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A UNIFORM CELL PROPAGATION DATA BASE FOR MEDIUMWAVE ALLOCATION STUDIES

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Abstract

A conductivity data base created from a uniform cell grid structure is described. The uniform cell data base, which is primarily intended for use in mediumwave band groundwave propagation studies, is based on the existing geographic latitude and longitude grid. Considerations in choosing fundamental cell parameters, such as size and shape, and applications of the data base to computerized mediumwave frequency allocation problems are also discussed.

1.0 Introduction

The problem of determining how best to allocate frequency spectrum space to serve the diverse requirements of the public and industry has demanded increasingly exact engineering methods for predicting the highest feasible density of assigned spectrum occupiers. In the dimensions of the spectrum assigned to broadcasting, the allocation problems are especially accute. This has led spectrum regulators to constantly look toward more accurate computerized engineering methods to replace existing methods based on estimated or extrapolated data which have been used for years.

For mediumwave stations operating during the daytime, channel allocations are largely controlled by the extent of groundwave propagation. All other factors being equal, the field strength of a groundwave at some distance from the transmitter is governed by the conductivity and permittivity of the surface and subsurface earth. Curves and calculation methods have been developed which predict with reasonable accuracy the field strength at a given distance with a given intervening conductivity. The limitation in the field strength prediction process has always been the lack of detailed and accurate conductivity data.

This paper will not deal with the problem of gathering accurate conductivity data, but rather suggest a form of conductivity data base which can be established now with existing data and readily updated as new information is obtained. Periodic revision of the data base will allow increasingly refined field strength contour predictions. The described data base is designed to be updated and accessed by computer programs which will allow automated calculation and plotting of groundwave field strength contours.

2.0 Current Methods

Soil conductivity data used in the United States for spectrum allocation purposes is presently in two forms. The first is a map of the country, shown in Figure 1, developed in the 1950's delineating regions of different conductivity which were originally established based on measurement data available at that time and estimates derived from geological information. This map, which has been digitized for use with computer programs, is still used to predict groundwave contour locations where no specific measurement data is available.

The second source of conductivity data is the vast quantity of actual field strength measurements which have been done on new and existing mediumwave broadcast stations since the time of the map's creation. This data primarily resides in the files of the FCC as part of special engineering studies and the normal proof-of-performance engineering exhibits submitted with AM license applications. The accuracy of this data, which is in both tabular and graphical form, depends on the engineering skills of the personnel conducting the measurements and analyzing the results. In some cases, measurements in the same area will indicate different conductivities due to different analysis methods, actual seasonal variations in ground characteristics, and terrain shielding differences affecting both the spacewave and groundwave field strength contributions at a measurement location, depending on the direction to the transmitter.

The task of organizing this data into a consistent form which can be used in computerized allocation studies is addressed in a recent Notice of Inquiry in FCC Docket B.C. 80-757 [1]. Beyond the large amount of data reduction which must be done, certain decisions must also be made about which of the data is valid and how conflicts in different measured conductivities in the same area can be resolved. Assuming such questions can be answered, and sufficient resources assigned to data reduction, the existing measurement data is a good start at improving the validity of field strength predictions.

The existing conductivity map (designated FCC Figure M3) consists of soil region boundary lines which meander their way across the countryside in what can be considered a completely random fashion from an analytical point of view. The digitized version of this map developed in 1978 [2], and implemented on the FCC computer in 1979, contains a long tabulation of short, straight line segments (actually great circle sectors) which represent the geographic location of the soil region boundaries and coastlines. Because the soil boundaries are randomly located, it is necessary to store both the location of each segment and the conductivity on each side of the segment.

The digitized M3 map data base has proven convenient for allocation studies involving only estimated data on the map. However, incorporating measurement data requires typing individual measured regions into the computer for the specific stations involved. To modify the map to reflect these measured zones would require redrawing the soil region boundaries on the map in some reasonable fashion, or constructing several small, discontinuous, oddly shaped cells around each area where a valid set of measurements

