Broadcast Propagation Prediction Methodology:

Knowing where your signal goes.

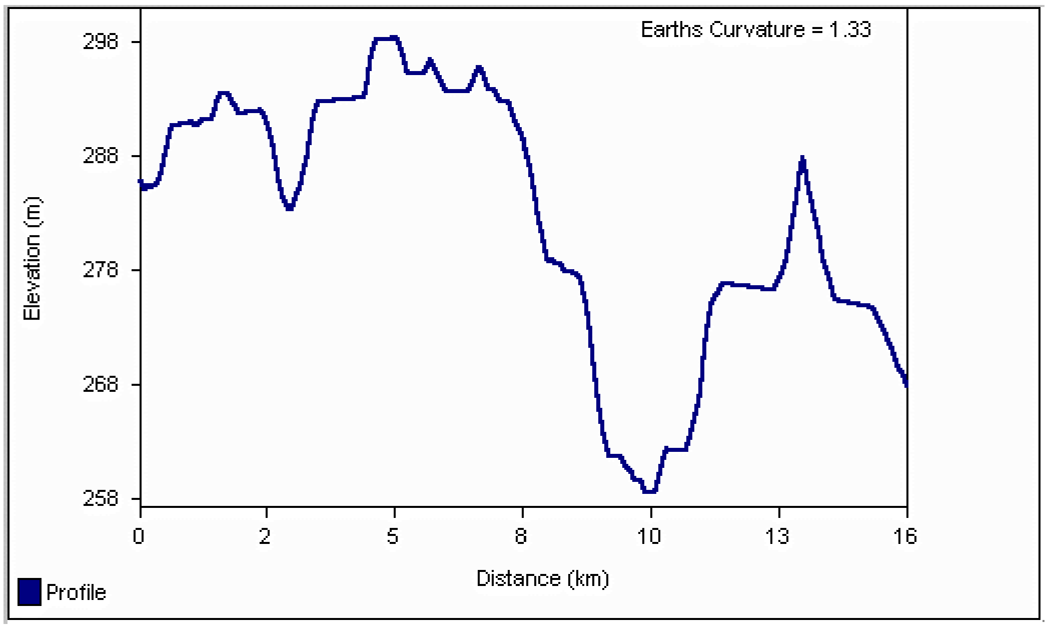
The broadcast industry today is dependent upon reaching people. Quality coverage is a key ingredient. Knowing where your signal goes through propagation prediction is both a science and art. It is based on the scientific modeling of the radio path as it travels from the transmitter to the receiver. A good model can accurately predict signal strength at various frequencies over distances influenced by ground conductivity, atmospherics and terrain. The propagation models we have today were developed and tested over a period of time and the models have been adjusted to better account for observed variances. How information gleaned from propagation predictions is presented to the reader is an art and an important part of making sense of what the predictions are telling us. In this chapter, we will discuss the primary, broadcast oriented, prediction models used in the U.S. today and provide information on how radio and television station engineers can use the models to assess the performance of their systems.

Why predict?

Predictions are used for all kinds of analysis of broadcast communications facilities. Coverage map predictions are required by the FCC and every station must have a map available for inspection in the stations' public file Management may ask the engineer for a coverage map to be used by the sales department. Coverage maps are used universally in the due diligence process to estimate the population within the station's service area. Coverage maps that contrast population can be used to evaluate upgrades and site relocations. While actual measurement can determine signal levels, measurements are difficult and time consuming to perform. Further, signal levels will often vary depending on the time of year, so predictions represent a quick and cost effective way to size up a station's performance.

FCC FM and TV prediction method:

The FCC method of determining FM and TV coverage involves calculating the effective antenna height of a given transmitter along a minimum of eight azimuths. For FM at least fifty terrain elevation points from 3 to 16 kilometers from the transmitter must be evaluated on the eight azimuth radials. (See Figure #1.) TV uses the distance from 3.2 kilometers to 16.1 kilometers. For many years topographic maps were used to derive the elevation points, but today nearly all such work is performed by computers using either the National Geophysical Data Center's 30 arc-second digital terrain database or another of the available databases offering higher resolution. Typically, when digital terrain elevation databases are in use the elevation points are spaced 0.1 kilometers apart. The points are averaged to produce an 'average elevation' for the radial. This figure is then subtracted from the antenna's center of radiation above mean sea level to determine the "height above average terrain" or HAAT along the radial. For FM, the distance to a signal contour is calculated using the FCC's F(50-50) curves found under section 73.333 where the FCC has published two sets of curves the F(50-50) for coverage and the F(50-10) for interference calculations. These curves were based on actual measurements with the receiving antenna at 9 meters or 30 feet. The F(50-50) curves show signal strength as a measure of distance under the statistical probability that the predicted signal will be at 50 percent of the locations for 50 percent of the time. The interfering signal curves are based on a signal of certain strength for 50 percent of the locations for only ten percent of the time. Therefore, since the interfering signal only needs to be at a certain level for ten percent of the time, it can be said to be available at greater distances.



