Communications
Canada

BTRB-6
(Issue 2)
July, 1989

2. REPORT ON PREDICTING TELEVISION GHOSTING INTERFERENCE AND PICTURE QUALITY

Prepared by:
1. J. S. Dadourian
W. E. Wright

Canada

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SUMMARY

This report outlines a procedure to predict TV ghosting interference as derived from the study program entitled "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. 36100-7-0613

This 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 different levels of picture quality. The second volume, dated November 1978, contains the development of a ghost prediction method.

A computer program to predict TV ghosting interference and to relate the levels to various grades of TV picture has been developed by the Department. The program follows the general pattern of E. W. Horrigan's ghost prediction model (Second volume, Nov. 1978).

1. Introduction

The purpose of this report is to provide a procedure to predict the magnitude of television ghosting interference caused by antenna towers or other metallic structures. It is intended to be used by broadcast consultants or other engineering representatives of broadcasters, to help in selecting a site or in designing the transmitting antenna towers.

While the procedure applies to television broadcasting frequencies, such as VHF and UHF, it is not intended to be used at higher or lower frequencies.

2. Description of the Problem

Television transmitting sites are selected to provide a suitable signal level to the immediate and surrounding areas of the station. This has frequently resulted in the selection of a site close to other telecommunication towers such as broadcasting, land mobile, cellular telephone etc. A television broadcasting antenna radiates electromagnetic waves which travel outward from the antenna and meet these metallic structures. The waves induce electrical currents to flow in these structures which in turn, can radiate their own electromagnetic waves (reflection) at the same frequency as the television station. This creates a second wave which has a longer signal path to receivers. Because the path of the reflected or re-radiated wave is longer, the reflected wave travelling this path reaches the receivers with a slight delay, and therefore to the right of the main signal (picture lines on a TV screen are drawn from left to right). The second picture on the screen formed by the re-radiated wave is generally known as a ghost and the associated interference is called ghosting interference.

3. Derivation of Ghost Level and Ghost Delay Equations

The severity of a ghost image or interference due to reflection (sometimes called multipath effect) is a function of the delay (t_d) of the reflected wave and the magnitude of the reflected wave with respect to the direct wave (G).

3.1 Definition of Parameters

The following is a list of parameters used in deriving the ghost equations, i.e. t_d and G.

f : Radio frequency in MHz,
λ : wavelength in metres,
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 transmitting tower to ghost tower in metres,
d_v : distance from transmitting tower to viewer's location in metres,
d_{gv}: distance from ghost tower to viewer in metres,
ϕ_g : azimuth of ghost tower in degrees,
ϕ_v : azimuth of viewer in degrees,
$F_h(\phi)$: relative horizontal field at a given azimuth,
$F_v(\theta)$: relative vertical field at a given depression angle.

3.2 Echo Delay Equation

An expression for echo delay (t_d) can be derived from the geometry of a triangle (See Appendix 1) as follows:

$$d_{gv}^2 = d_g^2 + d_v^2 - 2d_gd_v\cos(\theta_g-\theta_v) \quad (1)$$

The path difference between the distances of direct and reflected waves:

$$d = d_g + d_{gv} - d_v,$$

and the echo delay:

$$t_d = \frac{d}{c} = \frac{d_g + d_{gv} - d_v}{c} \qquad (2)$$

In microseconds the delay has the expression:

$$t_d(\mu s) = 3.33(d_g + d_{gv} - d_v) \times 10^{-3} \qquad (3)$$

3.3 Ghost Magnitude Equation

Ghost prediction methods now in use have not been realistic and practical. These models often ignore the effects of the shape of the radiating antenna pattern, ground reflection and the finite length of the ghost structure thereby giving unrealistic results.

To calculate the equation for ghost magnitude, the following assumptions are made:

a. the transmitting antenna is not necessarily an isotropic radiator,

b. the entire system is not in a free-space environment,

c. the re-radiating tower in question is not evenly illuminated or uniformly excited by a constant phase front.

3.3.1 Power Density at Viewer's Location

If P_t indicates the EIRP (Effective Isotropic Radiated Power) of the transmitting antenna and $F_h(\phi_v)$ and $F_v(\theta_v)$ the relative horizontal and vertical fields respectively at the viewer's location, the power density at the viewer's location is given by:

$$W_v = \frac{P_t}{4\Pi d_v^2} F_h^2(\phi_v) F_v^2(\theta_v) \qquad (4)$$

3.3.2 Power Density at Ghost Tower

Let us 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 d_g which is in the range of $h_t \leq d_g \leq 50h_t$. In this range, the effects of ground reflections cannot be ignored and it is necessary to define the incident power function.

The incident power density at a point of height h on the ghost tower is the sum of the direct and ground reflected waves (Appendix 1):

$$W_g(h) = \frac{P_t}{4\pi} Q^2(h)\ F_h^2(\phi_g) \qquad (5)$$

Where:

$$Q(h) = \frac{F_v(\theta_{gd})}{R_D} \exp(-j\beta R_D) - \frac{F_v(\theta_{gr})}{R_R} \exp(-j\beta R_R) \qquad (6)$$

R_D and R_R are the path lengths travelled by the direct and ground reflected waves to reach the point of height h on the tower:

$$R_D^2 = d_g^2 + (h_t - h)^2 \qquad (7a)$$

$$R_R^2 = d_g^2 + (h_t + h)^2 \qquad (7b)$$

$F_v(\theta_{gd})$ and $F_v(\theta_{gr})$ represent the relative vertical field values for the depression angles θ_{gd} and θ_{gr}, which correspond to the direct and ground reflected wave paths respectively.

The incident electric field has the expression:

$$E_i = E_D - E_R = \sqrt{\frac{\eta P_t}{4\pi}}\ F_h(\phi_g) Q(h) \qquad (8)$$

3.3.3 Power Density at Viewer's Location Due to Re-radiation from Ghost Tower

If σ is the scattering cross-section of a one wavelength high section of the ghost tower and if the assumption is made that the incident electric field is uniform on a one wavelength section (far field approximation) of the ghost tower, the reflected electric field at the viewer's location is given by:

$$\left| E_{ref} \right|^2 = \frac{\sigma}{4\pi} \left| E_i \right|^2 \frac{1}{d_{gv}^2} \qquad (9)$$

or:

$$E_{ref} = \sqrt{\frac{\sigma}{4\pi} \quad \frac{\eta P_t}{4\pi}} \; F_h(\phi_g) \quad X$$

$$X \quad \frac{Q(h)}{d_{gv}} \quad \exp(-j\beta d_{gv}) \qquad (10)$$

If the ghost tower is subdivided into n one wavelength high segments, the total reflected electric field is the sum:

$$E_{tot} = \sum_{i=1}^{n} E_{ref}(i)$$

$$E_{tot} = \sqrt{\frac{\sigma}{4\pi} \quad \frac{\eta P_t}{4\pi}} \quad F_h(\phi_g) \quad X$$

$$X \quad \sum_{i=1}^{n} \frac{Q(h)}{d_{gv}} \exp(-j\beta d_{gv}) \qquad (11)$$

Where: $Q(h) = Q(h(i))$ and $d_{gv} = d_{gv}(i)$.

