November 6, 2011

VIA ELECTRONIC FILING

Marlene H. Dortch, Secretary

Federal Communications Commission
445 Twelfth Street, S.W.
Washington, DC 20554

RE: ET Docket No. 04-186 Unlicensed Operation in the TV Broadcast Bands

Ex Parte Presentation

Dear Ms. Dortch:

The DSA / White Space Interoperability Work Group ("Group"), operating within the Wireless Innovation Forum, represents over 50 industry experts from more than 40 companies involved in all aspects of wireless technologies. Recently the Group approved the attached document, *Geographic Contour Calculation Guidelines*, as a draft guideline for White Space operations and, respectfully requests the Commission's advice, input, guidance and commentary on the document to assure that its interpretations and intentions match those of the Commission.

The Group is also requests the Commission use this document as a basis to clarify the Rules where necessary and, where sufficient divergence of interpretation or implementation may exist, to issue any declaratory rulings the Commission may find necessary to ensure a transparent, standardized and interoperable White Space ecosystem.

On behalf of the DSA / White Space Interoperability Work Group

Chairman

/s/

Jesse Caulfield, President

Key Bridge Global LLC

ATTACHMENT BEGINS ON THE FOLLOWING PAGE

Implementation Standard for White Space Administration

Geographic Contour Calculation Guidelines

White Space Contour Calculation Guidelines

Working Document WINNF-11-S-0015

Version V0.2.0

6 November 2011

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Table of Contents

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Geographic Contour Calculation Guidelines

1. Executive Summary

In the United States there are areas where spectrum allocated to TV broadcast is not fully utilized, and secondary use of this spectrum has been authorized by the FCC under Part-15 Rules, wherein one or more white space administrators (herein "Database" or, synonymously, "Administrator") provide available spectrum information to low-powered transmitters (also called white space devices or "WSDs") to ensure that primary spectrum users and services do not receive interference. [1]

In the white space rules the Federal Communications Commission addresses protected services from the context of two large categories:

- Those services already registered with the Commission and
- Those services not registered with the Commission but otherwise entitled to some form of protection

This document is intended to provide best practice and implementation guidelines necessary to consistently implement geographic separation (and interference avoidance) of the various primary services identified in the white space Rules. Accordingly, this document provides a technical assessment of the various elements and statue requirements, analysis of methods, techniques and data identified by the statue, and instruction for implementation.

Notes of Importance:

This document is an implementation guideline based upon Regulation. Where there may be room for interpretation or discretion is explicitly granted by Regulation the authors have attempted to enumerate possible options, weigh their cost and benefit and identify the most reasonable, economical, or standards-compliant option.

While the document is an interpretation of white space Rules, it is technical in nature and should not be used as a legal reference or position.

Impacts/Effects:

This document is intended to enable a consistent understanding of the technical aspects and limits of the white space Rules and to promote harmonization of implementation, testing, validation and conformance across various white space parties, including administrators, incumbent service providers, network planners, consumers and possibly regulators.

[1] See 47 CFR Part 15, Subpart H – *TV Band devices*

2. Introduction

The principle mechanism for interference avoidance in the Report & Order is geographic separation, and each protected service requires its own unique method and practice to calculate geographic separation requirements.

For each type of service identified in the White Space rules relevant statutory requirements are cited followed by a plain English interpretation of the statute. Some services with complicated calculation procedures may include additional discussion of individual steps.

A method and practice of implementation to calculate a protected contour for the service is then provided, followed by a discussion of calculation precision, accuracy and interpolation requirements.

Each section describing an individual service adheres to the following general approach:

- Requirement
- Interpretation
- Method and Procedure to Calculate Protected Contour
- Interpolation and Accuracy

3. Geographic Separation for Individual Services

3.1. Broadcast Television Service

3.1.1. Requirements

§ 15.712 Interference protection requirements.

(a) Digital television stations, and digital and analog Class A TV, low power TV, TV translator and TV booster stations:

(1) Protected contour. TVBDs must protect digital and analog TV services within the contours shown in the following table. These contours are calculated using the methodology in §73.684 of this chapter and the R–6602 curves contained in §73.699 of this chapter.

Type of Station	*Channel*		*Protected Contour* *Contour (dBu)*	*Propagation curve*
Analog: Class A TV, LPTV, translator and booster	*Low VHF*	*(2–6)*	*47*	*F(50,50)*
	High VHF	*(7–13)*	*56*	*F(50,50)*
	UHF	*(14–69)*	*64*	*F(50,50)*
Digital: Full service TV, Class A TV, LPTV, translator and booster	*Low VHF*	*(2–6)*	*28*	*F(50,90)*
	High VHF	*(7–13)*	*36*	*F(50,90)*
	UHF	*(14–51)*	*41*	*F(50,90)*

(2) Required separation distance.

TVBDs must be located outside the contours indicated in paragraph (a)(1) of this section of co-channel and adjacent channel stations by at least the minimum distances specified in the following table. Personal/portable TVBDs operating in Mode II must comply with the separation distances specified for an unlicensed device with an antenna height of less than 3 meters. Alternatively, Mode II personal/portable TVBDs may operate at closer separation distances, including inside the contour of adjacent channel stations, provided the power level is reduced to 40 mW or less as specified in §15.709(a)(2).

Antenna Height of Unlicensed Device	*Required Separation (km) From Digital or Analog TV (Full Service or Low Power) Protected Contour*	
	Co-channel	*Adjacent Channel*
Less than 3 meters	*6.0 km*	*0.1 km*
3 – Less than 10 meters	*8.0 km*	*0.1 km*
10 – 30 meters	*14.4 km*	*0.74 km*

§ 73.684 Prediction of coverage.

(a) All predictions of coverage made pursuant to this section shall be made without regard to interference and shall be made only on the basis of estimated field strengths. The peak power of the visual signal is used in making predictions of coverage.

(b) Predictions of coverage shall be made only for the same purposes as relate to the use of field strength contours as specified in §73.683(c).

(c) In predicting the distance to the field strength contours, the F (50,50) field strength charts (Figures 9 and 10 of §73.699) shall be used. If the 50% field strength is defined as that value exceeded for 50% of the time, these F (50,50) charts give the estimated 50% field strengths exceeded at 50% of the locations in dB above 1 uV/m. The charts are based on an effective power of 1 kW radiated form a half-wave dipole in free space, which produces an unattenuated field strength at 1.61 kilometers (1 mile) of about 103 dB above 1 uV/m. To use the charts to predict the distance to a given contour, the following procedure is used:

Convert the effective radiated power in kilowatts for the appropriate azimuth into decibel value referenced to 1 kW (dBu). If necessary, convert the selected contour to the decibel value (dBu) above 1 microvolt per meter (1 uV/m).

Subtract the power value in dBk from the contour value in dBu. Note that for power less than 1 kW, the difference value will be greater than the contour value because the power in dBk is negative.

Locate the difference value obtained on the vertical scale at the left edge of the chart.

Follow the horizontal line for that value into the chart to the point of intersection with the vertical line above the height of the antenna above average terrain for the appropriate azimuth located on the scale at the bottom of the chart. If the point of intersection does not fall exactly on a distance curve, interpolate between the distance curves below and above the intersection point.

The distance values for the curves are located along the right edge of the chart.

(d) The antenna height to be used with these charts is the height of the radiation center of the antenna above the average terrain along the radial in question.

In determining the average elevation of the terrain, the elevations between 3.2–16.1 kilometers (2–10 miles) from the antenna site are employed. Profile graphs shall be drawn for 8 radials beginning at the antenna site and extending 16.1 kilometers (10 miles) therefrom. The radials should be drawn for each 45 degrees of azimuth starting with the True North.

At least one radial must include the principal community to be served even though such community may be more than 16.1 kilometers (10 miles) from the antenna site.

However, in the event none of the evenly spaced radials include the principal community to be served and one or more such radials are drawn in addition to the 8 evenly spaced radials, such additional radials shall not be employed in computing the antenna height above average terrain.

Where the 3.2–16.1 kilometers (2–10 mile) portion of a radial extends in whole or in part over large bodies of water as specified in paragraph (e) of this section or extends over foreign territory but the Grade B strength contour encompasses land area within the United States beyond the 16.1 kilometers (10 mile) portion of the radial, the entire 3.2–16.1 kilometers (2–10 mile) portion of the radial shall be included in the computation of antenna height above average terrian. However, where the Grade B contour does not so encompass United States land area and (1) the entire 3.2–16.1 kilometers (2–10 mile) portion of the radial extends over large bodies of water of foreign territory, such radial shall be completely omitted from the computation of antenna height above average terrain, and (2) where a part of the 3.2–16.1 kilometers (2–10 mile) portion of a radial extends over large bodies of water or over foreign territory, only that part of the radial extending from the 3.2 kilometer (2 mile) sector to the outermost portion of land area within the United States covered by the radial shall be employed in the computation of antenna height above average terrian.

*The profile graph for each radial should be plotted by contour intervals of from 12.2–30.5 meters (40–100 feet) and, where the data permits**, at least 50 points of elevation (generally uniformly spaced) should be used for each radial.** In instances of very rugged terrain where the use of contour intervals of 30.5 meters (100 feet) would result in several points in a short distance, 61.0–122.0 meter (200–400 foot) contour intervals may be used for such distances. On the other hand, where the terrain is uniform or gently sloping the smallest contour interval indicated on the topograhic may (see paragraph (g) of this section) should be used, although only relatively few points may be available.*

The profile graphs should indicate the topography accurately for each radial, and the graphs should be plotted with the distance in kilometers as the abscissa and the elevation in meters above mean sea level as the ordinate. The profile graphs should indicate the source of the topographical data employed. The graph should also show the elevation of the center of the radiating system. The graph may be plotted either on rectangular coordinate paper or on special paper which shows the curvature of the earth. It is not necessary to take the curvature of the earth into consideration in this procedure, as this factor is taken care of in the charts showing signal strengths.

*The **average elevation** of the 12.9 kilometer (8 miles) distance between 3.2–16.1 kilometers (2–10 miles) from the antenna site **should then be determined from the profile graph for each radial**. This **may be obtained by averaging a large number of equally spaced point**s, by using a planimeter, **or by obtaining the median elevation (that exceeded for 50% of the distance) in sectors and averaging those values**.*

*(g) In the preparation of the profile graph previously described, and in determining the location and height above sea level of the antenna site, the elevation or contour intervals shall be taken from the United States Geological Survey Topographic Quadrangle Maps, United States Army Corps of Engineers' maps or Tennessee Valley Authority maps, whichever is the latest, for all areas for which such maps are available. … In lieu of maps, the **average terrain elevation may be computer generated**, except in the cases of dispute, **using elevations from a 30 second point or better topographic data file**. The **file must be identified and the data processed for intermediate points along each radial using linear interpolation techniques**. **The height above mean sea level of the antenna site must be obtained manually using appropriate topographic maps**.*

3.1.2. Interpretation

Section 15.711 of the Rules explains that the primary mechanism to protect against interference between incumbent, licensed transmitters and new, unlicensed TV Band devices is through geographic exclusion zones.

