AM Broadcast Antenna Engineering

Problem Report

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by

John Edwin Ross III, B.S.E.E.

Morgantown

West Virginia

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CHAPTER I. INTRODUCTION

A. BACKGROUND

Since the beginning days of radio broadcasting, the problem of providing interference-free reception has been of major concern. In 1921, the broadcast band consisted of two frequencies (750 kHz and 833 kHz). Anyone wealthy enough to afford the equipment and operating costs could broadcast on one of those two channels. At the outset, little thought was given to the problem of interference between competing broadcasters. As the number of broadcasters grew, however, interference became a severe problem. By 1923, the problem was completely out of hand, and a solution was urgently needed. Thus, in that year, the Secretary of Commerce decided to assign separate channels to each station to help alleviate the interference problem. In 1924, the broadcast band from 550 kHz to 1500 kHz with channel spacing of 10 kHz was established. The establishment of this broadcast band, and the desire to provide interference free broadcasts to consumers, forced upon us the problems of frequency allocation and interference protection that still remain today.

Although in the 1920's the methods of reducing interference were not as sophistocated as today, the concept of separating stations using the same frequency by a considerable distance or by limiting the hours of operation (time sharing) are still evident. The problem of providing interference protection to a neighboring station, and still having a sufficiently large coverage area was one of the most difficult problems faced by early radio engineers. This problem was compounded by the fact that the antenna systems of the day were essentially omnidirectional. Thus, any attempt to reduce

radiation for the sake of interference in one direction would automatically reduce it in all directions, hence, reducing the coverage area and the market audience available to the station. This dilemma was solved in 1932 by the construction of the first directional antenna for broadcast use[1]. A simple two tower array was used successfully by WFLA-WSUN in Clearwater, Florida to prevent interference to WTMJ in Milwaukee, Wisconsin. Thereafter, directional array (DA) antennas have been used extensively to limit interference and efficiently cover desired market areas.

To design antennas to meet specifications of interference level and coverage area, knowledge of how to compute the radiation from an antenna, and how this radiation is attenuated as it travels over the surface of the earth are of vital importance. For the engineers of fifty years ago, methods were available for predicting the fields radiated by single towers and arrays of towers. However, the solution to the attenuation problem was computationally intractable, and even the theoretical solutions were riddled with errors.

The problem of how the electromagnetic field is attenuated over a lossy surface was first addressed in a theoretical fashion in 1909 by Arnold Sommerfeld. Sommerfeld's original solution contained an error and was the cause of considerable confusion. It took until 1930 before the mistake was even recognized, and until 1936 that an acceptable solution was found. Here, the work of K. A. Norton was used for a solution that was valid for short distances. Later, in 1940, the Federal Communication Commission (FCC) Groundwave Charts were published. These charts utilized Norton's solution for short distances, and the work of Blath van der Pol and H. Bremmer for larger distances. The solution for middle distances was computationally intractable at

the time, so the FCC fit the curve between the largest distance where the Norton solution was valid and the shortest distance where the other solution was considered valid. In addition to the obvious error incurred by this process, there were also systematic errors in the drafting process, whereby the values at the larger distances were shifted upward. These curves have been updated several times since 1940, but these problems were not corrected. In 1979, the FCC attempted to recompute the curves using a computer program. Again, the middle distance area was not in full agreement with those of the International Radio Consultative Committee (CCIR) and other theoretical results. Finally, in 1986, the FCC published a computer program that made available a reliable and accurate means of computing the attenuation of the groundwave field strength over a lossy spherical earth[2].

Despite the availability of computers and computerized solutions to many of the problems of antenna radiation and radio wave propagation, there are still many problems to be surmounted by the broadcast engineers of the 1980's. A brief mention of some of these may be useful to set the stage for the objective of this report.

One subject that is always of great interest is obtaining a larger coverage area for a smaller amount of input power. This problem is usually approached by designing antennas whose directional properties are such that the largest portion of their radiation is along the ground. Historically, this was done by building taller and taller towers. This, however, led to other difficult problems, not the least of which was the cost of a the tower, and the fact that it is sometimes impossible to build an exceedingly tall tower in some locales due to both local zoning laws, and Federal Aviation Administration (FAA) rules.

Other topics that have been of interest are the bandwidth of the antenna, and the antenna feed elements[3,4,5,6,7,8,9]. The bandwidth is of some concern for stations broadcasting monaural program material and using DAs, since cases arise where the carrier frequency is greatly attenuated with respect to the sideband information. This will result in over-modulation distortion in receivers utilizing diode detectors. The effects of this type of interference on AM stereo broadcasts is a troublesome problem that is not yet fully resolved. Thus, suffice it to say, that a broadband antenna system is usually a goal of the antenna designer.

Finally, one topic that is of interest to virtually all broadcasters is the effect of reradiation of energy from parasitic elements (eg. tall buildings, electric utility poles, and other broadcast towers) [10,11]. The constant modernization and urbanization of once rural areas has forced this problem on broadcasters who purposely erected broadcast towers far from city structures. Fortunately, over the years, there have been numerous techniques developed to detune these parasitic structures, and thus minimize the reradiation of energy in undesired directions, although this still remains a problem.

In addition to the countless technical problems to be surmounted by the modern day consulting engineer, there are also other problems with which to be reckoned. One of the largest problems is obtaining up-to-the-minute information concerning the licensing status of all the stations that may have to be considered in an interference study. This can be overcome if the designer has the funds to obtain a data base of information covering the entire broadcast band and the time to keep the information organized. Otherwise, one is forced to make numerous visits to the public information reading room at the FCC headquarters in Washington, D.C. The engineer is also

responsible for being up to date on all of the latest FCC rulings and recommendations. New rulings are constantly appearing and old ones are being updated. The new rulings and updates are available on a subscription service, so that being current is only a matter of reading the material pertinent to the particular area of consulting with which one is involved.

Finally, even with the data bases and recent rules in hand, there are very few references available that outline the technical procedures required to design broadcast antennas in accordance with FCC rules and regulations. This, at first glance, may seem to be a minor problem in comparison with some of those mentioned previously; however, for the uninitiated, this problem can seem immense. Upon inspection, it does not take long to realize that the "legalese" contained in the FCC rules and regulations [12] governing the broadcast services is somewhat confusing. In addition, even though some of the technical matters seem to be completely specified, others are not, leaving some question as to the correct procedures. For the broadcaster who wants to have a radio station, the solution to getting a suitable antenna design is to contract a consulting engineer to do the job. It seems however, that perhaps due to intense competition, there is a reluctance for the knowlegable engineers to publicly reveal all of their methods in designing antennas. Short of trying to gain employment with these experienced engineers, until now there has been no way to learn these engineering techniques. This shortage of information on actual specification techniques for AM broadcast antenna patterns will be the focus of this report.

Before jumping in over one's head, it is useful to discuss the extent and nature of this documentation shortage. At one time, prior to the availability of the latest FCC computer program (See reference 2), there was a desperate

need for a new method for predicting ground wave field strengths. Not only were the old graphs in error, but they were completely unmanageable for serious design endeavors in the modern computer age. Moreover, attempts to digitize the curves for use in automated design seemed ridiculous in light of their already apparent shortcomings, but was done none-the-less to speed the process. A well-documented computer program was needed that would eliminate the errors contained in the old graphs and put the FCC methods on firm theoretical ground. Prior to beginning work on this problem report, it was thought that a major reworking of the FCC Ground Wave Charts would be the eventual focus of the report. A few phone calls to the FCC offices in Washington, D.C. revealed, however, the FCC had already developed a new program and documented it in a report (See reference 2) published only a few months prior to the author's inquires. It should be noted that the new program is excellent. It is written in a very portable version of FORTRAN, and requires no specialized mathematical functions, other than those common functions built into all current FORTRAN languages. The accompanying report is also excellent. It includes a complete history of the problems associated with the methods the FCC has used in estimating ground wave field strength, along with all of the flow diagrams, and a glossary of the variables used in the program and their symbolic counterparts used in the original works of Sommerfeld and Norton. The program is included in the listing of program PCMLL2 in Appendix A.

The next part of the documentation problem was determining how to design the antenna system. The FCC has ruled that the usual assumptions of a sinusoidal current distribution on the tower be a common starting point for all computations. This has eliminated the use of the modern method-of-moments

techniques currently employed for most difficult antenna problems in this frequency range. It therefore seemed useless to rehash the standard array theory seen in every undergraduate text on antennas. Moreover, the 1949 text by Smith[13] on the directional antenna system is specifically directed to the AM broadcast antenna engineer. This superb work is where the uninitiated must look for discussions of the types of antenna computations necessary for AM antenna engineering.

Although antenna and groundwave propagation theories are well documented, explanations of how to use these theories as tools to perform the interference studies and antenna synthesis are not as well documented. These explanations are essential for those engineers attempting to file construction permits with the FCC for AM broadcast stations.

B. OBJECTIVES

The objectives of this project were :

1. Provide documentation on the use of wave propagation and antenna theories as tools in performing an interference analysis for AM broadcast stations operating during daylight hours. The discussion is limited to operation during daylight hours since the propagation theory for ionospheric radio paths is not as well understood or as computationally tractable as the groundwave path, nor is it necessary for this specific project.
2. Illustrate the use of these wave propagation and antenna theories as tools in an actual design problem.

C. APPROACH

In an attempt to meet the objectives, several intermediate steps were performed. First, a literature search of pertinent subject material was initiated. This provided the background necessary to undertake the ensuing design and documentation project. As well as searching the literature for the theoretical aspects of the problem, several persons knowlegable in the area were contacted either by phone, or in person. These persons include the student's advisor, Dr. James F. Corum, an experienced radio consulting engineer; Mr. Wayne Fried, an applications reviewer for the FCC; Mr. Victor Tawil, an engineer with the FCC Office of Engineering Technology; and Mrs. Virginia Cannon, manager of the Downtown Copy Center (DCC), Washington, D.C. (DCC provides support service to consulting engineers for data base and rule changes). With pertinent literature and first hand information, some of the techniques for designing the antennas became clear. The next step was the development of the computer software necessary to rapidly implement the antenna and wave propagation theories. The computerization of these design tools is necessary due to the iterative nature of the interference study.

Simultaneously, with the development of the software, the acquisition of a data base of antenna information for stations on several frequencies was initiated. This data base is necessary to perform an interference study pursuant to the FCC Rules and Regulations, Part 73. As discussed with Dr. Corum, there were initially five different frequencies and corresponding locations suggested by employees of station WPLW in Pittsburg, Pennsylvania, for use as example problems and as potential profit making ventures. The WPLW engineers were interested in the feasibility of locating a station at these

sites and operating on their specified frequencies. (For confidentiality, these locations and frequencies, except for the example problem contained in this report, will not be disclosed.) Unfortunately, due to lack of funds, only a data base of stations on one of the suggested frequencies was obtained.

Throughout the duration of the project, the computer programs were constantly modified, tested against known examples, and debugged until accurate and reliable results were obtained for the purpose of proceeding with an actual design problem. The programs used to analyze antennas had to be written from scratch, even though excellent documentation existed (See reference 13). The program for prediction of field strengths, though available from the FCC, still had to be keyed in and modified slightly to work on the West Virginia University IBM mainframe computer. This program was subsequently enhanced to provide other features necessary for the interference analysis.

After some unsuccessful attempts at trying to reverse the FCC's equivalent distance method, so as to simplify the antenna synthesis part of the example problem, the real world example problems were attempted. Unfortunately, it was not possible to locate an antenna in the area suggested by the clients in Pittsburgh, due to interference from an adjacent channel station in Buffalo, New York. Thus, the synthesis problem was not fully illustrated. Subsequently, in an effort to demonstrate the actual synthesis of an antenna system, a possible service area was determined on the same frequency some 50 miles southeast of the original proposed site. At this point, it may have been possible to proceed with the synthesis had it not been for lack of time and resources.

Finally, a report describing the methods and tools required to perform an

interference study, and synthesis of an antenna system for use in the AM broadcast band was written.

CHAPTER II. OVERVIEW OF DESIGN PROCEEDURE

Before embarking on a discussion of numerous theoretical and practical details, it seems appropriate to first provide an overview of the major steps involved in designing an AM broadcast antenna.

The primary step in the design of an antenna system is to determine a suitable service area and frequency of operation. Sometimes, as this report will illustrate, the location and frequency are given by the broadcaster, who, after making a market study, has decided that it might be profitable to serve some particular area. More often, it will probably be the engineer who is responsible, at least in part, for narrowing the choices of which areas can be serviced, and on which frequencies this service can be established. Thus, it is necessary that the engineer be able to determine the protected service area (the area within the protected field strength contour) of existing stations on the frequency of interest (cochannel), as well as those on adjacent channels (stations on the next higher or lower frequencies).

Once the service areas of the existing stations are established, it is possible to determine which areas, if any, can be serviced by the new station. Many times, it is impossible to provide service to an area on a particluar frequency, and several frequencies must be examined for interference. With luck, a desirable service area and suitable frequency can be identified that will allow a new station to operate without causing objectionable interference to either cochannel or adjacent channel stations.

Once the service area and frequency have been established, the location of the antenna system must be determined. This is a very difficult task which demands a great deal of attention. The search for the best location must be

guided by experience and practice. A very limited list of factors to consider when deciding where to locate the antenna system would certainly include: the principle and secondary service areas, and their relationship to the protected service areas of other stations, the blanket area of the station, the conductivity of the ground at the site, the accessibility of the site, and whether the site is obtainable for the purpose of installing a broadcast antenna according to local zoning laws and FAA regulations. The location of the antenna is a very important and difficult assignment.

Once the engineer and client reach an agreement as to the location of the transmitter site, it is the engineer's responsibility to determine what type of antenna and what power level is required to provide adequate service to the desired areas, yet not produce interference in the protected service areas of other stations. The objective is to find the least expensive means of satisfying the above criteria on service area and interference. Sometimes, the designer will be fortunate in that a single tower will provide adequate coverage and not produce interference. More often than not the design will require at least two, usually three, and sometimes 6, 8, or as many as 12 towers arrayed together. These directional array antennas are used to produce a service area of the required shape or to limit interference to one or more stations in various directions from the transmitter site. Usually, the most economical design is one with the fewest towers of the smallest height.

As one proceeds with the design of the antenna to meet the above criteria, one quickly realizes the value of a computer. The process is essentially one of trial and error guided by experience. There are some guides to learning how the various parameters of the array affect the pattern for simpler arrays, but for an 8 tower array, the designer is probably on his

own. One reference that is essential for beginning estimates of the array parameters is the work by Carl Smith[14], entitled Directional Antenna Patterns. This book contains, in a systematic way, over 15,000 array patterns with their associated parameters for two and three tower arrays. The parameters include the orientation, spacing, height, sectionalization, loading, and the magnitude and phase of the current on the towers. Even with this reference, the antenna design is a very tedious and exhausting process, where experience and fast computers pay big dividends in time.

Once the antenna design is completed, the engineer proceeds to prepare a construction permit and submit it to the FCC. The construction permit indicates all of the essential information about the proposed location, frequency, antenna parameters and pattern, service areas, etc., as well as a supporting analysis showing that the proposed service area does not produce interference to other stations.

CHAPTER III. INTERFERENCE ANALYSIS TECHNIQUES

With the overview of the process in mind, some of the particulars will be addressed. The discussion will begin with details about how to determine the protected service area of a broadcast station using the FCC ground wave field strength prediction program (hereafter referred to as FCCGW). Then, an illustration of determining the feasibility of placing an antenna in a given location will be presented. At this point, assuming there exists a feasible location, a technique for estimating the maximum radiation in the azimuthal plane of the new station at the proposed location will be discussed. This maximum envelope will enable the techniques and patterns presented in the two works by Smith (See references 13 and 14) to be used to their fullest extent in the synthesis of the antenna.

A. DETERMINATION OF PROTECTED SERVICE AREAS

The protected service area of a station depends upon the class of the station and the class of the potential interfering station as set forth in the FCC Rules Part 73. Further, it is also dependent on the power radiated, the directional properties of the antenna, the frequency of operation, and the electrical properties of the ground surrounding the antenna.

As far as the influences of the class of the station and the interfering station are concerned, nothing difficult is involved. The Code of Federal Regulations (CFR) Title 47, Part 73.182 specifies what field strength contour is considered protected for the various classes of stations. The maximum allowable interfering signal permitted within the protected service area of the

station is also defined.

The directional characteristics of the antenna are also important in establishing the area within the protected contour. There are two general types of antennas: omnidirectional and directional. For omnidirectional antennas (i.e., single vertical towers), the field strength is equal in all directions in the azimuthal plane. For a directional antenna, the field strength varies as a function of the azimuth angle. The radiation also varies as a function of elevation angle for both types of antennas, but this variation is not usually important in the daytime interference study, where the ground wave is the principle mode of propagation. For both cases, information must be obtained on the unattenuated radiated field strength at one kilometer (i.e., the antenna pattern).

In the case of the omnidirectional antenna, the pattern is always presumed circular for the case of interference analysis, even if it might not be perfectly so in the real world. On file with the FCC is the expected value of field strength at one kilometer per kilowatt of input power. This value, along with the licensed power of the station, are necessary for establishing the protected service area for an omnidirectional antenna.

In the case of the directional antenna, there are several different types of patterns encountered in interference studies performed in conjunction with the FCC. The first pattern, the theoretical pattern, is described in detail in both the FCC rules Part 73.150, and in Smith's book. Essentially, this is the pattern given by superposition of the field radiated by each of the towers in the array. The field includes the effects of FCC specified losses in the tower and assumes a sinusoidal current distribution on all towers. The theoretical pattern is never used in computing interference. It is only used as a

reference point for establishing what is referred to as the standard pattern. This pattern is essentially the same as the theoretical pattern with the quadrature addition of some terms which the FCC requires to make the computed pattern more closely approximate the field strength the actual antennas tend to produce in the area of pattern nulls. The addition of these terms also provides some padding so that the field strength predicted should be larger in all directions than that actually produced by the antenna. This helps ensure that even for "tight fit" computed contours there will be not objectionable interference when the actual antenna is installed. Finally, there is the case of the augmented pattern. A station must file a pattern of this type when the actual measured radiation is significantly different from the computed standard pattern filed with the construction permit. This is only acceptable if the deviations from the computed standard pattern are not significant enough to cause objectionable interference to another station's service area. The methods for establishing the augmented pattern from the standard pattern, and actual measurements are set forth in FCC Rules Part 73.151 and 73.152. The program STDPATRN, used for computation of standard patterns is listed in Appendix B.

The distance from the transmitter to the protected contour and hence the protected service area of a station is dependent on the frequency of operation and the ground parameters, both at the location of the antenna and some distance from the antenna. The distance to the protected contour increases as the frequency decreases for a given field strength and set of ground parameters. It might be noted that only antennas which produce vertical polarization are used in the AM broadcast band due to the very high attenuation of the horizontal field component in this frequency range. As such,

the computer program FCCGW only considers vertically polarized fields.

At this point, it is useful to discuss the capabilities of the program FCCGW, and the modifications necessary to predict the distance from the transmitter site to the protected contour. First, the capabilities of FCCGW will be discussed. This program requires as inputs the following information:

- The unattenuated field strength in mV/m at a distance of 1 kilometer from the antenna. This information is tabulated and on file for all licensed stations at the FCC.
- The ground conductivity in mS/m over which the signal is to travel.
- The ground permittivity relative to free space over which the signal is to travel. Unless proven differently with measurements by the consultant, this value is always assumed to be 15 for the purposes of interference computations.
- The frequency in MHz.
- The distance over which the signal is to travel.

With these parameters, the FCCGW program can very accurately compute the field strength at a given distance from the transmitter. This is very useful, but not quite what is required to perform an interference analysis. What is desired, is the distance from the transmitter to some specific value of field strength (e.g., the 500 μV/m contour). Thus, additions to the FCCGW program are required to solve this problem.

The simplest means of finding the distance to a given contour is to use an iterative Newton Method of guessing the distance and computing the field strength. When the computed field strength is very close to the desired contour level, the distance used in the computation is the desired result. The subroutine CONTUR (Listed as part of PCMLL2 in Appendix A) was developed by the author for this purpose, and the program FCCGW was used as a subroutine to evaluate the field strengths.

It should be pointed out that there are several difficulties encountered with the iterative technique applied to the field strength as a function of distance relationship computed by FCCGW. The first of these is the fact that Newton's method will tend in some cases to compute as negative numbers as new guesses for the distance. This is a problem, since all distances entered into the FCCGW subroutine must be positive to avoid fatal program errors. The difficulties can be circumvented by simply checking for to see if the distance is negative. If it is, then simply divide the old guess by two. This is appropriate since a negative distance is indicating that the next guess must be smaller. Another problem arises due to the fact that FCCGW uses two different solution techniques, dependent on the distance from the transmitter and the frequency. If the distance is less than (80.0 / frequency) $^{1/3}$, then the program implements Sommerfeld's solution for flat earth with some curved earth correction terms. For greater distances, a more accurate residue sum solution is used. The two solutions, do not yield exactly the same results in the limit as the distance approaches (80.0 / frequency) $^{1/3}$. This produces a discontinuity in the field strength function, which in turn will cause the program to loop indefinitely between two different guesses for the distance, one guess on one side of the discontinuity and one guess on the other. This condition must be detected, and the more accurate residue sum solution used until the method converges to a value within the desired field strength tolerance. Both of these problems are already accounted for in the program listed in Appendix B.

The method discussed above can not account for the case where the ground conductivity changes as one moves away from the transmitter site. The effects due to changes in the conductivity must be included in the analysis

for accurate results. The FCC suggests that reasonably accurate results can be obtained by using the equivalent distance technique. This is described in Part 73.183 of the rules and illustrations of its use with the FCC Ground Wave Charts are provided.

For several years now, the FCC Ground Wave Charts have not been provided with copies of the Rules and Regulations in the CFR format, despite the fact that they are referred to in illustrations of interference computations and the equivalent distance technique! They are available, but at additional cost. Copies of older versions of these charts with distances in miles have been provided for convience in Appendix C. These charts, being photocopies of the originals, are not sufficient for use in an engineering study, but are useful when trying to follow the examples contained in the FCC rules and regulations. They can also provide a guide to the reasonableness of results obtained using the FCCGW, CONTOUR, and PCMLL2 programs.

The equivalent distance technique can be used when the unattenuated field strength at one kilometer (or one mile if using charts in Appendix C), the ground conductivity, and location of discontinuities in the conductivity are known. The method presumes that the field strength is the same on each side of the discontinuity, but the equivalent distance to the transmitter changes abruptly as the wave propagates over the discontinuity. Thus, the location of the imaginary transmitter can be effectively closer or further away, depending upon the values of the conductivity.

For example, consider the case of a station with a field in a given direction of 100 mV/m at 1 mile , operating on a frequency of 610 kHz. The conductivity is 10 mS/m for the first 10 miles, then abruptly changes to a value of 5 mS/m for the next 10 miles, at this point it changes again to a

value of 15 mS/m. It is desired to find the distance to the 0.5 mV/m contour of the station.

If the distance to the first discontinuity is greater than the distance to the 0.5 mV/m contour using the first value of conductivity, the problem can be solved using a single value for the conductivity. Using Graph 3 of Appendix C, one can see that the distance to the 0.5 mV/m contour using a conductivity of 10 mS/m is approximately 69 miles, much greater than the 10 miles to the first discontinuity. Since the equivalent distance technique is necessary, the field strength must be computed at the first discontinuity using a conductivity of 10 mS/m. This field strength is 8.4 mV/m. Now, the equivalent distance to the 8.4 mV/m contour must be established using a sigma of 5 mS/m. This distance can be read from the curve as about 8.5 miles. The imaginary transmitter appears to be 1.5 miles from the actual transmitter. Thus, the imaginary transmitter is closer to subsequent discontinuities in the conductivity. These distances must then be adjusted by -1.5 miles.

Proceeding as before, one must ascertain whether the distance to the 0.5 mV/m contour is less than the distance to the next discontinuity. The distance to this discontinuity must be adjusted by the -1.5 miles found above. The distance to the 0.5 mV/m contour is about 47 miles, much greater than the effective distance to the next contour of (20 - 1.5) = 18.5 miles. The field strength at 18.5 miles must now be found using a sigma of 5 mS/m. This is about 2.9 mV/m. Again, the equivalent distance to this contour must be found using a sigma of 15 mS/m. This distance is approximately 29 miles, effectively 11.5 miles more distant than the previous imaginary transmitter. The distance to all other discontinuities must be adjusted by +11.5 miles. Since there are no further changes in the conductivity, the next step is to find the distance to

the 0.5 mV/m contour using a sigma of 15. This distance is 84 miles. Now, bear in mind that this is the distance from an imaginary transmitter that is actually - (11.5 - 1.5) = - 10.0 miles from the actual transmitter site. Thus, the distance to the 0.5 mV/m contour from the actual transmitter site is 74 miles.

To simplify the computation of the distance to a given field strength contour when the equivalent distance technique must be used, a computer program was written to perform the necessary computations. This program, has been named PCMLL2, and is listed in Appendix A. It uses the CONTUR and FCCGW subroutines to compute the distances and field strengths necessary in the equivalent distance technique.

With a computerized method for predicting the distance to a field strength contour it is possible to determine the protected service area of a station. The conductivity profile as a function of the radial distance from the transmitter site must be obtained on 35 different bearings (every 10 degrees beginning at true North). This information, along with the field obtained from the standard or augmented pattern, is sufficient to compute the distance to the protected contour. By plotting these protected contour points on a suitable map, the service area can be identified as the area with in the envelope of these plotted points. For convienence, the program PCMLL2 will accept as input the location (lattitude and longitude) of the transmitter site, and compute the lattitude and longitude of each of the contour points. Plotting of the points using their lattitude and longitude is sometimes necessary, since plotting by the use of the bearing and radial distance method can incur errors due to the inherent distortions of flat maps.

Determination of the ground conductivity is to be made with the use of FCC map M-3, which shows the conductivity of the soil projected on a map of

the United States. A copy of Map R-3, a less detailed replica of map M-3, is shown in Figure 1. Values of conductivity used in analyses submitted to the FCC should use values from M-3. There have been attempts to digitize Map M-3, (See reference 15). The FCC allows the use of programs that can supply soil conductivity information from M-3, and this would be the preferred method for a determining the conductivity profile along the radials.

B. SITE FEASIBILITY AND GUIDES FOR PATTERN SHAPE AND SIZE

With the capabiltity to determine the protected contour of one station, it is just a matter of repetition of the process for many stations to evaluate whether a particular location is suitable for service on a specific frequency. To find out what stations are operating on a given frequency, one needs to obtain a copy of the listing of stations from the FCC in Washington D.C., alternatively, the list can be obtained by contacting either the designated FCC copying firm or the Downtown Copy Center. Using this list, and some common sense, it is possible to eliminate quickly 80 to 90 percent of the stations from consideration in an interference study. For example, if one desires to locate a station in Pennsylvania, there is no need consider a 1 kW Class IV station in California. It will be necessary to examine the listing carefully on the frequency of interest and adjacent frequencies up to 30 kHz away. Once the culling is complete, the standard / augmented pattern data will have to be obtained for stations using DAs from the FCC files. Sufficient information on omnidirectional antennas is provided in the data base listing itself. By examining the shape of the pattern of the most distant of the stations using DAs, sometimes a few more computations can be eliminated. For example, if the

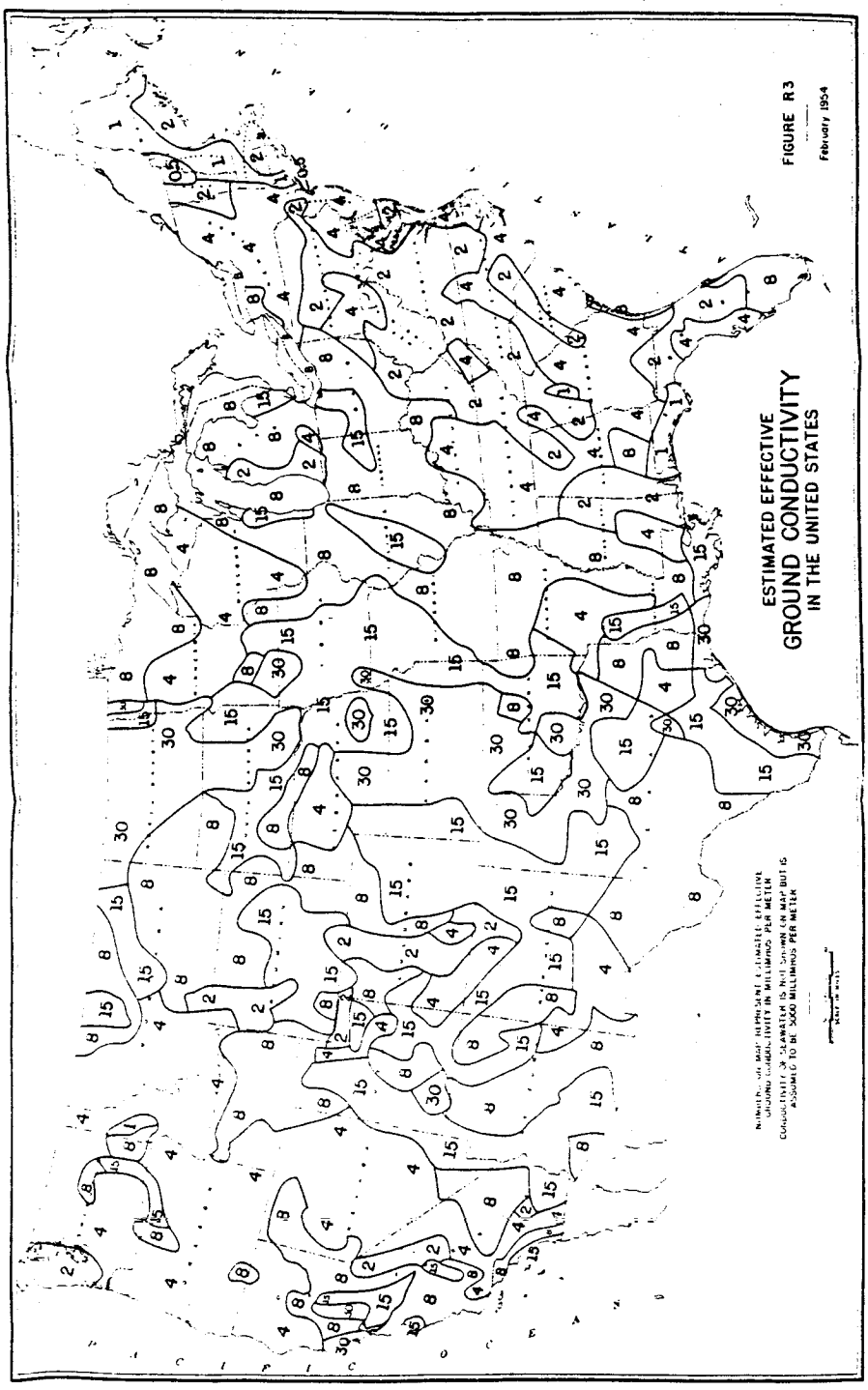

Figure 1. Ground Conductivity Map

radiation in the direction of the location of interest from station A is small, or on the order of that produced by another station that lies between station A and the desired location, then station A can usually be eliminated from further consideration.

After plotting the protected contour points of stations not culled on a suitable map, it becomes apparent where it is possible to locate a new station. If the desired market area is contained within the protected service area of any station using the desired frequency or adjacent frequencies, then it is impossible to locate a station at that site, and a new location or frequency must be chosen. If the protected contours of other stations are some distance from the desired site, then it may be possible to locate a station at the site. This is the point in the procedure where a specific location must be chosen for the antenna.

Once the precise location of the transmitter site is established, the engineer can attempt to design an antenna such that the desired service area provides a signal free from interference and fading and will not produce interference to other stations. At this point, there exits some disagreement between the work of Smith and the author on how to proceed with the synthesis. Smith states that " the pattern of each station is arranged so that a minimum of energy is directed toward other stations on the same channel. In addition, the arrays are located in a position with respect to their primary service area so that the main lobe of energy covers this primary area as completely as possible." The latter of these two statements is a well known technique of locating the antenna, and the author is in full agreement on this point. The first statement, however, must be clarified. When designing an antenna for the purpose of limiting interference, it is not necessarily in the

direction of the other transmitters where minimum energy should be directed. Instead, minimum energy should be directed toward protected service areas of the other stations.

What is generally done is to examine the jigsaw-like shape produced by the overlapping protected contours of other stations around the proposed site. Based on the shape of this area and the desired service area, the antenna parameters are estimated which are required to produce a radiation pattern that will provide service to as much of this jigsaw-like area as possible, yet not interfere with the other stations. Once the parameters are estimated and the standard pattern computed, the distance out to the maximum allowable field strength at the other station's protected contour is computed. If the point corresponding to this field strength level is not within the protected service area of another station, there is no objectionable interference.

At the beginning of the design, as outlined above, the engineer judges the parameters based on the shape of the unserviced area. In other words, the shape of the antenna pattern is assumed to approximate the shape of the unserviced area. This assumption can be very misleading, since the field strength at a constant radius about the antenna (the pattern) is not linearly related to the distance to the protected contour of the other stations. Moreover, when the conductivity changes greatly from one bearing to the next, the shape of the unserved area has almost nothing in common with the shape of the antenna pattern required to provide coverage to it.

Instead of computing the distance on each radial to the maximum allowable interfering field strength and then ascertaining if objectionable interference will result for every intermediate antenna change, or using the shape of the unserviced area as a guide to the pattern shape, the author proposes a

different technique. This method, if possible, will eliminate unnecessary computations and provide the antenna designer with an actual pattern envelope with which to proceed with design. In addition, the method will allow the techniques presented in Smith's books to be used more effectively, and hopefully lead to better and faster solutions to antenna synthesis problems.

The main objective of the method is to determine the unattenuated field strength at one kilometer from the proposed site that will produce the maximum allowable field strength at the protected contour points of the other stations. The maximum allowable field strength at the protected contour points is given in the FCC rules, and as stated previously, is dependent on the class of the station and whether the stations are operating on the same or adjacent channels. Typically, the interfering signal should be a factor of 1/20 the desired signal for cochannel stations. For adjacent channel stations, the level of the interfering signal can be equal to the level of the desired signal.

Even though the method would be useful, the exact methodology for solving the problem has not yet been solved for all cases. The method will work is when the soil conductivity between the transmitter site and the protected contour point is homogeneous. One must determine the attenuation resulting from propagation over the homogeneous path using FCCGW, then divide the maximum allowable field strength at the protected contour point by this attenuation. When the conductivity between transmitter and contour point is not homgeneous, the reverse of the FCC equivalent distance method must be employed. The author has spent considerable time looking at this problem, but as of yet has not found a solution. It seems that even though an exact solution is not available, it would still be better to estimate the pattern size and shape using the homogeneous case rather than guessing from the shape

of the service area. One could use the maximum value of conductivity found in a given path over the whole path, thus providing some margin of protection from interference in that particular direction.

CHAPTER IV. EXAMPLE PROBLEMS

A. FEASIBILITY STUDY FOR SMETHPORT, PENNSYLVANIA ON 560 KHZ

Due to the costs of obtaining the directional antenna information required for the studies, only one location and corresponding frequency was analyzed. The data base listing for stations on frequencies from 550 kHz to 570 kHz was obtained, along with all standard / augmented pattern information for stations using DAs on these frequencies. A feasibility study was performed for operation in the Smethport market area on 560 Khz.

