Your DTV Assignment – Does it Provide Optimum Coverage?

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ABSTRACT

A method for evaluating allocation conditions for DTV stations has been specified by the FCC in its Rules and in OET Bulletin No. 69. This method has been used to make initial DTV allocations for TV stations in the U.S. While stations are free to propose alternative allocations, rote application of this method may lead to unacceptable interference and to design of a facility having less than optimum coverage. By judicious application of the allocation criteria, opportunities may exist for improved DTV facilities.

The FCC allocation method for DTV stations is reviewed, providing detailed explanations of concepts such as replication directional antenna pattern, replication power level, assumed receive antenna, and DTV coverage. Some of the various assumptions made by the FCC in its allocation software are identified, as well as the inherent limitations of the specified method. Supplemental analysis methods are identified that can be used to design stations having optimum coverage, while still meeting the allocation criteria.

INTRODUCTION

Last year, the FCC culminated its ten-year investigation into advanced television and its impact upon the existing (NTSC) broadcast service with the adoption of a Table of Allotments for digital television (DTV) and rules for modifying that table.[1] Following release of the 5th and 6th Report and Order (R&O) documents, some 231 petitions were filed requesting reconsideration of various aspects of the Commission's decisions, as well as a number of oppositions to those petitions. Significantly, based upon the Commission's adoption of a spurious emission "mask,"[2] the Advanced Television Test Center (ATTC) revised its recommended DTV protection requirements for adjacent channel DTV operations.[3] Despite the presence of the pending petitions, the FCC issued a number of construction permits for DTV stations. With the February 1998 issuance of a Memorandum Opinion and Order, which changed some 71 of the entries in the original DTV Table, it appears that a few of the early applicants will have to apply to amend their DTV construction permits to conform to the revised table.

The actual coverage, both noise- and interference-limited, of a DTV station, and indeed the actual field performance of the Grand Alliance DTV system itself, is largely unproved. However, by focusing on coverage optimization at the allocation and design stages, one can maximize the probability of satisfactory DTV coverage. Examination of the methods used to produce the Table of DTV Allotments is a useful starting point for determining whether optimum coverage will be achieved.

DEFINITIONS

Use of the complex method described below for DTV coverage and interference analysis leads to several new terms-of-art that will appear in this paper and which one may encounter in general discussions about DTV coverage and allocation. These include:

DTV Threshold Coverage. An equivalent field strength that provides a "just usable" DTV signal most of the time. For UHF Channel 39, that value is 40.8 decibels above 1 microvolt per meter at the best 50% of locations 90% of the time, *i.e.*, an F(50,90) value of 40.8 dBu. The threshold field strength varies by channel. While analog systems, such as NTSC television, are evaluated by fidelity criteria, such as signal-to-noise ratio and TASO grade, digital systems are evaluated by probability of error, which is commonly expressed in terms of bit error rate (BER). A BER threshold value of 3 x 10^{-6} determines whether the DTV signal is usable or not. This BER threshold has been determined experimentally to exist at an equivalent carrier-to-noise ratio of 15.2 dB, which can be used to infer an equivalent field strength value, occurring statistically at a certain percentage of receive sites and a certain percentage of the time, with certain assumptions about the receiving system.

DTV Replication Pattern. The transmitting antenna azimuth pattern, calculated by the FCC on a radial basis, that causes the F(50,90) DTV coverage contour to match the F(50,50) Grade B coverage contour. Because of the non-linear relationships between these contours (particularly when the DTV channel allocation is in a different frequency band from the associated NTSC channel), the replication pattern may have a different shape from the associated NTSC antenna azimuth pattern.

Replication Power Level. The maximum effective radiated power (ERP) level assigned by the FCC to a DTV allotment. Because of the DTV replication pattern, described above, most DTV assignments assume the use of a directional antenna. The DTV replication power level is the maximum permitted in the direction of maximum radiation.

Assumed Receive Antenna. For purposes of coverage and interference calculation, use was assumed of a directional receiving antenna having specified gain and radiation pattern characteristics. Different gains and front-to-back (F/B) ratios were assumed for the NTSC and DTV antennas.