Section 15.713 of the Rules explains the purpose of a TV Bands "White Space" database ("Database" or "administrator") is to provide, subject to certain restrictions and constraints, a list of channels that are available for unlicensed use at a requesting TVBD's geographic location.

For purposes of interference avoidance the Database is required to collect and maintain records accurately locating incumbent fixed transmitters and to calculate their geographic protected contours. [2]

Section 15.712 of the Rules of the Order specifies analog and digital television protected contour field strength levels but does not describe their geometry. To calculate television service protected contour geometries we refer to the method (but not content) contained in sections *73.684 Prediction of coverage*.

The Order does not specifically discuss or require accommodations for directional antennae information. However, section 73.684(c)(3) of the Rules explains that antenna profiles must be taken into account.

Terrain roughness corrections are precluded. [3]

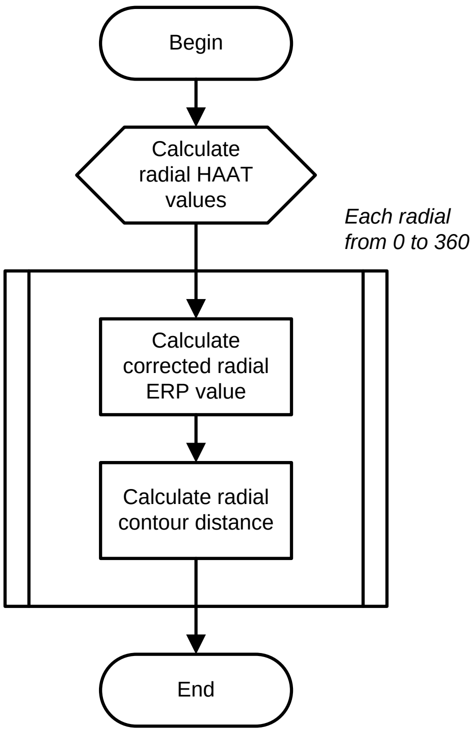
Section 7.684(g) explains that radial HAAT calculation by computer requires a minimum of 50 evenly spaced elevation samples along at least 8 radials from the transmitter site using 30-second or better elevation data.

[2] Protected incumbent transmitters are detailed in 15.712

[3] See FCC 75-1226 *Temporary Suspension of Certain Portions of Sections 73.313, 73.333, 73.684 and 73.699*, November 1975. This Order remains in effect.

3.1.3. Method and Procedure to Calculate Protected Contour Radius

Television service protected contours shall be calculated according to the following procedure:



1. Calculate the transmitter's **radial HAAT** values
   a. The result is a 360-field array containing values that represent the height above average terrain in a radial direction, measured in one-degree increments. The azimuthal direction of calculation is not important (e.g. clockwise, counter-clockwise).
   (See *Calculating Radial HAAT*)
2. For each radial (from zero to 360 degrees in 1-degree increments):
   a. Calculate a corrected **radial ERP** value by multiplying the facility's rated ERP with the antenna's radiation pattern in the direction of interest.
   (See *Calculating Radial ERP*)
   b. Calculate a radial **contour distance** using the appropriate *F(50,50)* or *F(50,90)* curves with, as inputs, the radial HAAT value (Step 1) and the radial corrected ERP value (Step 2a), following the method described in section 73.684 of the Rules.
   (See *Calculating Protected Service Contours*)

3.1.3.1. Calculating Radial HAAT [4], [5]

Antenna height above average terrain (HAAT), along with the Commission's FM and TV propagation curves, is commonly used in the prediction of coverage by television stations and by FM radio stations as well as some wireless radio services.[6]

The HAAT value represents an average of the terrain elevations within 16 km of the transmitter site and provides a single value on which general coverage calculations and regulatory requirements may be based.

A HAAT value is calculated by taking 50 evenly spaced elevation points (measured in meters above mean sea level [AMSL]) along at least 8 evenly spaced radials from the transmitter site, starting at 0 degrees [True North], sampled along their respective radial from 3 to 16 km.

The elevation samples along each radial are averaged to provide the final HAAT value for that radial (the radial HAAT).

Each radial HAAT number is then averaged together to calculate a final HAAT.

Terrain variations within 3 km (2 miles) of the transmitter site are considered to not influence n station coverage and so are excluded from sampling. Only the 3 to 16 km segment of each radial is used.

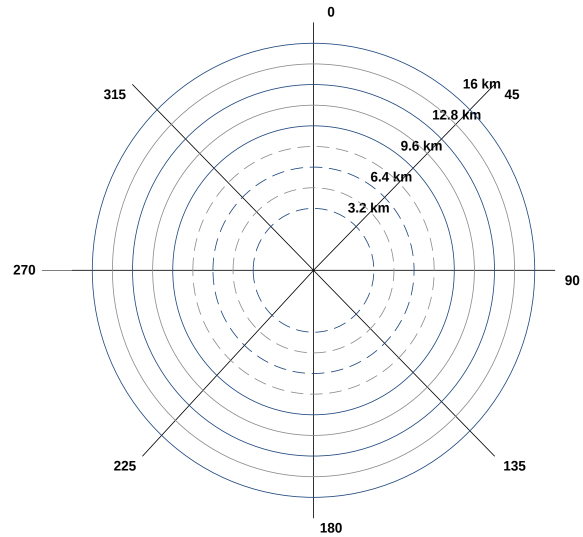


Figure 1: Radial HAAT calculation by computer requires a minimum of 50 evenly spaced elevation samples along at least 8 radials from the transmitter site using 30-second or better elevation data.

As background, when antenna height above average terrain was developed in the late 1930s and 1940s the process was manual. In 1984, the Commission permitted the use of terrain databases for computer calculation of HAAT and permitted the use of additional evenly spaced radials above eight. However the Commission did not extend the radial segment beyond 16 km. [7]

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[4] The FCC provides a similar technical explanation at http://www.fcc.gov/mb/audio/bickel/haat_calculator.html

[5] The Commission retains the manual computation method as the standard in cases where the HAAT is of questioned accuracy.

[6] See 73.313 for FM radio stations, 73.684 for television stations, 90.205 for wireless radio services

[7] See FCC 84-341: *Use of Computer-Generated Terrain Data for Determining Antenna Height Above Average Terrain*, July 13, 1984

Terrain Roughness adjustment cannot be used. In 1975, the Commission adopted a terrain roughness adjustment for predicting coverage, and shortly thereafter suspended it after numerous reports of inconsistent results. That rule suspension remains in effect.

Use the following procedure to calculate the radial HAAT for a station

- Beginning with the transmitting antennae's geographic location as the originating point P, the location's height above average terrain ("HAAT") will be calculated in a radial direction in not less than 45 degree increments.
- White space implementation recommends using 1 degree increments (with 0 degrees representing true north), where the result of this set of calculations is an array of 360 numeric values referred to as *Radial HAAT*.

Examples of two Radial HAAT calculations are plotted in Figure 2, illustrating the effects of mountainous versus relatively flat terrain on Radial HAAT profiles.

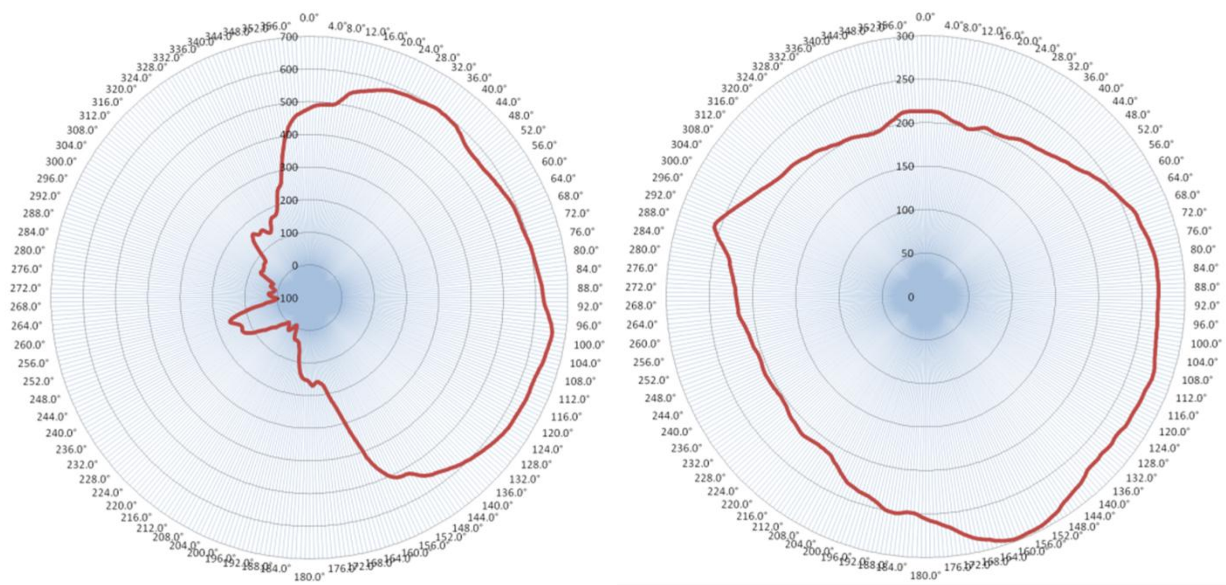


Figure 2: Plot of two Radial HAAT calculations. The attenuating effect of mountainous terrain is visible in the leftmost plot

3.1.3.2. Calculating Radial ERP

Directional antennae radiation profiles for certain licensed transmitters are provided in the Commission's CDBS database.[8] The FCC does not provide radiation profiles for non-directional antenna.

Radiation profile values range between zero and one and serve as a scaling multiplier. To calculate an antenna's radial ERP value simply multiply the antenna's maximum ERP by that antenna's corresponding radial radiation profile value. This is illustrated in Figure 3.

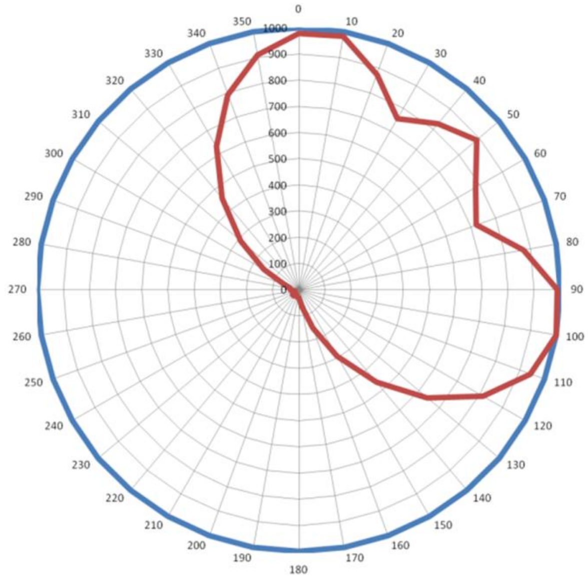


Figure 3: Example of a directional pattern showing maximum ERP in blue and calculated radial ERP values in red

Interpolation may be used to determine radial values between provided data points.

