E.W. HORRIGAN & ASSOCIATES LIMITED

REPORT No. 2

TELEVISION GHOSTING and FM. MULTIPATH DISTORTION INVESTIGATION

GHOST PREDICTION STUDY

and

TV GHOST and FM. MULTIPATH ANALYSIS PROGRAM

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TABLE OF CONTENTS

E.W. HORRIGAN & ASSOCIATES LIMITED

Summary of Report

This report covers the ghost prediction phase of this project and the integration of these results with those previously obtained to produce a complete television ghost and FM radio distortion analysis program.

All available prediction methods were examined and, in view of their oversimplifying assumptions or difficulty of application to relevant situations, a new ghost prediction and integrated analysis program was generated.

This new analysis program has been evaluated against known ghost situations (Halifax) and compared to results obtained using the various methods incorporated in the Department's computer program. This shows that the new program has a high value of correlation with the Halifax situation, and falls between the extremes of the EWH Target Gain Method and Knight's Method.

The complete analysis program relating TV picture grade and FM noise and distortion to ghost tower parameters has been prepared as a software package for the T.I. SR-59/PC100A Calculator/Printer.

E.W. Horrigan, P. Eng.

Report No. 2

TV & FM MULTIPATH INVESTIGATION

1.0 Introduction

This study program was commissioned by the Department of Communications under DSS Contract No. 36100-7-0615 to:

a) assess the validity of existing criteria and methods of evaluation, predicting and computing multipath distortion on TV and FM transmissions;

b) to set up, conduct and analyse subjective assessments of impaired transmissions;

c) to make recommendations which will assist the Department to establish "Standards" and "Procedures" in respect to TV and FM multipath impairment.

The Report No. 1 dated September 1978 covered the subjective and objective evaluation phase of the project. Several easily applied equations relating to "Typical Viewer" and "Expert Viewer" gradings and FM Radio extraneous noise and distortion were derived from this subjective and objective measurement phase of the project.

Report No. 2 deals specifically with the ghost prediction phase of this study program and with the integration of the resulting equations with those obtained in the previous phase covered in Report No. 1.

2.0 General Discussion

A thorough study was made of all available published documentation concerning re-radiation from towers and similar structures at radio frequencies. Discussions on this subject were also held with BBC and IBA personnel in the U.K. which included a session with Dr. P. Knight of the B.B.C. Research Division.

The general conclusion drawn from this survey session was that no existing method was entirely suitable for our purpose for various reasons.

a) The BBC documents are based on square section towers and make no claim to equate to the more typical triangular section towers used in Canada. Furthermore, although the BBC documents adequately consider the effects of transmitting antenna pattern characteristics, ground reflections and finite length of the ghost tower, they use an exponential mathematical format which is not easily applied. Simplification of the calculations as used in the DOC program produces results which are much too optimistic for practical purposes.

b) The programs based on the "Radar Equation" are also too simplistic and produce results which are, in general, too pessimistic for practical applications. Furthermore, those using equivalent cylinder scattering cross-sections are invalid in the more typical tower face width sizes of less than one wavelength (1λ).

c) The Target Gain method used a scattering parameter based on actual measurements of typical towers in the invalid equivalent cylinder range. However, this parameter was only valid for towers of small width and was not readily equated with structures expressed in normal cross-section dimensions. Furthermore, several of the simplifying assumptions made in the general equation were also invalid in real situations and lead to very pessimistic answers.

Therefore, it was necessary to completely re-evaluate the prediction process and develop a readily applied, more realistic general equation based on typical triangular tower sections and covering the tower face width range of less than one wavelength and, if possible, extending and merging with the equivalent cylinder cross-section for the larger tower sizes.

3.0 Cross-Section Measurements

In order to define a conventional scattering cross-section for typical triangular section towers as used in North America in the loop size range of 0.5λ to 2.5λ, it was decided to re-evaluate and extend a previous study made by this author.[1]

The technique used and the results obtained are outlined below:

a) Typical lightweight triangular tower sections were suspended horizontally on nylon tackle between two 35 ft. wooden poles in an area free from other structures. Directional transmitting and receiving antennas were aimed from ground level at the tower section directly above. The planes of polarization of the transmitting antenna and the receiving antenna were orthogonal to each other and mutually at $\pm 45^{\circ}$ to the tower section.

b) The transmitting antenna was fed by means of suitable VHF/UHF signal sources and the receiving antenna was coupled to field strength meters and signal analysers.

c) Prior to each test, the tower section was removed and the orientation of the tunable transmitting and receiving antennas carefully adjusted for minimum mutual coupling (90°) and this minimum reading was recorded.

1 "An Approach to the Problems of Calculating and Reducing Ghosts from Towers Adjacent to Television Radiators" CBC, EHQ, Nov.30, 1962.

d) A shorted $\lambda/2$ dipole was now suspended in the test position oriented in the plane of the horizontal tower section members ($\pm 45^{\circ}$ to both T_x and R_x antennas). The re-radiated signal was measured and if this was at least 20dB greater than the mutually coupled signal of c) above, the test dipole was replaced by the test tower section. If not, the operation in paragraph c) was repeated until this condition was obtained.

e) The test tower section re-radiation was measured and recorded.

f) The test frequency and/or tower section was changed to cover the loop dimension range of 0.5λ to 2.5λ, using approximately a one wavelength high tower section for each test.

g) This method of measuring re-radiation or scattering cross-section is considered to be valid because the 45° plane of polarization error is effectively cancelled by using ratio measurements relative to the shorted dipole. These measurements were made at distances of greater than five wavelengths in all cases. The test frequencies ranged from 180-600 MHz.

3.1 The results of these tests are listed below:

TABLE I

Loop Dimension λ	Relative Reflected Power Dipole	Relative Reflected Power Tower	Effective Area 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	

These tests indicate that the effective area of a shorted λ/2 dipole approximates 0.4 - 0.5 λ^2 and is in general agreement with accepted values. Therefore, the tower cross-sections are considered to be realistic values with a tolerance of ±25%. The measured cross-sections of the tower for unit wavelength height are shown in Figure 1, together with the general equation of the curve and equivalent cylinder.

4.0 Ghost Equations

Definitions: (Note: all dimensions are in metric units.)

(w)	width of ghost tower in metres
(s)	number of tower sides △ or □
(f)	radio frequency in MHz
(h_t)	transmitter centre of radiation above reference in metres
(h_s)	height of ghost tower above reference in metres
(h_v)	height of viewing antenna above/below reference in metres
(d_s)	distance to ghost tower in metres
(d_v)	distance to viewer 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_s)
(d_r)	distance from transmitter centre of radiation to point P on (h_s) via reference plane
(P_i)	incident power at point P on ghost tower
$(\emptyset H_g)$	azimuth to ghost tower in degrees
$(\emptyset H_v)$	azimuth to viewer in degrees
$(\emptyset V_1)$	depression angle to C/R of ghost tower (h_s) in degrees
$(\emptyset V_2)$	depression angle to reflection plane in degrees
$(\emptyset V_3)$	depression angle to viewer in degrees
$F(\emptyset V_1, \emptyset V_2, \ldots . \emptyset H_g \ldots ..)$	relative field at given azimuth or depression angle
(ℓ)	loop length in metres $(w) \times (s)$
(λ)	wavelength in metres $\frac{300}{(f)}$
$S_{(z)}$	Fresnel integral $\left[\frac{1}{2} - f(z)\cos(\frac{\pi}{2}z^2) - g(z)\sin(\frac{\pi}{2}z^2) \right]$

Definitions (cont'd)