The total reflected power density at viewer's location is:

$$W_{gv} = \frac{|E_{tot}|^2}{\eta} = \frac{\sigma}{4\pi} \frac{P_t}{4\pi} F_h^2(\phi_g) \quad X$$

$$X \left[\sum_{i=1}^{n} \quad \frac{Q(h)}{d_{gv}} \quad \exp(-j\beta d_{gv}) \right]^2 \qquad (12)$$

3.3.4 Ghost/Signal Ratio

The ghost to signal ratio at viewer's location is the ratio of the power density at the viewer's location due to re-radiation from ghost tower (equation 12) over the power density at the viewer's location of the direct wave (equation 4).

$$\frac{W_{gv}}{W_v} = \left[\frac{d_v}{d_{gv}}\right]^2 \frac{\sigma}{4\pi} \left[\frac{F_h(\phi_g)}{F_h(\phi_v)}\right]^2 \quad X$$

$$X \quad \frac{\left[\sum_{i=1}^{n} \right]^2}{F_v^2(\theta_v)} \qquad (13)$$

3.3.5 Complete Echo Magnitude Equation

The basic echo magnitude equation is given as follows:

$$G(\text{in dB}) = 10\log_{10}\left[\frac{\sigma}{4\pi}\left[\frac{d_v\lambda}{d_{gv}}\right]^2 L_{HG} \text{ X}\right.$$

$$\left.\text{X} \left[\frac{F_h(\phi_g)}{F_h(\phi_v)}\right]^2 \frac{\left[\sum_{i=1}^{n}\right]^2}{F_v^{2}(\theta_v)}\right] \qquad (14)$$

Where L_{HG} is the linear height-gain function (refer to Section 4.1) and σ is the cross-section in λ^2.

The equation (14) 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.

4. Review of Various Factors

4.1 Centre of Radiation of Ghost Tower

The linear height-gain function L_{HG} referred to the viewing location applies only where the direct path and ground reflected components of both ghost and direct signals are substantially out of phase. Where first Fresnel zone clearance exists (Appendix 5), the factor should be equated to one for realistic ghost computations. Thus if:

$$\frac{f(h_t - h_v)}{d_v} < 7.5 \text{ MHz and } \frac{f(\bar{h}_g - h_v)}{d_{gv}} < 7.5 \text{ MHz} \qquad (15a)$$

then; $L_{HG} = 1.0$,

$$\text{otherwise;} \quad L_{HG} = \left[\frac{\bar{h}_g - h_v}{h_t - h_v}\right]^2 \qquad (15b)$$

In order to calculate the linear height-gain function L_{HG} (equation 15a), the effective centre of re-radiation of the ghost

tower ($\bar{h}_g$) can be likened to the first moment centroid of Q(h), thus:

$$\bar{h}_g = \frac{\int_0^{h_g} hQ^2(h)\,dh}{\int_0^{h_g} Q^2(h)\,dh} \qquad (16)$$

4.2 Cross-Section

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

4.2.1 Scattering Cross-Section Measurements

The measurement of the scattering cross-section of a one wavelength high typical lattice type triangular section tower (square section towers have the same behaviour), were made for loop sizes in the range of 0.5λ to 2.5λ. The results of these tests are listed below:

Loop Dimension in λ	0.5	1.0	1.5	2.0	2.5
Effective Area σ per unit λ height	$0.36\ \lambda^2$	$1.6\lambda^2$	$1.0\lambda^2$	$2.7\lambda^2$	$2.3\lambda^2$

4.2.2 Scattering Cross-Section Equation

For horizontally polarized signal, the measured scattering cross-section values of one wavelength high triangular tower section as listed above, have been fitted to a suitable equation over the loop size range of 0.5λ to 3.0λ.

The working equation which adequately describes the measured data over the above loop range has the following format:

$$\sigma_t = f\left(\frac{l}{\lambda}\right) f\big(S(z)\big) \qquad (17)$$

Where l is equal to the loop length in metres. If w is the width of the tower in metres and N_s the number of tower sides, then:

$$l = N_s w$$

$$S(z) = \int_0^z \sin\left(\frac{\pi}{2}t^2\right) dt \qquad (18)$$

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

$$S(z) = 0.5 - f(z)\cos\left(\frac{\pi}{2}z^2\right) - g(z)\sin\left(\frac{\pi}{2}z^2\right) \qquad (19)$$

For computational purposes, the rational approximations [1] for f(z) and g(z) can be used to evaluate S(z):

$$f(z) = \frac{1 + 0.926z}{2 + 1.792z + 3.104z^2} + \xi(z) \qquad (20a)$$

$$g(z) = \frac{1}{2 + 4.142z + 3.492z^2 + 6.67z^3} + \xi(z), \qquad (20b)$$

where $\xi(z) \leq 2 \text{ X } 10^{-3}$.

$$\sigma = \frac{1}{1.2}\left(\frac{\pi}{2}\right)^2 \frac{1}{\lambda} \left(1 - \exp\left(\frac{21}{\lambda}\right)^2\right) S(z) \qquad (21)$$

where $z = \frac{1}{\lambda} + 0.5$.

The scattering cross-section of a large cylinder is defined as:

$$\sigma_{cyl} = 2\pi \frac{a}{\lambda} L^2 \qquad (22)$$

where: L = height of cylinder, a = radius of cylinder.

Let: $\frac{2\pi a}{\lambda} = \frac{1}{\lambda}$ and $L = \lambda$

The cross-section for $\frac{1}{\lambda} > 3.0$ becomes; $\sigma = \frac{1}{\lambda}$, otherwise for values of $0 < \frac{1}{\lambda} \leq 3.0$; equation 21 should be used.

The measured cross-sections of the tower for unit wavelength height are shown in Appendix 2, together with the general equation of the curve of equivalent cylinder (equation 22).

4.3 Transmitting Antenna Vertical Pattern Function

The vertical pattern of a vertically stacked antenna array of radiators is normally computed from the input currents of each radiator of the array and the vertical pattern of the single radiator. For the present application, only the normalized magnitude of the pattern is of interest. Thus, for an array of N identical radiators spaced uniformly one wavelength apart (mutual coupling effects can be ignored when the spacing between adjacent radiators is about one wavelength), and carrying identical currents, the vertical radiation pattern is given by:

$$F_V(\theta) = \frac{\sin[N\pi\sin\theta]}{N\sin[\pi\sin\theta]} f_V(\theta) \qquad (23)$$

$f_V(\theta)$ is the element pattern, and is approximated by the vertical pattern of a half-wave dipole:

$$f_V(\theta) = \frac{\cos(\frac{\pi}{2}\sin\theta)}{\cos\theta} \qquad (24)$$

These functions are generated internally by the program package to calculate the relative vertical fields for various depression angles.

So far it is assumed that the vertical radiation pattern under ideal conditions is being used. To allow for the effects of the tower, guy wires etc., a correction or quadratic factor is introduced. For a given depression angle θ, the required relative vertical field is obtained from the theoretical value of the radiation pattern by the following formula:

$$F_V(\theta) = [F_V^2(\theta) + A^2]^{\frac{1}{2}} \qquad (25)$$

Where A = 0.2 for most VHF/UHF broadcasting antennas and is not dependent on the depression angle.

5. Correction Factor for UHF Band

For the VHF band where $\frac{1}{\lambda} \leq 3$, 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 method in Section 3.

In the case of the UHF bands, where often $\frac{1}{\lambda} > 3$, the lattice type structures 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 $\frac{1}{\lambda} > 3$ (Appendix 3), pending further study to produce a general prediction formula for the cross-section covering both VHF and UHF ghosting situations.

6. Picture Quality

6.1 Grading 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. The five point scale system used in CCIR Recommendation 500-1 is selected as the basic scale to provide an adequate assessment of picture quality.

It is designated as follows:

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

6.2 Relationship between Picture Quality, Delay and Magnitude

For a particular picture grade, the shorter the time delay, the larger the permitted reflected wave. Subjective tests have shown a relationship between the two parameters and the graph in Appendix 4 shows this function for various TV picture grades.

Using the linear regression technique, the relationship could be expressed as follows for a typical viewing population sample:

$$N = 6 - \left[0.143G \exp\left(-\frac{0.637}{t_d}\right) + 6.65\exp\left(-\frac{0.475}{t_d}\right) \right] \qquad (26)$$

7. Limitations

The present method is a very simple and practical procedure to predict the ghost magnitude. It also provides an accurate solution for the majority of ghosting situations. Nevertheless, the validity of the method is largely dependent on the following criteria.