[8] Directional antenna radiation patterns are captured in the technical specifications section of FCC Form 301 *Application for Construction Permit for Commercial Broadcast Station*. See Page 15, 19, 22 (PDF document page 59, 63, 66) for TV, DTV and DTS services, respectively.

3.1.3.3. Calculating Protected Service Contours

For the purposes of calculation transmitter field strength measurements may be considered as a two-dimensional surface described by the generalized linear equation $z_i = FS(d_i,h_i)$ where h is the antenna height above average terrain (HAAT), d is distance from the transmitting antenna, and i is the radial iterator.

To determine a protected service contour one must calculate the radial distance d_i for a specified constant Field Strength value F. The procedure, as described in 47 CFR 73.684, implemented in FCC-provided software and illustrated in Figure 4, proceeds as follows and is iterated along each radial i, from zero to 360 degrees in one degree increments:

1. Convert the transmitter's radial ERP value from kiloWatt into decibel value referenced to 1 kW (dBu). Call this radial ERP value ERP_i
2. Subtract ERP_i from the appropriate protected contour level specified in 15.712(a)(1) of the Rules. Call this the radial field strength value FS_i
3. Trace an isobar along the appropriate $F(50,50)$ or $F(50,90)$ field strength surface at the value FS_i. The resultant is a two dimensional linear equation of the form

   $$d_i = C_1 h_i + C_2$$

   where

   h_i is the radial HAAT value calculated earlier

   C_1 is a second order spline interpolated using the Akima method [9]

   C_2 is a constant

4. Numerically solve for the protected contour distance d_i which is now only dependent upon the transmitting site's radial HAAT value h_i calculated earlier.

This method can be followed graphically in Figure 4 below.

[9] See FCC 88-41 *Designation of a Standard Computer Algorithm for Propagation Prediction in the FM and TV Broadcast Services*

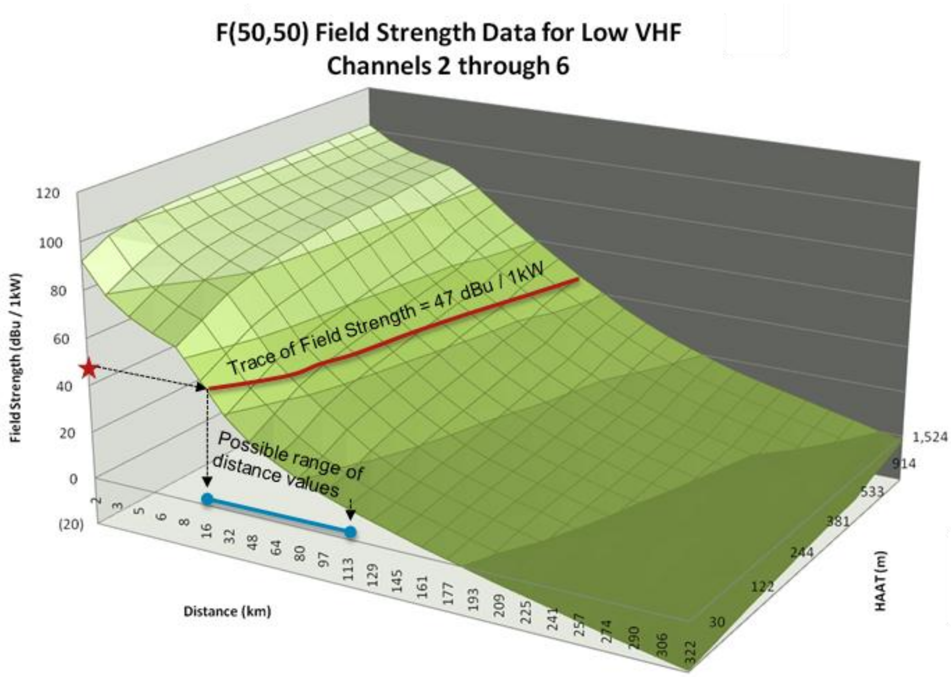


Figure 4 Plot of *F(50,50)* curve for Channels 2-6 as a 3D surface illustrating a method to solve for Distance using specified field strength and HAAT values.

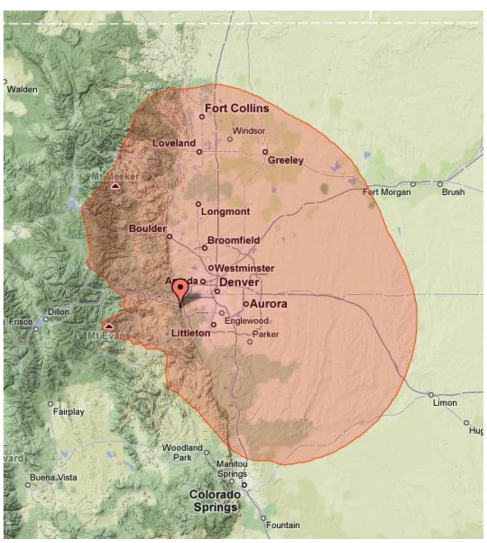


Figure 5: Example plot of a calculated TV service protected contour for KRMA-TV channel 18 in Denver, CO

As a historical note, the Commission's F(50,10) and *F(50,50)* curves represent normalized empirical measurements of the variances in field strength power as the transmitting antenna height above average terrain (HAAT) and distance from the transmitter are varied.

Radio propagation is frequency dependent and the Commission provides three sets of curve data to accommodate VHF Low (Channels 2-6), VHF High (7-13) and UHF frequencies (14-69).

The Commission's provide *F(50,90)* curves represent a calculated extrapolation from the F(50,10) and *F(50,50)* empirical data sets.

3.1.4. Contour radial distance precision and accuracy

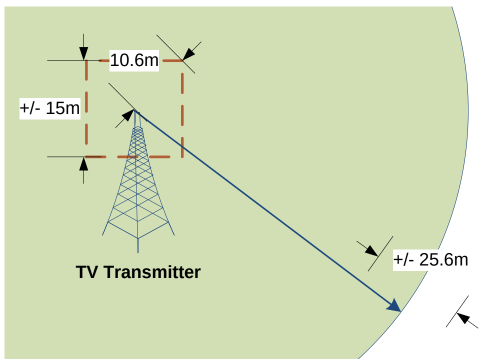


Figure 6: Illustration of estimated transmitter facility location error and subsequent maximum contour error, where the radius is calculated exactly.

The maximum precision allowable using the *F(50,50)* and *F(50,90)* curves is +/- 25.6 meter.

In this section we seek to establish the maximum available precision that may be expected when using the *F(50,50)* and *F(50,90)* curves to calculate a radial contour distance.

As one might logically expect and as is illustrated in Figure 4, field strength values measured for various antenna heights and distances from the transmitter produce a regular, continuous surface representative of a simple bivariate function (e.g. $Z = F(x,y)$). Accordingly, to interpolate values between measured points the Commission has specified that Akima's Method for Bivariate Interpolation shall be used. [10, 11]

Data within available source code and documentation shows the following precision profile: [12]

- Distances are provided with no precision.
  Values are noted (in miles) at 1, 2, 3, 4, 5, 10, 20, 30, etc.
- Antenna HAAT values are provided with no precision.
  Values are noted (in feet) 100, 200, 400, 600, etc.
- Measured field strength values (normalized to dBu/1kW) are provided with one decimal precision (e.g. 79.0, 84.8, 102.1, etc.)

To determine the expected precision of the *F(50,50)* and *F(50,90)* curves calculation it is also important to quantify the usable precision of the calculation inputs, which in this case are the antenna height above average terrain (HAAT) and the antenna's geo- location.

[10] FCC 88-41, *Designation of a Standard Computer Algorithm for Propagation Prediction in the FM and TV Broadcast Services*

[11] Hiroshi Akima, *Method for Estimating Partial Derivatives for Bivariate Interpolation of Scattered Data*, Rocky Mountain Journal of Mathematics

[12] See FCC Report No. RS 76-01, *Field Strength Calculations for TV and FM Broadcasting (Computer Program TVFMFS)* by Gary Kalagian, 1976 and source code revised 2003 by Dale Bickel

Station antenna height above ground is submitted by users according to FCC Form 301 with arbitrary precision and recorded within the Commission's CDBS database in such a manner as to be reasonably accurate to within +/- one meter in the NAD-27 datum.

Station transmitter location is also submitted by users according to FCC Form 301 and recorded within the Commission's CDBS database with precision limited to +/- one whole second of precision for latitude and for longitude. Station antenna tower locations must therefore be considered accurate to within +/- ½ second, which corresponds to +/- 15m in the horizontal and vertical directions at the equator (i.e. before adjustments are made for latitude scaling.)

Combining the assumed precision of transmitter and contour radius yields a *maximum precision error* that may be produced using the Commission's *F(50,50)* and *F(50,90)* curves algorithm with information provided in the CDBS database to determine the distance at which a transmitter's field strength value falls below a set value of +/- 25.6 m.

Accordingly, radial contour distance numbers produced by *F(50,50)* and *F(50,90)* curves algorithm using information from the CDBS database should be rounded to avoid representing false precision or confidence in contour radial distances.

For practical purposes of implementation, a contour radial distance value may be safely rounded to the nearest +/- 10 meters (e.g. '54.22 km' or '54,220 meter') in the NAD-83 datum, in both the horizontal and vertical directions, with the understanding that care should be taken to avoid introducing any bias in rounding.

3.2. TV Translator, LPTV and MVPD Receive Site plus Fixed Broadcast Auxiliary Service (BAS) Links

3.2.1. Requirement

§ 15.712 Interference protection requirements.

(b) TV translator, Low Power TV (including Class A) and Multi-channel Video Programming Distributor (MVPD) receive sites. MVPD, TV translator station and low power TV (including Class A) station receive sites located outside the protected contour of the TV station(s) being received may be registered in the TV bands database if they are no farther than 80 km outside the nearest edge of the relevant contour(s). Only channels received over the air and used by the MVPD, TV translator station or low power/Class A TV station may be registered. TVBDs may not operate within an arc of ±/−30 degrees from a line between a registered receive site and the contour of the TV station being received in the direction of the station's transmitter at a distance of up to 80 km from the edge of the protected contour of the received TV station for co-channel operation and up to 20 km from the registered receive site for adjacent channel operation, except that the protection distance shall not exceed the distance from the receive site to the protected contour. Outside of this ±/−30 degree arc, TVBDs may not operate within 8 km from the receive site for co-channel operation and 2 km from the receive site for adjacent channel operation. For purposes of this section, a TV station being received may include a full power TV station, TV translator station or low power TV/Class A TV station.