(P_t) = ERP

(z) = $(\frac{\ell}{\lambda} + 0.5)$

4.1 Echo Delay Equation

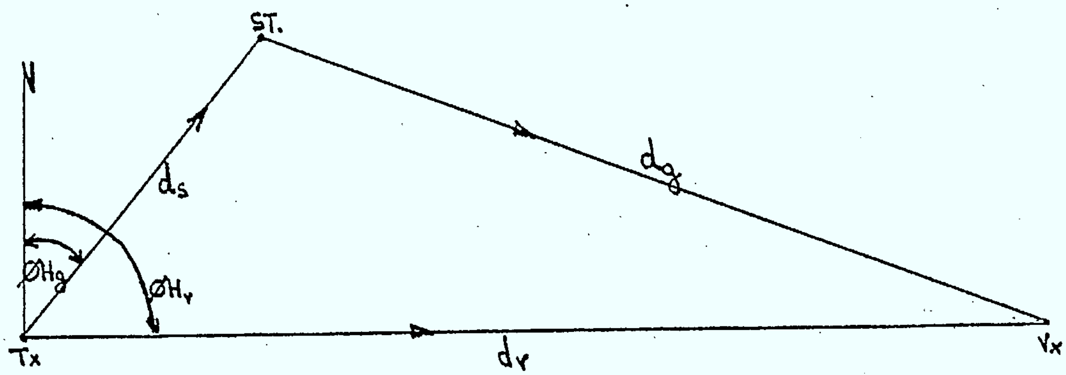

FIGURE 2

$$\text{Delay} = 3.3\dot{3}\{ d_s - d_v + [d_s^2 + d_v^2 - 2d_s d_v \cos(\phi H_g - \phi H_v)]^{\frac{1}{2}}\} \text{ nS} \quad ....(1)$$

4.2 Basic Ghost 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)

$$W_d = \frac{P_t}{4\pi \cdot (d_v)^2} = \frac{W}{m^2}$$

b) Power density at ghost tower location: (W_i)

$$W_i = \frac{P_t}{4\pi \ (d_s)^2} = \frac{W}{m^2}$$

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

$$W_g = \frac{W_i \sigma}{4\pi \ (d_g)^2}$$

, (where σ is the scattering cross-section)

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

d) Basic ghost/signal ratio

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

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

$$d_g = \left(d_s{}^2 + d_v{}^2 - 2d_s d_v \cos(\emptyset_g - \emptyset_v) \right)^{\frac{1}{2}}$$

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

$$d_g = d_v - d_s + \left(\frac{\text{Delay } \mu S}{3.3\dot{3}\text{x}10^{-3}}\right)$$

Therefore:

$$\frac{W_g}{W_d} = \sigma \frac{1}{4\pi}\left[\frac{d_v}{d_s\ \left(d_v - d_s + \frac{\mu S}{3.3\dot{3}\text{x}10^{-3}}\right)}\right]^2$$

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:

$$\text{Power} = {}_s\int S\ d_s = \frac{W}{\lambda^2}$$

Propagation factor: (p)

$$(p) = \frac{1}{4\pi}\left[\frac{d_v\lambda}{d_s(d_v - d_s + \frac{\mu S}{3.3\dot{3} \times 10^{-3}})}\right]^2 \qquad \ldots\ldots(2)$$

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

4.2.1 Scattering Cross-Sections

The measured scattering cross-sections (σ_t) of one wavelength high triangular tower sections as listed in Section 3.0 have been fitted to a suitable equation over the loop peripheral range of 0.5λ to 2.5λ. The radar cross-section for cylindrical structures have been defined in terms of loop circumference expressed in wavelength units and merged with the tower section equation at a suitable intercept as shown in Figure 1.

The measured triangular tower cross-section has the form of a modified Fresnel Integral over the loop peripheral range of 0.5λ to 2.5λ.

$$\sigma_t = f\left(\frac{h_s}{\lambda}\right) f\left(\frac{\ell}{\lambda}\right) f\left(S_{(z)}\right) \qquad \text{where: } S_{(z)} = \int_0^z \sin\left(\frac{\pi}{2} t^2\right) dt$$

A working equation was generated using this format which adequately describes the measured results over the loop range 0.5λ to 2.5λ.

$$\sigma_t = \frac{1}{1.2}\left(\frac{\pi}{2}\ \frac{h_s}{\lambda}\right)^2 \cdot \left[\frac{\ell}{\lambda}\left(1-e^{-\left(\frac{2\ell}{\lambda}\right)^2}\right) S_{(z)}\right]$$

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

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:

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

For computational purposes the rational approximations [2] for $f(z)$ and $g(z)$ can be used to evaluate $S_{(z)}$:

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

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

$$\text{where } |\xi(z)| \leq 2\times10^{-3}$$

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

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

The scattering cross-section of a right cylinder (σ_{cyl}) is defined as:[3]

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

where L = height of cylinder
a = radius of cylinder

let $\dfrac{2\pi a}{\lambda} = \dfrac{\ell}{\lambda}$

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

$$\sigma_{cyl} = \left[\frac{\ell}{\lambda}\left(\frac{h_s}{\lambda}\right)^2\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3A)$$

3 "Radar Fundamentals - Effective Areas", Reference Data for Radio Engineers, Table I, 29-6, 5th Ed. 1968, Howard W. Sams & Co. Inc. I.T.T. New York.

4.2.2 Incident Power on Ghost Tower

In the basic ghost magnitude equation we made the simplifying assumption 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.

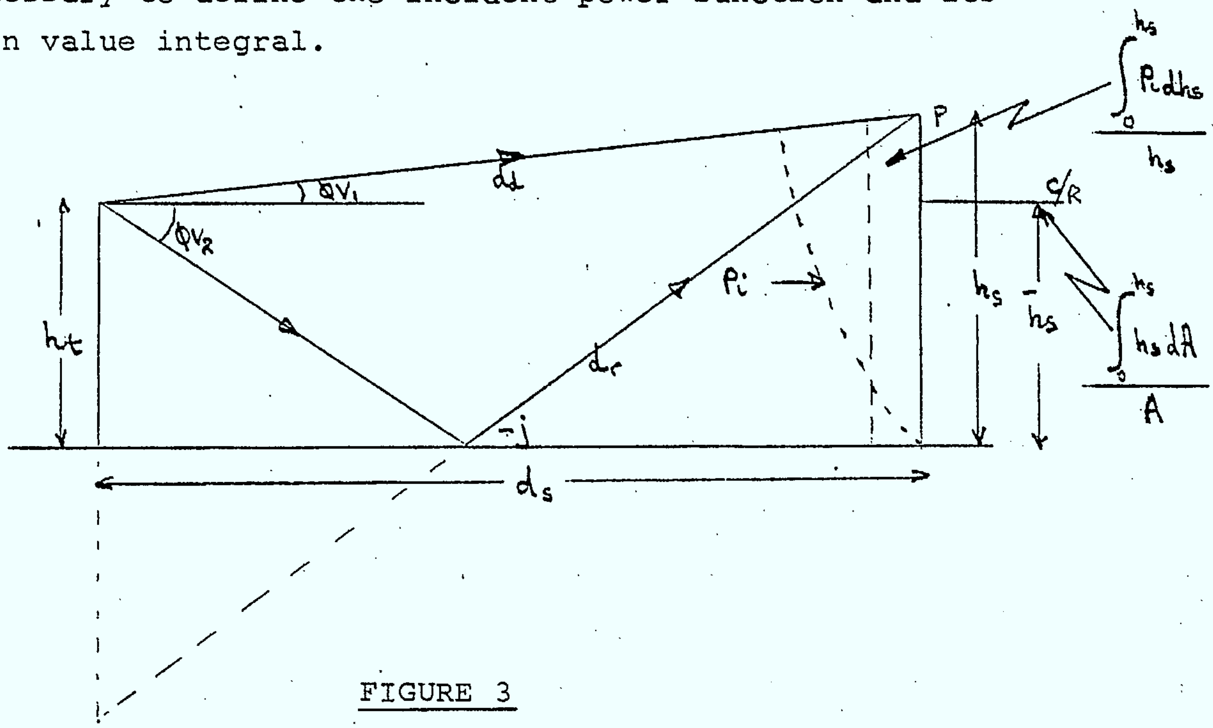

FIGURE 3

From the geometry of Figure 3 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:

