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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

Magalie Roman Salas
Secretary
Federal Communications Commission
1919 M Street, N.W.
Room 222
Washington, D.C. 20554

DOCKET FILE COPY ORIGINAL

Re: Amendment of Parts 21 and 74 To Enable Multipoint Distribution Service and Instructional Television Fixed Service Licensees To Engage In Fixed Two-Way Transmissions -- MM Docket No. 97-217 and RM-9060: NOTICE OF EX PARTE COMMUNICATION

Dear Ms. Salas:

In response to recent telephonic inquiries by Joseph Johnson of the staff of the Mass Media Bureau to George Harter, III of Hardin & Associates, Inc. and S. Merrill Weiss of The Merrill Weiss Group regarding the intent of several of the proposals previously advanced by the group of over 110 participants in the wireless cable industry that submitted the petition for rulemaking that commenced this proceeding (the "Petitioners"), the Petitioners are submitting herewith proposed minor revisions to certain of the rule proposals they have previously advanced, as well as further modifications to the Petitioners proposal for a standardized methodology for predicting interference from response station transmitters and to response station hubs and for submitting certain data to the Commission regarding response station systems.

The proposed minor editorial rule revisions are designed to serve the following purposes:

- Simplify the proposed MDS and ITFS response station hub application requirements by adopting a single coordination distance, providing even greater protection to neighboring stations than under the previous, very conservative approach and eliminating redundant provisions.

- Conforming the proposed MDS and ITFS response station hub application rules to incorporate concessions the Petitioners' made earlier in this proceeding to eliminate any suggestions that response station hub protection will be unduly preclusive of new facilities.

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- Clarifying that it is protected service areas and receive sites, not transmitting stations, that receive protection from response stations.

- Eliminating ambiguities regarding the protection to which MDS and ITFS response station hubs will be entitled.

- Clarifying that the 45 dB cochannel and 0 dB adjacent channel D/U ratios will apply to applications for MDS and ITFS booster stations.

The proposed revisions to the previously-filed proposed methodology provide additional detail regarding the propagation model, expand the description of the content of the electronic file that applicants for response station hub licenses should be serving on neighboring applicants and licensees and submitting to the Commission, and respond to staff concerns by making minor editorial revisions to provide greater clarity.

Finally, it should be noted that the enclosed rule revisions are limited to the specific rules being revised and are redlined against the version of the rules submitted by the Petitioners on May 22, 1998. Twice last month, the Petitioners submitted proposed rule revisions in response to discussions with and requests from the staff, reflecting the ongoing cooperation between the Commission's technical staff and the Petitioners in pursuit of the best possible MDS and ITFS rules. In each case, the Petitioners submitted an edit, non-redlined version of the entire Appendix C to the *Notice of Proposed Rulemaking*, as well as versions redlined against the original and interim iterations. While this has led to the filing of a great number of pages (even though the proposed rule changes were modest in number and scope), we believed that this approach simplified Commission review, since all of the rules (revised and original) would be readily at hand and changes could be readily identified. However, we now understand that at least one party to this proceeding has seized upon the volume of the Petitioners' submissions to advocate a delay in the issuance of final rules. The Petitioners view this request as utterly absurd given that the proposals advanced by the Petitioners in their recent filings are all well within the scope of the *Notice* in this proceeding. Nonetheless, in order to avoid "adding fuel to the flames," the Petitioners are submitting only those rule sections that are being revised, and are submitting only a version redlined against their latest filing. Should the staff request, however, the Petitioners would be pleased to submit a full version of Appendix C incorporating the proposed changes, and whatever redlined versions the staff desires.

Please contact the undersigned should you have any questions regarding this *ex parte* presentation.

Respectfully submitted,

Paul J. Sinderbrand

Counsel to the Petitioners

Enclosures

cc: Roy Stewart
Keith Larson
Charles Dziedzic
Joseph Johnson (via e-mail)
Michael Jacobs

I. PROPOSED REVISIONS TO PROPOSED SECTION 21.909(c)(3).

* * * * *

(iv) The combined signals of all simultaneously operating MDS response stations within all response service areas and oriented to transmit towards their respective response station hubs and all cochannel MDS stations and booster stations licensed to or applied for by the applicant will result in a desired to undesired signal ratio of at least 45 dB (or the appropriately adjusted value based upon the ratio of the channel-to-subchannel bandwidths) (i) within the protected service area of any authorized or previously proposed cochannel incumbent MDS or ITFS station with a 56.33 km (35 miles) protected service area with center coordinates located within 160.94 km (100 miles) of the proposed response station hub, (ii) within the booster service area of any cochannel booster station entitled to such protection pursuant to §§21.913(f) or 74.985(f) and located within 160.94 km (100 miles) of the proposed response station hub, or (iii) at any ~~cochannel response station hub entitled to such protection pursuant to §§21.909(h) or 74.939(g) and~~ registered receive site of any authorized or previously-proposed cochannel channel ITFS station or booster station located within 160.94 km (100 miles) of the proposed response station hub, or, in the alternative, that the licensee of or applicant for such cochannel station or hub consents to the application; and

(v) The combined signals of all simultaneously operating MDS response stations within all response service areas and oriented to transmit towards their respective response station hubs and all cochannel MDS stations and booster stations licensed to or applied for by the applicant will result in a desired to undesired signal ratio of at least 0 dB (or the appropriately adjusted value based upon the ratio of the channel to subchannel bandwidths) (i) within the protected service area of any authorized or previously proposed adjacent channel incumbent MDS or ITFS station with a 56.33 km (35 miles) protected service area with center coordinates located within 160.94 km (100 miles) of the proposed response station hub, (ii) within the booster service area of any adjacent channel booster station entitled to such protection pursuant to §§21.913(f) or 74.985(f) and located within 160.94 km (100 miles) of the proposed response station hub, or (iii) at any ~~adjacent channel response station hub entitled to such protection pursuant to §§21.909(h) or 74.939(g) and~~ registered receive site of any authorized or previously-proposed adjacent channel ITFS station or booster station located within 160.94 km (100 miles) of the proposed response station hub, or~~,~~ in the alternative, that the licensee of or applicant for such adjacent channel station or hub consents to the application; and

(vi) The combined signals of all simultaneously operating MDS response stations within all response service areas and oriented to transmit towards their respective response station hubs and all cochannel MDS stations and booster stations licensed to or applied for by the applicant will comply with the requirements of §§21.909(h) and 74.939(h) ~~result in a desired to undesired signal ratio of at least~~