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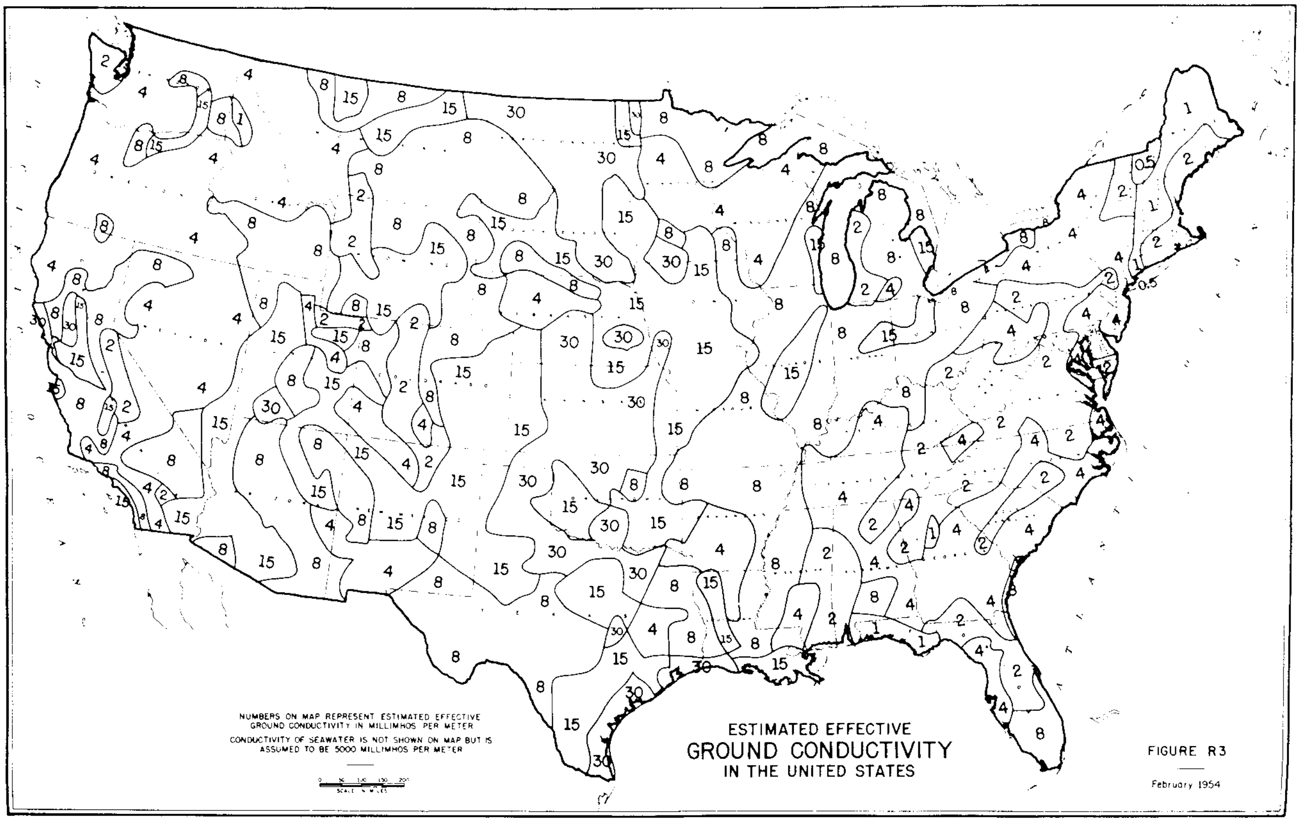

FIGURE 1. FCC M3 CONDUCTIVITY MAP.

had been done. Once the boundaries were redrawn, or the new cells constructed, the boundaries would have to be digitized in a form which was consistent with the existing data base. Every time new measurement data was received, this largely graphical process would have to be repeated. Rules for how existing boundaries would be moved, or new cells created, would be relatively complex and arbitrary. It seems apparent, then, that a new form of conductivity data base which is more amenable to conductivity changes would improve the field strength prediction process.

3.0 Uniform Cell Propagation Data Base

Many of the problems of updating the M3 map data base described above can be eliminated by creating a new data base which is not structured around digitized lines on map, but rather is made up of cells of uniform geographic size and shape. The conductivities assigned to each cell would be changeable based on valid measurement data. However, the cell boundaries would remain fixed, as would the structure and organization of the computer data file which contains the data. Establishing such a data base requires careful consideration of how the data will be used, what resolution is required, and what simple algorithms can be employed to refine the data base to reflect the most recent measurement data available. These issues are addressed in the following sections.

3.1 Considerations is Selecting Cell Size and Shape

The fundamental requirement is that the cell boundaries intersect in such a way that the entire surface can be included in the cell structure. Cell shapes based on a linear grid, such as squares, rectangles, equilateral triangles, and hexagons, are such cell shapes. Circular cells are not suitable. Though several shapes meet the fundamental requirement, only two shapes will be considered — the square and the isometric triangle. For this use, there is no apparent advantage of the rectangle over the square, and the hexagon is founded in the same grid structure as the isometric triangle. The square and isometric triangle, therefore, are representative of the practical cell shapes available.