7.1 Face Width

The face width of the scattering tower should be relatively narrow, i.e. $w \leq 3\lambda$ at VHF frequencies. For horizontal polarization, this condition provides a uniform scattering cross-section around a major portion of the azimuth and a larger value over the shadow region, behind the ghost tower [2]. In other words, except for the shadow region, the horizontal "re-radiation" pattern or the scattering pattern does not depend on the orientation of the ghost tower legs or faces with respect to the direction of the incident wave, and is practically a circle (within ± 2dB) for values of $w \leq 3\lambda$.

The maximum value on the other hand occurs toward the shadow region except for very small diameter of the ghost structure. However, due to very short time delays in the region, the picture quality is rarely affected by the magnitude of the ghost signal in the shadow region, and therefore ghosting interference is not a factor in this region.

7.2 Depression Angle to Viewer's Location

Measurements [3] done on similar type of re-radiating structures have indicated that the scattering pattern is somewhat directional in the vertical plane (about -3dB at θ = 15 degrees). If the depression angle to the viewer's location, as it is seen from the centre of re-radiation of the ghost tower, is too large; i.e. $\theta > 10°$, the predicted ghost magnitude will be unrealistically high. The standard upper limit is 10°, however, ghost predictions for values of $5° < \theta \leq 10°$ should be considered with some reservation.

7.3 Selection of Reference Plane

Since the summation of the incident power starts at the base of the ghost tower (equation 11), and the calculated cross-section σ is valid only for narrow, lattice-type antenna towers, the reference plane should always be selected to correspond to the base of the ghost tower. In the real world however, the following three topographical conditions may be envisaged:

a) both the transmitting and ghost towers have the same ground elevation,

b) the ground elevation of the transmitting tower is higher than that of the ghost tower,

c) the ground elevation of the ghost tower is higher than that of the transmitting tower.

Ghost predictions for a) and b) are considered to be realistic under most circumstances, because they satisfy the conditions discussed in the above paragraph. In the case of c), if the ground elevation of the ghost tower is relatively high, the land mass or the highrise which supports the scattering tower will create a significant amount of ghost reflection. The additional reflection will make the predictions unreliable.

7.4 Separation Between Towers

The report and the associated prediction model do not deal with time delays shorter than 0.5μs. Subjective effects of very short time delayed re-radiated signals appear to be more severe than the extrapolation of the curves (Appendix 4) would indicate in the range of 0-0.5μs. Limited tests and theoretical analyses have indicated that significant color saturation and hue changes can be anticipated where the ghost delay is approximately one half period, plus an integer number of periods of the color subcarrier frequency. Delays in this range result in phase and amplitude modulation of the color burst and chrominance signal. This aspect of ghost impairment is beyond the scope of this report.

Once the lower limit of the delay is clearly established, the minimum separation between towers can be calculated by the following formula:

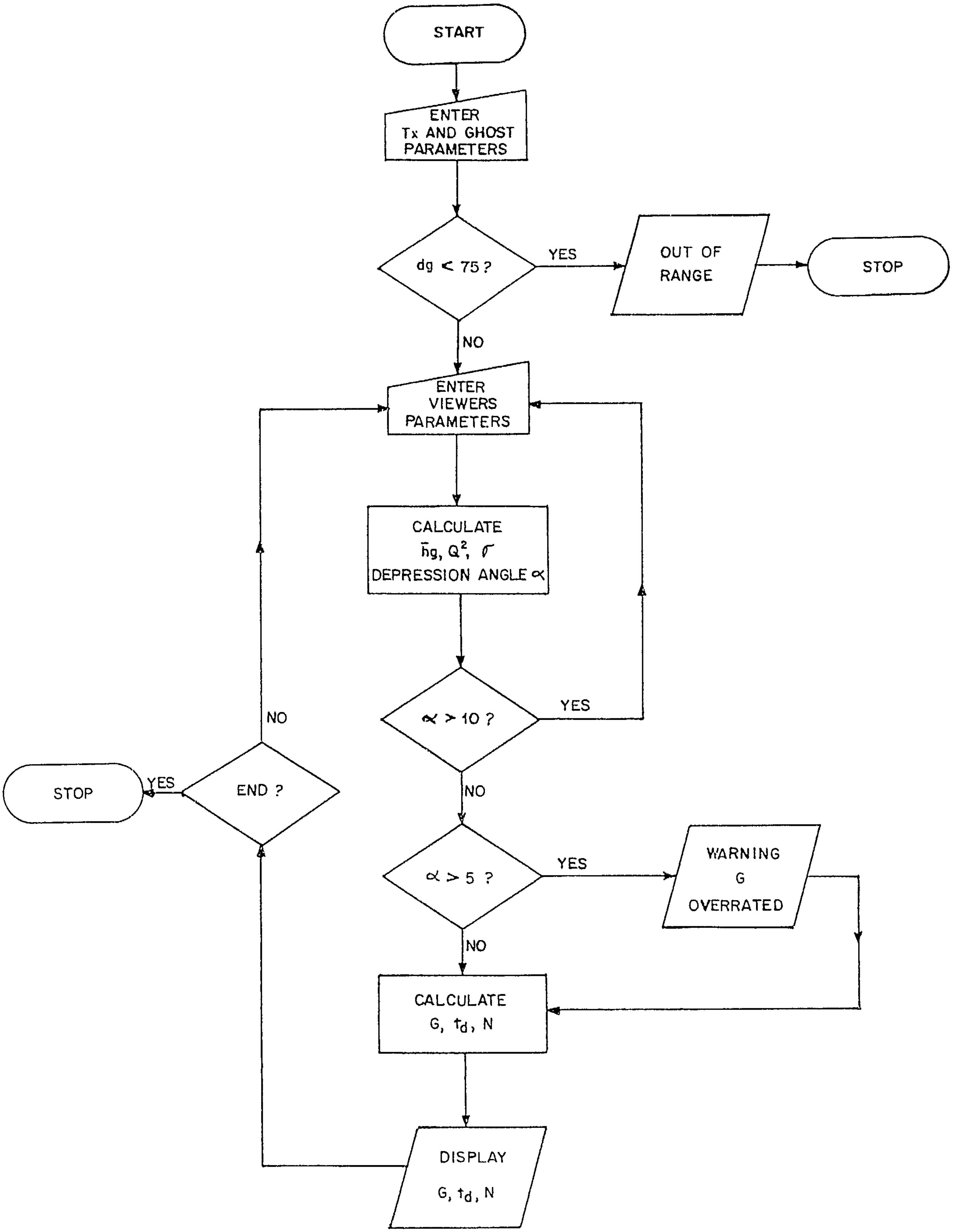
$$d_{min} = \frac{ct_d}{2}$$

for $t_d = 0.5\mu s$ and $c = 3X10^8 ms^{-1}$, the minimum separation will be $d_{min} = 75m$.

8. Software Package and Diagram

The software package in FORTRAN (Appendix 6) is designed to perform the following functions:

1. calculates and displays the echo delay in microseconds (equation 3),
2. calculates the effective centre of radiation of ghost tower (equation 16),
3. generates the vertical pattern of transmit antenna (equation 23),
4. calculates the power incident on ghost tower (equation 6),
5. calculates the cross-section of ghost tower (equation 21 or 22),
6. calculates transmitter to viewer path clearance and selects path treatment (equations 15a and 15b),
7. calculates and displays the echo magnitude in dB (equation 14),
8. calculates the correction factor for the UHF band if $1/\lambda>3$.
9. calculates and displays "Typical Viewer" grade of TV picture (equation 26).