The culling process described in the previous section was applied to the stations in the data base listing until the number of stations involved was small enough to begin actual computational work. At this point, a guess was made on which station would most likely prevent the Smethport station from becoming reality. The guess was WGR, a Class III station in Buffalo, New York. Class III stations are protected to the 0.5 mV/m contour. This station uses an omnidirectional antenna during daylight hours with with a power of 5 kW. From the data base listing, the unattenuated field strength at one kilometer for WGR is 294.51 mV/m/kW, thus the total unattenuated field strength is 1472.55 mV/m at one kilometer. With the field strength established, the next step was to determine the conductivity profile along the various radials from the WGR's transmitter site. Since a copy of Map M-3 was not available, conductivity values were read from Map R-3. In the area of Buffalo, the conductivity is given as 8 mS/m which abruptly changes to 4 mS/m in a very short distance as one proceeds southeast toward Smethport from Buffalo. For the purposes estimating the feasibility of the location, a sigma of 4 was used

for the entire path. This data was entered into the PCMLL2 program, and the resulting distance to the 0.5 mV/m contour of WGR was computed to be 186 kilometers. The distance between the the WGR transmitter site, and the Smethport location is only about 115 kilometers. Thus, it is impossible to install a new station in the Smethport area on 560 kHz.

B. POTENTIAL SERVICE AREAS ON 560 kHz IN PENNSYLVANIA

Since the Smethport location was deemed unsuitable, and data were not available for the other frequencies of interest, it was decided to determine if there was any location in Pennsylvania that might be suitable for a broadcast station on 560 Khz. Since the culling process for the Pennsylvania region had already been performed, the next step was to determine the protected contour points of these stations and plot them on a suitable map. The stations remaining for consideration after the culling process were:

1. WGR, Buffalo, New York. 5 kW omnidirectional on 550 kHz.
2. WHLM, Bloomsburg, Pennsylvania. 1 kW direcional on 550 kHz
3. WFRB, Frostburg, Maryland. 5 kW omnidirectional on 560 kHz.
4. WCKL, Catskill, New York. 1 kW direcional on 560 kHz.
5. WFIL, Philadelphia, Pennsylvania. 5 kW directional on 560 kHz.
7. WYSR, Syracuse, New York. 1 kW directional on 570 kHz.

The protected contours of each of these stations was computed using the PCMLL2 program. The PCMLL2 program provides the bearing and distance to the contour point, the lattitude and longitude of the point, and the bearing and distance of these points from the proposed site. After several station contours had been established, the area around Williamsport, Pennsylvania

seemed promising as a service area. The program output showing the location of the protected contour points of each of the stations listed above, and the bearing and distance of each of these contour points to a possible transmitter site in the Williamsport area are shown in Appendix D. By looking at the distance of the contour point to the proposed site, one can find the points that will be of significance in establishing a maximum pattern envelope. For example, on a given radial from the proposed site, there may be several protected contour points that fall within a few degrees of the bearing. There are always at least two for each station, one corresponding to the side of the protected contour nearest the site, and the other the side farthest from the site. Occasionally, there may even be more than two from a single station, and there are generally be some from other stations as well.

The question arises which of the many contour points are significant in the interference analysis, and in establishing the maximum pattern envelope. In the case of points from the same station, the significant contour point is the one nearest to the proposed site. When there is more than one station involved, this is not necessarily the case. The one that will limit the maximum field stength at one kilometer to the smallest value is the one that is most significant. In other words, if there is a protected contour point of an adjacent channel 40 miles from the proposed site, and a cochannel one 50 miles distant, the most significant one is probably the cochannel one at 50 miles since the field must be $1/20^{th}$ the protected contour at this point, and it can equal the protected contour at 40 miles.

Some of the protected contour points in the area around Williamsport are shown in Figure A1. The maps used for guiding this sketch were from the United States Geological Survey 1:500,000 series. Maps titled State of

Pennsylvania, and State of New York were necessary.

Again, due to the fact that a copy of Map M-3 was unavailable, R-3 values were used. To further simplify the analysis, a conductivity of 4 mS/m was used to compute the protected contours of all stations except WHLM, Bloomsburg, Pennsylvania. Examination of Map R-3 will reveal that most of Pennsylvania has a conductivity of either 2 or 4 mS/m. Thus, by assuming 4, distances to the protected contour points for paths that traverse through areas where the conductivity is really 2, will be greater than those computed if the equivalent distance was precisely applied. This error is of little significance for a feasibility study of this type. A value of 2 mS/m was used for computation of the protected contour of WHLM since it was centrally located in a large area with that conductivity value.

CHAPTER V. SUMMARY

A. RESULTS

The objectives of the project have been met. The use of antenna and wave propagation theory as tools for performing interference analyses used in AM broadcasting has been documented. The objective was not to be all inclusive, but rather as informative as possible within the confines of the problem report setting. The illustration of the use of the tools of antenna and propagation theory in a practical design problem has been illustrated to the extent possible given time and budget constraints. Clearly, by the analyses in Section III, it is not possible to locate a broadcast station in the Smethport, Pennsylvania area using a frequency of 560 kHz. Despite the null result, the problem illustrates a practical example of a real world problem. Secondly, even though time constraints did not allow the synthesis of a suitable antenna, the fact that a possible service area has been identified in the Williamsport, Pennsylvania area on a frequency of 560 kHz is still another demonstration of the use of antenna and propagation theory for interference analyses and possible antenna synthesis.

B. CONCLUSIONS

The project has served several useful purposes. It should be possible, with this document, a copy of the CFR Title 47 Parts 73., and the two books by Smith (See references 13 and 14), for a senior level electrical engineering undergraduate to become familiar and productive with the tools of the trade in

AM broadcast antenna engineering for daytime service.

The solutions to the practical problems, even though not as immediately profitable as one might like, are demonstrations of the tools of the trade, and constitude useful information to the WPLW personnel.

C. RECOMMENDATIONS

One suggestion, would be to extend the tutorial to the analysis of skywave interference. This is a much more involved problem and would be the next logical step in the work. Also, determination of a solution to the problem of working the equivalent distance method backwards would be of use in the engineering community. It might be interesting to find out if there is an analog to this problem in the case of the skywave propagation. Finally, it is recommended that the other four suggested locations and frequencies be evaluated for their potential development for broadcast use.

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APPENDIX A. STDPATRN SAMPLE INPUTS, OUTPUTS, AND PROGRAM LISTING

The program STDPATRN computes the standard and theoretical patterns of directional array antennas pursuant to the FCC Rules and Regulations. Use is made of the techniques presented by Smith (See reference 14) in computing the pattern size, and the driving point impedances when possible. For the case of antennas with tower heights not equal to 90 electrical degrees, information on the radius of the tower must be provided, if it is not, the program computes a pattern without including losses, and no impedance information in available. The same is true when the towers used are either top loaded or sectionalized, since analytical formulations are not generally available for evaluating the base and radiation impedances of these structures.

The program uses a simple card deck for input which can easily be expanded and modified according to individual needs. The deck should be set up in the following format.

CM - Indicates that the next card will contain the number of comment lines. These lines will follow immediately there after.
TR - Indicates that the next card will contain the number of towers in the array. Immediately following this, will be two cards for each tower in the array. The first of these cards will contain:
spacing degrees, bearing degrees, field ratio, phasing degrees
The second of these cards will contain:
tower type, A-sect degrees, B-sect degrees, C-sect degrees, D-sect degrees, radius degrees
PW - Indicates the next card will contain the power in kiloWatts.
PT - Indicates the next card will contain the information on pattern cuts. This card will contain the following:
theta start, theta step, number theta steps, phi start, phi step, number phi steps
EN - Indicates end of data set.

A sample data set is shown in Figure A1, and the resulting output is shown in Figure A2. Following this is the actual program listing.

```
CM
2
     WCKL 560 KHZ, CATSKILL, NY DAYTIME PATTERN
     3 ELEMENT DIRECTIONAL ARRAY
PW
     1.00
TR
       3
     0.0,      0.0,      1.0,    -149.
       1,     90.0,      0.0,     0.0,      0.0,      0.0
    60.0,    140.0,     1.96,     0.0
       1,     90.0,      0.0,     0.0,      0.0,      0.0
   120.0,    140.0,      1.0,   149.0
       1,     90.0,      0.0,     0.0,      0.0,      0.0
PT
     0.0,      1.0,        0,     0.0,     10.0,       35
EN
```

Figure A1. Sample Input Deck

FILE: WCKL-DA OUTPUT B VM/SP CONVERSATIONAL MONITOR SYSTEM

WCKL 560 KHZ, CATSKILL, DY DAYTIME PATTERN
3 ELEMENT DIRECTIONAL ARRAY

ARRAY INPUT POWER : 1.00 KW

ARRAY SPECIFICATIONS :

TWR #	SPACING	BEARING	RATIO	PHASE
1	0.00	0.00	1.0000	-149.00
2	60.00	140.00	1.0000	0.00
3	120.00	140.00	1.0000	149.00

TOWER SPECIFICATIONS :

TWR #	A-SECT	B-SECT	C-SECT	DSECT	RADIUS
1	90.00	0.00	0.00	0.00	0.00
2	90.00	0.00	0.00	0.00	0.00
3	90.00	0.00	0.00	0.00	0.00

CALCULATED TOWER BASE IMPEDANCE

TOWER # 1	37.53981	21.25775
TOWER # 2	37.53981	21.25775
TOWER # 3	37.53981	21.25775

MUTUAL IMPEDANCE BETWEEN TOWERS :

TOWER # 1 TO 2	28.81697	-5.71276
TOWER # 1 TO 3	10.70145	-18.38202
TOWER # 2 TO 1	28.81697	-5.71276
TOWER # 3 TO 1	10.70145	-18.38202

DRIVING POINT IMPEDANCE

TOWER # 1	-10.31348	41.86671
TOWER # 2	12.33476	26.25447
TOWER # 3	4.61341	2.58446

REFERENCE CURRENT = 5.29366E12
POWER RADIATED IS 0.836301982
K FACTOR = 316.568604
THEORETICAL ERMS = 316.679199 MV/M @ 1KM

PATTERN FIELD INTENSITY VALUES
(MV/M AT 1 KM)

THETA	PHI	THEORETICAL	STANDARD
0.00	0.00	477.616164	501.528809
0.00	10.00	399.440674	419.412598
0.00	20.00	313.522949	329.198975
0.00	30.00	226.520218	237.846268
0.00	40.00	145.688965	152.973434
0.00	50.00	77.769882	81.658371
0.00	60.00	27.716765	29.134094
0.00	70.00	2.103583	2.208762
0.00	80.00	12.566341	13.194660
0.00	90.00	7.148972	7.506421
0.00	100.00	8.804178	9.244386
0.00	110.00	29.237442	30.699310
0.00	120.00	48.451111	50.873703
0.00	130.00	61.966479	65.001801
0.00	140.00	66.719803	70.055801
0.00	150.00	61.966479	65.001801
0.00	160.00	48.451111	50.873703
0.00	170.00	29.237442	30.699310
0.00	180.00	8.804178	9.244386
0.00	190.00	7.148972	7.506421
0.00	200.00	12.566341	13.194660
0.00	210.00	2.103583	2.208762
0.00	220.00	27.716765	29.134094
0.00	230.00	77.769882	81.658371
0.00	240.00	145.688965	152.973434
0.00	250.00	226.520218	237.846268
0.00	260.00	313.522949	329.198975
0.00	270.00	399.440674	419.412598
0.00	280.00	477.616464	501.528809
0.00	290.00	542.891602	570.036133
0.00	300.00	591.549072	621.126465
0.00	310.00	621.451416	652.523926
0.00	320.00	631.523437	663.099609
0.00	330.00	621.451416	652.523926
0.00	340.00	591.549072	621.126465
0.00	350.00	542.891602	570.036133

Figure A2. Sample Output

```
C*********************************************************************
C
C  STDPATRN - THIS PROGRAM COMPUTES THE STANDARD PATTERN FOR
C    AM DIRECTIONAL BROADCAST ANTENNAS ACCORDING TO RULES SET FORTH
C    IN THE FEDERAL COMMUNICATIONS COMMISSION RULES AND REGULATIONS
C    PART 73.150.
C
      IMPLICIT REAL*4 (K), COMPLEX (Z)
C
      COMMON / ARRAY / S(10), BR(10), FR(10), PH(10)
      COMMON / PARM / NT, PKW, PRKW, K
      COMMON / TOWER / ISECT(10), A(10), B(10), C(10), D(10), R(10)
      COMMON / IMPED / Z(10,10), ZS(10), ZSL(10), ZB(10), ZBL(10)
      COMMON / PAT / THETA0, DTHETA, NTHETA, PHI0, DPHI, NPHI
      COMMON / INOUT / IN, IO
      COMMON / CONST / PI, DTR
C
C  INITIALIZE INPUT OUTPUT DEVICES.
C
      IN = 5
      IO = 6
C
C  INITIALIZE CONSTANTS
C
      PI = 3.1415927
      DTR = PI / 180.
C
C  READ ARRAY PARAMETERS FROM DATA FILE
C
      CALL INPUT
C
C  IF TOWER HEIGHT NOT ODD MULTIPLE OF 90.0, AND RADIUS = 0.0
C  THEN CANT INCLUDE LOSSES. THUS, ASSUME EFFICIENCY = 100%.
C
      DO 5, J = 1, NT
      IF ( R(J) .EQ. 0.0 .AND. A(J) .NE. 90.0 ) THEN
         PRKW = PKW
         GOTO 50
      ENDIF
 5    CONTINUE
C
C  COMPUTE RADIATION AND MUTUAL IMPEDANCES OF ARRAY ELEMENTS
C
      CALL ZCALC
C
C  COMPUTE BASE SELF IMPEDANCES OF EACH TOWER
C
      CALL ZBASE
C
C  SOLVE FOR CURRENT IN REFERENCE TOWER ASSUMING LOSSES
C
      SSV = 0.0
C
      DO 26, J = 1, NT
 26   SSV = SSV + FR(J)*FP(J) * REAL ( ZBL(J) )
C
      REF =  SQRT ( PKW * 1000. / SSV )
      WRITE ( IO, * ) 'REFERENCE CURRENT = ',REF
C
C  COMPUTE POWER RADIATED BY ARRAY
C
      PRAD = 0.0
      DO 27, J = 1, NT
 27   PRAD = PRAD + REAL( ZB(J) ) * ( FR(J) * REF ) ** 2
      PRKW = PRAD / 1000.
      WRITE ( IO, * ) 'POWER RADIATED IS ', PRKW
C
C  COMPUTE K FACTOR FOR ARRAY.
C
 50   CALL KFACTR ( THRMS0 )
C
      WRITE ( IO, * ) 'K FACTOR = ',K
C
C  COMPUTE THEORETICAL ERMS IN HORIZONTAL PLANE
C
      THERMS = K * THRMS0
C
      WRITE ( IO, * ) 'THEORETICAL ERMS = ',THERMS,'MV/M @ 1KM'
C
C  COMPUTE PATTERN VALUES FOR SPECIFIED THETA AND PHI VALUES
```

```
C
      CALL PATTRN                                                       STD00810
C                                                                       STD00820
      END                                                               STD00830
C                                                                       STD00840
C*********************************************************************  STD00850
C                                                                       STD00860
CCC   INPUT - THIS SUBROUTINE READS THE CARDS CONTAINING THE INFORMATION STD00870
CC      REQUIRED FOR STDPATRN AND PRINTS OUT THE INFO FOR REFERENCE.    STD00880
C                                                                       STD00890
      SUBROUTINE INPUT                                                  STD00900
C                                                                       STD00910
      IMPLICIT REAL (A), COMPLEX (Z)                                    STD00920
      CHARACTER * 80 CM(4)                                              STD00930
      CHARACTER * 2 CARD                                                STD00940
C                                                                       STD00950
      COMMON / ARRAY / S(10), BR(10), FR(10), PH(10)                    STD00960
      COMMON / PARM / NT, PKW, PRKW, K                                  STD00970
      COMMON / TOWER / ISECT(10), A(10), B(10), C(10), D(10), R(10)     STD00980
      COMMON / AUG / NAUG, PHIP(30), SPAN(30), EAUGO(30)                STD00990
      COMMON / PAT / THETAO, DTHETA, NTHETA, PHIO, DPHI, NPHI           STD01000
      COMMON / INOUT / IN, IO                                           STD01010
C                                                                       STD01020
C                                                                       STD01030
 10   READ ( IN, 1000 ) CARD                                           STD01040
      IF ( CARD .EQ. 'CM' ) THEN                                        STD01050
         READ ( IN, * ) NC                                              STD01060
         DO 20, J = 1, NC                                               STD01070
 20      READ ( IN, 1001 ) CM(J)                                        STD01080
      ENDIF                                                             STD01090
      IF ( CARD .EQ. 'TR' ) THEN                                        STD01100
         READ ( IN, * ) NT                                              STD01110
         DO 30, J = 1, NT                                               STD01120
         READ ( IN, * ) S(J), BR(J), FR(J), PH(J)                       STD01130
 30      READ ( IN, * ) ISECT(J), A(J), B(J), C(J), D(J), R(J)          STD01140
      ENDIF                                                             STD01150
      IF ( CARD .EQ. 'PW' ) THEN                                        STD01160
         READ ( IN, * ) PKW                                             STD01170
      ENDIF                                                             STD01180
      IF ( CARD .EQ. 'AG' ) THEN                                        STD01190
         READ ( IN, * ) NAUG                                            STD01200
         DO 40, J = 1, NAUG                                             STD01210
 40      READ ( IN, * ) PHIP(J), SPAN(J), EAUGO(J)                      STD01220
      ENDIF                                                             STD01230
      IF ( CARD .EQ. 'PT' ) THEN                                        STD01240
         READ ( IN, * ) THETAO, DTHETA, NTHETA, PHIO, DPHI, NPHI        STD01250
      ENDIF                                                             STD01260
      IF ( CARD .EQ. 'EN' ) THEN                                        STD01270
         GOTO 35                                                        STD01280
      ELSE                                                              STD01290
         GOTO 10                                                        STD01300
      ENDIF                                                             STD01310
C                                                                       STD01320
CC  PRINT OUT INFO READ FROM DATA FILE                                  STD01330
C                                                                       STD01340
 35   DO 50, J = 1, NC                                                 STD01350
 50   WRITE ( IO, 1001) CM(J)                                           STD01360
C                                                                       STD01370
      WRITE ( IO, 2000 ) PKW                                            STD01380
C                                                                       STD01390
      WRITE ( IO, 2001 )                                                STD01400
C                                                                       STD01410
      DO 60, J = 1, NT                                                  STD01420
 60   WRITE ( IO, 2002 ) J, S(J), BR(J), FR(J), PH(J)                   STD01430
C                                                                       STD01440
      WRITE ( IO, 2003 )                                                STD01450
C                                                                       STD01460
      DO 70, J = 1, NT                                                  STD01470
 70   WRITE ( IO, 2004 ) J, A(J), B(J), C(J), D(J), R(J)                STD01480
C                                                                       STD01490
      IF ( NAUG .EQ. 0 ) GOTO 100                                       STD01500
C                                                                       STD01510
      WRITE ( IO, 2005 )                                                STD01520
C                                                                       STD01530
      DO 80, J = 1, NAUG                                                STD01540
 80   WRITE ( IO, 2006 ) J, PHIP(J), SPAN(J), EAUGO(J)                  STD01550
C                                                                       STD01560
 100  RETURN                                                            STD01570
C                                                                       STD01580
 1000 FORMAT (A2)                                                       STD01590
                                                                        STD01600
```

```
 1001 FORMAT (A80)
 2000 FORMAT ( /,' ARRAY INPUT POWER : ',F6.2,' KW ',/ )
 2001 FORMAT ( /, ' ARRAY SPECIFICATIONS :',/,
     & '  TWR #     SPACING       BEARING        RATIO          PHASE',/)
 2002 FORMAT ( 3X, I2, 6X, F7.2, 6X, F7.2, 6X, F7.4, 6X, F7.2 )
 2003 FORMAT ( /, ' TOWER SPECIFICATIONS :',/,
     & '  TWR #       A-SECT        B-SECT        C-SECT        DSECT
     &  RADIUS',/ )
 2004 FORMAT ( 3X, I2, 5 ( 6X, F7.2 ) )
 2005 FORMAT ( /, ' PATTERN AUGMENTATION DATA :',/,
     & '  AUG #          PHI          SPAN          FAUG',/)
 2006 FORMAT ( 3X, I2, 3 ( 6X, F7.2 ) )
C
      END
C
C*********************************************************************
C
C  E - THIS SUBROUTINE COMPUTES THE THEORETICAL INVERSE DISTANCE FIELD
C    AT 1 KILOMETER FOR THE GIVEN AZIMUTH AND ELEVATION.
C
      SUBROUTINE E ( THETA, PHI, ETH )
C
      IMPLICIT REAL (K)
      COMPLEX ET
C
      COMMON / ARRAY / S(10), BR(10), FR(10), PH(10)
      COMMON / PARM / NT, PKW, PRKW, K
      COMMON / TOWER / ISECT(10), A(10), B(10), C(10), D(10), R(10)
      COMMON / CONST / PI, DTR
C
C  INITIALIZE VARIABLES
C
      ET = ( 0.0, 0.0 )
C
C  DO VECTOR SUM OF CONTRIBUTION FROM EACH TOWER
C
      DO 10, I = 1, NT
C
C  GET THE VERTICAL PLANE RADIATION CHARACTERISTIC F( THETA )
C
         CALL FELV ( THETA, I, F )
C
         ET = ET + FR(I) * F * EXP ( (0,1) * DTR * ( S(I) *
     &        COS ( DTR * THETA ) * COS ( DTR * ( BR(I) - PHI ) ) +
     &        PH(I) ) )
C
 10   CONTINUE
C
C  TAKE MAGNITUDE OF COMPLEX FIELD
C
      ETH = ABS ( ET )
C
      RETURN
C
      END
C
C*********************************************************************
C
C  FELV - COMPUTES THE ELEVATION PATTERN FACTOR FOR USE IN FIELD
C    CALCULATIONS.
C
      SUBROUTINE FELV ( THETA, I, F )
C
      COMMON / TOWER / ISECT(10), A(10), B(10), C(10), D(10), R(10)
      COMMON / CONST / PI, DTR
C
C  CONVERT ALL LENGTHS AND ANGLES FROM DEGREES TO RADIANS
C
      TH = DTR * THETA
      A1 = DTR * A(I)
      B1 = DTR * B(I)
      C1 = DTR * C(I)
      D1 = DTR * D(I)
      G = A1 + B1
      H = C1 + D1
      DEL = H - A1
C
C  FOR STANDARD TOWER
C
      IF ( ISECT(1) .EQ. 1 ) THEN
```

```
C
            F = ( COS (  A1 * SIN ( TH ) ) - COS ( A1 ) ) /                    STD02410
     &          ( ( 1.0 - COS ( A1 ) ) * COS ( TH ) )                         STD02420
C                                                                              STD02430
         ENDIF                                                                 STD02440
C                                                                              STD02450
CC   FOR TOP LOADED TOWER                                                      STD02460
CC                                                                             STD02470
         IF ( ISECT(I) .EQ. 2 ) THEN                                           STD02480
C                                                                              STD02490
            FNUM = COS ( B1 ) * COS ( A1 * SIN ( TH ) ) -                      STD02500
     &             SIN ( TH ) * SIN ( B1 ) * SIN ( A1 * SIN ( TH ) ) -         STD02510
     &             COS ( A1 + B1 )                                             STD02520
C                                                                              STD02530
            FDEN = COS ( TH ) * ( COS ( B1 ) - COS ( A1 + B1 ) )               STD02540
C                                                                              STD02550
            F = FNUM / FDEN                                                    STD02560
C                                                                              STD02570
         ENDIF                                                                 STD02580
CC                                                                             STD02590
CC   FOR A SECTIONALIZED TOWER WITH TOP LOADING                                STD02600
CC                                                                             STD02610
         IF ( ISECT(I) .EQ. 3 ) THEN                                           STD02620
C                                                                              STD02630
            FNUM = ( SIN ( DEL ) * ( COS ( B1 ) * COS ( A1 * SIN ( TH ) )      STD02640
     &             - COS ( G ) ) +                                             STD02650
     &             SIN ( B1 ) * ( COS ( D1 ) * COS ( C1 * SIN ( TH ) ) -       STD02660
     &             SIN ( TH ) * SIN ( D1 ) * SIN ( C1 * SIN ( TH ) ) -         STD02670
     &             COS ( DEL ) * COS ( A1 * SIN ( TH ) ) ) )                   STD02680
C                                                                              STD02690
            FDEN = COS ( TH ) * ( SIN ( DEL ) * ( COS ( B1 ) - COS ( C1 ) )    STD02700
     &             + SIN ( B1 ) * ( COS ( D1 ) - COS ( DEL ) ) )               STD02710
C                                                                              STD02720
            F = FNUM / FDEN                                                    STD02730
C                                                                              STD02740
         ENDIF                                                                 STD02750
C                                                                              STD02760
         RETURN                                                                STD02770
         END                                                                   STD02780
C                                                                              STD02790
CC*****************************************************************************STD02800
CCCCCC                                                                         STD02810
CC   KFACTR - THIS SUBROUTINE COMPUTES THE K FACTOR THAT DETERMINES THE        STD02820
CC     ARRAY SIZE. POWER FLOW INTEGRATION IS USED TO GET THE RMS FIELD         STD02830
CC     INTENSITY.                                                              STD02840
CC                                                                             STD02850
         SUBROUTINE KFACTR ( THRMS0 )                                          STD02860
C                                                                              STD02870
         IMPLICIT REAL (K)                                                     STD02880
C                                                                              STD02890
         COMMON / PARM / NT, PKW, PRKW, K                                      STD02900
         COMMON / CONST / PI, DTR                                              STD02910
C                                                                              STD02920
CC   INITIALIZE VARIABLES                                                      STD02930
C                                                                              STD02940
         E2P = 0.0                                                             STD02950
         E2T = 0.0                                                             STD02960
C                                                                              STD02970
CC   SET THETA AND PHI INCREMENTS TO 1.0 DEGREE                                STD02980
C                                                                              STD02990
         DTHETA =  1.0                                                         STD03000
         DPHI =  1.0                                                           STD03010
C                                                                              STD03020
CC   INTEGRATE OVER UPPER HEMISPHERE.                                          STD03030
C                                                                              STD03040
         DO 20, I = 0, 89                                                      STD03050
         THETA = I * DTHETA                                                    STD03060
C                                                                              STD03070
         E2P = 0.0                                                             STD03080
         DO 10, J = 0, 359                                                     STD03090
         PHI = J * DPHI                                                        STD03100
C                                                                              STD03110
         CALL E ( THETA, PHI, ETH )                                            STD03120
C                                                                              STD03130
            E2P = E2P + ETH * * 2                                              STD03140
C                                                                              STD03150
10    CONTINUE                                                                 STD03160
C                                                                              STD03170
         IF ( I .EQ. 0 ) THEN                                                  STD03180
C                                                                              STD03190
                                                                               STD03200
```

```
C  GET FACTOR FOR HORIZONTAL PLANE THEORETICAL RMS FIELD                  STD03210
C                                                                        STD03220
C        THRMSO = SQRT ( E2P / 360.)                                     STD03230
C                                                                        STD03240
         E2T = E2P / 2                                                   STD03250
      ELSE                                                               STD03260
         E2T = E2T + COS ( DTR * THETA ) * E2P                           STD03270
      ENDIF                                                              STD03280
C                                                                        STD03290
   20 CONTINUE                                                           STD03300
C                                                                        STD03310
      FP = SQRT ( ( PI / ( 180. * 360. ) ) * E2T )                       STD03320
C                                                                        STD03330
      K = 244.73 * SQRT ( PRKW ) / FP                                    STD03340
C                                                                        STD03350
      RETURN                                                             STD03360
C                                                                        STD03370
      END                                                                STD03380
C                                                                        STD03390
C*************************************************************************STD03400
C                                                                        STD03410
C  ZCALC - THIS SUBROUTINE COMPUTES THE RADIATION AND MUTUAL IMPEDANCE   STD03420
C    OF THE ARRAY ELEMENTS. ANALYTICAL EXPRESSIONS ARE EVALUATED FOR     STD03430
C    STANDARD TOWERS NOT USING TOP LOADING OR SECTIONALIZATION.          STD03440
C    FOR TOP LOADED OR SECTIONALIZED TOWERS.                             STD03450
C                                                                        STD03460
      SUBROUTINE ZCALC                                                   STD03470
C                                                                        STD03480
      IMPLICIT REAL ( K ), COMPLEX ( Z )                                 STD03490
C                                                                        STD03500
      COMPLEX RAD1, MUT1                                                 STD03510
C                                                                        STD03520
      EXTERNAL RAD1, MUT1                                                STD03530
C                                                                        STD03540
      COMMON / ARRAY / S(10),BR(10),FP(10),PH(10)                        STD03550
      COMMON / PARM / NT, PKW, PRKW, K                                   STD03560
      COMMON / TOWER / ISECT(10), A(10), B(10), C(10), D(10), R(10)      STD03570
      COMMON / IMPED / Z(10,10), ZS(10), ZSL(10), ZB(10), ZBL(10)        STD03580
      COMMON / CONST / PI, DTR                                           STD03590
C                                                                        STD03600
C     COMPUTE IMPEDANCE OF EACH TOWER TO ITSELF AND EVERY OTHER TOWER    STD03610
C                                                                        STD03620
      DO 20, J = 1, NT                                                   STD03630
      DO 10, I = 1, J                                                    STD03640
C                                                                        STD03650
      IF ( ( I .EQ. J ) .AND. ( ISECT( I ) .EQ. 1 ) ) THEN               STD03660
C                                                                        STD03670
C  COMPUTE RADIATION IMPEDANCE OF ELEMENT I                              STD03680
C                                                                        STD03690
         Z( 1, I ) = RAD1 ( A(I) )                                       STD03700
C                                                                        STD03710
      ENDIF                                                              STD03720
C                                                                        STD03730
      IF ( ( I .NE. J ) .AND. ( ISECT( I ) .EQ. 1 ) .AND.                STD03740
     &   ( ISECT( J ) .EQ. 1 ) ) THEN                                    STD03750
C                                                                        STD03760
C  COMPUTE DISTANCE BETWEEN ELEMENTS I AND J                             STD03770
C                                                                        STD03780
         SD = SQRT( S(J)*S(J) + S(I)*S(I) - 2.0 * S(J)*S(I) *            STD03790
     &        COS( DTR * ( BR(I)-BR(J) ) ) )                             STD03800
C                                                                        STD03810
C  COMPUTE MUTUAL IMPEDANCE BETWEEN I AND J. USE SYMMETRY FOR J AND I.   STD03820
C                                                                        STD03830
         Z( I, J ) = MUT1 ( A(I), A(J), SD )                             STD03840
         Z( J, I ) = Z( I, J )                                           STD03850
      ENDIF                                                              STD03860
C                                                                        STD03870
   10 CONTINUE                                                           STD03880
   20 CONTINUE                                                           STD03890
C                                                                        STD03900
      RETURN                                                             STD03910
      END                                                                STD03920
C                                                                        STD03930
C*************************************************************************STD03940
C                                                                        STD03950
C  ZBASE - COMPUTES THE BASE SELF IMPEDANCES AND DRIVING POINT           STD03960
C    IMPEDANCES FOR ALL TOWERS. BOTH LOSSLESS AND LOSSY CASES ARE        STD03970
C    CONSIDERED.                                                         STD03980
C                                                                        STD03990
      SUBROUTINE ZBASE                                                   STD04000
```

