November 1, 2002

Field Strength Prediction in Irregular Terrain – the PTP Model

Author: Harry K. Wong

Abstract

This report describes a prediction technique for the calculation of the field strength of radio waves over irregular terrain paths. The concept of an "equivalent rounded obstacle" is used to account for radio propagation losses over various possible irregular terrain shapes, including shapes which cannot easily be described geometrically. The technique replaces an arbitrary terrain profile with an equivalent rounded obstacle for which a value of path loss can be calculated using appropriate formulas.

Introduction

The technique presented here was first published in a report attached to a notice of proposed rulemaking in 1998[1,2] and was promoted as a possible means of streamlining certain regulatory procedures used to the coverage provided by broadcasting services. This update of that report incorporates improvements to the prediction model that overcome deficiencies pointed out by comments filed in that rule making proceeding. These improvements primarily involve accounting for effects of secondary obstacles, *i.e.*, those obstacles located in the propagation path on either side of the primary obstacle. Finally, to fine tune this new technique, adjustments were made in model parameters to achieve close agreement with actual measurement data collected over various propagation paths by the Television Allocations Study Organization (TASO).[3]

The technique was developed over a number of years in the course of examining many hundreds of applications involving FM and TV broadcasting stations. In these applications, broadcast stations were proposing to move their transmitting antenna to a new location that, according to the standard propagation prediction technique, would not have provided an adequate signal over their community of license. In these cases, most applicants were citing unusual terrain conditions that invalidate the prediction technique prescribed by FCC Rules, 47 C.F.R. §§ 73.333

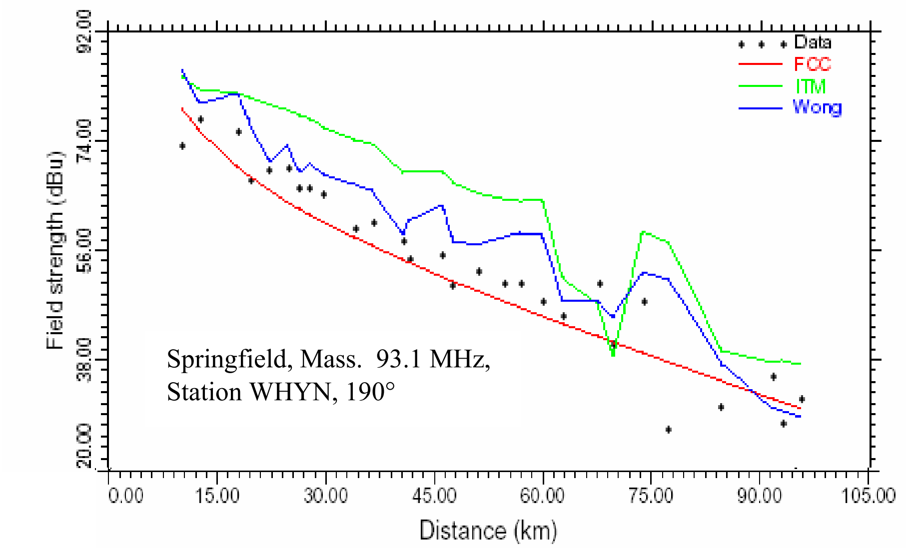
---

[1] *Notice of Proposed Rule Making and Order*, 1998 Biennial Regulatory Review – Streamlining of the Radio Technical Rules in Parts 73 and 74 of the Commission Rules, MM Docket No. 98-93, 13 FCC Rcd 14849 (1998).

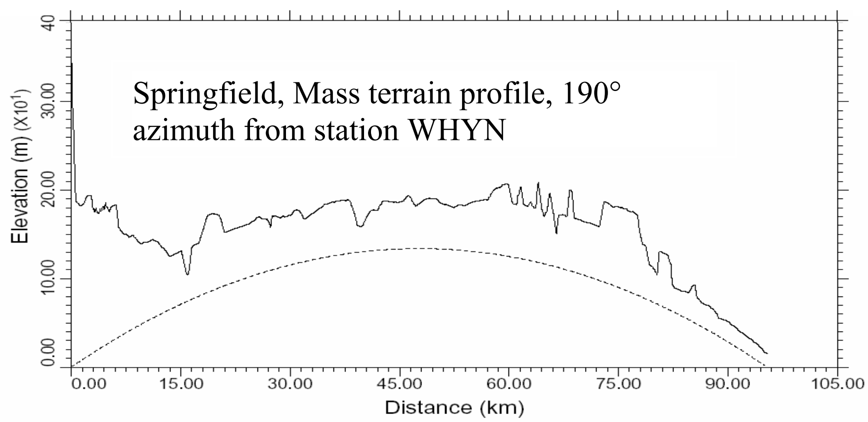
[2] The *Second Report and Order*, MM Docket No. 98-93, 15 FCC Rcd 21649 (2000) may be viewed at http://www.fcc.gov/Bureaus/Mass_Media/Orders/2000/fcc00368.pdf.

