*	*	*
24000.	1.97	3.98	8.09	12.33	16.69	21.17	*	*	*	*
27000.	1.97	3.97	8.06	12.26	16.58	21.00	*	*	*	*
30000.	1.97	3.97	8.04	12.21	16.49	20.86	*	*	*	*
33000.	1.97	3.96	8.02	12.17	16.41	20.75	*	*	*	*
36000.	1.97	3.96	8.00	12.13	16.35	20.65	*	*	*	*
39000.	1.97	3.95	7.99	12.10	16.30	20.57	24.92	*	*	*
42000.	1.97	3.95	7.98	12.08	16.25	20.50	24.82	*	*	*
45000.	1.97	3.95	7.97	12.06	16.21	20.44	24.73	*	*	*
48000.	1.96	3.95	7.96	12.04	16.18	20.39	24.66	*	*	*
51000.	1.96	3.94	7.95	12.02	16.15	20.34	24.59	*	*	*
54000.	1.96	3.94	7.94	12.00	16.12	20.30	24.53	*	*	*
57000.	1.96	3.94	7.94	11.99	16.10	20.26	24.47	*	*	*
60000.	1.96	3.94	7.93	11.98	16.07	20.22	24.42	*	*	*
		$\theta H = 120.0$ DEGREES								
DS metres	DV metres	500. μS	1000. μS	2000. μS	3000. μS	4000. μS	5000. μS	6000. μS	7000. μS	8000. μS
3000.	2.60	5.35	11.20	17.32	23.61	*	*	*	*	*
6000.	2.55	5.19	10.70	16.46	22.39	*	*	*	*	*
9000.	2.53	5.13	10.50	16.06	21.78	*	*	*	*	*
12000.	2.53	5.10	10.38	15.83	21.41	*	*	*	*	*
15000.	2.52	5.08	10.31	15.68	21.16	*	*	*	*	*
18000.	2.52	5.07	10.26	15.57	20.99	*	*	*	*	*
21000.	2.51	5.06	10.23	15.50	20.86	*	*	*	*	*
24000.	2.51	5.05	10.20	15.44	20.77	*	*	*	*	*
27000.	2.51	5.05	10.18	15.39	20.69	*	*	*	*	*
30000.	2.51	5.04	10.16	15.36	20.62	*	*	*	*	*
33000.	2.51	5.04	10.15	15.33	20.57	*	*	*	*	*
36000.	2.51	5.03	10.14	15.30	20.53	*	*	*	*	*
39000.	2.51	5.03	10.12	15.28	20.49	*	*	*	*	*
42000.	2.51	5.03	10.12	15.26	20.45	*	*	*	*	*
45000.	2.51	5.03	10.11	15.24	20.42	*	*	*	*	*
48000.	2.51	5.03	10.10	15.23	20.40	*	*	*	*	*
51000.	2.51	5.02	10.10	15.21	20.38	*	*	*	*	*
54000.	2.51	5.02	10.09	15.20	20.36	*	*	*	*	*
57000.	2.51	5.02	10.09	15.19	20.34	*	*	*	*	*
60000.	2.51	5.02	10.08	15.18	20.32	*	*	*	*	*

$\theta H = 140.0$ DEGREES

DS metres DV metres	500.	1000.	2000.	3000.	4000.	5000.	6000.	7000.	8000.
	μ s								
3000.	2.99	6.07	12.37	18.79	*	*	*	*	*
6000.	2.97	5.99	12.14	18.40	24.74	*	*	*	*
9000.	2.96	5.96	12.03	18.21	24.45	*	*	*	*
12000.	2.96	5.94	11.98	18.09	24.27	*	*	*	*
15000.	2.95	5.93	11.94	18.02	24.15	*	*	*	*
18000.	2.95	5.92	11.91	17.97	24.07	*	*	*	*
21000.	2.95	5.92	11.90	17.93	24.00	*	*	*	*
24000.	2.95	5.91	11.88	17.90	23.95	*	*	*	*
27000.	2.95	5.91	11.87	17.87	23.91	*	*	*	*
30000.	2.95	5.91	11.86	17.85	23.88	*	*	*	*
33000.	2.95	5.91	11.85	17.84	23.85	*	*	*	*
36000.	2.95	5.91	11.85	17.82	23.83	*	*	*	*
39000.	2.95	5.90	11.84	17.81	23.81	*	*	*	*
42000.	2.95	5.90	11.84	17.80	23.79	*	*	*	*
45000.	2.95	5.90	11.83	17.79	23.78	*	*	*	*
48000.	2.95	5.90	11.83	17.78	23.76	*	*	*	*
51000.	2.95	5.90	11.83	17.78	23.75	*	*	*	*
54000.	2.95	5.90	11.82	17.77	23.74	*	*	*	*
57000.	2.95	5.90	11.82	17.76	23.73	*	*	*	*
60000.	2.95	5.90	11.82	17.76	23.72	*	*	*	*

 $\theta H = 160.0$ DEGREES

DS metres DV metres	500.	1000.	2000.	3000.	4000.	5000.	6000.	7000.	8000.
	μ s								
3000.	3.25	6.52	13.09	19.70	*	*	*	*	*
6000.	3.24	6.49	13.03	19.60	*	*	*	*	*
9000.	3.24	6.49	13.00	19.55	*	*	*	*	*
12000.	3.24	6.48	12.99	19.52	*	*	*	*	*
15000.	3.24	6.48	12.98	19.50	*	*	*	*	*
18000.	3.24	6.48	12.97	19.48	*	*	*	*	*
21000.	3.24	6.47	12.97	19.47	*	*	*	*	*
24000.	3.23	6.47	12.96	19.46	*	*	*	*	*
27000.	3.23	6.47	12.96	19.46	*	*	*	*	*
30000.	3.23	6.47	12.96	19.45	*	*	*	*	*
33000.	3.23	6.47	12.95	19.45	*	*	*	*	*
36000.	3.23	6.47	12.95	19.44	*	*	*	*	*
39000.	3.23	6.47	12.95	19.44	*	*	*	*	*
42000.	3.23	6.47	12.95	19.44	*	*	*	*	*
45000.	3.23	6.47	12.95	19.43	*	*	*	*	*
48000.	3.23	6.47	12.95	19.43	*	*	*	*	*
51000.	3.23	6.47	12.95	19.43	*	*	*	*	*
54000.	3.23	6.47	12.95	19.43	*	*	*	*	*
57000.	3.23	6.47	12.94	19.43	*	*	*	*	*
60000.	3.23	6.47	12.94	19.42	*	*	*	*	*

* Values > 25 μ s