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C                                                                       STD04010
      IMPLICIT REAL (R), COMPLEX (Z)                                    STD04020
C                                                                       STD04030
      COMMON / ARRAY / S(10), BR(10), FR(10), PH(10)                    STD04040
      COMMON / PARM / NT, PKW, PRKW, K                                  STD04050
      COMMON / TOWER / ISECT(10), A(10), B(10), C(10), D(10), R(10)     STD04060
      COMMON / IMPED / Z(10,10), ZS(10), ZSL(10), ZB(10), ZBL(10)       STD04070
      COMMON / CONST / PI, DTR                                          STD04080
      COMMON / INOUT / IN, IO                                           STD04090
C                                                                       STD04100
C  COMPUTE BASE SELF IMPEDANCES OF EACH TOWER                           STD04110
C    THE ZS(I) ARE BASE IMPEDANCES NEGLECTING LOSSES                    STD04120
C    THE ZSL(I) ARE BASE IMPEDANCES INCLUDING LOSSES                    STD04130
C                                                                       STD04140
      WRITE ( IO, 2000 )                                                STD04150
C                                                                       STD04160
      DO 22, J = 1, NT                                                  STD04170
C                                                                       STD04180
      TR = SIN ( DTR * A(J) ) ** 2.0                                    STD04190
C                                                                       STD04200
      ZS(J) = Z(J,J) / TR                                               STD04210
C                                                                       STD04220
      IF ( A(J) .GE. 90.0 ) THEN                                        STD04230
        ZSL(J) = ( 1.0 + Z(J,J) ) / TR                                  STD04240
      ELSE                                                              STD04250
        ZSL(J) = 1.0 + Z(J,J)                                           STD04260
      ENDIF                                                             STD04270
C                                                                       STD04280
      WRITE ( IO, 2001 ) J, REAL( ZSL(J) ), AIMAG( ZSL(J) )             STD04290
C                                                                       STD04300
22    CONTINUE                                                          STD04310
C                                                                       STD04320
C  PRINT OUT MUTUAL IMPEDANCES BETWEEN TOWERS                           STD04330
C                                                                       STD04340
      WRITE ( IO, 2002 )                                                STD04350
C                                                                       STD04360
      DO 23, J = 1, NT                                                  STD04370
      DO 23, I = 1, NT - J + 1                                          STD04380
      IF ( J .EQ. I ) GOTO 23                                           STD04390
      WRITE ( IO, 2003 ) J, I, REAL( Z(J,I) ), AIMAG( Z(J,I) )          STD04400
23    CONTINUE                                                          STD04410
C                                                                       STD04420
      WRITE ( IO, 2004 )                                                STD04430
C                                                                       STD04440
C  COMPUTE BASE IMPEDANCE ACCOUNTING FOR MUTUAL EFFECTS                 STD04450
C    ZB(I) IS THE BASE IMPEDANCE NEGLECTING LOSS                        STD04460
C    ZBL(I) IS THE BASE IMPEDANCE INCLUDING LOSS                        STD04470
C                                                                       STD04480
      DO 25, J = 1, NT                                                  STD04490
C                                                                       STD04500
      ZB(J) = ( 0.0, 0.0 )                                              STD04510
      ZBL(J) = ( 0.0, 0.0 )                                             STD04520
C                                                                       STD04530
      DO 24, I = 1, NT                                                  STD04540
C                                                                       STD04550
      IF ( I .EQ. J ) GOTO 24                                           STD04560
C                                                                       STD04570
      ZB(J)=ZB(J)+FR(I)/FR(J)*EXP((0.,1.)*DTR*(PH(I)-PH(J)))*Z(J,I)     STD04580
C                                                                       STD04590
24    CONTINUE                                                          STD04600
C                                                                       STD04610
      ZBL(J) = ZB(J) + ZSL(J)                                           STD04620
      ZB(J) = ZS(J) + ZS(J)                                             STD04630
C                                                                       STD04640
      WRITE ( IO, 2005 ) J, REAL( ZBL(J) ), AIMAG( ZBL(J) )             STD04650
C                                                                       STD04660
25    CONTINUE                                                          STD04670
C                                                                       STD04680
 2000 FORMAT ( /, ' CALCULATED TOWER BASE IMPEDANCE ', / )              STD04690
 2001 FORMAT ( '     TOWER # ', I2, 5X, F10.5, 5X, F10.5 )              STD04700
 2002 FORMAT ( /, ' MUTUAL IMPEDANCE BETWEEN TOWERS :', / )             STD04710
 2003 FORMAT ( '     TOWER # ', I2, ' TO ', I2, 5X, F10.5, 5X, F10.5 )  STD04720
 2004 FORMAT ( /, ' DRIVING POINT IMPEDANCE ', / )                      STD04730
 2005 FORMAT ( '     TOWER # ', I2, 5X, F10.5, 5X, F10.5 )              STD04740
C                                                                       STD04750
      RETURN                                                            STD04760
C                                                                       STD04770
      END                                                               STD04780
C                                                                       STD04790
C*********************************************************************STD04800
```

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C                                                                       STD04810
C  RAD1  -  THIS FUNCTION EVALUATES THE RADIATION IMPEDANCE OF THE      STD04820
C    TOWER REFERRED TO THE CURRENT MAXIMUM WHEN NO OTHER TOWERS ARE     STD04830
C    PRESENT.                                                           STD04840
C                                                                       STD04850
      FUNCTION RAD1( H )                                                STD04860
C                                                                       STD04870
      EXTERNAL SI, CI                                                   STD04880
C                                                                       STD04890
      REAL IM, L                                                        STD04900
      COMPLEX RAD1                                                      STD04910
C                                                                       STD04920
      PI = 3.1415927                                                    STD04930
      DTR = PI / 180.                                                   STD04940
      ETA = 376.7343                                                    STD04950
      C = 0.577215664901532                                             STD04960
C                                                                       STD04970
      L = DTR * 2.0 * H                                                 STD04980
C                                                                       STD04990
CC  COMPUTE THE REAL PART OF THE IMPEDANCE                              STD05000
C                                                                       STD05010
      RE = ( ETA / ( 4.0 * PI ) ) * ( C + ALOG ( L ) - CI ( L ) +       STD05020
     &     0.5 * SIN ( L ) * ( SI ( 2.0 * L ) - 2.0 * SI ( L ) ) +      STD05030
     &     0.5 * COS ( L ) * ( C + ALOG ( L / 2.0 ) + CI ( 2.0 * L )-   STD05040
     &     2.0 * CI ( L ) ) )                                           STD05050
C                                                                       STD05060
CC  COMPUTE THE IMAGINARY PART OF THE IMPEDANCE                         STD05070
C                                                                       STD05080
      IM = ( ETA / ( 8.0 * PI ) ) * ( 2.0 * SI ( L ) + COS ( L ) *      STD05090
     &     ( 2.0 * SI ( L ) - SI ( 2.0 * L ) ) - SIN ( L ) *           STD05100
     &     ( 2.0 * CI ( L ) - CI ( 2.0 * L ) ) )                       STD05110
C                                                                       STD05120
      RAD1 = RE + ( 0.0, 1.0 ) * IM                                     STD05130
C                                                                       STD05140
      END                                                               STD05150
C                                                                       STD05160
C***********************************************************************STD05170
C                                                                       STD05180
C  MUT1 - THIS FUNCTION COMPUTE THE MUTUAL IMPEDANCE BETWEEN TWO        STD05190
C    TOWERS OF DIFFERENT HEIGHTS AND SEPARATED BY DISTANCE D.           STD05200
C    ( FORMULAS GIVEN BY WEBES REPORT )                                 STD05210
C                                                                       STD05220
      FUNCTION MUT1 ( H1, H2, D )                                       STD05230
C                                                                       STD05240
      COMPLEX MUT1                                                      STD05250
      REAL IM                                                           STD05260
      EXTERNAL CI, SI                                                   STD05270
C                                                                       STD05280
      PI = 3.1415927                                                    STD05290
      DTR = PI / 180.0                                                  STD05300
C                                                                       STD05310
      G1 = DTR * H1                                                     STD05320
      G2 = DTR * H2                                                     STD05330
      S = DTR * D                                                       STD05340
C                                                                       STD05350
      U0 = SQRT ( S*S + G1*G1 ) - G1                                    STD05360
      U1 = SQRT ( S*S + (G2-G1)**2.0 ) + G2 - G1                        STD05370
      V0 = SQRT ( S*S + G1*G1 ) + G1                                    STD05380
      V1 = SQRT ( S*S + (G2-G1)**2.0 ) - G1 + G1                        STD05390
      W0 = V0                                                           STD05400
      W1 = SQRT ( S*S + (G2+G1)**2.0 ) + G2 + G1                        STD05410
      X0 = U0                                                           STD05420
      X1 = SQRT ( S*S + (G2+G1)**2.0 ) - G2 - G1                        STD05430
      Y0 = S                                                            STD05440
      Y1 = SQRT ( S*S + G2*G2 ) + G2                                    STD05450
      S0 = Y0                                                           STD05460
      S1 = SQRT ( S*S + G2*G2 ) - G2                                    STD05470
C                                                                       STD05480
      CIU0 = CI( U0 )                                                   STD05490
      CIU1 = CI( U1 )                                                   STD05500
      CIV0 = CI( V0 )                                                   STD05510
      CIV1 = CI( V1 )                                                   STD05520
      CIW1 = CI( W1 )                                                   STD05530
      CIX1 = CI( X1 )                                                   STD05540
      CIY1 = CI( Y1 )                                                   STD05550
      CIS1 = CI( S1 )                                                   STD05560
      SIU0 = SI( U0 )                                                   STD05570
      SIU1 = SI( U1 )                                                   STD05580
      SIV0 = SI( V0 )                                                   STD05590
      SIV1 = SI( V1 )                                                   STD05600
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      SI1 = SI( A1 )                                                    STD05610
      SIX1 = SI( X1 )                                                   STD05620
      SIY1 = SI( Y1 )                                                   STD05630
      SIS1 = SI( S1 )                                                   STD05640
C                                                                       STD05650
      RE = ( 15.0 / ( SIN(G1)*SIN(G2) ) ) * ( COS (G2-G1) *             STD05660
     &     ( CIU1 - CIU0 + CIV1 - CIV0 + 2.0 * CIY0 - CIY1 - CIS1 )     STD05670
     &     + SIN(G2-G1) * ( SIU1 - SIU0 + SIV0 - SIV1 - SIY1 + SIS1 )   STD05680
     &     + COS(G2+G1) * ( CIW1 - CIV0 + CIX1 - CIU0 + 2.0 * CIY0      STD05690
     &     - CIY1 - CIS1 ) + SIN(G2+G1) * (SIW1 - SIV0 + SIU0           STD05700
     &     - SIX1 - SIY1 + SIS1 ) )                                     STD05710
C                                                                       STD05720
      IM = ( 15.0 / ( SIN(G1)*SIN(G2) ) ) * ( COS(G2-G1) *              STD05730
     &     ( SIU0 - SIU1 + SIV0 - SIV1 + SIY1 - 2.0 * SIY0              STD05740
     &     + SIS1 ) + SIN(G1-G1) * ( CIU1 - CIU0 + CIV0                 STD05750
     &     - CIY1 - CIY1 + CIS1 )                                       STD05760
     &     + COS(G2+G1) * ( SIV0 - SIW1 + SIU0 - SIX1 + SIY1            STD05770
     &     + SIS1 ) + SIN(G2+G1) * ( CIW1 - CIV0 + CIU0                 STD05780
     &     - CIX1 - CIY1 + CIS1 ) )                                     STD05790
C                                                                       STD05800
      MUT1 = RE + ( 0.0, 1.0 ) * IM                                     STD05810
C                                                                       STD05820
      END                                                               STD05830
C*********************************************************************STD05840
C                                                                       STD05850
C  CI - THIS FUNCTION EVALUATES THE COSINE INTEGRAL. THE INTEGRAL       STD05860
C    CIN(X) IS FIRST EVALUATED USING AN IMSL ROUTINE. THEN APPROPRIATE  STD05870
C    CORRECTION TERMS ARE ADDED TO GET THE CI(X) FUNCTION.              STD05880
C                                                                       STD05890
      FUNCTION CI ( ARG )                                               STD05900
C                                                                       STD05910
      REAL * 8 DCADRE, F1, A, B, AERR, RERR, ERROR                      STD05920
      INTEGER * 4 IER                                                   STD05930
      EXTERNAL F1                                                       STD05940
C                                                                       STD05950
      C = 0.577215664901532                                             STD05960
      A = 1.0 D -16                                                     STD05970
      B = ARG                                                           STD05980
      RERR = 1.0 D -16                                                  STD05990
      AERR = 1.0 D -16                                                  STD06000
C                                                                       STD06010
C  FUNCTION DCADRE INTEGRATES THE FUNCTION F1 BETWEEN A AND B           STD06020
C  WITH THE GIVEN VALUES OF ABSOLUTE AND RELATIVE ERROR.                STD06030
C                                                                       STD06040
      CI = DLOG(B) + C - DCADRE ( F1, A, B, AERR, RERR, ERROR, IER )    STD06050
C                                                                       STD06060
      END                                                               STD06070
C*********************************************************************STD06080
C                                                                       STD06090
C  SI - THIS FUNCTION EVALUATES THE SINE INTEGRAL USING AN IMSL         STD06100
C    INTEGRATION ROUTINE.                                               STD06110
C                                                                       STD06120
      FUNCTION SI ( ARG )                                               STD06130
C                                                                       STD06140
      REAL * 4 SI, ARG                                                  STD06150
      REAL * 8 DCADRE, F2, A, B, AERR, RERR, ERROR                      STD06160
      INTEGER * 4 IER                                                   STD06170
      EXTERNAL F2                                                       STD06180
C                                                                       STD06190
      A = 1.0 D -16                                                     STD06200
      B = ARG                                                           STD06210
      RERR = 1.0 D -16                                                  STD06220
      AERR = 1.0 D -16                                                  STD06230
C                                                                       STD06240
C  THE FUNCTION DCADRE INTEGRATES FUNCTION F2 BETWEEN A AND B           STD06250
C  WITH THE GIVEN RELATIVE AND ABSOLUTE ERROR.                          STD06260
C                                                                       STD06270
      SI = DCADRE( F2, A, B, AERR, RERR, ERROR, IER )                   STD06280
C                                                                       STD06290
      END                                                               STD06300
C                                                                       STD06310
C*********************************************************************STD06320
C                                                                       STD06330
C  F1 - THIS FUNCTION IS USED BY FUNCTION CI TO COMPUTE THE COSINE      STD06340
C    INTEGRAL                                                           STD06350
C                                                                       STD06360
      FUNCTION F1 ( X )                                                 STD06370
      REAL * 8 F1, X                                                    STD06380
                                                                        STD06390
                                                                        STD06400
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```
      F1 = ( 1.0 - DCOS( Y ) ) / X
      END
C
C*********************************************************************
C  F2 - THIS FUNCTION IS USED BY FUNCTION SI TO COMPUTE THE SINE
C    INTEGRAL.
C
      FUNCTION F2 ( X )
      REAL*8 F2, X
      F2 = DSIN( X ) / X
      END
C
C*********************************************************************
C
C  PATTRN - COMPUTES THE THEORETICAL AND STANDARD PATTERN FOR THE
C    VALUES OF THETA AND PHI SPECIFIED IN INPUT FILE
C
      SUBROUTINE PATTRN
C
      IMPLICIT REAL (K)
C
      COMMON / PARM / NT, PKW, PRKW, K
      COMMON / PAT / THETA0, DTHETA, NTHETA, PHI0, DPHI, NPHI
      COMMON / AUG / NAUG, PHIP(30), SPAN(30), EAUG0(30)
      COMMON / INOUT/ IN, IO
C
C  COMPUTE HEIGHT OF SMALLEST TOWER FOR Q VALUE COMPUTATION
C
      CALL HMIN ( JM, HM )
C
C  LOOP OVER THETA, PHI AND COMPUTE PATTERN VALUES
C
      WRITE ( IO, 2000 )
C
      DO 10, THETA = THETA0, NTHETA * DTHETA, DTHETA
C
C  COMPUTE THE Q FACTOR FOR THETA
C
       CALL QVAL ( THETA, JM, HM, Q )
C
      DO 10, PHI = PHI0, NPHI * DPHI, DPHI
C
      CALL E ( THETA, PHI, ET )
C
C  COMPUTE THE THEORETICAL VALUE OF THE ELECTRIC FIELD
C
      ETH = K * ET
C
C  COMPUTE THE STANDARD PATTERN VALUE
C
      ESTD = 1.05 * SQRT ( ETH*ETH + Q*Q )
C
C  COMPUTE AUGMENTED PATTERN VALUE IF AUGMENTATIONS SPECIFIED
C
      IF ( NAUG .NE. 0 ) THEN
      ENDIF
C
C  PRINT PATTERN INFORMATION
C
C     WRITE ( IO, 2001 ) THETA, PHI, ETH, ESTD
      WRITE ( IO, * ) 'BP'
      WRITE ( IO, 2001 ) PHI, ESTD
      WRITE ( IO, * ) '4.0, 999999'
C
 10   CONTINUE
C
 2000 FORMAT ( ///, '              PATTERN FIELD INTENSITY VALUES ', /,
     &                '                    ( MV/M AT 1 KM )', //,
     &'   THETA          PHI          THEORETICAL          STANDARD',// )
C2001 FORMAT ( 2X, F6.2, 6X, F6.2, 6X, F12.6, 6X, F12.6 )
 2001 FORMAT ( 2X,F6.2,2X,',',2X,F12.6)
C
      RETURN
C
      END
C
C*********************************************************************
C
C  HMIN - THIS SUBROUTINE DETERMINES THE SHORTEST TOWER USED IN THE
C  ARRAY. THIS IS REQUIRED TO EVALUATE THE Q FACTOR.
```

```
C
      SUBROUTINE HMIN ( JM, HM )                                        STD07210
C                                                                       STD07220
      IMPLICIT REAL (K)                                                 STD07230
C                                                                       STD07240
      COMMON / TOWER / ISECT(10), A(10), B(10), C(10), D(10), R(10)     STD07250
      COMMON / PARM / NT, PKW, PRKW, K                                  STD07260
C                                                                       STD07270
C  CHOOSE TOWER WITH SHORTEST ELECTRICAL HEIGHT.                        STD07280
C                                                                       STD07290
      DO 5, J = 1, NT                                                   STD07300
C                                                                       STD07310
      IF ( ISECT(J) .EQ. 1 ) H = A(J)                                   STD07320
      IF ( ISECT(J) .EQ. 2 ) H = A(J) + B(J)                            STD07330
      IF ( ISECT(J) .EQ. 3 ) H = C(J) + D(J)                            STD07340
C                                                                       STD07350
      IF ( J .EQ. 1 ) HM = H                                            STD07360
C                                                                       STD07370
      IF ( H .LT. HM ) THEN                                             STD07380
         HM = H                                                         STD07390
         JM = J                                                         STD07400
      ENDIF                                                             STD07410
C                                                                       STD07420
 5    CONTINUE                                                          STD07430
C                                                                       STD07440
      RETURN                                                            STD07450
C                                                                       STD07460
      END                                                               STD07470
C                                                                       STD07480
C***********************************************************************STD07490
C                                                                       STD07500
C  QFACT - COMPUTES THE VALUE Q USED IN FCC STANDARD PATTERN            STD07510
C    COMPUTATIONS.                                                      STD07520
C                                                                       STD07530
      SUBROUTINE QVAL ( THETA, JM, HM, Q )                              STD07540
C                                                                       STD07550
      IMPLICIT REAL (K)                                                 STD07560
C                                                                       STD07570
      COMMON / ARRAY / S(10), BR(10), FP(10), PH(10)                    STD07580
      COMMON / PARM / NT, PKW, PRKW, K                                  STD07590
C                                                                       STD07600
C  COMPUTE G(THETA) FACTOR                                              STD07610
C                                                                       STD07620
      CALL FELV( THETA, JM, F )                                         STD07630
C                                                                       STD07640
      IF ( HM .GT. 180. ) THEN                                          STD07650
         G = SQRT ( F*F + 0.0625 ) / 1.03776                            STD07660
      ELSE                                                              STD07670
         G = F                                                          STD07680
      ENDIF                                                             STD07690
C                                                                       STD07700
C  COMPUTE ERSS                                                         STD07710
C                                                                       STD07720
      SFI2 = 0.0                                                        STD07730
C                                                                       STD07740
      DO 10, I = 1, NT                                                  STD07750
 10   SFI2 = SFI2 + FR(I)*FR(I)                                         STD07760
C                                                                       STD07770
      ERSS = K * SQRT ( SFI2 )                                          STD07780
C                                                                       STD07790
      POWER = PKW                                                       STD07800
      IF ( PKW .LT. 1.0 ) POWER = 1.0                                   STD07810
C                                                                       STD07820
      Q1 = 0.025 * G * ERSS                                             STD07830
      Q2 = 10.0 * G * SQRT ( POWER )                                    STD07840
C                                                                       STD07850
      Q = MAX ( Q1, Q2 )                                                STD07860
C                                                                       STD07870
      RETURN                                                            STD07880
C                                                                       STD07890
      END                                                               STD07900
                                                                        STD07910
```

APPENDIX B. PCMLL2 SAMPLE INPUT, OUPUT, AND PROGRAM LISTING

The program PMCMLL2 computes the distance to a specified protected contour, given the unattenuated field strength at one kilometer, the conductivity profile, and the frequency. The program also accepts information on the location of the station, and the bearing in which the distance is to be computed, to provide the lattitude and longitude of the protected contour point. Additionally, the program also accepts the location of a proposed transmitter site, and computes the distance and bearing of all protected contour points from this location.

The program utilizes the equivalent distance technique, as previously described for paths where the conductivity is nonhomogeneous along a given radial. The subroutine CONTUR already described is used to compute distances to contour points when the conductivity is homogeneous. The subroutine FCCGW, is used in this iterative technique to compute the field strengths at a given distance. The subroutine FCCGW is a very slightly modified version of the program accompaining the 1986 FCC report (See reference 2).

The program uses a simple card deck input which can easily be expanded and modified to accomodate individual needs. The deck should be set up in the following format.

CM - Indicates that what ever else is on the line will be ignored. Useful for commenting data sets.

CL - Indicates that the following cards will contain the desired contour levels. Up to 10 different contour levels can be specified in a single execution of the program. Use a value of 999999 to indicate that there are no more contour levels to be read.

TL - Indicates that the next two cards will contain the lattitude and longitude of the transmitter site. The cards will contain:
lattitude degrees, minutes, seconds
longitude degrees, minutes, seconds

PL - Indicates that the next two cards will contain the lattitude and longitude of the proposed site. The cards will contain:

lattitude degrees, minutes, seconds
longitude degrees, minutes, seconds

FR - Indicates that the next card will contain the frequency in kHz.

BR - Indicates that the next card will specify the bearing from the transmitter site, the field at one kilometer from the antenna, the conductivity profile along a radial taken in the direction specified from the transmitter site will then be read. The first card will contain:

bearing in degrees, field strength at one kilometer

The conductivity will be specified beginning at the transmitter site in the following way:

conductivity in mS/m, distance to next discontinuty in km

Cards of this type continue to be read until a value of 999999 is encountered for the distance to the next discontinuity.

EN - Indicates the end of the data set.

A sample data set is shown in Figure B1., and the resulting output is shown in Figure B2.

```
CM    WCKL 560 KHZ, CATSKILL, NY DAYTIME PATTERN
CM    3 ELEMENT DIRECTIONAL ARRAY
CM
CM     ARRAY INPUT POWER :   1.00 KW
CM
CM     K FACTOR =   316.568604
CM     THEORETICAL ERMS =   316.679199 MV/M @ 1KM ( INCLUDING LOSS )
TL
42.0, 12.0, 0.0
73.0, 50.0, 7.0
PL
41.0, 12.0, 24.0
77.0, 2.0, 46.0
FR
560.0
CL
0.5
999999
BR
0.00, 501.528809
4.0, 999999
BR
10.00, 419.412598
4.0, 999999
BR
20.00, 329.198975
4.0, 999999
BR
30.00, 237.846268
4.0, 999999
BR
40.00, 152.973434
4.0, 999999
BR
50.00,  81.658371
4.0, 999999
BR
60.00,  29.134094
4.0, 999999
BR
70.00,   2.208762
4.0, 999999
BR
80.00,  13.194660
4.0, 999999
BR
90.00,   7.506421
4.0, 999999
BR
100.00,  9.244386
4.0, 999999
BR
110.00, 30.699310
4.0, 999999
BR
120.00. 50.873703
4.0, 999999
BR
130.00, 65.001801
4.0, 999999
BR
140.00, 70.055801
4.0, 999999
BR
150.00, 65.001801
4.0, 999999
BR
160.00, 50.873703
4.0, 999999
BR
170.00, 30.699310
4.0, 999999
BR
180.00,  9.244386
4.0, 999999
BR
190.00,  7.506421
4.0, 999999
BR
200.00, 13.194660
4.0, 999999
BR
210.00,  2.208762
4.0, 999999
BR
220.00, 29.134094
4.0, 999999
BR
230.00, 81.658371
4.0, 999999
BR
240.00, 152.973434
4.0, 999999
BR
250.00, 237.846268
4.0, 999999
BR
260.00, 329.198975
4.0, 999999
BR
270.00, 419.412598
4.0, 999999
BR
280.00, 501.528809
4.0, 999999
BR
290.00, 570.036133
4.0, 999999
BR
300.00, 621.126465
4.0, 999999
BR
310.00, 652.523926
4.0, 999999
BR
320.00, 663.099609
4.0, 999999
BR
330.00, 652.523926
4.0, 999999
BR
340.00, 621.126465
4.0, 999999
BR
350.00, 570.036133
4.0, 999999
EN
```

Figure B1. Sample Input Deck

FILE: SCAT OUTPUT B VM/SP CONVERSATIONAL MONITOR SYSTEM PAGE 00001

INTERFERING TRANSMITTER LOCATION

LATITUDE : 42. 12. 0.000 N
LONGITUDE : 73. 50. 7.000 W

PROPOSED NEW TRANSMITTER LOCATION

LATITUDE : 41. 12. 24.000 N
LONGITUDE : 77. 2. 46.000 W

FREQUENCY : 560.0 KHZ

****

PROTECTED CONTOUR LEVEL : 0.500000 MV/M

BEARING	FIELD @ KM	RADIUS	LATITUDE			LONGITUDE			DIST	BEARING
0.0	501.53	120.872	43.	17.	13.06	73.	50.	7.00	351.196	44.895
10.0	419.41	112.481	43.	11.	45.20	73.	35.	39.68	360.201	51.289
20.0	329.26	101.820	43.	3.	34.64	73.	24.	24.04	363.998	56.760
30.0	237.85	88.690	42.	53.	21.95	73.	17.	27.61	362.118	60.158
40.0	152.97	72.798	42.	42.	0.26	73.	15.	45.71	354.178	61.316
50.0	81.66	53.551	42.	30.	30.45	73.	20.	5.49	339.720	60.029
60.0	29.13	29.065	42.	19.	49.00	73.	31.	44.75	317.298	57.991
70.0	2.21	1.384	42.	12.	15.32	73.	49.	10.16	289.912	54.584
80.0	13.19	15.504	42.	13.	26.62	73.	38.	59.50	303.741	59.270
90.0	7.51	8.615	42.	11.	59.83	73.	43.	50.53	296.564	59.244
100.0	9.24	10.884	42.	10.	58.55	73.	42.	18.73	297.869	59.745
110.0	30.70	30.117	42.	6.	21.69	73.	29.	32.05	311.745	62.459
120.0	50.87	41.300	42.	0.	48.55	73.	24.	8.56	315.929	64.719
130.0	65.00	47.419	41.	55.	30.21	73.	23.	49.42	313.976	66.477
140.0	70.06	49.384	41.	51.	32.98	73.	27.	7.21	307.831	67.564
150.0	65.00	47.419	41.	49.	49.25	73.	32.	56.88	299.285	67.765
160.0	50.87	41.300	41.	51.	3.15	73.	39.	53.10	290.443	66.847
170.0	30.70	30.117	41.	55.	59.75	73.	46.	19.41	284.095	64.569
180.0	9.24	10.884	42.	0.	7.66	73.	50.	7.00	284.732	60.604
190.0	7.51	8.615	42.	2.	25.34	73.	51.	12.29	284.131	60.035
200.0	13.19	15.504	42.	4.	8.28	73.	53.	58.25	278.511	60.913
210.0	2.21	1.384	42.	11.	21.19	73.	50.	37.24	267.448	64.732
220.0	29.13	29.065	41.	59.	58.11	74.	3.	40.85	263.369	71.437
230.0	81.66	53.551	41.	53.	21.86	74.	19.	50.95	238.375	72.331
240.0	152.97	72.798	41.	52.	12.55	74.	35.	47.86	216.814	70.921
250.0	237.85	88.690	41.	55.	22.08	74.	50.	33.28	199.879	67.255
260.0	329.26	101.820	42.	2.	4.53	75.	2.	57.72	189.805	61.651
270.0	419.41	112.481	42.	11.	30.86	75.	12.	2.08	188.363	55.052
280.0	501.53	120.872	42.	22.	46.72	75.	17.	4.02	195.812	48.823
290.0	570.04	127.172	42.	34.	54.92	75.	17.	41.42	210.709	44.056
300.0	621.13	131.539	42.	46.	58.90	75.	13.	51.95	230.702	41.165
310.0	652.52	134.094	42.	58.	5.77	75.	5.	51.86	253.416	40.036
320.0	663.10	134.942	43.	7.	28.81	74.	54.	14.27	276.864	40.343
330.0	652.52	134.094	43.	14.	29.04	74.	39.	46.57	299.488	41.743
340.0	621.13	131.539	43.	18.	30.79	74.	23.	28.47	320.061	43.948
350.0	570.04	127.172	43.	19.	33.31	74.	6.	29.68	337.578	46.728

