SYSTEMATIC BIVARIATE ANALYSIS OF AM FIELD STRENGTH MEASUREMENT DATA

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Abstract

A systematic method for analyzing AM field strength measurement data to establish inverse distance field strength and ground conductivity zones is presented. The technique uses a simple bivariate error minimization routine to find the combination of radiation and conductivity which most closely matches the measurement data out to three kilometers. The balance of the conductivity zones are determined by a running average which again seeks minimum error when compared to digitized versions of the FCC groundwave propagation curves. An extension of the technique allows such net conductivities along a radial to be converted to equivalent "M3 map" conductivities. The mathematical algorithms provide unique and repeatable results, and are readily adapted for use in computer programs.

1.0 Introduction

A common problem in broadcast engineering is analyzing AM field strength measurement data to establish inverse distance field strength at one kilometer. Such analysis is used to verify pattern shape and size when a new station is built or when an existing station is modified or rebuilt. As prescribed in the FCC Rules, such proof-of-performance field strength measurements out of approximately 30 km are required along specified radials.

Once the measurements are completed, the Rules set forth a manual technique (Section 73.186) for analyzing them which requires the engineer to compare the plotted measured data with the groundwave propagation curves in the Rules and adjust the position of the plotted data to best fit one of these conductivity curves. The adjusted position of the plotted measurement points determines the value of inverse distance field strength. Given the variations which can result from different engineers analyzing the same data, and the overall difficulty using the method when the data is scattered due to reradiation sources, a more uniform, repeatable, and automated technique would be worthwhile improvement.

To eliminate the problems described above, a technique has been developed which uses the digitized versions of the groundwave propagation curves to perform an error analysis against the measurement data to find values of radiation and conductivity which most closely fit the data. Inverse distance field strength at 1 km is determined first by using data within 3 km of the antenna. By comparing the data against corresponding points on a range of conductivity curves when adjusted over a range of radiations, and taking into account corrections for nearfield pattern effects, the combination of conductivity and radiation which most closely matches the data is found. With the radiation and first conductivity established, the balance of the conductivity zones out to the last measurement point distance can be found by using a running average technique to find sections of the digitized conductivity curves which most closely match the measurement data.

The following sections of this paper describe the bivariate error minimization and running average techniques, and provide several samples of the output from a computer program designed to analyze AM data using the described methods.

2.0 Establishing Inverse Distance Field Strength

As mentioned in Section 1.0, the initial step in the analysis process is to establish the inverse distance field strength at 1 km; that is, the far field value of radiation extrapolated back to the 1 km distance assuming only free-space attenuation is in effect. For simplicity, this will be called the radiation in the balance of this paper.

To establish the radiation on a given radial, an engineer can make measurements along the radial and analyze them as described in Section 73.186 of the Rules, or for a directional antenna (DA) pattern, use the measurements to compare against measurement data at points established during the last full proof-of-performance, as described in Section 72.186(a)(5). Generally, the first measurements are taken using a single tower radiator with an essentially non-directional (ND) radiation pattern. The computer method described here is best used on the initial analysis of the ND pattern measurement data. Treatment of the DA case is discussed later.

There are two initial constraints which greatly simplify the analysis — 1) only the data out to 3 km is used to establish radiation, and 2) only one conductivity zone can occur in this 3 km distance. The 3 km limit was somewhat arbitrarily chosen as that distance at which a significant change in conductivity along the radial was unlikely to occur. It is also the distance to which the FCC recommends the densest measurement point spacing of 0.2 km. Choosing another distance is certainly possible with no required adjustment in the method, but no other distance seemed a more preferable choice.