~~45 dB (or the appropriately adjusted value based upon the ratio of the channel to subchannel bandwidths) at any registered receive site of any authorized or previously-proposed cochannel ITFS station or booster station, or at any ITFS response station hub, located within 113 km (70 miles) of the proposed response station hub, or, in the alternative, that the licensee of or applicant for such cochannel station or hub consents to the application; and~~

~~(vii) The combined signals of all simultaneously operating MDS response stations within all response service areas and oriented to transmit towards their respective response station hubs and all cochannel MDS stations and booster stations licensed to or applied for by the applicant will result in a desired to undesired signal ratio of at least 0 dB (or the appropriately adjusted value based upon the ratio of the channel to subchannel bandwidths) at any registered receive site of any authorized or previously-proposed adjacent channel ITFS station or booster station, or at any ITFS response station hub, located within 113 km (70 miles) of the proposed response station hub, or, in the alternative, that the licensee of or applicant for such adjacent channel station or hub consents to the application~~.

* * * * *

II. PROPOSED REVISIONS TO PROPOSED SECTION 21.909(c)(4).

* * * * *

(iv) every licensee of or applicant for any authorized or previously proposed ITFS station (including any booster station or response station hub) located within ~~113~~160.94 km (~~70~~100 miles) of the proposed response station hub.

* * * * *

III. PROPOSED REVISIONS TO SECTION 21.909(f).

* * * * *

(6) The response stations transmitting simultaneously at any time within any given region of the response service area utilized for purposes of analyzing the potential for interference by response stations shall conform to the numerical limits for each class of response station proposed in the application for the response station hub license. Notwithstanding the foregoing, the licensee of a response station hub license may alter the number of response stations of any class operated simultaneously in a given region without prior Commission authorization, provided that the licensee first notifies the Commission of the altered number of response stations of such class(es) to be operated simultaneously in such region, provides the

Commission with an analysis establishing that such alteration will not result in any increase in electrical interference to the protected service area or protected receive sites of any existing or proposed MDS or ITFS station~~,~~ or booster station~~ or response station hub or~~, to the protected service area of any MDS Basic Trading Area or Partitioned Service Area authorization ~~holder~~ entitled to protection pursuant to §21.909(c)(3) or to any response station hub, or that the applicant or licensee of such facility has consented to such interference, and serves a copy of such notification and analysis upon each party entitled to be served pursuant to §21.909(c)(4); and

* * * * *

IV. PROPOSED REVISIONS TO SECTION 21.909(h).

(h) (1) An applicant for any new or modified MDS or ITFS station (including any booster station or response station hub) shall be required to demonstrate interference protection to a response station hub within 160.94 km (100 miles) of the proposed facilities. In lieu of the interference protection requirements set forth in §§21.902, 21.938(b)(2) and 74.903, such demonstration shall establish that the proposed facility will not increase the ~~accumulated~~effective power flux density of the undesired signals~~ (measured at the output of the reception antenna)~~ generated by the proposed facility and any associated primary stations, booster stations or response stations at the response station hub ~~receiver~~antenna for any sector. In lieu of the foregoing, an applicant for a new MDS or ITFS primary station license or for a new or modified response station hub or booster license may demonstrate that the new facility will not increase the noise floor at a reception antenna of the response station hub by more than 1 dB for co-channel signals and ~~35~~45 dB for adjacent channel signals, provided that the entity submitting the application may only invoke this alternative once per response station hub reception antenna.

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V. PROPOSED REVISIONS TO SECTION 21.913(b).

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(3) In lieu of the requirements of §§21.902(c) and (i), a study which demonstrates that the proposed booster station will cause no harmful interference (as defined in §21.902(f)) to co-channel and adjacent-channel existing or previously-proposed ITFS and MDS stations with protected service area center coordinates as specified in §21.902(d) or, in the case of ITFS stations without protected service areas, transmitters~~,~~ within 160.9 kilometers (100 miles) of the proposed booster station's transmitter site, or any ITFS or MDS response station hubs or booster stations within 160.94 kilometers (100 miles) of the proposed

booster station s transmitter site. Such study shall consider the undesired signal levels generated by the proposed signal booster station, the primary station, all other licensed or previously proposed associated booster stations, and all simultaneously operating cochannel response stations licensed to or applied for by the applicant. In the alternative, a statement from the MDS or ITFS permittee, licensee or conditional licensee stating that it does not object to operation of the MDS signal booster station may be submitted; and

* * * * *

VI. PROPOSED REVISIONS TO SECTION 74.939(c)(3).

(iv) The combined signals of all simultaneously operating ITFS response stations within all response service areas and oriented to transmit towards their respective response station hubs and all cochannel ITFS stations and booster stations licensed to or applied for by the applicant will result in a desired to undesired signal ratio of at least 45 dB (or the appropriately adjusted value based upon the ratio of the channel-to-subchannel bandwidths) ~~(A)~~ (i) within the protected service area of any authorized or previously proposed cochannel incumbent MDS or ITFS station with a 56.33 km (35 miles) protected service area with center coordinates located within 160.94 km (100 miles) of the proposed response station hub, ~~(B)~~ (ii) within the booster service area of any cochannel booster station entitled to such protection pursuant to §§21.913(f) or 74.985(f) and located within 160.94 km (100 miles) of the proposed response station hub, or ~~(C)~~ (iii) at any ~~cochannel response station hub entitled to such protection pursuant to §§21.909(h) or 74.939(g) and~~ registered receive site of any authorized or previously-proposed cochannel channel ITFS station or booster station located within 160.94 km (100 miles) of the proposed response station hub, or, in the alternative, that the licensee of or applicant for such cochannel station or hub consents to the application; and

(v) The combined signals of all simultaneously operating ITFS response stations within all response service areas and oriented to transmit towards their respective response station hubs and all cochannel ITFS stations and booster stations licensed to or applied for by the applicant will result in a desired to undesired signal ratio of at least 0 dB (or the appropriately adjusted value based upon the ratio of the channel to subchannel bandwidths) (i) within the protected service area of any authorized or previously proposed adjacent channel incumbent MDS or ITFS station with a 56.33 km (35 miles) protected service area with center coordinates located within 160.94 km (100 miles) of the proposed response station hub, (ii) within the booster service area of any adjacent channel booster station entitled to such protection pursuant to §§21.913(f) or 74.985(f) and located within 160.94 km (100 miles) of the proposed response station hub, or (iii) at any ~~adjacent channel response station hub entitled to such protection pursuant to §§21.909(h) or~~