$$P_i = \left[(Fv\emptyset_1)^2 + (Fv\emptyset_2)^2 - 2Fv\emptyset_1 Fv\emptyset_2 \cos \frac{2\pi}{\lambda}\left\{\left[d_s^2 + (ht-hs)^2\right]^{\frac{1}{2}} - \left[d_s^2 + (ht+hs)^2\right]^{\frac{1}{2}}\right\}\right]$$

$$\text{where } v\emptyset_1 = \tan^{-1}\left(\frac{ht-hs}{d_s}\right)$$

$$v\emptyset_2 = \tan^{-1}\left(\frac{ht+hs}{d_s}\right)$$

To facilitate manipulation and computation let:

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

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

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

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

Radio Frequency = (f) MH_z

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

4.2.3 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 (χ) instead of (hs) the mean value integral (k) becomes:

$$k = \frac{\int_0^{\chi} P_i \, d\chi}{\chi} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

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

4.2.4 Centre of Radiation of Ghost Tower

The effective centre of radiation on the ghost tower ($\bar{h}_s$) can be likened to the 1st moment centroid of area of the integral of P_i in the plane normal to the reference surface.

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

With a view to the simplification of this factor several forms of illumination distribution have been examined and the likely range of the ratio $(\frac{\bar{h}_s}{h_s})$ 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.

Linear Height/Gain Function = $(\frac{\bar{h}_s}{h_t})^2$ .... (5)

Free Space Function = (1) .... (5A)

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

4.2.5 The Transmitting Antenna Vertical Pattern Function

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

$$\text{let} \quad \varnothing_1 = \tan^{-1}\left(\frac{h_t - \bar{h}_s}{d_s}\right)$$

$$\varnothing_3 = \tan^{-1}\left(\frac{h_t - h_v}{d_s}\right)$$

$$P_v = \left(\frac{Fv\varnothing_1}{Fv\varnothing_3}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

4.2.6 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 4.2.5 above.

The pattern factor relative power function P_h is derived below:

$$P_h = \left(\frac{Fh\varnothing_g}{Fh\varnothing_v}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

where $\varnothing_g$ = azimuth of ghost tower

$\varnothing_v$ = azimuth of viewer

4.3 The Complete Ghost Analysis Equations

It is now possible to generate complete ghost prediction equations providing an output as a picture impairment grade number or as an extraneous noise and distortion percentage for the FM radio service.

The subjective TV picture impairment equations contained in Report No. 1 relate ghost magnitude and delay to the CCIR Recommendation 500 five point grading scale.

The objective measurements of multipath FM radio noise and distortion were similarly reduced to an equation relating echo magnitude and delay to a percentage value of extraneous noise and distortion.

Therefore, the equations contained in this report can be integrated with those in Report No. 1 to provide output desired.

The "Typical Viewer" grade equation has been selected for this integrated TV analysis program:

$$\text{Viewer Grade No.} = \left[(0.143e^{-\frac{0.637}{td}})\ (G) + (6.65e^{-\frac{0.475}{td}}) \right]$$

$$\text{F.M. Noise/Dist\%} = 141.4 \left(\frac{\text{Log}^{-1}(G)}{20}\right) \sin(1.8td)$$

$$td = \frac{3.33}{1\times10^3}\{d_s - d_v + \left[d_s{}^2 + d_v{}^2 - 2d_s d_v \cos(\emptyset H_g - \emptyset H_v)\right]^{\frac{1}{2}}\} \quad \ldots\ldots \quad (1)$$

$$G = 10\ \text{Log}_{10}\ \{ \underbrace{\frac{1}{4\pi}\cdot\left(\frac{d_v\lambda}{d_s d_g}\right)^2}_{(2)} \cdot (\underbrace{\sigma_t}_{(3)}\ \text{OR}\ \underbrace{\sigma_{cyl}}_{(3A)}) \cdot \underbrace{\left(\frac{\int_o^{\chi} P_i\, d\chi}{\chi}\right)}_{(4)} \cdot \underbrace{\left(\frac{\bar{h}_s}{h_t}\right)^2}_{(5)} \cdot \underbrace{\left(\frac{Fv\emptyset_1}{Fv\emptyset_2}\right)^2}_{(6)} \cdot \underbrace{\left(\frac{F_h\emptyset_g}{F_h\emptyset_v}\right)^2}_{(7)} \}$$

(3): $\frac{\ell}{\lambda} \leq 2.25$; (3A): $2.25 < \frac{\ell}{\lambda}$

$$\frac{\ell}{\lambda} \leq 2.25 < \frac{\ell}{\lambda}$$

These complete equations have been programmed for the TI-SR59/PC100A Calculator/Printer. This program and the input/output format are contained in the appendix to this report.

5.0 Comparison with Measured Ghosts

The CBHT/CJCH-TV Halifax ghost problem was re-examined and ghost predictions were made based on parameters obtained from the original CBC engineering brief and the DOC report by D.M. Skanes of 1961.

Prediction calculations were made based on a viewing location at Site No. 1 and compared to those made by the DOC in 1961 and listed on page 6 of their report, for various tower heights of CJCH from 320 ft. and 600 ft.

These are listed below:

VIEWING SITE NO. 1	TOWER HEIGHT - CJCH-TV			
	320'	360'	445'	600'
Measured by DOC	32.2 dB	25.6 dB	19.7 dB	18.8 dB
Predicted by Equations	31.88	28.69	22.61	15.45
Difference	- 0.42dB	+ 3.09dB	+ 2.91dB	- 3.35dB

These differences are considered to be well within the range of experimental error.

A study of the Toronto Bank of Montreal situation was also made based on a 150 ft. tower of 2 ft. face width using the new program and the Department's computer program based on viewing sites at 2 miles and 40 miles.

DOC Ghost Program

Azm.	Dist. Mi.	BBC Re-radiation Coefficients Equiv-cyl.	Latt-Norm	Latt-Diag	Radar Equation-Ghost Cyl. xSec.	Target Gn.	Delay µSec.	In.
240.	2.0	-62.5	-59.7	-60.1	-37.8	-30.7	5.28	1.97
0.	40.0	-73.4	-64.6	-67.0	-48.6	-41.6	0.50	0.19

New Ghost Program

240°	2 mi.	-52.9 dB	5.27 µSec.
0°	40 mi.	-62.7 dB	0.50 µSec.

6.0 Conclusions

The ghost levels which are predicted using the above equations were compared to results obtained using the DOC computer program. In general, the results of this new prediction technique are between those predicted using the EWH "Target Gain" Method, which is an overly conservative method, and the BBC results, which are considered to be overly optimistic in the DOC program format.

The original Halifax ghost situation was re-examined in Section 5.0 of this report using the ghost prediction program. The results were compared to the Department's measurements of 1961 at Site No. 1. The predictions and measurements show a very high level of correlation.

