A Report to

The Metropolitan Television Alliance

Regarding

Urban DTV Planning Factors
For Distributed Transmission Systems

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MTVA DTV RECEPTION PLANNING FACTORS REPORT

INTRODUCTION

The Metropolitan Television Alliance (**MTVA**) has undertaken a project to deploy a small-scale implementation of a Distributed Transmission System (DTS) for Digital Television (DTV) in the New York City metropolitan area in either the UHF or high-VHF bands (low-VHF is not of any interest to the **MTVA** since no full-service post-transition DTV channels have been allocated in New York City). This project will enable **MTVA** to determine the practicality and feasibility for subsequent deployment of a large-scale DTS system in New York City prior to the February 2009 cessation of analog television transmissions. As part of this project, **MTVA** conducted a detailed study and assessment of the RF performance of current consumer indoor antennas and DTV receivers likely to be utilized by consumers for DTV reception in this area. **While *both* outdoor and indoor reception of DTV signals is vital and covered in this report, this project is specifically focused on *indoor* reception in the UHF and high-VHF television bands from multiple, synchronized DTS sources in a dense, urban environment such as New York City.** The results of the laboratory receiver tests and indoor consumer antennas will allow **MTVA** to develop appropriate *planning factors* to be used in predicting both indoor and outdoor DTV coverage and service analysis of the New York DTS system.

MTVA has retained the firm of Meintel, Sgrignoli, & Wallace (**MSW**) to provide consulting services for this and other related projects. The primary goal of this project is to use the data from the previous **MTVA** indoor antenna and receiver laboratory test reports along with many other laboratory and field test results from past publications to create a *preliminary* set of outdoor and indoor planning factors that can be used for coverage and service prediction for a DTS located in highly-urbanized areas such as New York City. It is expected that data from the upcoming New York DTS field test in the summer of 2007 might provide information that will help “fine tune” these initial *urban* planning factors.

This detailed report is broken down into two major sections:

> **Section I** contains *background information* regarding the history and development of FCC channel allocation methodology and the theory behind basic television coverage and service prediction in order to support the development of specific urban planning factor parameters.
>
> **Section II** contains the *specific analysis* for the outdoor and indoor urban DTS planning factors, the proposed preliminary parameter values, and justification for their selection.

SECTION I: BACKGROUND INFORMATION

TELEVISION CHANNEL ALLOCATION HISTORY

In November 1995, the Advisory Committee on Advanced Television Services (ACATS) created by the Federal Communications Commission (FCC) recommended the ATSC digital television (DTV) Standard (**Ref 1**) for the United States. This standard, which includes the 8-VSB *digital* transmission system was codified into the FCC rules in 1996 (**Ref 2**), and DTV service has been provided in the U.S. since late 1998. Prior to the beginning of this new DTV service, the FCC had to develop a means to properly allocate an *extra* 6 MHz television channel during the DTV transition to every eligible analog station. This meant essentially doubling the amount of television signals to be transmitted since analog NTSC signals would remain on the air along with the new DTV signals until the end of the digital transition. To perform this allocation process, the FCC and the broadcast industry performed a tremendous amount of work (theoretical, lab, and field work) during the development of the ATSC system to document the *system's performance* as well to develop computer *prediction models* for DTV coverage, service, and interference.

At the beginning of any discussion regarding allocation and propagation, the terms ***coverage*** and ***service*** must be properly defined and differentiated. **Coverage** simply refers to field strength availability in a given geographical area while **service** refers to the provision of "acceptable" television pictures and sound in that same area. Any misunderstanding or uncertainty regarding the basic meaning of these two words can be a source of massive confusion when discussing NTSC or DTV systems.

The FCC performed detailed analysis and spectrum planning using computer prediction models during the first round of channel allocations just prior to the beginning of the DTV transition in order to provide DTV stations a second RF channel. This allocation process was repeated again near the end of the transition for the broadcasters' final post-transition DTV channels, this time with the broadcasters making their channel election and the FCC verifying their selections. All of the post-transition DTV channels were required to be within the FCC's "core spectrum" (CH 2 – CH 51). Likewise, this same type of prediction analysis is still used by the FCC for full-service application processing for facility changes as well as Low Power Television (LPTV) waivers and digital applications. Similar methodology is also currently used in the Satellite Home Viewer Act (SHVERA) for determining distant network satellite delivery allowance (**Ref 3, Ref 4**). However, to date, the FCC has only considered 30' above ground level (AGL) *outdoor* DTV reception planning factors in their channel allocations, with no consideration of *indoor* reception. There are still no FCC indoor planning factors in existence, which has also been the case for the entire history of analog NTSC since the 1940s (i.e., no indoor planning factors were ever developed for NTSC).

Planning factors are important in the *prediction* of DTV field strength coverage as well as in the prediction of acceptable DTV television service. Certain factors and assumptions must be made for the broadcaster's transmission site implementation (**Ref 5**), such as antenna location, antenna height above average terrain (HAAT), absolute antenna gain, relative antenna azimuth and elevation patterns, and *average* effective radiated power (ERP). A similar process must be employed at the receive site. While there are an infinite number of variables to consider when modeling the entire electromagnetic propagation path from the transmitter to the receiver, some *assumptions* must be made regarding the propagation path, a "typical" DTV receive site, and DTV receiver RF performance.

Field strength prediction has been performed since the 1950s using the FCC *statistical* curves first developed in 1951 (**Ref 6**) then adopted by the FCC in 1952 (**Ref 7**), and then updated curves were developed by a consortium of broadcast industry members in the late 1950s and early 1960s (**Ref 8**). Statistical field strength prediction curves are necessary as RF signals will vary with both time (T) and location (L) as the RF signal propagates from the transmitter to the receiver over varied terrain and in varied meteorological and seasonal conditions. However, modern day technology allows for better field strength prediction using computer algorithms and models such as TIREM and Longley-Rice. Nevertheless, it helps to understand the history of how the FCC curves came about, on what basis they were created, and how they relate to the current, modern-day computer prediction methods.

ORIGINAL FCC SERVICE CONTOURS AND STATISTICAL PREDICTION CURVES

Before describing the process of field strength prediction for DTV stations, it is helpful to briefly review the process used for NTSC coverage and service prediction in order to build a foundation of knowledge so that subsequent comparisons to DTV can be made. Even though NTSC is made up to three narrowband carriers while DTV is a broadband, noise-like signal, they are both transmitted as analog RF signals in the VHF and UHF bands and experience the same propagation effects on their path from the transmitter to the receiver. The differences between these two systems lie in how the analog and digital *receivers* respond to their respective signals that have been subjected to various propagation effects.

From the early days of NTSC, the FCC Rules and Regulations (**Ref 2**) governed broadcasters and the signals that they transmitted over the public airwaves. Many NTSC broadcast requirements are listed in these rules, including the requirements for meeting the familiar Grade A and Grade B iso-service contours in the region that the stations serve. Both Grade A and Grade B contours are important not only for marketing and promotional efforts (population covered) and cable television regulations (retransmission), but also for the government requirements that require stations who freely use the *public* airwaves to provide acceptable signals to their viewers (**Ref 5**). In addition to the two required Grade A and Grade B field strength contours, the FCC rules also specified a "minimum field intensity" for *city-grade* coverage to the principle community that is 6 dB greater than that required at the Grade A contour (**Ref 5**).

It has always been understood that these contour values are just "rough estimates" for coverage, and facilitate both administrative and promotional aspects. However, while these particular service contours have been in existence and contained within the FCC Rules for many decades, the rules do *not* provide any tutorial material that defines them clearly nor do they provide any information regarding their significance or their original development. In other words, there is not really any information in the rules on the meaning of these contours (**Ref 5**). However, the basic data that was used to *derive* the contours can found in the original background information which led to the establishment of the NTSC broadcast service. The primary document with this information is the FCC's "Third Report" adopted on March 21, 1951 (**Ref 6)**. From this report and other information, the FCC issued a 6th Report and Order in 1952 (**Ref 7**) which included not only the Grade A and Grade B field strength contours but also the FCC statistical field strength prediction curves (**Ref 8**) that were ultimately determined in the late 1950s to be inaccurate. It is very likely that most broadcast engineers don't even know that this reference information exists or, if they do, where to find it. Therefore, many broadcast engineers probably are unaware of these original assumptions and the basis for the statistical propagation prediction curves. It is apparent that this type of tutorial information must come from industry sources (**Ref 5**).

It is important to define and understand the meaning of the FCC *statistical* field strength curves. Using the known heights of the transmit and receive antennas, and the effective radiated power, a field strength value can be theoretically calculated using free-space, line-of-sight formulas, the plane earth equation, or the smooth spherical earth equation. However, it is well known that both VHF and UHF field strengths vary with *time* and with *location.* This variation depends on various factors, such as signal frequency, antenna height, and the distance from the transmitter that the signal must propagate (**Ref 5**). This variability in field strength can be represented by *statistical* curves that are identified by the term **F(L, T)**, where L and T are the location and time percentages, respectively, that will have a given field strength value F that is *exceeded* at L% of the locations at least during T% of the time. While engineers would love to be able to say that they can theoretically predict these variations at any given moment in time, they can not. Even predictions of long term statistical averages can *not* be accomplished accurately with theoretical methods due to the large number of variables that must be used in any sophisticated computer model. In the 21st century, with very powerful computers and algorithms, research engineers have made much progress in this area. Nevertheless, it is still a struggle to accurately predict field strength coverage even with today's technology. It was even more of a problem back in the early days of NTSC when slide rules were the norm rather than calculators and personal computers.

Therefore, much *empirical* data was gathered and analyzed from many field tests to predict field strength for *average* terrain (i.e., gently rolling countryside) that exists between a transmitter antenna (at a given height above the average terrain and with a give n effective radiated power) and a receive antenna (at 30' AGL, the average antenna height installation for homes in the 1950s). If the actual terrain between the transmitter and receiver is much different from *average*, then the rules indicate that true coverage may vary greatly from estimates obtained from the FCC propagation curves. Likewise, the empirical data also allows the development of time-fading factors (ΔT) and location variability factors (ΔL) that could be used to help better predict signal strength conditions (**Ref 5**).

The time-fading factor ΔT represents the difference *in dB* between the median field strength, the field strength exceeded 50% of the time, and the field strength exceeded for some other percentage of the time (**Ref 5**). Time fading can occur diurnally (day-to-night) as well as seasonally. By comparing values between the F(50, 50) and the F(50, 90) curves, one can estimate statistically how much lower a signal level is expected to be so that it is exceeded for 90% of the time rather than at a higher signal level for 50% of the time.

The location variability factor ΔL represents the difference *in dB* between the median field, the field exceeded at 50% of the locations, and the field exceeded for some other percentage of the locations. With the very short wavelengths of VHF and especially UHF signals, field strengths can vary several dB over a relatively short distance of a few yards (**Ref 5**). This variation is a function of signal frequency and terrain, with more variability with higher frequencies and rougher terrain. This variability can be approximated by a Gaussian distribution (sometimes referred to as a normal distribution, which has the familiar bell-shaped probability curve).

If the basic F(50, 50) prediction field strength curves (i.e., *median* location and time values) are being used from the FCC rules (Figures 9 and 10 in **Section 73.699**), and it is desired to describe a service that would exist for at least 90% of the time and at least 70% of the locations, then the F(50, 50) field strength value would have to be altered by ΔT (in dB) and ΔL (in dB). Of course, some mechanism must exist to provide the values of ΔT and ΔL that are statistically correct, and these correction values do exist (**Ref 5**).

The definitions for Grade A and Grade B contours for NTSC service were not always well understood in the industry. The following definitions should serve to explain these contours (**Ref 5**):

> *"Grade A represents a specific value of ambient median field strength existing 30 feet above ground which is deemed to be sufficiently strong, in the absence of interference from other stations, but with due consideration given to man-made noise typical of urban areas, to provide a picture which the median observer would classify as of "acceptable" quality, assuming a receiving installation (antenna, transmission line, and receiver) considered to be typical of suburban or not too distant areas. This signal level is sufficiently strong to provide such a picture at least 90 percent of the time at the best 70 percent of receiving locations. The Grade A contour represents the outer geographic limits within which the median field strength equals or exceeds the Grade A value."*

> *"Grade B represents a specific value of ambient median field strength existing 30 feet above ground which is deemed to be sufficiently strong, in the absence of man-made noise or interference from other stations, to provide a picture which the median observer would classify as of "acceptable" quality, assuming a receiving installation (antenna, transmission line, and receiver) considered to be typical of outlying or near-fringe areas. This signal level is sufficiently strong to provide such a picture at least 90 percent of the time at the best 50 percent of receiving locations. The Grade B contour represents the outer geographic limits within which the median field strength equals or exceeds the Grade B value."*

The FCC selected specific field strength values (in dBµV/m) for these two contours, as shown in **Table 1**, along with values for a third field strength contour called "city grade" (which is defined as 6 dB above Grade A). Note that the FCC decided to use one value for *each* of the three television bands, selecting the geometric mean frequency of that band. This was for the convenience of broadcast engineers in the 1950s and 1960s that did not enjoy the benefits of electronic calculators and personal computers. The FCC rules do *not* explain the background of how the contour field strength values were selected, but this background will be covered in this report.

Table 1 FCC field strength values for NTSC Grade A and Grade B contours

Television Frequency Band	Channel (#) Frequency (MHz)	Geometric Mean Frequency (MHz)	City Grade Field Strength (dBµV/m)	Grade A Field Strength (dBµV/m)	Grade B Field Strength (dBµV/m)
Low VHF	CH 2-6 (54 – 88)	69	74	68	47
High VHF	CH 7 -13 (174 – 217)	194	77	71	56
UHF	CH 14 – 69* (470 – 806)	615	80	74	64

* Originally, the upper end of the UHF band was CH 83, but was changed to CH 69 in 1974.

Note that the FCC re-allocated channels 70 – 83 for land mobile use in 1974 (see FCC Docket 18262) and also re-allocated channels 14 – 20 in some cities for shared use with land mobile in 1974 (see FCC Docket 18261).

Some comments can be made about the two service contour definitions described above as well as some of the assumptions that are inherent in each.

1) These contours refer to a specific *median* field strength value, described in terms of dBµV/m (i.e., dB above 1 µV/m) that is required to be present at least 90% of the time at a 30' AGL receive antenna situated at either 70% of the *best* locations (Grade A) or 50% of the best locations (Grade B) in a given area. Note that these definitions introduce the concept of time and location variability. Also notice the use of the word "best" to describe the location variability (**Ref 5**).

2) Note that the time variability is defined as 90%, even though broadcast engineers were instructed to use the FCC's F(50, 50) curves. This has caused some confusion over the years since there were no F(50, 90) curves in existence at that time, although they could be calculated from both the F(50,50) and the subsequently-generated F(50, 10) curves. The actual Grade A and Grade B contour field strength values that were selected by the FCC had time and

location correction values applied to them to get to the 90% statistical values. Likewise, the 70% location variability needed for Grade A contour values had a location correction applied to it. Therefore, the engineers back in the early days could then use the F(50, 50) curves to calculate the solution to either the required ERP, HAAT, or distance from the transmitter (**Ref 5**).

3) Both field strength contours are defined by a long-term *median* ambient value of field strength, meaning that actual field strengths can (and do) vary above and below this value, sometimes by a significant amount. These variations can be statistically described by an acceptable percentage of time above the median value and an acceptable percentage of locations in the local area that have field strengths above the required median value.

4) These contours are defined as required field strengths in the *absence of interfering signals from other stations*. When interference signals exist, the required signal strength for the desired NTSC signal does produce an acceptable picture. In the early days of television, interference calculations were not part of the FCC calculations, but rather transmitter spacing (i.e., separation distance) determined acceptable interference conditions and were used in channel allocations.

5) These contour field strengths were determined with the consideration of a so-called "typical" receive site configuration made up of a passive outdoor antenna, downlead cable feedline loss, and receiver noise figure. These parameters were necessary since it is the level of the signal at the terminals of the television set that will determine if acceptable service is available (e.g., how far the received signal at the TV input is above the tuner's noise floor).

6) The definition of "acceptable picture" is not defined in the FCC rules, so certain *assumptions* were made. In viewing a picture on an analog television set (which can be considered the "window to the RF world"), there is a *subjective* nature based on the level of the viewer's critical nature as well as the psycho-visual aspect of the viewer. The assumption is typically made that an average (i.e., median) viewer is watching the television signals, and that a minimum signal-to-noise (SNR) of 30 dB (in a 4 MHz video bandwidth) is achieved on the television set. The actual definition that was most widely accepted was that from the Television Allocation Study Organization (TASO) report that was developed in the late 1950s: "the picture is of .acceptable quality with no objectionable interference", and was referred to as a "TASO Grade 3 picture". However, slightly less nebulous definitions were subsequently developed using CCIR *subjective* impairment scales.

7) City grade contours are *not* really defined in the FCC rules other than the fact that the signal strength must be 6 dB greater than that required for Grade A contours. No time or location variability is stated, but the assumption is that a higher percentage of time and locations would be expected with the application of even poorer receiving antennas and increased man-made noise.

Grade A and Grade B contour depictions were required to be filed with the FCC by each television station for construction permits (CP). These contours were calculated in accordance with a specific procedure described in **Section 73.684**. With the help of a topographic map, the transmitter's antenna center of radiation height above average terrain (HAAT) was calculated for 8 equally-spaced azimuths directions from the transmitter (or sometimes 9, to make sure the principal community of service was included) over a distance of 2 to 10 miles. Using the FCC's statistical field strength charts together with the transmit antenna HAAT and the effective radiated power (ERP), predicted field strength values could be determined at any distance from the transmitter by using the FCC statistical curves in **Section 73.699** of the FCC rules.

Both the FCC F(50, 50) and F(50, 10) statistical field strength prediction curves were ultimately updated to improve their accuracy, as will be described later in this report.

PLANNING FACTOR DEFINITIONS

In order to determine what NTSC field strength values were required for Grade A and Grade B contours at the input to the receive antenna, some assumptions in the early days of television had to be made about a "typical" receive system configuration. Of course, the same process had to be performed for DTV allocations as well during its development in the 1990s. The process of determining the required field strength values is described below.

The ultimate television system performance that is achieved is determined by the signal level at the receiver input terminals, not just the field strength at the antenna input. However, the channel allocation planning factors call for electromagnetic *field strengths* at the input to receive antennas at 30' AGL. Therefore, a conversion is needed between antenna input field strength and receiver input signal level. This conversion factor is dependent on the antenna characteristics, the cable feedline loss, and the receiver performance.

Fortunately, there is a very simple relationship that relates antenna input field strength and antenna output voltage that has been used for many years. This relationship is based on the principle of "effective length" of an antenna that "collects" the electro-magnetic waves from the air and develops a voltage at its output. For convenience, a reference half-wave dipole antenna (i.e., an antenna whose effective length is one-half of the signal's wavelength) is used. The simple formula (**Ref 5**) that relates this phenomenon is:

$$V'_{ANT}(V) = E\,(V/m) * \lambda(m) \;/\; \pi \qquad (1)$$

where V'_{ANT} (V) is the *open circuit* voltage at the antenna output when a signal with a wavelength and field strength of E is present at its input. However, a more important condition is when the antenna is properly loaded with its characteristic impedance so that maximum energy is transfer from the antenna to the load. A half-wave dipole antenna has an impedance of about 73.5 Ohms, which is approximately equal to the commonly used 75 Ohm coaxial cable impedance. When a dipole antenna is terminated in its matched load (source and load impedances are complex conjugates of each other), its open-circuit voltage is decreased to one-half (1/2). Therefore, a new defining equation (**Ref 5**) for the conversion from field strength to voltage can be written for a properly terminated antenna:

$$V_{ANT}(V) = E\,(V/m) * \lambda(m) \;/\; (2 * \pi) = E\,(V/m) * c(m/s) \;/\; [2 * \pi * F(Hz)] \qquad (2)$$

where

V_{ANT} = dipole antenna output signal voltage (in volts) when terminated in a matched impedance.

E = electric field strength (in V/m) at the load.

λ = signal carrier wavelength (in m) of the NTSC picture carrier.

c = the speed of light ($3x10^8$ m/s) in a vacuum.

F = signal carrier frequency (in Hz), which for NTSC is the picture carrier at 1.25 MHz above the lower bandedge.

From **Equation (2)**, it is clear that for a constant field strength value, the antenna output voltage decreases with increasing frequency. This means that UHF channels require more field strength than VHF channels in order to achieve the same antenna output signal level. This is called the "dipole effect" and simply explains why the FCC allows much more radiated power for UHF channels than for VHF channels.

Equation (2) can be written in a factored form that uses a constant scaling factor (for a *given* channel) for the antenna field-strength-to-voltage conversion process.

$$V_{ANT}(V) = K'_{VE}(m) * E(V/m) \qquad (3)$$

where K'_{VE} is the *linear* dipole scaling factor, although this scaling factor is a *not* a true ratio but rather has the dimension of length (in meters). However, this scaling factor K'_{VE} facilitates antenna output voltage calculations (**Ref 5**) since it is a constant for a given frequency, and is defined as:

$$K'_{VE} = c(m/s) \;/\; [2 * \pi * F(Hz)] \qquad (4)$$

A convenient method of working with antenna field-strength-to-voltage conversions is to express all the variables in *logarithmic* terms, just as is commonly done for signal power within circuits. For field strength, the logarithmic variable dBμ/m, which is the field strength reference to 1 μV, is defined as:

$$E(dB\mu V/m) = 20 * LOG\,[\,E\,(V/m) / (1\,\mu V)\,] \qquad (5)$$

Note that the constant in front of the logarithmic function is 20 rather than 10 since field strength is a *voltage* variable and <u>not</u> a power variable, and the more common *reference* level of 1 μV is used instead of 1 V.