Figure B2. Sample Output

```
C*****************************************************************      PCM00010
C                                                                       PCM00020
C  AM BROADCAST MIXED PATH FIELD STRENGTH CONTOUR PROGRAM               PCM00030
C                                                                       PCM00040
C  THIS PROGRAM COMPUTES THE DISTANCE TO A SPECIFIED FIELD-STRENGTH     PCM00050
C  CONTOUR OVER PATHS WITH VARRYING CONDUCTIVITY. IT USES A NEWTONS     PCM00060
C  METHOD APPROXIMATION TO SOLVE THE INVERSE PROPAGATION PROBLEM.       PCM00070
C  THE GROUND WAVE FIELD STRENGTH VALUES ARE COMPUTED USING THE FCC     PCM00080
C  EQUIVALENT DISTANCE TECHNIQUE. THE LATTITUDE AND LONGITUDE OF THE    PCM00090
C  FIELD STRENGTH POINT ARE PROVIDED.                                   PCM00100
C                                                                       PCM00110
      IMPLICIT REAL*8 ( A-H, O-Z )                                      PCM00120
C                                                                       PCM00130
      COMMON / SIGPRO / DISTA(36,10), DISTB(36,10), SIGMA(36,10)        PCM00140
      COMMON / PATRN / BET(36), FIELD(36), NBR                          PCM00150
      COMMON / TLOC / TLATDG, TLATMN, TLATSC, TLNGDG, TLNGMN, TLNGSC,   PCM00160
     &   FREQ                                                           PCM00170
      COMMON / CLEVEL / CL(10), NCL                                     PCM00180
      COMMON / RADIUS / RAD(36,10)                                      PCM00190
      COMMON / CONST / PI, DTR, SMTKM, SMTNM                            PCM00200
      COMMON / INOUT / IN, IO                                           PCM00210
C                                                                       PCM00220
C  DEFINE INPUT AND OUTPUT DEVICES                                      PCM00230
C                                                                       PCM00240
      IN = 5                                                            PCM00250
      IO = 6                                                            PCM00260
C                                                                       PCM00270
C  INITIALIZE CONSTANTS                                                 PCM00280
C                                                                       PCM00290
      PI = 3.14159 26535 89793 23846 26433                              PCM00300
      DTR = PI / 180.00                                                 PCM00310
      SMTKM = 1.60934                                                   PCM00320
      SMTNM = 1. / 1.151626418                                          PCM00330
C                                                                       PCM00340
C  READ NECESSARY PARAMETERS IN INPUT SUBROUTINE                        PCM00350
C                                                                       PCM00360
      CALL INPUT                                                        PCM00370
C                                                                       PCM00380
C  LOOP OVER CONTOUR LEVELS                                             PCM00390
C                                                                       PCM00400
      DO 100, II = 1, NCL - 1                                           PCM00410
C                                                                       PCM00420
C  LOOP OVER VARIOUS BEARINGS                                           PCM00430
C                                                                       PCM00440
      DO 90, JJ = 1, NBR                                                PCM00450
C                                                                       PCM00460
      D = 0.0                                                           PCM00470
      I = 1                                                             PCM00480
C                                                                       PCM00490
C  IF PROPAGATING OVER WATER, CHANGE PERMITTIVITY TO 80.0               PCM00500
C                                                                       PCM00510
 40   IF ( SIGMA(JJ,I) .EQ. 5000.0 ) THEN                               PCM00520
        EPSILN = 80.0                                                   PCM00530
      ELSE                                                              PCM00540
        EPSILN = 15.0                                                   PCM00550
      ENDIF                                                             PCM00560
C                                                                       PCM00570
C  COMPUTE DISTANCE TO CL(II) CONTOUR USING SIGMA(JJ,I)                 PCM00580
C                                                                       PCM00590
      CALL CONTUR( FIELD(JJ), SIGMA(JJ,I), EPSILN, FREQ, DIST, CL(II) ) PCM00600
C                                                                       PCM00610
C  IF THE DISTANCE TO THE SPECIFIED CONTOUR IS GREATER THAN THE         PCM00620
C  DISTANCE TO THE DISCONTINUITY IN CONDUCTIVITY, THEN COMPUTE          PCM00630
C  THE FIELD STRENGTH AT THE DISCONTINUITY.                             PCM00640
C                                                                       PCM00650
      IF ( DIST .GT. DISTA(JJ,I) ) THEN                                 PCM00660
C                                                                       PCM00670
C     WRITE (IO,*) 'CONTOUR LEVEL = ',CL(II)                            PCM00680
C     WRITE (IO,*) 'DISTANCE TO CONTOUR = ',DIST/1.609344               PCM00690
C     WRITE (IO,*) 'USING SIGMA = ', SIGMA(JJ,I)                        PCM00700
C     WRITE (IO,*) 'DISCONTINUITY AT ',DISTA(JJ,I)/1.609344             PCM00710
C                                                                       PCM00720
        CALL FCCGM( FIELD(JJ), SIGMA(JJ,I), EPSILN, FREQ,               PCM00730
     &              DISTA(JJ,I), FS1, 0 )                               PCM00740
C                                                                       PCM00750
C     WRITE (IO,*) 'FS AT DISTA USING ABOVE SIGMA = ',FS1               PCM00760
C                                                                       PCM00770
        I = I + 1                                                       PCM00780
C                                                                       PCM00790
C  IF PROPAGATING OVER WATER CHANGE PERMITTIVITY TO 80.0                PCM00800
```

```
C
            IF ( SIGMA(JJ,I) .EQ. 5000.0 ) THE
               EPSILN = 80.0
            ELSE
               EPSILN = 15.0
            ENDIF
C
CCCCC  COMPUTE THE EFFECTIVE DISTANCE TO THE FIELD COMPUTED AT THE
CCCCC  DISCONTINUITY IN THE CONDUCTIVITY
CCCCC
CCCCC       WRITE (IO,*) 'FOR SIGMA = ',SIGMA(JJ,I)
CCCCC
               CALL CONTUR( FIELD(JJ), SIGMA(JJ,I), EPSILN, FREQ, DIST, FS1 )
C
CCCCC  NOTE THE DIFFERENCE BETWEEN EFFECTIVE AND ACTUAL DISTANCES
CCCCC  ADJUST DISTA VALUE AND D TERM ACCORDINGLY
C
               D = D + ( DISTA(JJ,I-1) - DIST )
               DISTA(JJ,I) = DISTA(JJ,I) - D
C
CCCCC       WRITE (IO,*) 'EFFECTIVE DISTANCE TO ABOVE FS = ',DIST/1.609344
CCCCC       WRITE (IO,*) 'D FACTOR = ',D/1.609344
CCCCC       WRITE (IO,*)
C
               GOTO 40
            ELSE
C
CCCCC  ADJUST DISTANCE BY D TERM
CCCCC
CCCCC       WRITE ( IO, * ) 'DISTANCE TO FS CONTOUR = ',DIST/1.609
CCCCC       WRITE ( IO, * ) 'USING SIGMA = ',SIGMA(JJ,I)
C
               DIST = DIST + D
C
CCCCC       WRITE (IO,*) 'DISTANCE AFTER ADJUSTMENT = ',DIST/1.609
C
               RAD(JJ,II) = DIST
            ENDIF
C
CCC   RESTORE DATA TO DISTA ARRAY FOR NEXT CONTOUR LEVEL
C
            DO 80 K = 1, 10
 80         DISTA(JJ,K) = DISTB(JJ,K)
C
 90      CONTINUE
100      CONTINUE
C
CC    PROVIDE TEXT AND FILE OUTPUT OF DATA
C
         CALL OUTPUT
C
         END
C
CC*********************************************************************
CCC
CCC   INPUT - THIS SUBROUTINE READS THE CARDS CONTAINING THE INFORMATION
CCC   REQUIRED FOR PCLL1.
CCC
         SUBROUTINE INPUT
C
         IMPLICIT REAL*8 ( A-H, O-Z )
C
         CHARACTER * 2 CARD
C
         COMMON / SIGPRO / DISTA (36,10), DISTB (36,10), SIGMA(36,10)
         COMMON / PATRN / BFT(36), FIELD(36), NBR
         COMMON / TLOC / TLATDG, TLATMN, TLATSC, TLNGDG, TLNGMN, TLNGSC,
        &   FREQ
         COMMON / PLOC / PLATDG, PLATMN, PLATSC, PLNGDG, PLNGMN, PLNGSC
         COMMON / CLEVEL / CL(10), NCL
         COMMON / INOUT / IN, IO
C
CC    INITIALIZE VARIABLES
CC
         NBR = 0
         NCL = 0
C
CC    INITIALIZE ARRAYS
CC
         DO 5, J = 1, 36
```

```
            BFT(J) = 0.0                                                    PCM01610
            FIELD(J) = 0.0                                                  PCM01620
         DO 4, I = 1, 10                                                    PCM01630
            DISTA(J,I) = 0.0                                                PCM01640
            DISTB(J,I) = 0.0                                                PCM01650
            SIGMA(J,I) = 0.0                                                PCM01660
 4       CONTINUE                                                           PCM01670
 5       CONTINUE                                                           PCM01680
C                                                                           PCM01690
 10      READ ( IN, 1000 ) CARD                                             PCM01700
         IF ( CARD .EQ. 'CM' ) GOTO 10                                      PCM01710
C                                                                           PCM01720
         IF ( CARD .EQ. 'CL' ) THEN                                         PCM01730
 20         NCL = NCL + 1                                                  PCM01740
            READ ( IN, * ) CL(NCL)                                          PCM01750
            IF ( CL(NCL) .EQ. 999999 ) THEN                                 PCM01760
               GOTO 10                                                      PCM01770
            ELSE                                                            PCM01780
               GOTO 20                                                      PCM01790
            ENDIF                                                           PCM01800
         ENDIF                                                              PCM01810
C                                                                           PCM01820
         IF ( CARD .EQ. 'TL' ) THEN                                         PCM01830
            READ ( IN, * ) TLATDG, TLATMN, TLATSC                           PCM01840
            READ ( IN, * ) TLNGDG, TLNGMN, TLNGSC                           PCM01850
         ENDIF                                                              PCM01860
C                                                                           PCM01870
         IF ( CARD .EQ. 'PL' ) THEN                                         PCM01880
            READ ( IN, * ) PLATDG, PLATMN, PLATSC                           PCM01890
            READ ( IN, * ) PLNGDG, PLNGMN, PLNGSC                           PCM01900
         ENDIF                                                              PCM01910
C                                                                           PCM01920
         IF ( CARD .EQ. 'FR' ) THEN                                         PCM01930
            READ ( IN, * ) FREQ                                             PCM01940
            FREQ = FREQ / 1000.0                                            PCM01950
         ENDIF                                                              PCM01960
C                                                                           PCM01970
         IF ( CARD .EQ. 'BR' ) THEN                                         PCM01980
            J = 1                                                           PCM01990
            NBR = NBR + 1                                                   PCM02000
            READ ( IN, * ) BFT(NBR), FIELD(NBR)                             PCM02010
 30         READ ( IN, * ) SIGMA(NBR,J), DISTA(NBR,J)                       PCM02020
            DISTB(NBR,J) = DISTA(NBR,J)                                     PCM02030
            IF ( DISTA(NBR,J) .EQ. 999999 ) THEN                            PCM02040
               GOTO 10                                                      PCM02050
            ELSE                                                            PCM02060
               J = J + 1                                                    PCM02070
               GOTO 30                                                      PCM02080
            ENDIF                                                           PCM02090
         ENDIF                                                              PCM02100
C                                                                           PCM02110
         IF ( CARD .EQ. 'EN' ) THEN                                         PCM02120
            RETURN                                                          PCM02130
         ELSE                                                               PCM02140
            GOTO 10                                                         PCM02150
         ENDIF                                                              PCM02160
C                                                                           PCM02170
1000     FORMAT ( A2 )                                                      PCM02180
C                                                                           PCM02190
         END                                                                PCM02200
C                                                                           PCM02210
C*************************************************************************  PCM02220
C                                                                           PCM02230
C  OUTPUT - THIS SUBROUTINE PROVIDES THE TEXT AND FILE OUTPUT FOR           PCM02240
C  PCMLL1.                                                                  PCM02250
C                                                                           PCM02260
         SUBROUTINE OUTPUT                                                  PCM02270
C                                                                           PCM02280
         IMPLICIT REAL*8 ( A-H, O-Z )                                       PCM02290
C                                                                           PCM02300
         COMMON / SIGPRO / DISTA(36,10), DISTB(36,10), SIGMA(36,10)         PCM02310
         COMMON / PATRN / BFT(36), FIELD(36), NBR                           PCM02320
         COMMON / TLOC / TLATDG, TLATMN, TLATSC, TLNGDG, TLNGMN, TLNGSC,    PCM02330
        &    FREQ                                                           PCM02340
         COMMON / PLOC / PLATDG, PLATMN, PLATSC, PLNGDG, PLNGMN, PLNGSC     PCM02350
         COMMON / CLEVEL / CL(10), NCL                                      PCM02360
         COMMON / RADIUS / RAD(36,10)                                       PCM02370
         COMMON / CONST / PI, DTR, SMTKM, SMTNM                             PCM02380
         COMMON / INOUT / IN, IO                                            PCM02390
C                                                                           PCM02400
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C  WRITE TRANSMITTER LOCATION, FREQUENCY                                    PCM02410
C                                                                          PCM02420
      WRITE ( IO, 1000 ) TLATDG, TLATMN, TLATSC, TLNGDG, TLNGMN, TLNGSC    PCM02430
 1000 FORMAT ( /, 16X, 'INTERFERING TRANSMITTER LOCATION',/                PCM02440
     &   ' LATTITUDE :', 5X, F5.0, 5X, F3.0, 5X, F6.3, 2X, 'N',/           PCM02450
     &   ' LONGITUDE :', 5X, F5.0, 5X, F3.0, 5X, F6.3, 2X, 'W' )           PCM02460
      WRITE ( IO, 1005 ) PLATDG, PLATMN, PLATSC, PLNGDG, PLNGMN, PLNGSC    PCM02470
 1005 FORMAT ( /, 16Y, 'PROPOSED NEW TRANSMITTER LOCATION',/               PCM02480
     &   ' LATTITUDE :', 5X, F5.0, 5X, F3.0, 5X, F6.3, 2X, 'N',/           PCM02490
     &   ' LONGITUDE :', 5X, F5.0, 5X, F3.0, 5X, F6.3, 2X, 'W' )           PCM02500
      WRITE ( IO, 1010 ) FREQ * 1000.0                                     PCM02510
 1010 FORMAT ( /, ' FREQUENCY : ', 2X, F6.1, 2X, 'KHZ' )                   PCM02520
C                                                                          PCM02530
C  CONVERT LATTITUDE AND LONGITUDE TO DECIMAL EQUIVALENT                   PCM02540
C                                                                          PCM02550
      TLAT =  TLATDG + TLATMN / 60.0 + TLATSC / 3600.0                     PCM02560
      TLNG =  TLNGDG + TLNGMN / 60.0 + TLNGSC / 3600.0                     PCM02570
C                                                                          PCM02580
      PLAT = PLATDG + PLATMN / 60.0 + PLATSC / 3600.0                      PCM02590
      PLNG = PLNGDG + PLNGMN / 60.0 + PLNGSC / 3600.0                      PCM02600
C                                                                          PCM02610
C LOOP OVER CONTOUR LEVELS                                                 PCM02620
C                                                                          PCM02630
      DO 100, II = 1, NCL - 1                                              PCM02640
C                                                                          PCM02650
C  WRITE OUT CONTOUR LEVEL                                                 PCM02660
C                                                                          PCM02670
      WRITE ( IO, 1020 )                                                   PCM02680
 1020 FORMAT ( /, 80 ( '*' ), / )                                          PCM02690
      WRITE ( IO, 1030 ) CL(II)                                            PCM02700
 1030 FORMAT ( ' PROTECTED CONTOUR LEVEL : ', F12.6, 2X, 'MV/M' )          PCM02710
      WRITE ( IO, 1040 )                                                   PCM02720
 1040 FORMAT ( //, ' BEARING', 5X, 'FIELD @ KM', 5X, 'RADIUS', 9X,         PCM02730
     &          'LATTITUDE', 14X, 'LONGITUDE',                            PCM02740
     &          10X, 'DIST', 10X, 'BEARING' )                             PCM02750
C                                                                          PCM02760
C  LOOP OVER BEARINGS                                                      PCM02770
C                                                                          PCM02780
      DO 90, JJ = 1, NBR                                                   PCM02790
C                                                                          PCM02800
C  COMPUTE LATTITUDE AND LONGITUDE OF CONTOUR POINT                        PCM02810
C                                                                          PCM02820
      B1 = 90.0 - TLAT                                                     PCM02830
      R1 = RAD(JJ,II) / SMTKM * SMTNM / 60.0                               PCM02840
C                                                                          PCM02850
      A1 = ACOS ( COS( DTR * B1 ) * COS( DTR * R1 ) + SIN( DTR * B1 ) *    PCM02860
     &   SIN( DTR * R1 ) * COS( DTR * BFT(JJ) ) ) / DTR                    PCM02870
C                                                                          PCM02880
      CLAT = 90.0 - A1                                                     PCM02890
      CLNG =  - ASIN( SIN( DTR * R1 ) *                                    PCM02900
     &   SIN( DTR * BFT(JJ) ) / SIN( DTR * A1 ) ) / DTR  + TLNG            PCM02910
C                                                                          PCM02920
C  COMPUTE BEARING AND DISTANCE OF CONTOUR POINT FROM PROPOSED SITE        PCM02930
C                                                                          PCM02940
      G = CLNG - PLNG                                                      PCM02950
      A2 = 90.0 - PLAT                                                     PCM02960
      B2 = 90.0 - CLAT                                                     PCM02970
      C2 = ACOS ( COS( DTR * A2 ) * COS( DTR * B2 ) +                      PCM02980
     &     SIN( DTR * A2 ) * SIN( DTR * B2 ) * COS( DTR * G ) ) / DTR      PCM02990
C                                                                          PCM03000
      RPLPC = C2 * 60.0 * SMTKM / SMTNM                                    PCM03010
      THETA = - ASIN( SIN( DTR * G ) *  SIN( DTR * A2 ) /                  PCM03020
     &                  SIN( DTR * C2 )  ) / DTR                           PCM03030
      U = SIGN( 1.D0, THETA )                                              PCM03040
      V = SIGN( 1.D0, (CLAT-PLAT) )                                        PCM03050
      IF ( U .GT. 0 ) THEN                                                 PCM03060
         IF ( V .GT. 0 ) THEN                                              PCM03070
            RPLPC = THETA                                                  PCM03080
         ELSE                                                              PCM03090
            RPLPC = 180.0 - THETA                                          PCM03100
         ENDIF                                                             PCM03110
      ELSE                                                                 PCM03120
         IF ( V .GT. 0 ) THEN                                              PCM03130
            RPLPC = THETA + 360.0                                          PCM03140
         ELSE                                                              PCM03150
            RPLPC = 180.0 - THETA                                          PCM03160
         ENDIF                                                             PCM03170
      ENDIF                                                                PCM03180
C                                                                          PCM03190
C  CONVERT TO DEGREES, MINUTES, SECONDS                                    PCM03200
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C                                                                       PCM03210
      CLATDG = AINT ( CLAT )                                            PCM03220
      CLATMN = AINT ( ( CLAT - CLATDG ) * 60.0 )                        PCM03230
      CLATSC = ( CLAT - CLATDG - CLATMN / 60.0 ) * 3600.0               PCM03240
C                                                                       PCM03250
      CLNGDG = AINT ( CLNG )                                            PCM03260
      CLNGMN = AINT ( ( CLNG - CLNGDG ) * 60.0 )                        PCM03270
      CLNGSC = ( CLNG - CLNGDG - CLNGMN / 60.0 ) * 3600.0               PCM03280
C                                                                       PCM03290
C  WRITE OUT DATA FOR EACH BEARING                                      PCM03300
C                                                                       PCM03310
      WRITE ( 10, 1050 ) BRT(JJ), FIELD(JJ), RAD(JJ,II),               PCM03320
     &   CLATDG, CLATMN, CLATSC, CLNGDG, CLNGMN, CLNGSC,               PCM03330
     &   RPLPC, BPLPC                                                   PCM03340
C                                                                       PCM03350
 1050 FORMAT ( 3X, F5.1, 5X, F7.2, 5X, F8.3,                            PCM03360
     &         2 ( 5X, F4.0, 3X, F3.0, 3X, F5.2 ),                      PCM03370
     &         5X, F8.3, 5X, F8.3 )                                     PCM03380
C                                                                       PCM03390
   90 CONTINUE                                                          PCM03400
  100 CONTINUE                                                          PCM03410
C                                                                       PCM03420
      END                                                               PCM03430
C                                                                       PCM03440
C***********************************************************************PCM03450
C                                                                       PCM03460
C  CONTOR - COMPUTES THE DISTANCE TO A SPECIFIED FIELD STRENGTH CONTOUR  PCM03470
C  USING AN ITERATIVE NEWTON TECHNIQUE WITH THE FCC GROUND WAVE         PCM03480
C  FIELD STRENGTH PROGRAM.                                              PCM03490
C                                                                       PCM03500
      SUBROUTINE CONTOR ( FIELDO, SIGMA, EPSILN, FREQ, DIST, FS )       PCM03510
C                                                                       PCM03520
      IMPLICIT REAL*8 ( A-H, O-Z )                                      PCM03530
C                                                                       PCM03540
C  INITIALIZE COUNTER, AND SOLUTION TYPE FOR FCCGW                      PCM03550
C  IST = 0 - NORMAL SOLUTION USING MOST EFFICIENT METHOD                PCM03560
C  IST = 1 - RESIDUE SUM SOLUTION TO GIVE ACCURACY IN BULGE REGION      PCM03570
C                                                                       PCM03580
      I = 0                                                             PCM03590
      IST = 0                                                           PCM03600
C                                                                       PCM03610
C  SET INITIAL GUESS FOR DISTANCE TO DESIRED CONTOUR.                   PCM03620
C                                                                       PCM03630
      DIST = 10                                                         PCM03640
C                                                                       PCM03650
C  EVALUATE FIELD STRENGTH AT ASSUMED DISTANCE, AND A NEARBY POINT      PCM03660
C  SO THE SLOPE CAN BE COMPUTED.                                        PCM03670
C                                                                       PCM03680
   10 CALL FCCGW ( FIELDO, SIGMA, EPSILN, FREQ, DIST, FS1, IST )        PCM03690
      DIST1 = DIST + DIST * 0.00001                                     PCM03700
      CALL FCCGW ( FIELDO, SIGMA, EPSILN, FREQ, DIST1, FS2, IST )       PCM03710
C                                                                       PCM03720
C  CHECK TO SEE IF THE FIELD STRENGTH VALUE IS WITHIN TOLERANCE.        PCM03730
C  IF IT IS, THEN RETURN TO CALLING PROGRAM WITH DISTANCE.              PCM03740
C  IF IT IS NOT, THEN COMPUTE NEW GUESS FOR DISTANCE.                   PCM03750
C                                                                       PCM03760
      I = I + 1                                                         PCM03770
C                                                                       PCM03780
      IF ( ABS ( FS1 - FS ) .GT. 1.E-9 ) THEN                           PCM03790
      DISTN = DIST - ( FS1 - FS ) * ( DIST * 0.00001 ) / ( FS2 - FS1 )  PCM03800
C                                                                       PCM03810
      WRITE ( 6, * ) I,FS1-FS, DISTN                                    PCM03820
C                                                                       PCM03830
C  AVOID CONVERGERENCE PROBLEM WHEN DISTANCE IS CLOSE TO THE            PCM03840
C  CROSSOVER POINT FROM CORRECTION TERM SOLUTION TO RESIDUE SUM         PCM03850
C  SOLUTION.                                                            PCM03860
C                                                                       PCM03870
      IF ( INT( DSTN2 * 1E8 ) .EQ. INT( DISTN * 1E8 ) ) IST = 1         PCM03880
         IST = 1                                                        PCM03890
C                                                                       PCM03900
      IF ( ( I / 3. ) .EQ. INT( I / 3. ) ) DSTN2 = DISTN                PCM03910
C                                                                       PCM03920
C  WE MUST AVOID GUESSING DISTANCES THAT ARE LESS THAN OR EQUAL TO ZERO.PCM03930
C                                                                       PCM03940
         IF ( DISTN .LE. 0.0 ) THEN                                     PCM03950
            DIST = DIST / 2.0                                           PCM03960
         ELSE                                                           PCM03970
            DIST = DISTN                                                PCM03980
         ENDIF                                                          PCM03990
C                                                                       PCM04000
```

```
      GOTO 10
      ENDIF
C
C     WRITE ( 6, * ) I, FS1-FS, DIST
C
      RETURN
      END
C
C
C*********************************************************************
C
C  FCCGW - CALCULATED THE GROUND-WAVE FIELD STRENGHT FOR VERTICALLY
C  POLARIZED MF WAVES.
C
      SUBROUTINE FCCGW ( FIELDO, SIGMA, EPSILN, FREQ, DIST, FIELD, IST )
C
      IMPLICIT REAL*8 ( A-H, O-Z )
C
      REAL*8 K
C
      DATA PI / 3.1415927 /
C
C  DEFINE INPUT AND OUTPUT UNITS.
C
      COMMON  / INOUT / IN, IO
C
C  EVALUATE CONSTANTS REQUIRED BY MAJOR SUBROUTINES.
C
      CALL GWCNST(
     &   SIGMA, EPSILN, FREQ, DIST,
     &   P, B, K, CHI )
C
C  SET DISTANCE BEYOND WHICH TO USE RESIDUE SERIES.
C
      FAR = 80. / FREQ ** ( 1 / 3.0 )
C
C  CALCULATE GROUND-WAVE ATTENUATION BY APPROPRIATE METHOD.
C  IST ALLOWS SOLUTION TO BE FORCED TO RESIDUE SERIES METHOD TO
C  PREVENT CONVERGENCE PROBLEMS IN SUBROUTINE CONTUR.
C
      IF ( ( DIST .LE. FAR ) .AND. ( IST .EQ. 0 ) ) THEN
         CALL SURFAC ( P, B, K, A )
      ELSE
         PSI = 0.5 * B
         CALL RESIDU ( CHI, K, PSI, A )
      ENDIF
C
C  MULTIPLY INVERSE-DISTANCE FIELD THE ATTENUATION.
C  (160.93440 MV/M AT 1 KM = 100 MV/M AT 1 MILE)
C
      FIELD = A * FIELDO / DIST
C
      RETURN
      END
C
C
C*************************************************************
C
C  GWCNST - SET GROUNDWAVE CONSTANTS. THE INDEPENDENT VARIABLES
C  PASSED AS ARGUMENTS OF THIS SUBROUTINE ARE:
C
C     SIGMA, THE GROUND CONDUCTIVITY IN MILLISIEMENS/METER
C     EPSILN, THE RELATIVE DIELECTRIC CONSTANT (1.0 FOR AIR)
C     FREQ, THE FREQUENCY IN MHZ
C     DIST, RADIO PATH LENGTH IN KILOMETERS
C
C  QUANTITIES CALCULATED IN THIS SUBROUTINE AND RETURNED ARE:
C
C     P, AMPLITUDE OF THE COMPLEX NUMERICAL DISTANCE INTRODUCED
C     FOR THE SOLUTION OF RADIO PROPAGATION PROBLEMS BY ARNOLD
C     SOMMERFELD IN 1909.
C
C     B, PHASE ANGLE OF THE NUMERICAL DISTANCE
C
C     K, A DIMENSIONLESS PARAMETER PROPORTIONAL TO THE CUBE-
C     ROOT OF THE RATIO OF WAVELENGTH TO THE EFFECTIVE EARTH
C     RADIUS, AND DEPENDENT ALSO UPON THE GROUND CONSTANTS
C
C     CHI, A DIMENSIONLESS PARAMETER PROPORTIONAL TO THE CUBE-
C     ROOT OF THE EFFECTIVE EARTH RADIUS MEASURED IN WAVELENGTHS,
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C     AND PROPORTIONAL ALSO TO THE RADIO PATH DISTANCE MEASURED          PCM04810
C     AS THE ANGLE SUBTENDED FROM THE CENTER OF THE EARTH.               PCM04820
C                                                                        PCM04830
C  USE OF THE SYMBOLS P AND B FOR THE AMPLITUDE AND PHASE OF             PCM04840
C  THE NUMERICAL DISTANCE FOLLOWS NORTON, PROC. IRE 1941.                PCM04850
C                                                                        PCM04860
C  THE SYMBOL K IS USED TO DENOTE EXACTLY THE SAME QUANTITY IN           PCM04870
C  NBS TECH NOTE 101, IN NORTON'S 1941 IRE PAPER AND IN THE              PCM04880
C  1949 BOOK BY BREMMER.  SEE REFERENCE BELOW.                           PCM04890
C                                                                        PCM04900
C  CHI IS USED IN EVALUATING THE RESIDUE SERIES. THE GREEK LETTER        PCM04910
C  OF THAT NAME WAS USED FOR THIS QUANTITY BY BREMMER IN HIS 1949        PCM04920
C  BOOK.                                                                 PCM04930
C                                                                        PCM04940
C  REFERENCES:                                                           PCM04950
C                                                                        PCM04960
C     K. A. NORTON, THE CALCULATION OF GROUND-WAVE FIELD                 PCM04970
C     INTENSITY OVER A FINITELY CONDUCTING SPHERICAL EARTH,              PCM04980
C     PROC. IRE, DEC 1941, PAGES 623-639.                                PCM04990
C                                                                        PCM05000
C     H. BREMMER, TERESTRIAL RADIO WAVES, ELSEVIER                       PCM05010
C     PUBLISHING CO., 1949.                                              PCM05020
C                                                                        PCM05030
C***********************************************************           PCM05040
C                                                                        PCM05050
      SUBROUTINE GNCNST(                                                 PCM05060
     &   SIGMA, EPSILN, FREQ, DIST,                                      PCM05070
     &   P, B, K, CHI )                                                 PCM05080
C                                                                        PCM05090
      IMPLICIT REAL*8 ( A-H, O-Z )                                       PCM05100
      REAL*8 K                                                           PCM05110
C                                                                        PCM05120
      DATA PI / 3.1415927 /                                              PCM05130
C  RADIUS OF EARTH IN KILOMETERS.                                        PCM05140
      DATA EARTHR /6370. /                                               PCM05150
C  ASSUMED EFFECTIVE EARTH RADIUS FACTOR.                                PCM05160
      DATA FACTOR / 1.333333333333333 /                                  PCM05170
C                                                                        PCM05180
C  SPEED OF LIGHT IN AIR (REFACTIVE INDEX 1.00031) KM/SEC.               PCM05190
C                                                                        PCM05200
      DATA SPEED / 299700. /                                             PCM05210
C                                                                        PCM05220
C  BEGIN EXECUTION. DETERMINE EFFECTIVE EARTH RADIUS FROM                PCM05230
C  GIVEN EARTH RADIUS FACTOR.                                            PCM05240
C                                                                        PCM05250
      EFFRAD = FACTOR * EARTHR                                           PCM05260
C                                                                        PCM05270
C  FIND WAVELENGTH. DISTANCE AND THE EFFECTIVE EARTH RADIUS WILL         PCM05280
C  BE DIVDED BY WAVELENGTH TO PRODUCE DIMENSIONLESS QUANTITIES.          PCM05290
C                                                                        PCM05300
      WAVLGT = SPEED / ( 1E6 * FREQ )                                    PCM05310
C                                                                        PCM05320
C  INTERMEDIATE VARIABLES X, B1 AND B2 ARE DERIVED FROM THE              PCM05330
C  GROUND CONSTANTS BY FORMULAS THAT APPEAR IN NORTON, PROC.             PCM05340
C  IRE, 1941.                                                            PCM05350
C                                                                        PCM05360
      X = 17.97 * SIGMA / FREQ                                           PCM05370
      B1 = ATAN2( EPSILN - 1, X )                                        PCM05380
      B2 = DATAN2( EPSILN, X )                                           PCM05390
C                                                                        PCM05400
C  CALCULATION OF NUMERICAL DISTANCE, P, AND ITS PHASE ANGLE, B          PCM05410
C                                                                        PCM05420
      P = PI * ( DIST / WAVLGT ) * COS( B2 ) ** 2                        PCM05430
     &   / ( X * COS( B1 ) )                                             PCM05440
      B = 2 * B2 - B1                                                    PCM05450
C                                                                        PCM05460
C  CALCULATION OF K.  SEE NORTON, PROC. IRE, DEC 1941, PAGE 628.         PCM05470
C                                                                        PCM05480
      K = ( WAVLGT /                                                     PCM05490
     &   ( 2 * PI * EFFRAD ) ) ** ( 1./3. )                             PCM05500
     &   * SQRT( X * COS( B1 ) ) / COS( B2 )                            PCM05510
C                                                                        PCM05520
C  CALCULATION OF CHI. CONFER BREMMER, TERRESTRIAL RADIO WAVES,          PCM05530
C  PAGE 49, EQUATION (III, 31).                                          PCM05540
C                                                                        PCM05550
      CHI = DIST /EFFRAD *                                               PCM05560
     &   ( 2 * PI * EFFRAD /WAVLGT ) ** (1./3.)                         PCM05570
C                                                                        PCM05580
      RETURN                                                             PCM05590
      END                                                                PCM05600
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C                                                                       PCM05610
C***********************************************************          PCM05620
C                                                                       PCM05630
C  SURFAC - CALCULATION OF SURFACE WAVE ATTENUATION. THE                PCM05640
C  FLAT EARTH VALUE IS FOUND BY THE USUAL FORMULA DUE TO A.             PCM05650
C  SOMMERFELD.  CORRECTIONS FOR CURVED EARTH ARE THEN APPLIED.          PCM05660
C  THE CURVED EARTH CORRECTIONS ARE FROM H. BREMMER, APPLICATIONS       PCM05670
C  OF THE OPERATIONAL CALCULUS TO GROUND-WAVE PROPAGATION,              PCM05680
C  PARTICULARLY FOR LONG WAVES, IRE TRANSACTIONS ON ANTENNAS            PCM05690
C  AND PROPAGATION, JULY 1958.                                          PCM05700
C                                                                       PCM05710
C  INPUTS ARE THE NUMERICAL DISTANCE, P, ITS PHASE, B, AND              PCM05720
C  THE PARAMETER K.  THE PARAMETER K (SO DENOTED BY NORTON              PCM05730
C  AND IN NBS TECH NOTE 101) CARRIES INFORMATION CONCERNING             PCM05740
C  THE EFFECTIVE EARTH RADIUS SO THAT SPHERICAL EARTH                   PCM05750
C  CORRECTIONS CAN BE APPLIED.                                          PCM05760
C                                                                       PCM05770
C  OUTPUT IS THE ATTENUATION FACTOR, A, THE MAGNITUDE OF THE            PCM05780
C  RATIO OF THE GROUND-WAVE FIELD TO THE FIELD PRODUCED BY              PCM05790
C  THE SAME ANTENNA OVER A PERFECTLY CONDUCTING FLAT EARTH.             PCM05800
C                                                                       PCM05810
C***********************************************************          PCM05820
C                                                                       PCM05830
      SUBROUTINE SURFAC( P, B, K, A )                                   PCM05840
C                                                                       PCM05850
      IMPLICIT REAL*8 ( A-H, O-Y ),                                     PCM05860
     &          COMPLEX*16 ( Z )                                        PCM05870
      COMPLEX*16 DEL, RHO, ERFC, SRS1, SRS2                             PCM05880
      REAL*8  K                                                         PCM05890
C                                                                       PCM05900
      DATA PI / 3.1415927 /                                             PCM05910
C                                                                       PCM05920
C  SPHERICAL EARTH CORRECTION FORMULAS.  USE WHEN NUMERICAL             PCM05930
C  DISTANCE IS NOT CLOSE TO 0.  NOTICE FORMULAS ARE TO CASCADE          PCM05940
C  SO THAT THE LAST AUTOMATICALLY USES THOSE PREVIOUS, THEY             PCM05950
C  ARE WRITTEN THIS WAY SO THAT THEY CAN BE EXAMINED SEPARATELY,        PCM05960
C  BUT DIRECT REFERENCE IN THE PROGRAM IS MADE ONLY TO THE               PCM05970
C  LAST FORMULA.                                                        PCM05980
C                                                                       PCM05990
C  ZA DENOTES THE SOMMERFELD FLAT-EARTH ATTENUATION WHICH MUST          PCM06000
C  BE CALCULATED SEPARATELY.                                            PCM06010
C                                                                       PCM06020
      ZADJ1( DEL, RHO, ZA ) = ZA                                        PCM06030
     &    + DEL ** 3 *                                                 PCM06040
     &    1./2 * ( ( 1 + 2 * RHO ) * ZA                                PCM06050
     &    - 1 - (0,1) * SQRT( PI * RHO ) )                             PCM06060
C                                                                       PCM06070
      ZADJ2( DEL, RHO, ZA ) = ZADJ1( DEL, RHO, ZA )                     PCM06080
     &    + DEL ** 6 *                                                 PCM06090
     &    ( ( 1./2 * RHO ** 2 - 1 ) * ZA                               PCM06100
     &    + (0,1) * SQRT( PI * RHO ) * ( 1 - RHO )                     PCM06110
     &    + 1 - 2 * RHO + 5./6 * RHO ** 2 )                            PCM06120
C                                                                       PCM06130
C  BEGIN EXECUTION.  CONVERT INPUT VARIABLES P, B TO COMPLEX FORM.      PCM06140
C  THE RESULTING COMPLEX VARIABLE, RHO, WILL ALWAYS BE IN THE           PCM06150
C  UPPER HALF-PLANE.                                                    PCM06160
C                                                                       PCM06170
      RHO = P * ( COS( B ) + (0,1) * SIN( B ) )                         PCM06180
C                                                                       PCM06190
C  THE COMPLEX PARAMETER DEL IS DETERMINED BY K AND THE ANGLE B.        PCM06200
C                                                                       PCM06210
      DEL = K *                                                         PCM06220
     &    ( COS ( 3*PI/4 - B/2 ) + (0,1) * SIN ( 3*PI/4 - B/2 ) )      PCM06230
C                                                                       PCM06240
C  FIND COMPLEX ATTENUATION FOR FLAT EARTH                              PCM06250
C                                                                       PCM06260
      CALL SOMMER( RHO, ZA )                                            PCM06270
C                                                                       PCM06280
C  ADJUST FOR SPHERICAL EARTH.  THE FUNCTIONS SRS1 AND SR2 ARE          PCM06290
C  POWER SERIES CORRESPONDING TO ZADJ1 AND ZADJ2 RESPECTIVELY.          PCM06300
C  WHEN RHO IS SMALL AND CONSEQUENTLY ZA IS NEAR UNITY, THE POWER       PCM06310
C  SERIES MUST BE USED.  ZADJ1 AND ZADJ2 ARE NOT ACCURATE UNDER         PCM06320
C  THESE CONDITIONS BECAUSE THE FORMULAS INVOLVE THE DIFFERENCE         PCM06330
C  BETWEEN ZA AND A NUMBER NEAR UNITY.                                  PCM06340
C                                                                       PCM06350
      IF ( ABS( RHO ) .GT. 0.5 ) THEN                                   PCM06360
         ZADJ = ZADJ2( DEL, RHO, ZA )                                   PCM06370
      ELSE                                                              PCM06380
         Z1 = (0,1) * SQRT( RHO )                                       PCM06390
         Z3 = ( DEL * Z1 ) ** 3                                         PCM06400
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```
            ZADJ = ZA - Z3 * ( SRS1( Z1 )
     &                - Z3 * ( SRS2( Z1 ) ) )
         ENDIF
C
CC   RETURN THE AMPLITUDE
C
         A = ABS( ZADJ )
         RETURN
C
         END
C
C*****************************************************************
C
CCCC SOMMER - CALCULATION OF THE SURFACE WAVE ATTENUATION
CCCC FACTOR FOR GIVEN NUMERICAL DISTANCE.  NUMERICAL
CCCC DISTANCE IS THE PARAMETER INTRODUCED BY A. SOMMERFELD
CCCC IN 1909 WHEN HE SHOWED HOW TO FIND THE FIELD OF A SHORT
CCCC DIPOLE RADIATING OVER A FINITELY CONDUCTING PLANE EARTH.
CCCC
CCCC INPUT IS THE NUMERICAL DISTANCE IN COMPLEX FORM, RHO.
CCCC
CCCC OUTPUT ZA IS THE COMPLEX SURFACE WAVE ATTENUATION FACTOR
CCCC FOR A FLAT EARTH.
CCCC
C*****************************************************************
C
         SUBROUTINE SOMMER( RHO, ZA )
C
         IMPLICIT REAL*8 ( A-H, O-P, U, V, Y ),
     &           COMPLEX*16 ( S, T, W, Z )
         COMPLEX *16 ERFC, RHO, RHOROT
C
         DATA PI / 3.1415927 /
C
CCCC COEFFICIENTS C1, D1 ETC. TO APPROXIMATE W-FUNCTION OF
CCCC LARGE MODULUS (M. ABRAMOWITZ AND I. STEGUN, HANDBOOK OF
CCCC MATHEMATICAL FUNCTIONS, NATIONAL BUREAU OF STANDARDS,
CCCC 1964, PAGE 328).
C
         DATA C1, C2, C3 / 0.4613135, 0.09999216, 0.002883894 /
         DATA D1, D2, D3 / 0.1901635, 1.7844927,  5.5253437 /
C
CCCC APPROXIMATION FORMULA FOR W-FUNCTION OF LARGE MODULUS.
CCCC ERROR LESS THAT 2 PARTS IN 1E6 PROVIDED THE ABSOLUTE
CCCC VALUE OF X EXCEEDS 3.9, OR Y > 3.
C
         W( Z ) = (0,1) * Z *
     &     ( C1 / ( Z ** 2 - D1 )
     &     + C2 / ( Z ** 2 - D2 )
     &     + C3 / ( Z ** 2 - D3 ) )
C
CCCC BEGIN EXECUTION.  THE NUMERICAL DISTANCE, AS A COMPLEX
CCCC VARIABLE, SHOULD ALWAYS BE FOUND IN THE UPPER HALF-PLANE.
CCCC CALCULATE ITS SQUARE ROOT, RHOROOT, WHICH WILL BE LOCATED
CCCC IN THE FIRST QUADRANT.
C
         IF ( IMAG( RHO ) .LT. 0 ) STOP
     &     'ERROR: COMPLEX NUMERICAL DISTANCE IN LOWER HALF-PLANE'
         RHOROT = SQRT( RHO )
C
CCC  DETERMINE MOST APPROPRIATE METHOD.
C
         IF ( REAL ( RHOROT ) .GT. 3.9
     &     .OR. IMAG( RHOROT ) .GT. 3.0 ) GOTO 300
         IF ( ABS( RHOROT ) .GT. 1 ) GOTO 200
C
CCC  POWER SERIES FOR SMALL RHO.  FOR ABS( RHO ) = 1 OR LESS,
CCC  THE I-TH TERM WILL BE LESS THAN 1E-35 IN MAGNITUDE AFTER
CCC  33 TERMS.
C
  100 CONTINUE
         TERM = 1
         SUM = 1
         DO 110 I = 1, 33
            TERM = -2 * RHO * TERM / ( 2 * I - 1 )
            SUM = SUM + TERM
            IF ( ABS( TERM ) .LT. ABS( SUM ) / 1E5 )
     &         GO TO 120
  110    CONTINUE
  120    ZA = SUM + (0,1) * SQRT( PI * RHO ) * EXP( -RHO )
```

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PCM06410
PCM06420
PCM06430
PCM06440
PCM06450
PCM06460
PCM06470
PCM06480
PCM06490
PCM06500
PCM06510
PCM06520
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PCM06690
PCM06700
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PCM06980
PCM06990
PCM07000
PCM07010
PCM07020
PCM07030
PCM07040
PCM07050
PCM07060
PCM07070
PCM07080
PCM07090
PCM07100
PCM07110
PCM07120
PCM07130
PCM07140
PCM07150
PCM07160
PCM07170
PCM07180
PCM07190
PCM07200
```