Let E(n) = 1 . . . NPT represent the field strength measurement values out to 3 kilometers. Also let ECRV(n,k) represent the point on conductivity curve k (k = 1 . . . 17) at the distance point which corresponds to the distance of measurement point n. The sum of the squared differences or squared error between the measurement points and conductivity curve k can be written:

$$e(k) = \sum^{NPT} (E(n) - ECRV(n,k))^2 \qquad (1)$$

The conductivity curves themselves are expressed in terms of voltage levels at a given distance for a radiation of 100 mV/m at 1 km. To use them for other radiation values, each point must be multiplied by the ratio between the radiation value and 100 mV/m. The search for the correct radiation requires a range of conductivity and radiation combinations be evaluated. Representing the adjusted conductivity curve voltage values by ECRV(j,n,k) j = 1 . . . NR where NR is the number of radiation values to be searched, equation (1) becomes:

$$e(j,k) = \sum_{n=1}^{NPT} (E(n) - ECRV(j,n,k))^2 \qquad (2)$$

$$j = 1 \ldots NR \qquad k = 1 \ldots 17$$

Equation (2) is a fairly generic representation of a bivariate error squared summation. The range for n is given as the measurement points out to 3 km; the range for k is the 17 conductivity curves shown in the FCC Rules. However, the range of radiation values to be searched requires some thought. To allow a fairly fine resolution of radiation increments, the step size should be small. To keep the computational burden low, the total number of steps should also be as low as possible, so that searching radiations from 0.1 mV/m to 10,000 mV/m is clearly impractical.

In the computer implementation of this method, the radiation search range was chosen to be centered on the "expected" value of radiation; that is, the calculated theoretical radiation for a tower given its input power and typical efficiency. The radiation search range is established by ± 25 steps (NR = 50) around the center, with each

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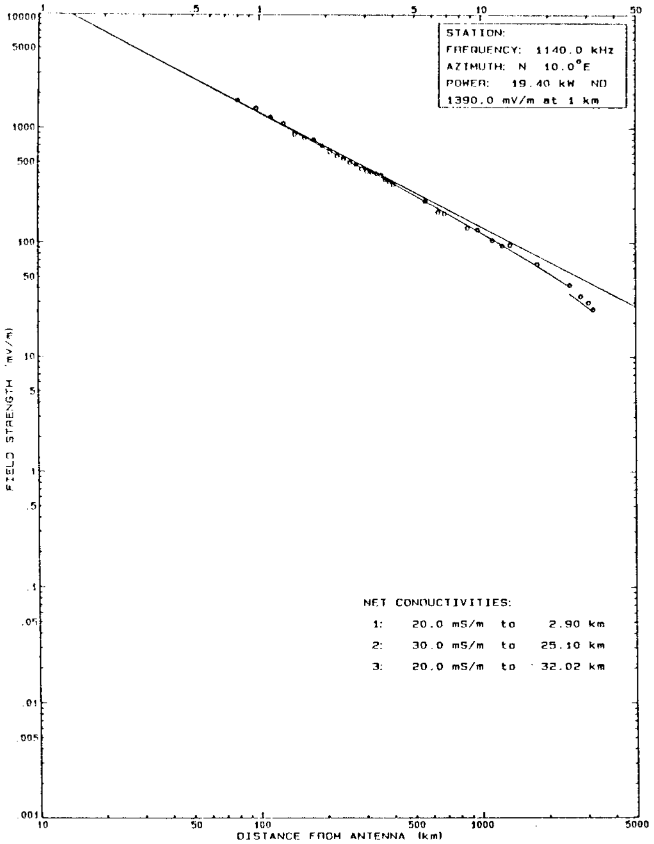

Fig. 1. Computer analysis of ND measurement data. Manual analysis: 1408 mV/m at 1 km.