The dipole conversion factor described in **Equation (4)** is easily applied in practice. For instance, **Equation (3)**, which is just the product of two variables, can be converted into a simple *algebraic* logarithmic equation by taking the log of both sides of the equation and applying the identity: log(ab) = log a + log(b). Therefore, it follows that:

$$V_{ANT}\,(dB\mu V) = E(dB\mu V/m) + K_{VE}(dB\mu V\text{-}dB\mu V/m) \qquad (6)$$

where the logarithmic dipole scaling factor K_{VE} is defined as:

$$K_{VE}\,(dB\mu V/m - dB\mu V) = 20 * LOG\,[\,K'_{VE}\,] = 20 * LOG\,[\,c(m/s) / (2 * \pi * F(Hz)\,] \qquad (7)$$

The logarithmic dipole factor described in **Equation (7)** is another convenient way to convert field strength to voltage in a reference half-wave dipole antenna, except this time in logarithmic terms. To put the frequency-dependent dipole factor into better perspective, when considering the geometric mean frequency for each television band, UHF channel field strength values would have to be 19 dB greater than those of a low-band VHF channel to produce the same signal voltage at the receive antenna output.

However, it is preferred to describe RF signal levels in *power* terms rather than *voltage* terms, particularly since power is the easier variable to measure. To convert voltage to power is a simple task. Of course, the circuit impedance (e.g., 50 Ohms or 75 Ohms) must be known as that will affect the voltage-to-power conversion factor. For the more common *consumer* receive site application, 75 Ohms will be used here. Using the well-known definition for signal power,

$$S_{ANT}\text{ (Watts)} = [V^2_{ANT}] / R = [K'_{VE}(m) * E(V/m)]^2 / R \quad (8)$$

where R is the impedance of the load. However, the *fixed*-value voltage-to-power conversion factor K_{PV} can then be written logarithmically as:

$$K_{PV}\text{ (dBm-dB}\mu\text{V)} = 10*LOG[(1\ \mu V)^2 / (75\ \Omega*1\ mW)] = 10*LOG[(1\ \mu V)^2 / (0.075*\ \Omega\text{-W})] = -108.8 \quad (9)$$

Note that for a given circuit impedance, the voltage-to-power conversion factor is constant with frequency unlike the field-strength-to-voltage dipole conversion factor.

By combining **Equation (7)** and **Equation (9)** into one conversion factor K_D, the output signal *power* S_{ANT} for a simple half-wave dipole can be written as:

$$S_{ANT}\text{ (dBm)} = E(\text{dB}\mu\text{V/m}) + K_{VE}(\text{dB}\mu\text{V-dBuV/m}) + K_{PV}\text{ (dBm-dB}\mu\text{V)} \quad (10)$$

$$S_{ANT}\text{ (dBm)} = E(\text{dB}\mu\text{V/m}) + K_D(\text{dBm- dB}\mu\text{V/m}) \quad (11)$$

where

$$K_D(\text{dBm- dB}\mu\text{V/m}) = K_{VE}(\text{dB}\mu\text{V-dBuV/m}) + K_{PV}\text{ (dBm-dB}\mu\text{V)} = K_{VE}(\text{dB}\mu\text{V-dB}\mu\text{V/m}) - 108.8 \quad (12)$$

As an example, the value of the dipole factor K_D at CH 38 (615 MHz) is -130.8 dBm-dBuV/m. If the antenna has gain (referenced to the simple half-wave dipole, in dBd), then the signal power is increased by that same amount. That is,

$$S_{ANT}\text{ (dBm)} = E(\text{dB}\mu\text{V/m}) + K_D(\text{dBm- dB}\mu\text{V/m}) + G_{ANT}(\text{dBd}) \quad (13)$$

Obviously, if the antenna is a half-wave dipole, it has a gain of 0 dBd (i.e., when referenced to itself, it has a gain of 1).

To complete the receive site planning factor equations, the effects of antenna gain referenced to a half-wave dipole (G_{ANT}), coaxial feedline loss (L), receiver noise floor (N_{FLOOR}) which is related to noise figure (NF), and minimum required signal-to-noise ratio (SNR) for acceptable reception must all be taken into consideration.

However, these are just algebraic terms when all the parameters are available as their *logarithmic* values. The input signal power to the receiver can be written as:

$$S_{IN}\text{ (dBm)} = S_{ANT}\text{ (dBm)} - L(\text{dB}) \quad (14)$$

$$S_{IN}\text{ (dBm)} = E(\text{dBuV/m}) + K_D(\text{dBm- dB}\mu\text{V/m}) + G_{ANT} - L(\text{dB}) \quad (15)$$

In order to find the required field strength for a given minimum input signal power, the minimum receiver input signal level must be determined. This is determined by knowing the receiver noise floor (N_{FLOOR}), which can be written as:

$$N_{FLOOR} = N_T + NF = kTB + NF = -106.2\text{ dBm/6 MHz} + NF \quad (16)$$

where N_T is the thermal noise floor, NF is the receiver's noise figure, k = Boltzman's constant (1.37×10^{-21} joules/°K), T is usually selected to be room temperature (290 °K), and B is the bandwidth (6 MHz for U.S. television channels). This primary noise source under consideration in this analysis is flat-spectrum, white Gaussian noise (sometimes referred to as Johnson noise) that is internal to the receiver's tuner. It is made up of two sources. The first source of noise (kTB) is due to the thermal agitation of electrons in any resistive device that is at a temperature above 0° K and is terminated in its matched impedance. The second source of noise is the additional noise that an active device adds to the source, and is represented by its noise figure (NF). In reality, there may be other *external* non-white noise sources for consideration, such as man-made noise, "sky noise", ignition noise, appliance motor noise, etc., particularly at lower frequencies such as the VHF band (**Ref 5**).

However, for this simple analysis, thermal noise is considered, with other noise sources considered later in this report. One justification for this is that the most important contour for analog television is Grade B and for digital television it is the noise-limited contour. Both of these define the useful outer coverage and service areas, and are typically in rural areas away from large urban areas where man-made noise is more pronounced, thus allowing a simple approximation (i.e., assumption) to be made. However, when one considers service throughout the entire viewing area, then external noise sources must be considered.

It should be noted that for NTSC purposes in the past, a 4 MHz channel bandwidth was utilized, which is approximately what the video bandwidth of the analog television signal occupies in the United States. However, in recent years during the DTV transition, when digital ATSC signals were allocated spectrum with analog NTSC signals, the channel bandwidth was considered to be 6 MHz for both signals, particularly when dealing with SNR values.

The minimum required input signal power (S_{IN}) can be determined by adding to the noise floor the minimum signal-to-noise ratio (SNR) for acceptable television reception. This value of SNR provides sufficient margin above the noise floor to ensure that the quality of the television signal is acceptable. That is,

$$S_{IN} = N_{FLOOR} + SNR = (kTB + NF) + SNR \quad (17)$$

$$S_{IN} = (-106.2 \text{ dBm/6 MHz} + NF) + SNR \quad (18)$$

In analog television, the original FCC assumptions for these planning factors are not in the rules. Rather, one must hunt supporting documents, usually in FCC Report and Orders (R&O), or in their Notice of proposed Rulemakings (NPRM), or even supporting FCC engineering reports. In the case of analog NTSC, the planning factors that were used to ultimately determine the Grade A and Grade B field strength values were created prior to 1952, and then included in the 1952 6th report and Order (**Ref 7**). It is believed that an SNR value of 30 dB was selected that would provide an acceptable video signal. While this determination is completely subjective for analog signals, this value is roughly comparable to a Grade 3 (passable) picture for a median non-expert viewer as determined in the subsequent TASO studies (**Ref 5**).

The final step is to solve for the field strength by inserting **Equation (17) into Equation (15)** and solving for the field strength:

$$E(\text{dBuV/m}) = kTB(\text{dBm}) + NF(\text{dB}) + SNR(\text{dB}) + L(\text{dB}) - K_D(\text{dBm- dB}\mu\text{V/m}) - G_{ANT} \quad (19)$$

This equation is valid for both analog NTSC and digital ATSC. The only differences are the choice of antenna gain, line loss, receiver noise figure, and minimum SNR *values* that are used in the respective FCC planning factors. For example, if the following UHF DTV planning factors are inserted into **Equation (19)**, i.e., an antenna gain of 10 dBd, a noise figure of 7 dB, a line loss of 4 dB, and a minimum SNR of 15 dB, the expected 40.8 dBµV/m field strength value is the result.

Note that the above equations for receive site planning factors do *not* take into account any baluns, couplers, or splitters, nor does it account for any mismatch loss between the antenna output impedance and the receiver input impedance (**Ref 5**). However, any losses from these items can be lumped into the line loss variable L.

If the location and time variability factors need to be added, then **Equation (19**) can be altered as follows:

$$E(\text{dBuV/m}) = kTB(\text{dBm}) + NF(\text{dB}) + SNR(\text{dB}) + L(\text{dB}) - K_D(\text{dBm- dB}\mu\text{V/m}) - G_{ANT} + \Delta T + \Delta L \quad (20)$$

Note that if the time ΔT and location ΔL variability percentages are higher than 50%, then these values will be *negative* since *lower* field strength values are required to meet the more stringent demands of higher time and location percentages of occurrences.

The following tables (**Table 2** and **Table 3**) illustrate the *original* FCC NTSC planning factors that were incorporated in the rules in 1952. These planning factors have not changed in over 50 years, and will likely remain throughout the end of the analog era when NTSC goes “dark” in February 2009. While some observers over the years have disagreed with the selection of some of the planning factor values, they nevertheless produced reasonable channel allocations. However, new planning factors were created for DTV in the late 1990s, and they are described in the section on OET-69 (Longley-Rice Methodology).

Table 2 Original and existing Grade A planning factors.

Planning Factor Parameter	Sign	Low-VHF (CH 2 - 6)	High-VHF (CH 7 – 13)	UHF (CH 14 – 69)
N_T (dBm/4 MHz)	+	-108.0	-108.0	-108.0
NF (dB)	+	12	12	15
SNR (dB)	+	30	30	30
K_D (dBm-dBμV/m)	-	-111.8	-120.8	-130.8
G_{ANT}	-	0	0	8
L (dB)	+	1	2	5
ΔT	+	3	3	3
ΔL	+	4	4	6
N_{EXT}	+	14	7	0
E (dBμV/m)	=	68	71	74

Table 3 Original and existing NTSC Grade B planning factors.

Planning Factor Parameter	Sign	Low-VHF (CH 2 - 6)	High-VHF (CH 7 – 13)	UHF (CH 14 – 69)
N_T (dBm/4 MHz)	+	-108.0	-108.0	-108.0
NF (dB)	+	12	12	15
SNR (dB)	+	30	30	30
K_D (dBm-dBμV/m)	-	-111.8	-120.8	-130.8
G_{ANT}	-	6	6	13
L (dB)	+	1	2	5
ΔT	+	6	5	4
ΔL	+	0	0	0
N_{EXT}	+	0	0	0
E (dBμV/m)	=	47	56	64

SUBSEQUENT PROPAGATION STUDIES: TASO AND RPAC

Spectrum planning has been an important issue from not only the early days of radio and then television, but it was also crucial at the beginning of the transition to the all-digital television system. It was important to have a solid scientific and technical foundation for the spectrum planning process. In 1948, the FCC issued a “freeze” order that suspended any new or pending applications for construction of television broadcasting facilities in order to study channel allocation methods as well as television (and FV radio) service and interference predictions. This freeze came about as television spectrum in the VHF band became too crowded, and a new set of frequencies, now called the UHF band, was being considered.

As stated above, the VHF and UHF statistical field strength prediction curves that were originally in the FCC rules came from field measurements in the late 1940s and early 1950s during the freeze. These measurements and their analysis came from an FCC Ad Hoc committee whose role was to evaluate radio propagation factors concerning both television and FM radio in the frequency range of 50 to 250 MHz (**Ref 8**). Note that the radio propagation factors that were studied only covered through 250 MHz, far short of the lowest UHF frequency of 470 MHz. However, it must be understood that very few, if any, UHF transmitters existed in the late 1940s from which field measurements could be made. Therefore, the UHF curves were essentially extrapolated from these lower frequency curves. These VHF and UHF curves were then included in the FCC rules as part of the 1952 6th Report and Order (**Ref 7**) which, among other things, created the UHF television band.

However, in the mid 1950s, concern grew for the accuracy of these VHF and UHF statistical field strength curves. Therefore, in late 1956, the FCC requested that the television industry establish a study group to conduct a major study of the technical principles which should be applied in television channel allocations” (**Ref 9**). This group was called the Television

Allocations Study Organization (TASO), and remained active from 1956 to 1959. The Charter, which was approved by the FCC, went on to state that "the objectives of the organization shall be to develop full, detailed and reliable technical information and engineering principles based thereon, concerning present and potential UHF and VHF television service … TASO's functions shall be limited solely to technical study, fact finding and investigation, and interpretation of technical data" (**Ref 9**). Five organizations sponsored TASO, representing both TV broadcasters and manufacturers, and members from these organizations formed the TASO Board of Directors which made policy. They were the Association of Maximum Service Telecaster who represented primarily high-power VHF stations, the Committee for Competitive Television who represented UHF broadcasters, the Electronic Industries Association who represented manufacturers, the Joint Council on educational Television who represented those in educational television, and the National Association of Broadcasters who represented broadcasters in general. The work was funded by these five sponsors as well as other broadcasters and manufacturers, thus making it an industry-funded project, i.e., no government money (**Ref 9**).

TASO's Board of Directors decided that various groups (i.e., panels) made up of engineering representatives from all aspects of the TV industry would conduct the studies in a similar manner as the earlier NTSC groups did when the black-and-white and color standards were created (**Ref 9**). The creation of a DTV standard was also handled in a similar manner in the late 1980s and early 1990s with the Advisory Committee on Advanced Television Services (ACATS).

While the FCC had hoped for a crash course on UHF equipment development to "jump-start" this new branch of the television industry, TASO had concluded that the *existing* commercial equipment that was to be used for the television system should only be characterized to avoid breaking antitrust laws. It also decided that VHF and UHF wave propagation phenomenon for both service and interference should be described as well as the means for practically measuring, collecting, and analyzing field strength data. Another area of study was acceptable interference levels that still provided satisfactory pictures and sound. Of course, a field test plan was created and then implemented. Finally, the complete television system needed to be analyzed and evaluated (**Ref 9**).

Members of TASO decided that the engineering factors affecting television spectrum allocations could be divided into 6 categories, with each factor being studied by an individual panel (**Ref 9**):

Transmitting equipment

Receiving equipment

Field Tests

Propagation Data

Analysis and Theory

Levels of picture quality

This organization, made up of 271 engineers from 139 companies, had 6 panels, 40 committees/subcommittees/task forces, with each having chairmen and vice chairmen who, together with the executive director, coordinated the overall engineering program. It put forth a major effort in its 3-year existence, creating over 750 formal documents, with the major product being a series of detailed engineering reports covering its work, findings, and conclusions. These reports were contained in a 731-page book titled "Engineering Aspects of Television Allocations" that was completed on March 16, 1959, and distributed on June 12, 1959 (**Ref 10**). It is important to note that TASO did not undertake any equipment R&D (to avoid anti-trust laws and patent considerations) nor did it create any channel allocation plan (which was the job of the FCC), but rather it provided the underlying *theory* and *engineering principles* by which such work could be accomplished subsequent to their study (**Ref 9**). It is believed that TASO work focusing on only theory and engineering principles is the primary reason that this diverse, industry-wide group was able to come together in the first place, and be so successful.

While picture quality in both the lab and in the field (i.e., at people's homes) were also tested and analyzed by both expert and lay observers, the biggest achievement of TASO was the *standardized* collection and analysis of significant amounts of reliable VHF and UHF ***propagation data*** **(Ref 9)**. TASO was not the first group to gather propagation data in the field. However, little data had been taken in this *new* UHF television band prior to TASO, which explains the reason for the previous inaccurate field strength curves. Also, previous field strength measurements were gathered in inconsistent ways such that it was difficult to compare data from different field tests. As a matter of fact, one of the first tasks for TASO was to develop standardized field test measurement methodology, which was adhered to in *all* of the TASO field studies (**Ref 9**). Most of these procedures were later incorporated into the FCC rules (in the 1970s), and included the 30' AGL receive antenna positioning and the use of "100-foot runs" to determine *median* field strengths due to location field strength variability.

During the TASO study, simultaneous VHF and UHF field strength data was consistently obtained from 13 different cities across the entire U.S. that included eight geographical regions, from VHF and UHF transmitters that were close in physical proximity and in HAAT. While using as many different UHF frequencies as possible, based on availability of UHF transmitters, many of the TASO tests occurred in the lower half of the new UHF band. Also important is the fact that this data was taken from areas with a *wide variety of topographic and climatic conditions*. This important data provided the basis for the improved propagation curves that relate <u>median</u> field strength and distance (from the transmitter). Analysis of this data also allowed for developing means of estimating location variability with reasonable accuracy.

The prediction methodology that was developed from this study was based on ***both*** <u>theoretical</u> analysis and <u>empirical</u> studies of field strength data. That is, "the recommended curves of median field strength as a function of distance are the theoretical smooth earth curves, suing an effective radius of the earth appropriate to existing meteorological conditions, and with empirically determined correction factors of -1 dB in the low-VHF band, -4 dB in the upper VHF band, and -22 dB in the UHF band" (**Ref 9**). Besides spot measurements of VHF and UHF signals, median field strength data was taken at 30' AGL over continuous 100' runs for direct comparisons of the variations between the two frequency bands.

The TASO report that was delivered to the FCC on March 16, 1959 (**Ref 9**) was very thorough and the data was well received. However, it was only *technical* analysis that was performed at the request of the FCC, and it was up to the FCC to decide how it wanted to use this data in future spectrum allocations. As with most things in Washington DC, the process to update the FCC propagation curves moved very slowly. After this, another group called the Radio Propagation Advisory Committee (RPAC), also made up of industry, FCC, and other government agency engineers, performed work, which, along with that of TASO, significantly helped FCC engineers subsequently develop a complete set of VHF and UHF propagation curves as well as an updated field strength measurement methodology. All of this work culminated in rule-making proceedings (FCC Docket No. 16004 and FCC Docket No. 18052) that proposed the inclusion of these new propagation curves into the FCC rules (**Ref 8**, **Ref 11**).

A lot of mobile "spot" and fixed long-term *field* data had been taken during the TASO studies and earlier, and were made available to the working group. The measurements at fixed sites were made primarily by the FCC, the Central Radio Propagation Laboratories (eventually to be renamed the Institute for Telecommunications or ITS, which is part of the Department of Commerce), and the National Bureau of Standards during a period between 1943 and 1954. Many mobile surveys were made between 1955 and 1962 (**Ref 11**).

A significant amount of data analysis was required to accurately determine smooth field strength propagation curves. Subsequently, the Association of Federal Communications Consulting Engineers (AFCCE) filed a Petition for Extension on the comment period, and requested an Engineering Conference to consider the new propagation curves. This conference was held on September 16, 1965 to review the information and set up working groups from AFCCE, the industry, the FCC, and other government agencies to evaluate all the data extensively. Ultimately, this working group developed new propagation curves which incorporated a terrain roughness correction factor, and published them in a report which recommended that the FCC include the correction factor in their rules (**Ref 12**), which was then inserted into the RPAC summary report (**Ref 8**). The following information explains some of the findings of this group.

While all these *empirical* FCC field strength curves are intended to be representative of *median* values for propagation over *average* terrain in the United States, the terrain roughness correction factor allowed some modification of the propagation curves for terrain that was rougher or smoother than average (**Ref 8**). All the field data was analyzed extensively to develop this terrain roughness correction factor, and it is based on the CCIR criterion for roughness, as described by the following equation:

$$\Delta F0 = 0.03\,\Delta h\,[\,(\lambda + 1)/\lambda\,] = 0.03\,[\,1 + (f/300)\,] \qquad (21)$$

where

$\Delta F0$ is the change in field strength due to terrain variations (i.e., roughness)

λ is the wavelength in meters

f is the frequency in MHz

Δh is the CCIR terrain roughness factor that is the difference elevation (in meters) between the levels exceeded for 10% and 90% of the terrain along the radial in the range of 6 to 31 miles from the transmitter. This is best understood by viewing **Figure 1,** which describes the roughness definition and includes a plot of the equation.

Interestingly enough, the FCC later (in 1975) added the terrain roughness correction factor to the rules only to subsequently put a "stay" on it a couple years after that (May 19, 1977; see **42 FR 25736**), meaning that it is still in the rules, but is not to be used "until further notice". It is believed that this was done because there were certain common situations where the terrain roughness correction factor was very inaccurate, such as when the transmitter was sitting up on top of a large mountain and propagating in a large valley (e.g., like in Los Angeles with Mount Wilson). However, these proposed VHF and UHF field strength propagation curves actually made use of this correction factor as all the measured field data had this factor applied to it. The assumption is that a value of 50 meters for Δh represents the *average* terrain roughness in the United States (**Ref 8**). It was recommended that this correction factor only be used out to 60 miles, and only for values of Δh up to 400 meters. It is important to note that when the updated curves first came out, a reminder was included in the report:

> "The corrections for terrain roughness are intended for application in estimating median (or average) field strengths over areas where the general character of the terrain is fairly uniform, or where there is no abrupt change in terrain roughness. It is not possible to accurately predict the field strength at any given receiver site. Useful predictions are possible when medians are required in describing the distributions of field strength over areas of appreciable extent. The standard error of estimate for median values will diminish when the area under consideration is increased."

Of course, this does not take into account obstructions such as hills, trees, buildings, inclinations of the land, and weather conditions over the propagation path. This reminder also applies in the modern era for the Longley-Rice methodology of predicting field strength, and will be described later (**Ref 8**).