```
      RETURN                                                            PCM07210
C                                                                       PCM07220
C   WHEN RHOROT IS OUTSIDE THE UNIT CIRCLE BUT BELOW THE HORIZONTAL     PCM07230
C   LINE Y = 3.0 AND LEFT OF X = 3.9, CALCULATE THE COMPLEX SURFACE     PCM07240
C   ATTENUATION IN TERMS OF THE COMPLEMENTARY ERROR FUNCTION            PCM07250
C   THE LATTER IS TO BE EVALUATED AT -(0,1) * RHOROT, AND THE SERIES    PCM07260
C   OF SALZER PROVIDES A CLOSE APPROXIMATION.                           PCM07270
C                                                                       PCM07280
  200 CONTINUE                                                          PCM07290
      ERFC = SALZER( -(0,1) * RHOROT )                                  PCM07300
      ZA = 1 + (0,1) * SQRT( PI * RHO ) * EXP( -RHO ) * ERFC            PCM07310
      RETURN                                                            PCM07320
C                                                                       PCM07330
C   FOR ARGUMENTS WITH LARGE ABSOLUTE MAGNITUDE, COMPUTE THE            PCM07340
C   COMPLEX ATTENUATION FUNCTION IN TERMS OF THE W-FUNCTION              PCM07350
C   DESCRIBED IN ABRAMOWITZ.                                            PCM07360
C                                                                       PCM07370
  300 CONTINUE                                                          PCM07380
      ZA = 1 + (0,1) * SQRT( PI * RHO ) * W( RHOROT )                   PCM07390
      RETURN                                                            PCM07400
C                                                                       PCM07410
      END                                                               PCM07420
C                                                                       PCM07430
C*********************************************************************  PCM07440
C                                                                       PCM07450
C   SALZER -  COMPUTE THE COMPLEMENTARY ERROR FUNCTION OF               PCM07460
C   THE COMPLEX ARGUMENT, Z, USING THE METHOD DESCRIBED BY              PCM07470
C   H. E. SALZER, FORMULAS FOR CALCULATING THE ERROR FUNCTION           PCM07480
C   OF A COMPLEX VARIABLE, MATH. TABLES AND OTHER AIDS TO               PCM07490
C   COMPUTATION (JOURNAL PUBLISHED BY NATIONAL RESEARCH COUNCIL),       PCM07500
C   VOL. V, 1951. THE FORMULAS ALSO APPEAR IN ABRAMOWITZ AND            PCM07510
C   STEGUN, PAGE 299.                                                   PCM07520
C                                                                       PCM07530
C*********************************************************************  PCM07540
C                                                                       PCM07550
      FUNCTION SALZER( Z )                                              PCM07560
C                                                                       PCM07570
      IMPLICIT REAL*8 ( A-H, O-R, T-Y ),                                PCM07580
     &         COMPLEX*16 ( S, Z )                                      PCM07590
      COMPLEX*16 TEST                                                   PCM07600
C                                                                       PCM07610
      COMMON / INOUT / IN, IO                                           PCM07620
      DATA PI / 3.1415927 /                                             PCM07630
C                                                                       PCM07640
C   COEFFICIENTS P, AND A1, A1, ETC. TO APPROXIMATE ERROR               PCM07650
C   FUNCTION OF REAL ARGUMENT (C. HASTINGS, APPROXIMATIONS              PCM07660
C   FOR DIGITAL COMPUTERS, PRINCETON UNIV. PRESS, 1955 )                PCM07670
C                                                                       PCM07680
      DATA P, A1, A2, A3, A4, A5 / 0.3275911, 0.2548296,                PCM07690
     &     -0.2844967, 1.4214137, -1.4531520, 1.0614054 /               PCM07700
C                                                                       PCM07710
C   APPROXIMATION OF COMPLEMENTARY ERROR FUNCTION FOR REAL,             PCM07720
C   NON-NEGATIVE ARGUMENTS.                                             PCM07730
C                                                                       PCM07740
      T( X ) = 1/ ( 1 + P * X )                                         PCM07750
      REERFC( X ) =                                                     PCM07760
     &          T( X ) *                                                PCM07770
     &    ( A1 + T( X ) *                                               PCM07780
     &    ( A2 + T( X ) *                                               PCM07790
     &    ( A3 + T( X ) *                                               PCM07800
     &    ( A4 + T( X ) *                                               PCM07810
     &    ( A5 )))))                                                    PCM07820
     &    * EXP( - X ** 2 )                                             PCM07830
C                                                                       PCM07840
C   FUNCTIONS FOR APPROXIMATING ERF OF COMPLEX ARGUMENTS.               PCM07850
C                                                                       PCM07860
      F( X, Y, N ) = 2 * X                                              PCM07870
     &    - 2 * X * COSH ( N * Y ) * COS( 2 * X * Y )                   PCM07880
     &        + N * SINH ( N * Y ) * SIN( 2 * X * Y )                   PCM07890
      G( X, Y, N ) =                                                    PCM07900
     &     2 * X * COSH( N * Y ) * SIN( 2 * X * Y )                     PCM07910
     &       + N * SINH( N * Y ) * COS( 2 * X * Y )                     PCM07920
C                                                                       PCM07930
C   BEGIN EXECUTION.                                                    PCM07940
C                                                                       PCM07950
      X = REAL ( Z )                                                    PCM07960
      Y = IMAG( Z )                                                     PCM07970
      SUM = 0                                                           PCM07980
      IF ( Y .EQ. 0 ) GOTO 20                                           PCM07990
C                                                                       PCM08000
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      N = MIN( ABS( 80./Y ), 50.D0 )                                    PCM08010
      DO 10 I = 1, N                                                    PCM08020
         SUM = SUM + EXP(-.25 * ( I ** 2 ) )                            PCM08030
     &       * ( F( X, Y, I ) + (0,1) * G( X, Y, I ) )                  PCM08040
     &       / ( I ** 2 + 4.0 * X ** 2 )                                PCM08050
         IF ( I .GT. 1 .AND.                                            PCM08060
     &    ABS( SUM - TEST ) .LT. ABS( TEST ) / 1E5 )                    PCM08070
     &    GOTO 20                                                       PCM08080
         TEST = SUM                                                     PCM08090
 10    CONTINUE                                                        PCM08100
       WRITE ( IO, * )                                                 PCM08110
     &    'UNEXPECTED ERRROR: SALZER SERIES FAILED TO CONVERGE'        PCM08120
C                                                                       PCM08130
 20    CONTINUE                                                        PCM08140
       SALZER = - 2 * EXP( - X ** 2 ) * SUM / PI                       PCM08150
       IF ( X .NE. 0. )                                                PCM08160
     &    SALZER = SALZER - EXP( - X ** 2 ) *                          PCM08170
     &       ( 1 - COS( 2 * X * Y ) + (0,1) * SIN( 2 * X * Y ) ) /     PCM08180
     &       ( 2 * PI * X )                                            PCM08190
C                                                                       PCM08200
C  WHEN CALLED TO AID EVALUATION OF THE SOMMERFELD COMPLEX              PCM08210
C  SURFACE WAVE ATTENUATION, THE VARIABLE Z WILL BE IN THE              PCM08220
C  4TH QUADRANT.  ADDITIONAL PROVISION IS MADE BELOW TO                 PCM08230
C  RETURN THE VALUE OF THE COMPLEMENTARY ERROR FUNCTION                 PCM08240
C  INDEPENDENT OF WHAT QUADRANT Z IS IN.                                PCM08250
C                                                                       PCM08260
       IF ( X .GE. 0. ) THEN                                           PCM08270
          SALZER = SALZER + REERFC( X )                                PCM08280
       ELSE                                                            PCM08290
          SALZER = SALZER + 2 - REERFC( -X )                           PCM08300
       ENDIF                                                           PCM08310
       RETURN                                                          PCM08320
C                                                                      PCM08330
       END                                                             PCM08340
C                                                                      PCM08350
C*********************************************************************PCM08360
C                                                                      PCM08370
C  SRS1 - COMPUTE THE FIRST OF TWO POWER SERIES ASSOCIATED             PCM08380
C  WITH CORRECTION TERMS TO THE COMPLEX SURFACE WAVE                   PCM08390
C  ATTENUATION.  AN EFFECTIVE EARTH RADIUS FACTOR IS NEEDED            PCM08400
C  TO APPLY THE CORRECTION, AND THE APPROPRIATE FACTOR IS              PCM08410
C  APPLIED TO THE SUUM OF THE POWER SERIES ADDRESSED BY THIS           PCM08420
C  SUBPROGRAM.                                                         PCM08430
C                                                                      PCM08440
C  THE INPUT IS A SINGLE COMPLEX VALUE, AND THE OUTPUT IS              PCM08450
C  ALSO COMPLEX.                                                       PCM08460
C                                                                      PCM08470
C*********************************************************************PCM08480
C                                                                      PCM08490
       FUNCTION SRS1( Z )                                              PCM08500
C                                                                      PCM08510
       IMPLICIT REAL*8 ( A-H, O-R, U-Y ),                              PCM08520
     &          COMPLEX*16 ( S, T, Z )                                 PCM08530
       COMPLEX*16 ODD, EVEN                                            PCM08540
C                                                                      PCM08550
       COMMON / INOUT / IN, IO                                         PCM08560
       DATA PI / 3.1415927 /                                           PCM08570
C                                                                      PCM08580
       ODD = 4 * Z / ( 3 * SQRT( PI ) )                                PCM08590
       EVEN = 1                                                        PCM08600
       SUM = 1 + 2 * ODD                                               PCM08610
       DO 100 I = 2, 50                                                PCM08620
          IF ( MOD( I, 2 ) .EQ. 0 ) THEN                               PCM08630
             EVEN = 2 * EVEN * Z ** 2 / ( I + 2 )                      PCM08640
             TERM = EVEN                                               PCM08650
          ELSE                                                         PCM08660
             ODD = 2 * ODD * Z ** 2 / ( I + 2 )                        PCM08670
             TERM = ODD                                                PCM08680
          END IF                                                       PCM08690
          SUM = SUM + ( I + 1 ) * TERM                                 PCM08700
          IF ( I .GT. 2 .AND.                                          PCM08710
     &       ABS( SUM - TEST ) .LT. ABS( TEST ) / 1E6 )                PCM08720
     &       GOTO 110                                                  PCM08730
          TEST = SUM                                                   PCM08740
  100  CONTINUE                                                        PCM08750
       WRITE ( IO, * ) 'SLOW CONVERGENCE IN SERIES 1'                  PCM08760
C                                                                      PCM08770
  110  SRS1 = SUM * SQRT( PI ) / 2                                     PCM08780
       RETURN                                                          PCM08790
C                                                                      PCM08800
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      END                                                               PCM08810
C                                                                       PCM08820
C***********************************************************************PCM08830
C                                                                       PCM08840
C  SRS2 - COMPUTE THE SECOND OF TWO POWER SERIES ASSOCIATED             PCM08850
C  WITH CORRECTION TERMS TO THE COMPLEX SURFACE WAVE                    PCM08860
C  ATTENUATION.  AN EFFECTIVE EARTH RADIUS FACTOR IS NEEDED             PCM08870
C  TO APPLY THE CORRECTION, AND THE APPROPRIATE FACTOR IS               PCM08880
C  APPLIED TO THE SUM OF THE POWER SERIES ADDRESSED BY THIS             PCM08890
C  SUBPROGRAM.                                                          PCM08900
C                                                                       PCM08910
C  THE INPUT IS A SINGLE COMPLEX VALUE, AND THE OUTPUT IS               PCM08920
C  ALSO COMPLEX.                                                        PCM08930
C                                                                       PCM08940
C***********************************************************************PCM08950
C                                                                       PCM08960
      FUNCTION SRS2( Z )                                                PCM08970
C                                                                       PCM08980
      IMPLICIT REAL*8 ( A-H, O-R, U-Y ),                                PCM08990
     &         COMPLEX*16 ( S, T, Z )                                   PCM09000
      COMPLEX*16 ODD, EVEN                                              PCM09010
C                                                                       PCM09020
      COMMON / INOUT / IN, IO                                           PCM09030
      DATA PI / 3.1415927 /                                             PCM09040
C                                                                       PCM09050
      EVEN = 9 / ( 15 * SQRT( PI ) )                                    PCM09060
      ODD = Z / 6                                                       PCM09070
      SUM = 7 * EVEN + 2 * 8 * ODD                                      PCM09080
      DO 200 I = 2, 50                                                  PCM09090
         IF ( MOD( I,2 ) .EQ. 0 ) THEN                                  PCM09100
            EVEN = 2 * EVEN * Z ** 2 / ( I + 5 )                        PCM09110
            TERM = EVEN                                                 PCM09120
         ELSE                                                           PCM09130
            ODD = 2 * ODD * Z ** 2 / ( I + 5 )                          PCM09140
            TERM = ODD                                                  PCM09150
         ENDIF                                                          PCM09160
         SUM = SUM + ( I + 1 ) * ( I + 7 ) * TERM                       PCM09170
         IF ( I .GT. 2 .AND.                                            PCM09180
     &        ABS( SUM - TEST ) .LT. ABS( TEST ) / 1E6 )                PCM09190
     &        GOTO 210                                                  PCM09200
         TEST = SUM                                                     PCM09210
 200  CONTINUE                                                          PCM09220
      WRITE ( IO, * ) 'SLOW CONVERGENCE IN SERIES 2'                    PCM09230
C                                                                       PCM09240
 210  SRS2 = SUM * SQRT( PI ) / 8                                       PCM09250
      RETURN                                                            PCM09260
C                                                                       PCM09270
      END                                                               PCM09280
C                                                                       PCM09290
C***********************************************************************PCM09300
C                                                                       PCM09310
C  RESIDU - CALCULATION OF DIFFRACTION LOSS OVER SMOOTH                 PCM09320
C  FINITELY CONDUCTING EARTH USING RESIDUE SERIES.                      PCM09330
C                                                                       PCM09340
C  THE COMPUTATIONS FOLLOW THE METHOD OUTLINED BY H. BREMMER,           PCM09350
C  TERRESTIAL RADIO WAVES, ELSEVIER PUBLISHING CO., 1949.               PCM09360
C                                                                       PCM09370
C***************************************************************       PCM09380
C                                                                       PCM09390
      SUBROUTINE RESIDU( CHI, K, PSI,                                   PCM09400
     &   ATTENU )                                                       PCM09410
C                                                                       PCM09420
      IMPLICIT REAL*8 ( A, B, E-H, O-P, R, S, U-Y ),                    PCM09430
     &         COMPLEX*16 ( C, D, O, T, Z )                             PCM09440
      REAL*8 K, CHI                                                     PCM09450
      INTEGER S                                                         PCM09460
      PARAMETER ( MTERMS = 30 )                                         PCM09470
C                                                                       PCM09480
C  TAU(S) DENOTES THE POINTS IN THE COMPLEX PLANE AT WHICH              PCM09490
C  RESIDUES OF THE DIFFRACTION FIELD INTEGRAND ARE TO BE                PCM09500
C  EVALUATED.                                                           PCM09510
C                                                                       PCM09520
      DIMENSION TAU( MTERMS )                                           PCM09530
C                                                                       PCM09540
C  NO NEED TO RECALCULATE RESIDUE POINTS IF NO CHANGE IN DEL.           PCM09550
C                                                                       PCM09560
      COMMON / SAVE / DEL, OSOR, TAU, NPTS                              PCM09570
      SAVE / SAVE /                                                     PCM09580
C                                                                       PCM09590
C  MTERMS REFERS TO HOW MANY TERMS MAY BE INCLUDED IN THE               PCM09600
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C  RESIDUE SERIES. THE NUMBER ACTUALLY INCLUDED WILL BE                  PCM09610
C  DETERMINED BY A CONVERGENCE CRITERION REPRESENTED BY THE              PCM09620
C  PARAMETER PRECIS.                                                    PCM09630
C                                                                       PCM09640
      DATA PRECIS / 1E-4 /                                              PCM09650
C                                                                       PCM09660
C  FINE DETERMINES THE SIZE OF THE THE ELEMENT OF INTEGRATION           PCM09670
C  USED TO LOCATE RESIDUE POINTS.                                       PCM09680
C                                                                       PCM09690
      DATA FINE / 0.05 /                                                PCM09700
      DATA PI / 3.1415927 /                                             PCM09710
C                                                                       PCM09720
C  TAU0 AND TAU1 DENOTE REFERENCE POINTS WHERE RESIDUES                 PCM09730
C  WOULD BE EVALUATED IN CERTAIN LIMITING CASES. THESE                  PCM09740
C  REFERENCE POINTS ARE ALL IN THE FIRST QUADRANT ON THE LINE           PCM09750
C  OF SLOPE 60 DEGREES. THE AMPLITUDES OF THE COMPLEX NUMBERS           PCM09760
C  REPRESENTING REFERENCE POINTS TAU0 AND TAU1 ARE DETERMINED           PCM09770
C  FROM THE AMPLITUDES OF CORRESPONDING ROOTS OF THE AIRY               PCM09780
C  FUNCTION AND ITS DERIVATIVE.                                         PCM09790
C                                                                       PCM09800
C  THE REQUIRED ROOTS OF THE AIRY FUNCTION AND ITS DERIVATIVE           PCM09810
C  ARE FOUND BY FUNCTION AIRY0 AND FUNCTION AIRY1 RESPECTIVELY.         PCM09820
C                                                                       PCM09830
C  FUNCTION PRODUCING TAU0 OR TAU1 FROM THE AMPLITUDE                   PCM09840
C  AIRY0 OR AIRY1:                                                      PCM09850
C                                                                       PCM09860
      TFN( AIRY ) = AIRY / 2 ** ( 1./3) * EXP( (0,1) * PI/3 )           PCM09870
C                                                                       PCM09880
C  FUNCTIONS FOR FINDING POINTS TAU, AT WHICH RESIDUES                  PCM09890
C  ARE EVALUATED, FROM THE REFERENCE POINTS TAU0. THESE                 PCM09900
C  FORMULAS ARE USED WHEN DEL IS SMALL.                                 PCM09910
C                                                                       PCM09920
      C3 ( TA ) = -2./3 * TA                                            PCM09930
      C5 ( TA ) = -4./5 * TA ** 2                                       PCM09940
      C6 ( TA ) = 14./9 * TA                                            PCM09950
      C7 ( TA ) = - ( 5 + 8 * TA ** 3 ) / 7                             PCM09960
      C8 ( TA ) = 58./15 * TA ** 2                                      PCM09970
      C9 ( TA ) = - TA * ( 2296./567 + 16/9 * TA ** 3 )                 PCM09980
      C10( TA ) = 47./35 + 4656/525 * TA ** 3                           PCM09990
C                                                                       PCM10000
      TAUFN0( TA, DEL ) =                                               PCM10010
     &                 TA + DEL *                                       PCM10020
     &    (             - 1 + DEL *                                     PCM10030
     &    (               0 + DEL *                                     PCM10040
     &    (   C3 ( TA ) + DEL *                                         PCM10050
     &    (   C5 ( TA ) + DEL *                                         PCM10060
     &    (         1./2 + DEL *                                        PCM10070
     &    (   C6 ( TA ) + DEL *                                         PCM10080
     &    (   C7 ( TA ) + DEL *                                         PCM10090
     &    (   C8 ( TA ) + DEL *                                         PCM10100
     &    (   C9 ( TA ) + DEL *                                         PCM10110
     &    (   C10( TA ) ))))))))))                                      PCM10120
C                                                                       PCM10130
C  FUNCTIONS FOR FINDING TAU FROM TAU1. USED WHEN DEL                   PCM10140
C  IS LARGE AFTER SETTING Q = 1/DEL.                                    PCM10150
C                                                                       PCM10160
      D1( TA )  =  -    1 / ( 2 * TA )                                  PCM10170
      D2( TA )  =  -    1 / ( 8 * TA ** 3 )                             PCM10180
      D3( TA )  =  -    1 / ( TA ** 2 ) *                               PCM10190
     &(     1./ 12 +    1 / ( 16 * TA ** 3 ) )                         PCM10200
      D4( TA )  =  -    1 / ( TA ** 4 ) *                               PCM10210
     &(     7./ 96 +    5 / ( 128 * TA ** 3 ) )                        PCM10220
      D5( TA )  =  -    1 / ( TA ** 3 ) *                               PCM10230
     &(     1./ 40 +    1 / ( TA ** 3 ) *                               PCM10240
     &(    21./320 +    7 / ( 256 * TA ** 3 )  ))                       PCM10250
      D6( TA )  =  -    1 / ( TA ** 5 ) *                               PCM10260
     &(    29./720 +    1 / ( TA ** 3 ) *                               PCM10270
     &(    77./1280 +  21 / ( 1024 * TA ** 3 ) ))                       PCM10280
      D7( TA )  =  -    1 / ( TA ** 4 ) *                               PCM10290
     &(     1./112 +    1 / ( TA ** 3 ) *                               PCM10300
     &(    19./360 +    1 / ( TA ** 3 ) *                               PCM10310
     &( 143./2560 +   33 / ( 2048 * TA ** 3 ))))                        PCM10320
      D8( TA )  =  -    1 / ( TA ** 6 ) *                               PCM10330
     &(    97./4480 +    1 / ( TA ** 3 ) *                             PCM10340
     &( 163./2560 +    1 / ( TA ** 3 ) *                               PCM10350
     &( 429./8192 + 429 / ( 32768 * TA ** 3 ))))                        PCM10360
C                                                                       PCM10370
      TAUFN1( TA, Q ) =                                                 PCM10380
     &                 TA + Q *                                         PCM10390
     &    ( D1( TA ) + Q *                                             PCM10400
```

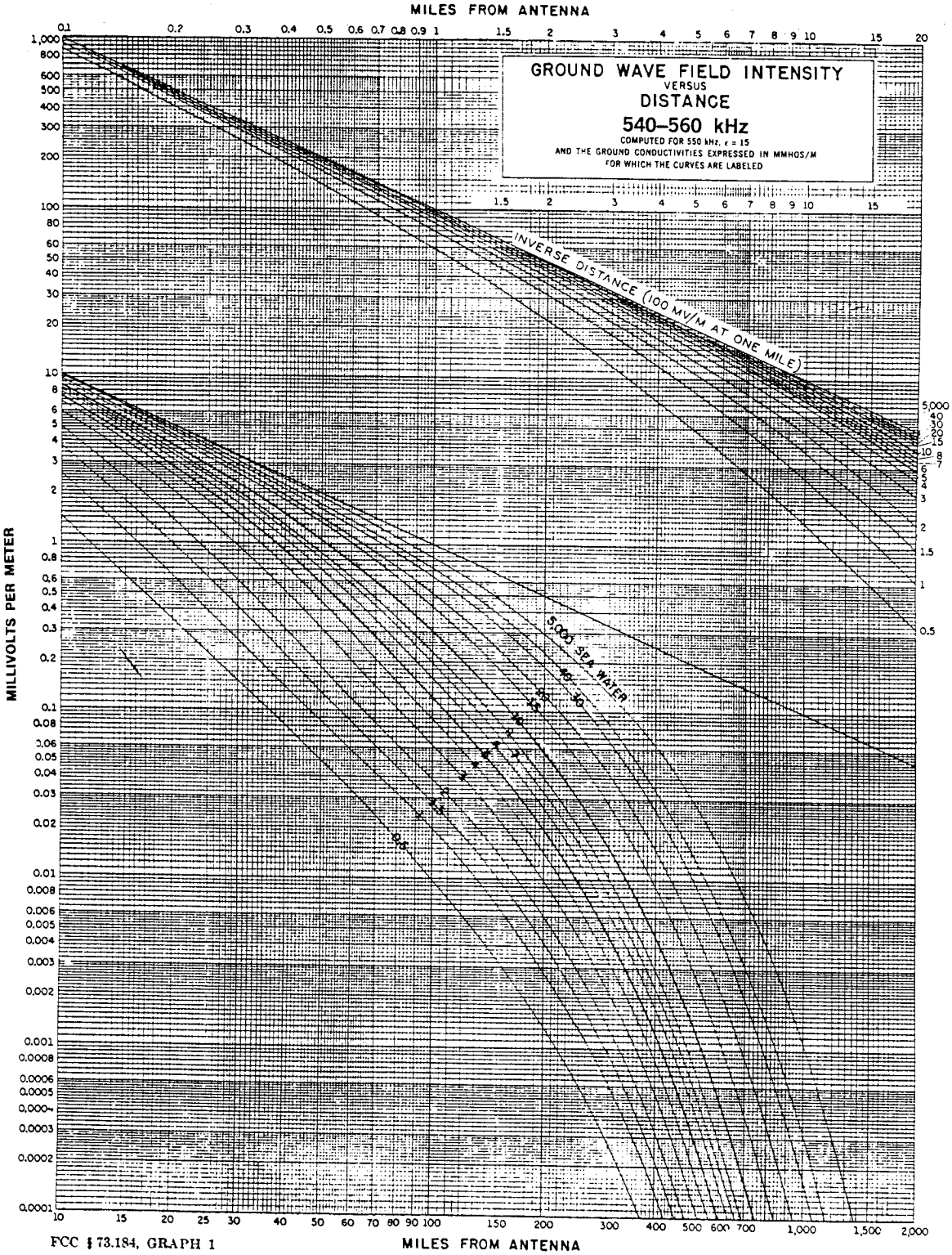
```
     &     ( D2( TA ) + 0 *
     &     ( D3( TA ) + 0 *
     &     ( D4( TA ) + 0 *
     &     ( D5( TA ) + 0 *
     &     ( D6( TA ) + 0 *
     &     ( D7( TA ) + 0 *
     &     ( D8( TA ) ))))))))
C
CC   FORMULA FOR FINDING TAU BY INTEGRATION
C
        DELTAU( TA, DEL, DELDEL ) =
     &     DELDEL / ( 2 * TA * DEL ** 2 - 1 )
C
CCC  BEGIN EXECUTION. DEFINE QUANTITIES THAT WILL BE USED
CCC  REPEATEDLY IN THE RESIDUE SUMMING LOOP.
C
        DELNEW = K * EXP( (0,1) * ( 3*PI/4 - PST ) )
        IF ( DELNEW .NE. DEL ) THEN
           DEL = DELNEW
           OSQR = ( 1 / DEL ) ** 2
           NPTS = 0
        ENDIF
C
CCC  CLEAR THE VARIABLE USED TO ACCUMULATE THE RESIDUE SUM, AND
CCC  INITIALIZE VARIABLE USED TO TEST CONVERGENCE.
C
        ZS = 0
        TEST = 0
C
CCC  BEGIN CALCULATION OF SUM OF RESIDUES. IF THE S-TH RESIDUE
CCC  POINT HAS BEEN LOCATED BY A PREVIOUS CALL TO THIS SUBROUTINE,
CCC  JUMP PAST THE CALCULATION OF TAU(S).
C
        DO 100 S = 1, MTERMS
           IF ( S .LE. NPTS ) GOTO 90
C
CCC  FIND TAU(S) FROM TAU0 IF K IS SMALL, OR FROM TAU1 IF K IS
CCC  LARGE.  FOR INTERMEDIATE VALUES OF K, ACCURACY REQUIRES AN
CCC  INTEGRATION PROCEEDURE.
C
           TAU0 = TFN( AIRY0( S ) )
           TAU1 = TFN( AIRY1( S ) )
           IF ( ABS( TAU0 * K ** 2 ) .LT. 0.25 ) THEN
              TAU( S ) = TAUFN0( TAU0, DEL )
           ELSE IF ( ABS( TAU1 * K ** 2 ) .GT. 1.0 ) THEN
              TAU( S ) = TAUFN1 ( TAU1, 1. / DEL )
           ELSE
              T = TAU0
              N = MAX( ABS( DEL ) / FINE, 2.D0 )
              DELDEL = DEL / N
C
CCC  INTEGRATE ALONG A DIAGONAL PATH IN THE COMPLEX DEL-PLANE
CCC  USING A FOURTH-ORDER RUNGE-KUTTA METHOD. THE VARIABLE OF
CCC  INTEGRATION, DEL1, RUNS FROM 0 TO DEL.
C
              DEL1 = 0
              DO 80 I = 1, N
                 TK1 = DELTAU( T, DEL1, DELDEL )
                 DEL1 = DEL1 + DELDEL/2
                 TK2 = DELTAU( T + TK1/2, DEL1, DELDEL )
                 TK3 = DELTAU( T + TK2/2, DEL1, DELDEL )
                 DEL1 = DEL1 + DELDEL/2
                 TK4 = DELTAU( T + TK3, DEL1, DELDEL )
                 T = T + ( TK1 + 2 * TK2 + 2 * TK3 + TK4 ) / 6
  80        CONTINUE
              TAU( S ) = T
           ENDIF
C
CCC  REMEMBER HOW MANY RESIDUE POINTS HAVE BEEN LOCATED. THIS
CCC  PERMITS REUSE OF THIS SUBROUTINE WITHOUT RECALCULATION OF
CCC  TAU( S ) SO LONG AS THE VALUE OF DEL REMAINS UNCHANGED, THAT
CCC  IS FOR CHANGES IN DISTANCE ONLY.
C
           NPTS = S
C
CCC  EVALUATE RESIDUE AT TAU( S ) .
C
  90       CONTINUE
              Z = EXP( (0,1) * TAU(S) * CHI ) /
     &           ( 2 * TAU(S) - OSQR )
```

```
PCM10410
PCM10420
PCM10430
PCM10440
PCM10450
PCM10460
PCM10470
PCM10480
PCM10490
PCM10500
PCM10510
PCM10520
PCM10530
PCM10540
PCM10550
PCM10560
PCM10570
PCM10580
PCM10590
PCM10600
PCM10610
PCM10620
PCM10630
PCM10640
PCM10650
PCM10660
PCM10670
PCM10680
PCM10690
PCM10700
PCM10710
PCM10720
PCM10730
PCM10740
PCM10750
PCM10760
PCM10770
PCM10780
PCM10790
PCM10800
PCM10810
PCM10820
PCM10830
PCM10840
PCM10850
PCM10860
PCM10870
PCM10880
PCM10890
PCM10900
PCM10910
PCM10920
PCM10930
PCM10940
PCM10950
PCM10960
PCM10970
PCM10980
PCM10990
PCM11000
PCM11010
PCM11020
PCM11030
PCM11040
PCM11050
PCM11060
PCM11070
PCM11080
PCM11090
PCM11100
PCM11110
PCM11120
PCM11130
PCM11140
PCM11150
PCM11160
PCM11170
PCM11180
PCM11190
PCM11200
```

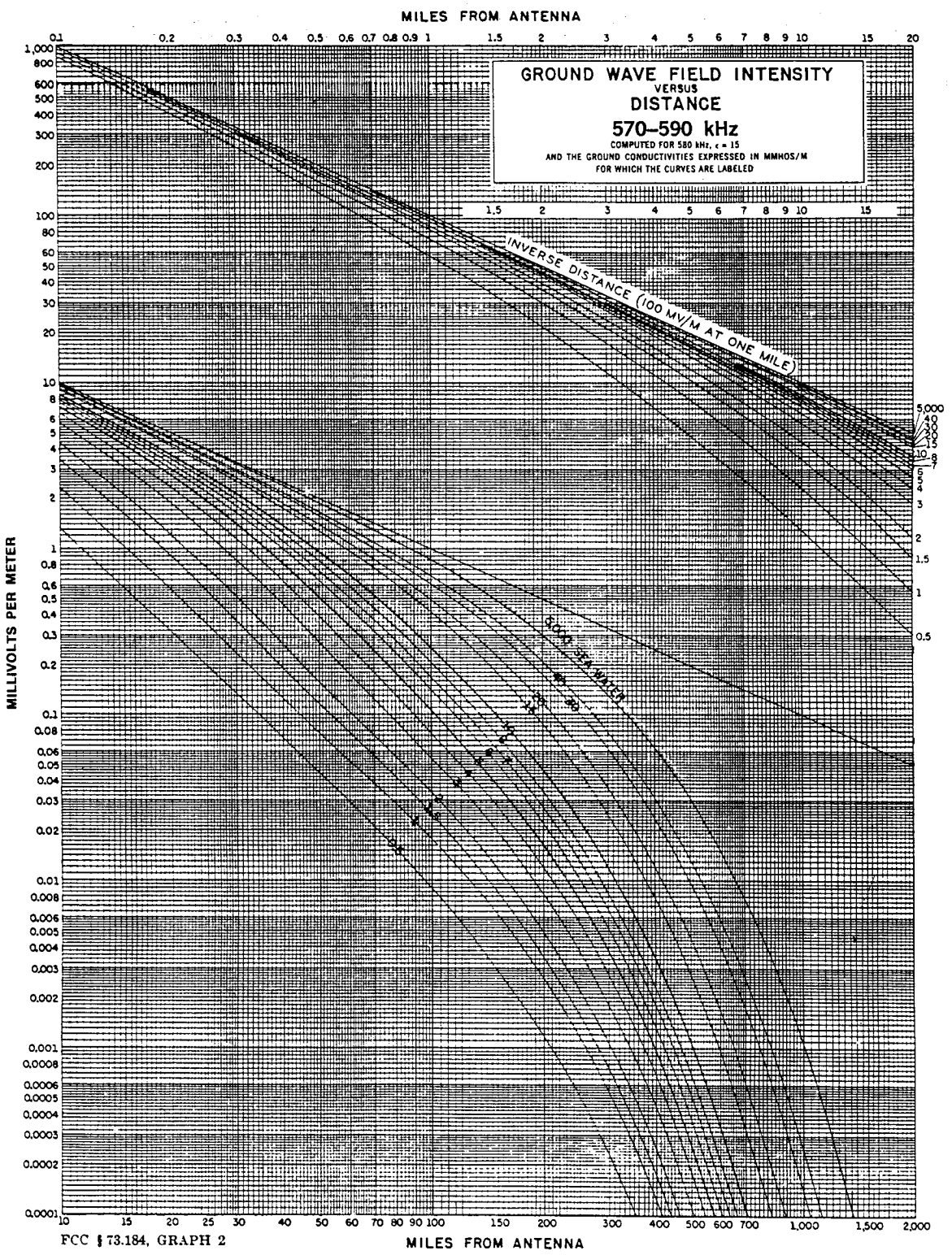
```
C
CCC   ACCUMULATE AND LOOP TO CALCULATE NEXT RESIDUE UNTIL
CCC   TEST INDICATES CONVERGENCE IS SATISFACTORY.
C
            ZS = ZS + Z
            IF ( ABS( ZS - TEST ) .LT. PRECIS * ABS( TEST ) )
     &          GOTO 200
            TEST = ZS
  100   CONTINUE
C
CC    EXIT WITH DIFFRACTION LOSS DETERMINED FROM SUM OF RESIDUES.
C
  200   CONTINUE
        ATTENU = ABS( ZS ) * SQRT( 2 * PI * CHI )
        RETURN
C
        END
C
CC*****************************************************************
CCC
CCC   AIRY0 - LOCATE THE ZEROES OF THE AIRY FUNCTION
CCC
CCC   THE ZEROS OF INTEREST ARE LOCATED ON THE NEGATIVE REAL
CCC   AXIS, AND THIS SUBPROGRAM RETURNS POSITIVE VALUES EQUAL
CCC   TO MINUS THE X-COORDINATE OF THESE ZEROES.
CCC
CCC   THE FIRST 10 VALUES OF AIRY0 ARE THOSE TABULATED IN
CCC   ABRAMOWITZ AND STEGUN, HANDBOOK OF FUNCTIONS, PAGE 478;
CCC   VALUES FOR INDICES LARGER THAT 10 ARE CALCULATED USING
CCC   EQUATIONS (10.4.94) ETC. ON PAGE 450 OF THE SAME REFERENCE.
CCC
CC*****************************************************************
C
        FUNCTION AIRY0( S )
C
        IMPLICIT REAL*8 ( A-H, O-Z )
        INTEGER S
        DIMENSION A0( 10 )
        DATA PI / 3.1415927 /
C
        DATA A0 /
     &    2.3381074,  4.0879494,  5.5205598,  6.7867081,
     &    7.9441336,  9.0226508, 10.0401743, 11.0085243,
     &   11.9360156, 12.8287767 /
C
CCC   FORMULAS USED TO CALCULATE THE AMPLITUDES A0( S ) FOR
CCC   FOR INDICES GREATER THAT 10.
C
        X( S ) = 3 * PI * ( 4 * S - 1 ) / 8
        F( Y ) = Y ** (2./3) * ( 1 + 5./48 * (1/Y) ** 2 )
C
        IF ( S .LE. 10 ) THEN
            AIRY0 = A0( S )
        ELSE
            AIRY0 = F( X( S ) )
        ENDIF
        RETURN
C
        END
C
CC*****************************************************************
CCC
CCC   AIRY1 - LOCATE THE ZEROES OF THE DERIVATIVE OF THE AIRY
CCC   FUNCTION.
CCC
CCC   THE ZEROES OF INTEREST ARE LOCATED ON THE NEGATIVE REAL
CCC   AXIS, AND THIS SUBPROGRAM RETURNS POSITIVE VALUES EQUAL
CCC   TO MINUS THE X-COORDINATES OF THESE ZEROES.
CCC
CCC   THE FIRST 10 VALUES OF AIRY1 ARE THOSE TABULATED IN
CCC   ABRAMOWITZ AND STEGUN, HANDBOOK OF FUNCTIONS, PAGE 478;
CCC   VALUES FOR INDICES LARGER THAN 10 ARE CALCULATED USING
CCC   EQUATIONS (10.4.94) ETC. ON PAGE 450 OF THE SAME REFERENCE.
CCC
CC*****************************************************************
C
        FUNCTION AIRY1( S )
C
        IMPLICIT REAL*8  ( A-H, O-Z )
        INTEGER S
```