[3] The measurement data used for comparison with PTP predictions are the results of field strength surveys conducted by A.D. Ring & Associates for the Association of Maximum Service Telecasters, Inc., mostly in the years 1957-1960. These data were supplied to a panel of the Television Allocation Study Organization (TASO), and they were used in development of the TV and FM broadcast curves which appear in FCC Rules as the standard method for predicting field strength contours. The se data are available for independent study at http://www.fcc.gov/oet/fm/ptp/data/.

and 73.699.[4] To verify the claims of adequate coverage presented in the applications, the Commission needed a procedure or propagation model derived from theoretical considerations that could be verified by measurements. This procedure or propagation model needed to accommodate difficult terrain features which were not handled adequately by the propagation curves in the FCC Rules. The Point-to-Point (PTP) model fulfills these requirements, and in addition, it is pictorially related to terrain elevation profiles in ways that provide insight into the cause of radio propagation loss in each particular case. The PTP model's implementation as a computer program is useful as a first cut at estimating the strength of signals within about 100 miles of the transmitter.



Comparison with actual propagation measurements, and with the results of other prediction procedures, demonstrates that path loss values calculated by the PTP model are relatively accurate; and moreover that the accuracy of the PTP model is as good as or better than that achieved by alternative procedures.[5] The accompanying figures illustrate the relative accuracy of the PTP model, identified in the figure as the Wong curve. The ITM curve is the corresponding prediction of the Longley-Rice model.[6] The fluctuations are due to terrain variations. Generally, the field is low when the receiving point is in a terrain depression. The standard procedure is to use the curves found in FCC Rules, 47 C.F.R. §§ 73.333 and 73.699. Notice in the figure that the FCC standard curves match the data pretty well but do not respond to terrain effects like the Wong and ITM curves. These standard curves are



[4] 47 C.F.R. §§ 73.333 and 73.699.

[5] See http://www.fcc.gov/Bureaus/Engineering_Technology/Documents/taso/graphs/ for study results.

[6] NTIA Report 82-100, *A Guide to the Use of the ITS Irregular Terrain Model* [ITM] *in the Area Prediction Mode*, authors G.A. Hufford, A.G. Longley and W.A. Kissick, U.S. Department of Commerce, April 1982. The computer program is described and can be downloaded from http://elbert.its.bldrdoc.gov/itm.html. ITS is the Institute for Telecommunications Sciences of the National Telecommunications and Information Administration (NTIA).

generally accepted as highly accurate on average, but they are of no use for evaluating the shadowing effects of specific terrain elevation features between transmitter and receiver. The Longley-Rice model (ITM in the figure) makes its predictions from terrain profiles, but the Longley-Rice computer program was developed for application to a wide range of distances and phenomena including troposcatter propagation at relatively great distances. For reception points of 100 miles and less, the Longley-Rice computer program often makes anomalous predictions that are inconsistent with the procedures of Technical Note 101, the document on which it is based.[7] The PTP model tends to resolve these anomalies and is consistent with Technical Note 101.

The PTP Model

To make its predictions, the PTP model incorporates the principal determinants of radio propagation over irregular terrain paths. These determinants are (1) the amount by which the direct ray clears terrain prominences or is blocked by them, (2) the position of terrain prominences or obstacles along the path, (3) the strong influence of the degree of roundness of these terrain features, and (4) the apparent earth flattening due to atmospheric refraction. Even in line-of-sight conditions when all terrain prominences lie below the direct ray, some may come close enough to weaken the received field. This weakening effect is evaluated in terms of the degree to which a prominence penetrates certain geometrically defined zones, called Fresnel zones, around the direct ray. Determinant (2), position of the prominence or obstacle along the path, is important because the football-shaped Fresnel zones are fatter and thus more deeply penetrated in the middle than at the transmitter and receiver ends.