In this report to the FCC, propagation curves for *both* the F(50, 50) median levels and the F(50, 10) interference levels were included. Also included was the methodology for *calculation* of field strength values for F(50, 90) were described based on the *assumption* that field strength time fading generally followed a Gaussian (i.e., normal) type of distribution between the 10% and the 90% levels. The terminology refers to the amount of time that the field strength value exceeds a given level at 50% of the locations during at least either 50% of the time (F(50, 50) or 10% o the time (F(50, 10) (**Ref 8**).

These FCC propagation curves were divided into three sections:

(1) Low-VHF (and FM) from 54 to 108 MHz

(2) High-VHF band from 174 to 216 MHz

(3) UHF from 470 to 890 MHz (remember that CH 83 used to be the high end of the UHF band until the late 70s)

All the data was normalized to various antenna heights above average terrain (i.e., HAAT) as defined by the average height of the electrical center of the antenna between 2 and 10 miles from the transmitter and a 1 kW effective radiated power (ERP). Smooth coherent curves were then drawn that accounted for terrain roughness. The data for the curves within-the-horizon primarily came from the mobile data (i.e., spot measurements at many locations in different directions from the transmitter), while the data for the curves beyond-the-horizon primarily came from fixed, long-term measurement sites. These two sets of curves were then merged together near the radio horizon in a complicated process (**Ref 8**).

The FCC had been looking for improved field strength measurement methodology that would "yield substantially the same results when measurements are made under similar conditions, by independent observers and at different times" (**Ref 11**). Apparently, there was consensus in the industry that the previous methodology described in the rules (**Section 73.686**) did not allow for consistent field measurements, and that it should be changed to something like that used in the TASO studies even though the TASO methodology did not account for temporal variations (i.e., time fading). However, field measurements are not generally allowed to determine contour field strengths (e.g., Grade A and Grade B), except by FCC allowance in response to specific requests (**Ref 11**). The rules state that, generally, "all contour determinations shall be made using the propagation curves included in the rules" (**Ref 11**).

The mobile measurements, as they are described in the literature of the 1960s, were made along radials at intervals of about 2 miles, using the techniques described by TASO (**Ref 10**). At each road segment, a 100' run was conducted with the antenna extended to 30' AGL. Chart recordings were made for each of these runs for subsequent analysis of median field strengths. The FCC rules agree with this, and require that the 2-mile measurement interval is a *maximum* increment, although shorter distances may be used. If a 100' run is not possible, a cluster of 5 measurements is permitted in lieu of the 100' run (**Ref 11**). The number of measurements in a community is to be determined approximately as 3 times the square root of the population in thousands (reduced to the expression of $0.1^* (P)^{1/2}$), with a minimum of 15 measurements. All measurements are to be made within the boundaries of the community. The rules uphold the use of a 30' AGL receive antenna for official field strength measurements.

After RPAC completed their work and published their report (**Ref 8**) in September 1966, another 9 years passed as the FCC considered these changes to the FCC propagation curves. After consolidating Docket 16004 (field strength curves) and Docket 18052 (field strength measurements) in a Further Notice of Proposed Rulemaking in 1971 (**Ref 13**), the FCC finally brought to consideration the amendment of their rules in 1975 to adopt the new F(50, 50) and F(50, 10) field strength propagation curves used for predictions in the television and FM radio services as well as to specify a modified procedure for making field strength measurements(**Ref 11**). In both cases, increased accuracy of the field strength *prediction* and field strength *measurement* was cited as the reason for consideration. Despite the challenges merging together technical advances with regulatory sensitivity, as well as *not* having an absolute consensus in the industry, the FCC did act to amend parts of their rules (**Sections 73.684, 73.686, and 73.699**).

What made this decision so difficult for the FCC was that the engineering facts were intertwined with the regulatory process. This means that while the engineering facts indicated the advantage of an improved set of propagation curves as well as an improved set of field measurement procedures, existing stations had a lot of their regulatory protection (including cable carriage) and commercial advertising worth tied up in their existing definitions of Grade A and Grade B curves. Changing the propagation curves, while more accurate, would change the regulatory nature for many stations, and therefore put the FCC in a precarious predicament. In addition to this, some of the commenting parties to the NPRM had obvious agendas they wanted to promote. An interesting side note was made by the FCC in the 1975 Report and Order (**Ref 11**) regarding the FNPRM comments of Motorola, GE, and the EIA relating to their "interest in improved spectrum management, which in the context presented appears a euphemism for increased opportunities for land mobile sharing of TV channels". Land Mobile had successfully "grabbed" UHF spectrum (CH 70-83 and parts of CH 14-20) from the broadcasters the year before (1974).

PROPAGATION BACKGROUND

Before describing the Longley-Rice model generally and receive site planning factors specifically, a brief description of basic propagation effects is in order. RF propagation is a very complex subject, and beyond the scope of this report. Therefore, the following is *not* meant to be an all-encompassing description, but rather just a review of the very basic principles of electromagnetic propagation. With a very basic understanding of these principles, the various planning factors that must be considered in coverage and service prediction will become clearer, especially in various environments such as urban, suburban, and rural. It is important to note that all of these predictive propagation models are *statistical* in nature, both with respect to location and to time.

There are four types of propagation (**Ref 3**):

Free Space: signal travels in a straight line in a vacuum.

Refraction: signal bends due to transmission medium.

Reflection: signal is altered by some obstacle in the transmission path.

Diffraction: signal bends by some object in the transmission path.

As the RF signal travels from the transmitter towards a receiver, it encounters losses on the way. These losses can be due to absorption by the medium, interaction with the earth (ground, mountains, hills, water, etc.) and destructive interference with various reflected versions of itself (i.e., multipath) (**Ref 3)**.

When the signal travels in a straight line in *free space*, with no absorptive or reflective objects in the way, the field strength E (in V/M) can be expressed as:

$$E = (30\,P\;G_{ANT})^{1/2}\;/\;d \qquad (22)$$

where "P" is the power (in Watts) delivered to the antenna, "G_{ANT}" is the *linear* isotropic gain of the antenna, and "d" is the distance (in meters) of the measurement site from the antenna. In terrestrial broadcasting, the field strength E is often expressed in logarithmic terms (dBμV) relative to 1 μV/m. However, in terrestrial television broadcast, the transmission medium is *not* a vacuum and the receive site is typically *not* exactly in line-of-sight with the transmitter and with no reflecting or refracting objects in the path.

Refraction occurs when the electromagnetic signals travel through a medium other than a vacuum, such as air in the troposphere (**Ref 3**). Air is not a uniform density medium, but rather changes with elevation due to random fluctuations in the dielectric constant in the troposphere. This redirects (i.e., "bends") a small amount of the incident signal back towards the receiver, thus "bending" the radio waves. Often, this redirection is time-varying, and randomly bending the transmitted signal. Since the incident wave is bending at slightly different locations within the troposphere, multiple time-varying paths exist from transmitter to receiver, causing dynamic multipath. As tropospheric conditions change with time, these multipath signals change their delay (and thus their relative phases) and vectorially add together either constructively or destructively to cause fading. The range of time delays that the signal experience is called delay spread. This random bending essentially *scatters* the incident signal, thus the name troposcatter is also used for this phenomenon (**Ref 14**). Since the radio waves emanate from near the earth's surface and they bend back towards earth, they can extend the distance where the waves hit the earth from the *optical* (line-of-sight) horizon to a new point called the *radio* horizon (i.e., over-the-horizon). Typical propagation paths that experience refraction tend to be arcs of circles, as shown in **Figure 2** (**Ref 3**).

The distance to the optical and radio horizons can be calculated with reasonable accuracy using the smooth earth model by the following formula:

$$D = (3Kh/2)^{1/2} \quad (23)$$

where: D = distance to the optical or radio horizon in miles (depending on the value of K)

h = height in feet above the earth

K = ratio of the effective to the true radius of the earth

The average value of K in temperate climates is 1.33, but can vary between about 0.6 and 5.0. The value in K will determine the distance to the optical and radial horizons. If K=1, the distance to the optical horizon can be approximated by:

$$D_{OPTICAL} \text{ (in miles)} = 1.22*\{H \text{ (in feet)}\}^{1/2} \quad \text{(optical horizon)} \quad (24)$$

If K=4/3, the distance to he radio horizon can be approximated by:

$$D_{RADIO} \text{ (in mile)} = 1.41*\{H \text{ (in feet)}\}^{1/2} \quad \text{(radio horizon)} \quad (25)$$

Figure 2 illustrates this distance in a diagram and contains the formula derivation. **Table 4** shows the distance to the optical horizon for some common antenna heights above ground.

Table 4 Distance to Optical Horizon for various antenna heights above ground

Antenna Height (in feet)	*Optical* Horizon (in miles)
10	3.9
20	5.5
30	6.7
100	12.2
200	17.3
500	27.3
1000	38.6
1250	43.1
1500	47.3
1750	51.0
2000	54.6

Reflections can occur from objects encountered in the propagation path, such as buildings, bridges, water towers, mountains, and the ground itself. When a transmitted signal can take more than one path to reach the receive site antenna, this is called multipath, as shown in **Figure 3**. When two or more modulated RF signals are added together, they will add vectorially based on the relative carrier phases. They can add in-phase (constructively) or out-of-phase (destructively), or they can add to any phase in-between. The relative carrier phases depend on the *difference* in length (distance measured in wavelengths) among the various propagation paths. This reflection effect is a function of something called path clearance, which is also referred to as the Fresnel-zone radius (**Ref 3**).

Diffraction is the bending of electromagnetic waves by some object in the signal's path, such as the peak of a mountain or a large urban building. This allows the radio waves to deviate from a straight path and "bend" around these objects. But the bending is not without consequence, as the signal exhibits some loss from this effect. Propagation experts describe two types of diffraction based on optics theory: smooth earth and irregular earth (e.g., hills modeled as knife edge objects) (**Ref 3**).

Figure 4 illustrates in a very simplistic manner a summary of the four modes of propagation described above. However, it should provide the reader with a basic understanding of propagation that allows insight into the Longley-Rice modeling to be described below.

LONGLEY-RICE MODEL

While there are a number of sophisticated field strength prediction algorithms available to broadcast spectrum planners, two of the more common broadcast field-strength prediction tools are TIREM and Longley-Rice. The TIREM prediction model, developed for the U.S. government, provides about the same overall accuracy as Longley-Rice, but multiple software implementations exist in the industry that can confuse the issue (**Ref 3**). One of the advantages of the Longley-Rice prediction model is that a single stable and documented version has been widely used in the industry for a number of years, and still is widely used (**Ref 15**).This was one of the reasons that the FCC selected the Longley-Rice model as *part* of the channel allocation methodology for evaluation of TV service coverage and interference, and put it into their rules (**47 C.F.R,, Par 73.622 & 73.623 and Par 74.704**). The FCC rules provide a basic channel allocation methodology that uses Longley-Rice as one *part* of an overall algorithm. However, at the request of the broadcast industry for additional clarity, the FCC published OET Bulletin No. 69 to clarify the use of this algorithm (**Ref 16**). OET 69 channel allocation methodology will be described in a subsequent section of this report.

A central part of the Longley-Rice model is based on basic electromagnetic propagation theory described above (**Ref 3**). Longley-Rice methodology uses a *semi-empirical* terrain-based point-to-point radio propagation model that predicts field strengths at various locations surrounding the transmitter. The actual propagation model, which was developed in the 1960s by the Institute for Telecommunications Sciences (ITS) group that is part of the National Telecommunication Information Administration's (NTIA), has as its official name the ITS Irregular Terrain model, and is a general purpose model that covers 20 MHz to 20 GHz (**Ref 3**).

The field strength prediction model is considered *semi*-empirical because it treats propagation from line-of-sight, reflection, refraction, and diffraction in theoretical manner, and then adjusts this theoretical value to fit with the empirical (measured) field data. In practice, using the appropriate transmitter and receiver information in the Longley-Rice model, the computer calculates the free space field strength for a specific geographical receive site, and then computes a path loss *adjustment* to this value based on various selected propagation parameters as well as the terrain profile between the transmit and receive sites (**Ref 3**). Results are considered *median* values.

When describing what the Longley-Rice algorithm was designed to do, one should also consider what it was *not* designed to do. The Longley-Rice model is considered applicable to a wide variety of "normal" conditions, but it is *not* intended for urban areas or dense forests. It is also *not* intended to predict short term variations but rather is meant to provide the basis for an *annual median*. This long-term basis of the results makes confirming Longley-Rice model predictions in the field a challenge. However, using a large number of test locations can provide some statistical relevance for evaluating the accuracy of the Longley-Rice model for given service areas (**Ref 3**).

The data used by the Longley-Rice model to adjust the theoretical field strength calculations is based on measurements of VHF land mobile service in Colorado and northern Ohio as well as measurements of VHF and UHF television measurements (**Ref 3**). A group of 271 engineers spent three years gathering and analyzing field strength data for TASO. These measurements also became the fundamental basis for updated FCC statistical propagation curves, as discussed above, that were used for NTSC station coverage determination for many decades.

The Longley-Rice methodology, while complex in details, can be simplified for description as a three-step process. The first step is to set up (define) the specific problem based on the coverage area of interest, then compute the reference attenuation (in dB) that the transmitted signal experiences, and finally compute adjustments to this reference attenuation based on the terrain, climate, desired statistics, and the empirical data files and subtract it from the reference field strength. Overall, it is a simple concept, but the complexity is in the details of each of these three steps (**Ref 3**).

The ***first*** step (set up) requires the specific environmental parameters to be determined, such as the transmitted signal frequency and ERP, the transmitter antenna height (AGL), the transmit antenna azimuth and elevation patterns, the polarization of the transmitted signal (e.g., horizontal or vertical), the distance and terrain profile between the transmit and receive sites, and the desired statistical field strength results (e.g., 50/50, 50/90, 50/10) that describe the percentages of locations and percentage of time. These are straightforward parameters that can be obtained relatively easily (**Ref 3**).

It is also necessary to define the default parameters that are used to calculate the adjusted path loss. These parameters are the actual and effective earth curvature (reciprocal of radius), the ground dielectric constant, the ground conductivity, surface refractivity, and climate. These parameters reflect the laws of physics that work on the propagating signal, and while simple in nature, accurate values are not always easily estimated. Of course, these values change from one part of the country to another, and can therefore be selected for a given area (**Ref 3**).

The ***second*** step (reference attenuation) computes the reference attenuation value, that is, the median attenuation relative to *free space*.

Finally, the ***third*** step (reference attenuation adjustment) is to calculate the path loss *adjustments*. However, the path loss attenuation must be compensated by allowing for deviations from the basic free-space attenuation values. This is where things can get a little "tricky", as some assumptions must be made. Both the transmit and receive antennas are adjusted to an effective height based on the intervening terrain. An assumption is made that bases the reflecting plane on a straight line fit of the terrain profile. Modification and weighting factors are also employed that are based on fits to measurement data. Perhaps one could say this is where some "art is added to the science", and that this is an area where further work could be done to improve the model for various kinds of terrain, even including more sophisticated modeling for major urban areas (**Ref 3**).

The reference attenuation adjustment accounts for the average climate (equatorial, continental subtropical, maritime subtropical, desert, continental temperate, maritime temperate over land, and maritime temperate over sea). The existing empirical data that is used to make these attenuation adjustments was obtained for continental and maritime temperate regions. The rest of the climates use data based on data curves from the CCIR. Also, it has been determined that there is very little difference between continental and maritime temperate regions in the first 100 km, but longer paths in maritime temperate regions are subject to super-refraction and ducting 10% of the time. Climatic adjustments in general are not very large within the same climate (**Ref 3**). In addition, this step also depends on the exact propagation mode (line-of-sight region, diffraction region, and tropospheric refractive scatter region) as well as factors such as the distance from the transmitter antenna, the antenna height, and the intervening terrain (**Ref 3**).

When considering field strength prediction, it is important to note that all the factors that affect field strength that are described above are not constant with time. For example, they will vary with temperature and weather, to name a couple. To complete these reference attenuation adjustment calculations, the desired *statistical* metric must be included such as percent of time, percent of locations, and a confidence factor. For DTV, the commonly used metrics for service prediction are 50% of the locations, 90% of the time, with a 50% confidence factor. For broadcast allocation work, the 50% confidence factor can be considered situation variability, and provides a *median* situation. This statistical adjustment is based on *empirical* data obtained from a large number of measurements for various climate, distance, and antenna heights parameters. These statistics are matched to the current evaluation in order to determine the appropriate attenuation adjustment value (**Ref 3**).

The computer implementation of the model is very complex, allowing many options for propagation parameters, and must be linked to various terrain data files (**Ref 16**). Also, specific values for the various parameters described above must be selected, such as relative permittivity of the ground, ground conductivity, and surface refractivity. Additionally, the height of the transmitter and receive antennas must be entered. Likewise, antenna patterns (azimuth and elevation) for the transmit antennas are also used in these calculations. Note that the receive antenna pattern is not needed for field strength calculations except in interference determination from distant stations that are off-axis from that of the desired transmitter station where signal discrimination is achieved. However, the receive antenna gain is required later when the receiver planning factors are used to calculate the RF signal level at the DTV receiver input.

Other details of the Longley-Rice methodology, which are beyond the scope of this report, as well as the FORTRAN computer code, can be found in an NTIA report 82-100 (**Ref 15**). Modifications to the code were described by G. A. Hufford in a memo dated January 30, 1985, and it is this version (1.2.2) that the FCC uses for its evaluations, and is the one that every broadcaster (or their consultant) must use to evaluate coverage, service, and interference when applying for new or modified DTV facilities.

The accuracy of any prediction software is determined by how well the theoretical model matches conditions in the field and how well the user of the software selects the various parameter values. The severe complexity of propagation encountered in nature makes this modeling extremely difficult. All models must make some compromises, but the Longley-Rice model makes some *reasonable* compromises. It must be remembered that these predictions are *statistical* in nature, and are based on annual *medians*. Therefore, one must evaluate results carefully, considering all the factors described above (**Ref 3**).

The accuracy of the Longley-Rice model has always drawn the interest of broadcast engineers, and it has been evaluated in recent years. One such analysis (**Ref 17**) was done in February 2001 using data from the 8-VSB/COFDM comparison field test that was performed between March 1998 and February 2000 as well as data from some individual station service evaluations. All the data was collected by experienced individuals in a consistent manner (i.e., with proper receive antennas, test equipment, collection methodology, etc.) with daily equipment calibrations. All the station parameters were verified as well. A total of 2937 test sites were measured, each one with a 30' above ground level (AGL) receive antenna. A variety of channels were measured, from low-VHF channel 2 up to UHF channel 48, and in various areas across the U.S. These tests areas included a variety of terrains, from flat to rolling to rugged. Field testing was performed in various seasons, and in a wide range of weather conditions, although most measurements were made during daylight hours. All the computer predictions were median values, using 3 second terrain data at 0.1 km intervals, and with both horizontal and vertical antenna patterns considered. The computer results for each test site are based on both theory and empirical field data.

The results showed that *individual* sites showed as much as ±40 dB differences between predicted and measured values. This is because the software predictions are ***not*** accurate for individual measurements but rather for ***long- term*** statistical median values. When evaluating all the data points and averaging them, the overall trend shows that Longley-Rice prediction tends to *over*-estimate field strength by anywhere from 8 dB at low-VHF to 16 dB at UHF. Longley-Rice actually was more accurate farther from the transmitter (e.g., near a distance of 100 km) than closer to the transmitter. Also interesting was the fact that it was more accurate when there was at least 1 terrain obstruction, and got better with more obstructions (up to 5). Longley-

Rice was the least accurate when sites had unobstructed views back to the transmitter, with between 10 dB to 18 dB of over-estimation.

In summary, the Longley-Rice model tends to over-estimate field strengths and thus optimistically predicts DTV service, sometimes showing coverage in locations well beyond the radio horizon (**Ref 18**). However, since the paths of interfering signals tend to be longer and therefore encounter obstructions, they are predicted more reliably. This coupled with the over-prediction of the desired signal in some cases causes a prediction of service when in fact the service has been lost due to interference. On the other hand, if the interferer is within the service area of the desired station where both signals are likely to be over-predicted, then the result of interference evaluation should be reasonably accurate.

One thing is for sure: prediction models are unreliable for *individual points* and times (**Ref 17**). One area for future consideration is to take better account of the effects of natural (vegetation) and man-made obstructions. Since many of the models used for propagation predictions (including Longley-Rice) have some empirical bases, the introduction of additional clutter factors can lead to "double counting" and therefore needs to be carefully implemented. Nevertheless, given the fact that the model and data points are between 30 – 50 years old, there is definitely much room for further optimizing the Longley-Rice model by gathering more field data (especially long term) and doing more analysis (**Ref 5, 8, 17**), either by an industry-wide consortium with like-minded interests or perhaps a Government-led group similar to TASO back in the late 1950s.

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The Longley-Rice field strength propagation model is useful for predicting the median field strength at a ***single*** receive point by taking into account not only the usual transmitter ERP and AGL parameters, but also specific geographical points based on the terrain profile that exists between the transmitter and the test point as well as a number of other factors as discussed above. This requires the use of a powerful computer since there are a large number of calculations that must be individually evaluated along the propagation path. If broad area field strength coverage evaluation is desired, these single point receive site calculations must be repeated many times. However, prediction of field strength coverage, whether to a single receive site or many receive sites, is *not* the ultimate desired goal for the broadcast engineer. The actual goal is for a television station is provide NTSC or DTV *service* (i.e., acceptable video and audio) to as many of its viewers as possible, and this is not determined solely on field strength. Service is also dependent on the receive site parameters that affect successful reception of the DTV signal, from the antenna down to the NTSC or DTV receiver. This includes not only the desired signal level at the receiver input but also the level of any analog or digital interfering signals present. Of course, RF performance of the DTV receiver is vital as well. Therefore, the Longley-Rice field strength prediction model and algorithm are but just one of the components used in channel spectrum evaluation and allocation.