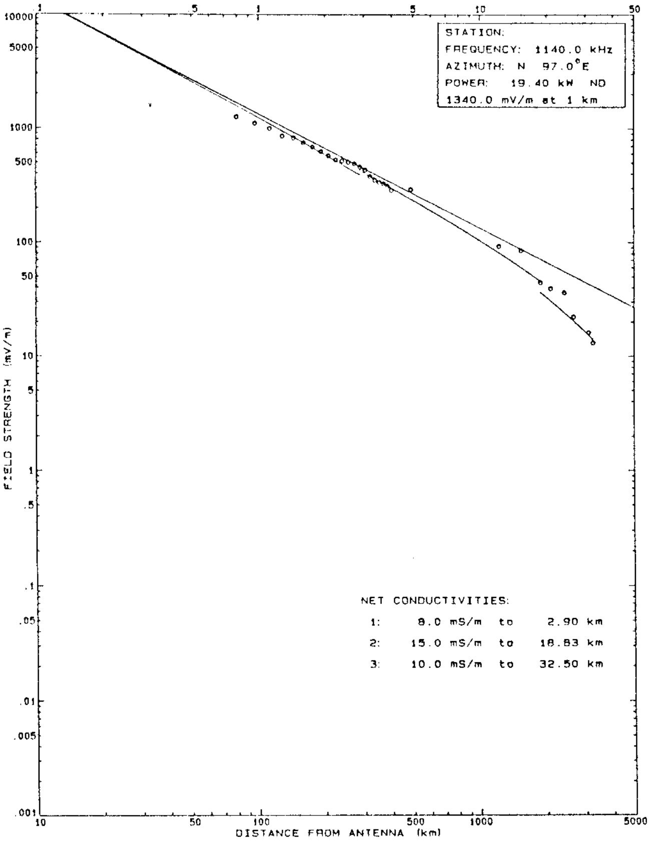

Fig. 2. Computer analysis of ND measurement data. Manual analysis: 1367 mV/m at 1 km.

step (in logarithmic terms) equal to 0.001 of the logarithm of the expected radiation. For an expected radiation of 1000 mV/m, this provides a radiation search range of 841 to 1188 mV/m. Increasing the range and resolution is certainly possible if the additional computational burden is acceptable.

With the radiation search range established, a computer program can be used to find the e(j,k) from equation (2). The combination of radiation and conductivity which best fits the data is the j,k which produces minimum error e(j,k) from (2).

Simply searching for minimum e(j,k) resulted in somewhat more scattered radiation values than seemed reasonable. Consequently, the method was modified so that it first finds the best fit conductivity curve by choosing that curve which yields minimum *total* error over all 50 radiation values. With a curve selected on this basis, the single value of radiation which resulted in minimum error among error values for that curve only was selected as the radiation for that radial.

Several examples of the plotted results of program operation are shown in Figures 1 through 8 which used real ND pattern measurement data from two different stations as input. The radiation calculated by the program is shown in the title block of each Figure; the radiation determined by a completely independent manual analysis is given in the Figure label. By comparing the two numbers, it can be seen that agreement is within 3% in most cases. In all cases, the program produced results which are entirely plausible given the measurement data, and in some cases the program analysis appears more reasonable and consistent than the manual analysis. The difference in the computer analysis radiation should therefore not be thought of as an "error," but rather a difference which may, in fact, more accurately estimate the actual radiation than the manual analysis.

The process described above yields both the radiation and the conductivity for the first 3 km of the radial. Determining conductivities to match measurement points beyond 3 km is discussed in the next section.

3.0 Determining Conductivity Zones Beyond the First Zone

The objective in determining outlying conductivity zones is to find the conductivity curve which best matches the measurement points. Once again, this is done by finding the error between the data and corresponding points on the conductivity curve, and then selecting that curve which yields minimum error. This process is simplified from that described in Section 2.0 because the radiation has already been established, and thus only a single radiation rather than a range of radiation adjustments to the conductivity curve is required.