Beyond the fundamental requirement, there are three primary considerations which affect cell size and shape, as follows:

1. The physical (geographic) resolution deemed necessary and technically justifiable given the intended use of the data base and the accuracy of the measurement/update process.
2. The number of cell boundary crossings which will be encountered in a radial direction from a station. This impacts program calculation speed.
3. Compatibility with the existing geographic grid.

3.1.1 Required Resolution

The first issue is the most difficult to deal with since several critical factors involving allocation rules and field strength measurement accuracy are included. Instead of a lengthy treatment of these subjects, an example will be drawn from the resolution of the existing M3 map data base.

This data base was constructed so that the straight line segments which represent the soil zone boundaries not extend beyond the width of the boundary lines printed on the actual map. These lines, printed in red, are roughly 5 kilometers wide at map scale. Line segments representing coastlines in general follow the coastline within about one

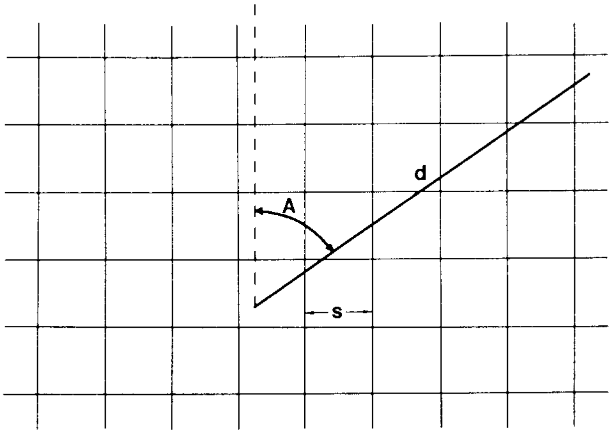

FIGURE 2. SQUARE CELL STRUCTURE.

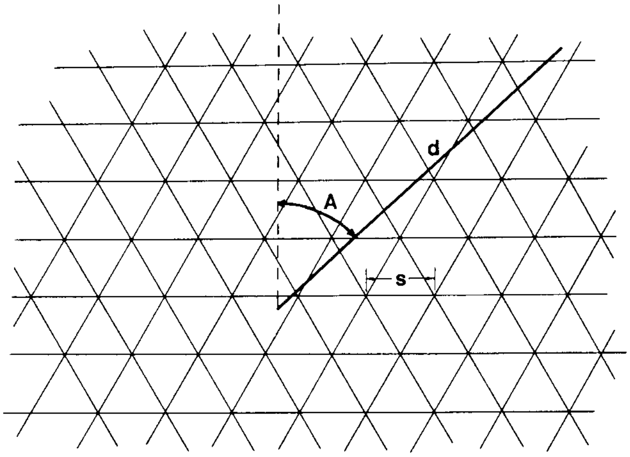

FIGURE 3. ISOMETRIC TRIANGLE CELL STRUCTURE.

half of this distance. To retain comparable resolution with the uniform cell data base, a cell size on the order of the soil zone boundary line width would be indicated.

3.1.2 Number of Cell Boundary Crossings

The impact of cell size on computation difficulties is the second factor affecting cell size and shape selection. As the cell size decreases, the number of cell boundaries crossed on a given radial increases, with a corresponding increase in the computations required.

No statistical data is available for the number of boundary crossings encountered with the existing M3 map data base. However, in the existing software, the relevant arrays are diminsioned to 50. It is understood that this limit has never been encountered, although 20 to 30 crossings on an 800 kilometer radial along the eastern coastline are not uncommon.

Unlike the issue previously addressed, it is possible to readily determine the impact of cell size and shape on the number of boundary crossings and the length of those crossings. A linear (non-geographic) square cell structure is shown in Figure 2 with a radial at azimuth A. The number of crossings can be easily calculated if the grid is considered as two sets of parallel lines which intersect at right angles, and the number of crossings for each set determined separately.

Given a radial distance, D, and a grid spacing, S, the number of horizontal lines crossed, NH, is:

$$NH = (D/S) \times \sin A$$

Similarly, for vertical lines:

$$NV = (D/S) \times \cos A$$

The total number of crossings, NT, becomes:

$$NT = (D/S) \times (\sin A + \cos A)$$

A similar method for an isometric triangle cell structure shown in Figure 3 can be used by considering three sets of parallel lines at 60 degree angles to each other. Considering each group separately, and summing, yields:

$$NT = (D/S) \times (\sin (A+30.) + \sin (A-30.) + \cos (A))$$

for the triangle grid.