The original small FM tower on the Bank of Montreal Building in Toronto was examined relative to CFTO-TV Channel 9 transmissions and ghost levels of about 53dB were predicted in the downtown area as a result of this structure.

It is, therefore, considered that the proposed method provides a reasonably simple way of assessing the impairment to a television or FM radio service caused by the establishment of another tower in proximity to the broadcast radiator.

Furthermore, the method provides results which should ensure that serious ghost situations are avoided while not unduly restricting the extension of the broadcast service.

The previous report dealing with subjective and objective effects of multipath signals indicated that the FM radio service was less impaired than the TV service for similar echo levels and delays.

The BBC measurements on square section towers gave similar values for the re-radiation co-efficients for both vertical and horizontal incident polarization. The nodal positions relative to face width were not identical but the magnitudes were not greatly different.

Therefore, it is considered that the echo amplitude equations developed in this report are reasonably valid for FM multi-path distortion analysis purposes.

7.0 Recommendations

It is considered that this study program has produced an easily applied method of predicting TV ghost and FM multipath echo levels and delays which result from radio towers adjacent to the broadcast antenna. Furthermore, these prediction methods can be integrated with the results of companion study into subjective and objective impairments caused by ghost or multipath signals.

The complete analysis program as presented in these reports can be used as a basis for "Standards" and "Procedures" or as a "Notice to Broadcast Consultants".

Therefore, it is recommended that the "Standards" for TV ghost impairment and FM multipath distortion be based on a specific grade of service or percentage noise and distortion as the case may be rather than as specific echo amplitude for a given delay.

It is further recommended that the minimum "Grade Number" for acceptable television service be equal to or better than Grade 1.5 (Very Good) for the major portion of the service area. The equivalent FM impairment grade for extraneous noise and distortion is considered to be 2% (-34dB).

It is recommended that the "Procedures" should be as follows:

7.1 Television Ghosting

i) The echo amplitude and delay will be computed by the method described in Broadcast Procedure X, Section Y, using a computer program or by any other technique considered acceptable to the Department.

ii) The service grade will be computed by means of Figure 19 or by any other technique considered acceptable to the Department.

7.2 F.M. Multipath Distortion

i) The echo amplitude and delay will be computed by the method described in Broadcast Procedure X, Section Y, using any technique considered acceptable to the Department.

ii) The service grade will be computed by means of Figure 29 or by any other technique considered acceptable to the Department.

An examination of the equations used in this analysis and those of Knight's will reveal the amount of mathematical manipulation, the complexity of the equations, the opportunity for inadvertant error, and finally, the time required to cross-check the results.

Any attempt to simplify these equations results in unreliable predictions which often produce restrictive answers not conducive to service expansion in order to "play safe".

Considerable time has been spent in attempting to produce easily applied nomograms and curves which provided realistic answers to these complex equations. Unfortunately, little success was achieved or envisioned in the cost and time scale allocated to this part of the project. Therefore, the only satisfactory method available is to use some computational device such as a computer or advanced programmable calculator of sufficient memory capability.

In view of this conclusion, the following comments are made:

1. It is extremely necessary to provide the Broadcast Consultants with an agreed computational package to ensure unified results in a given situation.

2. It would be convenient to provide consultants with a computational package written for a specific processor to ensure unified results in a given situation.

3. It may create an impression that the Department is endorsing a specific processor if DOC provides Items 1 or 2.

Therefore, it is recommended that such packages based on the equations of Reports No. 1 and No. 2 be made available at modest cost to consultants and other interested engineers and agencies through the CAB or CABC.

However, this creates a problem in respect to a published "Procedure" which would either have to specify the whole method including several pages of equations, refer to Reports No. 1 and No. 2 and make these available on demand, or refer to a published paper based on Reports No. 1 and No. 2 and/or a suggested source of computational package.

8.0 Areas for Further Study

Several problem areas beyond the current study program have been briefly examined and these are outlined below:

8.1 Ghost Computation "Procedures"

A method of defining a "Procedure" for ghost level computation as discussed in Section 7.0 of this report.

8.2 Ghost Measurement Techniques

A method of measuring ghost amplitudes which eliminates the errors inherent in simple methods as outlined in Section 7.2 of Report No. 1.

8.3 Echo Suppression Techniques

It is recommended that a study be made of the feasibility of suppressing ghost signals where these are present at the input to a translator system or cable television head-end. This refers to the situation where the ghost source is at the sending end and cannot be modified by receiving antenna orientation. The technique involves the injection of antiphased RF ghost signals derived from the direct signal.

9.0 ENGINEERING SEAL & SIGNATURE

SEAL

SIGNATURE ______________________ P. Eng.
Edwin W. Horrigan,
Principal Investigator