Six curves for analog TV can be found under Section 73.699 of the Commission's.[1] These curves are divided into F(50-50) and F(50-10) curves for low VHF (2-6), high VHF(7-13) and UHF (14-69). For digital TV, the coverage is predicted using F(50-90) calculations. In other words, the signal from a DTV station is at 50 percent of the locations for 90 percent of the time. Section 73.625 (b) describes how F(50-90) signal values can be calculated using the Section 73.699 F(50-50) and F(50-10) charts. Today, nearly all signal calculations are done with computers that use digitized versions of the Commission's curves. Computers provide speed and accuracy which give us

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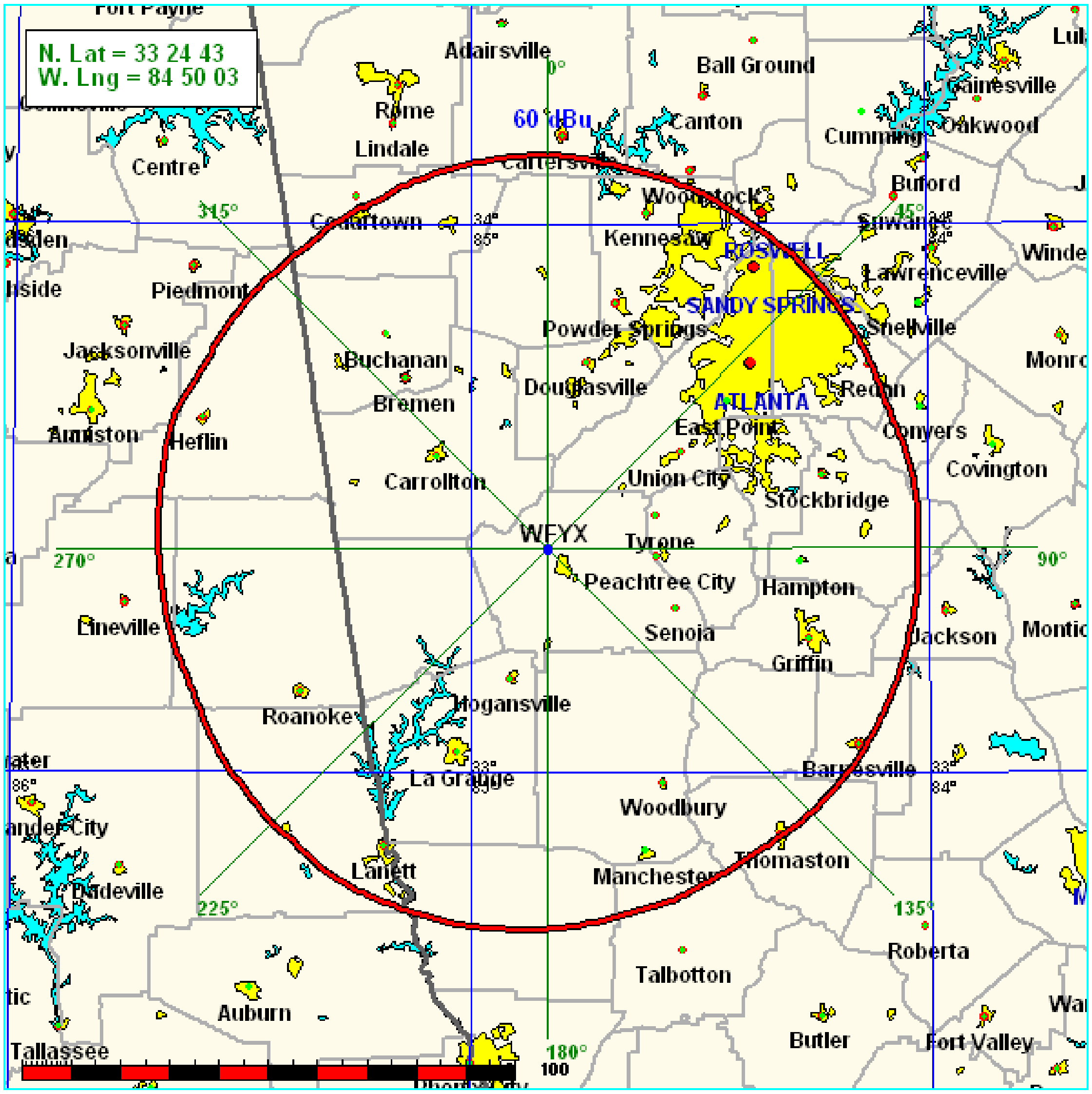
[1] The FCC has recently placed new, easier to read, FM and TV field strength curves on its web site at: http://www.fcc.gov/encyclopedia/fm-and-tv-propagation-curves-graphs-sections-73333-73525-and-73699

For the first time, these curves include F(50-90) DTV curves that do not require use of the F(50-50) and F(50-90) curves to derive distance to contour values.

the opportunity to produce extensive and complicated predictions in a matter of seconds.