~~74.939(g) and~~ registered receive site of any authorized or previously-proposed adjacent channel ITFS station or booster station located within 160.94 km (100 miles) of the proposed response station hub, or~~,~~ in the alternative, that the licensee of or applicant for such adjacent channel station or hub consents to the application; and

(vi) The combined signals of all simultaneously operating ITFS response stations within all response service areas and oriented to transmit towards their respective response station hubs and all cochannel ITFS stations and booster stations licensed to or applied for by the applicant will comply with the requirements of §§21.909(h) and 74.939(h) ~~result in a desired to undesired signal ratio of at least 45 dB (or the appropriately adjusted value based upon the ratio of the channel to subchannel bandwidths) at any registered receive site of any authorized or previously-proposed cochannel ITFS station or booster station, or at any ITFS response station hub, located within 113 km (70 miles) of the proposed response station hub, or, in the alternative, that the licensee of or applicant for such cochannel station or hub consents to the application; and~~

~~(vii) The combined signals of all simultaneously operating MDS response stations within all response service areas and oriented to transmit towards their respective response station hubs and all cochannel MDS stations and booster stations licensed to or applied for by the applicant will result in a desired to undesired signal ratio of at least 0 dB (or the appropriately adjusted value based upon the ratio of the channel to subchannel bandwidths) at any registered receive site of any authorized or previously-proposed adjacent channel ITFS station or booster station, or at any ITFS response station hub, located within 113 km (70 miles) of the proposed response station hub, or, in the alternative, that the licensee of or applicant for such adjacent channel station or hub consents to the application~~.

* * * * *

VI. PROPOSED REVISIONS TO SECTION 74.939(c)(4).

(iv) every licensee of or applicant for any authorized or previously proposed ITFS station (including any booster station or response station hub) located within ~~113~~160.94 km (~~70~~100 miles) of the proposed response station hub

* * * * *

VII. PROPOSED REVISIONS TO SECTION 74.939(f).

* * * * *

(6) The response stations transmitting simultaneously at any time within any given region of the response service area utilized for purposes of analyzing the potential for interference by response stations shall conform to the numerical limits for each class of response station proposed in the application for the response station hub license; Notwithstanding the foregoing, the licensee of a response station hub license may alter the number of response stations of any class operating simultaneously in a given region without prior Commission authorization, provided the licensee first notifies the Commission of the altered number of response stations of such class(es) to be operated simultaneously in such region, provides the Commission with an analysis establishing that such alteration will not result in any increase in electrical interference to the protected service area or protected receive sites of any existing or proposed MDS or ITFS station~~;~~ or booster station~~ or response station hub or~~, to protected service area of any MDS Basic Trading Area or Partitioned Service Area authorization ~~holder~~ entitled to protection pursuant to §74.939(c)(3) or to any response station hub, or that the applicant or licensee of such facility has consented to such interference, and serves a copy of such notification and analysis upon each party entitled to be served pursuant to §74.939(c)(4).

* * * * *

VIII. PROPOSED REVISIONS TO PROPOSED SECTION 74.939(h).

(h) (1) An applicant for any new or modified MDS or ITFS station (including any booster station or response station hub) shall be required to demonstrate interference protection to a response station hub within 160.94 km (100 miles) of the proposed facilities. In lieu of the interference protection requirements set forth in §§21.902, 21.938(b)(2) and 74.903, such demonstration shall establish that the proposed facility will not increase the ~~predicted~~effective power flux density of the undesired signals generated by the proposed facility and any associated primary stations, booster stations or response stations at the response station hub ~~receiver~~antenna for any sector. In lieu of the foregoing, an applicant for a new MDS or ITFS primary station license or for a new or modified response station hub or booster license may demonstrate that the new facility will not increase the noise floor at a reception antenna of the response station hub by more than 1 dB for co-channel signals and ~~35~~45 dB for adjacent channel signals, provided that the entity submitting the application may only invoke this alternative once per response station hub reception antenna.

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IX. PROPOSED REVISIONS TO PROPOSED SECTION 74.985(b).

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(5) In lieu of the requirements of §74.903, a demonstration that the proposed signal booster station will cause no harmful interference (as defined in §74.903(a)(1) and (2)) to co-channel or adjacent-channel, authorized or previously-proposed ITFS, MDS, or MMDS stations with protected service area center coordinates as specified in §21.902(d) or, in the case of ITFS stations without protected service areas, transmitters within 160.94 kilometers (100 miles) of the proposed booster station's transmitter site, or any ITFS or MDS response station hubs or booster stations within 160.94 kilometers (100 miles) of the proposed booster station's transmitter site. Such study shall consider the undesired signal levels generated by the proposed signal booster station, the primary station, all other licensed or previously proposed associated booster stations, and all simultaneously operating cochannel response stations licensed to or applied for by the applicant. In the alternative, a statement from the MDS or ITFS licensee or conditional licensee stating that it does not object to operation of the ITFS signal booster station may be submitted; and

PROPOSED TEXT OF ATTACHMENT TO REPORT AND ORDER SETTING FORTH "METHODS FOR PREDICTING INTERFERENCE FROM RESPONSE STATION TRANSMITTERS AND TO RESPONSE STATION HUBS AND FOR SUPPLYING DATA ON RESPONSE STATION SYSTEMS."

This document explains the methods to be used in carrying out three requirements with respect to response station systems in the MMDS and ITFS services. It details the methods for conducting interference studies from response stations to other systems; it details the methods for assuring interference protection to response station hubs; and it defines a file format to be used in submitting data for response station hub licenses. It also describes the propagation analysis techniques to be used in these studies.

Four Major Steps for Response Station Interference Analysis

In carrying out the studies of interference from response station transmitters required by this section, the aggregate power of the interfering signals to be expected from the response station transmitters shall be determined using a process comprising four major steps, as described below. First, a grid of points shall be defined that is statistically representative of the distribution of transmitters to be expected within the response service area, and the elevations to be associated with each of them shall be determined. Second, any regions and any classes of response stations to be used shall be defined. Third, the appropriate transmitter configuration to be used in each interference study shall be determined. Finally, the equivalent power of each of the representative transmitters shall be determined and used in the various required interference studies. The parameters used in the studies shall be provided in a prescribed electronic form as described later in this document.