The relative roundness of terrain features along the path is of special concern because the radio field beyond a sharp obstacle is considerably greater than the field found beyond more rounded terrain features. The extremes are a knife-edge idealization in contrast to smooth earth with consequent differences in field strength of 20 dB or more. Applications to the FCC for broadcasting license changes may claim strong or weak signals to some extent as the applicant wishes because terrain elevation data from the U.S. Geological Survey is not of sufficient resolution for a precise determination of roundness. Some judgment is necessary that usually must be based on the roughness of the terrain in the general area. Automating this judgment requirement, and thus streamlining the processing of applications that include engineering claims, was a principal motivation for developing the PTP model. The PTP model estimates an equivalent roundness in terms of the statistical variation of neighboring terrain elevations. If this statistical variation is small, the intermediate terrain is considered to have the effect of a relatively round obstacle. Sharpness thus corresponds to a large statistical variance.

1. DIFFRACTION LOSS CALCULATIONS

Diffraction loss for an ideal knife-edge obstruction can be calculated from the famous Fresnel integral. This integral originated in studies of optics by Augustin-Jean Fresnel in the early 19th

[7] National Bureau of Standards Technical Note 101, *Transmission Loss Predictions for Tropospheric Communication Circuits*, authors P.L. Rice, A.G. Longley, K.A. Norton, and A.P. Barsis, January, 1967.

century. In application to radio propagation, formulas based on this integral have frequently provided close approximations to the diffraction effects of isolated mountain ridges.

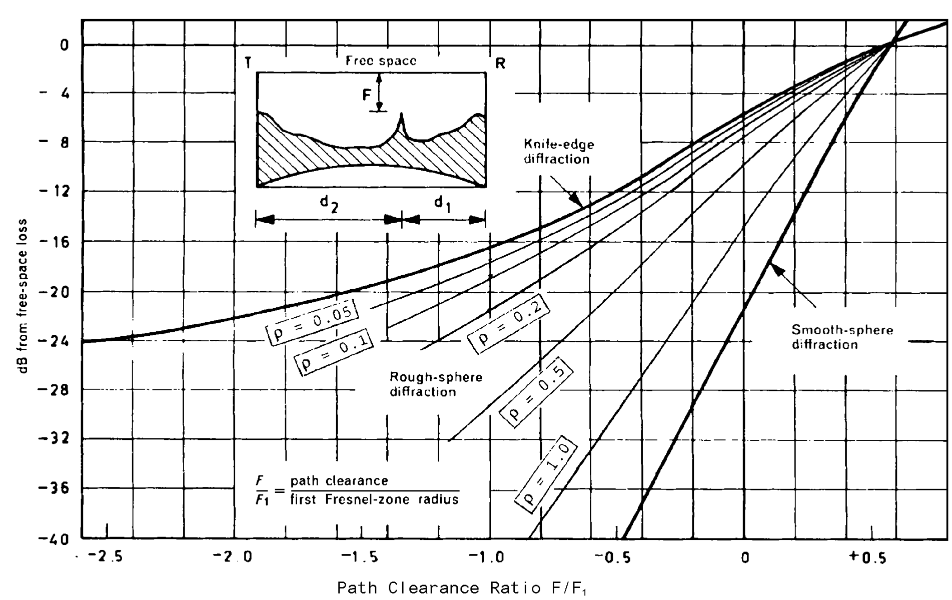
In most situations however, the terrain does not at all resemble a simple knife-edge, and to represent obstructions in this simple way would underestimate the diffraction loss. Solutions for the diffraction loss over an isolated "rounded" obstacle have been given by Rice [1], Neugebauer and Bachynski [2][3], Wait and Conda [4]. In addition, Dougherty and Maloney [5] provide a readily evaluated formula for computing the diffraction loss over a rounded obstacle in terms of quantities υ and ρ, where υ is the dimensionless parameter of the Fresnel-Kirchhoff diffraction formula and ρ is a mathematically convenient dimensionless index of curvature for the crest radius of the rounded obstacle. Diffraction loss is greater for broader obstacles of this type, increasing as the radius of curvature and ρ become larger.

The diffraction loss in every situation is somewhat less than would be calculated by replacing irregular terrain with a smooth spherical earth, the ultimate rounded obstacle. Methods of calculating the diffraction loss over a smooth spherical earth have been given by Burrows and Gray [6] and by Norton [7]. (These methods are difficult to apply, however, and here we resort to a formula obtained by fitting a curve in a CCIR graph as discussed in the next section.)