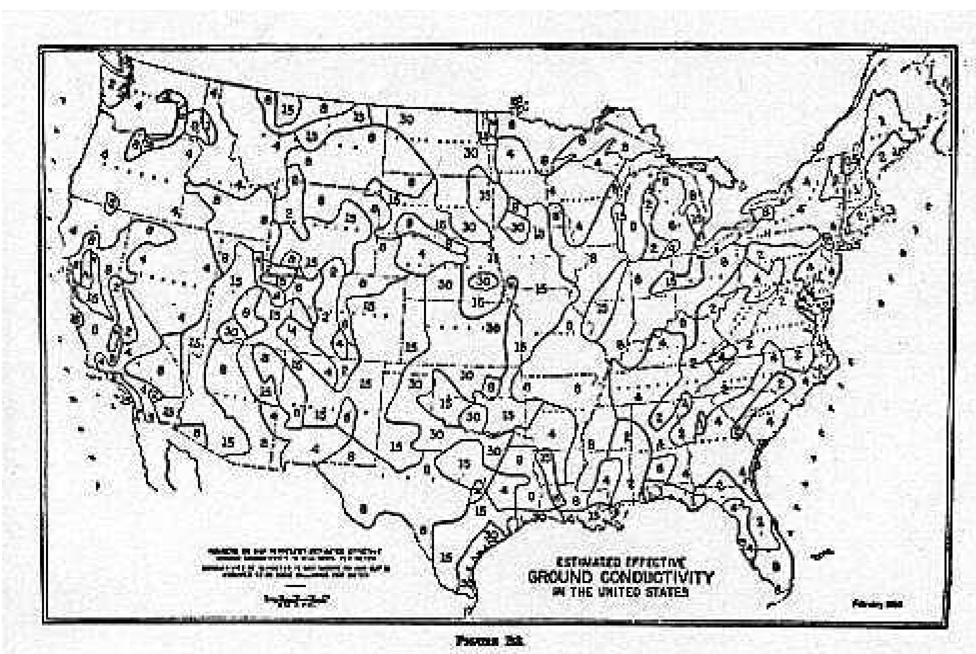


A typical 60 dBu FCC F(50-50) coverage contour map

The FCC uses predictions in its various allocation schemes for radio and television and auxiliary services. A protected station's signal strength at a given location is calculated and the interfering station's signal strength is also calculated at the same location. The undesired to desired (U/D) ratios are then used to determine if the ratio between the interfering signal and the protected signal meets the Commission's standards. The U/D ratios we use today for FM radio were originally established in 1947, when the FCC "Laboratory Division" conducted tests on FM Radios and published reports on "Characteristics of Commercial FM Broadcast Receivers". Included in the project were tests concerning the interference rejection ratios on co-channel and adjacent channels. These measurements were the basis for the interference ratios used in the FM rules first adopted in 1951. Although the U/D method has regular use for predicting the existence of interference at various points, for FM under short spacing, NCE FM and FM translators and analog LPTV and translators the FCC typically uses a more rudimentary method of overlapping contours. For FM class A, C3, C2, C1, C0 and C stations, the 60 dBu F(50-50) signal contour is considered the protected contour. For class B1 it's the 57 dBu and for class B it's the 54 dBu. In the case of co-channel stations, the applicable U/D ratio is -20 dB, so the 40 dBu F(50-10) interference contour of an interfering station may not cross the F(50-50) 60 dBu contour of a class A or one of the class C designated stations. The ratio for first adjacent stations is -6 dB and for 2nd and 3rd adjacent stations the ratio is +40 dB. For low VHF, full-service, analog TV the protected contour is the grade B contour at 47 dBu, for high VHF the 56 dBu is protected and for UHF the protected contour at 64 dBu. Low power TV or TV translators are protected to the 62, 68 and 74 dBu contours respectively. DTV stations are protected within their noise limited signal contours which are the 28 dBu for low VHF, 36 dBu for high VHF and 41 dBu for UHF.