Selecting a set of conductivities to match the data beyond 3 km is done by a running average technique. The program considers the first 3 points beyond 3 km and determine which conductivity curve they best match (using a formula such as equation (1)). If they match the conductivity of the first zone, the distance for that zone is extended to the first of the three points, and the process is repeated for the next "window" of three points beyond the point which was just added. This process will continue as long as the 3 point average matches the preceeding conductivity. If the 3 points are a better match to some other conductivity, an enlarged window of 7 points is considered. If the best fit to this window still justifies a conductivity change, the program will accept this as a valid conductivity change and begin again with the 3 point analysis at the end of the 7 point window. Conceivably, the 7 point window analysis could radify the preceeding conductivity in which case the preceeding conductivity is extended for one more point and the program reverts to the 3 point window analysis.

This procedure provides acceptable results but could probably be improved. Its weakness is that a decision to change conductivities is based solely on minimum error, even if that error is only slightly smaller than the computed error for the preceeding conductivity. The result is more "jumping" to nearby conductivities than might reasonably be expected. The jump to 15 mmho/m in Figure 4 is an example. An alter-

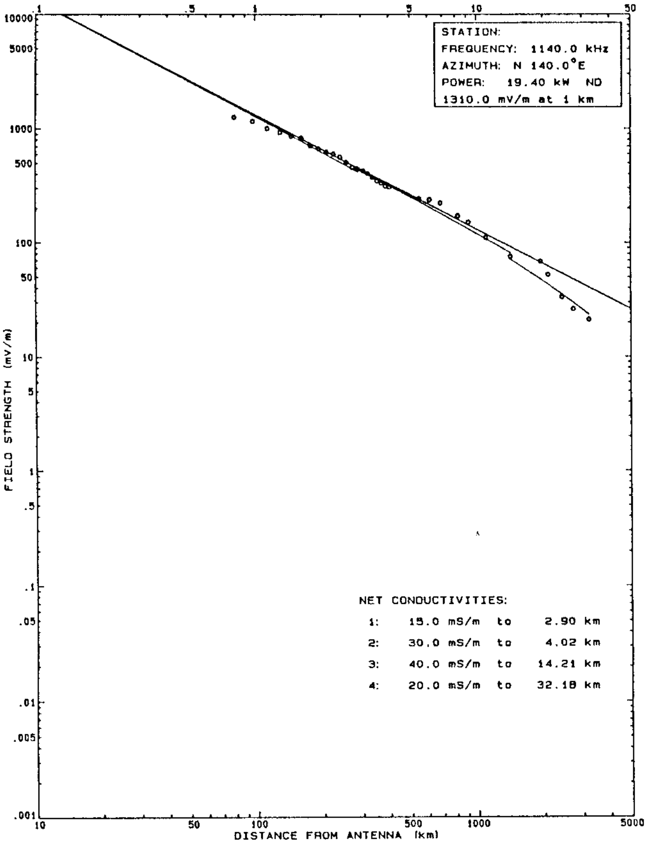

Fig. 3. Computer analysis of ND measurement data. Manual analysis: 1408 mV/m at 1 km.