These simple equations ignore starting points between grid lines and the increase in boundary crossings with diminishing meridian spacings at increasing latitudes. Moving the radial starting point inside a cell will only have a small effect on the number of boundary crossings and consequently, not greatly impact the distribution of the number of crossings.

The decreasing cell width at increasing latitudes can be approximated, for comparison purposes, by choosing a linear grid spacing which roughly corresponds to the average height and width of a geographical cell at some appropriate mid-latitude.

Using these equations, a short computer program was written to calculate the number of crossings for each of 1000 azimuths between 0 and 90 degrees. The program then plotted the percentage occurrence of each number of crossings as a function of the number of crossings. The resulting plots for two radial distances, 2 cell sizes and the square and triangle cell shapes suggested by the previous analysis are shown in Figures 4 and 5.

3.1.3 Compatibility With the Geographic Grid

The final issue in choosing a cell size and shape is "compatibility" with the existing geographic grid. The geographic grid is divided into degrees, minutes, and seconds; unfortunately, not a decimal system. The entire country has been mapped with successive division by 2 of each degree, so that 7.5 minute maps are now available for nearly the whole country. Of course, the grid structure is rectilinear in latitude and longitude, a fact which is perhaps the strongest argument against using an isometric triangle cell shape.

A likely candidate for a cell size and shape is that area exactly covered by a 7.5 minute topographic map. At a latitude of 35 degrees, such a block would be approximately 10.7 kilometers by 14 kilometers, somewhat larger than the block sizes suggested by other considerations, and nearly twice as large (half the resolution) of the block size indicated by the need to maintain resolution comparable to the existing M3 map data base. Subdividing each 7.5 minute section into four parts (256 cells per square degree) would yield a block size of about 5.3 by 7 kilometers at 35 degrees latitude, and resolution approximately equivalent to that of the current data base. Figures 4A and 4B show the number of crossings distribution for a square block of about the same area.

A rough count indicates that about 950 square degrees cover the continental United States. With 256 cells per square degree, a total of approximately 243,200 cells would be included in the data base for this country.

3.2 Data Base Updating

The major justification for creating the new data base is the relative ease with which it can be updated to incorporate