Predicting AM coverage:

As opposed to VHF and UHF frequency waves that travel primarily through the air standard band AM daytime propagation uses groundwaves. The M3 map, shown below, appears in Section 73.190 of the Commission's rules. It shows the conductivity regions in various areas of the U.S. A similar map for region 2,



defines the conductivity, in less detail, for the entire Western Hemisphere. Section 73.183 and 73.184 refer to field strength curves that, when used with the M3 or R2 charts, will predict the distance to contours for AM stations during daylight hours. [2]

Nighttime propagation for standard band AM is calculated using a combination of the FCC's skywave calculations and ground conductivity calculations. Class C stations use only groundwave for both day and night. Class A stations, sometimes called clear channels, are protected by U.S. stations on the co-channel to the 0.5 millivolt per meter groundwave contour. Stations operating at night also have to protect the root-sum-square (RSS) limit, sometimes called "interference free", signal contours of other stations. Calculation of nighttime interference-free service is accomplished by evaluating the signals on co- and first adjacent frequencies in order of decreasing magnitude by adding the squares of the values and extracting the square root of the sum, excluding those signals which are less than 50% of the RSS values of the higher signals already included.[3]

Alternative Propagation Methods:

While the FCC's standard method has served the agency well over the years it has its failings. Since radial HAATs are evaluated from approximately 2 miles from the transmitter to ten miles, the method can miss seeing huge mountains just beyond the ten-mile markers. Also, the Commission usually evaluates contour overlap using a 30 arc-second N.G.D.C. terrain digital terrain set that was distilled from the original 3 arc-second database made by digitizing elevations from 1:250,000 topographic maps. Since these maps have minimal elevation contours when compared to 7 1/2 minute topos, for example, many of the real elevation peaks are missing from the digitized product resulting in overall lower average terrain elevations. (30 arc-second terrain resolution has an elevation point approximately every 3,000 feet.) Consequently, since the average terrain is lower, this will result in an antenna that appears to be higher than it really is. So, the FCC method, particularly when used with the low resolution 30 arc-second terrain elevation database, can often over predict both coverage and interference distances. This may not be a bad thing, since the method's over predictions will better protect stations from interference which is the Commission's main goal. [4]

The **point-to-point** (PTP) propagation method. In the 1998 Biennial Regulatory Review (Streamlining of Radio Technical Rules in MM Docket No. 98-93, 98-117) the Commission proposed the PTP method. Authored by Harry Wong of the FCC's Office and Engineering Technology, this method provided for an analysis of the entire path between the transmitter and receiver. It based its process on radio diffraction and attenuation to the free space path

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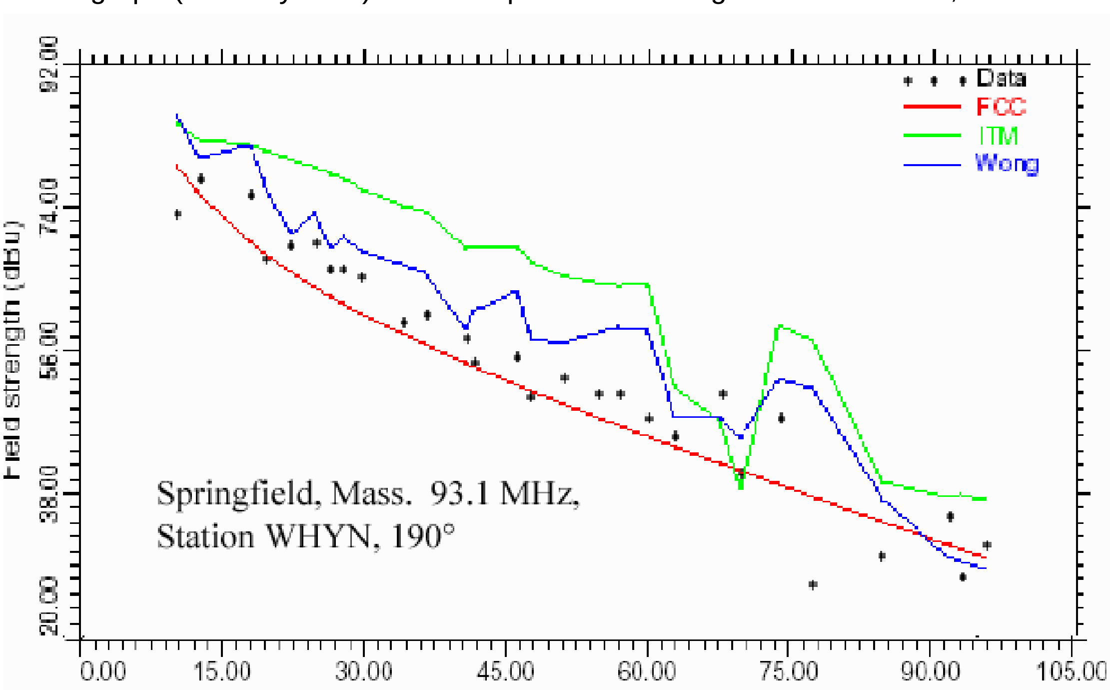
[2] Field strength curves for AM frequencies are available from the FCC's web site http://www.fcc.gov/mb/audio/73184/index.html

[3] See Section 73.182 (k) of the Commission's rules.