November 15, 1978

10.0 APPENDIX

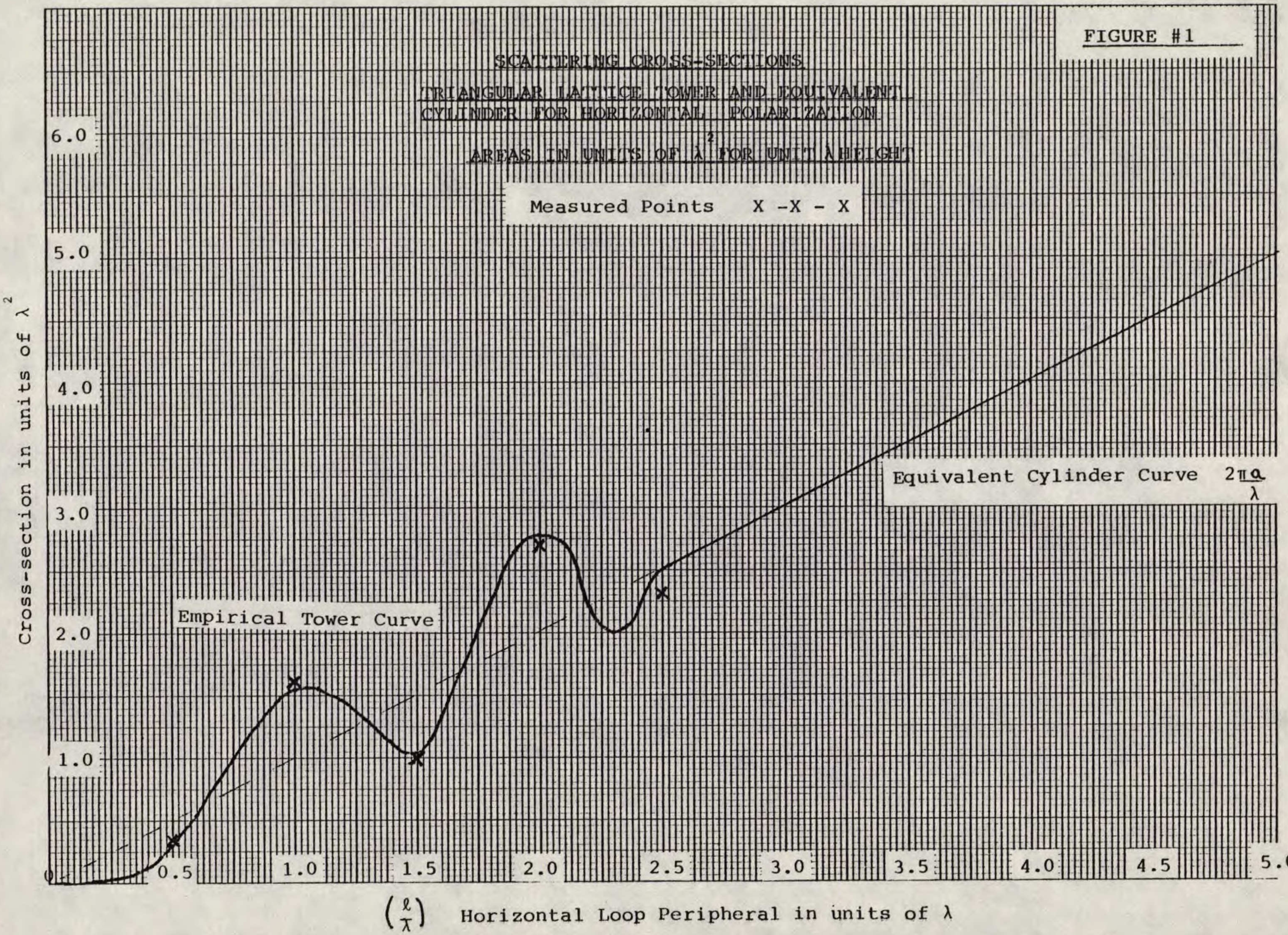

FIGURE #1

SCATTERING CROSS-SECTIONS
TRIANGULAR LATTICE TOWER AND EQUIVALENT CYLINDER FOR HORIZONTAL POLARIZATION

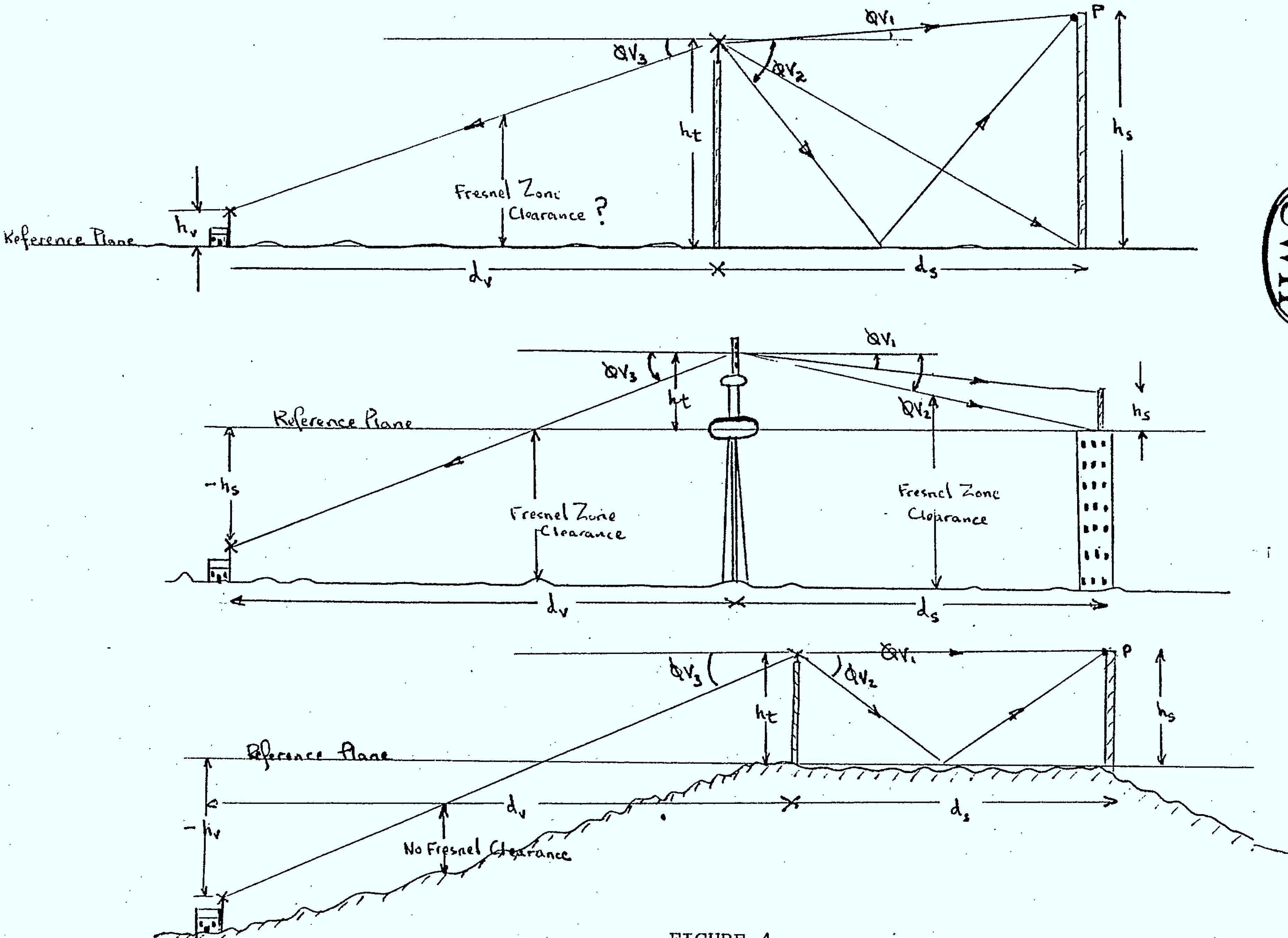

FIGURE 4

TYPICAL GHOST ELEVATION SITUATIONS

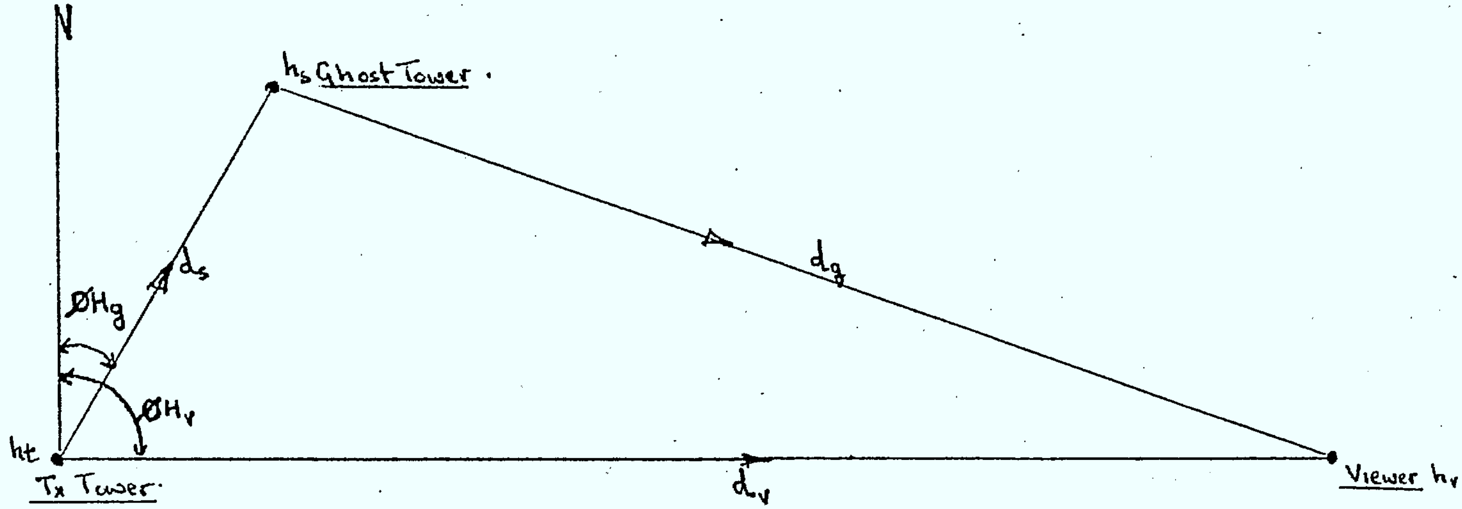

FIGURE 5

TYPICAL GHOST AZIMUTH SITUATION

10.2.2 Method of Application

1. The Software Package

The computational package performs the following functions when provided with the listed inputs shown on page 39 of this report.

a) computes and records the echo delay in microseconds
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 Tx antenna horizontal pattern co-efficient
i) computes Tx antenna vertical pattern co-efficient
j) computes and records echo amplitude in -dB
k) computes and records "Typical Viewer" grade of TV service
l) computes and records FM Radio extraneous noise and distortion as percentage.