(c) Fixed Broadcast Auxiliary Service (BAS) Links . For permanent BAS receive sites appearing in the Commission's Universal Licensing System or temporary BAS receive sites registered in the TV bands database, TVBDs may not operate within an arc of ±30 degrees from a line between the BAS receive site and its associated permanent transmitter within a distance of 80 km from the receive site for co-channel operation and 20 km for adjacent channel operation. Outside this ±30 degree arc, TVBDs may not operate within 8 km from the receive site for co-channel operation and 2 km from the receive site for adjacent channel operation.

3.2.2. Interpretation

The Rule describes similar protected contours geometries for all three classes of service resembling a "key hole" shape, originating at the protected receiver, with fixed circular contours and extended arc dimensions determined by the relative locations of the transmitter and receiver.

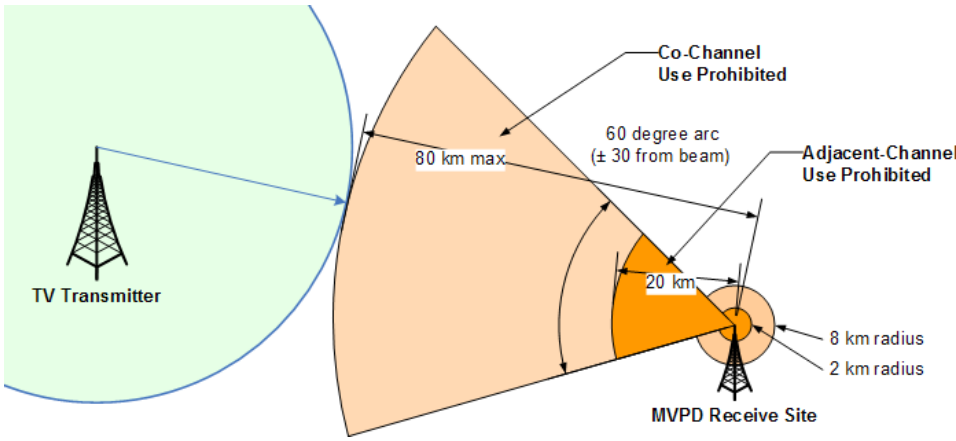


Figure 7 Illustration of TV transmitter and MBPD receiver with co and adjacent channel protected contours.

The maximum allowed distance between a television protected contour's edge to the translator or cable head-end receiver site (RX) is 80 km.

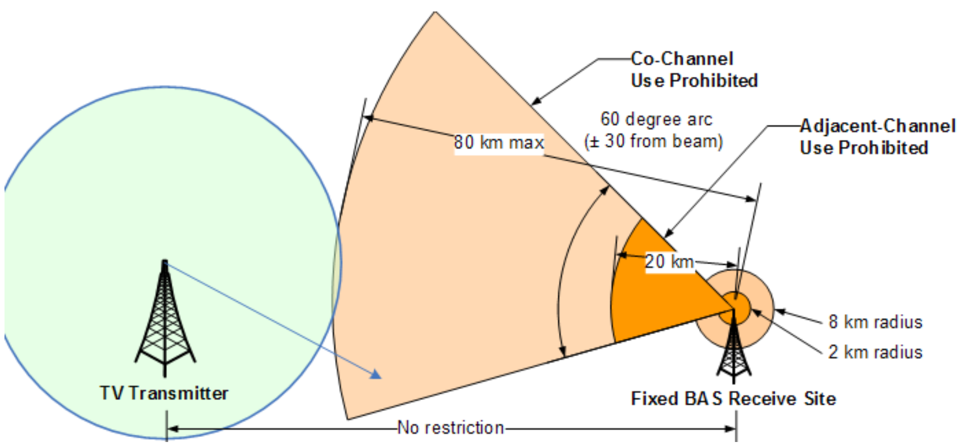


Figure 8 Illustration of TV transmitter and BAS receiver with case of overlapping protected contours

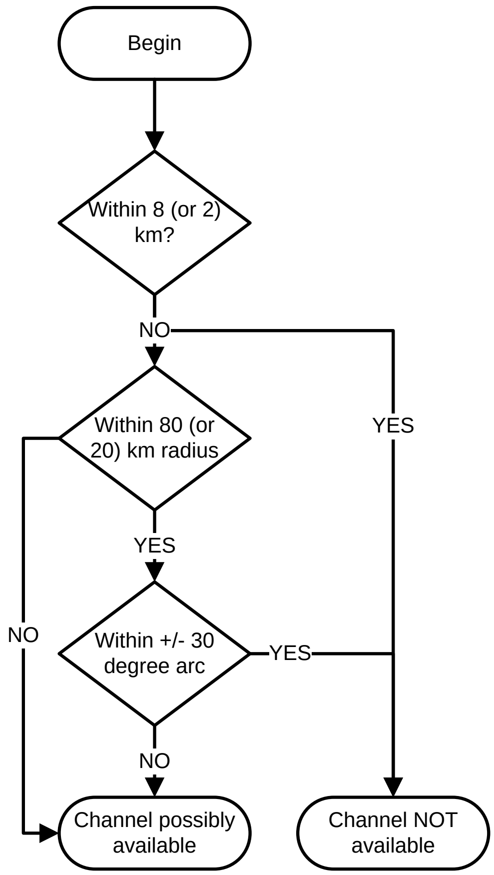
The maximum protected contour distance between a television transmitter and a BAS receiver is 80 km.

3.2.3. Method and Procedure to Calculate Protected Contour

Translator and Cable Head end receive sites are always paired with a transmitter. The two latitude/longitude points create a surface vector described by the distance between transmitter and receiver plus the course between points.

Channel protection for Cable/Translator/BAS links is calculated subsequent to calculating TV protection. An inquiring device located at a point QP is therefore assumed to be outside the TV Protected Contour.

Administrator will first calculate the distance *d* between transmitter and receiver with methods described in this document to ensure the receive site is within the 80 km (or 80 km plus contour radius) limit and entitle to protection. The Database will then calculate the inverse course angle (pointing from RX site to TX site). Channel protection will be determined as follows:



- Does the query point QP lie within either of the protected 8 or 2 km inner contours?
  - If yes, the site's protected channels are NOT available.
- Does the query point QP lie within an 80km co-channel or 20km adjacent channel radius to the RX site?
  - If yes, does the query point QP lie within the +/- 30 degree arc?
    - If yes, the site's protected channels are NOT available

3.2.4. Interpolation and Accuracy

No interpolation is required. While service contours may be calculated with arbitrary precision, tower locations are stored in the database with 1 whole second minimum precision. We therefore assume tower locations may be considered accurate to within +/- ½ second (+/- 15m.)

3.3. PLMRS / CMRS Operations

3.3.1. Requirement

§ 15.712 Interference protection requirements.

(d) PLMRS/CMRS operations: TVBDs may not operate at distances less than 134 km for co-channel operations and 131 km for adjacent channel operations from the coordinates of the metropolitan areas and on the channels listed in §90.303(a) of this chapter. For PLMRS/CMRS operations authorized by waiver outside of the metropolitan areas listed in §90.303(a) of this chapter, co-channel and adjacent channel TVBDs may not operate closer than 54 km and 51 km, respectively from a base station.

§ 90.303 Availability of frequencies.

(a) Frequencies in the band 470–512 MHz are available for assignment as described below. Note: coordinates are referenced to the North American Datum 1983 (NAD83).

(b) The following table lists frequency bands that are available for assignment in specific urban areas. The available frequencies are listed in §90.311 of this part.

		Geographic center			
Urbanized area		*Latitude (N)*	*Longitude (W)*	*Bands (MHz)*	*TV channels*
Boston	*MA*	*42°21'24.4"*	*71°03'23.2"*	*470–476, 482–488*	*14, 16*
Chicago	*IL*	*41°52'28.1"*	*87°38'22.2"*	*470–476, 476–482*	*14, 15*
Cleveland	*OH*	*41°29'51.2"*	*81°49'49.5"*	*470–476, 476–482*	*14, 15*
Dallas/Fort Worth	*TX*	*32°47'09.5"*	*96°47'38.0"*	*482–488*	*16*
Detroit	*MI*	*42°19'48.1"*	*83°02'56.7"*	*476–482, 482–488*	*15, 16*
Houston	*TX*	*29°45'26.8"*	*95°21'37.8"*	*488–494*	*17*
Los Angeles	*CA*	*34°03'15.0"*	*118°14'31.3"*	*470–476, 482–488, 506–512*	*14, 16, 20*
Miami	*FL*	*25°46'38.4"*	*80°11'31.2"*	*470–476*	*14*
New York	*NY/NE NJ*	*40°45'06.4"*	*73°59'37.5"*	*470–476, 476–482, 482–488*	*14, 15, 16*
Philadelphia	*PA*	*39°56'58.4"*	*75°09'19.6"*	*500–506, 506–512*	*19, 20*
Pittsburgh	*PA*	*40°26'19.2"*	*79°59'59.2"*	*470–476, 494–500*	*14, 18*
San Francisco/Oakland	*CA*	*37°46'38.7"*	*122°24'43.9"*	*482–488, 488–494*	*16, 17*
Washington, DC/MD/VA	*DC/MD/VA*	*38°53'51.4"*	*77°00'31.9"*	*488–494, 494–500*	*17, 18*

Table 1 Enumerated urbanized areas with geographic center coordinates enjoying PLMRS/CMRS protection.

*UPDATE**:** Although the Rules identify thirteen urbanized areas the Commission has communicated that the entry for Cleveland, OH is not correct and should not be afforded protection.*

3.3.2. Interpretation

The Rules describe a simple circular radius around 13 enumerated metropolitan centers with accommodations for an additional circle extending the protected contour for co-channel and adjacent channel protection. Protected contours are represented as a circle with a fixed radius of 134 and 131 km for co-channel and adjacent channel frequencies, respectively. Base station contours are represented as a circle with a fixed radius of 54 and 51 km for co-channel and adjacent channel frequencies, respectively. This is illustrated in Figure 9.

PLMRS/CMRS protected contours are the union of both geometries.