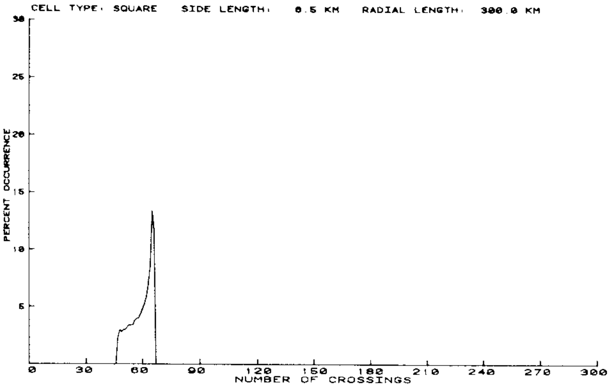

FIGURE 4A

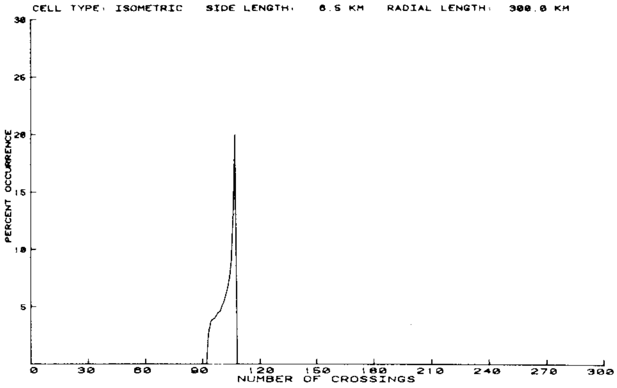

FIGURE 5A

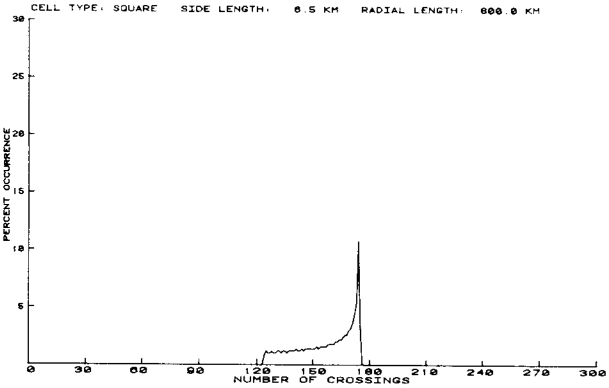

FIGURE 4B

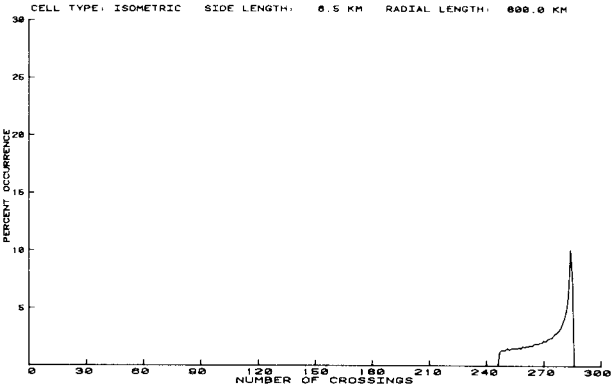

FIGURE 5B

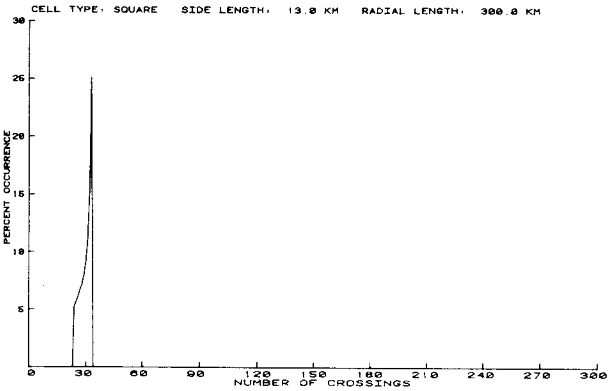

FIGURE 4C

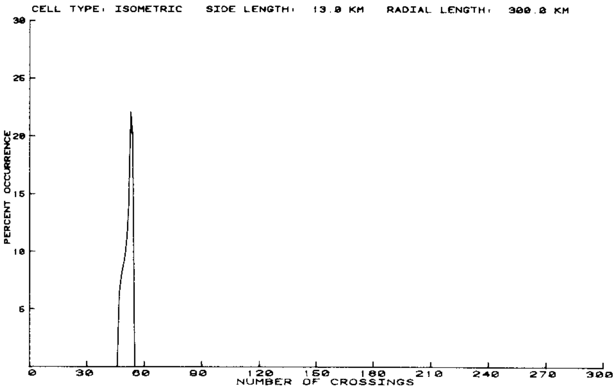

FIGURE 5C

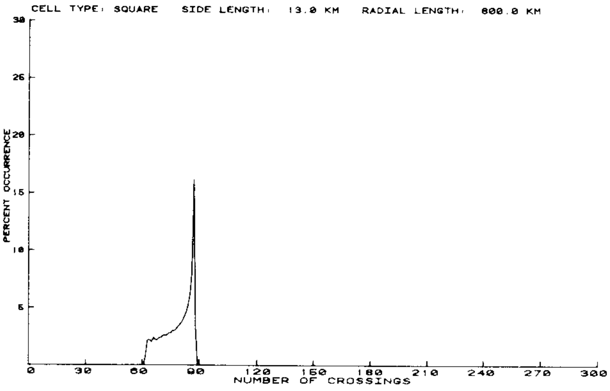

FIGURE 4D

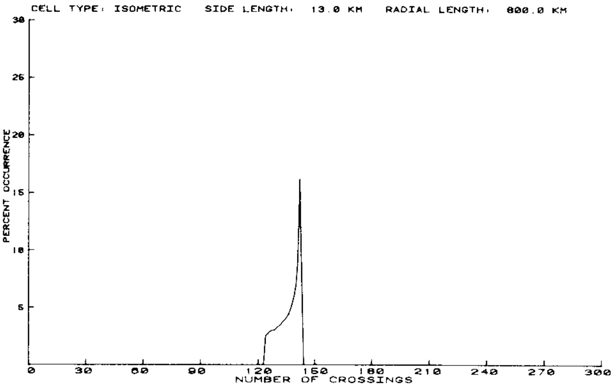

FIGURE 5D

new measurement data. Assuming a method has been developed for judging whether or not a set of measurements warrants a conductivity assignment, a simple test based on where the measurement data is relative to a given cell can be developed to update the conductivities. Such a test could be primarily a function of how much of the valid measurement data was inside the cell boundaries. There are many variations on this basic idea which would consider angle of radial crossing and the overall distance from the transmitter.