Defining Grid of Points for Analysis

Since it is impossible to know *a priori* where response stations will be located, a grid of points is used to represent statistically, in a relatively small number of locations, the potentially much larger number of response stations that are likely to be installed in the areas surrounding each of the points. Once defined, the same grid of points shall be used by all parties conducting interference analyses involving the subject response station system.

Defining the representative grid of points to use in all the interference studies required in Sections 21.909 and 74.939 begins by geographically defining the response service area (RSA) of the response station hub (RSH). This may be done using either a list of coordinates or a radius from the response station hub location. When coordinates are used, straight lines shall interconnect one location with the next in the order given in the list, and the last location described shall be connected to the first location by a straight line. When a radius from the response station hub location is used, the value shall be expressed in miles, with any fractional part expressed as a decimal value to three places. The boundaries described are administrative and serve to circumscribe the area in which response station transmitters may be located.

The characteristics of any sectors in the RSH receiving antenna also must be described in two ways: geographically, so as to limit the locations from which response stations will transmit to each sector, and electrically, by providing data on the electrical field response of the antenna pattern in each sector. Sectors may overlap one another geographically. The geographic boundaries of a sector shall be defined using either a list of coordinates or a list of bearings. Electrical field response data shall be relative to the direction of maximum response of the sector antenna and shall be provided every one (1) degree completely around the antenna. Both azimuth and elevation field patterns shall be supplied for each polarization to be used with a given antenna type. The geographic orientation of each sector to the nearest degree and the polarization in each sector also shall be specified. When response stations share channels or sub-channels by transmitting simultaneously on them, the maximum number of response stations that will be permitted to transmit simultaneously within each sector must be specified.

The RSA may be subdivided into regions to allow different characteristics to be used for response stations in different portions of the RSA. (For details on regions and their use, see the section below on Defining Regions and Classes for Analysis.) Any regions to be used when analyzing interference must also be described in a manner similar to that used to describe the RSA itself. Analysis of the regions involves use of one or more classes of response station characteristics. For each such class, a combination must be specified of the maximum antenna height, the maximum equivalent isotropic radiated power (EIRP), and the worst case antenna pattern that will be used in practice in installations of response stations associated with that class within the respective regions. (For details on classes and their use, see the section below on Defining Regions and Classes for Analysis.) When response stations share channels or sub-channels by transmitting simultaneously on them, the maximum number of response stations associated with each class that will be permitted to transmit simultaneously within each region and each sector must be specified.

To define the grid of points, a line is first established surrounding the RSA, following the shape of the RSA boundary, ½ mile outside the RSA, and never more than ½ mile from the RSA boundary at any point. This is termed the "analysis line" and will be used in determining that an adequate number of grid points representing transmitters is being used in the interference analyses. A starting point is defined on the analysis line due north (true) of the response station hub. A series of analysis points is then spaced along the analysis line with the starting point being one of those points. The analysis points must occur with a spacing no greater than every ½ mile along the analysis line or every 5 degrees (as seen from the response station hub), whichever yields the largest number of analysis points. When an RSA has a non-circular shape, the choice of distance along the analysis line or angle from the response station hub must be made for each portion of the line so as to maximize the number of analysis points in that portion. The analysis points are to be described by their geographic coordinates. (The results of this method are that, for a circular RSA, a minimum of 72 analysis points will be used, and that, for portions of the analysis line of any RSA more than 5.73 miles from the response station hub, the distance method will be used.)

Next, the grid of points is defined within the RSA to statistically represent the response stations. The grid uses uniform, square spacing of the points, as measured in integer seconds of latitude and longitude, with the first square surrounding the RSH and with its points equidistant from it. The lines connecting the points on one side of any grid square point true north, east, south, or west. The grid is defined so as to include all points within or on the boundary of the RSA, with the exceptions noted below. The result is that the grid can be defined by only two values — the coordinates of the hub and the separation between adjacent grid points in seconds — combined with the description of the RSA boundary.

Any points falling at locations at which it would be physically impossible to install a response station (such as in the middle of a lake, but not the middle of a forest) are removed from the grid. The points of the grid so removed are to be described by their geographic coordinates.

The grid of points is then divided into two groups. The division is to be done using a checkerboard (or quincunx) pattern so that alternating points along the east-west and north-south axes belong to opposite groups and points along any diagonal line belong to the same group.

The combination of the grid of points within the RSA and the points on the analysis line is next used to determine that the number of grid points is truly representative of a uniform distribution of response station transmitters within the RSA. This is done by conducting a power flux density analysis from each grid point within the RSA to each point on the analysis line. For this analysis, a single response station should be assumed to be located at each grid point, that response station having the combined worst case antenna pattern without regard to polarization of all response station classes assigned to that grid point and the maximum EIRP of any response station class assigned to that grid point. (For details on the method for determining the combined worst case antenna pattern, see the section below on Defining Regions and Classes for Analysis.) The response station antennas all should be oriented toward the response station hub.

The analysis of grid point adequacy should be done using free space path loss over flat earth only and should not include the effects of terrain in the calculation of received signal levels. At each point on the analysis line, the power flux density from all grid points in each group of the checkerboard pattern should be aggregated. This is done by converting power received from each assumed transmitter from dBW/m^2 to W/m^2, summing the power in W/m^2 from all transmitters in each group, and then converting the sum back to dBW/m^2.

After the aggregated power flux density from each of the two groups has been calculated, the received power flux densities from the two groups are compared at each of the points on the analysis line. The power flux densities from the two groups must be within 3 dB of one another at each of the points on the analysis line. In addition, there must be no closer spacing of grid points that allows a difference of greater than 3 dB between the

groups. If the power flux densities of both groups are within 3 dB at every analysis point, a sufficient number of grid points is included for use in further analyses. If they are not within 3 dB at every analysis point, a larger number of grid points (i.e., closer spacing of grid points) must be used so that the 3 dB criterion is met.

In cases in which sectorized response station hubs are used, a further test is required to assure that an adequate number of grid points is used. In addition to meeting the requirements of the preceding paragraph, each sector must contain a number of grid points equal to or greater than the distance from the hub to the furthest point in the sector, expressed in miles, divided by two, with a minimum of five grid points per sector. Should an insufficient number of grid points fall within any sector after meeting the 3 dB criterion, the point spacing for the entire RSA must be decreased until this additional requirement is satisfied.