FCC ANALYSIS METHOD

A new Section of the FCC Rules, §73.623(c), references both Appendix B of the 6th R&O and Office of Engineering and Technology (OET) Bulletin No. 69 as sources for the procedure required to evaluate proposed modifications to allotted DTV facilities. However, neither source provides adequately thorough guidance for conducting interference evaluations involving the newly-allotted DTV channels, with regard to potential interference to and from existing authorized NTSC facilities, and other allotted DTV facilities. In fact, many details are contained only in the actual computer code and input files used by the FCC and could therefore be subject to substantial change with just a few keystrokes.

The Commission's program utilized a complex set of analysis tools to generate the Table, that may be briefly described as follows:

For any given NTSC or DTV station to be studied, the FCC analysis model first determines the location of the conventional F(50,50) Grade B contour of the NTSC station, or of the NTSC station associated with an assigned DTV station, using antenna azimuth pattern information contained in the FCC engineering database and an assumed antenna elevation pattern. The model treats that contour as an envelope, outside of which no protection from interference is implied or afforded. The location of the Grade B contour is also used to determine the assigned power for the DTV station, once again using the F(50,50) curves to produce single-valued (but sometimes discontinuous) contours and then working backward to determine the power necessary on a radial basis to generate the associated F(50,90) DTV coverage contour for the assigned DTV channel (40.8 dBu for UHF adjusted by a dipole factor, 35.8 dBu for high-VHF Channels 7–13, and 27.8 dBu for low-VHF Channels 2–6). The maximum power determined using this method was assigned as the DTV operating power, provided it was calculated to be above established minimum power levels; otherwise, a minimum power level (50 kilowatts for UHF channels, 3.2 kW for high-VHF channels, and 1.0 kW for low-VHF channels) was assigned. Note that the use of this method usually creates a directional antenna pattern, *even for DTV assignments to NTSC TV stations that are presently omnidirectional.* The FCC requires that a DTV facility employ an antenna design that "fits" within the calculated pattern, or that a nondirectional antenna be employed that does not exceed the Grade B envelope in any direction, unless it can be demonstrated that no new interference is created.

In addition to the use of the Grade B envelope and an assumed directional transmitting antenna for all DTV facilities, the model assumes the use of directional receiving antennas at each studied location, or "cell." The characteristics of the receiving antennas are different not only for the low VHF, high VHF, and UHF frequency bands, but also for NTSC and DTV reception, where, based on the FCC model, more directive antennas are assumed to be used to receive DTV signals.