[4] The FCC method can also under predict over certain paths where the base of an antenna is located on a hill or mountain that enters into the 3-16 kilometer average elevation calculation. See graph , next page.

caused by irregular terrain entering the Fresnel zone. According to Wong, major determinants of this method include, “(1.) the amount by which the direct ray clears terrain prominences or is blocked by them, (2) the position of terrain prominences 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.” The original code for the PTP method used the 30 arc-second terrain elevation database and applied a static 5 dB of attenuation at points along the path to represent urban clutter. The Commission chose not to adopt this method but reported that it planned to do more work on the model, modifying it to use 3 arc-second terrain and to provide for more flexible clutter calculations.[5] Mr. Wong updated his method in an abstract available from the FCC, dated November 1, 2002.[6] Here he reports that “Comparison with actual propagation measurements, and with the results of other prediction procedures, demonstrates that path loss values calculated by the PTP model are relative accurate; and moreover the accuracy of the PTP model is as good or better than that achieved by alternative prediction procedures.” A copy of the FORTRAN code developed for this method is available at the OET web site. (http://www.fcc.gov/oet/fm/ptp/)

The graph (courtesy FCC) contrasts predictions using the FCC method, PTP and ITM



Longley-Rice Model

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[5] Second Report and Order : The 1998 Biennial Regulatory Review - Streamlining of Radio Technical Rules in MM Docket No. 98-93, 98-117. Parts 73 and 74 of the Commission’s Rules

[6] Field Prediction in Irregular Terrain – The PTP Model, Harry Wong, FCC OET, November 1, 2002: FCC URL: http://www.fcc.gov/oet/fm/ptp/report.pdf

This propagation model is more commonly used to project coverage and interference relationships than the PTP method. In the mid-sixties, the National Bureau of Standards published Technical Note 101. P. L. Rice, A. G. Longley, A. Norton and A. P. Barsis authored this two-volume propagation treatise in the course of their work at the Institute for telecommunications Sciences and Aeronomy at Boulder, Colorado. The concepts expressed in these documents were incorporated into a series of computer routines that came to be known as the "Longley-Rice Model". This model has been employed by the Commission to determine the DTV allocation scheme. It has now become a standard alternative prediction method. Going well beyond the FCC curves, the Longley-Rice method considers atmospheric absorption including absorption by water vapor and Oxygen, loss due to sky-noise temperature and attenuation caused by rain and clouds. It considers terrain roughness, knife-edge, (with and without ground-reflections), loss due to isolated obstacles, diffraction, forward scatter and long-term power fading. The following are the input parameters required of the user.

Frequency (20 - 20,000 MHz)

Transmitter antenna parameters:

Transmitter antenna height (above mean sea level - meters.)

Transmitter antenna height (above ground - meters.)

Transmitter power

Transmitter antenna pattern.

Receiver antenna height (above ground - meters)

System antenna polarization (vertical or horizontal)

System Ground Conductivity (mhoS/m)

- .001 = Poor Ground
- .005 = Average ground
- .020 = Good ground
- 5.000 = Sea water
- .010 = Fresh Water

System dielectric constant (Permittivity)

- 4.0 = Poor ground
- 15.0 = Average ground
- 25.0 = Good ground
- 81.0 = Sea and fresh water

System minimum monthly mean surface refractivity (Adjusted to sea level.)

- 200 to 450 (available from refractivity map, 301 N-units is default.)

Climate Code:

- 1 = Equatorial
- 2 = Continental sub-tropical
- 3 = Maritime Subtropical
- 4 = Desert
- 5 = Continental temperate (default for U.S. continent)
- 6 = Maritime temperate
- 7 = Maritime temperate overseas

Probability Factors:

- Qt = (Time variability) The percentage of time the actual path loss is equal or less than the predicted path loss (Standard broadcast coverage = 50%)
- Ql = (Location Variability) The percentage of paths (all with similar characteristics) whose actual path loss is less than or equal to the predicted path loss. (Used with area mode only.)
- Qc = (Prediction Confidence or "Quality") The percentage of the measured data values the model is based on that are within the predicted path loss. (Standard broadcast = 50%, DTV = 90%.)

Longley-Rice Computer Implementation

Since Longley-Rice evaluates the terrain along the entire path between the transmitter and receiver a computer is essential to keep up will the high number of calculations required. The current Longley-Rice computer program used by the FCC is version 1.2.2.[7] In practice, Longley Rice calculations are often used to evaluate signal strength within grid points. The grid point spacing can be usually be set by the user. For display purposes, the signal strength value calculated for each grid point can then be coded either by color or by a black and white line patterns. This procedure produces identifiable pools of coverage at certain signal values which makes it easy for a reader to understand how geography and terrain interact to affect signals. Further, population centroids with the grid points can be interrogated to produce population totals and other demographics within each selected signal value.