In comparing new measurement data to be added to the data base with the conductivity already assigned to a cell, it would be useful to have an indication of the degree of confidence placed in the current cell conductivity assignment versus that of the data to be added. For example, a conductivity assignment based only on an M3 map estimate should have slight weight when considered against extensive measurements. Consequently, it would be appropriate to store a number for each cell which indicates both the conductivity assignment and the confidence factor of that assignment. If an integer number is used for each cell, for 8 bit (2 bytes per integer) computers, the maximum values which can be represented are ±32768. With this many possible values for each cell, 100 confidence levels for each of 16 conductivities would only consume 1600 of the possible 65536 values. Other values beyond 1600 could perhaps be used to code other propagation information about the cell, such as terrain roughness.

Alternately, the 65536 values could be used to encode conductivities for four subcells within a cell. With 16 conductivities for each of 4 subcells, exactly 65536 combinations are possible. With a simple binary encoding and decoding scheme, the resolution of the data base can be doubled without increasing the data base size. With this data "enhancement", storing confidence information for the subcells is not possible.

The uniform cell conductivity data base also allows establishing data files and suitable software for allocation studies in areas of the world where little or no information on ground conductivity is now available. The cell structure could be set up with cell codes corresponding to "unknown." As new mediumwave stations were built, or existing stations measured, the cell conductivities would be updated to reflect the newly gathered data. The grid structure also lends itself to an organized conductivity survey using temporary test transmitters located at grid intersections.

4.0 Comparison of Uniform Cell and Line Segment Techniques

In order to test the speed of calculations done with the uniform cell data base, a prototype data base and computer program were developed. To make the comparison, a new line segment conductivity data base was also developed for the section of South America north of the equator. After digitizing the soil region boundaries and coastlines in the usual way, the plotted map shown in Figure 6 is the result.

One objective of the prototype test was to determine the viability of such software and data bases running on inexpensive 8 bit microcomputers typical of those currently available from several manufacturers. The particular computer used in these tests is a Z-80A based machine running at 4 MHz with 64 kbytes of user memory, 2 five inch floppy disk drives, and a CP/M operating system. All programs were written in disk BASIC which is commonly available for computers of this type. All calculations and runtime results are using this machine and single precision arithmetic.

4.1 Line Segment Data Base and Software

The line segment conductivity data base for this study was prepared by digitizing the location of short, straight line segments which represent a piecewise linear approximation to the curved soil zone boundary lines and coastlines on the map. For soil zones in the section of South America shown in Figure 6, a total of 989 segments were required. Conductivity values on the east and west sides of the lines were also stored during the digitizing process.

The BASIC computer program to access the data base is functionally identical to the FORTRAN program FNDM3 described in [2]. Because most BASIC languages do not have built-in double precision trigonometric functions, all spherical bearing and distance calculations were done in single precision. Appropriate interpretations were added to the program to avoid small number problems which might arise because of this simplification.

4.2 Prototype Uniform Cell Data Base

The objective of the data base organization is to allow the most rapid access to the data given a known set of cell coordinates. By using a random access rather than sequential access file, the program can skip to reading only data for one particular group of cells, rather than the entire data base.

In general, a random data file is composed of records; each record contains a fixed number of bytes of information. The number of bytes per record is selected by the programmer within the limitations imposed by the particular computer, programming language, and storage device. The computer used for these tests has a maximum record length of 128 bytes. If a single integer is stored for each cell (2 bytes per integer), data for up to 64 cells can be stored in each record.

The preliminary analysis done in Section 3 suggested that a square cell of 0.0625 degrees on a side would be appropriate. This value was used in the prototype data base. In calculating distances to cell crossings, it is easy to determine the latitude and longitude index number for a cell by dividing the coordinate in decimal degrees by 0.0625 degrees to determine an integer index. These latitude and longitude indicies can then be used directly to determine the record number and the position in the record for a given cell.

The prototype data base is constructed with the longitude index determining the record and the latitude determining the position in the record. With a limit of 64 cells per record, each record will contain data for a column of cells 4 degrees high, starting at the equator. The ascending records proceed west from the Greenwich Meridian — the record number 2880 is at 180 degrees longitude. At this point the data base goes back to 0 degrees longitude to begin a second "strip" of data representing the cells between 4 and 8 degrees latitude. Records 2881 to 5760 thus contain this second layer of information. This process can continue until the entire quadrisphere is in the data base, resulting in a total of 64,800 records. The other 3 quadrispheres could be similarly represented and stored.

In a random data base, not all records need be stored. For example, it is possible to store records 1000 to 2000 without storing data for the first 999 records. By this means small relevant sections (over land) can be developed without requiring all records for the quadrisphere to be present.