Diffraction losses due to multiple knife-edges also lie somewhere in the range between those for single knife-edge and smooth-earth terrain models. Deygout [8] provides easily implemented procedures for calculation when the terrain can be represented this way. The technique described in this report does not involve multiple knife-edge considerations. However, we have found that the equivalent rounded obstacle approach gives results closely approximating those of other methods even in situations better described by multiple knife-edges.

2. GRAPH OF DIFFRACTION LOSS

CCIR [9] provides a graphical representation of knife-edge and smooth-sphere diffraction loss relative to that of free-space in terms of the ratio of path clearance to the radius of the first Fresnel zone. The figure below is the CCIR graph with the addition of the Dougherty-Maloney



diffraction adjustments for rounded obstacles. Note: the ratio of path clearance to first Fresnel radius, F/F_1 in the figure, equals the Dougherty-Maloney parameter υ divided by the square root of 2.

It is found in the figure that the diffraction loss for ρ=1.0 is 0.6 of the way downward between the losses for knife-edge and smooth-sphere for all path clearance ratios, that is, for all values of F/F_1. A similar proportion holds for the other values ρ, and hence we can characterize rounded obstacles by this proportion just as well as by the values of the Dougherty-Maloney parameter ρ. We denote this proportion by the symbol R, and call it the equivalent roundness factor. This graphical interpretation of the figure is the basis of the formulas used in the equivalent rounded obstacle model. Knife-edge diffraction corresponds to R = 0.0; smooth-earth to R = 1.0.

The bounding curves in the figure, that is, those for knife-edge and smooth earth, can be described by approximate formulas. Letting $x = F/F_1$, the diffraction loss (relative to free-space) for a smooth-sphere diffraction is approximately

$$\text{Smooth-sphere Loss} = -38.68x + 21.66 \text{ dB},$$

and for a knife-edge

$$\text{Knife-edge Loss} = 1.377x^2 - 11.31x + 6.0 \text{ dB} \quad \text{for } x > -0.5$$

$$= -50.4/(1.6 - x) + 36.0 \text{ dB for } x < -.5.$$

Now when both F/F_1 and R are given, path loss by the equivalent roundness model is be found by

$$\text{Path Loss} = \text{Knife-edge Loss} + R\,(\text{Smooth-sphere Loss} - \text{Knife-edge Loss}).$$

Section 3 describes how F/F_1 is determined; section 4 discusses the estimation of the equivalent roundness factor, R.

3. PATH CLEARANCE RATIO, F/F_1

A major factor in determining diffraction loss is the clearance ratio, F/F_1. The inset diagram in the CCIR figure indicates how this quantity is defined. Consider a specific point-to-point path and the terrain elevations at all intermediate points from the transmitter. The height of the transmitter is presumed to be given, the receiver height is assumed to be 9.1 meters above the surface of the earth in FM radio service applications, and these heights determine a line of sight which may pass through or over obstacles. At a specific point along the path, the clearance F is the difference in height between the line of sight and the terrain elevation. At that same point we calculate the radius F_1 of the first Fresnel zone and form the ratio F/F_1. The primary obstacle is at the point where this ratio is a minimum.

The first Fresnel radius in meters is given by

$$F_1 = \sqrt{c\,d_1 d_2/(fd)} = 547.8\sqrt{d_1 d_2/(fd)}$$

where c = speed of light in km/s,
d_1 = distance to the near end of path in km, d_2 = distance to the far end of path in km,
$d = d_1 + d_2$ = total path length in km f = frequency in MHz.

4. TERRAIN VARIATION AND EQUIVALENT ROUNDNESS FACTOR

An equivalent roundness factor must be defined to complete the model. We can imagine a statistical project in which propagation measurements are to be arranged in groups with each group having approximately the same loss and the same path clearance ratio. In this project we would then try to identify commonalities in the various groups of terrain profiles. In place of this project, which would probably be very costly, we make a guess that terrain variation (ΔH in what follows) occurring near the primary obstacle is the major commonality that would be found. This amounts to assuming that equivalent roundness is highly correlated with the terrain variation parameter. We also establish an *a priori* relationship between R and ΔH. This relationship is

$$R = 75 / (\Delta H + 75).$$

ΔH is defined as follows: A straight-line least-squares fit is made to the terrain elevations within 10 km of the primary obstacle. The variance of these terrain elevations relative to the straight-line fit is then calculated, and ΔH is set equal to 90 percent of the standard deviation.