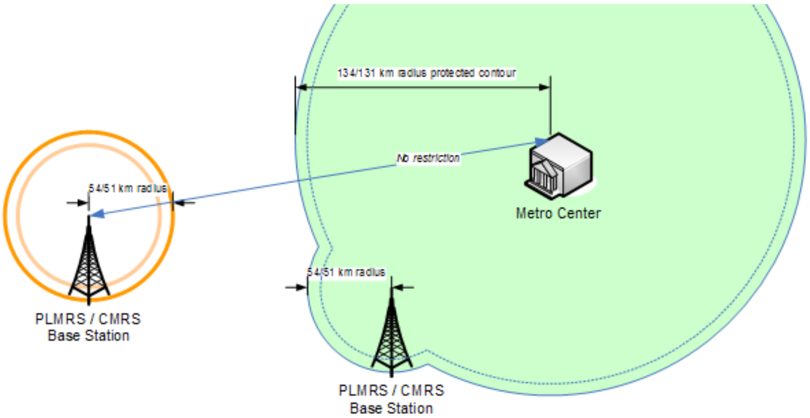


Figure 9 PLMRS and CMRS operate on one or two channels in 13 urbanized areas. The protected contour is a circular area of fixed radius, potentially extended in certain circumstances (as shown). There is no restriction placed upon the distance between a base station and the urbanized area center, which may reside outside the urbanized area contour. This is illustrated on the left.

3.3.3. Method and Procedure to Calculate Protected Contour

For PLMRS/CMRS base stations located less than 76 km from their metropolitan center no additional analysis is required as the base station's 54 km radius is entirely contained within the metropolitan's protected contour.

For PLMRS/CMRS base stations located greater than 76 km from their respective metro-center the Database will add a second set of 54/51 km radius protected contours centered on the base station location. The net protected contour will be the union of these two circles. This is illustrated in Figure 9.

3.3.4. Interpolation and Accuracy

No interpolation is required. PLMRS/CMRS protected contours can be calculated with an expected accuracy of +/- 1.5 m. Geographic center locations are represented with 1/10th of a second precision implying an accuracy of +/- 0.05 second (+/- 1.5 m.)

3.4. Offshore Radiotelephone service

3.4.1. Requirement

§ 15.712 Interference protection requirements.

(e) Offshore Radiotelephone Service. TVBDs may not operate on channels used by the Offshore Radio Service within the geographic areas specified in §74.709(e) of this chapter.

§ 74.709 Land mobile station protection.

(e) To protect stations in the Offshore Radio Service, a low power TV or TV translator station construction permit application will not be accepted if it specifies operation on channels 15, 16, 17 or 18 in the following areas. West Longitude and North Latitude are abbreviated as W.L. and N.L. respectively.

(1) On Channel 15: west of 92°00' W.L.; east of 98°30' W.L.; and south of a line extending due west from 30°30' N.L., 92°00' W.L. to 30°30' N.L., 96°00' W.L.; and then due southwest to 28°00' N.L., 98°30' W.L.

(2) On Channel 16: west of 86°40' W.L.; east of 96°30' W.L.; and south of a line extending due west from 31°00' N.L., 86°40' W.L. to 31°00' N.L., 95°00' W.L. and then due southwest to 29°30' N.L., 96°30' W.L.

(3) On Channel 17: west of 86°30' W.L.; east of 96°00' W.L.; and south of a line extending due west from 31°00' N.L., 86°30' W.L. to 31°30' N.L., 94°00' W.L. and then due southwest to 29°30' N.L., 96°00' W.L.

(4) On Channel 18: west of 87°00' W.L.; east of 95°00' W.L.; and south of 31°00' N.L.

3.4.2. Interpretation

74.709(e) describes four geographic contours in the US Gulf of Mexico with protection for channels 15, 16, 17 and 18. The respective, overlaid contours are illustrated in Figure 10.

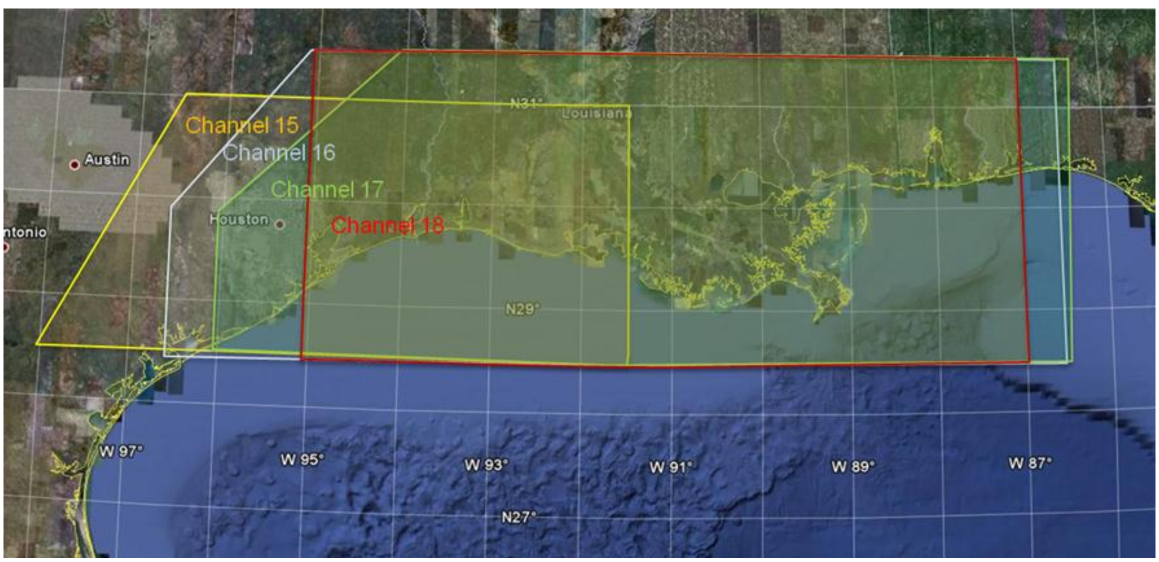


Figure 10 Map illustrating the geographic protection allotted to offshore radiotelephone services in the Gulf of Mexico

3.4.3. Method and Procedure to Calculate Protected Contour

No calculations are required.

3.4.4. Interpolation and Accuracy

No interpolations are required. Section 74.709 specifies coordinates with one minute precision.

Because coordinates are assigned to the nearest 10-minute latitude/longitude, the Rule is interpreted to mean coordinates should be interpreted as precise assignments and not measured values. The coordinates are therefore considered exact, and administrators shall calculate contours accurate to less than 1 m.

3.5. Low power auxiliary services, including wireless microphones

3.5.1. Requirement

§ 15.712 Interference protection requirements.

(f) Low power auxiliary services, including wireless microphones: (1) Fixed TVBDs are not permitted to operate within 1 km, and personal/portable TVBDs will not be permitted to operate within 400 meters, of the coordinates of registered low power auxiliary station sites on the registered channels during the designated times they are used by low power auxiliary stations.

(2) TVBDs are not permitted to operate on the first channel on each side of TV channel 37 (608–614 MHz) that is not occupied by a licensed service.

§ 15.713 TV bands database.

(8) Licensed low power auxiliary stations, including wireless microphones and wireless assist video devices. Use of licensed low power auxiliary stations at well defined times and locations may be registered in the database. Multiple registrations that specify more than one point in the facility may be entered for very large sites. Registrations will be valid for no more than one year, after which they may be renewed. Registrations must include the following information:

(i) Name of the individual or business responsible for the low power auxiliary device(s);

(ii) An address for the contact person;

(iii) An email address for the contact person (optional);

(iv) A phone number for the contact person;

(v) Coordinates where the device(s) are used (latitude and longitude in NAD 83, accurate to ±/− 50 m);

(vi) Channels used by the low power auxiliary devices operated at the site;

(vii) Specific months, weeks, days of the week and times when the device(s) are used (on dates when microphones are not used the site will not be protected); and

(viii) The stations call sign.

(9) Unlicensed wireless microphones at venues of events and productions/shows that use large numbers of wireless microphones that cannot be accommodated in the two reserved channels and other channels that are not available for use by TVBDs at that location. Such sites of large events and productions/shows with significant wireless microphone use at well defined times and locations may be registered in the database. Entities responsible for eligible event venues registering their site with a TV bands data base are required to first make use of the two reserved channels and other channels that are not available for use by TVBDs at that location. As a benchmark, at least 6–8 wireless microphones should be operating in each channel used at such venues (both licensed and unlicensed wireless microphones used at the event may be counted to comply with this benchmark). Multiple registrations that specify more than one point in the facility may be entered for very large sites. Sites of eligible event venues using unlicensed wireless microphones must be registered with the Commission at least 30 days in advance and the Commission will provide this information to the data base managers. Parties responsible for eligible event venues filing registration requests must certify that they are making use of all TV channels not available to TV bands devices and on which wireless microphones can practicably be used, including channels 7–51 (except channel 37). The Commission will make requests for registration of sites that use unlicensed wireless microphones public and will provide an opportunity for public comment or objections. Registrations will be valid for one year, after which they may be renewed. The Commission will take actions against parties that file inaccurate or incomplete information, such as denial of registration in the database, removal of information from the database pursuant to paragraph (i) of this section, or other sanctions as appropriate to ensure compliance with the rules. Registrations must include the following information:

(i) Name of the individual or business that owns the unlicensed wireless microphones;

(ii) An address for the contact person;

(iii) An e-mail address for the contact person (optional);

(iv) A phone number for the contact person;

(v) Coordinates where the device(s) are used (latitude and longitude in NAD 83, accurate to ±/− 50 m);

(vi) Channels used by the wireless microphones operated at the site and the number of wireless microphones used in each channel. As a benchmark, least 6–8 wireless microphones must be used in each channel. Registration requests that do not meet this criteria will not be registered in the TV bands data bases;

(vii) Specific months, weeks, days of the week and times when the device(s) are used (on dates when microphones are not used the site will not be protected); and

(viii) The name of the venue.

3.5.2. Interpretation

Low power auxiliary services, including wireless microphones (LPAUX), are entitled to one or more circular protected contours each with a radius of 1 km for Fixed TV Band Devices and 400 meter for personal/portable TVBDs.

Multiple reserved contours must touch or overlap. The net protected contour is their union and represents a continuous, larger contour with no holes. This is illustrated in Figure 11. Microphone end-users may use this ability to ‘paint’ a contour with a 1-km wide brush.

As a practical matter, the same result can be more efficiently delivered by enabling microphone users to specify an exact contour that provides sufficient geographic protection. There are two methods for LPAUX protected contour definition: a so-called “bubble method” and user-defined contours.[13]

[13] Attendee consensus following a verbal discussion led by Ira Keltz during the 3rd white space workshop, May 25, 2011

The "Bubble method"

For single point microphone venue registrations the protected contour is represented by a single circle with 1 km radius (or 400m for Personal/Portable devices).

For extended microphone venues a multi-point registration may be used, where the geometric unions of each 1 km radius (and corresponding 400m) circle must be calculated. The net protected contour is a polygon calculated as the geometric union of all registered "circles". An example is shown in Figure 11.