4.3 Prototype Uniform Cell Computer Program

The BASIC program to access the uniform cell data base

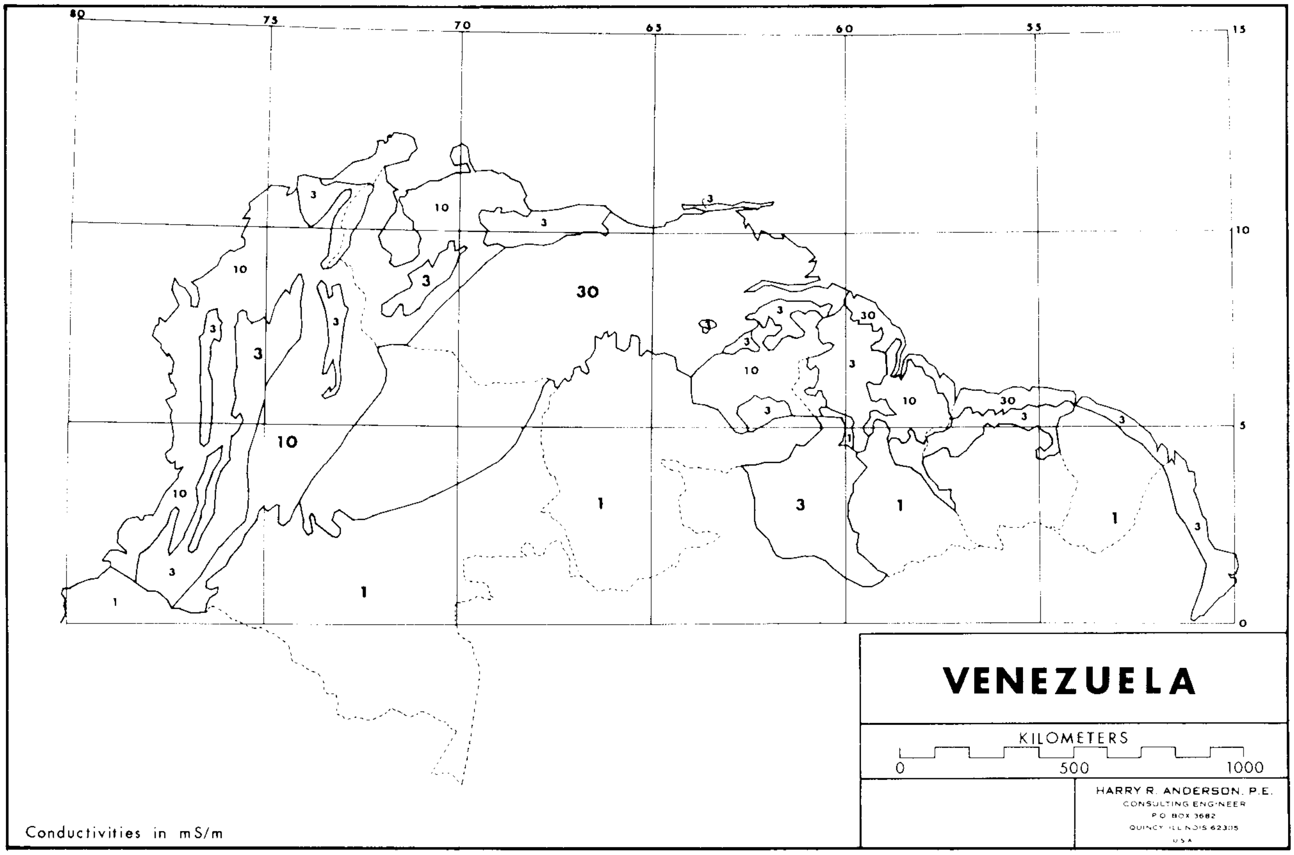

FIGURE 6. GROUND CONDUCTIVITIES FOR SOFTWARE TEST REGION

is very simple, totalling less than 200 lines. Following the technique of the preliminary analysis, the program computes the distances to the meridian and parallel crossings separately using spherical trigonometry, and then reorders the crossings by ascending distances. It also generates the latitude and longitude index numbers for each cell crossed by a radial to determine the proper access location in the data base. Finally, after reading the data base, it generates a file which contains conductivities and distances by azimuth.

4.4 Comparison Results

Using the area of South America centered around Venezuela shown in Figure 6, program runs using identical station locations, search distances (800 km), and 36 radials, were done to compare execution speed. The results are shown in Table 1.

It can be seen that the uniform cell technique is considerably faster at the expense of a larger data base. The prime advantage, however, is the resolution. As increasingly refined conductivity data is used, the uniform cell execution time will remain constant, as will the data base size, while the line segment data base size and execution time will increase as more segments are added to define the conductivity regions. The 100 km resolution given in Table 1 is roughly the average length of soil zone crossings on the 36 azimuths run in the test case. Of course, it will vary with the station location within a particular region.