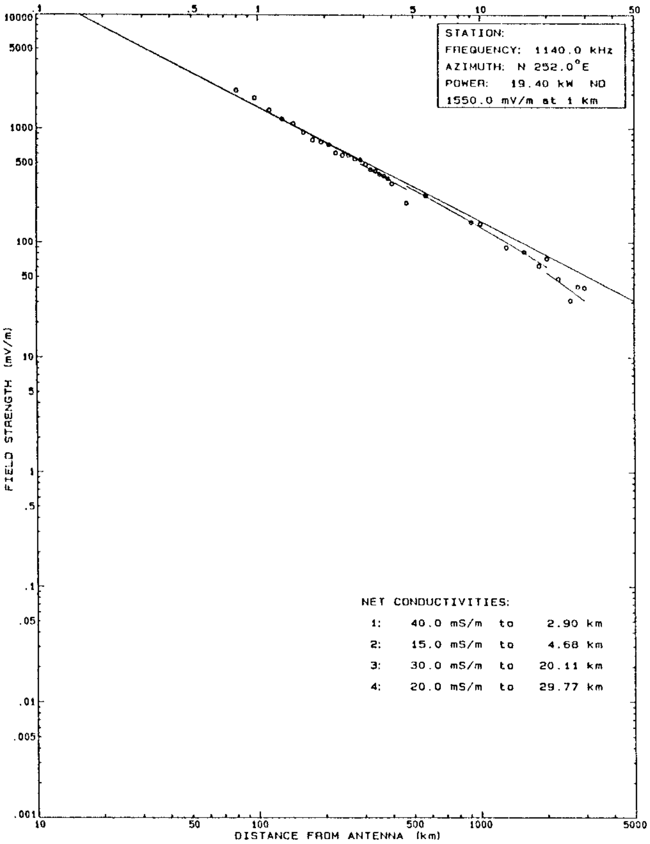

Fig. 4. Computer analysis of ND measurement data. Manual analysis: 1569 mV/m at 1 km.

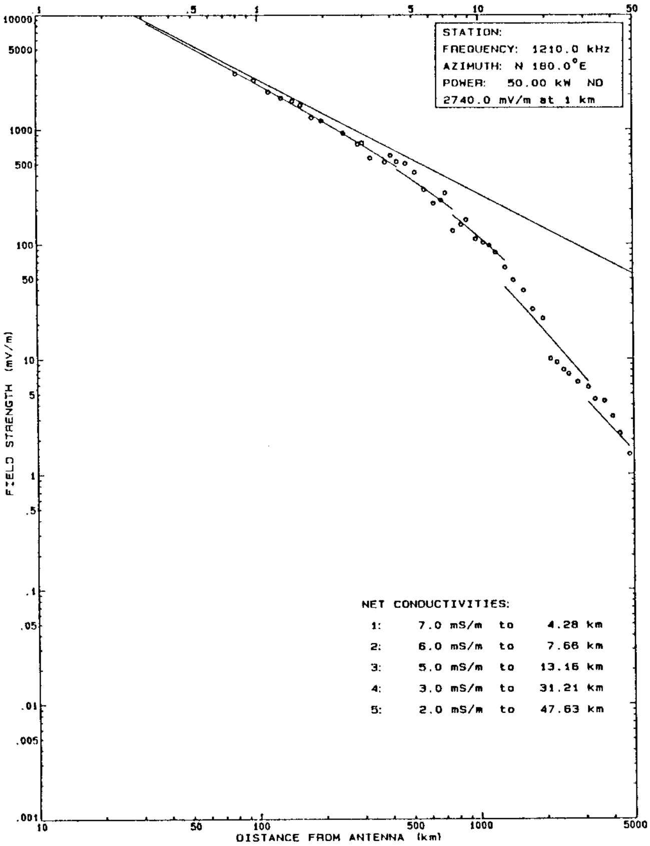

Fig. 5. Computer analysis of ND measurement data. Manual analysis: 2896 mV/m at 1 km.