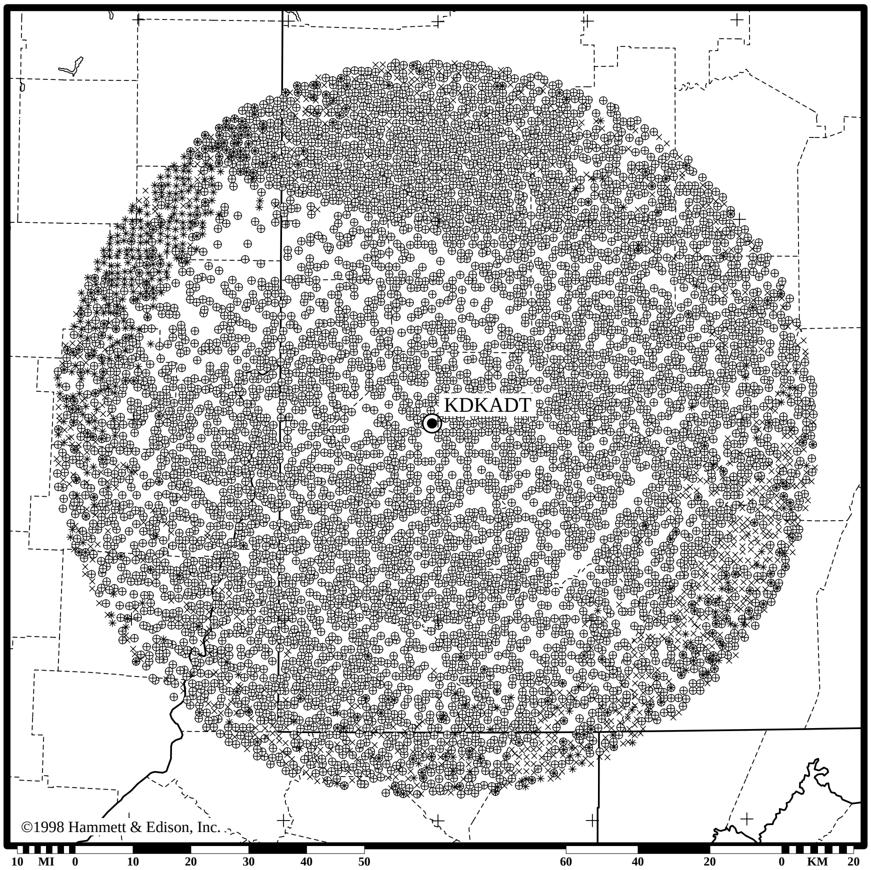

Figure 1. As discussed in the text, the Longley-Rice propagation loss prediction algorithm cannot always calculate (within certain confidence limits) a field strength level at each cell. As an example, the DTV coverage area of KDKA-DT contains many cells where the program reported results that were "dubious or unusable." For purposes of its replication calculations, the FCC always assumed interference-free coverage in such situations.

The FCC analysis technique employs terrain-sensitive calculation methods based on Version 1.2.2 of the ITS Irregular Terrain Model, also known as the Longley-Rice model. For each NTSC or DTV station to be studied, a grid of cells, each two kilometers on a side, fills the associated Grade B contour. The program first determines which of the cells is predicted to receive service from the associated station, using Longley-Rice with F(50,50) statistical weighting for NTSC stations and F(50,90) statistical weighting for DTV stations. Cells determined to have no service are not studied for interference from other stations. Once cells having service are determined, the software analyzes potential interference from other NTSC or DTV stations, again using the Longley-Rice propagation algorithm and F(50,10) statistical weighting for all potential interfering signals. Each cell is evaluated using the desired-to-undesired ratios presented in FCC Rules §73.623 for each channel relationship, and cells determined to have interference are flagged and summed with the study results of other cells, resulting in the generation of total interference area figures and tabulations of total population contained within the summed cells.

LIMITATIONS OF THE FCC METHOD

Experience gained by using the FCC analysis program has led to the identification of several factors that are, at least, unusual, and do raise significant concerns about the validity of some of the assumptions made.

"Interference-Free" Areas

The interference analysis technique employed by the FCC and specified for study of proposed DTV facility changes employs terrain-sensitive calculation methods based on the Longley-Rice model. The model is used to analyze paths between the transmitter and assumed receiver locations that are contained within a grid of square cells that fill the entire protected service area. However, the Longley-Rice model is not always capable of determining, within certain confidence limits, whether a particular cell has service.[4] Specifically, in cases where the actual horizon from a given receive cell or transmitter location is less than 0.1 times or greater than 3 times the distance to the smooth earth horizon, the Longley-Rice algorithm will return an "Error Marker 3." According to the program documentation, this means that internal program calculations show parameters out of range, and any reported results are dubious or

			Longley-Rice Errors (*as % of Grade B*)			
Market		Example Station	Area, sq. km		Population (1990)	
#2	Los Angeles, CA	KABC(N07/D53)	9,002	*26.8%*	768,975	*5.3%*
#5	San Francisco, CA	KDTV(N14/D51)	6,134	*32.5%*	990,688	*15.8%*
#6	Boston, MA	WGBH(N02/D19)	6,697	*27.1%*	1,373,952	*19.7%*
#12	Seattle, WA	KTZZ(N22/D25)	7,360	*37.3%*	385,679	*13.0%*
#17	Phoenix, AZ	KPHO(N05/D17)	7,862	*16.5%*	40,830	*1.8%*
#18	Denver, CO	KCNC(N04/D35)	9,211	*22.0%*	204,553	*7.8%*
#19	Pittsburgh, PA	KDKA(N02/D25)	17,074	*50.5%*	2,041,954	*52.3%*
#24	Portland, OR	KOPB(N10/D27)	13,739	*35.8%*	121,680	*5.8%*
#29	Raleigh, NC	WLFL(N22/D57)	3,964	*12.6%*	239,358	*11.3%*

Table 1. There are many markets where terrain causes significant Longley-Rice errors. This table lists markets where the assumption of interference-free service contributed greatly to the apparent close replication of NTSC service area and population listed in the Table of Allotments.

unusable. Incredibly, the procedure used by the FCC when such a Longley-Rice error occurs, whether during determination of potential service or potential interference, is to assume that cell is enjoying “interference-free service.”