START
ENTER Tx AND GHOST PARAMETERS
dg < 75 ?
YES
OUT OF RANGE
STOP
NO
ENTER VIEWERS PARAMETERS
CALCULATE $\bar{h}g$, Q^2, σ DEPRESSION ANGLE α
$\alpha > 10$?
YES
NO
$\alpha > 5$?
YES
WARNING G OVERRATED
NO
CALCULATE G, t_d, N
DISPLAY G, t_d, N
END ?
YES
STOP
NO

9. Examples of Computations and Comparison with Measured Ghost

Typical examples of TV signal ghosting interference calculations for various ghosting situations are given below.

Example 1:

Ghosting interference was observed for television channel 13 in Sudbury, Ontario, following the erection of a non-broadcasting tower in the immediate vicinity of the television station. Subsequent tests carried out at selected monitoring sites located on one to three kilometre arcs confirmed the observations and also revealed that the reflections (ghosts) were actually caused by the new non-broadcasting tower. The ghosting interference was particularly obvious at locations no. 2 and no. 7 (refer to the list of test points below). The degradation of the picture due to ghosting at these two locations provided a picture grade of between 3.5 and 4, based on the 5 point grading scale (refer to Section 6.1). The highest ghost levels observed at these locations were in the order of 20 to 26 dB down from the direct signal.

Transmitting Tower Parameters:

TV frequency (in MHz):	211.24 (Ch. 13)
Number of bays:	4
Height of C/R above ground (in m):	80.8
Height of C/R above ref. plane (in m):	103

Ghost Tower Parameters:

Width of tower (in m):	1
Number of tower sides:	3 (triangular)
Height above ref. plane (in m):	109.7
Separation between towers (in m):	253.6
Azimuth (in degrees):	327
Rel horiz. field at ghost tower azimuth:	0.90

Viewing Location Parameters:

Location	Distance(m)	Height above(+) /below(-)ref.plane(m)	Azim.(deg.)	Rel. Field
1	1730	-76	89	0.52
2	2190	-37	45	0.43
3	2120	-62	331	0.88
4	1540	-48	264	0.97
5	2420	-80	225	0.83
6	1850	-45	203	0.69
7	1770	-54	134	0.41
8	3810	-40	183	0.55
9	4770	-82	223	0.82
10	2885	-65	285	0.99

Program Output:

Location	Delay(μs)	Ghost Ratio(dB)	Picture Grade
1	1.335	-26.16	3.66
2	0.717	-25.55	4.07
3	0.002	-30.41	delay too short
4	0.521	-30.75	4.62 (overrated)
5	1.062	-32.19	4.27
6	1.355	-31.08	4.09
7	1.672	-26.89	3.62
8	1.538	-26.42	3.61
9	1.071	-28.97	4.02
10	0.235	-31.73	delay too short

Although test results are not available in full detail, especially in relation to the amplitude of ghost at various locations, the overall results indicate a good correlation (maximum ghost predicted for locations no. 2 and no. 7 and comparable relative amplitudes i.e. -20 to -26 dB versus -26 dB and ghosting interference experienced at all locations).

Example 2:

In 1977, T. M. Gluyas investigated the ghost interference to TV station WPBT in Miami, Florida [4]. The situation is summarized as follows: In the fall of 1977, and shortly after starting operation from a new site, WPBT received complaints of ghost reflections. An investigation revealed that a major problem was signal reflections from two other television towers in the vicinity of the WPBT tower site. These two towers were located 595 and 961 metres due north of the transmitting antenna of WPBT.

The measurement of ghost interference to WPBT's signal was made by transmitting test signal waveforms rather than pictures. Five testing locations were selected and they ranged in distance between 5 and 7.8 km from the transmitting tower of WPBT.

Transmitting Tower Parameters:

TV frequency (in MHz) : 55.25
Number of bays : 6
Height of C/R above ground (in m) : 282
Height of C/R above ref. plane (in m) : 282

Ghost Tower Parameters:

Width of tower (in m) : 2.13 (ch. 7) and 2.29 (ch. 10)
Number of tower sides : 3 (both triangular)
Height above ref. plane (in m) : 305.4 (ch. 7) and 320 (ch. 10)
Separation between towers (in m) : 595 (ch 7) and 961 (ch. 10)
Azimuth (in degrees) : 0 for both
Ref. horiz. field ghost tower azimuth : 0.96 for both

Viewing Location Parameters:

Location	Distance(m)	Height above(+) /below(-)ref.plane(m)	Azim.(deg.)	Rel. Field
1	5270	10	184	0.98
2	7760	10	186	0.99
3	6510	10	86	0.87
5	4990	10	227	0.96
S	7270	10	135	0.96

Correlation for ch. 7 Tower Ghost

Location	Delay(μs)	Ghost Ratio (dB)Calculated	Ghost Ratio (dB) Measured	Predicted Picture Grade
1	3.96	-29.76	-32.77	3.72
2	3.96	-30.19	-27.96	3.78
3	1.94	-28.19	-26.94	3.70
5	3.39	-29.32	-27.23	3.69
S	3.42	-29.71	-30.75	3.74

Correlation for ch. 10 Tower Ghost

Location	Delay(μs)	Ghost Ratio (dB)Calculated	Ghost Ratio (dB)Measured	Predicted Picture Grade
1	6.40	-33.86	-33.56	4.21
2	6.39	-32.97	-27.96	4.09
5	5.53	-33.82	-29.56	4.20
S	5.57	-32.63	-32.40	4.06

As the above Tables indicate, there is no significant difference between the measured and predicted ghost magnitude.

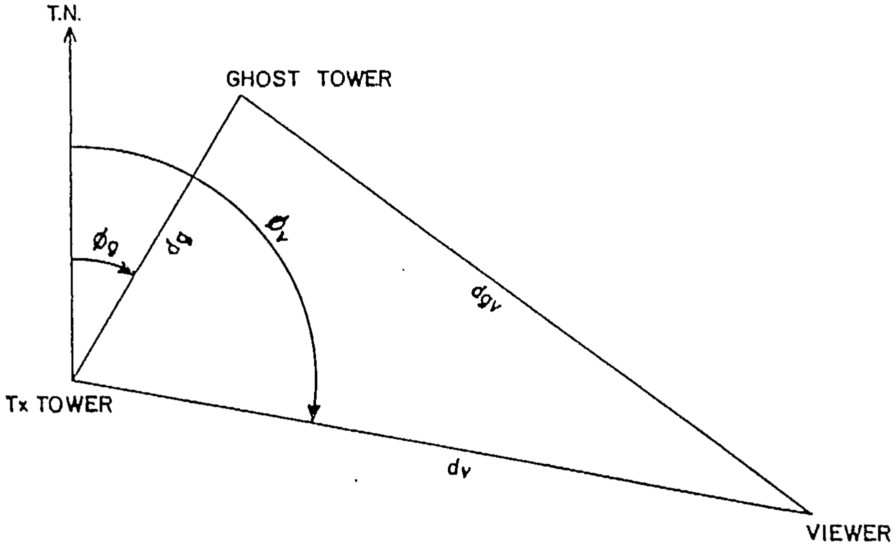
10. Conclusion

The most effective approach to minimize or eliminate ghosting problems is to consider shared antenna towers. When a number of closely spaced transmitting towers are located in the same general area, reflections from the nearby towers cannot be ignored specially for television signals. This study of ghosts provides a prediction tool which is reasonably accurate and simple enough to be implemented on most personal computers. This report can also be utilized to understand ghosting phenomenon and to forecast the extent of ghosting interference at the planning stage of a transmitting tower.