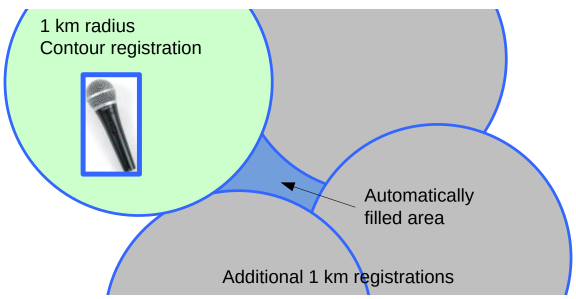


Figure 11: Example LPAUX reservation illustrating multiple 1 km contours and an enclosed area which is automatically filled. The net protected contour is the outer border from a union of all registered 1 km (and corresponding 400m) circles

"User defined contours"

An alternate method for registering extended microphone venues employs a user-defined geographic contour.

User-defined contours are closed and simple polygons defined by an arbitrary number of geographic points.

An example is provided in Figure 12.

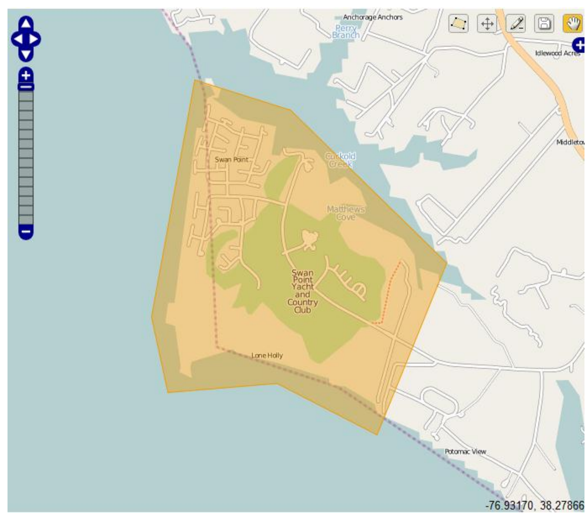


Figure 12: Microphone protection contours may also be registered with white space administrators as user-defined geographic boundaries

3.5.3. Interpolation and Accuracy

No interpolation is required. Microphone contour origination points are considered accurate to +/- 50m. Contour radii shall be calculated accurate to less than 1 m.

User defined geographic boundaries are assumed to be exact according to the user provided coordinates.

3.6. Border Areas near Canada and Mexico

3.6.1. Requirement

§ 15.712 Interference protection requirements.

(g) Border areas near Canada and Mexico: Fixed and personal/portable TVBDs shall comply with the required separation distances in §15.712(a)(2) from the protected contours of TV stations in Canada and Mexico. TVBDs are not required to comply with these separation distances from portions of the protected contours of Canadian or Mexican TV stations that fall within the United States.

3.6.2. Interpretation

Canadian and Mexican television station service contours shall be respected and protected except when the contour, as calculated with the FCC's *F(50,50)* and *F(50,90)* curves procedure described elsewhere in this document, extends within the territorial boundaries of the United States, where it shall not receive protection within the United States.

3.6.3. Method and Procedure to Calculate Protected Contour

Official border coordinates in the form of shape data are available from the US Department of the Interior, US Geological Survey (USGS).

Unlicensed devices shall not operate within the separation distances specified in §15.712(a)(2) from the protected contours of TV stations in Canada and Mexico. Canadian and Mexican television station service contours that lie close to or cross the US border shall protected within Canada and Mexico through implementation of a buffer within the United States of up to, but not more than, the separation distance specified for the white space device's antenna height.

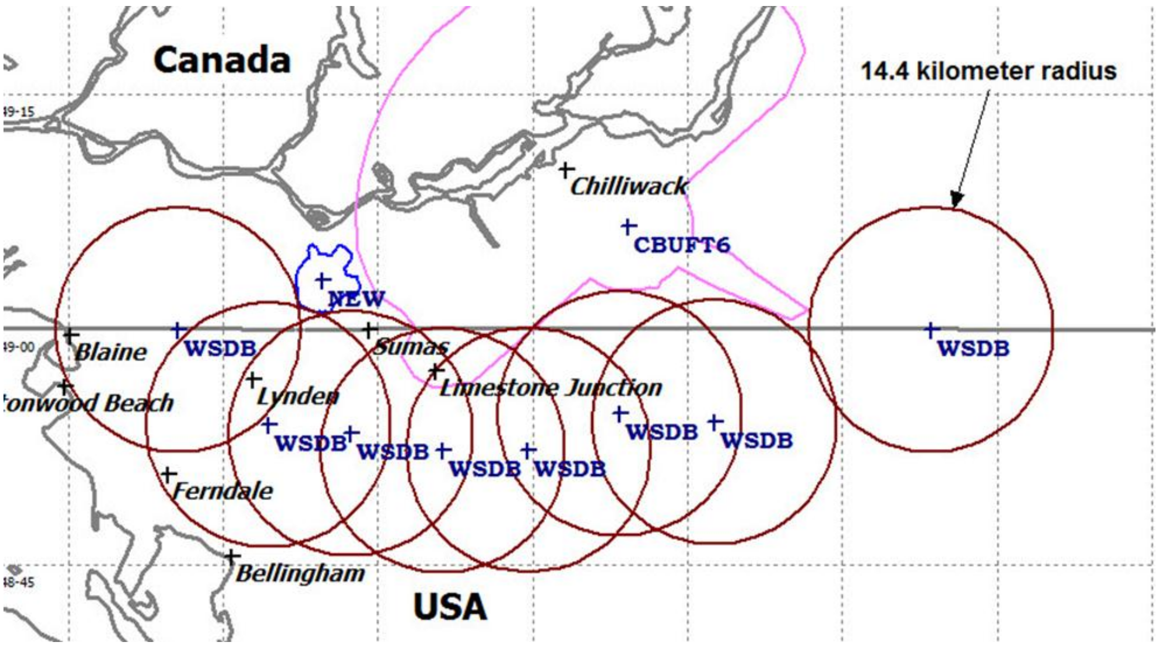


Figure 13: Border area protection example showing fixed WSD devices and their required geographic separation from Canadian stations. Foreign contours are protected up the border.[14]

3.6.4. Interpolation and Accuracy

USGS data is accurate and indicated with precision greater than 1 m. Administrator distance calculations from the Canada and Mexico border will be accurate to +/- 0.5 m.

[14] Image Copyright © 2011 Peter Moncure, RadioSoft. Used with permission.

3.7. Radio Astronomy Services

3.7.1. Requirement

§ 15.712 Interference protection requirements.

(h) Radio astronomy services. Operation of fixed and personal/portable TVBDs is prohibited on all channels within 2.4 kilometers at the following locations.

(1) The Naval Radio Research Observatory in Sugar Grove, West Virginia.

(2) The Table Mountain Radio Receiving Zone (TMRZ) at 40°07'50" N and 105°15'40" W.

(3) The following facilities.

Observatory	*Longitude (deg/min/sec)*	*Latitude*
Allen Telescope Array	*121°28'24" W*	*40°49'04" N.*
Arecibo Observatory	*066°45'11" W*	*18°20'46" N.*
Green Bank Telescope (GBT)	*079°50'24" W*	*38°25'59" N.*
Very Large Array (VLA)	*Rectangle between latitudes 33 58 22 N and 34 14 56 N, and longitudes 107 24 40 W and 107 48 22 W*	
Very Long Baseline Array (VLBA) Stations:		
Pie Town, AZ	*108°07'07" W*	*34°18'04" N.*
Kitt Peak, AZ	*111°36'42" W*	*31°57'22" N.*
Los Alamos, NM	*106°14'42" W*	*35°46'30" N.*
Ft. Davis, TX	*103°56'39" W*	*30°38'06" N.*
N. Liberty, IA	*091°34'26" W*	*41°46'17" N.*
Brewster, WA	*119°40'55" W*	*48°07'53" N.*
Owens Valley, CA	*118°16'34" W*	*37°13'54" N.*
St. Croix, VI	*064°35'03" W*	*17°45'31" N.*
Hancock, NH	*071°59'12" W*	*42°56'01" N.*
Mauna Kea, HI	*155°27'29" W*	*19°48'16" N.*

***UPDATE**: In the third White Space workshop the Commission provided corrections to a number of radio astronomy locations.* [15] *These corrections are noted below.*

Telescope	Name	City	State	NSF Lat	NSF Lon
Allen Telescope Array	Allen Telescope Array	Hat Creek	CA	40 49 04 N	121 28 24 W
National Astronomy and Ionosphere Center (NAIC), Arecibo Observatory	Arecibo Observatory	Arecibo	PR	18 20 37 N	66 45 11 W
National Radio Astronomy Observatory (NRAO), Robert C. Byrd Green Bank Telescope	Green Bank Telescope	Green Bank	WV	38 25 59 N	79 50 23 W
National Radio Astronomy Observatory (NRAO), Very Long Baseline Array Station	VLBA - Brewster, WA	Brewster	WA	48 07 52 N	119 41 00 W
National Radio Astronomy Observatory (NRAO), Very Long Baseline Array Station	VLBA - Fort Davis, TX	Fort Davis	TX	30 38 06 N	103 56 41 W
National Radio Astronomy Observatory (NRAO), Very Long Baseline Array Station	VLBA - Hancock, NH	Hancock	NH	42 56 01 N	71 59 12 W
National Radio Astronomy Observatory (NRAO), Very Long Baseline Array Station	VLBA - Kitt Peak, AZ	Kitt Peak	AZ	31 57 23 N	111 36 45 W
National Radio Astronomy Observatory (NRAO), Very Long Baseline Array Station	VLBA - Los Alamos, NM	Los Alamos	NM	35 46 30 N	106 14 44 W
National Radio Astronomy Observatory (NRAO), Very Long Baseline Array Station	VLBA - Mauna Kea, HI	Mauna Kea	HI	19 48 05 N	155 27 20 W
National Radio Astronomy Observatory (NRAO), Very Long Baseline Array Station	VLBA - North Liberty, IA	North Liberty	IA	41 46 17 N	91 34 27 W
National Radio Astronomy Observatory (NRAO), Very Long Baseline Array Station	VLBA - Owens Valley, CA	Owens Valley	CA	37 13 54 N	118 16 37 W
National Radio Astronomy Observatory (NRAO), Very Long Baseline Array Station	VLBA - Pie Town, NM	Pie Town	NM	34 18 04 N	108 07 09 W
National Radio Astronomy Observatory (NRAO), Very Long Baseline Array Station	VLBA - Saint Croix, VI	Saint Croix	VI	17 45 24 N	64 35 01 W

3.7.2. Interpretation

For section 15.712(h)(1) of the Rules the Naval Radio Research Observatory in Sugar Grove, West Virginia is located at 38 30 58 N and 79 16 48 W.

3.7.3. Method and Procedure to Calculate Protected Contour

For each enumerated site a single circle of 2.4 km fixed radius will be calculated.