While this assumption appears not to introduce significant overall errors in areas of relatively flat terrain, it has been found that the error code is returned much more often for studies involving mountainous or even hilly terrain. For example, Figure 1 shows predicted interference to the coverage area of the DTV Channel 25 allocation assigned to Station KDKA-TV, Pittsburgh, from various other NTSC stations, and DTV assignments. While the FCC DTV analysis returned a result of interference to about 172,000 persons, it simply ignored possible interference to nearly 2.6 million persons within the KDKA-DT coverage area, considering all of that area to be “interference-free” coverage due to Longley-Rice errors.

This problem is not restricted to a few markets. Table 1 summarizes for a number of top markets the tremendous arbitrary designation of service occurring due to Longley-Rice errors. It is obvious that there are situations within the top 30 markets where Longley-Rice errors are the only justification for classifying over half of the area or over half of the population with “interference-free” service.

Receive Antenna Models Assumed

The DTV analysis program assumed that the consumer antennas used for reception of the DTV signals would be better-performing than the ones used for reception of the NTSC signals, despite the fact that both operations are on the same general frequencies and that no one, in fact, had suggested that consumers would be at all inclined to replace their existing antennas or to install second, larger antennas just for DTV. The off-axis rejections (front-to-back ratios) of the DTV antennas are also higher, as shown in Table 2.

However, such antennas would not necessarily be purchased and installed by consumers viewing the DTV stations off-air. In fact, a more reasonable assumption might be that they will *not.* Therefore, DTV service will be more interference-limited than assumed and replication of NTSC service will not, in practice, be achieved.

Receive Antenna Characteristic	Low VHF	High VHF	UHF (all)
NTSC Gain	0 dBd	0 dBd	0 dBd
DTV Gain	4	6	10
DTV-NTSC Difference	4	6	10
NTSC Front-to-back ratio	6 dB	6 dB	6 dB
DTV Front-to-back ratio	10	12	14
DTV-NTSC Difference	4	6	8

Table 2. In calculating coverage and interference, different receiving antennas were assumed for NTSC and DTV service.

Establishment of Grade B Contour

Several simplifying calculations were made that

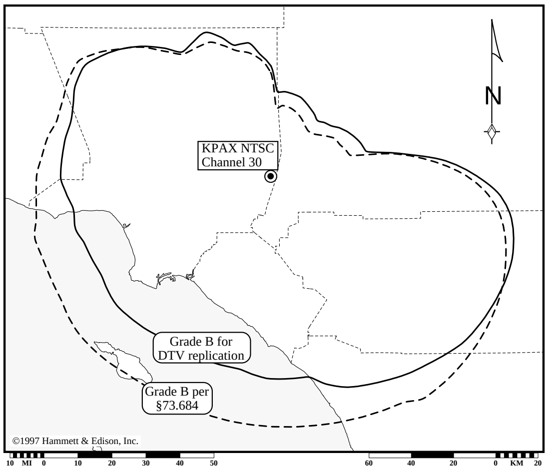

Figure 2. Because the Grade B contour was not calculated in accordance with FCC Rules in developing the Table of DTV Allotments, the allotted DTV power level and directional pattern often do not replicate the true Grade B coverage. This is demonstrated by the actual and replication Grade B contours calculated for a station in the Los Angeles market.

are not consistent with the definition of the Grade B coverage contour contained in the FCC Rules, including:

Elevation Plane Pattern. The method by which the FCC projected NTSC Grade B contours for the DTV allotment project does not comply with Rule §73.684, which defines prediction of coverage for NTSC facilities. First, the requirements of §73.684(c)(2) were not followed, such that full radiation is to be assumed whenever the radiation toward the radio horizon is at least 90% of the maximum. This would tend to understate the distance to the Grade B contour. Of course, without the actual elevation plane pattern employed by the station, the determination of radiation toward the radio horizon would be expected to be in error. Even though a standard elevation plan radiation pattern was used, it may not be appropriate for high-gain antennas, for which it would overstate the radiation, and certainly would not be appropriate when electrical beam tilt and/or mechanical tilt is employed, for which the error could be in either direction.

Azimuth Plane Pattern. Second, the horizontal plane azimuth pattern, as taken from the FCC database, was employed with an assumed standard elevation radiation pattern, to generate a protected NTSC Grade B contours for an associated DTV facility. However, the database contains only the projection of the actual azimuth pattern onto the horizontal plane and so may significantly understate the radiation in particular directions if mechanical tilt is employed.