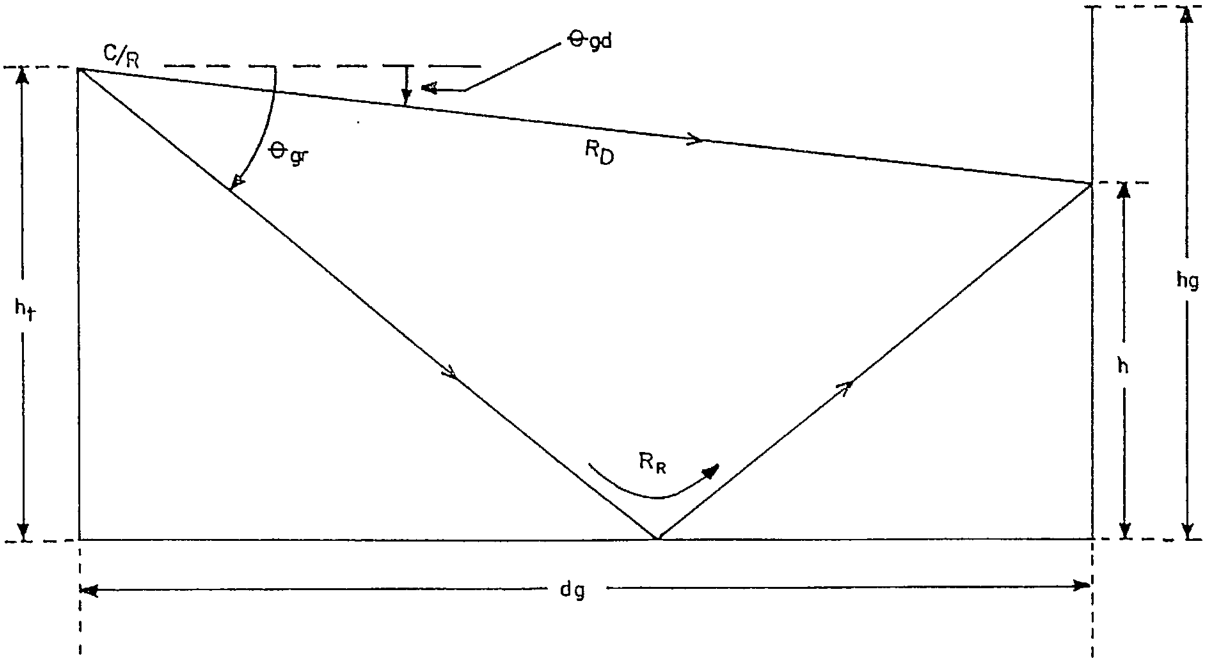
The study of ghosting is more significant now that the development of high definition television (HDTV) is becoming a reality. Although HDTV parameters are not fully defined yet, the increased number of horizontal lines in an HDTV system translates to larger displacements of ghost pictures on the screen, for the same time delays. Thus, the ghosting analysis related to the investigation of the scattering environment around television towers promises to be more critical in the near future.