2. Input Procedure

Using page 39 of this report as a guide, define and list the required inputs. The various parameters, with the exception of those which are self-explanatory, are shown in Figures 4 and 5.

Antenna vertical and horizontal relative field patterns for the transmitting antenna are also required.

The calculator should be loaded in the stated sequence always ensuring that the previous operation has been completed prior to the next entry. Subsequent to operation 12 the calculator will print several vertical depression angles. Each printed angle requires the entry of the relevant vertical field value.

The calculator will request a lower limit of ghost tower integration several seconds after the entry of $FØV_3$. If the reference plane was drawn in accordance with any of the three elevation situations shown in Figure 4, the limit is zero and the Run/Stop button should be pressed to complete the computation. However, if an unusual situation exists and the reference plane does not intercept the ghost tower base because of topographical features, etc., the following action should be taken:

> Define new lower limit as ratio of total ghost tower height (i.e. 25%). Recall Store 10 (RCL 10), multiply display by 0.25 and enter using "User Defined" Key 'A'. The computation will then continue using this new lower limit of integration for the incident power over the ghost tower (h_s).

3. Output Procedure

The calculator will print the outputs one space below the inputs in the following sequence:

i) Ghost Level in -dB
ii) Echo Delay in μSecs.
iii) "Typical Viewer" Grade No.
iv) FM Radio Extraneous Noise/Distortion in percentage

"Measured" FM Radio Scale Dist.	S/N		"Typical Viewer" TV Grade Scale		
1 %	-40 dB		1.0	-	Excellent
2 %	-34 dB	Suggested Minimum	1.5	-	Very Good
3 %	-30 dB		2.0	-	Good
4 %	-28 dB		2.5	-	Fairly Good
5 %	-26 dB		3.0	-	Fair
7.5%	-22.5dB		3.5	-	Rather Poor
10 %	-20 dB		4.0	-	Poor

4. 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 3 (previous page).

a) Calculate delay using Eq.(1) on page 8.

b) Calculate propagation factor from Eq.(2) on page 11.

c) Obtain $\frac{\sigma_t}{\lambda}$ or $\frac{\sigma_{cyl}}{\lambda}$ factor from Figure 1 for relevant $(\frac{\ell}{\lambda})$.

d) Multiply c) by $(\frac{h_s}{\lambda})^2$ to obtain either σ_{cyl} or σ_t as required - Eq.(3) or Eq.(3A).

e) Obtain rough approximation to Eq.(4) by computing the incident power P_i as shown on page 15 and dividing by $2\,\frac{ERP}{4\pi(d_s)^2}$ or by using:

a second order approximation outlined below:

i) compute the relative field at $\emptyset V_1 = F\emptyset V_1$ where $\emptyset V_1$ is defined as on page 15

$$\emptyset V_1 = \tan^{-1}\left(\frac{h_t - h_s}{d_s}\right)$$

ii) $$\text{Eq.(4)} \sim \left(\frac{F\emptyset V_1}{2}\right)^2$$

f) Compute qualifying equations on page 17 and obtain Eq. (5) or (5A) as required.

g) Compute Eq. (6) on page 18 of this report.

h) Compute Eq. (7) on page 18 of this report.

i) Obtain Ghost in dB as follows:

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

j) Obtain TV Grade No. from Figure 19 of Report No. 1 using a) and i) above.

k) Obtain FM Radio Noise/Dist. % from Figure 29 of Report No. 1 using a) and i) above.

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

TITLE TV.& FM. GHOST ANALYSIS PAGE 1 OF 6

PROGRAMMER E.W.HORRIGAN DATE 25/10/78

TI Programmable Program Record

Partitioning (Op 17) 7,2,9,2,9 Library Module M.L.-09 Printer 100A Cards 2

PROGRAM DESCRIPTION

Program predicts TV. and FM. echo levels in dBs and echo delays in u.Secs. and also provides the Grade No. of impairment for the 'Typical Viewer' and the average % of extraneous noise and distortion for FM. reception.

The program requires the inputs which are listed below which are loaded sequentially A new input should not be attempted until the previous input has been executed.

The command R/S at the end of the program will return the calculator to Step 7 retaining Inputs 1 - 6 in memory. This is used to evaluate new viewer locations based on the same Ghost situation. The command RST resets the program for a new ghost situation.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS	STEP	PRINT OUT	DISPLAY	TYPICAL INPUTS
1	Width of Ghost Tower(m) All units are metric	(w)	R/S	1	(w)		
2	Number of tower sides	(s)	R/S	2	(s)		
3	TV. or FM. Frequency (MHz)	(f)	R/S	3	(f)		
4	Height of Tx tower above reference plane (m)	(h_t)	R/S	4	(ht)		
5	Distance to Ghost tower (m)	(d_s)	R/S	5	(ds)		
6	Height of ghost tower above reference (m)	(h_s)	R/S	6	(hs)		
7	Distance to Viewer (m)	(d_v)	R/S	7	(dv)		
8	Height of viewer above/below reference ±(m)	(h_v)	R/S	8	(hv)		
9	Azimuth of Ghost tower (Degrees)	($ØH_g$)	R/S	9	ØHg		
10	Azimuth of Viewer (Degrees)	($ØH_v$)	R/S	10	ØHv		ØV1
11	Relative Horiz. Field at ($ØH_g$)	F($ØH_g$)	R/S	11	FHg		
12	" " " ($ØH_v$)	F($ØH_v$)	R/S	12	FHv		ØV2
13	Rel. Vert. Field at angle displayed ($ØV_1$)	F($ØV_1$)	R/S	13	FV1		ØV3
14	" " " " " ($ØV_2$)	F($ØV_2$)	R/S	14	FV2		Low limit
15	" " " " " ($ØV_3$)	F($ØV_3$)	R/S	15	FV3	OUTPUT	
16	Lower limit of integration - Incident power on Ghost tower. If zero press R/S		R/S	16			Ghost dB Delay µS. TV Grade FM Dist %

USER DEFINED KEYS		DATA REGISTERS (INV list)					DATA REGISTERS (INV list) 3rd overwrite			
A	Parameters for Simpson's Rule	0	$(1+a+b)^{\frac{1}{2}}$ Simpson's Rule	$\int_0^{\phi} R\,d\phi$	10	X for Eq 3	$\frac{1}{4\pi}\left(\frac{d_v\lambda}{d_s d_g}\right)^2$	20	td(u.S.)		0	TV + FM Grades Eq's.
B		1		Ghost - dB	11	Freq		21	$(FHg/FHv)^2$		1	
C		2		f(z)	12	%λ		22	FVØ1		2	
D		3		g(z)	13	(z)		23	FVØ2		3	
E	Select σ_t	4		g(z)cost	14	(ht)		24	FVØ3		4	
A'	Select ML-09	5		f(z)sint	15	(hs/λ)		25	$(FVØ_1/FVØ_3)^2$		5	
π	Select Free space	6		S(z)	16	(ds)		26	$(d_s)^2$		6	
C'	Select Grade	7	σ_{cyl}		17	(hs)		27	a)	Partial Ghost Height/Gain Factor	7	
D'		8	$(1-e^{-(\frac{3\pi s}{\lambda})})$		18	(dv)		28	b)		8	
E'	Select σ_{cyl}.	9	σ_{tower}		19	(hv)		29	$\bar{h}_s$		9	