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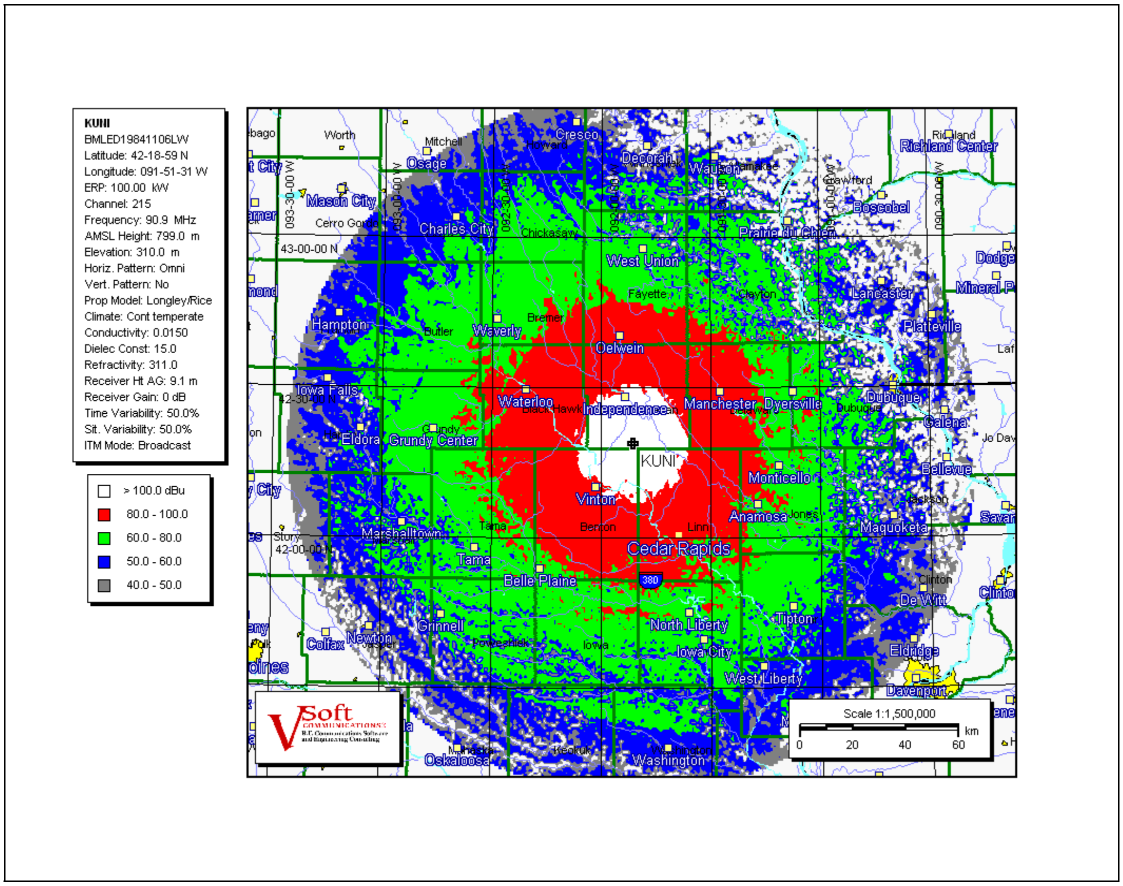
[7] Computer code for the Longley-Rice implementation can be found in an appendix of Report 82-100, A Guide to the use of the I.T.S. Irregular Terrain Model in the Area Prediction Mode, G.A. Hufford, A.G. Longley, and W.A. Kissack, U.S. Dept. of Commerce, April 1982. A complete description of this model with downloadable FORTRAN computer code can be found at: http://flattop.its.bldrdoc.gov/itm.html.



Longley-Rice Coverage Map

OET 69

The FCC's Office of Engineering Technology's bulletin #69 provides detailed information on using Longley-Rice to determine digital television coverage and interference.[8] The bulletin is divided into three parts, coverage or service calculation, interference calculations and use of Longley-Rice in the methodology. The Commission used OET 69 to analyze the service contours of existing analog TV stations in its allocation proceedings that resulted in the assignment of a second DTV channel having comparable coverage. Analog coverage was calculated within the grade B service area using the following contour levels as modified by the dipole factor: 20 Log(615/channel mid-frequency in MHz.)