Assuming that terrain variations tend to be somewhat similar within a relatively small area, ΔH will give an indication of the type of primary obstacle (smooth rolling hill, rugged mountain, etc.). Note the following:

- For $\Delta H = 0$ m, there is no terrain variation. Terrain is assumed to be smooth and the primary obstacle is that of a smooth earth.

- $\Delta H = 50$ m corresponds to a hill about 55 meters high. This indicates rolling terrain in which hilltops usually have a fairly large radius of curvature. Limited field strength measurements indicate a diffraction loss equivalent to that for a rounded obstacle with an index of curvature, ρ, of 1.0 (0.6 of the diffraction loss from knife-edge to smooth-earth).

- $\Delta H = 200$ m indicates a large mountain where the peak is fairly sharp. A rounded obstacle with an index of curvature, ρ, of 0.5 (0.25 of the diffraction loss from knife-edge to smooth-earth) provides a close estimate.

This formulation is based on experience in examining many hundreds of real situations considering the various possibilities in each case for representing the terrain high points as obstacles for classical diffraction calculations. The parameters of the equivalent roundness approach have been chosen so that results approximate those of classical diffraction calculations. The agreement is generally as close as that between classical approaches themselves.

5. SECONDARY OBSTACLES

The equivalent roundness approach was designed at first for situations in which prominent terrain features are concentrated in a single primary region between transmitter and receiver. Improvements made since the notice of proposed rulemaking in 1998 (cited above) take account of secondary obstacles that may lie near the transmitter, the receiver, or both. This is done by examining the path from transmitter, or receiver, to the peak of the primary obstacle to determine an equivalent roundness of this intermediate terrain. Finally, the effects of these secondary obstacles are attributed to an increased roundness of the primary obstacle by itself. The primary obstacle, at first limited to 10 km on each side of the point of least clearance, is broadened making it act rounder and more like the smooth earth condition which causes maximum diffraction loss.

Conclusions

The PTP model relates the statistical variance of terrain elevations to classical diffraction theory, and predictions made by the model agree closely with measured data. Classical diffraction theory itself cannot make precise calculations of radio fields over irregular terrain because descriptions of the irregularities in sufficiently high resolution are not feasible. While other prediction models construct simple approximations to the terrain as combinations of classical diffraction edges, the PTP model constructs an equivalent rounded obstacle in terms of terrain elevation statistics. The relative accuracy of the PTP model is established by its agreement with measurement data rather than by diffraction theory. Neither approach is perfect. Therefore predictions of the PTP model should be checked by other methods if they are to support critical decisions.

REFERENCES

[1] Rice, S.O.; "Diffraction of Plane Radio Waves by a Parabolic Cylinder", *Bell Systems Tech. J.*,Vol. 33, No. 2, pp 417-504, 1954.

[2] Neugebauer, H.E.J. and M.P. Bachynski; "Diffraction by Smooth Cylindrical Mountains", *Proc. IRE* 46, No. 9, pp 1619-1627, 1958.

[3] Neugebauer, H.E.J. and M.P. Bachynski; "Diffraction by Smooth Conical Obstacles", *J. Res. NBS* 64D (Radio Prop.), No. 4, pp 317-329, July-Aug 1960.

[4] Wait, J.R. and A.M. Conda; "Diffraction of Electromagnetic Waves by Smooth Obstacles for Grazing Angles", *J. Res. NBS* 63D (Radio Prop.), No. 2, pp 181-197, Sept-Oct 1959.

[6] Dougherty, H.T. and L.J. Maloney; "Application of Diffractions by Convex Surfaces to Irregular Terrain Situations"; *Radio Science Journal of Research*, NBS/USNC-URSI Vol. 68D, No. 2, Feb 1964.

[6] Burrows, C.W. and M.C. Gray; "The Effect of the Earth's Curvature on Ground Wave Propagation", *Proc. IRE*, Vol. 29, pp 16-24, Jan 1941.

[7] Norton, K.A.; " The Calculation of Ground-wave Field Intensities Over a Finitely Conducting Spherical Earth", *Proc. IRE,* Vol. 29, pp 623-639, Dec. 1941.

[8] Deygout, J., Multiple Knife-edge Diffraction of Microwaves, *IEEE Trans. Antennas and Propagation*, Vol. AP-14, No. 4, pp 480-489, 1966.

[9] CCITT/CCIR Report; "Propagation", Appendix to Section B.IV.3 of the Handbook "Economic and Technical Aspects of the Choice of Transmission Systems", Published by The International Telecommunication Union, 1971.