One benefit of predicting service, however, is to determine the number of DTV stations that can be allocated an RF channel across a given area. In the U.S., the FCC has the authority to allocate television channels, and it must do so fairly, with acceptable coverage and service areas, and yet without causing unacceptable interference among broadcasters. This channel allocation process was done at the beginning of the DTV transition period when every eligible analog television station was given a 2nd 6 MHz channel for digital television transmission based on the principle of service replication between analog NTSC and digital ATSC signals. The basic principle of channel allocation at that time was to ***replicate*** the NTSC service area (to a subjective CCIR-3 level or better) with DTV service. This process was repeated again just prior to the end of the DTV transition when all the eligible stations selected a final post-transition channel (and verified by the FCC) for subsequent DTV-only transmission after the cessation of analog NTSC. And the process can be applied again in the future if a new channel allotment is desired or an existing station wants to determine if it can modify its facilities.

On April 3, 1997, the FCC set up some principles in the *6th Report and Order* (**MM Docket No. 87-268, FCC 97-115**) for this channel allocation process as well as any subsequent desired changes to a television broadcaster's facilities. These principles were then codified in the FCC rules (4**7 C.F.R,, Par 73.622 & 73.623 and Par 74.704**), and were *based* on the Longley-Rice field strength prediction methodology. However, there was an apparent need for further clarification and guidance regarding all the logistical details surrounding the evaluation of TV *service* and *interference* in accordance with FCC rules. Therefore, at the request of the broadcast community, the FCC published OET Bulletin No. 69 (**Ref 16**) to provide this guidance and further certainty regarding use of the Longley-Rice allocation methodology. Note that the February 6, 2004 updated bulletin supersedes an earlier version dated July 2, 1997.

The FCC has specific requirements for using the Longley-Rice model, and published FORTRAN computer code (**Ref 15**) in a 1982 NTIA report. This code was subsequently modified and documented in 1985, and is referred to a Version 1.2.2 of the Longley-Rice model (**Ref 16**). This is the official code and algorithm sanctioned by the FCC for performing these service and interference studies to obtain new channels or make changes to existing facilities.

OET 69 is divided up into three sections: service, interference, and the computer program.

The exact logistical details involving the Longley-Rice computer program are complex, and beyond the scope of this report. However, the overall basic *methodology* of channel allocation *under FCC rules* is straightforward and can be summarized from OET-69 as follows:

1 **IDENTIFY MINIMUM REQUIRED NTSC FIELD STRENGTH VALUES**: Minimum required field strength values for Grade B contour (for a 30' AGL receive antenna) for NTSC have existed for many years (at least since 1952). They represent median values that have 50% location variability and 90% time variability (see previous section on FCC propagation curves). Analog Grade B is defined as a field strength that provides a video picture with a CCIR-3 subjective impairment rating ("slightly annoying") on an analog NTSC television set in the absence of any interfering signals. This condition is defined by the following fixed NTSC field strengths (except for UHF, where a frequency-dependent dipole correction factor is applied when used in the OET-69 context):

TABLE 5 Field strength values defining area subject to calculation for *analog* stations

Band	Channels	Field Strength for CCIR-3 Pictures (dBμV/m)
Low-VHF	2-6	47
High-VHF	7-13	56
UHF	14-69	64 – 20*LOG[615/CH mid-frequency in MHz]

NOTE: These values are only useful as long as NTSC stations are still transmitting NTSC signals, which will cease for full-service analog stations on February 17, 2009 and some time after that for LPTV stations and translators.

2 **IDENTIFY RECEIVE SITE PLANNING FACTORS**: Planning factors were created by the FCC for a "typical" DTV receive site. These factors are assumed to characterize the receive site equipment, including the antenna, downlead cable, and DTV receiver. These values were used to create the minimum required DTV field strength values in **Table 7**. The following receive site planning factors are described below in **Table 6**:

TABLE 6 Planning factors for DTV reception (i.e., a "typical" receive site with a 30' AGL receive antenna)

Planning Factor	Symbol	Low-VHF	High-VHF	UHF	Units
Geometric Mean Frequency	F	69	194	615	MHz
Dipole Factor	K_d	-111.8	-120.8	-130.8	(dBm-dBμV/m)
Dipole Factor Adjustment	K_a	None	None	See Text	-----
Thermal Noise	N_t	-106.2	-106.2	-106.2	dBm/6 MHz
Antenna Gain	G	4	6	10	dBd
Downlead Line Loss	L	1	2	4	dB
System Noise Figure	N_s	10	10	7	dB
Required SNR	SNR	15	15	15	dB
Required Minimum Field Strength	FS_{MIN}	28	36	41	dBμV/m

NOTE: The above planning factors do not include parameters for multipath-induced noise enhancement, antenna/receiver mismatch loss, antenna/receiver mismatch noise figure enhancement, man-made noise, and sky noise nor do they account for the presence of any baluns, couplers, or splitters. The dipole adjustment factor Ka = 20 * log[615/CH mid-frequency in MHz], which according to FCC rules is applied *only* for UHF channels, accounts for the fact that field strength *requirements* are greater for channels above the UHF band's geometric mean frequency (615 MHz) and smaller for UHF channels below the geometric mean frequency. The geometric mean frequency of the UHF band is 615 MHz, approximately the center-frequency of CH 38. This dipole adjustment factor is applied to the modified Grade B contour UHF field strength for analog NTSC channels (**Table 5**) as well as to the noise-limited contour for UHF field strength for digital ATSC channels (**Table 7**). The value for required minimum field strength can be calculated from the following simple algebraic equation:

$$\mathbf{FS_{MIN} = Nt + Ns + SNR + L - Kd - Ka - G} \quad (26)$$

3 **IDENTIFY MINIMUM REQUIRED DTV FIELD STRENGTH VALUES**: Using the planning factors from **Table 6** and placing them into the **Equation (26)** formula for minimum required field strength FS_{MIN}, values can be calculated for each frequency band. These are the field strength values that represent threshold of visible errors (TOV at the "digital cliff") and define the noise-limited contour for a DTV station. This condition is defined by the following fixed DTV field strengths (except for UHF, which applies a dipole correction factor that is channel/frequency dependent):

TABLE 7 Field strength values defining area subject to calculation for *digital* stations

Band	Channels	Field Strength for CCIR-3 Pictures (dBμV/m)
Low-VHF	2-6	28
High-VHF	7-13	36
UHF	14-69	41 – 20*LOG[615/CH mid-frequency in MHz]

NOTE: During the DTV channel allocation process that required NTSC replication, the DTV noise-limited contour that determined the area of service calculations was defined to be identical to it analog NTSC companion Grade B contour except at UHF when the ERP required for replication either was below 50 kW or above 1,000 kW. In these cases, the DTV ERP was set to either 50 kW or 1,000 kW, which caused the resulting DTV service contour to not replicate the Grade B contour of the paired analog station.

4 **DETERMINE DTV REFERENCE ERP VALUES**: Reference ERP values for every DTV transmitter were included in Appendix B of the *Sixth Report and Order*. These values, determined by the FCC, are the *maximum* of all the values needed to (approximately) replicate the service contour of the paired analog station in each azimuth direction, assuming the new DTV station was *co-sited* with its paired analog station and that both the analog and digital antennas were at the *same height*. The FCC calculated the reference ERP using the following methodology.

a. The transmitter HAAT was calculated at various azimuth angles (at least 8 angles every 45 degrees) around the transmitter (using antenna height and terrain elevation data describing the terrain from 2 to 10 miles from the transmitter, applying linear interpolation where appropriate).

b. The *distance* to the analog NTSC Grade B contour in *each* of 360 uniformly-spaced compass directions around the transmitter was determined by using the known analog transmitter ERP (from the 4/3/97 FCC database) and antenna pattern, the radial-specific HAAT, the **F(50, 50)** statistical curves (see FCC rules **Section 73.699**), and the Grade B field strength values in **Table 5**. Despite the use of the **F(50, 50)** curves, the Grade B field strength values from the 1950s had a time fading correction factor applied to them to increase the time variability to 90%. The FCC field strength prediction curves assume a 30' AGL receive antenna. If a directional transmit antenna was employed, linear interpolation of the antenna pattern data was performed, and the relative field values were squared and multiplied by the overall maximum ERP listed for the station in the FCC records. **NOTE**: This NTSC Grade B contour defined the service area contour (replication requirement) that would be subject to subsequent Longley-Rice DTV evaluation.

c. The *ERP values* for the DTV station in *each* of 360 uniformly-spaced compass directions around the transmitter was determined by using the radial-specific HAAT value, the **F(50, 90)** statistical curves (see FCC rules **Section 73.699**), the distance to the previously calculated analog Grade B contour (for replication purposes), and the noise-limited contour field strength values in **Table 7**. (Note that the FCC field strength prediction curves assume a 30' AGL receive antenna).

d. The ERP values calculated for each compass direction for the DTV station was modified, if necessary, so as to not exceed 1 MWatt and not drop below 50 kWatts. To do this, the FCC *scaled* the azimuthal power pattern by a factor equal to the maximum calculated value rather than truncated it. This maximum value was cited in **Section 73.622** of the FCC rules as part of the initial allotment plan. Subsequent modifications were made to the plan as individual stations requested changes, including maximization.

5 **DETERMINE REQUIRED DTV TRANSMIT ANTENNA PATTERN**: The required DTV antenna pattern is determined. In general, the calculated ERP values for the DTV station that matched the noise-limited contour with the analog Grade B contour (replication requirement) typically varied for each compass direction around the transmitter, indicating that a non-omni-directional DTV antenna pattern was often necessary. This was

typical for NTSC VHF stations that had omni-directional antenna patterns but ended up with distorted (i.e., slightly directional) DTV UHF antenna patterns. This is due to two reasons. First, the effects of the terrain had a different effect on propagation in the two television bands as affected by varying HAAT values (versus azimuth angle) and different FCC curves (versus frequency). Additionally, the 90% time variability allowance for DTV also had an affect on the DTV pattern. Therefore, the above procedure effectively derived a new directional antenna pattern whenever a precise replication was attempted. This antenna pattern was documented and archived by the FCC as part of the initial allotment plan.

6 **IDENTIFY LONGLEY-RICE COMPUTER PROGRAM PARAMETER VALUES**: The Longley-Rice computer program generally allows different values to be selected for some of the propagation parameters. However, for use in FCC-approved analysis regarding spectrum allocation and facility maximization, the FCC requires that version 1.2.2 be used with the following specific values, including the usual 50% of the locations, 90% of the time, and 50% confidence (i.e., median field strengths). Likewise, the FCC requires the use of a generic (typical) transmit antenna *elevation* pattern rather than using the broadcasters' actual transmit antenna elevation pattern. This has been a bit of a controversy over the years, and was presumably decided by the FCC that it would have either been too complicated to handle each station's actual pattern or perhaps that it would have been too easy for errors to creep in to the data base. Note that there are different antenna elevation patterns for each television (frequency) band as well as analog versus digital. The antenna elevation pattern difference between analog and digital is due to the typical difference in required gain between the two television signals (digital with its lower ERP requirements often uses lower gain antennas). The following parameter values are required by the FCC to be used in all Longley-Rice DTV field strength calculations, and they happen to be the same values used by the Broadcasters' Caucus to evaluate various DTV allotment tables in 1996 and 1997.

Table 8 FCC-required Longley-Rice parameter values

Parameter	Value	Meaning / Comment
EPS	15.0	Relative permittivity of the ground
SGM	0.005	Ground conductivity (Siemens per meter)
ZSYS	0.0	Coordinated with setting of EN0 (see page 72 of NTIA Report)
EN0	301.0	Surface refractivity in N-units (parts per million)
IPOL	0	Denotes horizontal polarization
MIDVAR	3	Code 3 sets broadcast mode of variability calculations
KLIM	5	Climate code 5 for continental temperate
HG(1)	Actual	Transmitter antenna height of the radiation center above ground (in meters)
HG(2)	10 m	Receiver antenna height above ground (in meters)
L	50	Location variability: location at or above the calculated field strength value (in %)
T	90	Time variability: time at or above the calculated field strength value (in %)
C	50	Confidence factor: degree of confidence (median) of field strength variable (in %)

Table 9 Transmitter vertical antenna patterns: Gain expressed as relative field strength

Elevation Angle	Low VHF	High VHF		UHF	
(degrees)	Analog & DTV	Analog	DTV	Analog	DTV
0.75	1.000	1.000	1.000	1.000	1.000
1.50	1.000	0.950	0.970	0.740	0.880
2.00	0.990	0.860	0.940	0.520	0.690
2.50	0.980	0.730	0.890	0.330	0.460
3.0	0.970	0.600	0.820	0.220	0.260
3.5	0.950	0.470	0.730	0.170	0.235
4.0	0.930	0.370	0.650	0.150	0.210
5.0	0.880	0.370	0.470	0.130	0.200
6.0	0.820	0.370	0.330	0.110	0.150
7.0	0.740	0.370	0.280	0.110	0.150
8.0	0.637	0.310	0.280	0.110	0.150
9.0	0.570	0.220	0.280	0.110	0.150
10.0	0.480	0.170	0.250	0.110	0.150

7 **DETERMINE DTV SERVICE WITHIN CONTOUR WITH LONGLEY-RICE ALGORITHM**: The DTV replication service area subject to calculation as determined by FCC rules (e.g., Grade B contour if NTSC replication is desired) is divided into rectangular cells (2 km x 2 km maximum). The Longley-Rice *point-to-point* propagation model (version 1.2.2) is then applied (with the transmitter ERP and the antenna AGL, azimuth and elevation patterns as well as all the terrain propagation parameters included) to each rectangular cell within the area of the defined contours. The specific point within the rectangular cell that is used for the Longley-Rice calculation depends on whether there is population present. If so, the point that represents the population centroid is used; otherwise, the geometric center is used. The calculated desired DTV field strength at this single point within the cell represents the entire cell, and determines if there is digital service for that particular cell. The required terrain elevation data must be *uniformly* spaced points over the propagation path between the transmitter and receiver, and is taken from a database with values every 3 arc-seconds of latitude and longitude. While the program retrieves this data at a regularly spaced increment which is selected by the user, the FCC typically uses 1 km increments, although smaller increments can be used. DTV service in a given cell is presumed if the *desired* field strength is above the threshold values given in **Table 7**.

8 **IDENTIFY D/U INTERFERENCE THRESHOLD RATIOS**: These desired-to-undesired (D/U) interference ratios are part of the planning factors used by the FCC. D/U ratios exist for all four possible interference scenarios (A-into-A, D-into-A, A-into-D, and D-into-D) since channel allocations involve not only finding new channels for DTV stations that will provide service free of interference, but also protection of *existing* analog and digital channels from interference from this new DTV station.

The analog-into-analog and digital-into-analog protection ratios are still relevant since interference from a new DTV station into a cell that might *potentially* be able to receive this distant analog signal will not even be considered if that cell already has *unacceptable* NTSC reception due to interference from a third (analog or digital) station. Not only was this important during the channel allocation process in 1996 but also is important for any station that is modifying their facilities during the transition. These protection ratios, which must be met for acceptable television reception, are specified in **Section 73.623** of the FCC rules (and repeated in **Table 10**) for interference involving desired or undesired DTV stations**.** The FCC essentially determined these interference criteria by using the ACATS laboratory results from the tests that were performed at the ATTC in 1995. Note that the FCC did not require any UHF taboo protection for desired DTV signals because the Grand Alliance prototype DTV receiver had better than -60 dB performance, and this had little effect on the channel allocations. However, few (if any) of the current consumer DTV receivers meet this -60 dB taboo protection ratio.

Table 10 Interference criteria: D/U ratios

Channel Offset	D/U Ratios (in dB)			
Channel Offset Relative to Desired Channel N	**Analog Into Analog**	**DTV Into Analog**	**Analog Into DTV**	**DTV Into DTV**
N-8	-32	-32	NC	NC
N-7	-30	-35	NC	NC
N-4	NC	-34	NC	NC
N-3	-33	-30	NC	NC
N-2	-26	-24	NC	NC
N-1	-3	-14	-48	-28
N	+28	+34	+2	+15
N+1	-13	-17	-49	-26
N+2	-29	-28	NC	NC
M+3	-34	-34	NC	NC
N+4	-23	-25	NC	NC
N+7	-33	-43	NC	NC
N+8	-41	-43	NC	NC
N+14	-25	-33	NC	NC
N+15	-9	-31	NC	NC

Note: NC means "Not Considered"

Two other threshold limits must be modified if the desired signal is near the receiver noise floor. When co-channel interference into a desired DTV signal from an analog NTSC signal occurs, the D/U ratios (N+0) in **Table 10** are valid only for SNR conditions of 25 dB or greater. If the SNR is less than 25 dB, then D/U ratios in **Table 11** must be applied (with linear interpolation if SNR values fall between the table entries).

Table 11 Minimum Co-channel D/U Ratios for *Analog* Interference to DTV

DTV Signal-to-Noise (SNR) In the Absence of Interference (dB)	Desired-to-Undesired Ratio (D/U) to Protect DTV Reception from Co-Channel Analog Transmission (dB)
16.00	21.00
16.35	19.94
17.35	17.69
18.35	16.44
19.35	7.19
20.35	4.69
21.35	3.69
22.35	2.94
23.35	2.44
25.00	2.00

On the other hand, when co-channel interference into a desired DTV signal from another noise-like DTV signal occurs (which means that there is a mathematical way to treat this noise-plus-noise-like addition of signals), the values in **Table 10** are valid only for SNR conditions of 28 dB or greater. If the SNR value is less than 28 dB, then the D/U ratios must be modified by calculation according to **Equation (27)**.

$$D/U = 15 + 10 * LOG [1.0 / (1.- - 10^{-x/10})] \quad \text{where } x = SNR – 15.19 \text{ dB} \qquad (27)$$

9 **IDENTIFY POSSIBLE INTERFERENCE SOURCES**: When undesired signals *might* be interference sources or receptors of interference from the DTV station under evaluation, their separation distance is the determining factor for their consideration. This separation distance is dependent on the channel offset relationship, and is shown in **Table 12**. These interference source distance relationships are not only for analog or digital interference into the desired DTV signal under evaluation, but also for the interference that the desired DTV signal under evaluation might cause to these neighboring television stations.

Table 12 Separation distances for determination of potential interfering sources

Undesired Channel Relative to Desired Channel	Maximum Distance from Cell to Undesired Stations (km)			
	Analog Into Analog	**DTV Into Analog**	**Analog Into DTV**	**DTV Into DTV**
N-8	35	35	NC	NC
N-7	100	35	NC	NC
N-4	NC	35	NC	NC
N-3	35	35	NC	NC
N-2	35	35	NC	NC
N-1	100	100	100	100
N	300	300	300	300
N+1	100	100	100	100
N+2	35	35	NC	NC
M+3	35	35	NC	NC
N+4	35	35	NC	NC
N+7	100	35	NC	NC
N+8	35	35	NC	NC
N+14	100	35	NC	NC
N+15	125	35	NC	NC

Note: NC means "Not Considered" since it is presumed that stations at the indicated offset do not cause interference even though they may be close in distance e to the cell of interest.

10 **RECEIVE ANTENNA PATTERN:** The receiving antenna is assumed to have a directional gain pattern which tends to discriminate against off-axis undesired stations. The FCC estimated the typical *outdoor* receive antenna pattern by the fourth-power cosine function of the angle between the lines joining the desired and undesired stations to the reception point. This is the same pattern that the ACATS working group developed and was also used by the Broadcasters' Caucus in the mid-1990s.

However, the amount of discrimination is *never* allowed to be greater than the front-to-back ratios identified in **Table 13**.

Table 13 Receive antenna front-to-back ratios

TV Service	**Front-to-Back Ratio (dB)**		
	Low-VHF	**High-VHF**	**UHF**
Analog	6	6	6
DTV	10	12	14

11 **DETERMINE DTV INTERFERENCE WITHIN CONTOUR WITH LONGLEY-RICE ALGORITHM**: DTV service is not only dependent on the desired DTV field strength that exists at the receive antenna's input but it also depends on the field strength of any undesired analog or digital signals that are simultaneously present as well. The signal levels of any undesired interferer signals are also determined by use of the Longley-Rice modeling to evaluate the propagation path between any undesired TV transmitters and the cell under

investigation. However, these Longley-Rice calculations for the interfering signals are performed with 50% location variability, 10% time variability, and 50% confidence factors.

The selection of which "nearby" analog and digital transmitters for analysis of possible interference into the desired DTV signal is determined by distance, as defined in **Table 12**. For interference to the desired DTV signal into nearby signals, only cells that had acceptable signal levels (i.e., above threshold of noise as defined in **Table 5** and **Table 7**) are evaluated. If the signal from the desired station is above the service threshold, then a further evaluation is made to determine if any of the signals from the other nearby stations cause unacceptable interference ratios (i.e., as defined in **Table 10** and **Table 11** and **Equation (27)**). All interference determination is performed using the receive antenna fourth-power cosine discrimination pattern and front-to-back ratios in **Table 13**). In other words, a cell is examined first to determine if it has sufficient signal strength for acceptable analog or digital reception from its respective desired station, and then secondly evaluated to determine if it has acceptable reception in light of interference from other nearby *3rd party* analog and digital television stations. Only if the cell under evaluation meets these two criteria is it further evaluated to determine if the proposed new or modified DTV facility causes interference to its desired DTV signal. This means that a proposed DTV station is assumed to not cause interference (and is therefore not penalized) to analog or digital neighboring stations in places where there already is no service there because of weak signals or *existing* analog or digital interference.

The above procedures describe the channel allocation process. However, similar procedures can be and are used to determine if station modifications can be made, even after the DTV transition when no analog NTSC signals will be transmitted.