APPENDICES

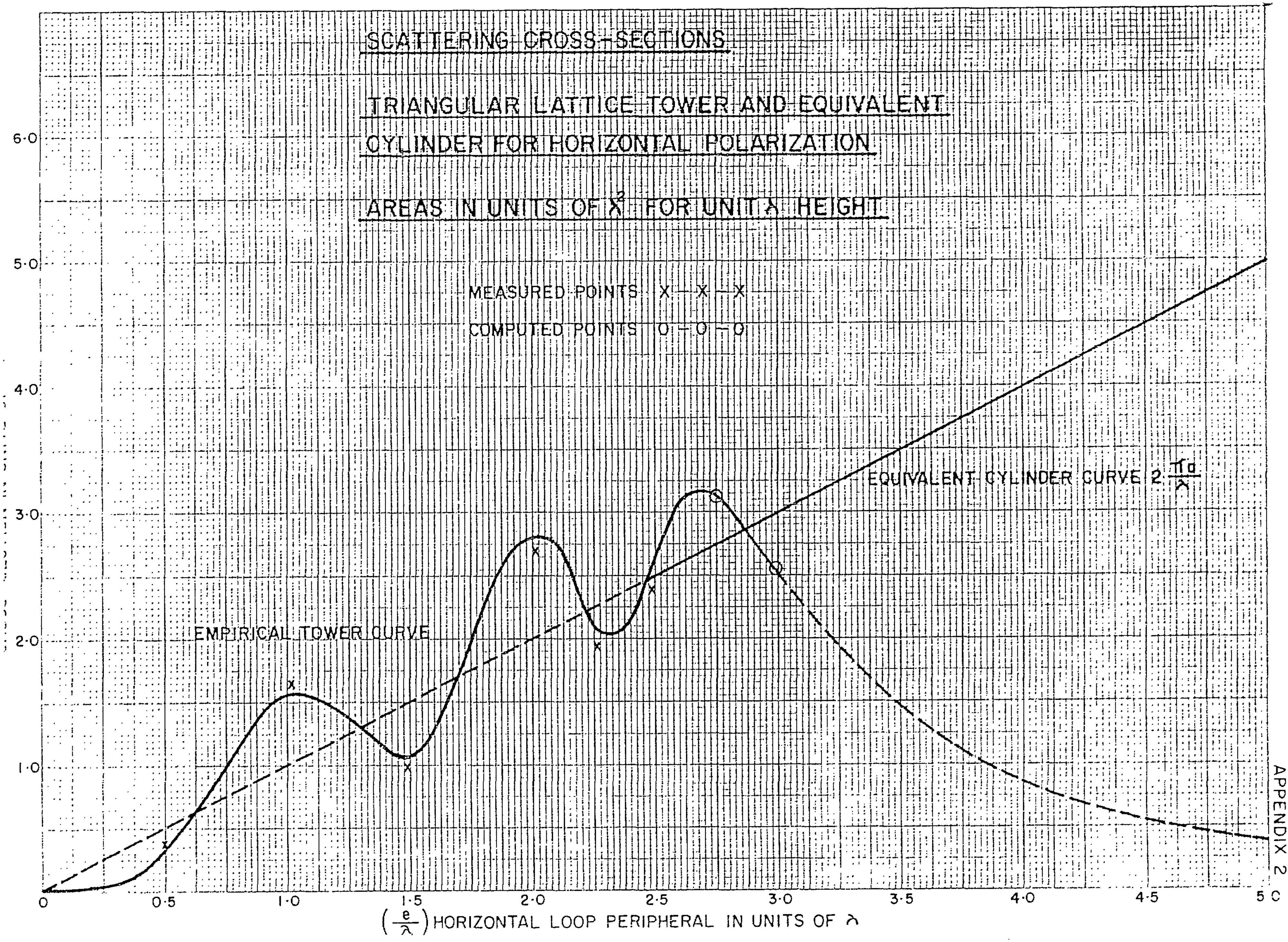
APPENDIX 1



TYPICAL GHOST AZIMUTH SITUATION



EFFECTS OF GROUND REFLECTION

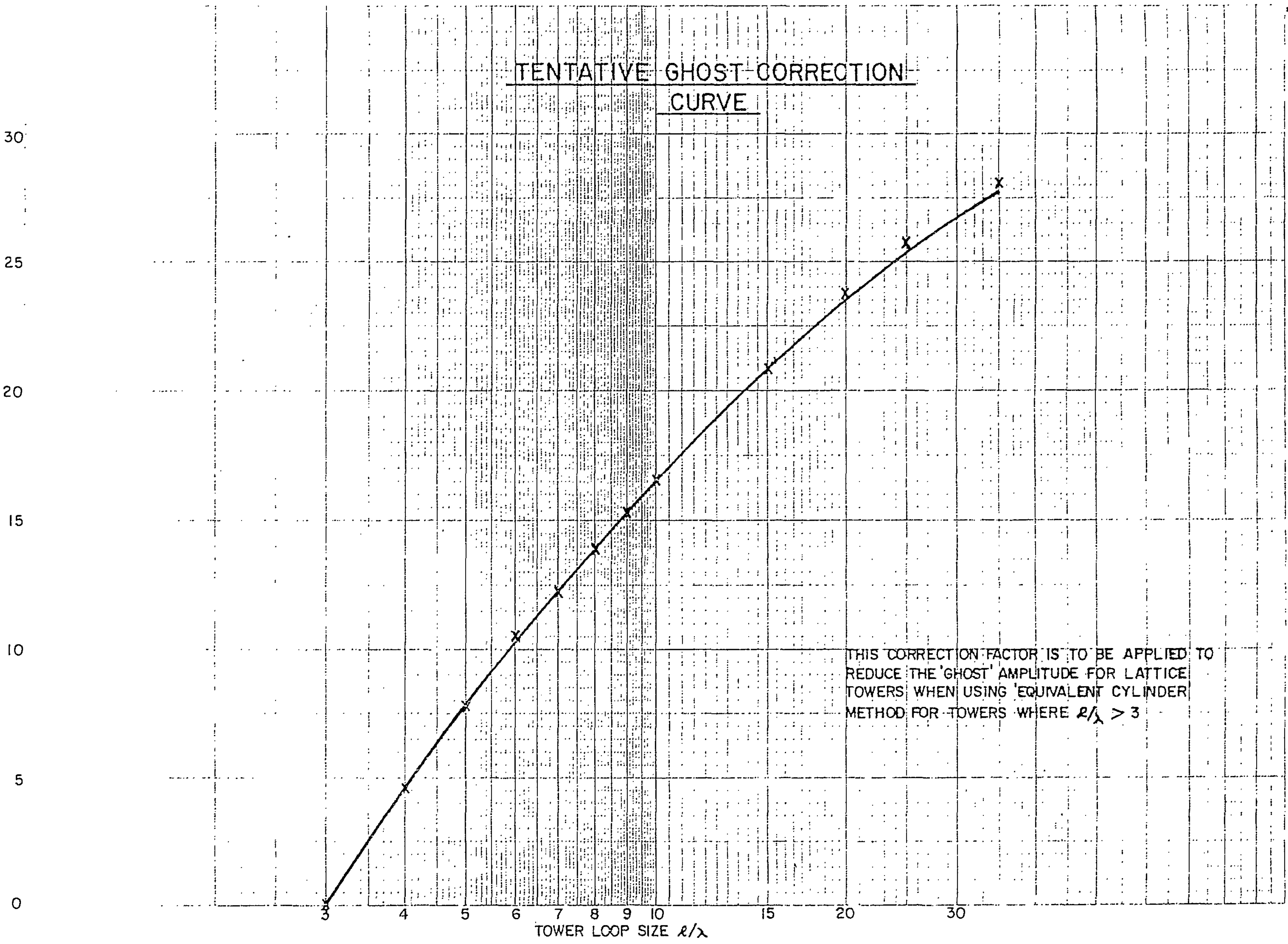


SCATTERING CROSS-SECTIONS

TRIANGULAR LATTICE TOWER AND EQUIVALENT CYLINDER FOR HORIZONTAL POLARIZATION

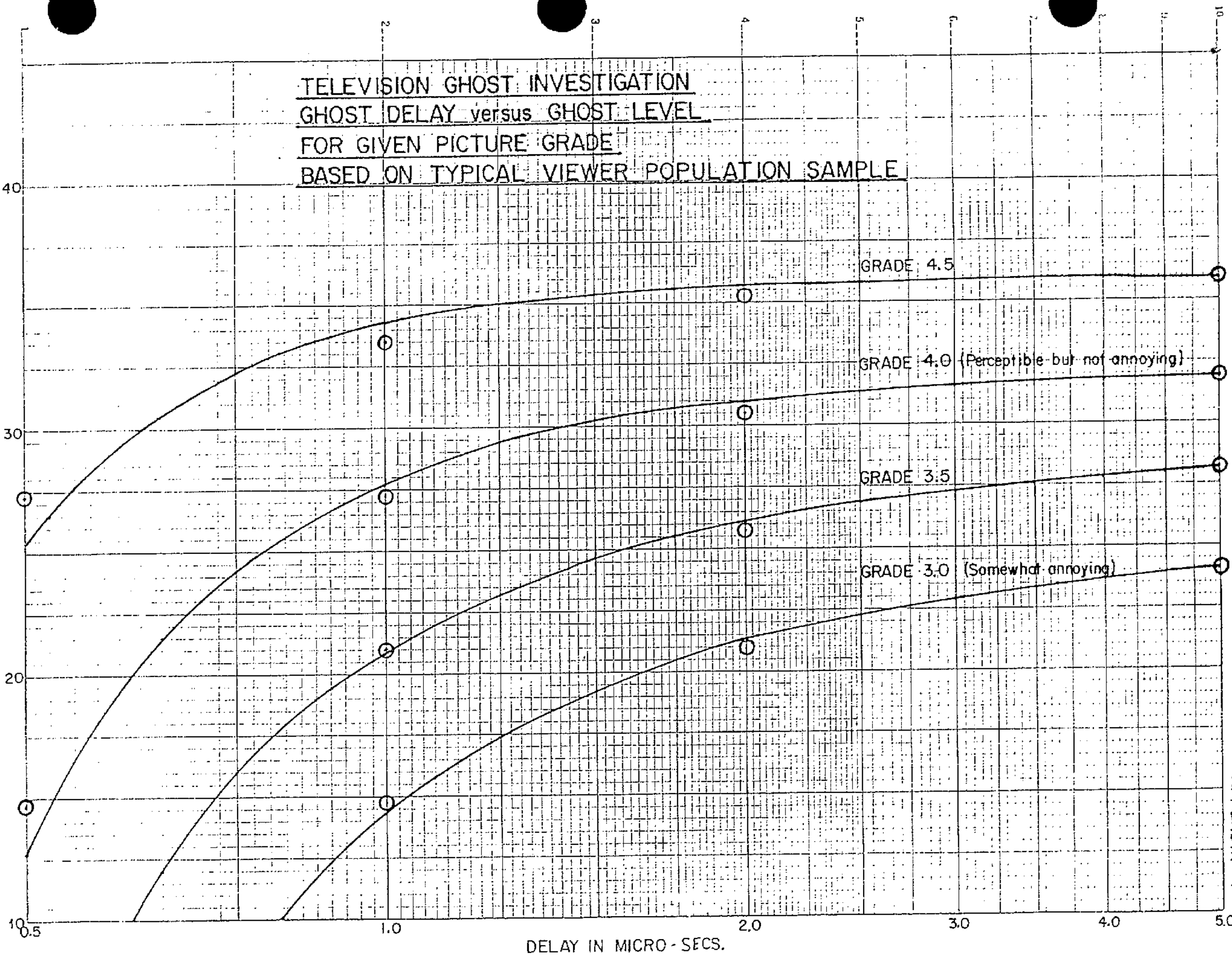
AREAS IN UNITS OF λ^2 FOR UNIT λ HEIGHT

APPENDIX 2



THIS CORRECTION FACTOR IS TO BE APPLIED TO REDUCE THE 'GHOST' AMPLITUDE FOR LATTICE TOWERS WHEN USING 'EQUIVALENT CYLINDER' METHOD FOR TOWERS WHERE $\ell/\lambda > 3$