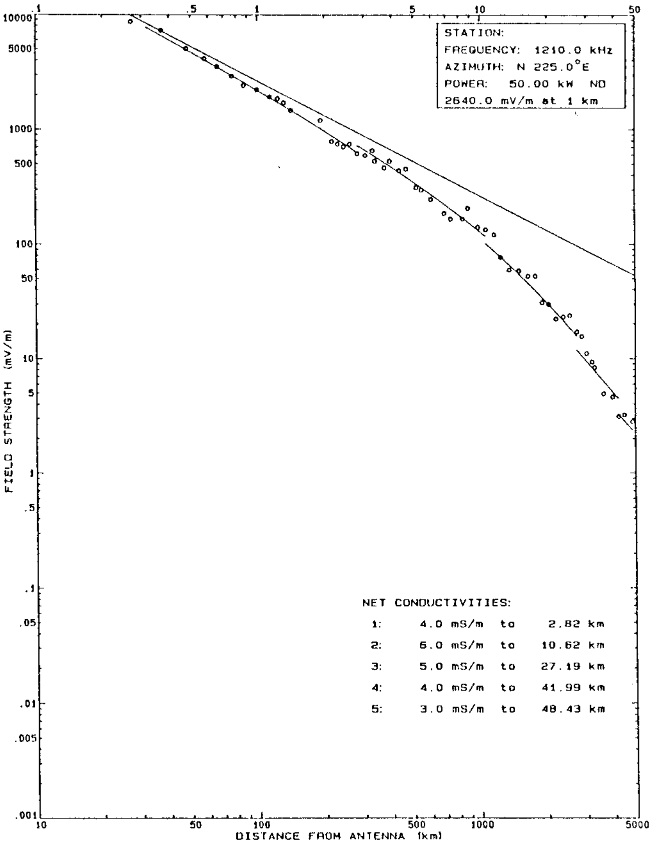

Fig. 6. Computer analysis of ND measurement data. Manual analysis: 2735 mV/m at 1 km.

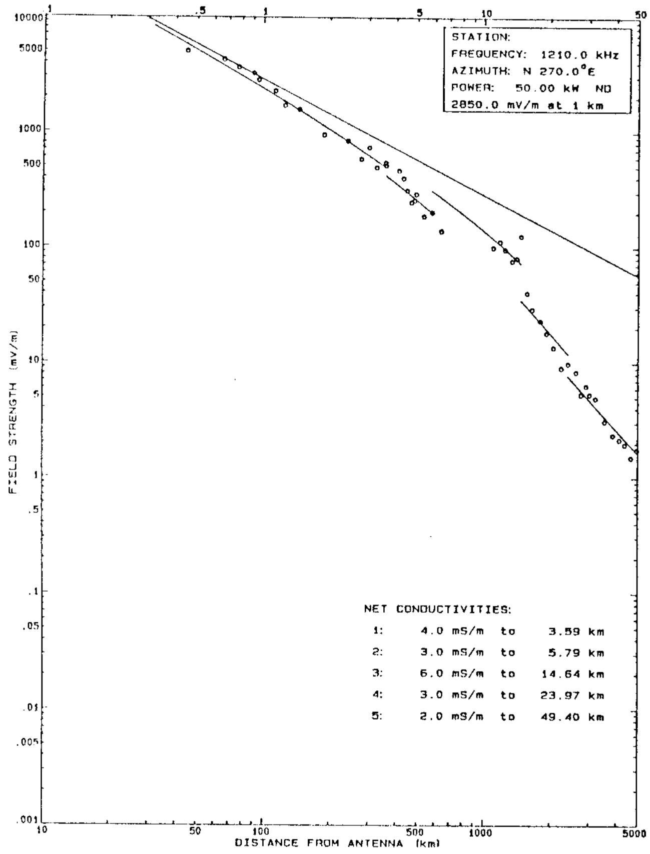

Fig. 7. Computer analysis of ND measurement data. Manual analysis: 2896 mV/m at 1 km.