SECTION II: MTVA DTS OUTDOOR AND INDOOR PLANNING FACTORS

INTRODUCTION

The purpose of this report is to identify new and updated receive site planning factors for better prediction of outdoor and indoor *urban* DTV reception in the UHF and high-VHF bands. Low-VHF will not be addressed in this report. Updated planning factors allow more accurate computer models to be developed that then allow better predictions of DTV coverage and service. However, care must be taken when using computer simulation programs. These computer programs can perform very accurate calculations for a great number of locations and in a very short time. However, these prediction results are only as accurate as the model employed. The Longley-Rice model, while more accurate than the FCC statistical field strength curves since it accounts for the actual terrain between the transmitter and the receiver, still has “accuracy issues” for outdoor field strength predictions. The challenge gets much greater when prediction of outdoor sites in large *urban* areas is desired, and is further complicated if *indoor* reception prediction is sought. A lower receive antenna height means more ground reflections that can create prediction errors, while building penetration attenuation is extremely variable when different building construction materials are considered. Modeling large urban areas accurately is difficult, although some have tried in the past. Therefore, one must proceed with extreme caution when creating *urban* planning factors for outdoor and indoor DTV reception. There is just not enough data yet for each type of local “urban clutter” situation. Nevertheless, some kind of computer model must be used.

This report seeks to define all the pertinent planning factors that best predict DTV service. Planning factors for RF signal propagation are taken from previously published literature regarding signal loss versus height and building penetration loss, although some interpolation and extrapolation is required since not all of the previous data is based on broadband digital television signals in the VHF and UHF bands. With regard to receivers, ATSC has provided some guidelines regarding performance parameters and test procedures, along with some recommended performance values (**Ref 19**). However, these recommendations were based on 2004 VSB receiver technology, and updates in the future are possible as VSB technology continues to advance. Individual broadcast groups such as the **MTVA** have studied DTV reception issues such as the indoor antenna survey project (**Ref 20**), the indoor antenna laboratory measurement project (**Ref 21**) and the DTV receiver performance laboratory testing project (**Ref 22**). These measurement projects provide significant amounts of data from which to create some reasonable initial urban outdoor and indoor planning factors updates, with the understanding that more laboratory and field testing in the future will allow further “tweaking” of these planning factors. Likewise, previously published in-band performance reports from the CRC on early prototype receivers from Linx (**Ref 23**), Zenith (**Ref 24**), and Samsung (**Ref 25**) as well as a laboratory test report by the FCC regarding the evaluation of twenty-eight 2005 consumer DTV receivers (**Ref 26**). This data was further supplemented by reports on the subject of DTV-into-DTV adjacent channel and taboo interference from the CRC (**Ref 27**) and the FCC (**Ref 28**).

These updated DTV service planning factor parameters will be described in the following sections, with suggested values for four different reception scenarios. The first scenario will be the typical outdoor reception in an urban area with the receive antenna at 30’ AGL. These outdoor planning factors will be similar to those used by the FCC, except with a few extra parameter considerations that were left out of the original FCC model. The remaining three scenarios are for indoor urban planning factors, which will give system designers a little flexibility when modeling different scenarios of urban receive conditions.

The FCC has determined outdoor planning factors (**Ref 2**, **Ref 16**), and these are required whenever a television station is requesting a change in their facilities. These planning factor parameters, for the most part, have reasonable values assigned to them. However, some important parameters are missing such as multipath noise enhancement, mismatch loss, multipath fading, sky and man-made noise, and taboo interference protection ratios. The first adjacent interference protection ratios are not desired signal-amplitude dependent as they should be, but rather constant values.

Indoor planning factors start with the DTV field strength at 30’ AGL at the desired building, which is the FCC-assumed receive antenna height. To determine indoor coverage and then ultimately indoor DTV service, a number of factors must be considered.

1) Receiver Antenna Height Differential Attenuation (compared to 30’ AGL)

2) Building Penetration Loss

3) Receive Antenna Characteristics

4) Cable Feedline Loss

5) Receiver Performance Characteristics:

A) Theoretical Matched Noise Floor

B) Noise Figure

C) White Noise Threshold SNR

D) Multipath Diversity Antenna Advantage

E) Multipath Noise Enhancement

F) Multipath Signal Fading Level

G) Sky and Man-Made Noise Enhancement

H) Mismatch Loss

I) Interference Protection D/U Ratios

Each of these parameters, with the exception of the first two (Receiver Antenna Height Differential Attenuation and Building Penetration Loss) can all be applied to outdoor planning factors as well.

The following material will describe each of these factors in detail, and provide a rough estimate of planning factor values for each one. The estimated values were obtained from a variety of sources: literature search, analysis of previous field data, and analysis of recent indoor antenna and DTV receiver laboratory test data. It should be understood that prediction of outdoor DTV field strength and service is tenuous at best, and prediction of indoor DTV field strength and service is even more challenging. There are an infinite number of variables and values that can be used. Therefore, the following material is just a starting point in this planning factor process, and should be followed up with field test data analysis and subsequent revisiting of these planning factors.

Typical indoor and outdoor receive site planning factors are shown in **Table 20** (UHF) and **Table 21** (high-VHF) as well as in **Table 22 (**interference D/U ratios). A geometric mean frequency for each band is selected for simplicity, with only the need for application of a dipole *frequency-dependent* factor (see description above) to adjust the factors for another frequency. The *indoor* planning factors are broken down into three scenarios: a *best* case, a *typical* case, and a *worst* case. The various parameter values that were selected for each of these scenarios can be seen in the tables, and are the best engineering estimates at the present time.

1) RECEIVE ANTENNA HEIGHT

The outdoor *receive* antenna height standard has been 30’ AGL since the 1940s, and is used today by the FCC. It is *still* recommended to be used in most applications in order to compare results with previous field tests and prediction analyses. However, in specific applications, a value different from 30’ AGL can be used with some general mathematical corrections, with the understanding that reasonable accuracy is *not* guaranteed in many instances.

The field strength in a given coverage area will vary with receive antenna height above ground level due to reflections and diffraction from various objects in the electromagnetic propagation path as well as from refraction in the atmosphere. Therefore, field strength predictions must attempt to account for receive antenna height in order to better estimate signal levels at the receive site.

A 1995 ITU Recommendation (**Ref 29**) suggests a calculation for a *median* value for the “gain” (i.e., signal level deviation) of an RF signal at a height different from that of the FCC 30’ AGL reference height.

$$G(\text{in dB}) = (K/6)*20*\text{LOG}[H/30] \qquad 1.5 \leq H \leq 40 \qquad (28)$$

where “K” is either 4, 6, or 8 for UHF or 4, 5, and 6 for VHF in rural, suburban, and urban areas, respectively, and “H” is the height (in feet) of the receive antenna above ground level. Of course, negative values of gain G indicate signal loss compared to the 30’ AGL receive antenna height. From **Equation 28**, a receive antenna height of 15’ AGL in a suburban area (i.e., K = 6) would yield a field strength value that would be 6 dB lower than if it were at 30’ AGL, and a receive antenna height of 6’ would yield a field strength value that is 14 dB lower. However, there are many factors that affect field strength versus receive antenna height, especially as the antenna is placed very close to the ground. Antennas close to the ground are affected significantly by ground clutter reflections. Therefore, some field data should be evaluated to verify these very rough attenuation numbers, and like the ITU equation, different correction factors should be used in different areas (e.g., rural, suburban, urban).

The NAB Handbook 9th Edition Chapter 6.9 Television Field Strength Measurements contains similar information on how to adjust measured field strength values to correct for receive antenna height. That discussion indicates that it has been common practice to assume that field strengths vary *linearly* with height. For example, the field strength adjustment for a difference between 6’ AGL and 30’ AGL would simply be 0.2 (i.e., 6/30) or in terms of decibels -14 dB (i.e., 20*LOG[0.2]). This is the same adjustment as noted above for the Recommendation ITU-R P.370-7 for the suburban situation. The Handbook article goes on to say that such adjustments generally apply in relatively flat terrain and indicates that the adjustments will likely be smaller in hilly or rugged terrain. The latter statement is also true in urban areas where large buildings have an effect similar to that of rugged terrain. In either case, the receive site is being shielded from the transmit site and the effect of the shielding is more significant than reflections from the ground or from nearby objects.

Another new theoretical model for predicting field strengths in a suburban area has been developed (**Ref 30**). It consists of rows of residential buildings of 2 to 4 stories in height. The prediction results were indicated to compare favorably with measured field data. In a comparison of predicted height gain/loss between this proposed new model and an ITU model, the proposed model shows a loss of approximately 13 to 14 dB for a 6’ AGL antenna with a reference of 0 dB for 30’ AGL, which is almost the same as the ITU model. Again, it is noted that the height gain/loss in areas where the building heights exceed the 2 to 4 stories used in this model is likely to be less significant as discussed above.

Besides theoretical studies, actual field measurements can also provide some answers as well. One such field analysis was performed in Charlotte NC to study the effects of field strength variation with receive antenna height (**Ref 31**). The first ACATS field test in Charlotte NC was performed in the spring and summer of 1994 for the purpose of evaluating the new Grand Alliance (GA) DTV transmission subsystem performance under “real-world” conditions of multipath and other propagation phenomena. However, these propagation tests were performed using a receive antenna at the nominal FCC *outdoor* reception height of 30’ AGL. Just prior to the beginning of the second round of Charlotte field testing that began in the summer of 1995, the Joint Technical Committee on Advanced Broadcasting (JTCAB) in Canada decided to perform a field test at many of the same ACATS test sites. The purpose of this test was to obtain propagation data for reception of a wideband (6 MHz) signal at lower receive antenna heights than 30’ AGL and with lower gain antennas since *indoor* and *portable* reception is often expected to operate in these types of environments.

This field test, which occurred between May 26, 1995 and June 9, 1995, utilized the ACATS Charlotte CH 53 transmitter and tower and the omni-directional transmit antenna at 1337’ AGL. A 31.6 kW (ERP) pseudo-random QPSK signal on CH 53 simulated the wideband (6 MHz) flat-spectrum 8-VSB signal. Radial, grid, and cluster locations at 94 of the ACATS test sites were visited, in addition to other *new* locations (arcs and grids) so that a good estimate of coverage could be obtained at these lower receive antenna heights. A mobile van with a low gain, omni-directional antenna mounted on the roof was used for these tests. This receive antenna was approximately 6’ AGL, and the total integrated 6 MHz *average* test signal power was the measured metric. Many of the measurements were recorded continuously as the van was moving. Analysis of this data provided an idea of real-world DTV field strength coverage for indoor and portable receivers as well as established a *height correlation* between 30’ and 6’ AGL. In other words, they were searching for some *indoor* planning factors. Likewise, they would be able to determine the appropriateness of statistical predictive propagation models with respect to location variability and overall reception reliability. Many data points were taken.

The average CH 53 field strength *difference* between 30’ and 6’ AGL result for 117 test sites was 12.8 dB. This was obtained averaging the 11.6 dB difference from the 61 test sites in the grid and clusters (urban and suburban) and the 14.0 dB difference from the 56 points in the radial locations (suburban and rural). This averaged value (12.8 dB) is in good agreement with the calculations discussed above for areas of *non*-rugged terrain and without large numbers of tall buildings (typical conditions in the Charlotte, NC area).

Another evaluation was done recently (**Ref 32**) using recent field strength measurement data from various field tests undertaken in the U.S. This evaluation assessed the performance of DTV at a number of field locations where field strength measurements were performed at both 30’ AGL and 6’ AGL. An analysis of 522 of those field strength measurements yielded the following statistics:

Average loss 30 feet to 6 feet	5.01 dB
Median loss 30 feet to 6 feet	4.88 dB
Standard deviation 30 feet to 6 feet	8.53 dB
Average + Standard deviation	13.54 dB

As can be seen from the above statistics, there are locations where the measured field strength at 6’ AGL was actually *greater* than that at 30 feet AGL. While this may not be very common, it can certainly occur in the field as seen by the data results. This can be attributed to a number of factors such as ground reflections and/or reflections from other nearby objects, signal fading in between the times the two measurements were performed, or the measurements were not made at exactly the same location. The last point is due to the fact that the 30’ AGL measurements in these tests were made using a truck-mounted pneumatic mast whereas the 6’ AGL measurements were made using a nearby tripod mounted antenna. The smaller difference in the average and median height gain/loss values for this study are likely attributed to that fact that a number of the measurements points were obstructed paths (at both 30 and 6 foot) either form terrain and/or buildings, which would agree with the observations noted above concerning less significant differences on obstructed paths.

From the information above, **it appears that UHF and high-VHF planning factors for receive antenna height loss from 30' to 6' for the three scenarios noted above should be approximately 14 dB (worst case), 9 dB (typical case) and 5 dB (best case).** It is noted that "best case" scenario with respect to height loss is likely to occur at locations with overall poor reception.

2) Building Penetration Loss

Building penetration loss (i.e., attenuation) is a very difficult parameter to estimate since there are so many different type of building structures and materials. In addition, the loss will also depend on the receive location within the structure. For instance, if the indoor antenna is positioned near a window of sufficient size so as to not obstruct the incoming signal, and is located on the side of the building facing the transmit site, then the loss will be negligible. On the other hand, if the location is in an interior room of a structure with wire lath plastered walls, the loss will then be very high.

Numerous studies have been undertaken to assess building penetration loss, and some of the useful information found in the literature is used to support the planning factors proposed in this report.

In a published paper (**Ref 33**), loss is affected by not only material type but by the angle of incidence and the amount of water that has been absorbed in the material. Therefore, in areas that experience significant rainfall, the attenuation will be greater due to the water content in exterior walls (assuming the wall material absorbs moisture). It was also confirmed that attenuation increases with signal frequency. However, in the case where a widow is in the path of the incoming signal, the attenuation will be higher at lower frequencies where the wavelength is such that the size of the window presents a Fresnel zone clearance issue. In that situation, the attenuation will drop significantly when the wavelength becomes sufficiently small to have Fresnel zone clearance, and then again increase with frequency due to the penetration loss though the glass. The report shows that, for a windowed wall, the attenuation in the broadcast band ranged from less than 1 dB to almost 4 dB depending on the frequency.

In another published paper (**Ref 34**), measurement results summarizing the loss through various building material at 840 MHz was given, as shown in **Table 14**:

Table 14 Signal penetration loss for various materials

At 840 MHz	
Construction Material	**Penetration Loss (in dB)**
15 cm brick wall	2.5
28.5 cm brick wall	3.5
3.5 cm wood block wall	0.5

In another published study (**Ref 35**), signal penetration measurements were made to determine the loss through various building materials. The results are shown in **Table 15**:

Table 15 Signal penetration loss for various materials

Construction Material	Signal Frequency	Approximate Penetration Loss
35 cm heavily reinforced concrete wall	1.0 GHz	22.0 dB
12 cm lightly reinforced uniform concrete wall	500 MHz	7.0 dB
12 cm plasterboard wall	800 MHz	4.0 dB
12 cm lightly reinforced non-uniform concrete wall	500 MHz	7.0 dB

A university researcher (**Ref 36**) reported on test measurements regarding signal loss through a 30 cm thick concrete wall covered with plaster. The result was 5.8 dB of loss at 800 MHz, which is at the current UHF channel 69 frequency.

In a paper (**Ref 37**), the following losses are reported for the frequency band 1.9 GHz to 2.5 GHz. Although the frequencies are above the UHF television broadcast band, the information is useful since it can be expected that the losses shown here for these high frequencies will be greater than will be experienced at the lower frequencies used for broadcast television. A summary of the penetration losses is included in **Table 16**:

Table 16 Signal penetration losses for various materials at frequencies between 1.9 GHz and 2.5 GHz.

Commercial Building Type	Code	Buildings tested	90TH Percentile Signal Loss dB
1. Brick and Glass	B1	28	30.32
2. Concrete and Glass	B2	28	33.30
3. Cinderblock and Glass	B3	0	NA
4. Metalized Glass and Steel	B4	5	23.88
5. Wood Frame and Glass	B5	1	14.00
6. Stucco and Glass	B6	4	35.27
7. Brick/Stucco/Glass	B7	2	20.97
8. Metal/Glass	B8	0	NA

Residential Building Type	Code	Buildings tested	Signal Loss dB'
1. Apartment Building Brick and Glass	R1	2	14.65
2. Brick and Glass	R2	19	19.13
2. Brick and Glass 3. Single Family Wood Frame and Glass	R2 and R3	25	20.75
3. Single Family Wood Frame and Glass	R3	8	15.74
4. Apartment Building Wood Frame and Glass	R4	0	NA
5. Stone Façade with Wood and Glass	R5	5	17.28
6. Apt. Combo Brick/Wood/Glass	R6	5	17.29
7. Apt Concrete/Glass	R7	0	NA

Continuing on with the reference material, another report (**Ref 38**) states that, based on over 300 measurement in 40 residential houses, apartment buildings and office buildings, the *typical* building penetration loss in 90% of the buildings will be smaller than 15 dB. It goes on to say that the combined height/building penetration loss compared with a 10 m AGL (i.e., 30' AGL) outdoor antenna will be less than 22 dB in 90% of the buildings.

Another published paper (**Ref 39**) indicates that building attenuation to be in the range of 10 – 25 dB, although no supporting documentation is provided.

A large study of indoor measurements in 33 residential building in Great Britain was analyzed and documented (**Ref 40)**. While the report is silent on the type of buildings that were measured, the assumption is that these are apartment-type buildings in that the measurements were conducted on the ground floor as well as on two *additional* floors. The purpose of the measurements was to determine the required field strength outside at 10 m (approximately 30') AGL in order to have a decodable signal inside. It should be noted that the desired minimum field strength in this case was assumed to be 45 dBµV/m since the test was performed with the European DVB system, which has a higher noise threshold that the ATSC transmission system used in the U.S. However, the report is useful in that it provides additional information showing the affects of height gain/loss and building penetration loss. The results of these measurements were broken down as shown in the **Table 17** and **Table 18**.

Table 17 Statistical description of required outdoor field strength at 30' AGL for indoor reception

	50% of Rooms		**All Rooms**	
Room Category	**50% of locations within room**	**90% of locations within room**	**50% of locations within room**	**90% of locations within room**
Ground Floor	74	79	86	91
1st Floor	69	74	81	86
2nd Floor	68	74	79	84
Minimum Field Strength Required (dB uV/m) at 10 meters outside to achieve various levels of indoor coverage (signal was decodable)				

Table 18 Statistical description of height and penetration loss for indoor reception

	50% of Rooms		**All Rooms**	
Room Category	**50% of locations within room**	**90% of locations within room**	**50% of locations within room**	**90% of locations within room**
Ground Floor	29	34	41	46
1st Floor	24	29	36	41
2nd Floor	23	29	34	39
Combined height and building penetration loss (dB) based on the above table of Minimum Field Required Strengths				

In the United States, part of the field strength measurement program discussed earlier in this report also included indoor measurements with corresponding outdoor measurements at 6' AGL. An analysis of 110 measurements on UHF channels produced the results shown in **Table 19**:

Table 19 Summary of building loss estimates

Average Loss in dB	11.58
Median Loss in dB	11.65
Standard Deviation	9.87

A report **(Ref 42)** discussing radio propagation in urban areas notes that a study was undertaken in the early 1960's by the FCC to evaluate the usefulness of UHF television broadcasting in the New York City area. This project included measurements of TV channels 2, 7 and 31 at almost 4,000 fixed locations with half of them being in Manhattan. That report indicated that the combined height and building penetration from rooftop to inside was about 30 dB at VHF and 26 dB at UHF in Manhattan and 5 dB less in the surrounding areas out to 25 miles from the transmitter site (Empire State Building).

Based on the various reports discussed above and the expectation that viewers will attempt to find suitable locations for reception within the home, **the following UHF and VHF planning factors for building penetration loss for the three situations noted above should be approximately 20 dB (worst case), 12 dB (typical case) and 5 dB (best case).**

3) Receive Antenna Characteristics

The FCC assumes (**Ref 16**) that outdoor directional antennas are at 30' AGL (and pointed towards the desired transmitter) with the OET-69 published gains (10 dBd for UHF and 6 dBd for high-VHF) and front-to-back ratios (14 dBd for UHF and 12 dBd for high-VHF) for each television band. At this time, **there is no reason to change these outdoor antenna characteristic values.**

Consumer antennas of comparable performance are currently available on the market for reasonable prices. Certainly, if a television viewer residing on the fringe (i.e., near the noise-limited contour) is attempting to watch DTV signals, there are the usual options to increase the chances of successful reception by changing some of the receive site parameters such as installing a larger gain antenna, increasing the height of the outdoor antenna above the ground, adding a robust antenna preamplifier (or buying an "active" antenna that has the preamplifier built inside), and/or installing lower loss coaxial feedline cable. Active outdoor antennas with low noise figures (.e.g., 4 dB) and high gain amplification (> 20 dB) will *lower* the effective system noise figure (which typically has a total value of 11 dB due to the 7 dB noise figure plus 4 dB cable loss in a passive configuration) by perhaps as much as 7 – 8 dB in an active configuration. In addition to lowering the effective system noise figure, the active antenna can also improve the antenna mismatch loss to the cable/receiver system, minimizing strong reflections and minimizing an increased receiver noise figure due to severe mismatches. In markets with transmitters in diverse locations, viewers can also employ remote-controlled rotors or multiple combined antennas. Therefore, there are ways to mitigate these problems for outdoor reception.

However, the FCC has no *indoor* antenna planning factors. Indoor reception may be a fairly common way to view broadcast television in some of the large urban areas such as New York City. In creating indoor antenna planning factors, there are a variety of characteristics to consider (**Ref 20**, **Ref 21**). For example, either passive or active antennas can be utilized. Another issue is one of directionality. Indoor antennas can be directional (e.g., small log periodic or Yagi with narrow beamwidth azimuth patterns), pseudo directional (e.g., a dipole with a “figure-8” azimuth pattern or “rabbit ears” at 45 degrees) or omni-directional (e.g. cross-dipole or vertical “whip” antenna). Another consideration is diversity (e.g., spatial, polarization, or directional/rotational). Finally, in the modern era, a “smart” antenna can be utilized where one or more of the antenna characteristics (e.g., gain, main lobe direction or polarization) are varied under control of the DTV receiver. There already exists a CEA-909 smart antenna control interface standard that uses a separate connector to exchange information between the smart controller and the antenna. However, an updated version of this CEA standard that allows this communication to take place over the coaxial RF cable is expected to be approved in June 2007.