HAAT. Third, the FCC program did not truncate, as required by §73.684(d), radials used to determine height above average terrain (HAAT) when they extended over large bodies of water or over foreign territory.

For example, Figure 2 shows the projection of the Grade B contour for TV Station KPAX, NTSC Channel 30, San Bernardino, California, in accordance with the FCC Rules (dashed line) and as determined by the FCC's DTV replication program (solid line). The obvious errors represent the cumulative effect of two of the three problems identified above and have a significant affect on the station's DTV replication power and pattern.

Scaling of Replication Pattern

The FCC replication program used a procedure that derived the Grade B contour for an existing NTSC station, and then redefined that contour as the limit of protected service for the DTV facility. Using the appropriate F(50,90) curves, the DTV power necessary to reach the NTSC Grade B contour location was determined radially. When the maximum calculated power was found to be above the maximum power allowed for a given channel, the pattern was scaled to that maximum. However, the scaling process will necessarily reduce the directional replication pattern to power levels *below* that maximum for all other azimuths, even though the replication power at those azimuths may not have exceeded the maximum power. Therefore, by scaling the pattern instead of truncating it at the maximum power level, the DTV station is further limited from replicating its Grade B coverage.

Some Protected Areas Not Studied

The FCC replication program studied for interference protection only those stations within certain distances, which are specified in OET-69. Many of the distances specified are often not sufficient to allow the entire Grade B area of a station to be studied. This effect can result in truncation of a station's Grade B contour, and also in areas of further interference within the Grade B contour that have not even been checked, leading to further exaggeration of the degree of replication.

DTV FACILITY OPTIMIZATION

The 6th R&O encourages DTV stations to "maximize" their facilities,[5] with coverage up to that of the largest station within each market, such that no significant new interference is caused to other stations. Fundamental to the prediction (or optimization) of coverage is knowledge of the effective sensitivity of the receiving system. As previously mentioned, only scant data is available concerning the field performance of the DTV system, so it is prudent to make conservative choices when estimating coverage and interference performance.

Definition of Coverage

Whereas the coverage of NTSC television stations is often described in terms of three types of service (City Grade, Grade A, and Grade B), which are related to the quality of the assumed receiving installation and picture fidelity, the FCC has provided only one definition of coverage for DTV: the threshold. The well-known "cliff effect," whereby a small reduction in received signal strength causes a perfect DTV picture to become abruptly unusable, suggests that an adequate margin is necessary to ensure that a usable DTV picture will exist over the long term. Implicit in the FCC's definition of DTV coverage is that the specified field strength would be available at least 90% of the time. Obviously, households receiving no picture 10% of the time will not be dedicated viewers of your station.

Improvement of the long-term reliability of the signal can be ensured by adding an additional fade margin factor to the threshold coverage signal level. Additional fade margin factors can be derived by assuming that the fading ratios tend to follow log-normal distributions.[6] For example, a DTV station assigned to a UHF channel might apply an additional factor of 3–9 dB to increase the time variability factor from 90% to 99%.

Similarly, if one believes that some viewers may use back-of-set antennas for DTV reception, the assumed receive antenna gain might be reduced by 10 dB (at UHF). Additionally, building penetration losses might be expected in the range 6–12 dB.[7] Accounting for just these three factors, one might increase the required field strength by 19–31 dB above the threshold value. So, DTV coverage should be optimized not at the threshold value (around 41 dBu at UHF), but 20–40 dB above it (around 60–80 dBu at UHF).

Antenna Pattern Selection

In order to maximize the potential audience of a DTV station, knowledge of the population distribution in the region surrounding the transmitter site is required. One method of visualizing the population distribution is to utilize the U.S. Census data, calculating the azimuth and depression angles from the transmitting antenna to each Census Block. An example of this technique is shown in Figure 3. This type of analysis suggests an appropriate elevation pattern, including appropriate values of electrical and mechanical beam tilt.

The specification of optimum elevation-plane radiation characteristics (including beam tilts) is especially critical for stations allotted facilities of less than 1,000 kilowatts at UHF, but desiring to increase to the maximum value. The FCC recognizes the use of beam tilting techniques for improving coverage through increased main-beam ERP within a market, while limiting interference outside of that market.