FLAGS	0	1	2	3	4	5	6	7	8	9

 1014966-1

TITLE T.V. + F.M. GHOST ANALYSIS PAGE 2 OF 6

PROGRAMMER E.W. Horrigan. DATE 25/10/78

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
000	99	PRT	
001	65	×	
002	91	R/S	
003	99	PRT	
004	65	×	
005	91	R/S	
006	99	PRT	
007	42	STO	
008	11	11	
009	55	÷	
010	03	3	
011	00	0	
012	00	0	
013	95	=	
014	42	STO	
015	12	12	
016	85	+	
017	93	.	
018	05	5	
019	95	=	
020	42	STO	
021	13	13	
022	91	R/S	
023	99	PRT	
024	42	STO	
025	14	14	
026	91	R/S	
027	99	PRT	
028	42	STO	
029	16	16	
030	91	R/S	
031	99	PRT	
032	42	STO	
033	17	17	
034	65	×	
035	43	RCL	
036	11	11	
037	55	÷	
038	03	3	
039	00	0	
040	00	0	
041	95	=	
042	42	STO	
043	15	15	
044	43	RCL	
045	17	17	
046	65	×	
047	03	3	
048	55	÷	
049	04	4	
050	95	=	
051	42	STO	
052	29	29	
053	91	R/S	
054	99	PRT	
055	42	STO	
056	18	18	
057	91	R/S	
058	99	PRT	
059	42	STO	
060	19	19	
061	91	R/S	
062	99	PRT	
063	75	-	
064	91	R/S	
065	99	PRT	
066	95	=	
067	33	X²	
068	34	√X	
069	39	COS	
070	65	×	
071	02	2	
072	65	×	
073	43	RCL	
074	16	16	
075	65	×	
076	43	RCL	
077	18	18	
078	75	-	
079	53	(	
080	43	RCL	
081	16	16	
082	33	X²	
083	54	)	
084	75	-	
085	53	(	
086	43	RCL	
087	18	18	
088	33	X²	
089	54	)	
090	95	=	
091	33	X²	
092	34	√X	
093	34	√X	
094	75	-	
095	43	RCL	
096	18	18	
097	85	+	
098	43	RCL	
099	16	16	
100	95	=	
101	55	÷	
102	03	3	
103	00	0	
104	00	0	
105	68	NOP	
106	95	=	
107	42	STO	
108	20	20	
109	58	FIX	
110	02	02	
111	91	R/S	
112	99	PRT	
113	55	÷	
114	91	R/S	
115	99	PRT	
116	95	=	
117	33	X²	
118	42	STO	
119	21	21	
120	43	RCL	
121	14	14	
122	75	-	
123	43	RCL	
124	29	29	
125	95	=	
126	55	÷	
127	43	RCL	
128	16	16	
129	95	=	
130	22	INV	
131	30	TAN	
132	99	PRT	
133	91	R/S	
134	99	PRT	
135	42	STO	
136	22	22	
137	43	RCL	
138	14	14	
139	85	+	
140	43	RCL	
141	29	29	
142	95	=	
143	55	÷	
144	43	RCL	
145	16	16	
146	95	=	
147	22	INV	
148	30	TAN	
149	99	PRT	
150	91	R/S	
151	99	PRT	
152	42	STO	
153	23	23	
154	43	RCL	
155	14	14	
156	75	-	
157	43	RCL	
158	19	19	

MERGED CODES

62 Pgm Ind	72 STO Ind	83 GTO Ind
63 Exc Ind	73 RCL Ind	84 Op Ind
64 Prd Ind	74 SUM Ind	92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24151

TITLE T.V. + F.M. GHOST ANALYSIS PAGE 3 OF 6

PROGRAMMER E.W. HORRIGAN DATE 25/10/78

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
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161	43	RCL		216	43	RCL		271	85	+	
162	18	18		217	27	27		272	43	RCL	
163	95	=		218	75	-		273	23	23	
164	22	INV		219	43	RCL		274	33	X^2	
165	30	TAN		220	28	28		275	54	)	
166	99	PRT		221	95	=		276	92	RTN	
167	91	R/S		222	34	√X		277	00	0	
168	99	PRT		223	54	)		278	99	PRT	
169	42	STO		224	42	STO		279	76	LBL	
170	24	24		225	00	00		280	11	A	
171	55	÷		226	53	(		281	36	PGM	
172	43	RCL		227	01	1		282	09	09	
173	22	22		228	85	+		283	11	A	
174	95	=		229	43	RCL		284	43	RCL	
175	35	1/X		230	27	27		285	10	10	
176	33	X^2		231	85	+		286	76	LBL	
177	42	STO		232	43	RCL		287	12	B	
178	25	25		233	28	28		288	36	PGM	
179	43	RCL		234	95	=		289	09	09	
180	17	17		235	34	√X		290	12	B	
181	33	X^2		236	54	)		291	01	1	
182	85	+		237	75	-		292	00	0	
183	53	(		238	43	RCL		293	76	LBL	
184	42	RCL		239	00	00		294	13	C	
185	14	14		240	95	=		295	36	PGM	
186	33	X^2		241	65	×		296	09	09	
187	54	)		242	43	RCL		297	13	C	
188	95	=		243	11	11		298	36	PGM	
189	55	÷		244	65	×		299	09	09	
190	53	(		245	01	1		300	14	D	
191	43	RCL		246	93	.		301	55	÷	
192	16	16		247	02	2		302	43	RCL	
193	33	X^2		248	65	×		303	10	10	
194	42	STO		249	43	RCL		304	95	=	
195	26	26		250	16	16		305	42	STO	
196	54	)		251	95	=		306	00	00	
197	95	=		252	42	STO		307	43	RCL	
198	42	STO		253	10	10		308	13	13	
199	27	27		254	76	LBL		309	33	X^2	
200	43	RCL		255	16	A'		310	65	×	
201	14	14		256	53	(		311	03	3	
202	65	×		257	39	COS		312	93	.	
203	43	RCL		258	65	×		313	01	1	
204	17	17		259	02	2		314	85	+	
205	65	×		260	94	+/-		315	02	2	
206	02	2		261	65	×		316	85	+	
207	55	÷		262	43	RCL		317	53	(	
208	43	RCL		263	22	22		318	43	RCL	
209	26	26		264	65	×		319	13	13	
210	95	=		265	43	RCL		320	65	×	
211	42	STO		266	23	23		321	01	1	
212	28	28		267	85	+		322	93	.	
213	53	(		268	43	RCL		323	08	8	