Once the geographic locations of the grid points are determined, the elevations to be attributed to each must be decided. This is done by creating a geographic square uniformly spaced around each grid point having a width and a height equal to the spacing between grid points and oriented in the same directions as the lines between grid points used to lay out the grid structure. Each such square is then examined with respect to all of the data points of the U.S. Coast & Geodetic Survey 3-second database falling within the square to find the elevation of the highest such data point, expressed in feet. That elevation is ascribed to the associated grid point and shall be used for the elevation of that grid point in all further and future analyses of the response station system.

Defining Regions and Classes for Analysis

To provide flexibility in system design, regions may optionally be created within response service areas. Regions may be of arbitrary size, shape, and location. The territory within a region must be contiguous. Regions within a single RSA may not overlap one another. Within regions, response stations are apt to be randomly distributed and for analysis purposes are to be assumed to be uniformly distributed. Regions are to be defined by their boundaries in the same manner as are response service areas. (For details on describing boundaries, see the section above on Defining Grid of Points for Analysis.)

Within each region, at least one class of response station with defined characteristics must be specified to match the interference predicted to be caused with the types of installations to be made. The classes are to be used in interference analyses and to provide limitations on the installations that may be made in the related region. The characteristics of each such class of response stations shall include the maximum height above ground level (AGL) for antennas, the maximum equivalent isotropic radiated power (EIRP), and the combined worst-case antenna radiation pattern – for each polarization when both are used – for all response stations of that class to be installed. When response stations share a channel by transmitting simultaneously (see section below on Determining Transmitter Configuration), for each class of response stations

within each region, the maximum number of such response stations that may transmit simultaneously on any channel or sub-channel shall be specified.

The combined worst-case antenna azimuth radiation pattern is required to be specified collectively for all of the classes of response stations located at each grid point (in the procedure above, in the section on Defining Grid of Points for Analysis, for confirming that the required number of grid points is specified) and individually for each of the classes defined for each region of the RSA. In the case of the collective pattern used to determine adequacy of the number of grid points, if both polarizations are used in the system, the horizontally- and vertically-polarized azimuth patterns of each antenna should be treated as deriving from separate antennas and should be combined with one another and with the patterns from all the other antennas at that grid point. In the cases of the individual patterns for each class used for interference analyses, if both polarizations are used in the system, the horizontally- and vertically-polarized combined worst-case azimuth patterns should be determined separately for all classes defined. Similarly, the cross-polarized worst-case patterns should be determined for each polarization.

These combined worst-case patterns are derived by setting the maximum forward signal power of all antenna types to be used within the class or classes to the same value and then using the highest level of radiation in each direction from any of the antennas as the value in that direction for the combined antenna pattern. The same method is used to determine both plane- and cross-polarized patterns, which are used separately in interference analyses. The combined worst-case plane- and cross-polarized patterns for each class will be used in all of the interference studies and are not to be exceeded in actual installations of response stations within a class to which the pattern applies.

Determining Transmitter Configuration

Several factors in the configuration of a system determine whether or not transmitters located at specific grid points could cause interference to particular neighboring systems. In order to simplify the study of interference to those neighbors, the system configuration is taken into account so as to reduce the number of calculations required by eliminating the study of interference from specific grid points when possible. The main factor that determines whether to eliminate certain grid points from consideration is terrain blockage.

When grid points are completely blocked from line-of-sight to any part of a neighboring system, they can be eliminated from the aggregation of power used in calculating interference to that system. To determine whether to eliminate a grid point for this reason, a shadow study can be conducted from each grid point in the direction of the neighboring system. Separate studies can be conducted for classes of response stations that have different maximum elevations above ground. If there is no area within the protected service area or at any of the registered receiving locations of the neighboring system to which a particular class of station at a grid point has line-of-sight, it can be eliminated from the calculations that determine the power of interfering signals at the neighbor's location. Alternatively, lack of line-of-sight can be evaluated from each class

at each grid point to each location analyzed within the neighboring system (see section below on Calculating Aggregated Power from Transmitters), and grid points can be eliminated on a location-by-location basis, if that process is more easily implemented.

There are two ways in which a large number of response stations can share channels: They can take turns using the channels so that only one transmitter will be turned on at any particular instant on each channel or sub-channel being received by a separate receiver in the system, or they can transmit at the same time and use special filtering techniques at the receiver to separate the signals they are sending simultaneously to that receiver. These two cases will result in different levels of power being radiated into neighboring systems, and therefore they must be analyzed slightly differently.

In the case of response stations that take turns using a channel or sub-channel, the grid point and class of station that produces the worst case of interference to each analyzed location in the neighboring system must be determined for each group of response stations that share a channel (e.g., within a response station hub receiving antenna sector). In this case, the interfering signal source can be treated as a single transmitter occupying the full bandwidth of the channel or sub-channels used from that location and having a power level equal to the aggregate of the power transmitted on all of the sub-channels, if sub-channels are used.

In the case of response stations that simultaneously share a channel or sub-channel, the grid point and class of station that produces the worst case of interference to each analyzed location in the neighboring system must be determined for each group of response stations that share a channel (e.g., within a response station hub receiving antenna sector). In this case, the interfering signal source can be treated as a single grid point at which are located all of the simultaneously operating transmitters, occupying the full bandwidth of the channel or sub-channels used from that location, and having a power level equal to the aggregate of the power transmitted by all of the response stations operating simultaneously on all of the sub-channels, if sub-channels are used.

In cases of shared-channel operation in which the number of simultaneously operating response stations of a class is limited by a region that crosses sector boundaries, the number of such response stations considered within some sectors may be limited so that the total included in the analysis in all sectors does not exceed the total permitted for the region. The objective in analyzing these cases is to find the worst case situation with regard to the maximum number of simultaneously operating transmitters, assigning them collectively to the locations at which they cause the most interference to each location analyzed within neighboring systems, while respecting the limits imposed on the number of such transmitters by sector and by region. A statement describing in detail the process or algorithm followed in selecting the number and classes of response stations analyzed at each grid point shall be appended to the application and distributed as a standard ASCII text file along with the data file described below in the section on the File Format.