```
      DIMENSION A1( 10 )                                                PCM12010
      DATA PI / 3.1415927 /                                             PCM12020
C                                                                       PCM12030
      DATA A1 /                                                         PCM12040
     &     1.0187930,  3.2481976, 4.8200992,  6.1633074,                PCM12050
     &     7.3721773,  8.4884867, 9.5354491, 10.5276604,                PCM12060
     &    11.4750566, 12.3847984 /                                      PCM12070
C                                                                       PCM12080
C  FORMULAS USED TO CALCULATE THE AMPLITUDE A1( S ) FOR                 PCM12090
C  INDICES GREATER THAT 10.                                             PCM12100
C                                                                       PCM12110
      Y( S ) = 3 * PI * ( 4 * S - 3 ) / 8                               PCM12120
      G( X ) = X ** (2./3) * ( 1 - 7./48 * (1/X) ** 2 )                 PCM12130
C                                                                       PCM12140
      IF ( S .LE. 10 ) THEN                                             PCM12150
         AIRY1 = A1( S )                                                PCM12160
      ELSE                                                              PCM12170
         AIRY1 = G( Y( S ) )                                            PCM12180
      ENDIF                                                             PCM12190
      RETURN                                                            PCM12200
C                                                                       PCM12210
      END                                                               PCM12220
```

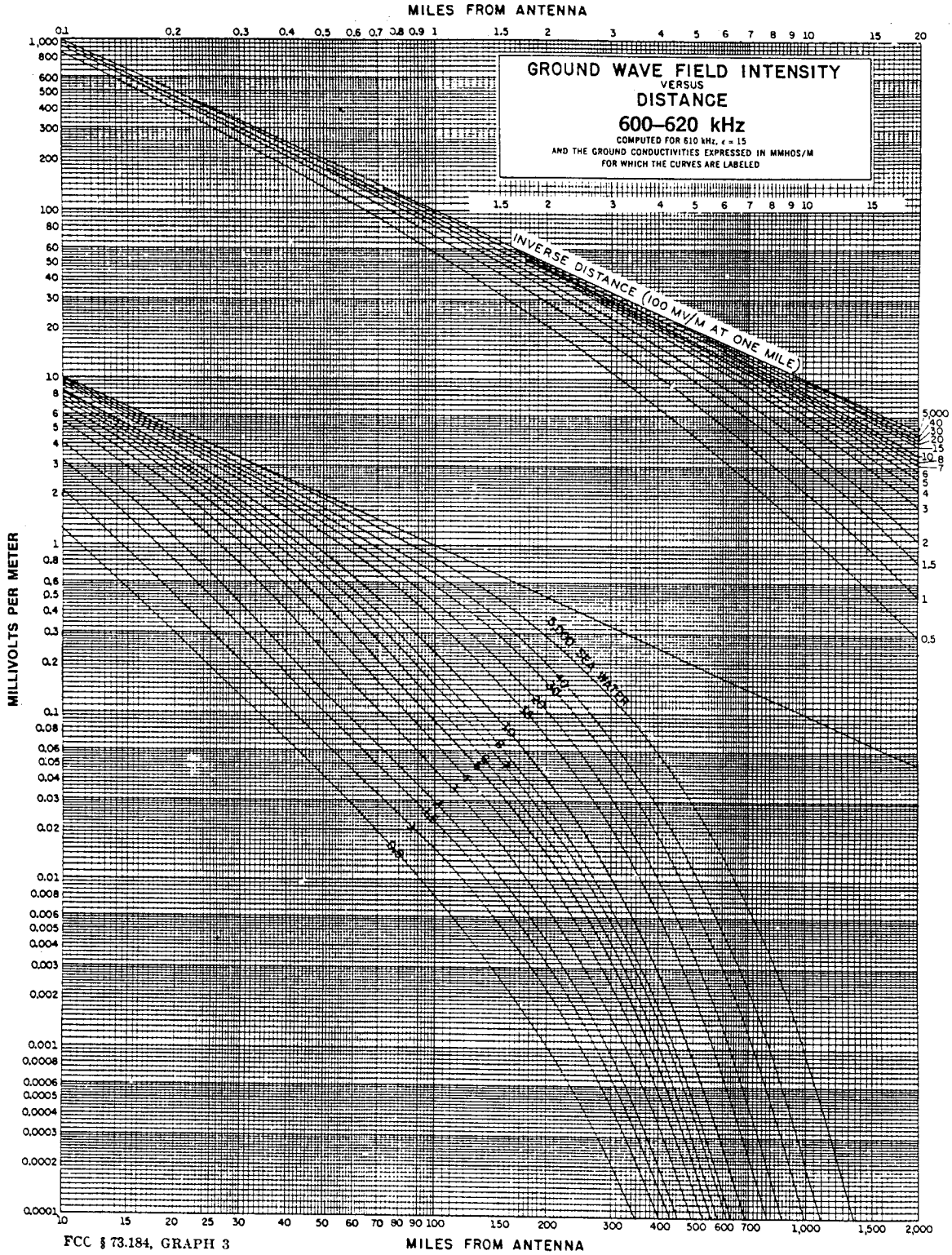
APPENDIX C. FCC GROUND WAVE FIELD STRENGTH CHARTS



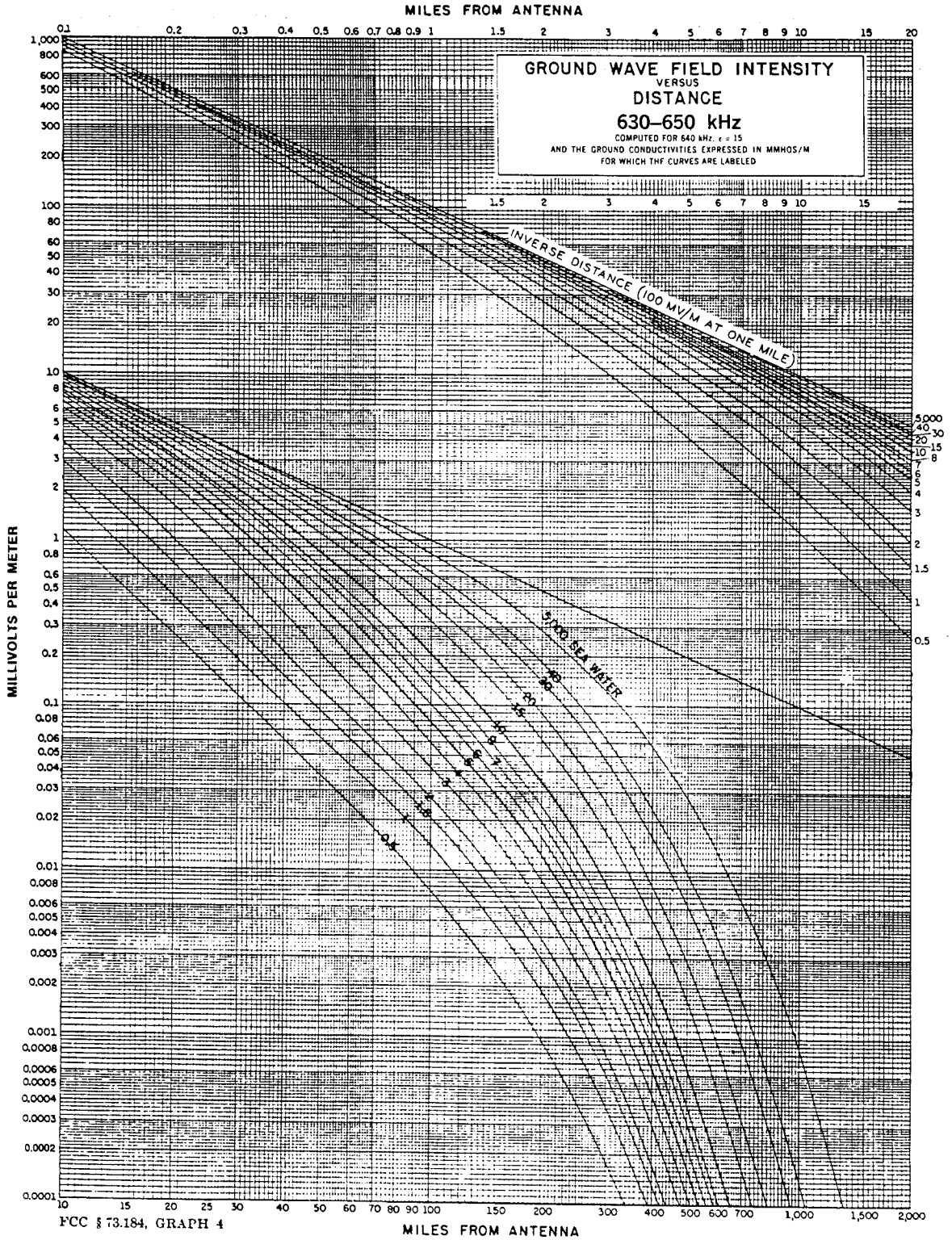
FCC § 73.184, GRAPH 1



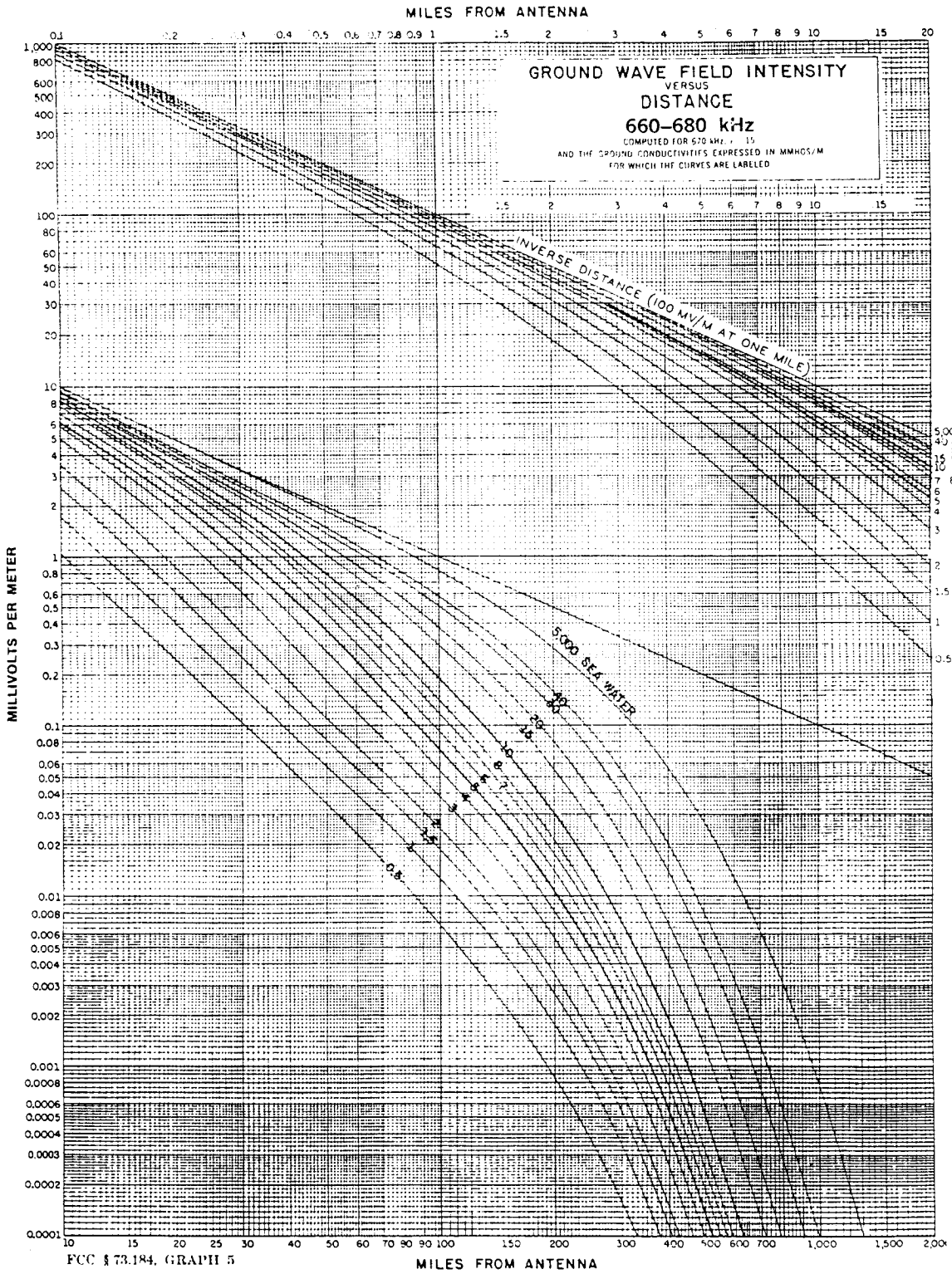
FCC § 73.184, GRAPH 2



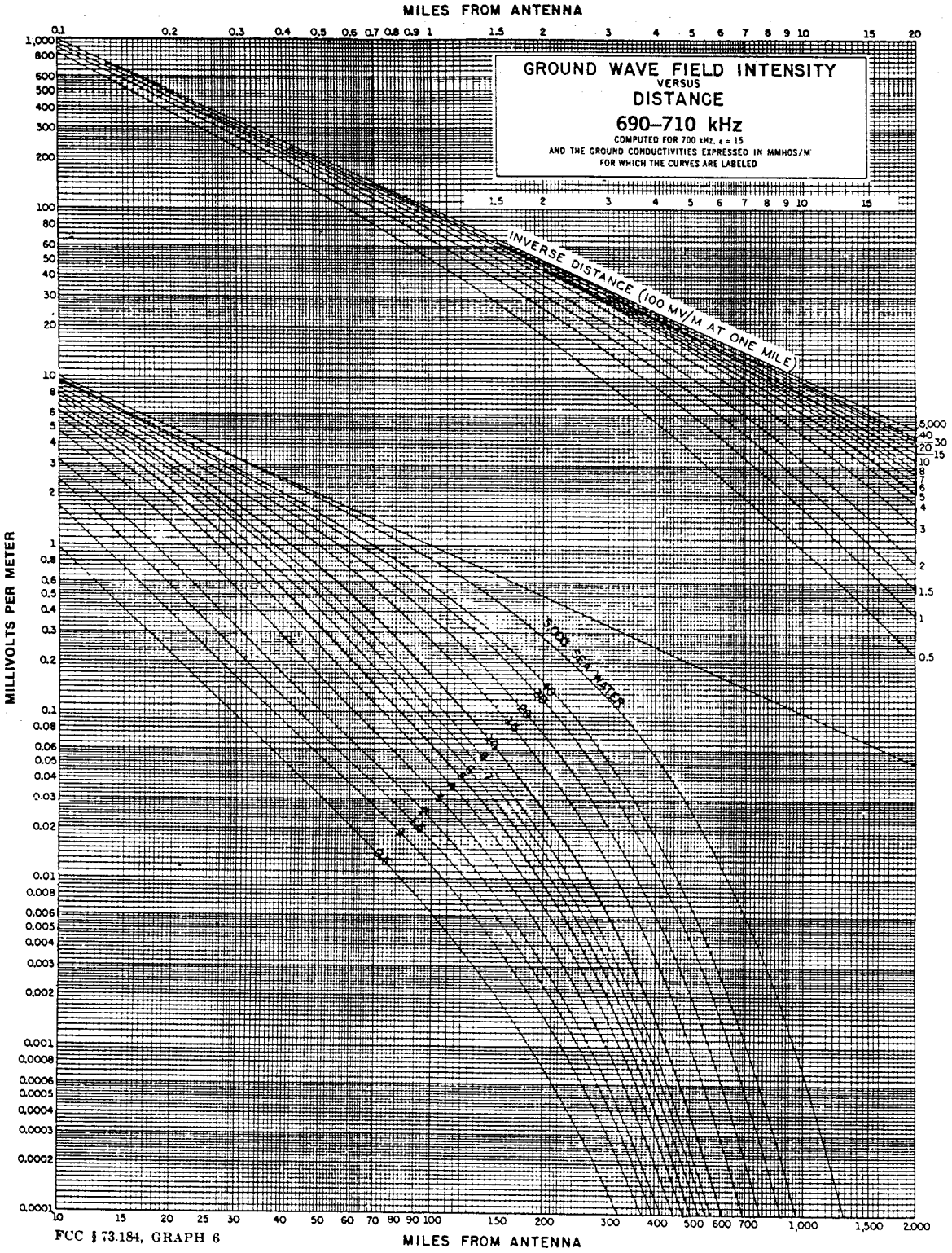
FCC § 73.184, GRAPH 3



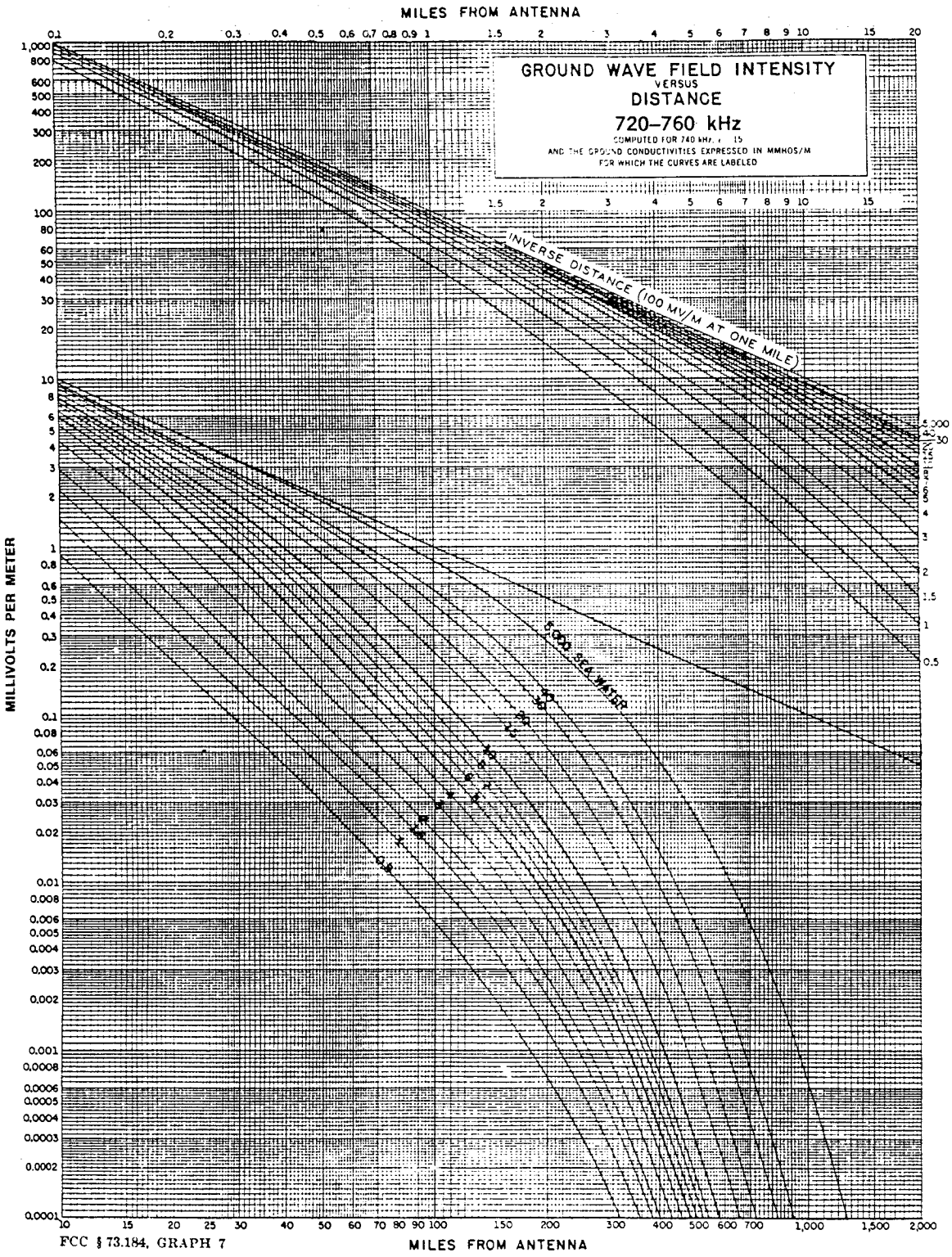
FCC § 73.184, GRAPH 4



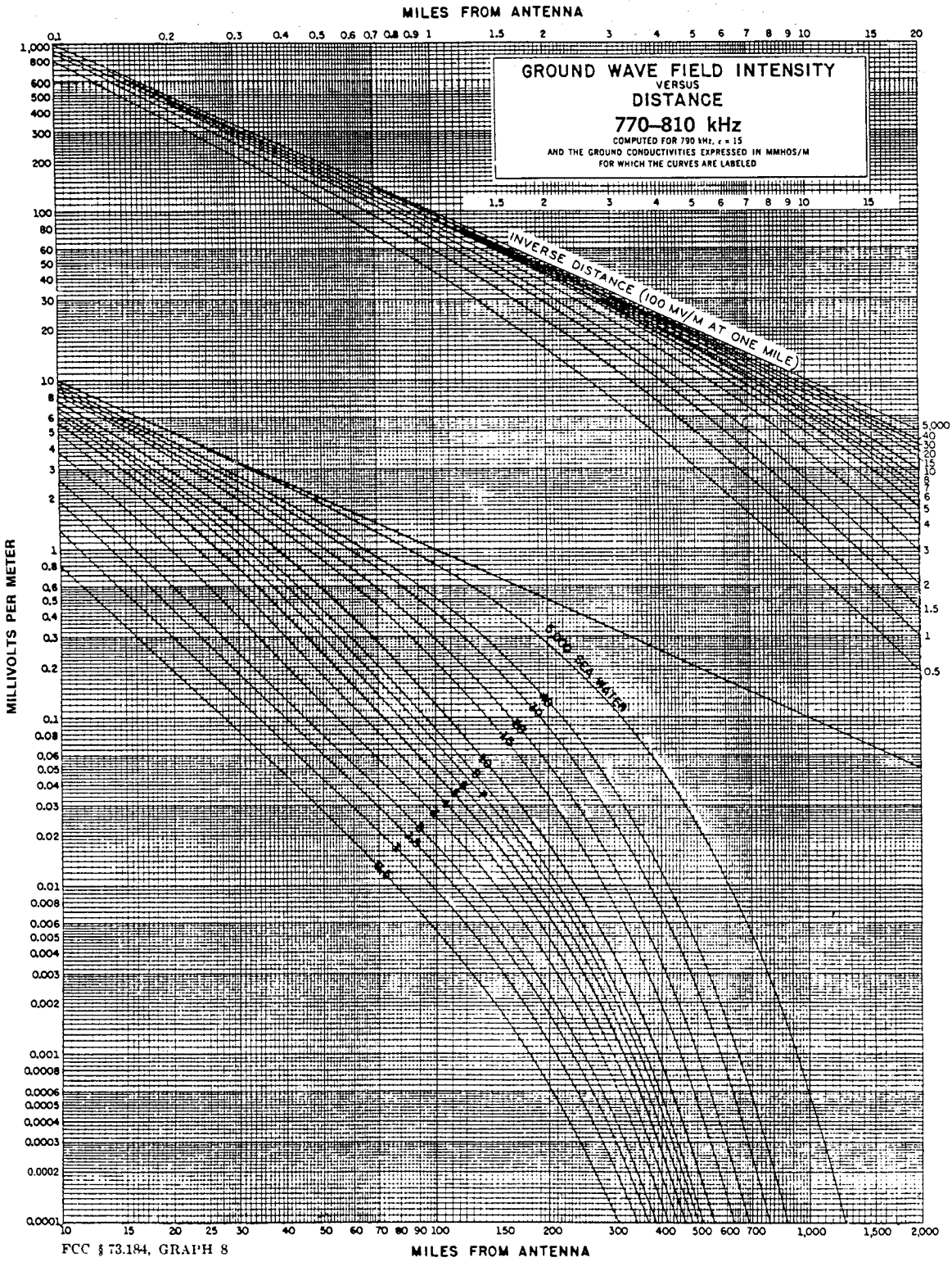
FCC § 73.184, GRAPH 5



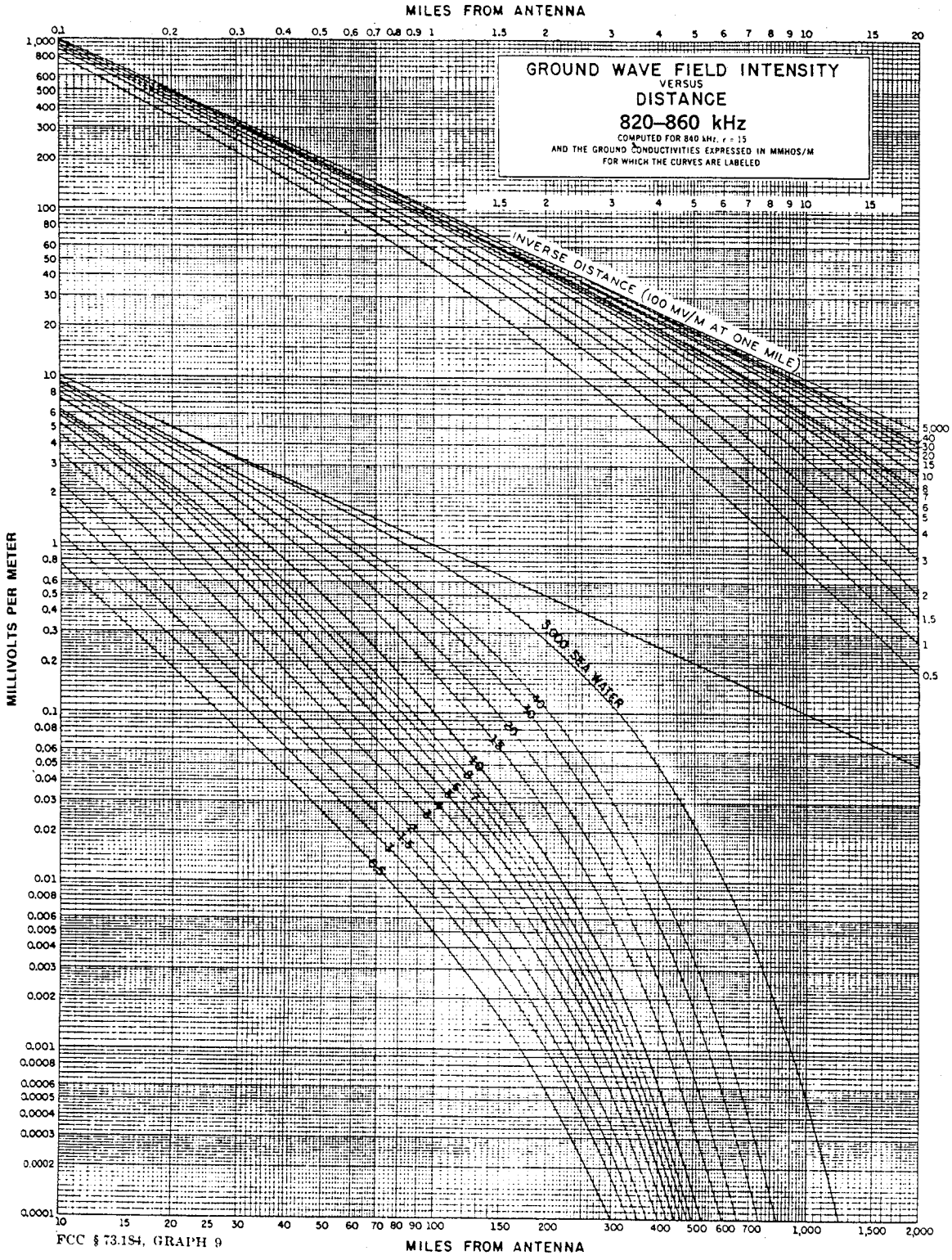
FCC § 73.184, GRAPH 6



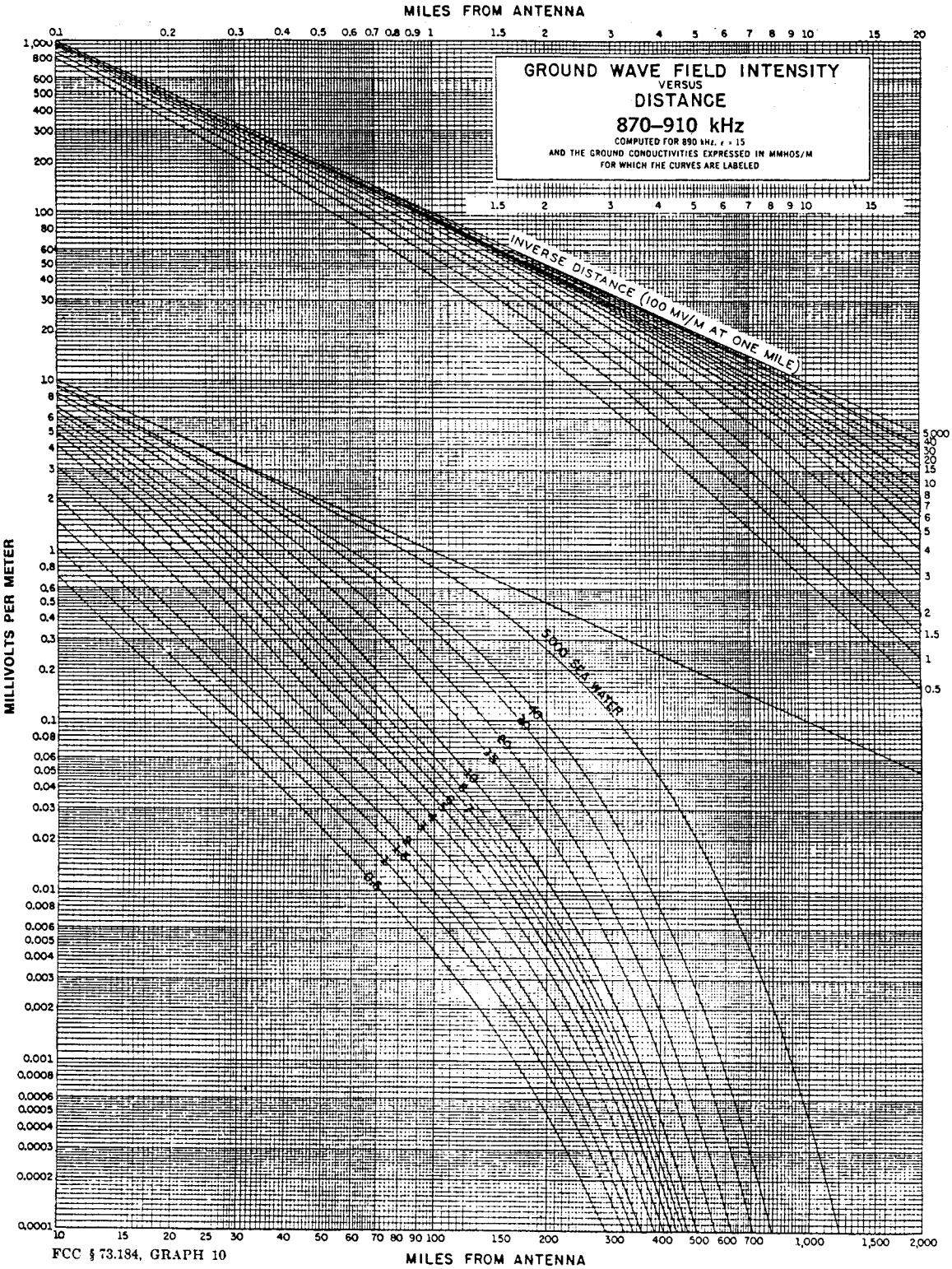
FCC § 73.184, GRAPH 7



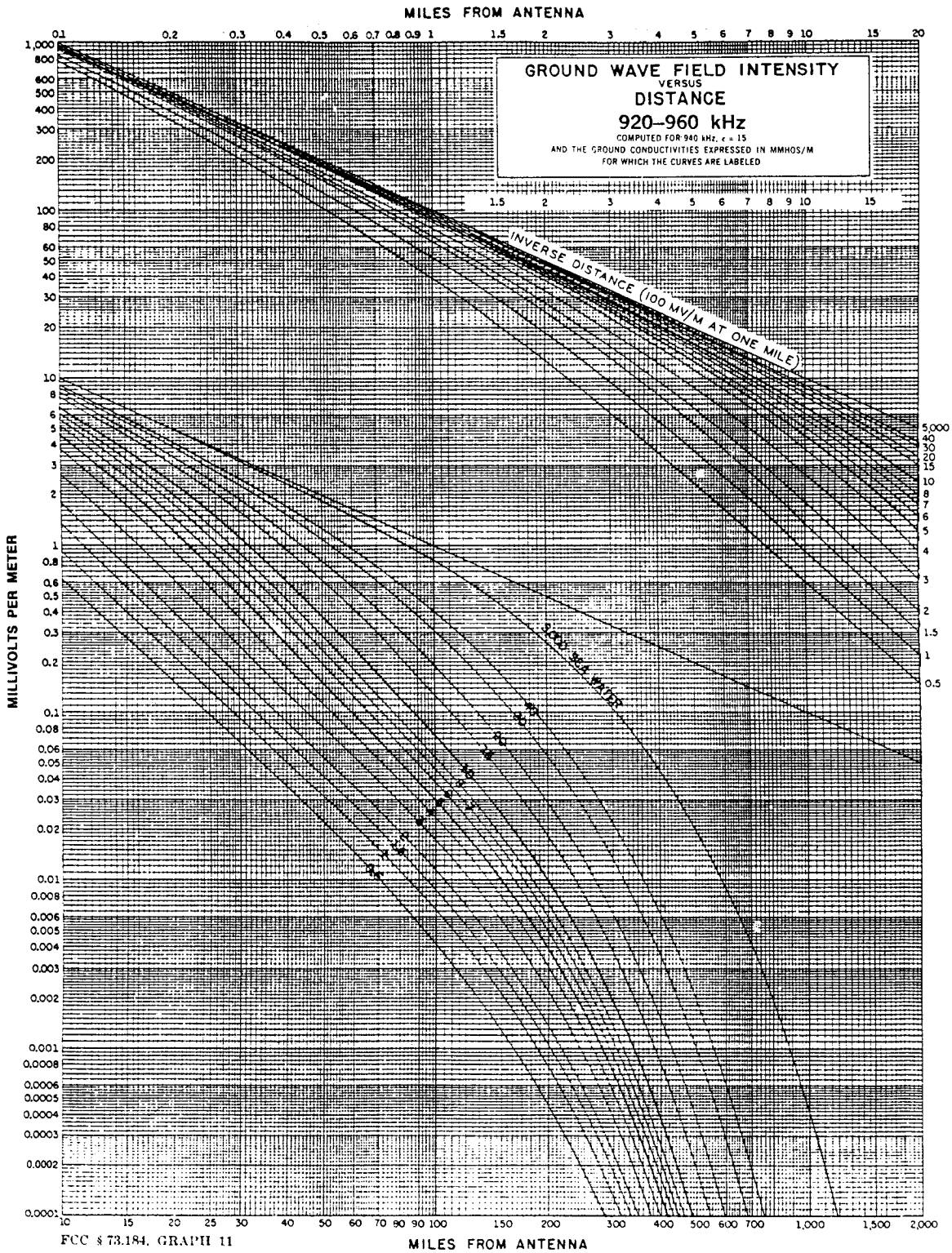
FCC § 73.184, GRAPH 8



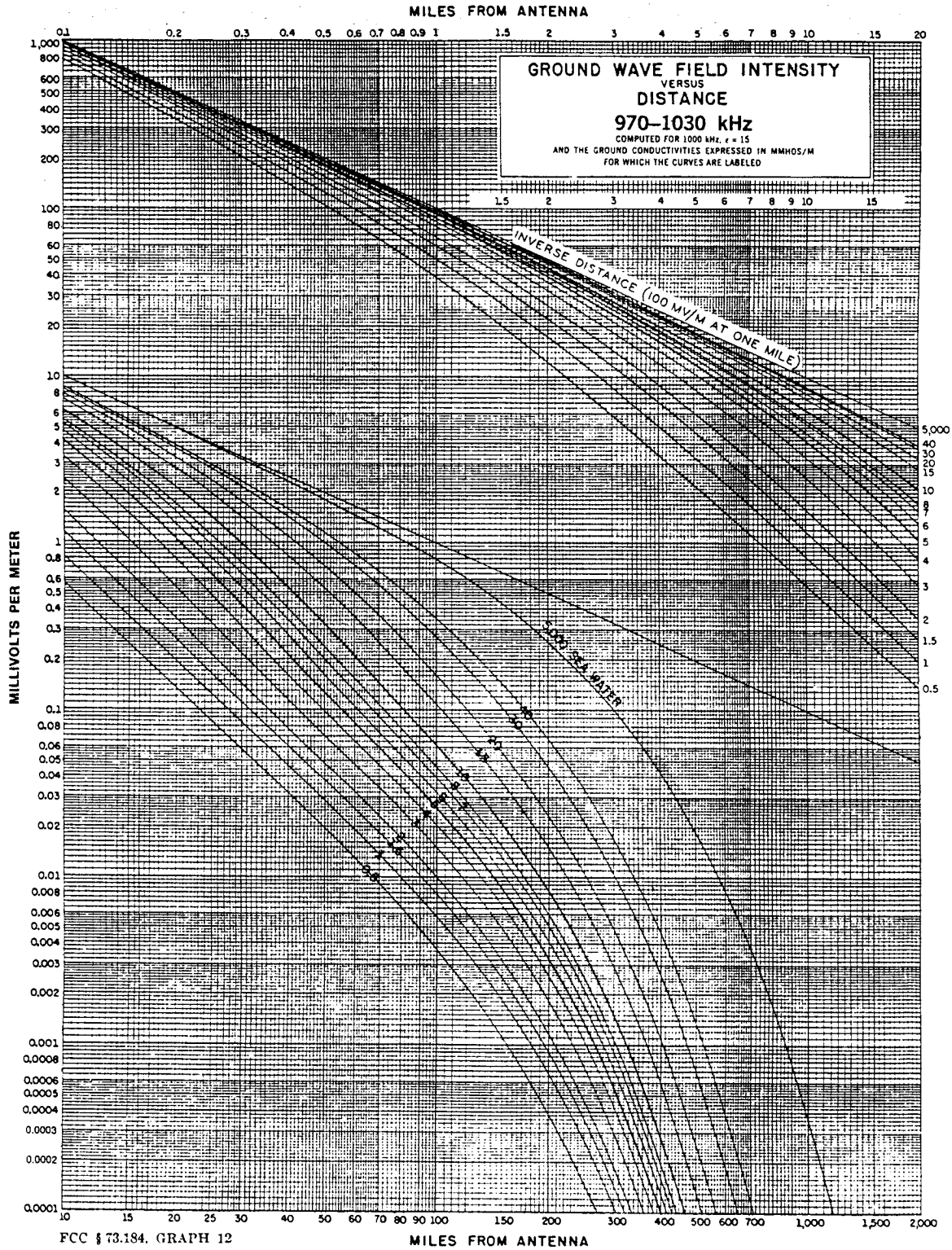
FCC § 73.184, GRAPH 9



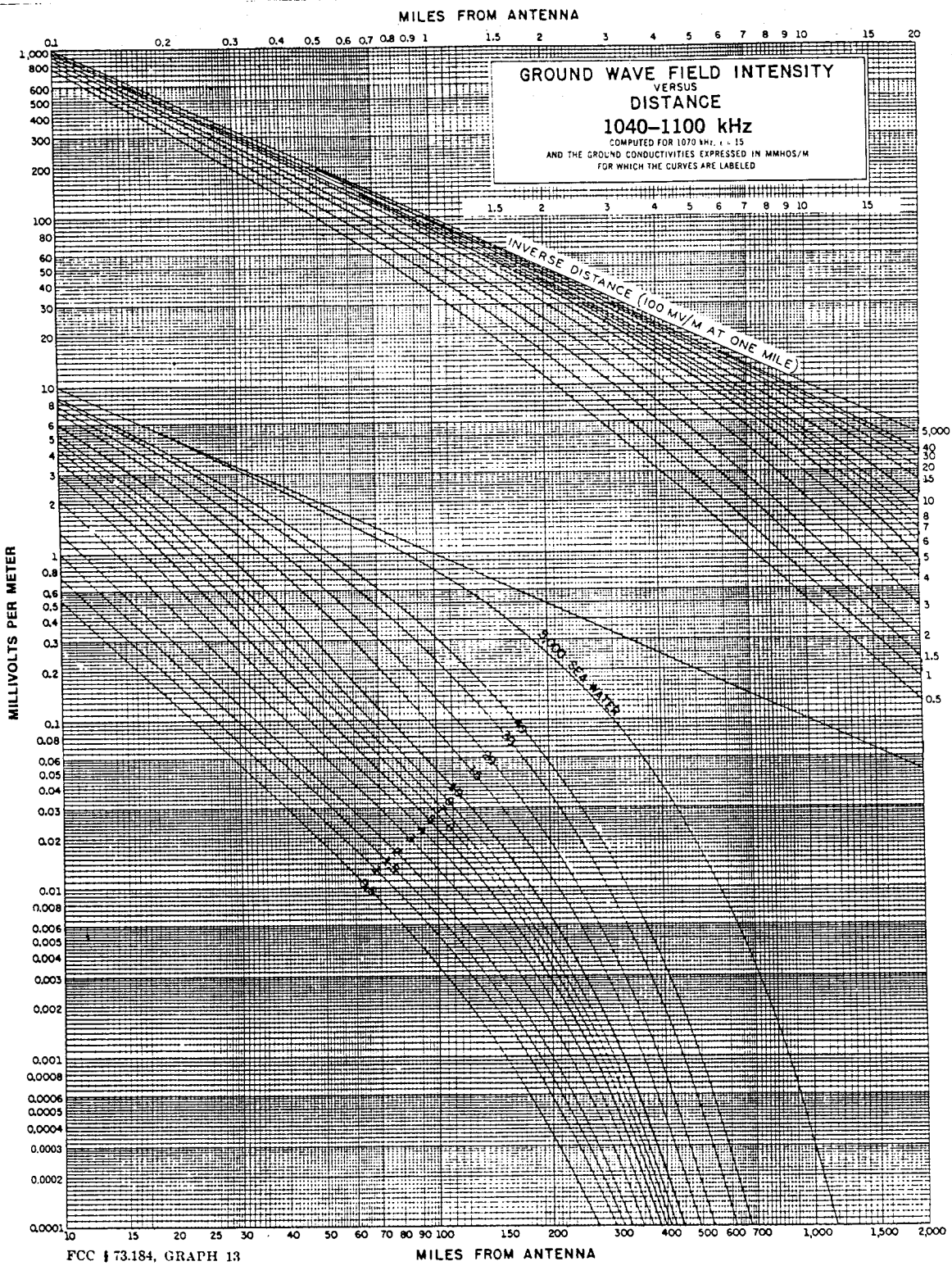
FCC § 73.184, GRAPH 10



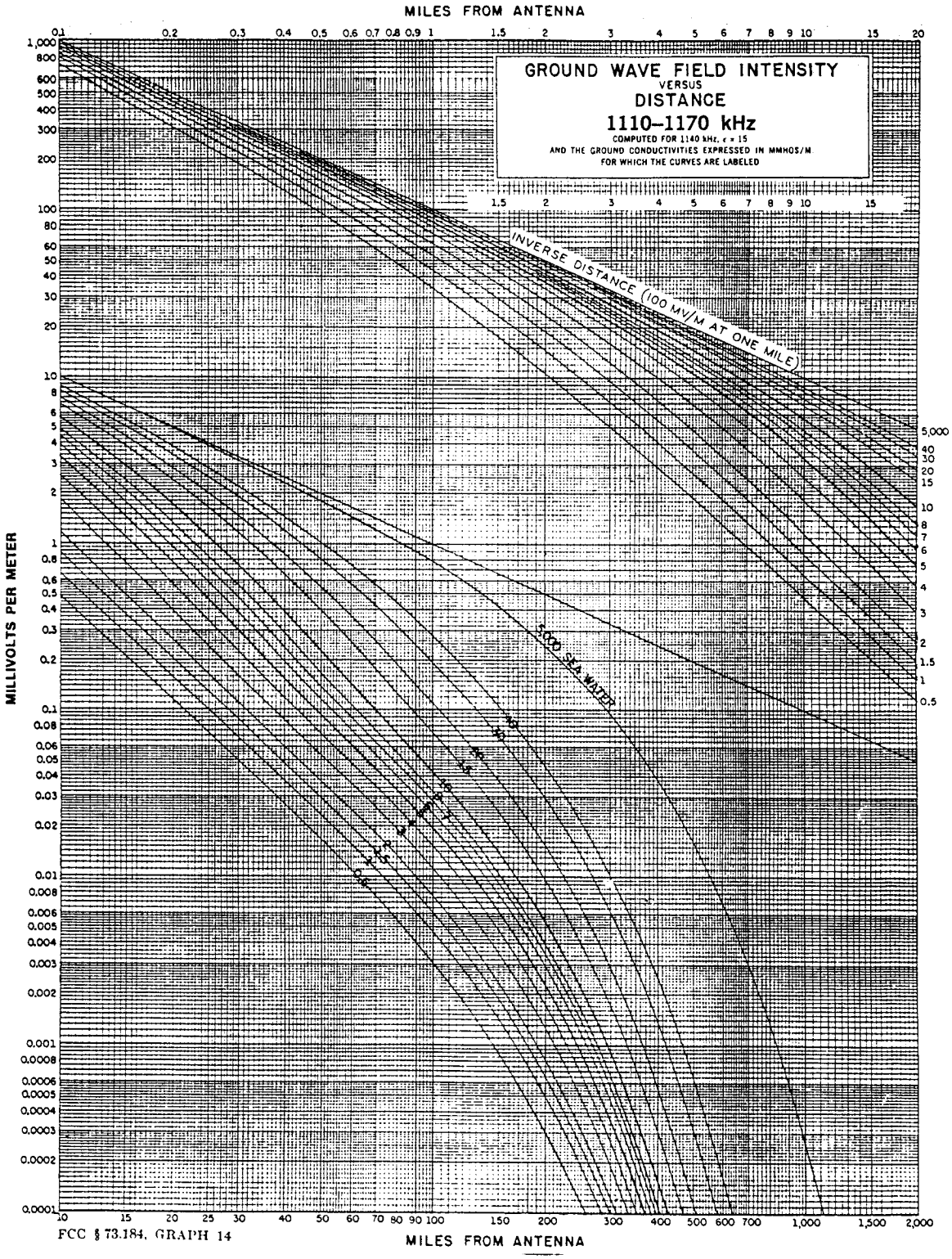
FCC § 73.184, GRAPH 11



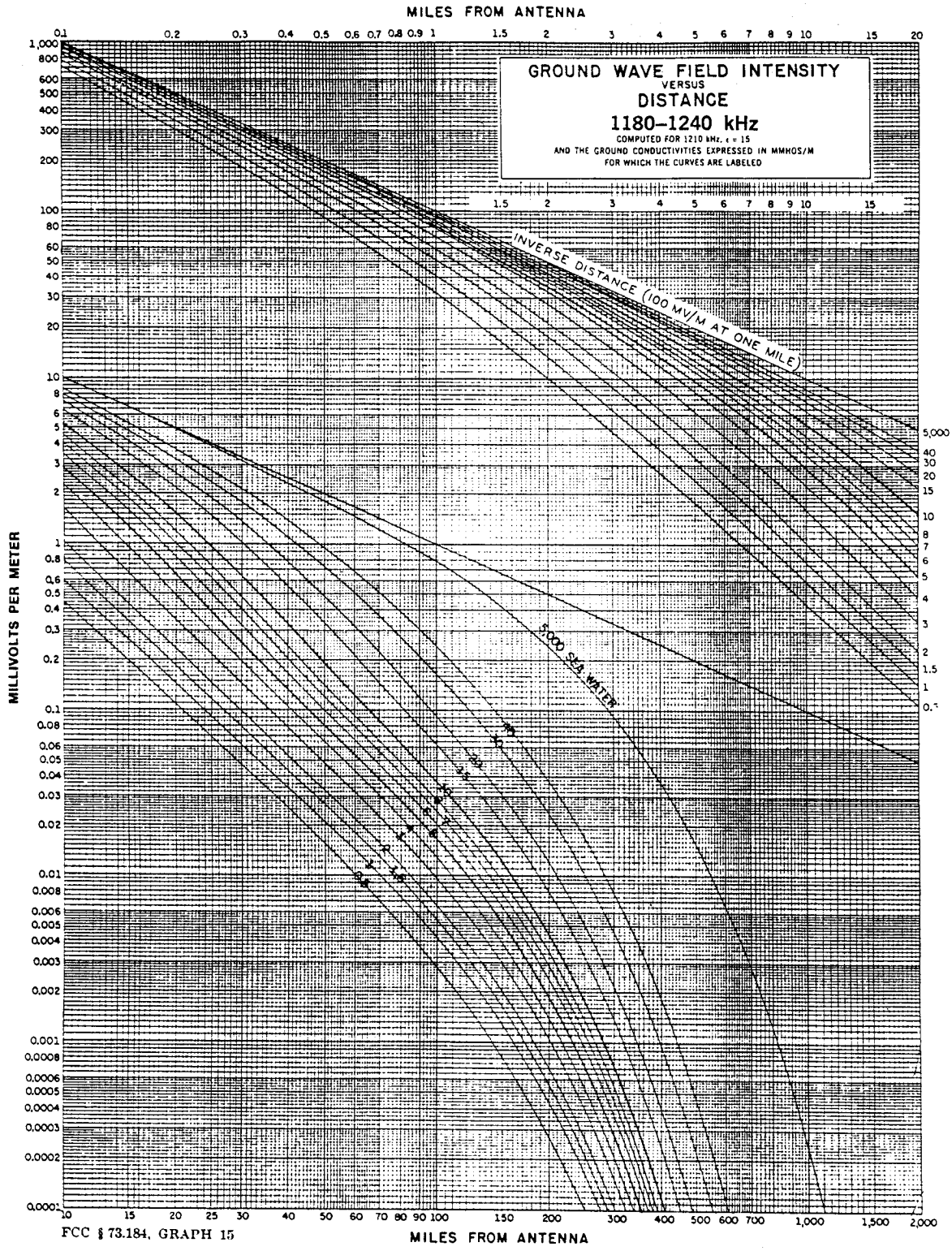
FCC § 73.184, GRAPH 12



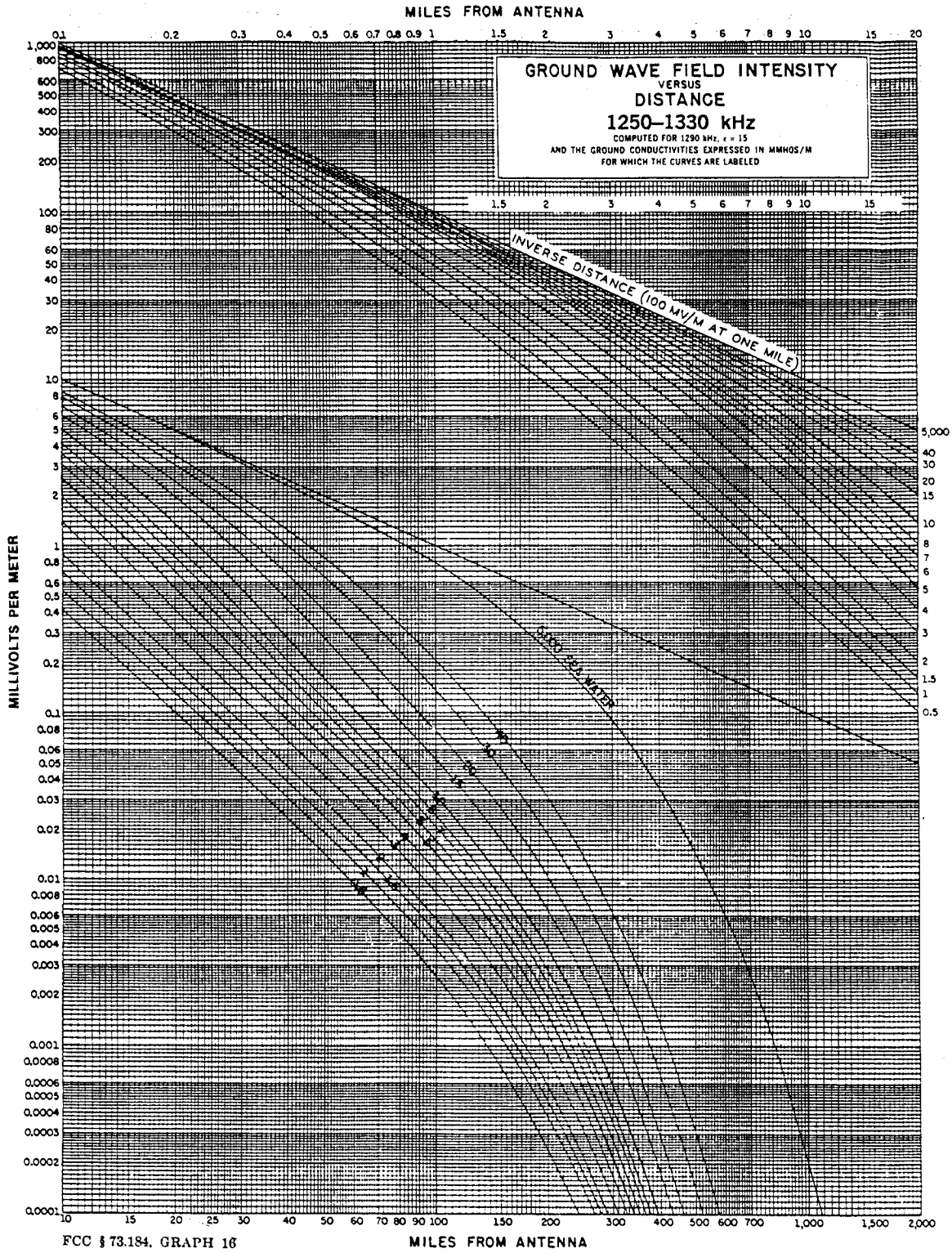
FCC § 73.184, GRAPH 13



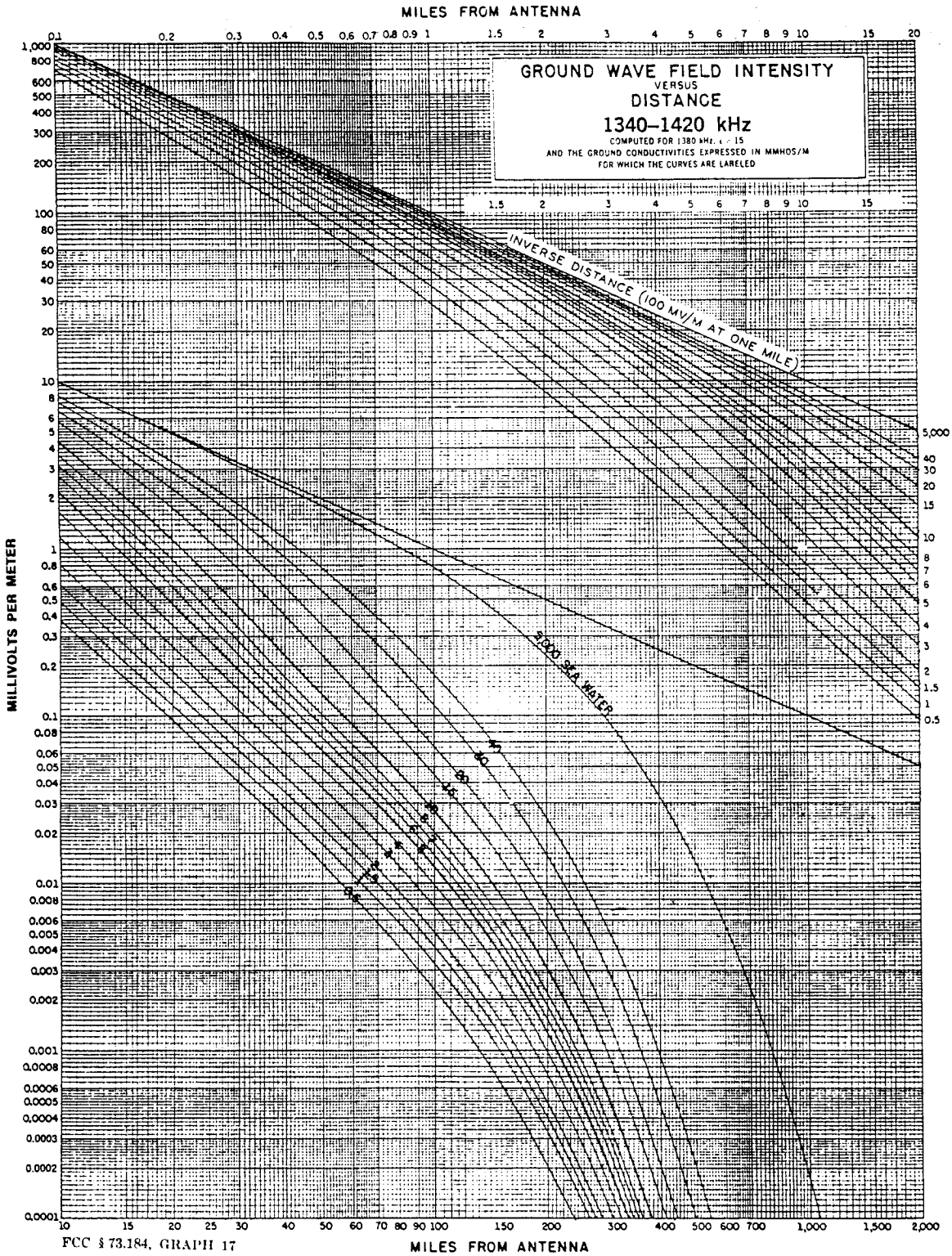
FCC § 73.184, GRAPH 14



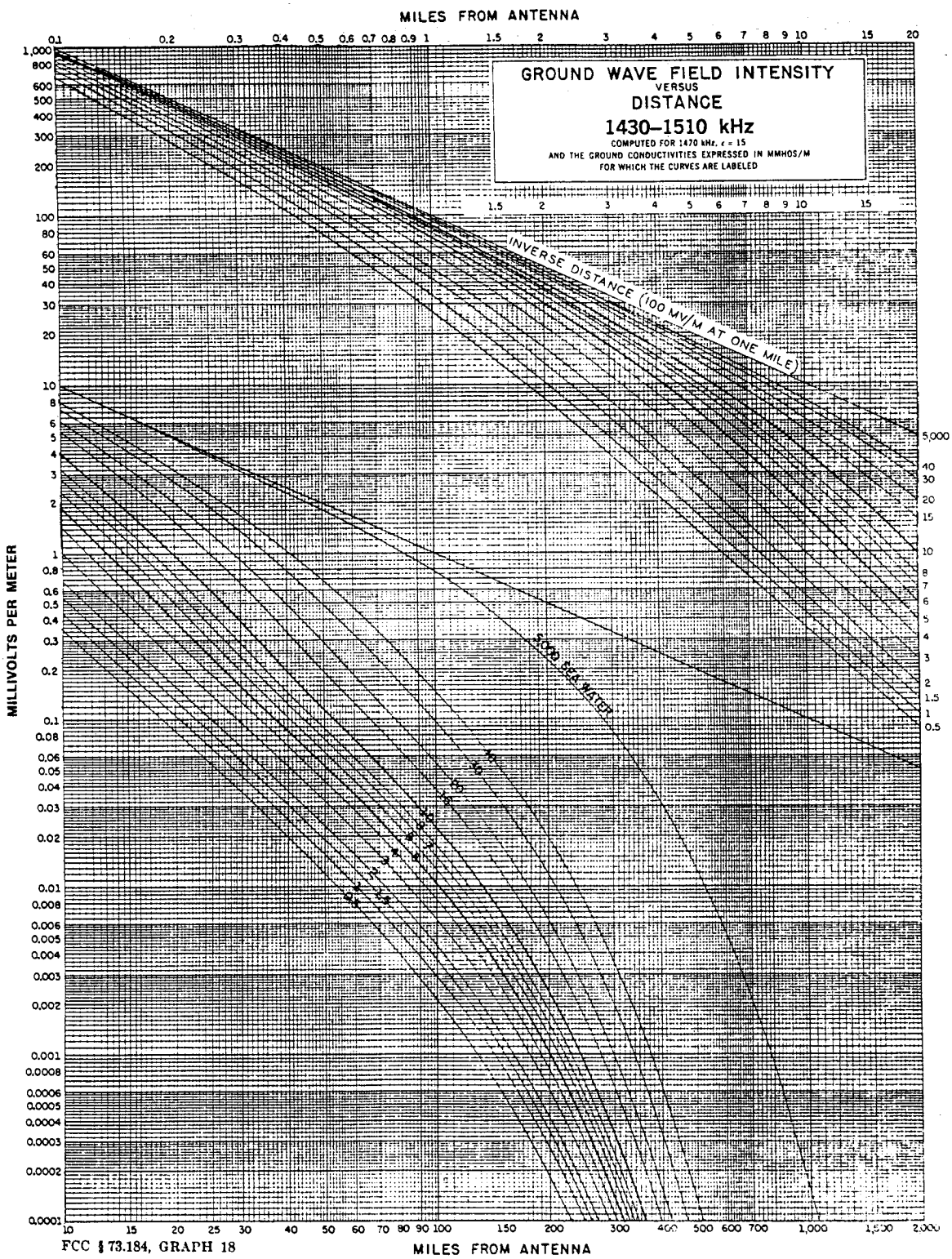
FCC § 73.184, GRAPH 15



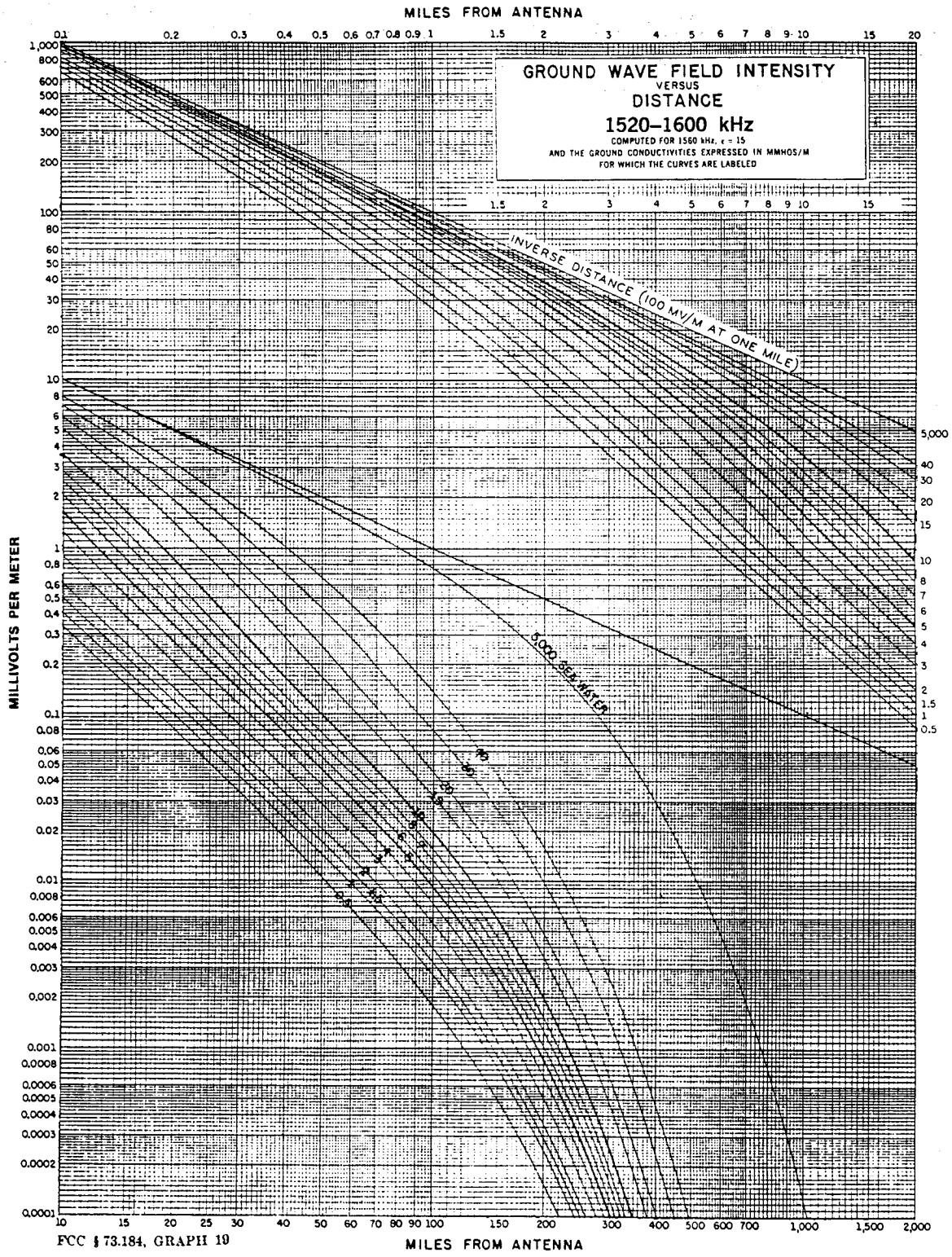
FCC § 73.184, GRAPH 16



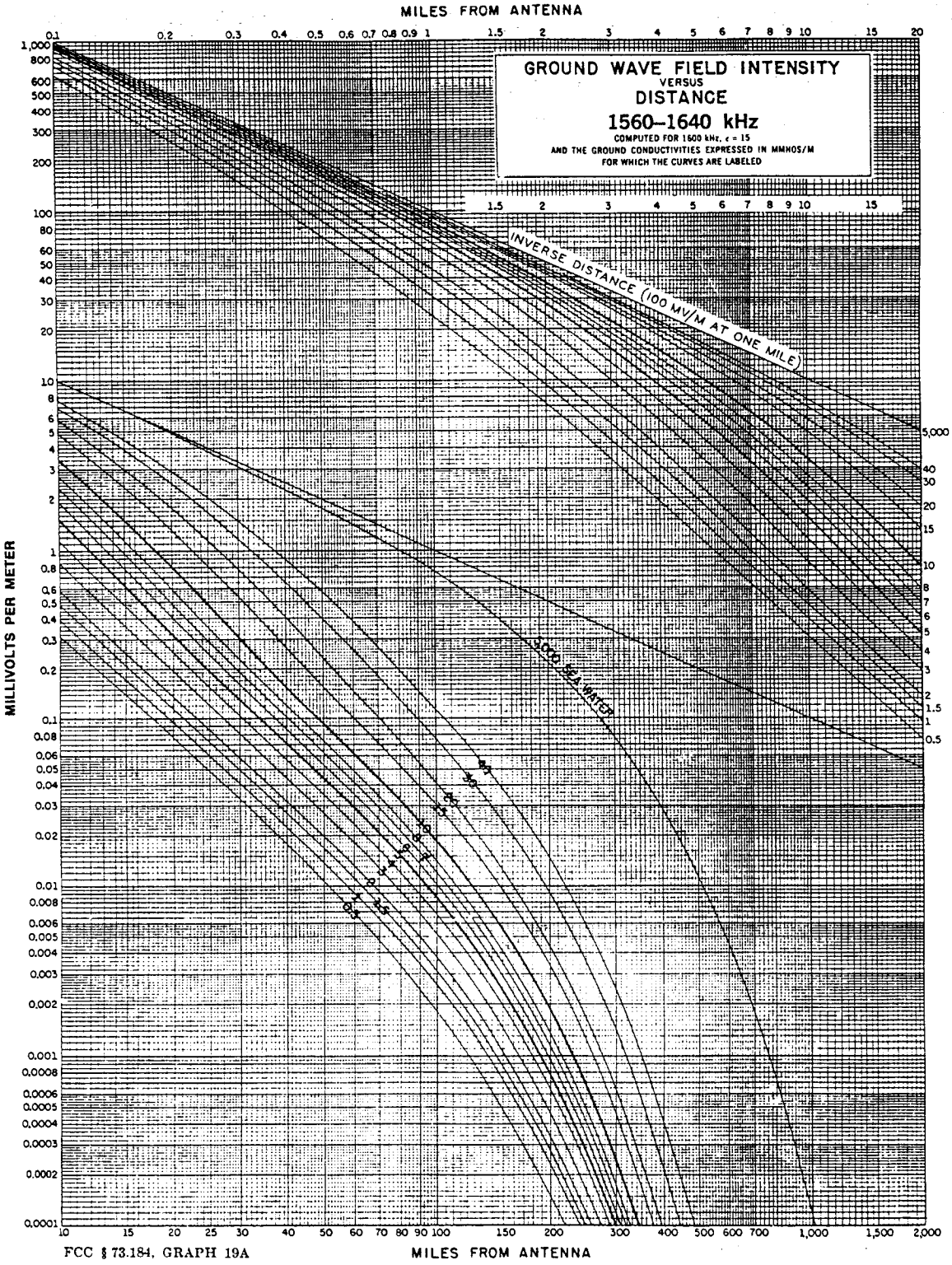
FCC § 73.184, GRAPH 17



FCC § 73.184, GRAPH 18



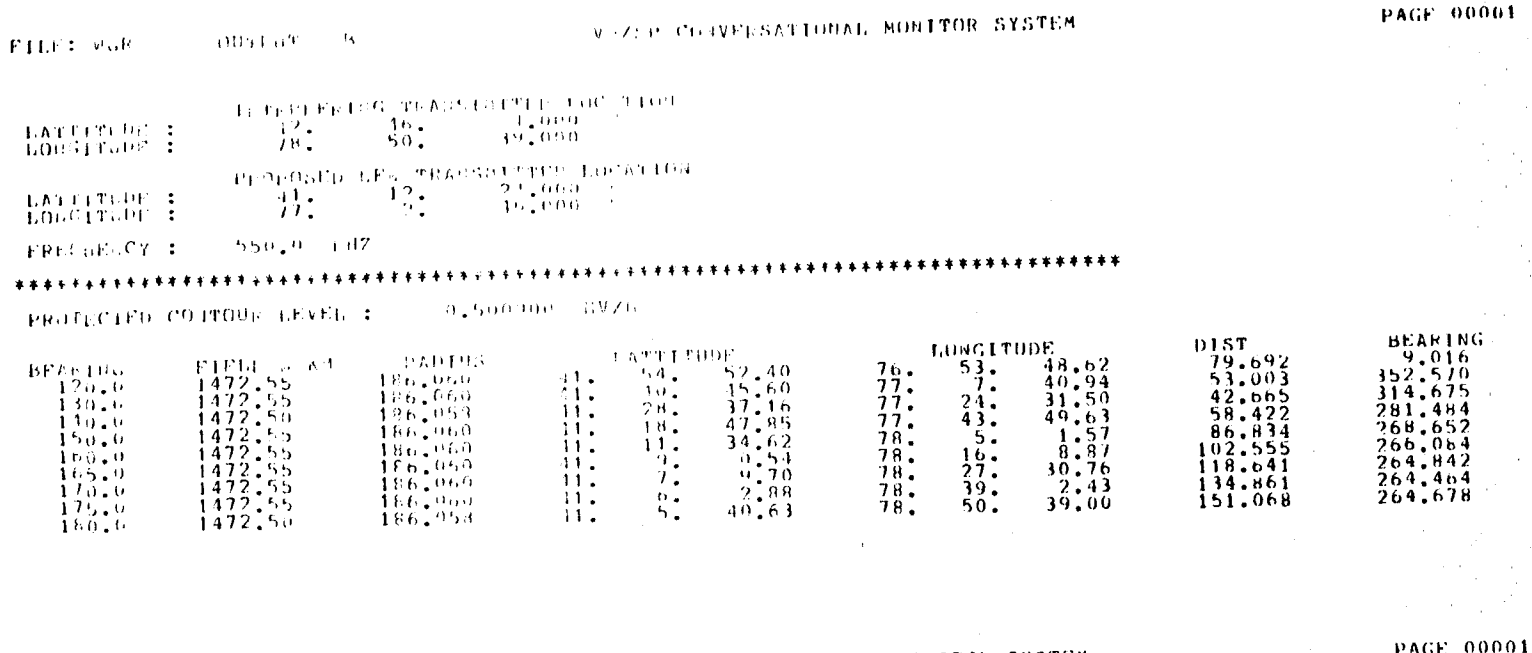
FCC § 73.184, GRAPH 19



FCC § 73.184, GRAPH 19A

APPENDIX D. EXAMPLE PROBLEM

This appendix contains the protected contour information of those stations not culled from the data base listing for feasibility studies of both the Smethport, and Williamsport, Pennsylvania service areas. These results were obtained using program PCMLL2, and the assumptions stated in Chapter IV. Figures D1 through D5 show the actual program output for the 0.5 mV/m contour for the stations listed on page 29. Figure D6 shows the location of the protected contours sketched in Figure D7 on a map of Pennsylvania. Figure D8 shows the maximum pattern envelope resulting from these contours.



FILE: WGR OUTPUT A V-FSP CONVERSATIONAL MONITOR SYSTEM PAGE 00001

INTERFERING TRANSMITTER LOCATION

LATITUDE : 42. 16. 1.000
LONGITUDE : 78. 50. 49.000

PROPOSED LPS TRANSMITTER LOCATION

LATITUDE : 41. 12. 21.000
LONGITUDE : 77. 2. 10.000

FREQUENCY : 550.0 KHZ

PROTECTED CONTOUR LEVEL : 0.500000 MV/M

BEARING	FIELD @ KM	RADIUS	LATITUDE			LONGITUDE			DIST	BEARING
120.0	1472.55	186.060	41.	54.	52.40	76.	53.	48.62	79.692	9.016
130.0	1472.55	186.060	41.	50.	15.60	77.	7.	40.94	53.003	352.570
140.0	1472.55	186.053	41.	28.	37.16	77.	24.	31.50	42.665	314.675
150.0	1472.55	186.060	41.	18.	47.85	77.	43.	49.63	58.422	281.484
160.0	1472.55	186.060	41.	11.	34.62	78.	5.	1.57	86.834	268.652
165.0	1472.55	186.060	41.	9.	0.54	78.	16.	8.87	102.555	266.064
170.0	1472.55	186.060	41.	7.	0.70	78.	27.	30.76	118.641	264.842