3.7.4. Interpolation and Accuracy

Radio astronomy locations are provided with 1 whole second minimum precision. We therefore assume their location may be considered accurate to within +/- ½ second (+/- 15m.)

[15] See FCC Office of Engineering and Technology. TV Bands Database Administrator Workshop 3, page 30, available online at http://transition.fcc.gov/bureaus/oet/whitespace/TVWS_Workshop3/TVWS_Workshop_3_Presentations_5-26-11_v11.pdf

3.8. DTV Distributed transmission systems

Distributed Television Stations (DTS) are not specifically identified in subpart H of the Rules but must be afforded protection. The regulations for TV distributed transmission systems are in Section 73.626 of the Commission's rules. In short form, the rules require protection of the combined noise-limited contours of a station's DTS transmitters (which are required to cover all of a station's authorized service area for a single transmitter location) excluding any population in areas that are outside both the station's authorized service area and a distance limit that depends on the station's channel and zone.

3.8.1. Requirement

§ 73.626 DTV distributed transmission systems.

(b) For purposes of compliance with this section, a station's "authorized service area" is defined as the area within its predicted noise-limited service contour determined using the facilities authorized for the station in a license or construction permit for non-DTS, single-transmitter-location operation.

(c) Table of Distances. The following Table of Distances describes (by channel and zone) a station's maximum service area that can be obtained in applying for a DTS authorization.

Channel	*Zone*	*F(50,90) (dBu)*	*Distance (km)*
2-6	*1*	*28*	*108*
2-6	*2,3*	*28*	*128*
7-13	*1*	*36*	*101*
7-13	*2,3*	*36*	*123*
14-51	*1,2,3*	*41*	*103*

(1) DTV station zones are defined in §73.609.

(2) DTS reference point. A station's DTS reference point is established in the FCC Order that created or made final modifications to the Post-Transition DTV Table of Allotments, §73.622(i), and the corresponding facilities for the station's channel assignment as set forth in that FCC Order.

(e) DTS protection from interference. A DTS station must be protected from interference in accordance with the criteria specified in §73.616. To determine compliance with the interference protection requirements of §73.616, the population served by a DTS station shall be the population within the station's combined coverage contour, excluding the population in areas that are outside both the DTV station's authorized service area and the Table of Distances area (in paragraph (c) of this section). Only population that is predicted to receive service by the method described in §73.622(e)(2) from at least one individual DTS transmitter will be considered.

3.8.2. Interpretation

DTS protected service contours may be formally defined and visualized as the relative complement of the intersection of the authorized service area with the union of each DTS station, with the maximum service area:

$$Protected\ area = (A \cap DTS)^C \cap M$$

Where

A is the Authorized Service Area,

DTS is the Union of all component DTS contours

M is the Maximum Service Area

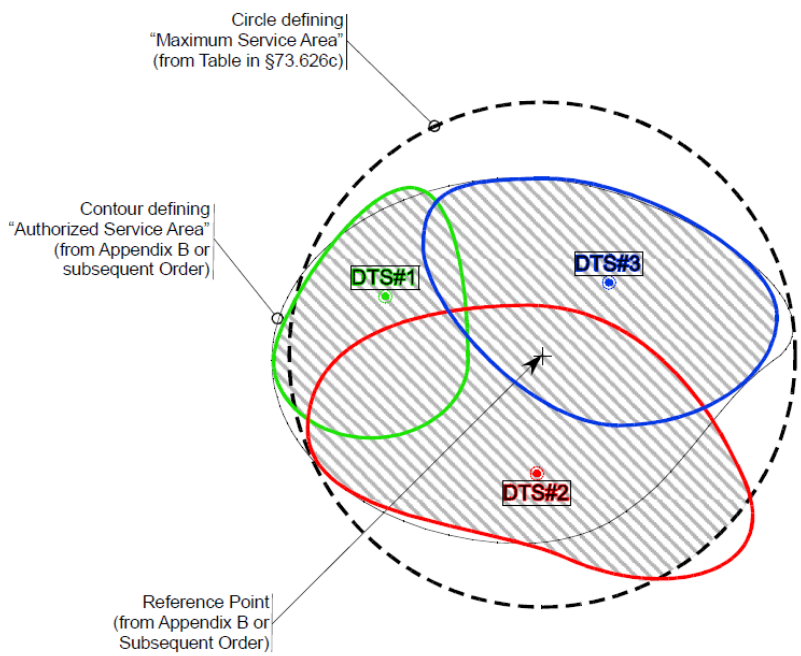
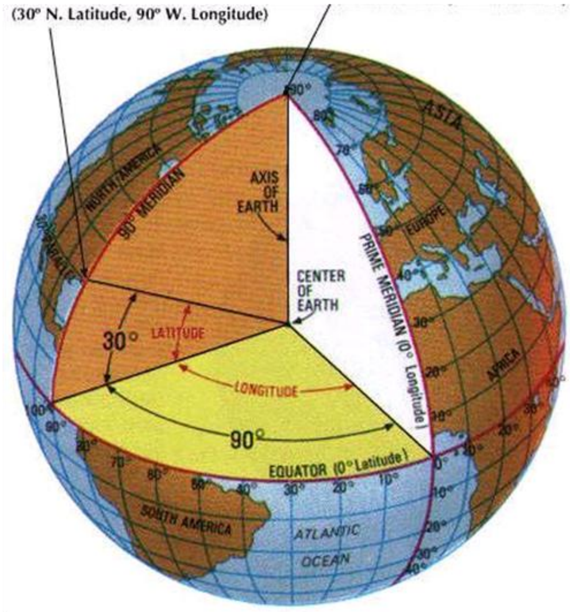


Figure 14: Protected area is the intersection of the primary station contour with the union of each DTS contour

For DTS records the reference point coordinates are in the CDBS tv_eng_data table where the first row is designated as site_number =0.

4. Standard Equations for Calculating Geographic Values



Following are a number of useful geometry equations providing transforms, distance and angle calculations along the surface of a sphere unless otherwise noted.

These equations form the basis where distance and angle calculations are required to determine protected contour geometries.

For convenience, North latitudes and West longitudes are treated as positive and South latitudes and East longitudes negative. This is to accommodate calculations over the United States and its territories. Care should be taken to reconvert longitude results to their proper negative sign where necessary.

4.1. FCC Distance Computations

§ 73.208 Reference points and distance computations.

(c) The method given in this paragraph shall be used to compute the distance between two reference points, except that, for computation of distance involving stations in Canada and Mexico, the method for distance computation specified in the applicable international agreement shall be used instead. The method set forth in this paragraph is valid only for distances not exceeding 475 km (295 miles).

(1) Convert the latitudes and longitudes of each reference point from degree-minute-second format to degree-decimal format by dividing minutes by 60 and seconds by 3600, then adding the results to degrees.

(2) Calculate the middle latitude between the two reference points by averaging the two latitudes as follows:

$$ML = (LAT1_{dd} + LAT2_{dd}) \div 2$$

(3) Calculate the number of kilometers per degree latitude difference for the middle latitude calculated in paragraph (c)(2) as follows:

$$KPD_{lat} = 111.13209 - 0.56605 \cos(2ML) + 0.00120 \cos(4ML)$$

(4) Calculate the number of kilometers per degree longitude difference for the middle latitude calculated in paragraph (c)(2) as follows:

$$KPD_{lon} = 111.41513 \cos(ML) - 0.09455 \cos(3ML) + 0.00012 \cos(5ML)$$

(5) Calculate the North-South distance in kilometers as follows:

$$NS = KPD_{lat}(LAT1_{dd} - LAT2_{dd})$$

(6) Calculate the East-West distance in kilometers as follows:

$$EW = KPD_{lon}(LON1_{dd} - LON2_{dd})$$

(7) Calculate the distance between the two reference points by taking the square root of the sum of the squares of the East-West and North-South distances as follows:

$$DIST = \sqrt{NS^2 + EW^2}$$

(8) Round the distance to the nearest kilometer.

(9) Terms used in this section are defined as follows:

(i) $LAT1_{dd}$ and $LON1_{dd}$ = the coordinates of the first reference point in degree-decimal format

(ii) $LAT2_{dd}$ and $LON2_{dd}$ = the coordinates of the second reference point in degree-decimal format

(iii) ML = the middle latitude in degree-decimal format

(iv) KPD_{lat} = the number of kilometers per degree of latitude at a given middle latitude

(v) KPD_{lon} = the number of kilometers per degree of longitude at a given middle latitude

(vi) NS = the North-South distance in kilometers

(vii) EW = the East-West distance in kilometers

(viii) DIST = the distance between the two reference points, in kilometers

4.1.1. Applicability to Protected Contours

§ 73.611 Reference points and distance computations.

(d) To calculate the distance between two reference points see paragraph (c), §73.208. However, distances shall be rounded to the nearest tenth of a kilometer.

NOTE: In the 3rd TV White Space workshop the Commission specified that Vicenty's formulae shall be used for the calculation of distance between any two latitude/longitude points on the Earth's surface.

4.2. Course angle between two points

It follows directly from 73.208 (above) that the initial course angle, theta, measured from point 1 to point 2 can be obtained by a simple trigonometric transformation. As in 73.208, this is assumed accurate only for relatively short distances (< 475 km) where the Earth's curvature introduces only a marginal effect on internal spherical angles. The course angle between two points $P_1(lat_1, lat_2)$ and $P_2(lat_1, lat_2)$ may be calculated as:

$$\theta = atan\left(\frac{lon_2 - lon_1}{lat_2 - lat_1}\right)$$

For distances greater than 475 km spherical coordinates and the following set of equations may instead be used. For two points not on either pole, where the vector has negative slope, the course angle between those two points is described by:

$$\theta = acos\left(\frac{sin(lat_2) - sin(lat_1) * cos\, d}{sin\, d * cos(lat_1)}\right)$$

For two points not on either pole, where the vector has positive slope, an simple adjustment is required:

$$\theta = 2\pi - acos\left(\frac{sin(lat_2) - sin(lat_1) * cos\, d}{sin\, d * cos(lat_1)}\right)$$

where

d is the distance between the two points.

The vector slope is defined as:

$$\varphi = sin(lon_2 - lon_1)$$

4.3. The Haversine and Vincenty formulae

The Haversine formula is widely recognized as a standard tool for calculating great-circle distances between two points on a sphere.

NOTE: For distances greater than 475 km a more accurate method to calculate distance and headings should be used.

The Haversine formulae to calculate the distance between two geographic points is:

$$haversin\left(\frac{d}{R}\right) = haversin(\varphi_1 - \varphi_2) + cos(\varphi_2)haversin(\Delta lon)$$

where *haversin* is the Haversine function

d	is the spherical distance between two points
R	is the radius of the sphere
φ_1	is the latitude in radians of point 1
φ_2	is the latitude in radians of point 1
Δlon	is the longitude separation in radians

A more accurate method of calculation is given by Vicenty's formulae, which accounts for the Earth's eccentricity.[16]

Vincenty's formulae are iterative methods for calculating geodesic distances between a pair of latitude/longitude points on the earth's surface, using an accurate ellipsoidal model of the earth. Vincenty's formula is accurate to within 0.5mm, or 0.000015″, on the ellipsoid being used. Calculations based on a spherical model, such as the (much simpler) Haversine, are accurate to around 0.3%.