An example of the case just described of shared-channel operation with the number of simultaneously operating transmitters limited both by region and by sector is one in which a region comprises an annular ring that stretches from half the radius to the full radius of a circular RSA. The region has a limit of 200 simultaneously operating transmitters of a particular class, and each of 20 sectors is limited to 20 simultaneously operating transmitters. If the worst case interference from each sector were caused by the subject class and all were used in analyzing interference to a neighboring system, the result would be the use of 400 such response stations (20 x 20) in the analysis, while the region is limited to 200. Consequently, the 10 regions (10 x 20 meets the limit of 200) causing the most interference to the neighbor would be selected, and, in the other 10 sectors, the classes of station causing the second largest amount of interference to the neighbor would be selected for use in the analysis. In choosing the secondary interfering response station classes, the same type of limitations would have to be observed. The process for making these selections based on the appropriate limitations would have to be followed for each analyzed point in the neighboring system.

Calculating Aggregated Power from Transmitters

The final major step in calculating interference from response station transmitters is the calculation of the equivalent isotropic radiated power (EIRP) to be attributed to each of the selected grid points in the various interference studies so as to be representative of the number of response stations that are expected to be in operation simultaneously within the RSA. When analyzing systems in which the response stations take turns using a channel or sub-channels, this means, for each location analyzed in the neighboring system, selecting the grid point and class of station within each sector that radiates the strongest signal to that location and aggregating the power from all such selected grid points and classes, using the maximum EIRP (for all sub-channels taken together), the maximum antenna height, and the worst case antenna pattern for a single station of that class at each selected grid point.

For systems in which response stations simultaneously share the channel or sub-channels to each receiver at each hub, this means doing substantially the same analysis. The difference is that the maximum number of simultaneously operating response stations within each sector is placed at each selected grid point, in turn. The maximum EIRP (for all sub-channels taken together) for each regional class at each grid point or additional point, expressed in dBW, is converted to Watts. The power is then multiplied by the number of simultaneously operating transmitters in the regional class assigned to that grid point or additional point, and the resulting power in Watts is converted back to dBW. When the number of simultaneously operating transmitters within a sector in the class and at the grid point that causes the most signal to be propagated to a location in the neighboring system does not equal the number of simultaneously operating transmitters permitted in that sector, the grid point and class of station that cause the next largest amount of signal to be so propagated shall be used to account for the remaining number of simultaneously operating transmitters permitted in the sector, and so on as necessary. At each location analyzed within the neighboring system, the power received from the

selected grid points within each sector is aggregated through conversion from dBW to Watts, addition of power levels, and conversion back to dBW. In each case, the values so calculated are the aggregated powers of all the simultaneously operating response station transmitters sharing the same channel or sub-channel frequency, from all sectors, for use as the undesired signal levels in interference analyses.

In a system using both polarizations, the response stations represented by each grid point are to be assumed to use the polarization of the response station hub antenna sector in which they are located. The appropriate horizontal or vertical combined worst-case antenna pattern is to be used in interference studies depending upon the polarization of the sector in which each grid point is located. In a system using only one polarization, the effect of antenna sectors can be ignored and the choice between horizontal and vertical polarization patterns made identically for all grid points.

Finally, the aggregate power of each active regional class at each active grid point is used in conducting the required interference studies described in the relevant Rules. For example, to determine that the -73 dBW/m^2 limitation is met, a field strength contour is calculated by first calculating a matrix of field strengths from each regional class at each grid point in the RSA in the region of the PSA or other boundary to be protected using the terrain-based propagation analysis tool specified below (i.e., free space path loss plus reflection and multiple diffractions — see section below on Propagation Analysis Tool). The matrix represents an array of locations on a square grid separated by a short distance (no more than 1 mile). Once the matrix is calculated for each regional class at each grid point or additional point, the matrices are summed by first converting from dBW/m^2 to W/m^2, adding the field strength values from all regional classes at all grid points at each matrix point, and converting from W/m^2 back to dBW/m^2. The summed matrix is then used to route a contour by interpolating between matrix points. The contour so determined should not cross the boundary under consideration.

Similar methods should be used in conducting the other interference studies required in this section. These include the desired-to-undesired (D/U) signal ratio studies for co-channel and adjacent channel interference. In all of these studies, the analysis should use the aggregate power of each regional class at each grid point or additional point, the worst case plane- or cross-polarized antenna pattern, as appropriate, for each regional class, with the antennas at each grid point aimed toward the response station hub, and the maximum antenna height above ground specified for each regional class at each grid point or additional point.

Protection to Response Station Hubs

Protection to response station hubs is required from two types of neighboring systems: those applied for or licensed prior to the licensing of the subject response station hub and those applied for or licensed subsequent to the licensing of the subject response station hub. In cases in which the neighboring system was licensed first, the protection to be provided to the response station hub after any modifications of the neighboring system

shall be no less than that provided prior to the modifications. In cases in which the neighboring system is licensed later, the protection to be provided to the response station hub after construction of the neighboring system shall be such as not to degrade the noise floor of hub receivers by more that 1 dB for co-channel signals and 45 dB for adjacent channel signals. The methods to be used to determine the amount of protection provided or the amount of degradation follow.

For purposes of interference protection calculations, an applicant for a response station hub shall specify the geographic coordinates of the hub location and, for each sector, (1) the height of the antenna above ground (AGL) and above mean sea level (AMSL), (2) the hub receiving antenna pattern (both in azimuth and elevation, both co- and cross-polarized in the main vertical lobe), (3) the hub receiving antenna gain in the main lobe (in dBi), (4) the azimuth of the main lobe, (5) any mechanical tilt to be utilitized, and (6) the polarization of the receiving antenna.

The level of interference caused to a response station hub by either an existing or a new MDS or ITFS station shall be independently determined for each sector. In making such a determination, the power from all sources (main, booster, and response stations) related to a particular primary license of an individual licensee shall be aggregated to yield an effective power flux density of the interfering signal(s). The resulting summation can then be used for comparisons between old and new values when existing stations are modified or for comparison against the specified receiver degradation threshold for new stations that are proposed.

In calculating the effective power flux density value, the effective isotropic radiated power (EIRP) radiated in the direction of the response station hub from each main, booster, or response station (as represented by the selected grid points described earlier in the section Four Major Steps for Response Station Interference Analysis) of the neighboring system shall first be determined. The power arriving at the response station hub shall be analyzed using the propagation analysis tool described in the following section on that subject. The aggregation of power from all related sources shall take account of the angular displacement of each particular source from the peak of the main lobe of the receiving antenna and the relative polarization of each interfering signal source.