The *indoor* antenna planning factors can be difficult to assess since there are so many different types of antennas that viewers might use and within many various room locations within different style buildings. However, some choices have to be made, and they are made for three different reception scenarios. For this report, consideration of *indoor* antenna planning factors was based on the recent MSW antenna measurement report to the **MTVA** (**Ref 21**).

The UHF band is considered first. In the best-case indoor scenario at 15’ AGL, an amplified directional Sharpshooter antenna, with a gain of +11 dBd is selected. For the typical-case indoor scenario at 6’ AGL, a passive directional UHF Silver Sensor (log periodic) antenna with a +5 dBd gain is selected. And for the worst-case scenario, a passive dipole antenna (e.g. bow tie or loop) with a 0 dBd gain is selected.

The high-VHF band is considered next. In the best-case indoor scenario at 15’ AGL, an amplified directional Sharpshooter antenna, with a +2 dBd gain is selected. For the typical-case indoor scenario, a passive pseudo-directional dipole antenna with a 0 dBd gain is selected. In the worst-case scenario, a passive mostly omni-directional model ANT115 set of 45-degree “rabbit ears” with a -2 dBd gain is selected.

4) Cable Feedline Characteristics

The FCC selected the outdoor planning factors for cable feedline loss (**Ref 16**) assuming 50’ of coaxial cable in a typical installation. The FCC assumes a cable loss of 4 dB for UHF and 2 dB for high-VHF. **At this time, there is no reason to change these outdoor cable feedline loss values.**

Since there are no indoor planning factors in existence, cable loss values must be selected. It is expected that no more than 3’ of coaxial cable is used in the typical installation. **Loss value of 0.5 dB for UHF** and **0.25 dB for high-VHF are assumed.** These are conservative values, but one can also assume that perhaps some indoor antennas might be used with a power inserter that exhibits a nominal value of loss.

5) RECEIVER PERFORMANCE CHARACTERISTICS

The RF performance of the DTV receiver plays a pivotal role in whether DTV reception is possible specifically in a given location or statistically in a large area. The following receiver characteristics describe a typical (i.e., median) receiver’s performance for the purpose of planning factors that can be used to predict DTV performance. Whenever possible, values slightly more conservative than median were selected.

A) Theoretical Matched Noise Floor

The theoretical white noise floor of a matched system is defined as kTB (**Ref 5**), and is equal to -106.2 dBm/6 MHz. This 6 MHz channel noise power value, which describes the amount of noise at the front end of a theoretically perfect (i.e., noise-free) tuner, is the same for both UHF and high-VHF.

B) Noise Figure

Dynamic range is often *not* described as a planning factor, albeit it is a very important receiver characteristic that greatly affects a DTV receiver's ability for successful reception. It is defined as the ratio of maximum allowable *unimpaired* input signal level to the minimum unimpaired input signal level that produces error-free video and audio. The DTV receiver sensitivities measured in the *early* prototype receivers on CH 54 for Zenith (**Ref 24**) and Samsung (**Ref 25**) were -78.4 dBm/6 MHz, and -84.7 dBm/6 MHz respectively (Linx was not tested for RF sensitivity). The FCC tests on twenty-eight 4th and 5th generation consumer DTV sets from 2005 (**Ref 26**) had *median* sensitivity value of -83.2 dBm/6 MHz for high-VHF (range from -78.9 to 84.9) and -83.9 dBm/6 MHz for UHF (range from -81.4 to -85.3). The MSW tests had *median* UHF sensitivities (measured on channels 14, 33, and 65) of -83.9 dBm (range from -79.5 to -84.1). On high-VHF (measured on channel 12), the *median* sensitivity value for the five 5th generation units measured by MSW was -83.3 dBm/6 MHz (range of -78.4 to -84.3), with the median value increasing if the USB receiver is ignored. While sensitivity is not a "direct" planning factor that is used, but rather a calculated value from other receive site planning factors (theoretical kTB noise floor plus noise figure plus white noise threshold SNR), it is useful to see if actual consumer receivers can meet the -84 dBm theoretical value. **Therefore, the test data indicates that the *median* sensitivity value of tested consumer receivers does meet the -84 dBm/6 MHz value for both UHF and high-VHF. On the other hand, the maximum signal level that can handled, as measured in the MSW laboratory tests, can be safely set at 0 dBm/6 MHz as the *worst* case measured value was +1.6 dBm/6 MHz.**

The importance of laboratory sensitivity tests is that the receiver *noise figure* planning factor can be calculated. **Given that the measured median sensitivity values are close to the -84 dBm/6 MHz value, the *calculated* noise figure is about 7 dB for *both* UHF and VHF.** This is a reasonable median value based on the laboratory measurements, especially if consideration that the tests included some older generation receivers.

C) White Noise Threshold SNR

The white noise thresholds measured in the early prototype receivers at moderate DTV levels (i.e., -53 dBm/6 MHz) for Linx (**Ref 23**), Zenith (**Ref 24**) and Samsung (**Ref 25**) were 15.1, 15.5 dB, 15.0 dB respectively. The FCC performed tests on 28 4th and 5th generation consumer DTV sets from 2005 (**Ref 26**), with results varying from 14.9 dB to 15.8 dB (median of 15.3 dB). Additionally, it was determined by the FCC that the better performing receivers for multipath (i.e., the 5th generation), actually had *lower* white noise thresholds (< 15.5 dB). The MSW laboratory tests (**Ref 22**), which evaluated the performance of 5 of the fifth-generation DTV receivers, resulted in white noise thresholds that varied from 14.9 dB – 15.4 dB. **Therefore, the test data indicates that a range of 15.0 – 15.5 dB is acceptable for white noise threshold planning factors.**

D) Multipath Diversity Antenna Advantage

This parameter takes advantage of multiple receive antennas (often only two in simple consumer receivers) in enhancing DTV reception in severe multipath conditions. By using some form of diversity (e.g., spatial, polarization, or directional/rotational), the received signal can be enhanced by subsequent digital signal processing, and perhaps avoid to a large extent the complete fading of the distorted signal.

In this report, it is assumed that <u>*no*</u> diversity receive antennas will be used (i.e., 0 dB signal enhancement), but rather only simple active or passive indoor or outdoor antennas.

E) Multipath Noise Enhancement

Multipath is a *linear* distortion that is removed with a *linear* equalizer that every DTV receiver has within its circuitry. However, the removal of multipath does not come without a cost. For example, as the taps of the tapped delay line that makes up a time-domain equalizer are increased in order cancel the various correlated echoes, the uncorrelated white noise at the input to the DTV tuner is enhanced, with its level increased by an amount depending on the strength and type of the multipath that is being cancelled. This is referred to as *multipath noise enhancement* that occurs in DTV equalizers.

Before any quantitative values for noise enhancement can be determined, an assumption must be made regarding the equalizer echo cancellation range. Since a DTS system generates its own echoes, albeit in a reasonably controlled manner (delay optimization), the 5G receivers must have a cancellation range of at least ±20 µsecs. This does not sound like a difficult requirement since the MSW tests indicate much longer cancellation ranges. However, the paired echo test, where two echoes are *simultaneously* applied with approximately the same absolute delay but one is a pre-echo and the other is a post-echo, is important to show the necessary equalizer performance. This is due to the fact that the recent 5G receivers have *variable positioning* of the center tap, which means that while a receiver might cancel a -47 µsecs echo and a +47 µsecs echo separately, they can only cancel a *pair* of simultaneously-applied echoes of ±23 µsecs. Since DTS systems have multiple low-power repeaters, it generates multiple simultaneous echoes, and they are timed so that the ensemble of "artificial" DTS echoes are short as possible, with both pre-echoes and post-echoes being possible.

To quantify indoor and outdoor multipath noise enhancement for DTV reception, the laboratory test data from MSW (**Ref 22**) is considered. For instance, the static Brazil B multipath ensemble is made up a combination of short and medium length strong echoes. The five consumer DTV receivers had a median value of noise enhancement around 4.5 dB. The static Brazil C multipath ensemble has *very* strong short post-echoes, and caused the five receivers to have a 6 dB median noise enhancement. Finally, the static Brazil D multipath ensemble has very strong pre-echoes, and caused the five receivers to have an 8 dB median noise enhancement (the pre-echoes causing more noise enhancement than the post echoes). Another good multipath test that simulates short echoes like those found indoors is the CRC modified Brazil C ensemble. It has all the same echo delays and amplitudes as the Brazil C (and D) ensembles except that a post-echo (pre-echo) is set to the highest level before errors occur. Since this value was 0 dB for all 5 receivers under test (meaning the equalizer could handle this 100% echo in the presence of 4 other strong echoes), white noise was added. It was determined that the median noise enhancement for the five receivers was about 4.5 dB for the post-echo ensemble and 7 dB for the pre-echo ensemble. Again, the multipath ensemble with the pre-echoes has higher noise enhancement than the one with post-echoes.

Therefore, conservative planning factors of 4, 6, and 8 dB for the best-, typical-, and worst-case scenarios seem appropriate for both UHF and high-VHF.

Of course, all of these laboratory tests indicate results that do *not* account for *antenna adjustment* by the viewer in the field that might account for slightly better reception conditions. For example, if a directional antenna is used, and slightly rotated, some of the severe 75% - 95% amplitude echoes might be reduced below 75% and cause much less noise enhancement. Or by adjusting a bi-directional antenna slightly might change difficult pre-echoes into post-echoes and gain some improvement in noise-enhancement. Likewise, if smart antennas become prevalent in the next couple of years, the same results might occur as well.

The above ensembles are typically much stronger than what is experienced with an outdoor antenna. **Therefore, a slightly lower noise enhancement value of 3 dB was selected.** This median value may be slightly conservatively for most typical outdoor reception venues; however, for highly urbanized areas such as New York City, this value may be appropriate even for outdoor reception.

F) Multipath Signal Fading Level

This parameter describes the inherent signal fading that occurs during propagation, sometime caused by pure broadband signal level fades or when short delay multipath is present in such a phase that it adds destructively and also causes a fairly broadband signal fade. This signal fading, which is an effect caused by RF propagation, is treated separately from multipath noise enhancement, which is an effect caused within the receiver itself. At the moment, more study is required to understand the magnitude of this problem, which can occur near the noise-limited contour when receive sites might be just over the horizon or in nearby urban areas with no line-of-sight to the transmitter.

For now, signal fading levels 1 dB for outdoor reception and of 2, 3, and 4 dB for indoor reception can be used until more information **becomes available.** It is believed that the Doppler frequency of these fades is well within the speed of the AGC and equalizer circuits.

G) Sky and Man-Made Noise Enhancement

This parameter describes the external man-made noise that exists in the lower frequency television bands. The FCC, in its calculation of minimum field strengths for the NTSC Grade A *urban* contour, assumed man-made noise enhancement of 14 dB for low-VHF and 7 dB for high-VHF. These man-made external noise values actually came from the 6th Report and Order in the 1950s (**Ref 7**), were described by O'Connor in 1968 (**Ref 5**), but were reviewed and re-evaluated in 1977 (**Ref 41**). However, its NTSC Grade B rural contour assumed no man-made noise enhancement since it was out in the rural areas far away from the strong urban noise effects. Currently, there is debate concerning how much extra margin is required to account for this extra man-made noise enhancement in this modern, high-tech era. While the NTSC Grade B contour is analogous to the noise-limited contour with DTV, a similar philosophy can be applied to the outdoor limits described by the outdoor DTV planning factors since they refer to the rural noise-limited regions.

However, when considering *indoor* planning factors, which are assumed to describe reception scenarios within 25 miles of the transmitter and primarily in *urban* areas, it seems reasonable to account for some amount of man-made noise enhancement. More data and field measurements are needed since very little current data exists. **Therefore, until further data is available, a noise enhancement of 7 dB can be added to the high-VHF planning factors, and none to the UHF planning factors.**

H) Mismatch Loss

Mismatch loss is the situation of a receive antenna source impedance not having a matched load impedance (i.e., the DTV receiver tuner input). Since optimum power transfer occurs with a matched load (i.e., the load impedance is the complex conjugate of the source impedance), anything other than a matched load will cause a signal power loss.

Mismatch loss in DTV receivers is ***not*** yet quite well established or well-documented, and therefore more laboratory measurements must be made. Some of the mismatched impedance causes plain signal loss, while other mismatch loss may cause receiver noise figure degradation. There are some references to it made in published papers (**Ref 18**), but some of these predicted values seem extreme and therefore need to be verified. **For now, some place holders of 1, 2, and 3 dB are used for the best-, typical-, and worst-case scenarios for both UHF and VHF.** Of course, some of the mismatch loss can be mitigated with an *active* receive antenna that has better output return loss than a passive antenna.

I) Interference Protection D/U Ratios

Interference performance characteristics are related to the relative signal strength of undesired interfering television signals to the desired DTV signal. During the transition, both analog and digital interferors were considered. In this analysis, only DTV-into-DTV is being considered as this work is primarily focused on DTV reception *after* the transition.

Currently, there are no UHF *taboo* protection ratios in the FCC rules for DTV-into-DTV interference. Only first adjacent channel protection exists from interfering DTV signals. ATSC A/74 (**Ref 19**) has a list of *recommended* adjacent channel and taboo specifications. All of these protection ratios, along with the recommended MSW protection ratios can be found in **Table 22**.

In order to develop such a table of recommended specs, analysis was performed on recent data obtained from the CRC, FCC, and MSW laboratory tests. The CRC data came from a report (**Ref 27**) that was published in January of 2007 that contained test results of 5 DTV receivers of varying ages. The FCC test data came from a report (**Ref 28**) that was published in March 2007 which described test results of 8 relatively recent DTV receivers (2005 and 2006 models). In both of these reports, UHF adjacent channel and taboo interference testing was performed and documented. All of this data, along with the MSW laboratory data taken in March 2007, was summarized in **Table 23**, **Table 24**, and **Table 25** of this current report for strong, moderate, and weak desired DTV signal levels, respectively.

Median values of the various D/U ratios from the 10 receivers in the CRC and MSW laboratory tests were calculated for each channel offset from the desired. These median values were then compared to the FCC's median values from their lab test of the twenty-eight 4th and 5th generation consumer DTV receivers. A *conservative* median value was then selected for each channel offset D/U ratio. This means that instead of a real median value, a value that would encompass perhaps up to 70% or 80% of the measured receivers.

Further evaluation needs to be done on *multiple* DTV interferers, and how they might be described in terms of planning factors for interference protection ratios. D/U ratios should not only be based on the two special interferers (e.g., N+1/N+2 or N-2/N-4, etc.) having equal signal amplitudes, but also when they do not have equal amplitudes. This work is on-going, and requires further evaluation.

OVERALL ANALYSIS

The calculated minimum field strength values (in dBμV/m) for the outdoor case and the three indoor scenarios are shown in **Table 20** and **Table 21** for UHF and VHF, respectively. The equation to calculate the minimum required field strength for successful DTV reception is:

$$E = N_{kTB} + NF + SNR_{TOV} - MDAA + MNE + MFL + LM - L_C - K_D - G_A \tag{29}$$

The updated *outdoor* field strength to achieve outdoor UHF DTV reception is 47 dBμV/m, which is about 6 dB above the FCC planning factors (i.e., 41 dBμV/m). In actual applications, those viewers on the fringe would need to use receive equipment that was rated better than the FCC planning factors. However, this is easily done by using higher gain "fringe" antennas mounted higher above the ground and/or using robust antenna preamplifiers.

The three *indoor* UHF scenarios require minimum outdoor field strengths to achieve *indoor* DTV reception that vary quite a bit (more than 35 dB). The calculated UHF outdoor field strengths are 53 dBμV/m for the best case scenario, 76 dBμV/m for the typical-case scenario, and 99 dBμV/m for the worst-case scenario. However, it should be stressed that this worst-case value is ***not*** recommended for DTS operation in large urban areas as it has a higher probability of causing interference to other analog and digital signals that are present, especially in the vicinity of DTS transmitters where signal strengths are highest. The DTS system is often considered an *interference-limited service*, where managing interference levels to nearby television signals is a primary concern. Therefore, this worst-case scenario is shown for illustrative purposes, and to emphasize that viewer education on what to do and what NOT to do at receive sites regarding location and type of antennas is needed. The typical field strength value of 76 dBμV/m is a reasonable value to assume.

The updated *outdoor* field strength to achieve outdoor high-VHF DTV reception is 46 dBμV/m, which is about 10 dB above the FCC's planning factor (36 dBμV/m). The large part of this additional 10 dB difference is due to the use of the 7 dB man-made noise factor to account for use in urban areas. Just like the UHF situation, better outdoor antennas or robust antenna preamplifiers can be used, if necessary.

The three *indoor* high-VHF scenarios require minimum outdoor field strength values to achieve *indoor* DTV reception that vary quite a bit (more than 35 dB). The calculated high-VHF outdoor field strengths are 59 dBμV/m for the best case, 77 dBμV/m for the typical case, and 98 dBμV/m for the worst case. Again, it is *not* recommended to use the worst case value due to increased risk of interference to other television services. The typical field strength value of 77 dBμV/m is a reasonable value to assume.

The multipath performance was observed to be excellent in the recent 5G DTV receivers, handling many of the difficult RF data captures and the severe multipath ensembles generated in the laboratory. Multipath noise enhancement, which is ignored in the FCC planning factors, can be assumed to be only 3 dB for most outdoor reception scenarios, but between 4 – 8 dB for severe indoor ensemble echoes. This is not as bad as the predicted values of 10 – 15 dB in the very early days of the transition.

The interference rejection ratios are representative of recent consumer products and not just a reference prototype like the 1995 Grand Alliance receiver that was tested at Advanced Television Test Center (ATTC). The other important aspect is that *non*-constant interference protection D/U ratios are now proposed that will vary with strong (-28 dBm/6 MHz), moderate (-53 dBm/6 MHz), and weak (-68 dBm/6 MHz) desired DTV signals levels.

Based on these various planning factor values, the required minimum field strength can be calculated in a given frequency band (e.g, UHF or high-VHF) for a given set of propagation and receive site conditions. An updated version of the outdoor planning factors can be utilized for urban areas that extends the analysis (and requirements) of the FCC's rules. Three new sets of indoor planning factors are provided so that the broadcaster who wants to predict indoor DTV reception in a variety of urban conditions can do so with some flexibility.

SUMMARY

This report provides a summary of the basics of both propagation and receiver site theory as it relates to DTV field strength and service prediction with and without DTS service. Both indoor and outdoor service is of great importance to the broadcast industry. Reasonably accurate planning factors are a key part of the modeling that is required by computer prediction algorithms and programs. Two basic parts of DTV and NTSC service prediction are (1) propagation analysis and (2) receiver RF performance.

Propagation effects are clearly not trivial to describe or analyze due to the large number of variables and conditions that the electromagnetic waves must endure. Prediction models, such as Longley-Rice, attempt to account for as many of the terrain variables as possible, and they are an improvement over the FCC's statistical field strength curves that assume "average terrain." Nevertheless, further development of these models is needed if better prediction accuracy is desired. This is especially true for coverage and field strength prediction in highly urban areas, the so-called "concrete canyons" such as New York City, Chicago, and Los Angeles. Understanding of the effects of densely-situated building structures is critical in these areas. In the mean time, the previous literature provide some rough estimates of urban area performance for VHF and UHF television propagation, as described in this report regarding signal loss with reduced height and building penetration loss at both VHF and UHF frequencies.

Receiver RF performance effects also play a major role in the accuracy of DTV service. This report is based on the current 5th generation receiver performance, starting with some of the early *prototypes*, followed by *early production* models in 2005, and the followed by the very recent 2006 *products* as well as NTIA D/A converter *prototypes*. While all the RF performance factors play a role in successful DTV reception, of particular interest is the performance of (1) the tuner's interference capability, and (2) the equalizer's multipath cancellation. Both of these performance planning factors are critical to both understanding and predicting *urban* outdoor and indoor DTV reception. Evidence is abundant that RF performance of each generation of VSB receiver is still improving with each laboratory and field study that is performed. There is no reason to believe that further DTV receiver improvements will not continue.

The above description of the planning factor ***parameters*** is meant to be all-encompassing as possible. However, while ***values*** selected for some of the parameters are quite well-established and generally accepted, many of these parameters are only based on theoretical assertions or limited field measurements that are not necessarily statistically relevant for urban outdoor or indoor DTV reception. The accuracy of any prediction requires not only a complete set of defining parameters, but also accurate, real-world *values* for those parameters. The modifications to the FCC *outdoor* planning factors that are described in the FCC rules (and re-iterated in OET Bulletin 69) seem to be reasonable, although a couple of the parameters need further development. On the other hand, the newly proposed *indoor* planning factors have many parameters that need significant development of reasonable values based on real-world measurement and analysis.

All the planning factor parameters should be evaluated from time to time to see if new data analysis indicates updates are needed. One important parameter, especially for DTS systems with remote low-power repeaters, is the transmit antenna elevation patterns. Actual elevation patterns should be used in the planning factors and not the reference pattern that appears for full-service stations in OET Bulletin 69.

Nevertheless, these proposed planning factors can be viewed as a ***preliminary*** engineering attempt to define DTV reception in urban areas for both outdoor and especially indoor receiver sites. It is definitely anticipated that these planning factors will require updates and revisions as more scientific *laboratory* and *field* tests are performed followed by detailed scientific analysis. The upcoming **MTVA** field test may help further the work towards better planning factors and more accurate *indoor* DTV service prediction.