Table 1

Field Strengths Defining the Area Subject to Calculation for Analog Stations

Channels	Defining Field Strength, dBu, to be predicted using F(50, 50) curves
2 - 6	47
7 - 13	56
14 - 69	64 - 20 log[615/(channel mid-frequency in MHz)]

[8] Updated Feb 6, 2004: available at: http://www.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet69/oet69.pdf

The Commission was able to approximately replicate analog coverage with digital coverage for the majority of the existing television stations. The table below defines the signal value at the noise limited DTV coverage:

Table 2

Field Strengths Defining the Area subject to Calculation for DTV Stations

Channels	Defining Field Strength, dBu, to be predicted for 50% of locations, 90% of time
2 - 6	28
7 - 13	36
14 - 69	41 - 20 log[615/(channel mid-frequency in MHz)]

DTV coverage calculations were based on the DTV planning factors:

Table 3

Planning Factors for DTV Reception

Planning Factor	Symbol	Low VHF	High VHF	UHF
Geometric mean frequency (MHz)	F	69	194	615
Dipole factor (dBm-dBu)	K_d	-111.8	-120.8	-130.8
Dipole factor adjustment	K_a	none	none	see text
Thermal noise (dBm)	N_t	-106.2	-106.2	-106.2
Antenna Gain (dBd)	G	4	6	10
Downlead line loss (dB)	L	1	2	4
System noise figure (dB)	N_s	10	10	7
Required Carrier to Noise ratio (dB)	C/N	15	15	15

The planning factors are those assumed for home DTV receiving equipment including antenna systems. The values from table 3 are calculated from the equation: C/N = Field + Kd + Ka + G – L – N1 – Ns.

Interference calculations:

The calculated service area is divided into square cells (typically 2 km on a side) and the Longley-Rice point-to-point propagation model is applied to a point in each cell to determine whether the predicted field strength is above the “threshold for reception” which is the value shown in Table 1 or Table 2. If the observed signal is above the threshold, the 10 % interfering signal strength of the undesired stations are calculated at each point. For co-channel and adjacent channel relationships, if the D/U relationship does not meet the minimum expressed in Table 4, below, the point is said to have interference. If the interference is masked at the point by another station's interference the interference is not counted. Tables for analog I.F. taboo protections and front-to-back antenna pattern discrimination are also found in the bulletin. Once the area of interference is determined, the population within the interference area is calculated using 1990 U.S. census population centroids.[9]

OET 69 Longley-Rice implementation:

The Commission has implemented the somewhat complex OET 69 method using FORTRAN code on its Sun Microsystem Enterprise 3500 and UltraSPARC computers. The FORTRAN code currently used by the Media Bureau is available for downloading on the FCC's OET web site. The Commission warns that "The individual installing it should have computer programming skills and experience as a system administrator on the system on which it is being installed because linking the data files, which occupy, 1.6 gigabytes of disk space will be a site-specific task." What the Commission leaves unsaid is that to accurately replicate the program's answers requires an identical computer CPU. Because of rounding differences that occur in the processors, implementations on other systems, whether using FORTRAN or a substitute …

Interference Criteria for Co- and Adjacent Channels[1]

Channel Offset	D/U Ratio, dB			
	Analog into Analog	DTV into Analog	Analog into DTV	DTV into DTV
-1 (lower adjacent)	-3	-14	-48	-28
0 (co-channel)	+28	+34	+2	+15
+1 (upper adjacent)	-13	-17	-49	-26

Table 4

program language, do not deliver the required accuracy.

The Commission's rules allow a DTV station to cause up to 2% interference to the population of a given station as long as this interference does not cause the station to have more than 10% interference from all stations in total. LPTV stations can cause up to 0.5% to other LPTV stations, TV translators and full

[9] The 2000 census continues to be used because it was the basis for original service area calculations used by stations in receiving their channel assignments, power and antenna heights.

service TV stations. DTV channel assignments that did not fully replicate the analog TV service area population are to be considered at their 10% maximums.

Individual Location Longley-Rice (ILLR) model:

In 1999 Congress enacted the Satellite Home Viewer Improvement Act (SHVIA.) This legislation instructed the Commission to "…developed and prescribe by rule a point-to-point predictive model for reliably and presumptively determining the ability of individual locations to receive signals in accordance to the signal intensity standard in effect under 119(d) (10) A of Title 17 (United States Code)."[10] Section 339 (c) (3) of the Communications Act provides that "[i]n prescribing such model, the Commission shall rely on the Individual Location Longley-Rice [ILLR] model set forth by the Federal Communications Commission in Docket 98-201 and ensure that such model takes into consideration terrain, building structures, and other land cover variations." ILLR is used to determine whether a given viewer is within the qualifying signal strength of a local TV station. The presence of terrain impediments, man-made structures and foliage in the radio path tends to reduce the strength of received signals. If the test determines that the viewer is not able to adequately receive a local station the viewer is allowed to receive by satellite a more distant station having the same network. [11]

The ILLR method uses Longley-Rice analysis in the individual point-to-point mode and then augments the results by considering land use and land cover (LULC) clutter losses. [12]

TIREM

TIREM stands for Terrain Integrated Rough Earth Model. The model is licensed by Alion Science and Technology Corporation, Annapolis, Maryland. This model started with a Tech Note 101 base but has been modified over the years to make up for believed inaccuracies in the Longley-Rice model.