175.0	1472.55	186.060	41.	6.	2.88	78.	39.	2.43	134.861	264.464
180.0	1472.56	186.058	41.	5.	40.63	78.	50.	39.00	151.068	264.678

FILE: WFRB OUTPUT B V-FSP CONVERSATIONAL MONITOR SYSTEM PAGE 00001

INTERFERING TRANSMITTER LOCATION

LATITUDE : 42. 11. 2.000
LONGITUDE : 78. 57. 57.000

PROPOSED LPS TRANSMITTER LOCATION

LATITUDE : 41. 12. 21.000
LONGITUDE : 77. 2. 10.000

FREQUENCY : 540.0 KHZ

PROTECTED CONTOUR LEVEL : 0.500000 MV/M

BEARING	FIELD @ KM	RADIUS	LATITUDE			LONGITUDE			DIST	BEARING
0.0	1529.00	185.070	41.	20.	53.37	78.	57.	57.00	161.199	274.967
10.0	1529.00	185.070	41.	19.	20.09	78.	34.	51.86	128.944	275.214
20.0	1529.00	185.070	41.	11.	43.31	78.	12.	31.96	97.344	272.150
30.0	1529.00	185.070	41.	7.	12.06	77.	51.	40.74	68.923	261.695
40.0	1529.00	185.070	41.	5.	0.99	77.	32.	58.18	50.925	235.789
50.0	1529.00	185.070	41.	5.	29.82	77.	16.	59.31	55.411	200.970
60.0	1529.00	185.070	41.	8.	2.56	77.	4.	13.08	78.530	181.477
70.0	1529.00	185.070	41.	11.	6.64	76.	55.	1.50	108.577	174.294
80.0	1529.00	185.070	41.	14.	11.91	76.	49.	39.20	140.591	172.527

Figure D1. Results for WGR and WFRB

EXISTING TRANSMITTER LOCATION

LATITUDE : 40. 5. 59.000 N
LONGITUDE : 75. 15. 47.000 W

PROPOSED NEW TRANSMITTER LOCATION

LATITUDE : 41. 12. 24.000 N
LONGITUDE : 77. 2. 46.000 W

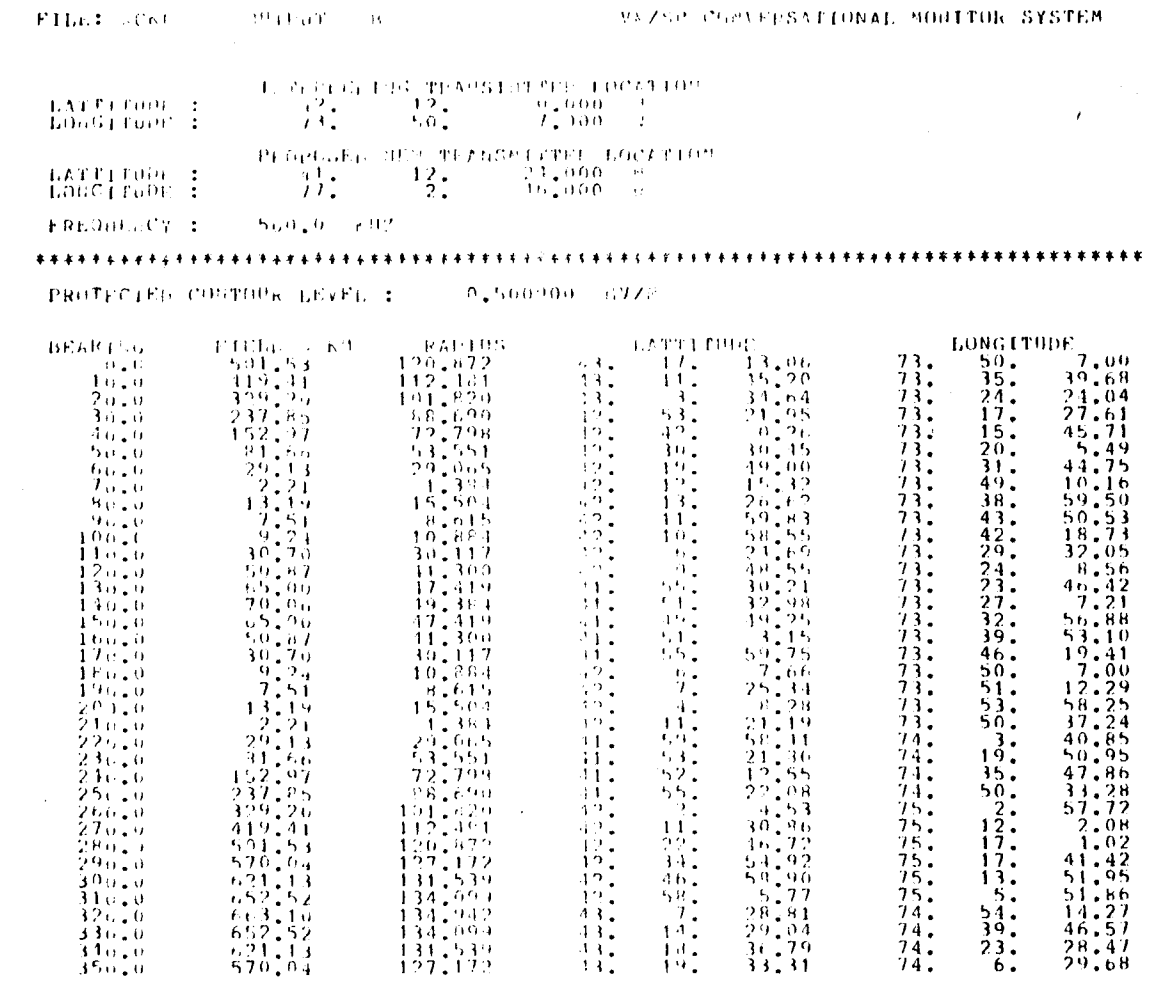
FREQUENCY : 560.0 KHZ

****

PROTECTED CONTOUR LEVEL : 0.500000 MV/M

BEARING	FIELD AT KM	RADIUS	LATITUDE			LONGITUDE			DIST	BEARING
0.0	504.36	121.143	41.	11.	20.84	75.	15.	47.00	149.203	91.336
10.0	397.32	110.030	41.	4.	26.15	75.	2.	6.54	169.052	95.670
20.0	357.69	105.385	40.	59.	22.12	74.	50.	1.18	186.965	98.148
30.0	357.69	105.386	40.	55.	7.59	74.	38.	9.55	204.590	99.793
40.0	356.88	105.287	40.	49.	20.13	74.	27.	31.78	221.250	101.987
50.0	361.85	105.889	40.	42.	28.22	74.	18.	2.81	237.119	104.426
60.0	424.87	113.072	40.	36.	8.53	74.	6.	11.57	256.291	106.160
70.0	571.15	127.270	40.	31.	57.33	73.	50.	56.52	280.721	107.708
80.0	767.65	142.821	40.	28.	39.36	73.	36.	15.36	306.519	110.080
90.0	971.55	156.273	40.	27.	6.76	73.	25.	34.06	329.877	113.382
100.0	1151.73	166.614	39.	59.	25.08	73.	20.	30.00	348.855	117.350
110.0	1288.71	173.749	39.	32.	58.81	73.	21.	31.65	362.609	121.722
120.0	1371.73	177.815	39.	17.	10.89	73.	28.	25.79	370.802	126.301
130.0	1395.81	178.969	39.	4.	15.59	73.	40.	31.74	373.327	130.945
140.0	1359.74	177.239	38.	52.	16.50	73.	56.	49.95	370.156	135.536
150.0	1265.34	172.571	38.	45.	5.19	74.	16.	5.36	361.311	139.960
160.0	1118.67	164.807	38.	32.	18.76	74.	36.	48.83	346.911	144.073
170.0	931.86	153.619	38.	14.	13.49	74.	57.	18.53	327.343	147.689
180.0	726.53	139.618	37.	50.	32.60	75.	15.	47.00	303.588	150.563
190.0	536.39	124.149	37.	30.	50.95	75.	30.	45.00	277.891	152.497
200.0	405.34	110.930	37.	9.	41.37	75.	42.	11.03	254.435	153.788
210.0	358.12	105.438	36.	56.	37.07	75.	52.	31.71	236.470	155.529
220.0	357.67	105.383	36.	42.	15.87	76.	3.	3.70	220.880	157.855
230.0	356.92	105.292	36.	29.	11.21	76.	12.	10.40	204.115	159.778
240.0	360.55	105.769	36.	17.	9.18	76.	19.	56.68	186.581	161.334
250.0	413.46	111.230	36.	4.	57.33	76.	29.	31.91	168.702	164.055
260.0	532.26	123.768	35.	54.	51.58	76.	41.	30.55	148.609	168.494
270.0	686.46	136.772	35.	45.	18.99	76.	52.	14.91	125.207	173.273
280.0	837.91	147.710	35.	39.	3.88	76.	58.	43.69	99.012	176.740
290.0	959.75	155.551	35.	33.	55.15	76.	59.	36.44	71.456	176.465
300.0	1035.91	160.111	35.	28.	29.91	76.	54.	37.85	45.766	165.648
310.0	1058.31	161.407	41.	1.	24.10	76.	44.	12.70	32.960	128.283
320.0	1024.82	159.469	41.	11.	30.58	76.	29.	16.53	46.733	92.207
330.0	938.65	154.244	41.	17.	50.39	76.	11.	10.04	72.601	82.301
340.0	809.30	145.753	41.	19.	47.51	75.	51.	35.99	100.080	82.524
350.0	654.76	131.278	41.	17.	18.82	75.	32.	31.53	126.077	86.354

Figure D2. Results for WFIL



PROTECTED CONTOUR LEVEL : 0.500000 dBZ

BEARING	FIELD - KM	RADIUS	LATITUDE			LONGITUDE			DIST	BEARING
0.00	501.53	120.872	43.	17.	13.06	73.	50.	7.00	351.196	49.895
10.00	419.41	112.161	43.	11.	35.20	73.	35.	39.68	360.201	53.289
20.00	399.26	101.820	43.	3.	34.64	73.	24.	24.04	363.998	56.760
30.00	237.85	86.699	42.	53.	21.95	73.	17.	27.61	362.118	60.158
40.00	152.97	72.798	42.	49.	0.96	73.	15.	45.71	354.178	64.316
50.00	81.56	58.551	42.	30.	30.15	73.	20.	5.49	339.720	66.029
60.00	29.13	29.065	42.	19.	49.00	73.	31.	44.75	317.298	67.991
70.00	2.21	1.381	42.	12.	15.32	73.	49.	10.16	289.912	68.584
80.00	13.19	15.504	42.	13.	26.62	73.	38.	59.50	303.741	69.270
90.00	7.51	8.915	42.	11.	59.83	73.	43.	50.53	296.564	69.244
100.00	9.24	10.884	42.	10.	58.55	73.	42.	18.73	297.869	69.745