APPENDIX 3

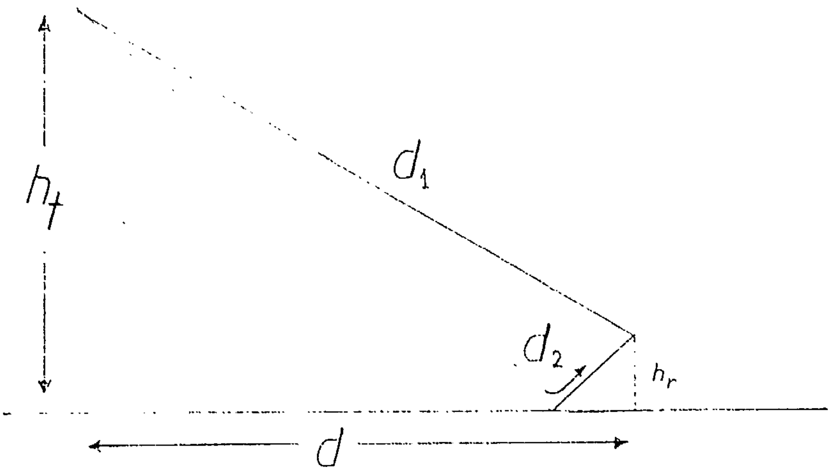


TELEVISION GHOST INVESTIGATION
GHOST DELAY versus GHOST LEVEL
FOR GIVEN PICTURE GRADE
BASED ON TYPICAL VIEWER POPULATION SAMPLE

APPENDIX-4

APPENDIX 5

Fresnel Zone Clearance



The path lengths d_1 and d_2 from the C/R of the transmitting antenna to the viewer are calculated as follows:

$$d_1^2 = (h_t - h_r)^2 + d^2$$

$$d_2^2 = (h_t + h_r)^2 + d^2$$

if $h_t + h_r \ll d$ the following approximation can be made:

$$d_1 \cong d\sqrt{1 + \frac{(h_t - h_r)^2}{2d^2}} \qquad \text{and}$$

$$d_2 \cong d\sqrt{1 + \frac{(h_t + h_r)^2}{2d^2}}$$

The difference in path length is obtained by:

$$d_2 - d_1 = \frac{1}{2d}\left[(h_t + h_r)^2 - (h_t - h_r)^2\right]$$

or

$$d_2 - d_1 = \frac{2h_t h_r}{d} .$$

First Fresnel zone clearance exists if the path length difference is less than λ/2. If the frequency of the transmitted signal is expressed in MHz.

$$d_2 - d_1 \le \frac{\lambda}{2} \rightarrow f\frac{h_t h_r}{d} \le 75 \text{ MHz.}$$

With h_r = 10m and $h_t = h_t - h_v$:

$$f\frac{(h_t - h_v)}{d} \le 7.5 \text{ MHz.}$$

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C     -----------------------------------------------
      TELEVISION GHOST PREDICTION PROGRAM
C     THIS METHOD IS BASED ON A STUDY DONE
C     FOR THE DEPARTMENT BY E. W. HORRIGAN.
C     PROGRAM PREPARED BY : J.S. DADOURIAN
C     DEPARTMENT OF COMMUNICATIONS
C     OTTAWA, CANADA
C     DATE : APRIL 1989
C     -----------------------------------------------
C
      DIMENSION H(1601),P(1601),F(47)
      DIMENSION CPA(1601),GV(1601)
      REAL LMB
      COMMON /COMO/ PI
      COMMON /COM1/ LMB
      COMPLEX CPA,CJ,CPAT
      CJ = (0.0,1.0)
      PI = 3.141592654
   10 OUTPUT(102)'ENTER TV FREQUENCY IN MHz'
      INPUT(101) FR
      IF(FR.GE.54..AND.FR.LE.804.) GO TO 20
      OUTPUT(102)'FREQUENCY OUT OF RANGE'
      GO TO 10
   20 LMB = 300./FR
      BE = 2.*PI/LMB
   22 OUTPUT(102)'ENTER NUMBER OF BAYS OF TRANSMIT. ANTENNA'
      OUTPUT(102)'(MAXIMUM 16)'
      INPUT(101) NBA
      IF(NBA.GT.16.OR.NBA.LT.1)  OUTPUT(102)'UNACCEPTABLE';GO  TO
22
      CALL VERPAT(F,NBA)
      OUTPUT(102)'ENTER THE WIDTH OF GHOST TOWER IN METRES'
      INPUT(101) W
      OUTPUT(102)'ENTER THE NUMBER OF TOWER SIDES'
      OUTPUT(102)'(NORMALLY 3 OR 4 BUT HIGHER NUMBERS'
      OUTPUT(102)'ARE ALSO ACCEPTABLE)'
      INPUT(101) NS
      AL = NS*W/LMB
      IF(AL.LE.9.) GO TO 25
      IF(FR.GT.216.AND.AL.LE.30.) GO TO 25
      OUTPUT(102)'TOWER TOO WIDE, ACCURATE GHOST'
      OUTPUT(102)'PREDICTIONS CANNOT BE MADE'
      GO TO 120
   25 OUTPUT(102)'THE REFERENCE PLANE SHOULD BE AT'
      OUTPUT(102)'AT THE BASE OF THE GHOST TOWER'
      OUTPUT(102)' '
      OUTPUT(102)'ENTER HEIGHT OF TRANSMITTER TOWER'
      OUTPUT(102)'ABOVE REFERENCE PLANE IN METRES'
      INPUT(101) HT
      OUTPUT(102)'TRANSMITTER TOWER IS THE CENTRE'
      OUTPUT(102)'OF POLAR CO-ORDINATES SYSTEM'
      OUTPUT(102)' '
      OUTPUT(102)'ENTER DISTANCE TO GHOST TOWER IN METRES'
      INPUT(101) DG
```

```
      IF(DG.GE.75.) GO TO 30
      OUTPUT(102)'GHOST DELAYS TOO SHORT. PICTURE QUALITY'
      OUTPUT(102)'CONNOT BE ASSESSED'
      GO TO 120
   30 OUTPUT(102)'ENTER HEIGHT OF GHOST TOWER'
      OUTPUT(102)'ABOVE REFERENCE PLANE IN METRES'
      INPUT(101) HG
      HGL = HG/LMB
      OUTPUT(102)'ENTER AZIMUTH OF GHOST TOWER IN DEGREES'
      OUTPUT(102)'RELATIVE TO TRUE NORTH'
      INPUT(101) AG
      OUTPUT(102)'ENTER  RELATIVE  HORIZ.  FIELD AT  GHOST  TOWER
 AZI.'
      INPUT(101) FG
   40 OUTPUT(102)'ENTER DISTANCE TO VIEWER IN METRES'
      OUTPUT(102)'(ENTER 0.0 TO STOP)'
      INPUT(101) DV; IF(DV.LE.0.0) STOP
      OUTPUT(102)'ENTER HEIGHT OF VIEWER ABOVE(+)/BELOW(-)'
      OUTPUT(102)'REFERENCE PLANE IN METRES'
      INPUT(101) HV
      OUTPUT(102)'ENTER AZIMUTH OF VIEWER IN DEGREES'
      OUTPUT(102)'RELATIVE TO TRUE NORTH'
      INPUT(101) AV
      GMV = (AG-AV)*PI/180.
      DGV = DG*DG + DV*DV - 2.*DG*DV*COS(GMV)
      DGV = SQRT(DGV)
      GS = ((DG-DV+DGV)*1.0E-8)/3.
      GSM = GS*1.0E+6
   50 OUTPUT(102)'ENTER RELATIVE HORIZ. FIELD AT VIEWERS AZI.'
      INPUT(101) FV
      RHF = FG/FV
      RHF2 = RHF*RHF
      CALL SIGMA(1.0,AL,SIG)
      NGB = INT(HGL)
      DO 60 I=1,NGB
        AH = (2*I-1)*LMB/2.
        H(I) = HG - AH
   60 CONTINUE
      DO 70 J=1,NGB
        V01 = ATAN2(HT-H(J),DG)
        V03 = ATAN2(HT+H(J),DG)
        V01 = V01*180./PI
        V03 = V03*180./PI
        V01 = ABS(V01)
        V03 = ABS(V03)
        RD2 = DG*DG + (HT-H(J))*(HT-H(J))
        RR2 = DG*DG + (HT+H(J))*(HT+H(J))
        RD = SQRT(RD2)
        RR = SQRT(RR2)
        CALL VPINTP(F,FV01,V01)
        CALL VPINTP(F,FV03.V03)
        CPA(J) = FV01*CEXP(-CJ*BE*RD)/RD
        CPA(J) = CPA(J) - FV03*CEXP(-CJ*BE*RR)/RR
        PA = FV01*FV01/RD2 + FV03*FV03/RR2
```