To determine the effective power flux density, the following formula shall be used:

$$PFD_{EFF} = 10\log_{10}\sum_{1}^{n} 10^{\frac{ISi+G_{REL}i}{10}} \qquad (1)$$

Where

PFD_{EFF} = *Effective Power Flux Density* (dBW/m^2)

n = *Number of Interfering Signal Sources* (*units*)

ISi = *Interfering Signal Power Flux Density of ith Source* (dBW/m^2)

$G_{REL}i$ = *Relative Gain of Hub Sector in Direction of ith Source* (*dB*) (*includes antenna discrimination & polarization effects*)

For neighboring systems licensed first, it is necessary to ascertain that the value of the effective power flux density after a modification, as predicted for each response station hub antenna sector, does not exceed the value predicted for the same sector prior to the modification. For new neighboring systems, an additional step is required to ascertain that the predicted value of the effective power flux density does not exceed the allowed threshold values for both co-channel and adjacent channel signals.

To calculate the relationship of the effective power flux density to the threshold values for co-channel and adjacent channel signals, the level of the noise floor of the hub receiver first must be figured. It is given by the formula:

$$P_{THERMAL} = 10\log\left[k\left\{\tfrac{5}{9}(T-32)+273\right\}BW\right] \tag{2}$$

Where

$P_{THERMAL}$ = *Noise Power from Thermal Sources* (dBW)

k = *Boltzmann's Constant* $\left(1.380662x10^{-23}\right)$

T = *Noise Temperature* $(degrees\ Fahrenheit)$

BW = *Bandwidth* (Hz)

With a typical noise temperature of 63 deg. F and a bandwidth of 6 MHz, Equation 2 yields a thermal noise power of -136.2 dBW. The equivalent total power flux density of the thermal noise power plus the effective power flux density of the interfering signal(s) is given by:

$$PFD_{EQUIV} = 10\log_{10}\left(10^{\frac{PFD_{EFF}}{10}} + 10^{\frac{P_{THERMAL}-L_C+NF+G_{ANT}}{10}}\right) \tag{3}$$

Where

PFD_{EQUIV} = *Equivalent Total Power Flux Density* (dBW/m^2)

L_C = *Cable Losses* (dB)

NF = *Noise Figure of First Amplifier* (dB)

G_{ANT} = *Antenna Gain* (dBi)

Compliance with the limits for co-channel and adjacent channel interference from new stations to response station hubs can be determined by first calculating the equivalent total power flux density with the effective power flux density of the interference set to zero and then re-computing with the true effective power flux density. The two values found should not differ by more than 1 dB for co-channel interference nor by more than 35 dB for adjacent channel interference.

Propagation Model

When analyzing interference from response stations to other systems and from other systems to response station hubs, a propagation model shall be used that takes into account the effects of terrain and certain other factors. The model is derived from basic

calculations described in NTIS Technical Note 101.[1] It is intended as a tool for analysis of wide area coverage of microwave transmissions, and it is available built into commercial propagation analysis software packages that are widely used by the MDS/ITFS industry for coverage and interference prediction.[2]

In the model described, two loss terms are computed — the free space path loss based solely on distance and the excess path loss (XPL) that derives from terrain obstacles and other elements in the environment. Among the inputs required for some implementations of the model are location and time variability factors. Other factors for such items as clutter and foliage losses can be considered by some software versions, but they will not be used in analyzing the systems considered herein.

The excess path loss portion of the calculation considers several conditions that impact signal propagation. These include whether the path is "line of sight" for the direct ray, whether there is 0.6 first Fresnel zone clearance, or whether the path is totally obstructed. When the path is unobstructed, a single ground reflection is added to the direct ray to determine path loss. When the first Fresnel zone is partially obstructed, an additional loss up to 6 dB is included by the model. When the path is totally obstructed, the path loss is calculated using the Epstein-Peterson method[3] that considers the diffraction losses over successive terrain obstacles. In this case, each obstacle is treated separately, with the preceding obstacle (or the transmitter, in the first instance) considered to be the transmitter and the succeeding obstacle (or the receiver, in the last instance) considered to be the receiver.

Some software implementations of the methods described herein may provide for setting parameters for both location and time variability in terms of the percentage of the locations or of the time that signals meet or exceed studied levels. For purposes of analyzing the interference from response stations and to response station hubs, both the location and the time variability factors shall be set to 50 percent in all cases. When available as a parameter, the confidence level shall be set to 50 percent.

In conducting analyses of interference from response stations, the minimum acceptable signal threshold shall be set to the noise floor for the bandwidth involved, as calculated per Equation 2 above. Thus for a 6 MHz channel, the minimum signal level considered would be -136.2 dBW or -106.2 dBm. As a result of this setting, when the desired signal

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[1] "Transmission Loss Prediction for Tropospheric Communication Circuits," Technical Note 101, NTIS Access Number AD 687-820, National Technical Information Service, US Department of Commerce, Springfield, VA.

[2] An example of such a software implementation is the Free Space + RMD™ method included in some products of EDX Engineering, Inc.

[3] J. Epstein and D.W. Peterson. "An experimental study of wave propagation at 850 Mc.," Proc. IRE, vol. 41, no. 5, pp. 595-611, May, 1953.

falls below this level, the D/U ratio from any interfering signal source will be ignored. These studies shall be conducted based exclusively upon the levels of the desired and undesired signals without the addition of thermal noise.

Propagation Model Outline

For the purposes of these Rules, the propagation model has three basic elements that affect the predicted field strength at the receiver:

1) Line-of-Sight (LOS) mode, using basic two-ray theory with constraints

2) Non-line-of-sight (NLOS) mode, using multiple wedge diffraction

3) Partial first Fresnel zone obstruction losses applicable to either mode

The LOS and NLOS modes are mutually exclusive — a given path between a transmitter and a receiver is either LOS or not. The fundamental decision as to whether a path is LOS is based on the path geometry. That decision is described in the next subsection, which also defines the LOS mode for the model.

Line-of-Sight (LOS) Mode

The determination of whether a path between a transmitter and a receiver is LOS is made by comparing the depression angle of the path between the transmitter and receiver with the depression angle to each terrain elevation point along the path. The depression angle from transmitter to receiver is computed using an equation of the form:

$$\theta_{t-r} = \frac{h_r - h_t}{d_r} - \frac{d_r}{2a} \tag{4}$$

where:

θ_{t-r} is the depression angle relative to horizontal from the transmitter to the receiver in radians

h_t is the elevation of the transmit antenna center of radiation above mean sea level in meters

h_r is the elevation of the receive antenna center of radiation above mean sea level in meters

d_r is the great circle distance from the transmitter to the receiver in meters

a is the effective earth radius in meters taking into account atmospheric refractivity

The atmospheric refractivity is usually called the K factor. A typical value of K is 1.333, and using the actual earth radius of 6340 kilometers, a would equal 8451 kilometers, or 8,451,000 meters. For the purpose of these Rules, K = 1.333 shall be used.