The execution time in each case will be approximately 100 times faster on typical 16 bit computers with hardware floating point processors, and about 1000 times faster on large mainframe computers.

TABLE 1. RESULTS OF SOFTWARE COMPARISON

	Line Segments	Uniform Cells
1. Total execution time 36 radials, 800 km	75 minutes	45 minutes
2. Data base size	42 kbytes (8 bit) sequential file	120 kbytes (8 bit) random file
3. Data Resolution at Equator	100km (see text)	6.9 km

5.0 Uniform Cell Data Base Problems

The two major problems with the uniform cell data base are its storage size and the large number of cell crossings, which makes it entirely unsuitable for hand calculations, and the limited resolution possible with a finite number of cells. If it is assumed that maintaining hand calculation ability is not required, and that everybody interested in using the data base will have suitable computer resources, the first problem disappears. If this is not the case, some thought could be given to the interesting problem of creating a conductivity map from a uniform cell data base; such a map could then be used for hand calculations.

The limited resolution of the data base would only become critical where sharp changes in conductivity occur, such as moving from land to sea water. For third adjacent channel contour overlap problems, where contour distances are short, the block-like structure of the data could cause anomolous contour overlap conditions which do not occur where considering the actual coastline. There is also the difficulty of assigning conductivities to a cell which is half land and half sea water. Two radials with equally valid measurement data could be run through the cell, each showing quite different conductivity values, yet each being equally correct. Which conductivity value should prevail? Perhaps some coding technique could be developed for such cases.

6.0 Comments On Cellular Propagation Data Bases

The conductivity-confidence code assigned to each cell could be extended to embody more general propagation concepts. The ultimate purpose of the data base is to provide accurate predictions of field strengths at a given location resulting from the emissions of a particular transmitter. The numbers stored in the data base are relative indications of the degree of additional attenuation experienced by the signal beyond that from the free-space, distant-dependent geometric attenuation of a radiating wave. Rather than consider the number assigned to a cell as a conductivity, it is perhaps more useful to regard it as a "propagation index" which indicates what degree of attenuation one might expect as the signal traverses the cell. In some summarizing way, the propagation index could represent effects due to terrain shielding, groundwave diffraction around greatly dissimilar subsurface media boundaries, and even manmade signal degradation sources.

Beyond daytime mediumwave propagation, FM and TV field strength prediction suffers from lack of a readily accessible terrain elevation data base. Though digitized topographic data is available for the entire United States, the amount of data and computer resources required for accessing it are well beyond the capabilities of most engineers dealing with broadcast propagation problems. An extension of the cell structure would place average cell elevation and terrain roughness values into the data base in place of the conductivity. Thus, using the same data base structure and accessing software, relevant propagation data could be extracted for use in FM and TV field strength predictions. Certainly, calculation results with such a data base would be less accurate than those based on a properly constructed terrain profile, but they would have the advantage of originating in an easily accessible propagation data base with an identical structure for each broadcast service.

The concept of a cellular spectrum-space structure could be generalized to a multidimensional propagation matrix containing propagation indicies for paths between each cell and every other cell in the spectrum-space structure, with additional dimensions of the matrix representing the frequency and time dependence of the propagation indices. Using matrix solution methods, it is conceivable that an analytical approach to spectrum allocation problems could be found. Such an approach would require spectrum planners to establish field strength requirements in each cell, at each frequency and time, and from which source. Using the propagation matrix as a linear operator, a set of sources distributed among the cells might be directly calculated to satisfy, to some degree of accuracy, the planned field strength requirements.

7.0 Conclusions

There are several expected tradeoffs between the value of the suggested data base in streamlining and refining spectrum allocation studies, and the awkward anomolies, such as those described, which must be resolved.

The uniform cell propagation data base presented here is a suggestion for improving the accuracy of groundwave field strength predictions for mediumwave allocation purposes. It's primary advantage is the ease with which it can be updated and accessed by computer programs. The disadvantages are its requirement for reasonable computer storage, and the necessary development of criteria for updating the data base and administering its use in spectrum regulation.

The Venezuela propagation study example demonstrated that the prototype uniform cell data base and software can perform soil zone crossing calculations with much greater speed and resolution than the computer line segment method which is currently in use.

8.0 References

[1] Notice of Inquiry. B.C. Docket 80-757. Federal Communications Commission. December 15, 1980.

[2] H.R. Anderson. "A Computer Program System for Predicting and Plotting Mediumwave Broadcast Groundwave Field Strength Contours." IEEE Transactions on Broadcasting, Volume BC-26, Number 3 (1980).