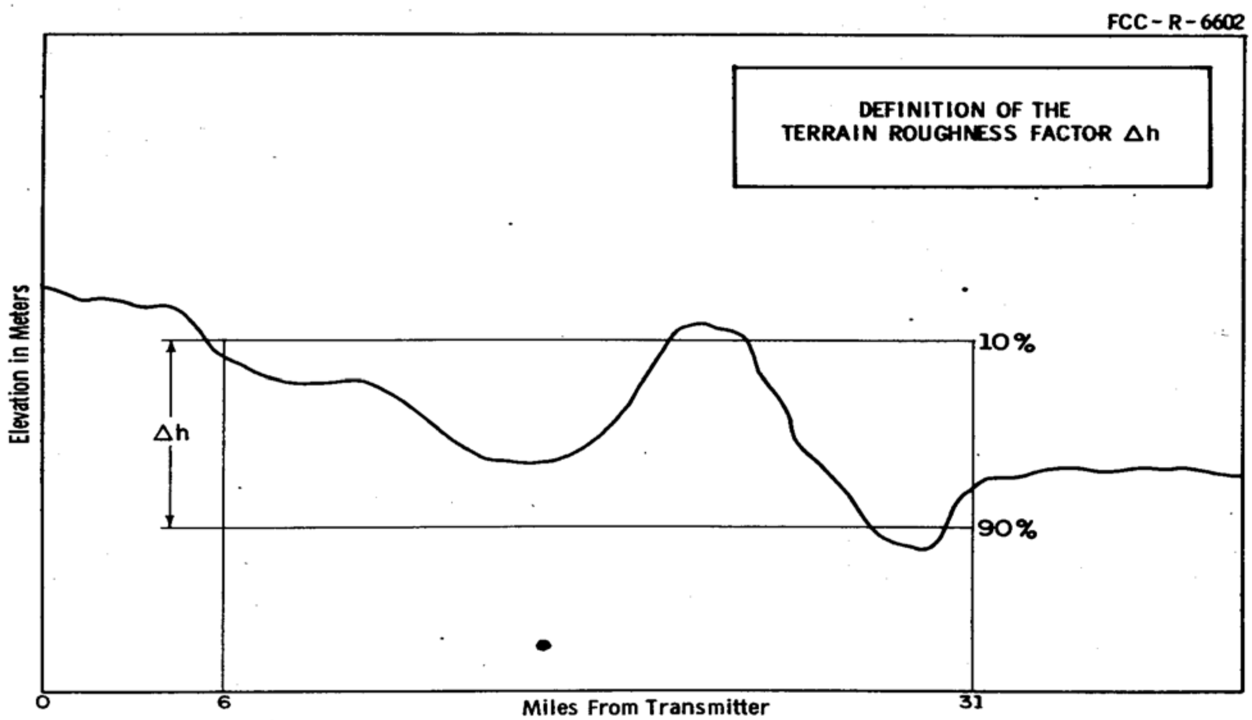


Figure 1 Terrain roughness correction factor

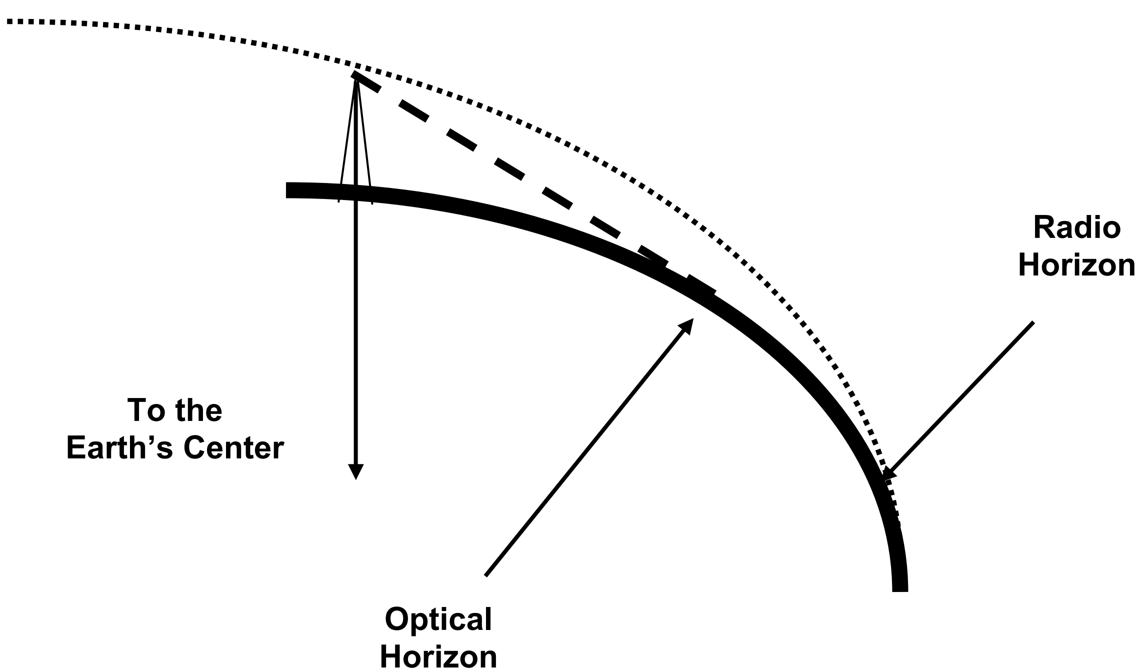


Figure 2 Comparison of optical and radio horizon

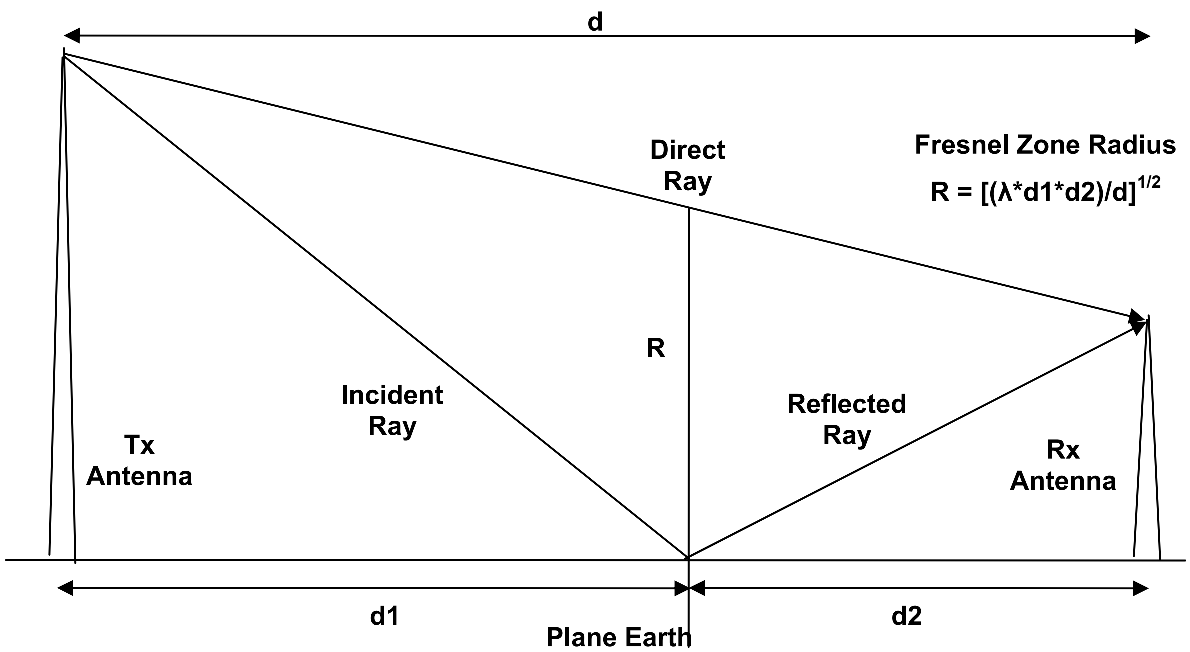


Figure 3 Multipath from ground reflections, which can be either constructive or destructive.

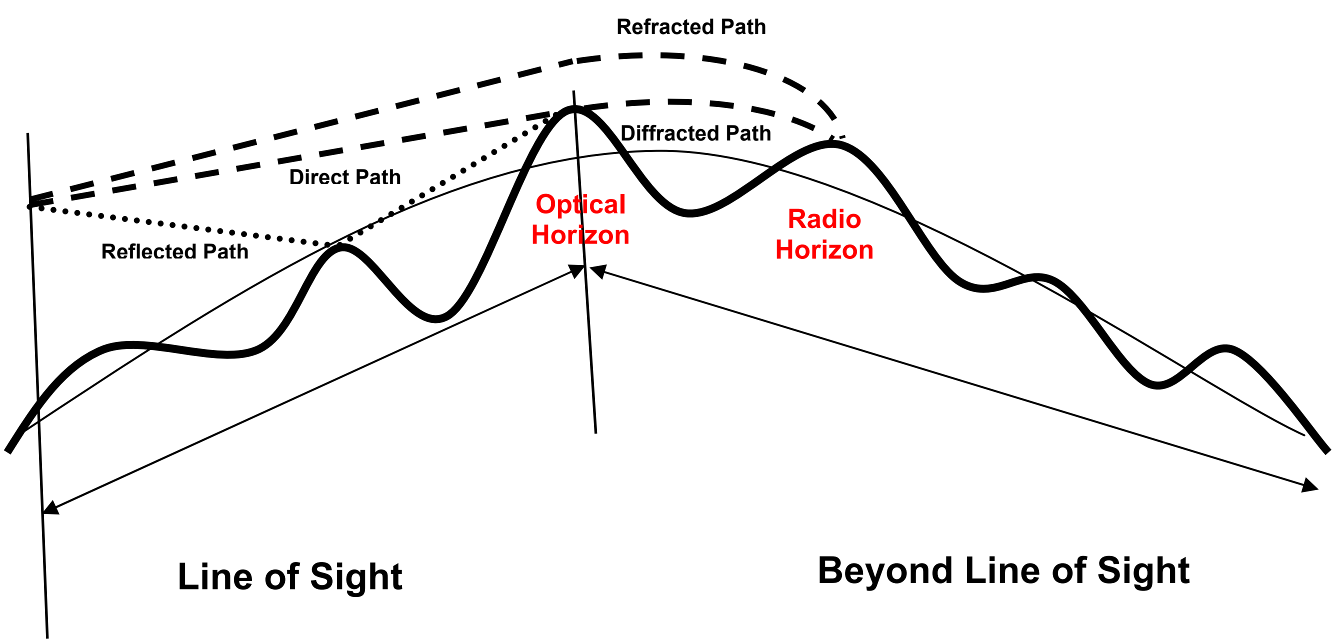
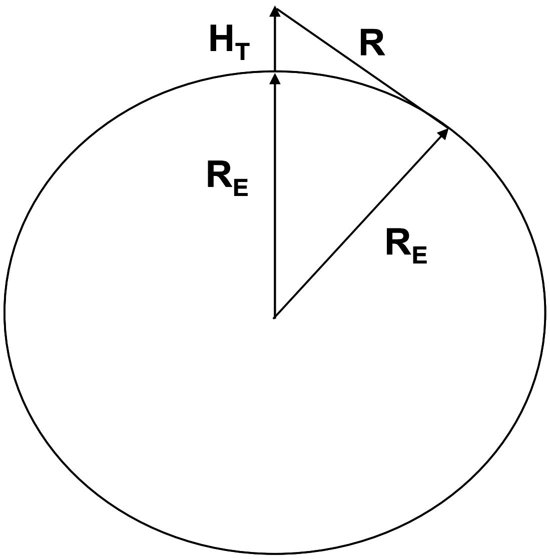


Figure 4 Summary of modes of propagation as a function of distance and terrain.



R = Line-of-Sight Distance

H_T = Tx Height (AGL)

R_E = Radius of Earth

$R_E \approx$ 6250 km = 3880 miles = 2.1x10^7 feet

NOTE

1 inch = 2.54 cm = 25.4 mm

1 meter = 39.4 inches = 3.28 feet

1 foot = 12 inches = 0.30 meters

1 mile = 1.61 km = 5280 feet

1 km = 0.62 mile = 3280 feet

- **Using Pythagorean Theorem:**
  - $R^2 + R_E^2 = (R_E + H_T)^2 = R_E^2 + 2\,R_E\,H_T + H_T^2$
  - $R^2 = 2\,R_E\,H_T + H_T^2$
  - $R = \text{SQRT}\{\,2\,R_E\,H_T + H_T^2\,\} \approx \text{SQRT}\{\,2\,R_E\,H_T\,\}$ if $R_E >> H_T$
  - $R = 1.22 * \text{SQRT}\{\,H_T\,\}$ where H_T is in feet

Figure 5 Distance to *optical* horizon calculation (replace 1.22 with 1.414 for *radio* horizon)

References

1 "ATSC Digital Television Standard", Document A/53E, www.atsc.org.

2 FCC rules, CFR 47, Subpart E, Section 73.601 – 73.699.

3 "Longley-Rice 101", W. Meintel, NAB Broadcast Engineering Conference, Las Vegas, NV, April 6, 2003.

4 Implementation of the Satellite Home Viewer Extension and Reauthorization Act 0f 204, Report & Order, FCC-05-187, adopted 11/02/05, released 11/03/05.

5 "Understanding Television's Grade A and Grade B Service Contours", Robert A. O'Connor, originally written in 1968, but republished in IEEE Transactions on Broadcasting, Vol 47, No. 3, September 2001.

6 "Third Report", FCC Rept. 51-244, adopted March 21, 1951.

7 "6th Report and Order", FCC-52-294, Docket # 8736, 8975, 9175, 8976, adopted 4/11/52; released 4/14/52.

8 "Development of VHF and UHF Propagation Curves for TV and FM Broadcasting", Jack Damelin, William A. Daniel, Harry Fine, and George V. Waldo, FCC Report No. R-6602, September 7, 1966.

9 "The Television Allocations Study Organization – A Summary of Its Objectives, Organization and Accomplishments", George R. Town, Proceedings of the IRE, 1960.

10 "Engineering Aspects of TV Allocations", TV Allocations Study Organization Reports to FCC, March 16, 1959, and June 13, 1960. See also Proc. IRE, June 1960.

11 "Report and Order: Field Strength Curves and Field Strength Measurements", FCC 75-636, Docket # 16004 and 18052, adopted May 29, 1975; released June 27, 1975.

12 "Report of the Working Group for the Engineering Conference in Docket No. 16004 on the Development of New FM and TV Propagation Curves", Harry Fine, chairman, April 1966. (FCC report has both dates)

13 "Further Notice of Proposed Rulemaking: Field Strength Curves and Field Strength Measurements", FCC 71-422, 36 Fed. Reg 8699, 1971.

14 "Fading Channel Communications", Peter Monsen, IEEE Communications Magazine, January 1980.

15 "A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Model", NTIA Report 82-100, G.A. Hufford, A.G. Longley, and W.A. Kissick, U.S. Department of Commerce, April 1982 [NTIA – ITS, 325 Broadway, Boulder, CO 80303-3328].

16 "Longley Rice Methodology for Evaluating TV Coverage and Interference", OET Bulletin No. 69, February 6, 2004.

17 "Television Service Predictions: Actual Measurements Vs Computer Modeling", W. Meintel, NAB Broadcast Engineering Conference, Las Vegas, NV, April 23, 2001.

18 "DTV Coverage and Service Prediction, Measurement and Performance Indices", O. Bendov, J. Browne, C. Rhodes, Y. Wu, and P. Bouchard, IEEE Transactions on Broadcasting, Vol 47, No. 3, September 2001.

19 "ATSC Recommended Practice: Receiver Performance Guidelines", Document A/74, June 18, 2004, www.atsc.org.

20 "A Report to the Metropolitan Television Alliance Regarding Survey and Report of Consumer Indoor Antennas for DTV Reception", William Meintel of MSW, January 23, 2007.

21 "A Report to the Metropolitan Television Alliance Regarding Measurements and Assessments of Consumer Indoor Antennas for DTV Reception", Gary Sgrignoli of MSW, January 23, 2007.

22 "A Report to the Metropolitan Television Alliance Regarding Results of Laboratory Testing of Digital Television Receiver RF Performance", William Meintel, Gary Sgrignoli, and Dennis Wallace of MSW, April 29, 2007.

23 "Results of the Laboratory Evaluation of Linx ATSC Prototype Receiver with 8-VSB Modulation for Terrestrial Broadcasting", Communications Research Centre Canada, April 4, 2002, see CRC website.

24 "Results of the Laboratory Evaluation of Zenith 5th Generation VSB Television Receiver for Terrestrial Broadcasting", Communications Research Centre Canada, September, 2003, see CRC website.

25 "Laboratory Evaluation of (Samsung) VSB Television Receiver for Terrestrial Broadcasting", Communications Research Centre Canada, August 30, 2005, see CRC website.

26 “Tests of ATSC 8-VSB Reception Performance of Consumer Digital Television Receivers Available in 2005”, FCC/OET TR 05-1017, Stephen R. Martin, November 2, 2005.

27 “Laboratory Evaluation of Five VSB Television Receivers in DTV Adjacent Channel Interference”, Sebastien Lafleche and Yiyan Wu, Charles Nadeau, Benoit Ledoux, Khalil Salehian, Communications Research Centre, January 31, 2007.

28 “Interference Rejection Thresholds of Consumer Digital Television Receivers Available in 2005 and 2006”, FCC/OET 07-TR-1003, Stephen Martin, Office of Engineering and Technology, Federal Communications Commission, March 30, 2007.

29 “VHF and UHF Propagation Curves for the Frequency Range from 30 MHz to 1000 MHz”, Recommendation ITU-R, pp 370-377, 1995.

30 “Range-Dependent Path-Loss Model in Residential Areas for the VHF and UHF Bands”, IEEE Transactions on Antennas & Propagation, Vol. 50, NO. 1, January 2002

31 “Digital Television Broadcasting: Report on Field Strength Measurements (ATV Coverage Area, Charlotte, N.C.)”, D. Tyrie, Industry Canada (Ottawa, CA), October 1995.

32 “Analysis of Field Strength Values at different Heights from Various DTV Field Tests”, W. Meintel, internal MSW report, March 25, 2007.

33 “Factors Influencing Outdoor-to-Indoor Radio Wave Propagation”, S. Stavrou and **S.R.** Saunders, Centre for Communication Systems Research University of Surrey, United Kingdom, presented at an IEEE Antennas and Propagation Society conference in 2003.

34 “Determining the Average Penetration Loss: Measurement, Procedure and Results”, Jefferson Costa e Silva, Alfred0 Gomes Neto, Joabson Nogueira de Carvalho, Marcelo Sampaio Alencar, Proceedings Microwave and Optoelectronics Conference, 1999.

35 “Measurements of the Characteristics of Indoor Penetration Loss”, Y. P. Zhang and Y. Hwang, Department of Electronic Engineering - Chinese University of Hong Kong Hong Kong, IEEE 44th Vehicular Technology Conference, 1994.

36 “Characterization of Indoor Radio Wave Propagation at University Buildings”, Prof. Khalil, H. Sayidmane, and Yessar E. M. Ali, College of Engineering - University of Mosul (IRAQ) , Radio Science Conference Proceedings, 2004.

37 “In-building Penetration Loss Modeling and Measurement in Suburban, Urban and Dense Urban Morphologies”, Osama W. Ata, IEEE Antennas and Propagation Society, International Symposium, 2005.

38 “Propagation of Broadcast Signals into Buildings at 762 MHz, Paul de Bot, Antoine Wijlaars, Henry Vermeer, and Hans Kollenbranded, IEEE Second Symposium on Communications and Vehicular Technology in the Benelux, 1994.

39 “Comparison of Terrestrial DTV Transmission Systems: The ATSC 8-VSB, the DVB-T COFDM, and the ISDB-T BST-OFDM” Yiyan Wu, Ewa Pliszka, Bernard Caron, Pierre Bouchard, and Gerald Chouinard, IEEE Transactions on Broadcasting, Vol. 46, No. 2, June 2000.

40 “DTV Coverage Predictions and Measurements”, I. R. Pullen, BBC.

41 “A Review of the Technical Planning Factors for VHF Television Service”, FCC-OCE-RS77-01, March 1, 1977.

42 “Radio Propagation in Urban Areas”, OT Report 78-144, A. G. Longley, ITS/NTIA/U.S. Department of Commerce, April 1978.