Other Propagation Models

Because of the inherent limitations of Longley-Rice, as discussed above, it is prudent to explore other propagation prediction models when evaluating methods to optimize coverage. Proprietary, commercial, and public-domain analysis software has been developed that employs all of the analysis features described above, as well as several other more subtle elements employed in the FCC allotment program. Such programs can provide a graphical element that allows the identification of all interference cells on a map with an associated tabulation, and generates a DTV antenna pattern envelope that shows areas that can be maximized without creating interference in any cells that were not already receiving interference. Such programs can be used to test implementation scenarios that involve changes to antenna height, antenna pattern, channel number, and transmitter location. Additionally, such programs can determine

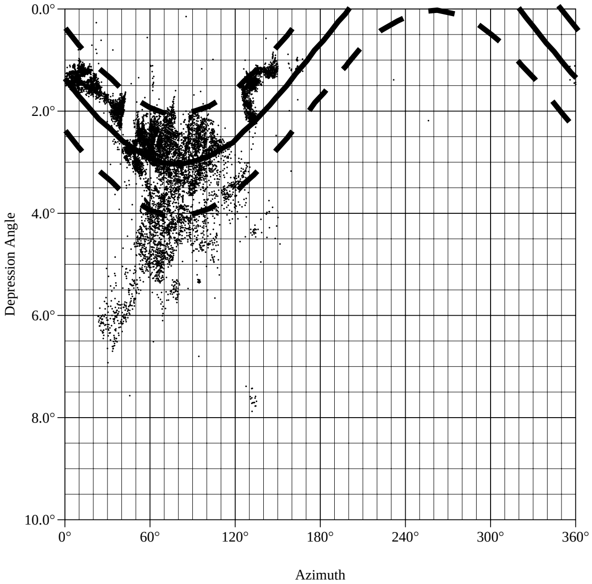

Figure 3. Each dot represents a U.S. Census Block (*i.e.,* one or more potential viewers). The depression angle from the transmitting antenna to each Census Block was calculated as a function of azimuth. The main beam elevation pattern of a hypothetical antenna is shown as the solid black line, with the half-power points shown as dashed lines. In this case (Farnsworth Peak, near Salt Lake City), use of both electrical beam tilt (1°) and mechanical tilt (2° toward 80°T) seems appropriate for optimum coverage. Population at depression angles exceeding 4° (*i.e.,* close to the transmitter site) would be treated with null fill.

coverage areas of DTV and NTSC stations, with interference cells omitted (*i.e.*, noise-limited coverage) at almost arbitrarily fine resolution, rather than the relatively coarse 2-kilometer square cells used in an FCC-style analysis.

CONCLUSION

In developing its Table of Allotments, the FCC made a number of simplifying assumptions, which are entirely appropriate for allotment and allocation use. One should not, however, rely upon such methods for facility design or optimization, since inherent in many of those assumptions are factors that can reduce coverage, exacerbate interference, or both. Proper facility design requires an understanding both of the procedures used to establish the DTV allotments and of their limitations. Design of optimum DTV transmitting facilities should take advantage of opportunities existing within the regulatory framework, while realizing that the regulatory procedures are intended as spectrum management tools rather than station design procedures.

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1 FCC, Fifth and Sixth Reports and Orders, MM Docket 87-268, both adopted April 3, 1997, amended by the Memorandum Opinion and Order on Reconsideration of the Sixth Report and Order, adopted February 17, 1998.

2 Section 73.622(h) specifies attenuation in dB of $46 + (\Delta f^2)/1.44$ out to 6 MHz from the channel edge, with 71 dB being required at all frequencies beyond 6 MHz. Δf is the frequency difference in MHz from the edge of the channel.

3 ATTC Document #97-04, "An Evaluation of the FCC RF Mask for the Protection of DTV Signals for Adjacent Channel DTV Interference," July 16, 1997.

4 This is one of the reasons that H&E uses TIREM (Terrain-Integrated Rough Earth Model), a more sophisticated propagation loss algorithm of which the Longley-Rice routine is only a part. See "Coverage Prediction for Advanced Television," Proceedings of the 1994 NAB Engineering Conference for further information.

5 6th R&O, at ¶31.

6 Harry Fine, The Normal Distribution as Applied to VHF Broadcast Service Problems, FCC T.I.D. Report No. 4.2.2 (Washington, DC: FCC, 1949).

7 Macario, "How Building Penetration Loss Varies with Frequency," IEEE Vehicular Technology Society News, Vol. 40, No. 4 (1993), p. 26.