The first (direct) method computes the location of a point which is a given distance and azimuth (direction) from another point.

The second (inverse) method computes the geographical distance and azimuth between two given points.

[16] T.Vicenty, *Direct and Inverse Solutions of Geodesics on the Ellipsoid with Application of Nested Equations.* Survey Review, April 1975

4.3.1. Vicenty Inverse Formula

This method computes the geographical distance and azimuth between two given points. Given two point coordinates (φ_1, L_1) and (φ_2, L_2), this method finds the azimuths α_1, α_2 and the ellipsoidal distance *s*.

Begin by defining the following parameters:

a	major axis length of the ellipsoid (e.g. radius at equator)
b	minor axis length of the ellipsoid
f	flattening of the ellipsoid $(a - b)/a$
$\varphi1$, $\varphi2$	geodetic latitude of the first and second points, respectively
L	difference in longitude of the two points
$U_1 = atan[(1-f)\,tan\ \varphi_1]$ $U_2 = atan[(1-f)\,tan\,\varphi_2]$	reduced latitude
$\lambda_{1,}\lambda_1$	longitude of the points on an auxiliary sphere
a_1, a_2	forward azimuths at the first and second points, respectively
α	azimuth at the equator
s	ellipsoidal distance between the two points
α	arc length between points on the auxiliary sphere

First calculate values for U_1, U_2 and L and set the initial value of $\lambda = L$. Then iteratively evaluate the following equations until λ converges to a negligible value (e.g. $< \ 10^{-12} \approx 0.06$mm)

$$sin\,\sigma = ((cos\,U_2\,sin\,\lambda)^2 + (cos\,U_1\,sin\,U_1 - sin\,U_1\,cos\,U_2\,cos\,\lambda)^2)^{1/2}$$

$$cos\,\sigma = sin\,U_1\,sin\,U_2 + cos\,U_1\,cos\,U_2\,cos\,\lambda$$

$$\sigma = atan\left(\frac{sin\,\sigma}{cos\,\sigma}\right)$$

$$sin\,\alpha = \frac{cos\,U_1\,cos\,U_2\,sin\,\lambda}{sin\,\sigma}$$

$$(cos\,\alpha)^2 = 1 - (sin\,\alpha)^2$$

$$cos\,2\sigma_m = cos\,\sigma - \frac{2\,sin\,U_1\,sin\,U_2}{cos\,\alpha}$$

$$C = \frac{f}{16}(\cos\alpha)^2[4 + f(4 - 3(\cos\alpha)^2)]$$

$$\lambda = L + (1 - C)\, f \sin\alpha \left(\alpha + C \sin\alpha \left(\cos(2\sigma_m) + C \cos\sigma \left(-1 + 2\left(\cos(2\sigma_m)\right)^2\right)\right)\right)$$

After λ has converged use the following equations to determine the distance between the two points and course angles.

$$u^2 = (\cos\alpha)^2 \frac{a^2 - b^2}{b^2}$$

$$A = 1 + \frac{u^2}{16384}\left(4096 + u^2\left(-768 + u^2(320 - 175u^2)\right)\right)$$

$$B = \frac{u^2}{1024}\left(256 + u^2\left(-128 + u^2(74 - 47u^2)\right)\right)$$

$$\Delta\sigma = B \sin\sigma \left(\cos(2\sigma_m) + \frac{B}{4}\left(\cos\sigma\left(-1 + 2\left(\cos(2\sigma_m)\right)^2\right) - \frac{B}{6}\cos(2\sigma_m)(-3 + 4(\sin\sigma)^2)(-3 + 4\left(\cos(2\,\sigma_m)\right)^2)\right)\right)$$

$$s = b\,A\,(\sigma - \Delta\sigma)$$

$$\alpha_1 = atan\left(\frac{\cos U_2 \sin\lambda}{\cos U_1 \sin U_1 - \sin U_1 \cos U_2 \cos\lambda}\right)$$

$$\alpha_2 = atan\left(\frac{\cos U_1 \sin\lambda}{-\sin U_1 \cos U_2 - \cos U_1 \sin U_2 \cos\lambda}\right)$$

Where:

s	is the distance (in the same units as a & b)
α_1	is the initial bearing, or forward azimuth
α_2	is the final bearing (in direction p1→p2)

The most accurate and widely used globally-applicable model for the earth ellipsoid is WGS-84, which is specified by the Rules.

4.3.2. Ellipsoids

Other ellipsoids offering a better fit to the local geoid include Airy (1830) in the UK, International 1924 in much of Europe, Clarke (1880) in Africa, and GRS-67 in South America. America (NAD83) and Australia (GDA) use GRS-80, which are functionally equivalent to the WGS-84 ellipsoid.

WGS-84	**a = 6 378 137 m (±2 m)**	**b = 6 356 752.3142 m**	**f = 1 / 298.257223563**
GRS-80	a = 6 378 137 m	b = 6 356 752.3141 m	f = 1 / 298.257222101
Airy (1830)	a = 6 377 563.396 m	b = 6 356 256.909 m	f = 1 / 299.3249646
Int'l 1924	a = 6 378 388 m	b = 6 356 911.946 m	f = 1 / 297
Clarke (1880)	a = 6 378 249.145 m	b = 6 356 514.86955 m	f = 1 / 293.465
GRS-67	a = 6 378 160 m	b = 6 356 774.719 m	f = 1 / 298.25

4.4. Vincenty 'Direct' formula

In addition to the formula for calculating distance between two points on an accurate ellipsoidal model of the earth, Vincenty devised a formula for deriving the destination point given a start point, an initial bearing, and a distance travelled.

Given an initial point (φ_1, L_1) and initial azimuth, α_1, and a distance, s, along the geodesic, the Vincenty direct formula finds the end point (φ_2, L_2) and azimuth angle α_2.

Employing the same definitions as before, begin by evaluating the following:

$$\tan U_1 = (1-f)\tan\varphi_1$$

$$\sigma_1 = \operatorname{atan}\left(\frac{\tan U_1}{\cos\alpha_1}\right)$$

$$\sin\alpha = \cos U_1 \sin\alpha_1$$

$$(\cos\alpha)^2 = (1-\sin\alpha)(1+\sin\alpha)$$

$$u^2 = (\cos\alpha)^2\frac{a^2-b^2}{b^2}$$

$$A = 1+\frac{u^2}{16384}\left(4096+u^2\left(-768+u^2(320-175u^2)\right)\right)$$

$$B = \frac{u^2}{1024}\left(256+u^2\left(-128+u^2(74-47u^2)\right)\right)$$

Using an initial seed value of $\sigma = s/bA$, iterate the following calculations until the value of σ converges to the desired accuracy. (e.g. until $|\sigma-\sigma'| < 10^{-12}$ or approx 0.06mm)

$$2\sigma_m = 2\sigma_1 + \sigma$$

$$\Delta\sigma = B\sin\sigma\left(\cos(2\sigma_m) + \frac{B}{4}\left(\cos\sigma\,(-1+2\,(\cos(2\sigma_m))^2) - \frac{B}{6}\cos(2\sigma_m)(-3+4\,(\sin\alpha)^2)(-3+4\,(\cos(2\sigma_m))^2)\right)\right)$$

$$\sigma = \frac{s}{bA}+\Delta\sigma$$

Once the value of σ has sufficiently converged, the angles and end points may be evaluated as follows:

$$\varphi_2 = \operatorname{atan}\left(\frac{\sin U_1\cos\sigma+\cos U_1\sin\sigma\cos\alpha_1}{(1-f)\left((\sin\alpha)^2+(\sin U_1\sin\sigma-\cos U_1\cos\sigma\cos\alpha_1)^2\right)^{-2}}\right)$$

$$\lambda = atan\left(\frac{sin\,\sigma\, sin\,\alpha_1}{cos\,U_1\, cos\,\sigma - sin\,U_1\, sin\,\sigma\, sin\,\alpha_1}\right)$$

$$C = \frac{f}{16}(cos\,\alpha\,)^2[4 + f(4 - 3(cos\,\alpha)^2)]$$

$$L = \lambda - (1 - C)\, f\, sin\,\alpha \left(\alpha + C\, sin\,\alpha\, \left(cos(2\sigma_m) + C\, cos\,\sigma\, \left(-1 + 2\left(cos(2\sigma_m)\right)^2\right)\right)\right)$$

$$\alpha_2 = atan\left(\frac{sin\,\alpha}{-sin\,U_1\, sin\,\sigma - cos\,U_1\, cos\,\sigma\, cos\,\alpha_2}\right)$$

4.5. Alternate to Vicenty Direct formula

For coordinates not on a pole, a new point P{lat_P,lon_P} can be determined for any distance *d* on any radial angle *ra* originating from point *P1{lat_1,lon_1}*:

$$lat_p = asin(sin(lat_1))\, cos\, d + cos(lat_1)\, sin\, d\, cos(ra)$$

$$lon_p = mod\left(lon_1 - asin(ra)\frac{sin\, d}{cos(lat_1)} + \pi\,, 2\pi\right) - \pi$$

These equations are limited to distances less than one quarter of the circumference of the Earth in longitude.

4.6. Intermediate points on a great circle

An arbitrary point *P{lat,lon}* along a given fraction of the total distance *d* between two fixed points may be calculated as follows. For a starting point P1{*lat1*,*lon1*} and final point P2{*lat2*,*lon2*}, the new point $P\{lat_f, lon_f\}$ located a fraction *f* along the great circle route between points P1 and P2 is calculated as:

For P1: *f*=0 For P2: *f*=1

The intermediate latitude and longitude is then given by evaluating the following equations:

$$A = sin\left(\frac{(1-f)d}{sin\,d}\right)$$

$$B = sin\left(\frac{fd}{sin\,d}\right)$$

$$x = A\,cos(lat_1)\,cos(lon_1) + Bcos\,(lat_2)\,cos(lon_2)$$

$$y = A\,cos(lat_1)\,sin(lon_1) + Bcos\,(lat_2)\,sin(lon_2)$$

$$z = A\,sin(lat_1) + B\,sin(lat_2)$$

$$lat_f = atan\left(\frac{z}{(x^2+y^2)^{-2}}\right)$$

$$lon_f = atan\left(\frac{y}{x}\right)$$

Note that the two points cannot be antipodal (i.e. lat_1+lat_2 cannot equal zero and the absolute value of lon_1-lon_2 cannot equal *pi*) as the route is undefined.