Using an equation of the same form, the depression angle from the transmitter to any terrain elevation point can be found as:

$$\theta_{t-p} = \frac{h_p - h_t}{d_p} - \frac{d_p}{2a} \tag{5}$$

where:

θ_{t-p} is the depression angle relative to horizontal for the ray between the transmitter and the point on the terrain profile

h_p is the elevation of the terrain point above mean sea level in meters

d_p is the great circle path distance from the transmitter to the point on the terrain path in meters

h_t and a are as defined above following Equation (4).

The variable θ_{t-p} is calculated at every point along the path between the transmitter and the receiver and compared to θ_{t-r}. If the condition $\theta_{t-p} > \theta_{t-r}$ is true at any point, then the path is considered NLOS and the model formulations in the subsection on Non-Line-of-Sight (NLOS) Mode below are used. If $\theta_{t-p} \leq \theta_{t-r}$ is true at every point, then the transmitter-receiver path is LOS and the formulations in this subsection apply.

For LOS paths, the field strength at the receiver is calculated as the vector combination of a directly received ray and a single reflected ray. This calculation is presented next. If the geometry is such that a terrain elevation point along the path between the transmitter and receiver extends into the 0.6 first Fresnel zone, then an additional loss ranging from 0 to 6 dB is included for partial Fresnel zone obstruction. This is discussed in a subsequent subsection.

Two-Ray Field Strength at the Receiver Using a Single Ground Reflection

For an LOS path, the field at the receiver consists of the directly received ray from the transmitter and a number of other rays received from a variety of reflecting and scattering sources. For low antenna heights (on either the transmit or receive end of the path) the field at the receiver is dominated by the direct ray and a single reflected ray which intersects the ground near the transmitter or receiver, whichever is nearer to the ground. The *height-gain function* in which a field at the antenna increases as the height of the antenna above ground increases is a direct result of the direct and ground reflection rays adding vectorially so that the magnitude of the resultant manifests this effect. The height-

gain function is modeled here by considering the actual ground reflected ray and the direct ray in vector addition. The magnitude of the direct ray is given by:

$$E_r = \frac{1}{d_r}\sqrt{\frac{P_T G_T \eta}{4\pi}} \tag{6}$$

where E_r is the field strength at the receive point, P_T is the transmitter power delivered to the terminals of the transmit antenna, G_T is the transmit antenna gain in the direction of the receive point (or the ray departure direction), η is the plane wave free space impedance (377 ohms), and d_r is the path distance from the transmitter to the receive point in kilometers.

Written in dB terms, this reduces to:

$$E_r = 76.92 - 20.0\log(d_r) + P_T \quad \text{dBuV / m} \tag{7}$$

In Equation (7), P_T is effective radiated power (ERP_d) in dBW. The magnitude and phase of the ground-reflected ray is found by first calculating the complex reflection coefficient as follows:

$$R = R_s g \tag{8}$$

where R_s is the smooth surface reflection coefficient and g is the surface roughness attenuation factor (a scalar quantity).

For parallel and perpendicular polarizations, respectively, the smooth surface reflection coefficients are:

$$R_{s\parallel} = \frac{\varepsilon \sin\gamma_0 - \sqrt{\varepsilon - \cos^2\gamma_0}}{\varepsilon \sin\gamma_0 + \sqrt{\varepsilon - \cos^2\gamma_0}} \quad \text{parallel polarization} \tag{9}$$

$$R_{s\perp} = \frac{\sin\gamma_0 - \sqrt{\varepsilon - \cos^2\gamma_0}}{\sin\gamma_0 + \sqrt{\varepsilon - \cos^2\gamma_0}} \quad \text{perpendicular polarization} \tag{10}$$

where γ_0 is the angle of incidence and ε is the complex permittivity given by:

$$\varepsilon = \varepsilon_1 - j60\sigma_1\lambda \tag{11}$$

where ε_1 is the relative dielectric constant of the reflecting surface, σ_1 is the conductivity of the reflecting surface in Siemens/m, and λ is the (free space) wavelength of the incident radiation. For the case of a ground reflection, vertical polarization is parallel polarization and horizontal polarization is perpendicular polarization.

For the model defined here, it is assumed that the local surface roughness is 0 (smooth surface) so that the term g in Equation (8) is one. Also, values of $\sigma_1 = 0.008$ Siemens/meter and $\varepsilon_i = 15$ are commonly used for ground constants and shall be employed for the purpose of these Rules..

Since the lengths of the reflected path and the direct path are essentially the same (differing by only a few wavelengths or less), the amplitude of the two rays due to spatial attenuation (path length) is assumed to be the same. The reflected ray, however, is multiplied by the reflection coefficient as given above and then shifted (retarded) in phase as a result of the longer path length compared to the direct ray. The vector addition of the two rays at the receiver is thus:

$$E_r = E_d \sin(\omega t) + E_d R \sin(\omega t + \Delta\varphi) \tag{12}$$

where:

E_d is the magnitude of the direct ray
ω is the carrier frequency in radians
R is the complex reflection coefficient given above
$\Delta\varphi$ is the phase delay of reflected ray in radians

The carrier term is usually suppressed so that Equation (12) becomes

$$E_r = E_d\left(1 + |R|\angle(\varphi_r + \Delta\varphi)\right) \tag{13}$$

where φ_r is the phase angle of the reflection coefficient. The term $\Delta\varphi$ is found from the actual path length difference in meters. For a two-ray path geometry over a curved earth, the path length difference is given by:

$$\Delta r = \frac{2h_t' h_r'}{d_r} \tag{14}$$

where:

h_t' is the height of the transmit antenna *above the reflecting plane* in meters
h_r' is the height of the receive antenna *above the reflecting plane* in meters

so that

$$\Delta\varphi = \frac{2\pi\Delta r}{\lambda} \quad \text{(modulo } 2\pi \text{ radians)} \tag{15}$$

The usual issue in using this approach is defining where the reflecting plane is for a complex terrain profile between transmitter and receiver. The reflection point is found by evaluating the angle of incidence and reflection at every terrain elevation point along the