110.00	30.70	30.117	42.	6.	21.69	73.	29.	32.05	311.745	72.459
120.00	50.87	41.300	42.	3.	48.55	73.	24.	8.56	315.929	74.719
130.00	65.00	47.419	41.	55.	30.21	73.	23.	46.42	313.976	76.477
140.00	70.06	49.384	41.	51.	32.98	73.	27.	7.21	307.831	77.564
150.00	65.00	47.419	41.	47.	34.25	73.	32.	56.88	299.285	77.765
160.00	50.87	41.300	41.	43.	8.15	73.	39.	53.10	290.443	76.847
170.00	30.70	30.117	41.	39.	59.75	73.	46.	19.41	284.095	74.569
180.00	9.24	10.884	41.	38.	7.66	73.	50.	7.00	284.732	70.604
190.00	7.51	8.915	41.	37.	25.34	73.	51.	12.29	284.131	70.035
200.00	13.19	15.504	41.	36.	8.28	73.	53.	58.25	278.511	70.913
210.00	2.21	1.381	41.	31.	21.19	73.	50.	37.24	287.448	68.732
220.00	29.13	29.065	41.	29.	58.11	74.	3.	40.85	263.369	71.137
230.00	81.56	58.551	41.	28.	21.36	74.	19.	50.95	238.375	72.333
240.00	152.97	72.798	41.	32.	12.55	74.	35.	47.86	216.814	70.921
250.00	237.85	86.699	41.	35.	22.08	74.	50.	34.28	199.879	67.255
260.00	399.26	101.820	42.	2.	4.53	75.	2.	57.72	189.805	61.651
270.00	419.41	112.161	42.	11.	30.86	75.	12.	2.08	188.363	55.052
280.00	501.53	120.872	42.	22.	16.72	75.	17.	1.02	195.812	48.823
290.00	570.04	127.172	42.	34.	54.92	75.	17.	41.42	210.709	44.056
300.00	621.13	131.539	42.	46.	58.96	75.	13.	51.95	230.702	41.165
310.00	652.52	134.094	42.	58.	5.77	75.	5.	51.86	253.416	40.036
320.00	663.10	134.942	43.	7.	28.81	74.	54.	14.27	276.864	40.343
330.00	652.52	134.094	43.	14.	29.04	74.	39.	46.57	299.488	41.743
340.00	621.13	131.539	43.	14.	36.79	74.	23.	28.47	320.061	43.948
350.00	570.04	127.172	43.	14.	33.31	74.	6.	29.68	337.578	46.728

Figure D3. Results for WCKL

PAGE 00001

Figure D4. Results for WHLM

LATITUDE : 42. 59. 13.000
LONGITUDE : 77. 9. 9.000

LATITUDE : 41. 12. 24.000
LONGITUDE : 77. 9. 10.000

FREQUENCY : 572.0 MHZ

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PROFILES CONTOUR LEVEL : [illegible] FT/SEC

FEET(M)	FIELD (DB)	FEET	LATITUDE			LONGITUDE			DIST	BEARING
0.0	626.77	190.141	41.	9.	4.25	76.	9.	9.00	335.449	12.883
10.0	591.56	180.535	41.	6.	26.00	75.	52.	38.38	336.404	16.905
20.0	591.56	180.533	41.	3.	17.90	75.	36.	39.55	337.784	20.829
30.0	626.77	190.134	41.	54.	31.71	75.	20.	30.92	339.636	24.804
40.0	699.10	135.073	41.	51.	41.51	75.	4.	7.39	341.676	28.967
50.0	806.96	142.783	41.	48.	15.35	74.	47.	22.61	342.981	33.404
60.0	938.36	151.118	41.	39.	13.10	74.	31.	31.70	341.918	38.087
70.0	1055.96	158.229	41.	27.	31.77	74.	18.	38.30	336.544	42.849
80.0	1121.94	161.856	41.	14.	22.10	74.	11.	6.80	325.210	47.391
90.0	1093.37	160.291	41.	58.	12.17	74.	10.	56.36	307.057	51.284
100.0	952.69	152.116	41.	44.	4.82	74.	19.	4.49	282.373	53.927
110.0	719.27	136.573	41.	33.	22.18	74.	35.	8.46	252.995	54.448
120.0	417.02	114.169	41.	28.	18.74	74.	57.	27.55	222.993	51.584
130.0	216.02	83.417	41.	30.	7.88	75.	22.	23.02	199.879	44.450
140.0	164.56	73.869	41.	34.	35.97	75.	44.	25.06	186.609	41.313
150.0	215.02	88.215	41.	47.	51.40	76.	6.	57.85	169.742	44.816
160.0	304.92	96.699	42.	10.	8.92	76.	45.	4.52	151.712	45.566
170.0	333.01	100.433	42.	5.	50.27	76.	56.	28.12	135.046	43.199
180.0	317.55	102.110	42.	4.	7.32	76.	9.	9.00	121.261	38.064
190.0	353.61	102.865	42.	3.	33.33	76.	22.	7.88	111.855	30.435
200.0	353.61	102.815	42.	7.	1.16	76.	34.	44.10	108.423	21.131
210.0	317.55	102.110	42.	11.	24.13	76.	46.	19.74	111.693	11.842
220.0	333.01	100.433	42.	17.	32.55	76.	56.	14.34	121.070	4.312
230.0	304.92	96.699	42.	25.	28.04	77.	3.	17.55	135.422	359.690
240.0	245.89	88.286	42.	35.	10.90	77.	5.	9.35	153.460	358.756
250.0	164.56	73.869	42.	45.	23.82	77.	0.	9.30	172.395	1.211
260.0	216.02	83.417	42.	51.	8.13	77.	9.	36.76	183.235	357.013
270.0	417.02	114.169	42.	56.	42.68	77.	32.	36.75	201.262	348.065
280.0	719.27	136.573	43.	11.	17.72	77.	48.	41.29	229.196	343.774
290.0	952.69	152.116	43.	26.	28.71	77.	55.	24.00	258.746	343.519
300.0	1093.37	160.291	43.	41.	11.27	77.	52.	44.87	284.997	345.841
310.0	1121.94	161.856	43.	54.	13.97	77.	42.	0.96	305.593	349.680
320.0	1055.96	158.229	44.	1.	11.21	77.	25.	40.81	319.890	354.307
330.0	938.36	151.118	44.	0.	36.74	77.	5.	59.23	328.468	359.216
340.0	806.96	142.783	44.	11.	30.81	76.	45.	53.77	332.756	4.056
350.0	699.10	135.073	44.	10.	58.01	76.	26.	47.78	334.554	8.626

Figure D5. Results for WSYR

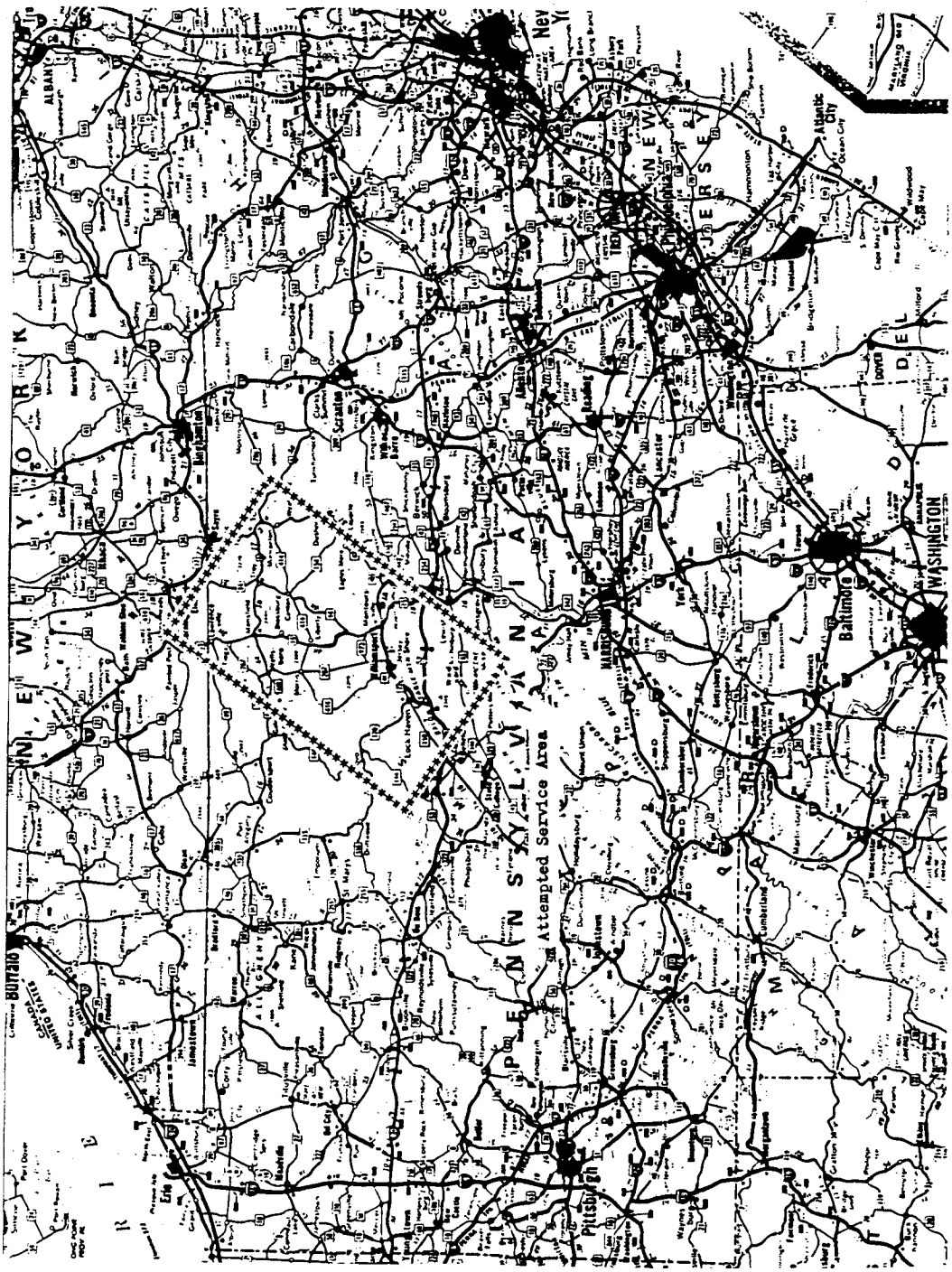

Figure D6. Attempted Service Area

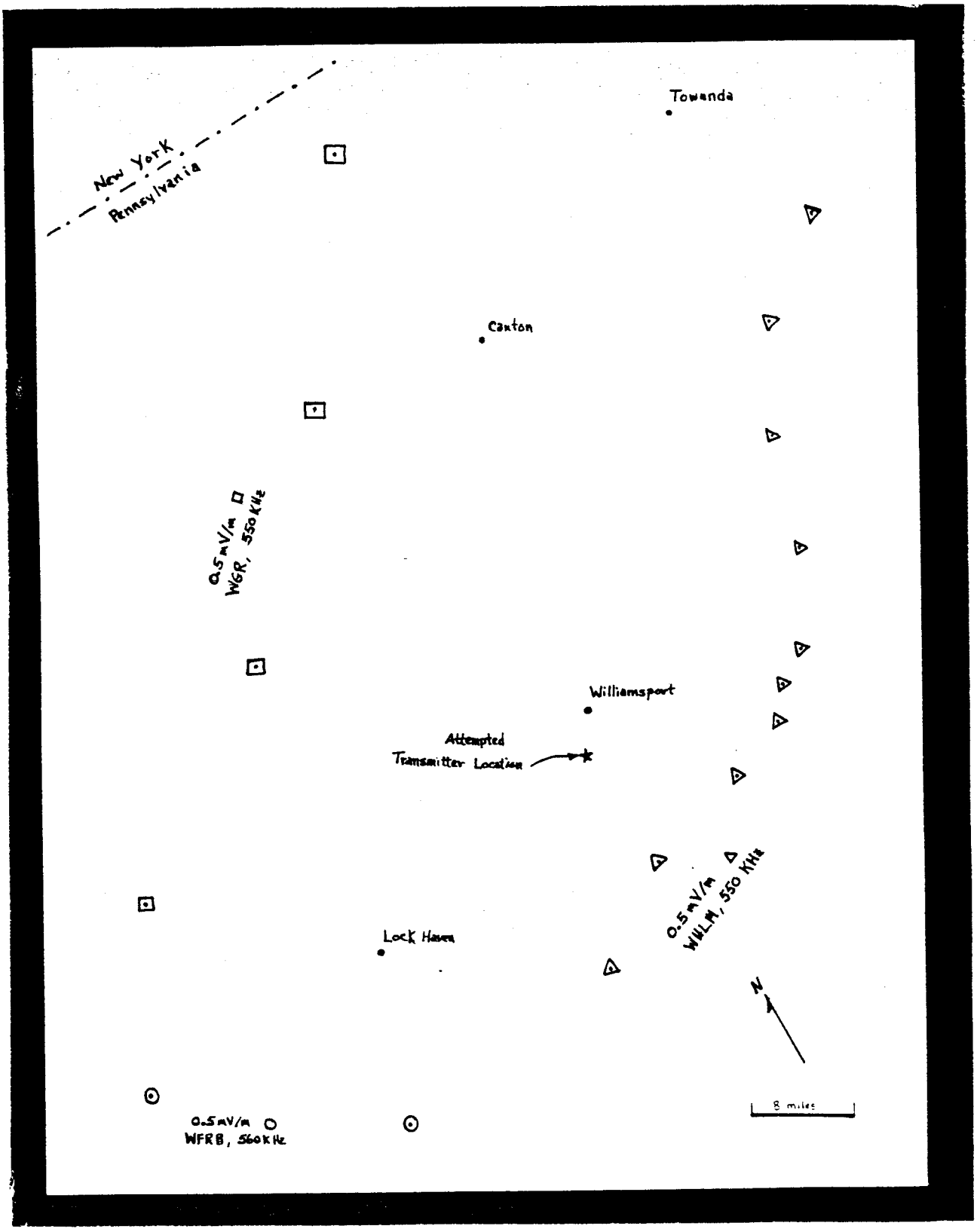

Figure D7. Protected Contour Points

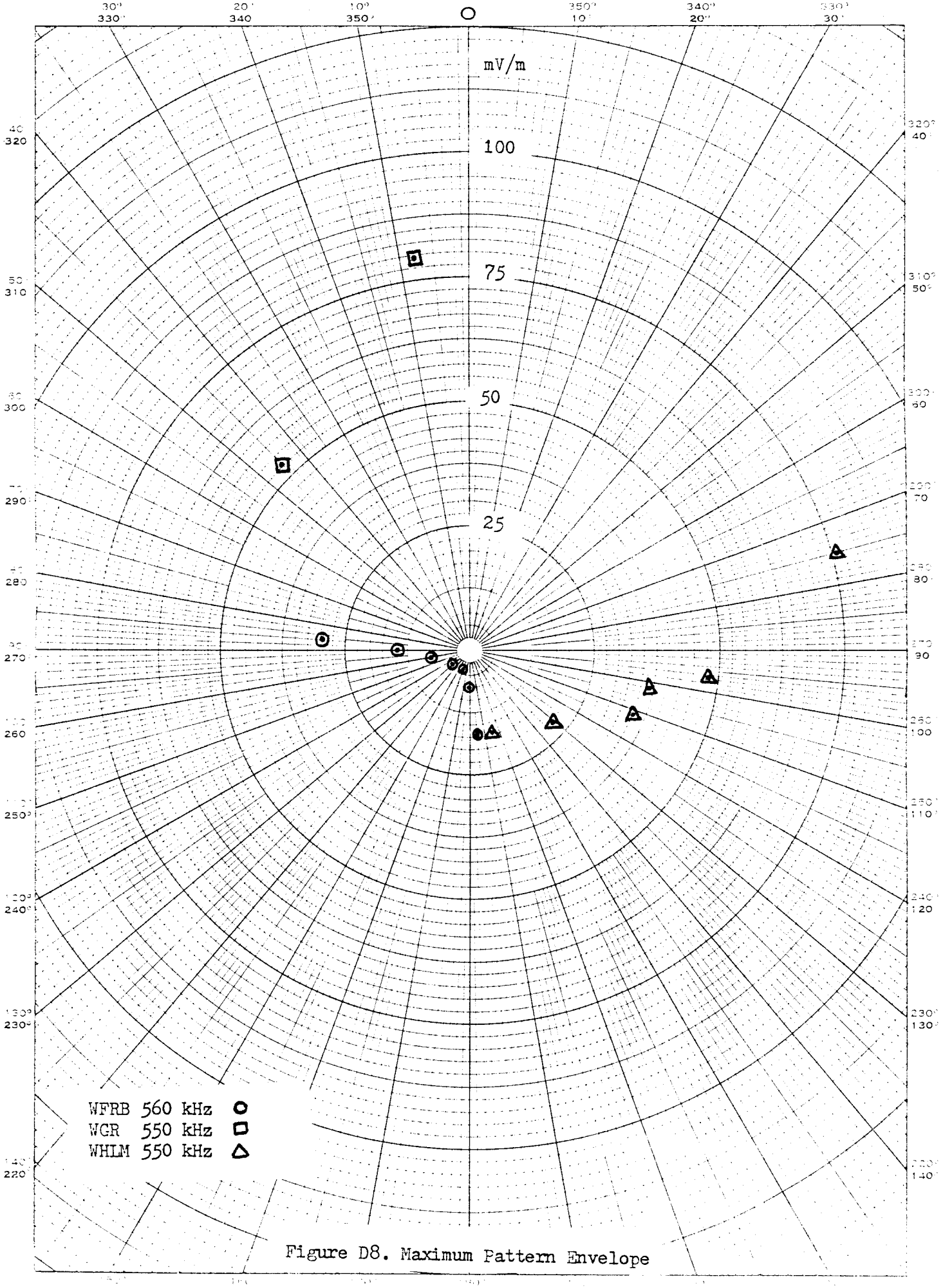

Figure D8. Maximum Pattern Envelope

APPROVAL OF EXAMINING COMMITTEE

Wils L. Cooley, Ph.D.

Mark A. Jerabek, Ph.D.

Date

James F. Corum, Ph.D., Chairman