83 GTO
84
92 INV SBR
ENTS

TI-24151

TITLE TV + FM GHOST ANALYSIS PAGE 4 OF 6

PROGRAMMER E.W. HORRIGAN DATE 25/10/78

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
324	54	)	
325	95	=	
326	35	1/X	
327	65	×	
328	53	(	
329	43	RCL	
330	13	13	
331	65	×	
332	93	.	
333	09	9	
334	03	3	
335	85	+	
336	01	1	
337	54	)	
338	95	=	
339	42	STO	
340	02	02	
341	43	RCL	
342	13	13	
343	45	Y^X	
344	03	3	
345	65	×	
346	06	6	
347	93	.	
348	07	7	
349	85	+	
350	53	(	
351	43	RCL	
352	13	13	
353	33	X^2	
354	65	×	
355	03	3	
356	93	.	
357	05	5	
358	54	)	
359	85	+	
360	43	RCL	
361	13	13	
362	65	×	
363	04	4	
364	93	.	
365	01	1	
366	04	4	
367	54	)	
368	85	+	
369	02	2	
370	95	=	
371	35	1/X	
372	42	STO	
373	03	03	
374	43	RCL	
375	13	13	
376	33	X^2	
377	65	×	
378	09	9	
379	00	0	
380	95	=	
381	38	SIN	
382	65	×	
383	43	RCL	
384	03	03	
385	95	=	
386	42	STO	
387	04	04	
388	43	RCL	
389	13	13	
390	33	X^2	
391	65	×	
392	09	9	
393	00	0	
394	95	=	
395	39	COS	
396	65	×	
397	43	RCL	
398	02	02	
399	95	=	
400	42	STO	
401	05	05	
402	53	(	
403	93	.	
404	05	5	
405	75	-	
406	43	RCL	
407	04	04	
408	75	-	
409	43	RCL	
410	05	05	
411	54	)	
412	95	=	
413	65	×	
414	02	2	
415	93	.	
416	02	2	
417	05	5	
418	95	=	
419	42	STO	
420	06	06	
421	43	RCL	
422	12	12	
423	65	×	
424	53	(	
425	43	RCL	
426	15	15	
427	33	X^2	
428	54	)	
429	95	=	
430	42	STO	
431	07	07	
432	43	RCL	
433	12	12	
434	65	×	
435	02	2	
436	95	=	
437	33	X^2	
438	94	+/-	
439	22	INV	
440	23	LNX	
441	95	=	
442	75	-	
443	01	1	
444	95	=	
445	94	+/-	
446	42	STO	
447	08	08	
448	65	×	
449	53	(	
450	43	RCL	
451	15	15	
452	33	X^2	
453	54	)	
454	65	×	
455	43	RCL	
456	06	06	
457	65	×	
458	43	RCL	
459	12	12	
460	95	=	
461	42	STO	
462	09	09	
463	43	RCL	
464	18	18	
465	55	÷	
466	43	RCL	
467	11	11	
468	65	×	
469	03	3	
470	00	0	
471	00	0	
472	55	÷	
473	43	RCL	
474	16	16	
475	55	÷	
476	53	(	
477	43	RCL	
478	20	20	
479	65	×	
480	01	1	
481	00	0	
482	00	0	
483	.00	0	
484	55	÷	
485	03	3	
486	85	+	
487	43	RCL	
488	18	18	

83 GTO
84
92 INV SBR

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TI-24151

TITLE TV.+FM. GHOST ANALYSIS PAGE 5 OF 6

TI Programmable Coding Form

PROGRAMMER E.W. HORRIGAN. DATE

LOC	CODE	KEY	COMMENTS
489	75	-	
490	43	RCL	
491	16	16	
492	54	)	
493	95	=	
494	33	X²	
495	55	÷	
496	04	4	
497	55	÷	
498	89	π	
499	95	=	
500	42	STO	
501	10	10	
502	53	(	
503	02	2	
504	93	.	
505	02	2	
506	05	5	
507	54	)	
508	32	X:T	
509	43	RCL	
510	12	12	
511	77	GE	
512	15	E	
513	43	RCL	
514	09	09	
515	61	GTO	
516	10	E'	
517	76	LBL	
518	15	E	
519	43	RCL	
520	07	07	
521	76	LBL	
522	10	E'	
523	65	×	
524	43	RCL	
525	10	10	
526	65	×	
527	43	RCL	
528	00	00	
529	65	×	
530	43	RCL	
531	25	25	
532	65	×	
533	43	RCL	
534	21	21	
535	95	=	
536	42	STO	
537	27	27	
538	43	RCL	
539	29	29	
540	55	÷	
541	43	RCL	
542	14	14	
543	54	)	
544	33	X²	
545	95	=	
546	42	STO	
547	28	28	
548	53	(	
549	07	7	
550	93	.	
551	05	5	
552	32	X:T	
553	43	RCL	
554	11	11	
555	65	×	
556	53	(	
557	43	RCL	
558	14	14	
559	75	-	
560	43	RCL	
561	19	19	
562	85	+	
563	01	1	
564	00	0	
565	54	)	
566	55	÷	
567	43	RCL	
568	18	18	
569	95	=	
570	22	INV	
571	77	GE	
572	89	π	
573	01	1	
574	42	STO	
575	28	28	
576	76	LBL	
577	89	π	
578	43	RCL	
579	28	28	
580	65	×	
581	43	RCL	
582	27	27	
583	95	=	
584	28	LOG	
585	65	×	
586	01	1	
587	00	0	
588	95	=	
589	98	ADV	
590	99	PRT	
591	42	STO	
592	01	01	
593	43	RCL	
594	20	20	
595	99	PRT	
596	53	(	
597	93	.	
598	06	6	
599	03	3	
600	07	7	
601	55	÷	
602	43	RCL	
603	20	20	
604	95	=	
605	94	+/-	
606	22	INV	
607	23	LNX	
608	65	×	
609	93	.	
610	01	1	
611	04	4	
612	03	3	
613	54	)	
614	65	×	
615	43	RCL	
616	01	01	
617	95	=	
618	42	STO	
619	03	03	
620	53	(	
621	93	.	
622	04	4	
623	07	7	
624	05	5	
625	55	÷	
626	43	RCL	
627	20	20	
628	95	=	
629	94	+/-	
630	22	INV	
631	23	LNX	
632	65	×	
633	06	6	
634	93	.	
635	06	6	
636	05	5	
637	54	)	
638	85	+	
639	43	RCL	
640	03	03	
641	95	=	
642	42	STO	
643	06	06	
644	53	(	
645	01	1	
646	54	)	
647	32	X:T	
648	43	RCL	

MERGED CODES

62 Pgm Ind	72 STO Ind	83 GTO Ind
63 Exc Ind	73 RCL Ind	84 Op Ind
64 Prd Ind	74 SUM Ind	92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24151

TITLE T.V. + F.M. GHOST ANALYSIS PAGE 6 OF 6

PROGRAMMER E. W. HORRIGAN DATE 25/10/78

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
649	06	06	
650	77	GE	
651	18	C'	
652	01	1	
653	42	STO	
654	06	06	
655	76	LBL	
656	18	C'	
657	43	RCL	
658	06	06	
659	99	PRT	
660	43	RCL	
661	20	20	
662	65	×	
663	01	1	
664	93	.	
665	08	8	
666	95	=	
667	38	SIN	
668	65	×	
669	01	1	
670	04	4	
671	01	1	
672	93	.	
673	04	4	
674	95	=	
675	42	STO	
676	04	04	
677	43	RCL	
678	01	01	
679	55	÷	
680	02	2	
681	00	0	
682	95	=	
683	22	INV	
684	28	LOG	
685	65	×	
686	43	RCL	
687	04	04	
688	95	=	
689	99	PRT	
690	98	ADV	
691	22	INV	
692	58	FIX	
693	25	CLR	
694	61	GTO	
695	00	00	
696	52	52	

MERGED CODES

62 Pgm Ind	72 STO Ind	83 GTO Ind
63 Exc Ind	73 RCL Ind	84 Op Ind
64 Prd Ind	74 SUM Ind	92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24151