TIREM predicts median propagation loss from 1 MHz to 40 GHz. The techniques used to calculate these losses include:

- Free-space spreading

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[10] 47 U.S.C. Sec. 339 (c) (3)

[11] The ILLR Computer Program, OET Bulletin #72, Office of Engineering Technology, July 2, 2002, Federal Communications Commission. FCC URL: http://www.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet72/oet72.pdf

[12] The United States Geological Survey (USGS) maintains a database on land use and land cover, often called the LULC database. URL: http://edc.usgs.gov/products/landcover/lulc.html

- Reflection
- Diffraction
- Surface-wave
- Tropospheric-scatter
- Atmospheric absorption

As opposed to Longley-Rice, TIREM has built-in routines for evaluating radio paths over sea water. TIREM is used in numerous modeling and simulation (M&S) tools at the Department of Defense.

Since the TIREM is a proprietary model it is not possible to tell exactly what its code is doing, which makes the model less attractive to the FCC and other users.

Influence of Terrain: While there are propagation models that calculate in the area mode, the computer models used for broadcasting depend on their links to digital terrain elevation database. The accuracy and resolution of these databases is important to prediction accuracy. The digital terrain elevation databases discussed below are not meant to be exclusive with regard to propagation analysis systems. There are others in use; however the ones we list below are the most popular implementations.

3 arc-second and 30 arc-second U.S.G.S. databases in use today have the least accuracy of available databases. The 30 arc-second database was derived from the original 3 arc-second U.S.G.S. data base which was digitized from 1:250,000 scale maps. Since each second of latitude approximates 100 feet, the 30 arc-second terrain elevation database will have an elevation point every 3,000 feet. The 3 arc- second database will have a point every 300 feet. Both databases are said to have a number of errors in them such as mountain peaks being off as much as 15 seconds.

In 2004 the USGS released the **National Elevation Datum** (NED) data set.[13] They announced that this dataset had been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous US and 1:63,360-scale DEM data for Alaska. The dataset provides seamless coverage of the United States including Hawaii, Alaska, Puerto Rico and the Caribbean islands. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). The horizontal datum is NAD83, except for Alaska, which is NAD27. The vertical datum is NAVD88, except for Alaska, which is NAVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10m) data covers the US, then this will also be a seamless dataset.

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[13] Additional information on the NED database can be found at: URL http://ned.usgs.gov/

The newest database to be released is from the **Shuttle Radar Topography Mission** (SRTM).[14] In this mission NASA obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of the Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA).

SRTM elevation data is available for the entire populated world. While the database has unparalleled accuracy because, among other things, it contains buildings in its scans, there are some holes in the data caused by cloud cover at the time of the data capture. Therefore, the use of this database requires interpolation of the measured points around some of the holes or a fall back to an existing database of lesser resolution at the few places where the holes were found to be large.

Population databases: All professional propagation software today has an associated population database. The database in common use is the U.S. Census Bureau's Summary File 1 (SF1).[15] This database contains 286 detailed tables focusing on age, race, sex, households, families, and housing units.

SF1 presents data for the United States, the 50 states, and the District of Columbia in a hierarchical sequence down to the block level for many tabulations, but only to the census tract level for others. Typically, each block contains an associated latitude and longitude called a centroid. The usual method of counting these centroids is that if a given signal contour includes the centroid the point is counted. The centroid is not counted if it is outside the signal contour, even though the population block may contain people on each side.

Propagation Prediction Programs: With the advent of the personal computer there are now a number of excellent commercial programs available that predict broadcast propagation and perform allocation studies. These programs seamlessly integrate geographic mapping with digital terrain and population databases. While price may be a significant obstacle for some, others will find these programs valuable, if not essential, in the support of broadcast radio and television coverage analysis. Not all programs are the same in user convenience, accuracy and presentation, so it pays to shop around and take advantage of demonstrations such companies offer. The programs with the best price may not offer the best features, map clarity or the accuracy you need. V-Soft Communications invites you to review its award

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[14] See URL: http://www2.jpl.nasa.gov/srtm/
[15] See URL: http://www.census.gov/Press-Release/www/2001/sumfile1.html

winning coverage and allocation mapping products found at WWW.V-Soft.com.

On-Line Services:

On line services offer the user the opportunity to use propagation or allocation systems on the pay as you go method. If cost is a concern, running studies on a cost basis may be an answer. However one should be advised that, if numerous studies are to be run, on-line studies may end up costing more in the long run, particularly if the studies need to be repeated due to input errors. In general, the on-line systems available today do not offer the higher resolution mapping available in off-line professional level propagation prediction PC programs.