```
        PA = PA - 2.*FV01*FV03*COS(BE*(RD-RR))/(RD*RR)
        P(J) = PA
70    CONTINUE
      PRC = 0.0
      DO 80 K=1.NGB
        PRC = PRC + P(K)*H(K)
80    CONTINUE
      HRC = 0.0
      DO 90 K=1,NGB
        HRC = HRC + P(K)
90    CONTINUE
      HGRC = PRC/HRC
      OUTPUT(102)'EFFECTIVE HEIGHT OF THE CENTRE'
      OUTPUT(102)'OF RE-RAD OF GHOST TOWER IN METRES',HGRC
      RH1 = HGRC - HV
      RH2 = HT - HV
      RH = RH1/RH2
      RHSQ = RH*RH
      ANM = ATAN2(RH1.DGV)
      ANM = ANM*180./PI
      IF(ANM.LE.10.) GO TO 93
      OUTPUT(102)'DISTANCE TO VIEWER TOO SHORT FOR THIS CASE'
      OUTPUT(102)'DIFFICULT TO MAKE ACCURATE GHOST ESTIMATES'
      OUTPUT(102)' '
      GO TO 40
93    IF(ANM.LE.5.) GO TO 95
      OUTPUT(102)'********** WARNING **********'
      OUTPUT(102)'GHOST AMPLITUDE IS OVERRATED'
      OUTPUT(102)'THE ACTUAL PICTURE GRADE WILL'
      OUTPUT(102)'BE HIGHER AT THIS LOCATION'
      OUTPUT(102)' '
95    DO 96 K=1,NGB
        GV(K) = (H(K)-HV)*(H(K)-HV)
        GV(K) = GV(K) + DGV*DGV
        GV(K) = SQRT(GV(K))
96    CONTINUE
      DO 97 K=1,NGB
        CPA(K) = CPA(K)*CEXP(-CJ*BE*GV(K))/GV(K)
97    CONTINUE
      CPAT = (0.0,0.0)
      DO 98 K=1,NGB
        CPAT = CPAT + CPA(K)
98    CONTINUE
      RINT = CABS(CPAT)
      RINT = RINT*RINT
      V02 = ATAN2(RH2,DV)
      V02 = V02*180./PI
      CALL VPINTP(F,FV02,V02)
      RV = RINT/(FV02*FV02)
      AA = DV*LMB
      AA = AA*AA
      AA = AA*SIG
      AA = AA/(4.*PI)
      AA = AA*RHF2
```

```
      AA = AA*RV
      FRENT = 10.*FR*(HT-HV)/DV
      FRENG = 10.*FR*(HGRC-HV)/DGV
      IF(FRENT.LT.75..AND.FRENG.LT.75.) RHH=1.; GO TO 100
      RHH = RHSQ
 100  AA = AA*RHH
      DBAA = 10.*LOG10(AA)
      IF(FR.LT.470.) GO TO 110
      CALL CORREC(AL,CR)
      DBAA = DBAA - CR
 110  OUTPUT(102)'RELATIVE GHOST AMPLITUDE IN dB = ',DBAA
      OUTPUT(102)'GHOST DELAY IN MICROSECONDS = ',GSM
      IF(GSM.GE.0.5) GO TO 115
      OUTPUT(102)'DELAY TOO SHORT,'
      OUTPUT(102)'PICTURE QUALITY CANNOT BE ASSESSED'
      OUTPUT(102)' '
      GO TO 40
 115  CALL GRADE(DBAA,GSM,GR)
      OUTPUT(102)'TELEVISION IMPAIRMENT GRADE = ',GR
      GO TO 40
 120  END

C     SUBROUTINE TO CALCULATE THE CROSS-SECTION OF A CYLINDER.
      SUBROUTINE SIGMA(RH,A,SI)
      COMMON /COM0/ PI
      PIO2 = PI/2.
      IF(A.GT.3.) SI=A*RH*RH; GO TO 10
      Z = A + 0.5
      DFZ = 2.0 + 1.792*Z + 3.104*Z*Z
      FZ = 1.0 + 0.926*Z
      FZ = FZ/DFZ
      DGZ = 2.0 + 4.142*Z + 3.492*Z*Z + 6.67*Z*Z*Z
      GZ = 1./DGZ
      ARGU = PIO2*Z*Z
      SZ = 0.5 - FZ*COS(ARGU) - GZ*SIN(ARGU)
      SI = PIO2*PIO2/1.2
      SI = SI*RH*RH*A*(1.0-EXP(-4.*A*A))
      SI = SI*SZ
  10  RETURN
      END

C     SUBROUTINE TO DETERMINE THE RELATIVE VERTICAL
C     FIELD BY LINEAR INTERPOLATION
      SUBROUTINE VPINTP(F,FV0,V0)
      DIMENSION F(1)
      F(0) = 1.0
      J = 1
  10  IF(V0.LT.1.99*J) GO TO 20
      J = J + 1
      GO TO 10
  20  FV0 = F(J-1) + (V0-1.99*(J-1))*(F(J)-F(J-1))/1.99
      RETURN
      END
```

```
C     SUBROUTINE TO CORRECT THE GHOST AMPLITUDE
      FOR UHF FREQUENCIES
      SUBROUTINE CORREC(EC,CO)
      IF(EC.LE.3.) CO=0.0; GO TO 20
      IF(EC.GT.3.AND.EC.LE.10) GO TO 10
      A1 = -4.1371
      B1 = 21.1371
      GO TO 15
  10  A1 = -15.5123
      B1 = 32.5123
  15  CO = A1 + B1*ALOG10(EC)
  20  RETURN
      END

C     SUBROUTINE TO CALCULATE THE PICTURE GRADE
      SUBROUTINE GRADE(A,B,G)
      U = 0.143*A*EXP(-0.637/B)
      G = 6.0 - (U+6.65*EXP(-0.475/B))
      IF(G.GT.5.0) G=5.0
      RETURN
      END

C     SUBROUTINE TO GENERATE THE VERTICAL PATTERN
C     OF AN 'N' BAYS TELEVISION ANTENNA SYSTEM
      SUBROUTINE VERPAT(F,N)
      DIMENSION F(1)
      COMMON /COM0/ PI
      DO 10 J=1,45
        THETA = 1.99*J
        THETA = THETA*PI/180.
        CTHE = COS(THETA)
        STHE = SIN(THETA)
        ARG1 = PI*STHE/2.
        FTH = COS(ARG1)/CTHE
        FTH = ABS(FTH)
        ARG2 = N*PI*STHE
        ARG3 = PI*STHE
        ETH = SIN(ARG2)
        ETH = ETH/SIN(ARG3)
        ETH = ABS(ETH)/N
        ETH = ETH*FTH
        ETH = ETH*ETH + 0.04
        ETH = SQRT(ETH)
        F(J) = ETH
  10  CONTINUE
      RETURN
      END
```

List of References

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

2. "Television Engineering Handbook", K. Blair Benson, Chapter 8 by Oded Ben-Dov and Krishna Praba, McGraw-Hill Book Company, 1986.

3. "The Distortion of AM Broadcast Antenna Patterns as Caused by Nearby Towers and Highrise Buildings", G. M. Royer, Communications Research Centre, DOC, Ottawa, CRC Report No. 1379, March 1985.

4. "Measurement and Evaluation of Television Signal Reflections", T. M. Gluyas, Report presented in 1978 Broadcasting Symposium, Washington, D.C.