Table 20 Recommended UHF Service Receive Site Planning Factors

Parameter	Variable	Outdoor	Indoor #1 Best Case	Indoor #2 Typical Case	Indoor #3 Worst Case	Units
Required ***Outdoor*** Field Strength	FS_{30}	47.0	53.3	75.5	98.8	dBμV/m
Channel Number	CH	38	38	38	38	-----
Channel Center Frequency	F_C	615	615	615	615	MHz
Antenna Height AGL	H_{AGL}	30	15	6	6	feet
Height Differential Attenuation	A_H	0	5	9	14	dB
Building Material	M	NONE	Glass	Brick	Brick	-----
Room Location	---	NONE	Exterior	Exterior	Interior	-----
Building Penetration Loss	A_B	0	5	12	20	dB
Required ***Indoor*** Field Strength	FS_{IN}	+47.0	+43.3	+54.5	+64.8	dBμV/m
Antenna Type	A	Log Periodic	Amplified Directional (Sharp Shooter)	Passive Directional (Silver Sensor)	Passive Dipole (Bow Tie)	-----
Antenna Gain (maximum)	G_A	+10	+11	+5	0	dBd
Dipole Factor	K_D	-131.0	-131.0	-131.0	-131.0	dBμV/m-dBm
Antenna Output Power (75 Ω)	P_A	-74.0	-76.7	-71.5	-66.2	dBm/6 MHz
Coaxial Cable Length	X_C	50	3	3	3	feet
Coaxial Cable Loss	L_C	4	0.5	0.5	0.5	dB
Minimum Signal Level (Raleigh Channel)	P_{IN2}	-78.0	-77.2	-72.0	-66.7	dBm/6 MHz
Mismatch Loss (Antenna & Receiver)	LM	1	1	2	3	dB
Sky & Man-Made Noise Enhancement	L_I	0	0	0	0	dB
Multipath Fading Level	MFL	1	2	3	4	dB
Multipath Rx Noise Enhancement *	MNE	3	4	6	8	dB
Multipath Rx Diversity Antenna Advantage	MDAA	0	0	0	0	dB
Minimum Signal Level (Gaussian Channel)	P_{IN1}	-83.0	-84.2	-83.0	-81.7	dBm/6 MHz
Rx White Noise Threshold for TOV	SNR_{TOV}	15.2	15.0	15.2	15.5	dB
Rx Input Noise Floor	N_{IN}	-98.2	-99.2	-98.2	-97.2	dBm/6 MHz
Rx Input Noise Figure	NF	8	7	8	9	dB
Rx kTB Noise Floor (theoretical, matched system)	N_{kTB}	-106.2	-106.2	-106.2	-106.2	dBm/6 MHz

NOTE: DTV receiver equalizers are assumed to have at least ±20 μsecs of cancellation range.

Table 21 Recommended High-VHF Service Receive Site Planning Factors

Parameter	Variable	Outdoor	Indoor #1 Best Case	Indoor #2 Typical Case	Indoor #3 Worst Case	Units
Required ***Outdoor*** Field Strength	FS_{30}	46.0	59.1	77.3	97.6	dBμV/m
Channel Number	CH	10	10	10	10	-----
Channel Center Frequency	F_C	195	195	195	195	MHz
Antenna Height AGL	H_{AGL}	30	15	6	6	feet
Height Loss	A_H	0	5	9	14	dB
Building Material	M	NONE	Glass	Brick	Brick	-----
Room Location	---	NONE	Exterior	Exterior	Interior	-----
Building Penetration Loss	A_B	0	5	12	20	dB
Required ***Indoor*** Field Strength	FS_{IN}	+46.0	49.1	56.3	63.6	dBμV/m
Antenna Type	A	Log Periodic	Amplified Directional (Sharp Shooter)	Passive Dipole	Rabbit Ears (ANT115)	-----
Antenna Gain (maximum)	G_A	6	+2	0	-2	dBd
Dipole Factor	K_D	-121.0	-121.0	-121.0	-121.0	dBμV/m-dBm
Antenna Output Power (75 Ω)	P_A	-69.0	-70.0	-64.8	-59.5	dBm/6 MHz
Coaxial Cable Length	X_C	50	3	3	3	feet
Coaxial Cable Loss	L_C	2	0.25	0.25	0.25	dB
Minimum Signal Level (Raleigh Channel)	P_{IN2}	-71.0	-70.2	-65.0	-59.7	dBm/6 MHz
Mismatch Loss (Antenna & Receiver)	LM	1	1	2	3	dB
Sky & Man-Made Noise Enhancement	L_I	7	7	7	7	dB
Multipath Fading Level	MFL	1	2	3	4	dB
Multipath Rx Noise Enhancement *	MNE	3	4	6	8	dB
Multipath Rx Diversity Antenna Advantage	MDAA	0	0	0	0	dB
Minimum Signal Level (Gaussian Channel)	P_{IN1}	-83.0	-84.2	-83.0	-81.7	dBm/6 MHz
Rx White Noise Threshold for TOV	SNR_{TOV}	15.2	15.0	15.2	15.5	dB
Rx Input Noise Floor	N_{IN}	-98.2	-98.2	-98.5		dBm/6 MHz
Rx Input Noise Figure	NF	8	7	8	9	dB
Rx kTB Noise Floor (theoretical, matched system)	N_{kTB}	-106.2	-106.2	-106.2	-106.2	dBm/6 MHz

NOTE: DTV receiver equalizers are assumed to have at least ±20 μsecs of cancellation range.

Table 22 Recommended UHF Interference D/U Ratio Planning Factors

Undesired Channel Offset	**Weak Desired Level D/U (dB)**	**Moderate Desired Level D/U (dB)**	**Strong Desired Level D/U (dB)**	**ATSC A/74 Recommended D/U (dB)**	**OET-69 Required D/U (dB)**
N-15	-60	-53	-28	-50 / -45 / -20	NC
N-14	-60	-53	-28	-50 / -45 / -20	NC
N-13	-60	-53	-28	-57 / -45 / -20	NC
N-12	-60	-50	-28	-57 / -45 / -20	NC
N-11	-60	-50	-28	-57 / -45 / -20	NC
N-10	-60	-50	-28	-57 / -45 / -20	NC
N-9	-60	-50	-28	-57 / -45 / -20	NC
N-8	-56	-50	-28	-57 / -45 / -20	NC
N-7	-56	-45	-28	-57 / -45 / -20	NC
N-6	-56	-48	-28	-57 / -45 / -20	NC
N-5	-56	-48	-28	-56 / -42 / -20	NC
N-4	-50	-48	-28	-52 / -40 / -20	NC
N-3	-50	-48	-28	-48 /-40 / -20	NC
N-2	-43	-40	-28	-44 / -40 / -20	NC
N-1	-33	-33	-23	-33 / -33 / -20	-28
N+1	-33	-33	-23	-33 / -33 / -20	26
N+2	-43	-40	-28	-44 / -40 / -20	NC
N+3	-53	-48	-28	-48 /-40 / -20	NC
N+4	-56	-48	-28	-52 / -40 / -20	NC
N+5	-56	-48	-28	-56 / -42 / -20	NC
N+6	-60	-48	-28	-57 / -45 / -20	NC
N+7	-56	-43	-28	-57 / -45 / -20	NC
N+8	-60	-50	-28	-57 / -45 / -20	NC
N+9	-60	-50	-28	-57 / -45 / -20	NC
N+10	-60	-50	-28	-57 / -45 / -20	NC
N+11	-60	-60	-28	-57 / -45 / -20	NC
N+12	-60	-60	-28	-57 / -45 / -20	NC
N+13	-60	-60	-28	-57 / -45 / -20	NC
N+14	-54	-50	-28	-50 / -45 / -20	NC
N+15	-54	-50	-28	-50 / -45 / -20	NC

NOTE: NC indicates planning factor was not considered

Table 23 *Strong* UHF signal D-into-D Interference D/U ratios from CRC lab test, FCC lab test, and MSW lab test

	CRC Laboratory Tests					MSW Laboratory Tests					CRC/MSW Laboratory Tests		FCC Laboratory Tests	
Undesired Channel	Rx 1 (dB)	Rx 2 (dB)	Rx 3 (dB)	Rx 4 (dB)	Rx 5 (dB)	Rx 6 (dB)	Rx 7 (dB)	Rx 8 (dB)	Rx 9 (dB)	Rx 10 (dB)	Med (dB)	Std Dev (dB)	Med (dB)	Std Dev (dB)
N-15	<-39.7	<-39.7	<-39.7	<-39.7	-29.2	-36.0	-34.0	-32.0	-41.9	-41.9	-39.7	4.4	<-27.3	> 0.2
N-14	<-39.7	<-39.7	<-39.7	<-39.7	-29.2	-36.7	-33.0	-30.9	-40.8	-41.8	-39.7	4.5	<-27.5	> 0.2
N-13	<-39.6	<-39.6	<-39.6	<-39.6	-29.1						-39.6	4.7	<-27.8	> 0.2
N-12	<-39.7	<-39.7	<-39.7	<-39.7	-29.7						-39.7	4.5	<-27.8	> 0.2
N-11	<-39.6	<-39.6	<-39.6	-38.6	-29.6						-39.6	4.4	<-27.8	> 0.2
N-10	<-39.5	<-39.5	<-39.5	-36.0	-29.0						-39.5	4.6	<-27.8	> 0.2
N-9	<-39.6	<-39.6	<-39.6	-33.1	-28.6						-39.6	5.0	<-27.7	> 0.2
N-8	<-39.7	<-39.7	<-39.7	-30.7	-28.7						-39.7	5.5	<-27.5	> 0.2
N-7	<-39.7	<-39.7	<-39.7	-29.7	-28.7						-39.7	5.8	<-27.3	> 0.1
N-6	<-39.7	<-39.7	<-39.7	-28.7	-28.2						-39.7	6.2	<-27.1	> 0.1
N-5	<-39.7	<-39.7	-39.2	-29.7	-28.7	-38.7	-36.7	-31.7	-39.7	-43.9	-39.0	5.0	<-26.9	> 0.1
N-4	<-39.7	<-39.7	-37.2	-39.2	-27.2	-38.7	-38.7	-39.7	-39.7	-45.0	-39.5	4.4	<-26.9	> 0.1
N-3	<-39.8	-39.3	-34.3	-38.8	-27.8	-35.3	-37.5	-37.5	-36.4	-43.5	-37.5	4.1	<-26.8	> 0.1
N-2	<-39.6	<-39.6	-32.1	-36.1	-27.1	-30.3	-35.7	-33.3	-33.3	-43.8	-34.5	4.9	<-26.5	> 0.1
N-1	-30.8	-27.3	-24.8	-27.3	-22.8	-26.7	-26.7	-26.7	-24.6	-34.5	-26.7	3.3	<-20.8	> 0.0
N+1	-26.5	-29.5	-24.0	-29.0	-23.0	-27.2	-26.2	-29.1	-25.2	-32.1	-26.9	2.8	<-20.2	> 0.1
N+2	-36.1	<-39.6	-34.1	<-39.6	-28.1	-31.1	-30.1	-37.0	-36.0	-39.0	-36.1	4.1	<-26.0	> 0.1
N+3	<-39.6	<-39.6	-37.1	-35.1	-29.1	-34.7	-34.7	-41.7	-38.7	-42.7	-37.9	4.0	<-25.9	> 0.2
N+4	<-39.6	<-39.6	-35.1	-39.1	-30.1	-35.5	-32.7	-40.5	-37.5	-42.5	-38.3	3.8	<-25.8	> 0.1
N+5	<-39.7	<-39.7	-34.2	-39.2	-29.7	-33.4	-35.2	-38.2	-38.2	-43.1	-38.2	3.9	<-26.0	> 0.1
N+6	<-39.7	<-39.7	-38.2	<-39.7	-30.7						-39.7	3.9	<-26.3	> 0.1
N+7	-32.6	<-39.6	-24.1	-37.6	-29.6						-32.6	6.2	<-26.4	> 2.3
N+8	<-39.9	<-39.9	-39.4	<-39.9	-29.9						-39.9	4.4	<-26.4	> 0.1
N+9	<-39.7	<-39.7	<-39.7	<-39.7	-29.2						-39.7	4.7	<-26.3	> 0.2
N+10	<-39.6	<-39.6	<-39.6	<-39.6	-29.6						-39.6	4.5	<-26.2	> 0.2
N+11	<-39.7	<-39.7	<-39.7	<-39.7	-30.2						-39.7	4.2	<-25.9	> 0.2
N+12	<-39.7	<-39.7	<-39.7	<-39.7	-31.2						-39.7	3.8	<-25.8	> 0.2
N+13	<-39.8	<-39.8	<-39.8	<-39.8	-30.8						-39.8	4.0	<-25.5	> 0.2
N+14	-32.1	<-39.6	<-39.6	<-39.6	-30.1	-35.8	-37.8	-41.8	-41.8	-41.8	-39.6	4.1	<-25.2	> 0.2
N+15	-28.6	<-39.6	-37.6	<-39.6	-29.1	-33.6	-37.6	-41.6	-41.6	-41.6	-38.6	5.0	<-24.7	> 0.2

Table 24 *Moderate* UHF signal D-into-D Interference D/U ratios from CRC lab test, FCC lab test, and MSW lab test

	CRC Laboratory Tests					MSW Laboratory Tests					CRC/MSW Laboratory Tests		FCC Laboratory Tests	
Undesired Channel	Rx 1 (dB)	Rx 2 (dB)	Rx 3 (dB)	Rx 4 (dB)	Rx 5 (dB)	Rx 6 (dB)	Rx 7 (dB)	Rx 8 (dB)	Rx 9 (dB)	Rx 10 (dB)	Med (dB)	Std Dev (dB)	Med (dB)	Std Dev (dB)
N-15	-58.7	<-64.7	-49.2	-63.2	-53.7	-58.8	-55.8	-53.9	-53.9	-55.8	-55.8	4.0	<-51.9	> 2.5
N-14	-58.2	<-64.7	-47.2	-58.7	-53.2	-59.6	-55.6	-52.6	-52.6	-55.6	-55.6	3.9	<-52.1	> 2.8
N-13	-58.1	<-64.6	-44.6	-54.6	-53.1						-53.9	5.7	-51.9	> 2.9
N-12	-57.7	-64.2	-43.2	-53.2	-52.7						-53.2	7.7	-50.8	> 3.1
N-11	-57.1	-63.1	-41.1	-50.6	-52.1						-52.1	8.2	-51.0	> 3.5
N-10	-57.0	-61.0	-39.5	-47.5	-52.0						-52.0	8.4	-52.3	> 3.7
N-9	-56.1	-59.6	-37.6	-45.6	-51.1						-51.1	8.7	-52.2	> 3.9
N-8	-55.7	-62.2	-37.2	-43.2	-49.7						-49.7	9.9	-51.4	> 4.3
N-7	-56.2	<-64.7	-36.2	-40.7	-49.2						-45.0	8.9	-50.5	> 4.7
N-6	-56.2	-64.2	-58.2	-39.7	-52.7						-56.2	9.1	-47.7	> 7.3
N-5	-53.2	-63.7	-58.7	-38.2	-52.2	-55.6	-60.7	-55.6	-54.6	-60.7	-55.6	7.1	-51.6	> 6.2
N-4	-45.7	-57.7	-54.7	-54.2	-51.7	-47.6	-58.7	-60.8	-57.7	-53.8	-54.5	4.8	-47.0	> 6.6
N-3	-41.8	-48.8	-45.8	-57.8	-49.8	-53.1	-55.1	-53.1	-50.1	-51.1	-50.6	4.6	-49.2	> 3.3
N-2	-40.6	-40.6	-51.6	-52.6	-42.1	-34.1	-49.8	-46.9	-42.9	-44.9	-43.9	5.7	-41.5	7.1
N-1	-30.3	-33.8	-37.8	-40.3	-39.3	-33.4	-32.4	-33.4	-31.4	-33.4	-33.4	3.4	-39.0	1.8
N+1	-26.5	-38.0	-38.0	-41.0	-39.5	-34.2	-36.2	-34.2	-32.2	-32.2	-35.2	4.3	-39.4	1.9
N+2	-37.1	-49.6	-53.1	-62.1	-48.6	-38.9	-49.6	-47.1	-47.1	-37.9	-47.9	7.7	-42.1	6.3
N+3	-45.1	-62.1	-30.6	-45.6	-51.1	-53.7	-53.7	-57.8	-53.7	-46.7	-52.4	8.7	-49.8	> 8.8
N+4	-44.1	<-64.6	-32.6	-49.6	-52.6	-49.8	-54.7	-59.7	-40.0	-51.8	-50.8	9.3	-50.1	> 7.4
N+5	-53.2	-55.7	-33.2	-49.2	-52.2	-45.6	-51.5	-57.4	-39.5	-56.4	-51.9	7.8	-49.0	> 6.5
N+6	-54.7	-57.7	-42.2	-56.7	-51.2						-54.7	6.3	-50.8	> 4.1
N+7	-34.6	-58.1	-29.1	-52.6	-43.1						-43.1	12.1	-38.7	8.0
N+8	-53.4	-61.4	-52.9	-60.9	-51.4						-53.4	4.8	<-51.4	> 1.1
N+9	-53.7	-62.7	-56.2	-61.7	-51.7						-56.2	4.8	<-51.3	> 0.8
N+10	-53.6	-61.6	-57.1	-61.1	-51.6						-57.1	4.4	<-51.2	> 0.5
N+11	-53.2	<-64.7	-63.7	-63.7	-52.2						-63.7	6.2	<-51.0	> 0.3
N+12	-53.2	<-64.7	<-64.7	-64.2	-52.7						-64.2	6.4	<-50.8	> 0.3
N+13	-53.8	<-64.8	<-64.8	<-64.8	-52.8						-64.8	6.3	<-50.5	> 0.2
N+14	-35.1	-61.6	-37.6	-48.1	-52.1	-53.9	-53.9	-67.0	-47.1	-61.0	-53.0	10.2	<-50.1	> 0.2
N+15	-31.6	-60.1	-34.1	-46.6	-51.6	-48.8	-53.6	-66.9	-45.8	-59.6	-50.2	11.1	<-49.7	> 0.8

Table 25 *Weak* UHF signal D-into-D Adjacent channel Interference D/U ratios from CRC lab test, FCC lab test, and MSW lab test

	CRC Laboratory Tests					MSW Laboratory Tests					CRC/MSW Laboratory Tests		FCC Laboratory Tests	
Undesired Channel	Rx 1 (dB)	Rx 2 (dB)	Rx 3 (dB)	Rx 4 (dB)	Rx 5 (dB)	Rx 6 (dB)	Rx 7 (dB)	Rx 8 (dB)	Rx 9 (dB)	Rx 10 (dB)	Med (dB)	Std Dev (dB)	Med (dB)	Std Dev (dB)
N-15	-56.7	<-79.7	-63.7	-75.7	-68.2	-69.7	-69.7	-67.8	-67.8	-69.7	-69.0	6.2	-64.1	> 2.7
N-14	-56.7	<-79.7	-58.7	-69.7	-68.2	-72.5	-69.5	-66.6	-67.6	-69.5	-68.9	6.5	-64.1	> 2.8
N-13	-56.6	<-79.6	-54.1	-65.1	-67.6						-65.1	10.1	-64.1	2.8
N-12	-56.2	-79.2	-56.2	-66.7	-67.7						-66.7	9.6	-62.7	2.7
N-11	-55.6	-77.1	-55.6	-64.6	-67.1						-64.6	9.0	-61.9	2.8
N-10	-55.0	-75.5	-53.5	-60.0	-66.0						-60.0	9.0	-63.5	2.9
N-9	-55.1	-73.6	-52.1	-59.1	-64.6						-59.1	8.5	-60.9	3.1
N-8	-55.2	-73.7	-50.7	-56.7	-62.2						-56.7	8.8	-58.0	4.5
N-7	-55.7	-76.7	-49.2	-54.7	-59.2						-55.7	10.5	-58.2	5.1
N-6	-55.7	-70.2	-48.7	-53.7	-66.2						-55.7	9.0	-52.9	9.7
N-5	-52.7	-63.2	-60.7	-52.2	-65.7	-56.8	-61.9	-62.9	-49.9	-57.8	-59.3	5.4	-55.5	5.7
N-4	-45.7	-55.2	-48.2	-52.7	-59.2	-47.9	-56.9	-58.8	-56.9	-51.9	-54.0	4.8	-47.4	6.3
N-3	-41.3	-46.8	-45.3	-56.8	-51.3	-55.2	-53.1	-52.1	-50.1	-50.1	-50.7	4.7	-49.6	6.3
N-2	-40.6	-39.1	-50.6	-51.1	-44.1	-34.3	-46.2	-44.2	-43.2	-43.2	-43.7	5.0	-40.8	7.4
N-1	-30.3	-32.8	-36.8	-39.8	-38.8	-33.7	-30.7	-33.7	-30.7	-33.7	-33.7	3.4	-39.3	0.8
N+1	-27.5	-38.0	-37.5	-40.5	-37.0	-33.3	-33.3	-33.3	-31.3	-32.3	-33.3	3.8	-39.7	1.4
N+2	-37.1	-49.6	-52.6	-61.6	-48.6	-41.1	-58.1	-48.3	-47.3	-39.5	-48.5	7.8	-42.3	6.9
N+3	-45.6	-62.1	-46.1	-59.6	-60.1	-57.8	-64.7	-57.8	-54.7	-45.0	-57.8	7.3	-54.7	5.8
N+4	-44.6	-66.6	-46.6	-57.1	-60.1	-56.9	-56.9	-67.7	-52.9	-50.9	-56.9	7.6	-56.6	5.9
N+5	-54.7	-61.2	-43.7	-59.2	-59.2	-58.6	-65.5	-63.5	-50.8	-61.6	-59.2	6.5	-58.4	7.1
N+6	-55.7	-70.2	-54.2	-69.2	-64.2						-64.2	7.4	-63.1	> 4.6
N+7	-35.1	-71.6	-45.6	-66.6	-57.6						-57.6	15.0	-53.2	6.8
N+8	-53.9	-74.4	-67.4	-75.9	-66.4						-67.4	8.7	-65.0	> 2.0
N+9	-54.7	-74.7	-68.2	-75.2	-66.7						-68.2	8.3	-65.8	> 1.6
N+10	-54.6	-70.1	-66.6	-72.1	-64.6						-66.6	6.8	-65.0	> 1.4
N+11	-54.2	-77.7	-71.7	-77.2	-67.2						-71.7	9.6	<-65.8	> 1.3
N+12	-54.7	-79.2	<-79.7	-79.2	-67.7						-79.2	11.0	<-65.7	> 1.3
N+13	-54.8	<-79.8	<-79.8	-79.3	-68.3						-79.3	11.0	<-65.5	> 1.1
N+14	-35.6	-61.6	-38.1	-47.6	-57.1	-53.8	-54.8	-76.8	-46.9	-69.7	-54.3	13.0	-60.3	> 5.2
N+15	-31.6	-59.6	-35.1	-46.6	-55.6	-47.9	-53.6	-72.6	-45.9	-66.6	-50.8	12.9	-55.1	> 5.7