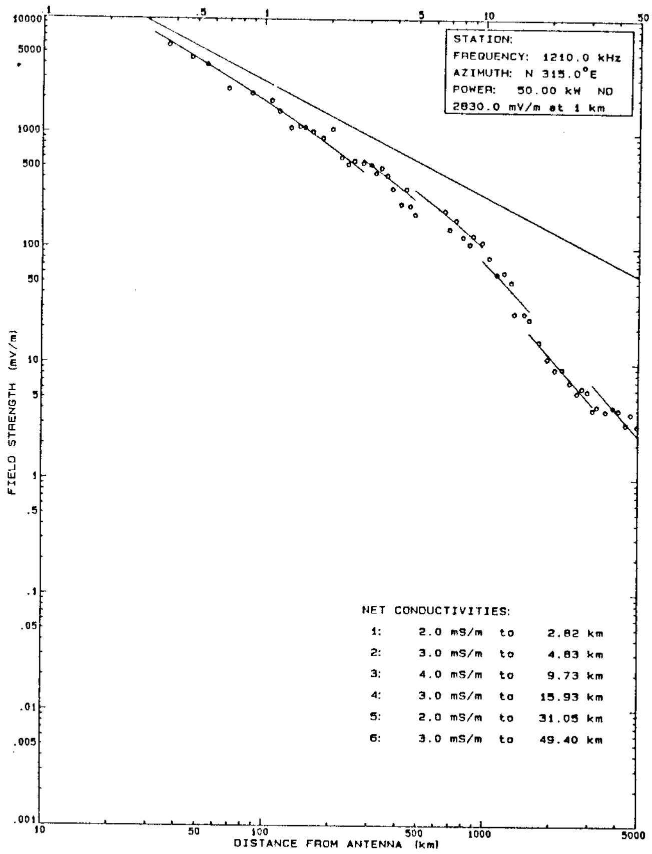

Fig. 8. Computer analysis of ND measurement data. Manual analysis: 2574 mV/m at 1 km.

nate approach which is under investigation would only allow a conductivity change when the difference between the preceeding conductivity and the proposed new conductivity is statistically significant given the calculated standard deviation of the measurement points around each propagation curve.

4.0 Analyzing Measurement Data for Directional Antennas

When ND data along a radial is available, The DA radiation is usually established by an average arithmetic or logarithmic ratio between the ND data points (assuming the ND and DA points are in the same place), and applying that ratio to the radiation established in the ND case. The conductivity zones established in the ND case are also plotted along with the DA measurement data to further assess the reasonableness of the DA radiation value.

Of course, a completely independent analysis of the DA data as described in Section 2.0 and 3.0 can be done, but experimentation with real data shows that such an analysis almost always results in different conductivity zones on the radial than those established in the ND case (which is not reasonable), and a radiation value which is unsatisfactorily different from that calculated by the ratio method. The ratio method is also attractive because by using a ratio against the ND data, reradiation contributions at particular measurement points can, to some extent, be averaged out. Such reradiation from conductive objects in a DA pattern's main lobe which show up at measurement points along low radiation (null) radials is one of the larger contributions to the scattered nature of measurement data on these radials.

A problem of particular concern when analyzing the DA data for some stations is accounting for nearfield effects at close-in measurement points. Nearfield pattern calculations become important when the measurement point is sufficiently close to the antenna that the array of towers no longer appears as essentially a point source. A common rule of thumb for the distance to the end of the nearfield range is

$$d = 2\,L^2/\lambda \qquad (3)$$

where L is the overall aperture length of the array. In their longest dimension, some arrays can be 1 km in length, resulting in a nearfield distance at 1 MHz of more than 6 kilometers.

The nearfield radiation is calculated by considering the actual geometry from the measurement point to each tower in the array. The space phase delays and distance differentials thus derived are considered along with the driven power and phase of each tower to arrive at the calculated field at a point.

Another factor of less importance is the fact that at very close-in points the magnetic field orientation will not be the same for the field from each tower. Since AM field strength measurements are usually done with a loop antenna measuring magnetic field strength, the correction to measurement data at nearfield points should also account for this effect.

A nearfield radiation value calculated by the described procedure is used to correct the measurement voltage to a point where it would be if no nearfield effect were present. This is done by calculating the ratio between the nearfield value at each measurement location on a radial and the corresponding point on the inverse distance field strength line established by the theoretical farfield radiation calculated from the theoretical tower parameters. This ratio is then applied to the measurement data before ratioing against the ND data to finally establish a DA radiation.

Figures 9 through 12 show the computer program analysis on actual data for four DA pattern radials which correspond to the four ND radials in Figures 1 through 4. The same conductivities were applied to the DA plots; the DA radiations were established by the arithmetic ratio method against the computer ND radiation values in Figures 1 through 4. Figures 9, 11, and 12 show measurement point data which is impacted by the nearfield effects of the array. The computer program method has adequately handled these nearfield effects to produce reasonable estimates of the DA radiation on each radial.

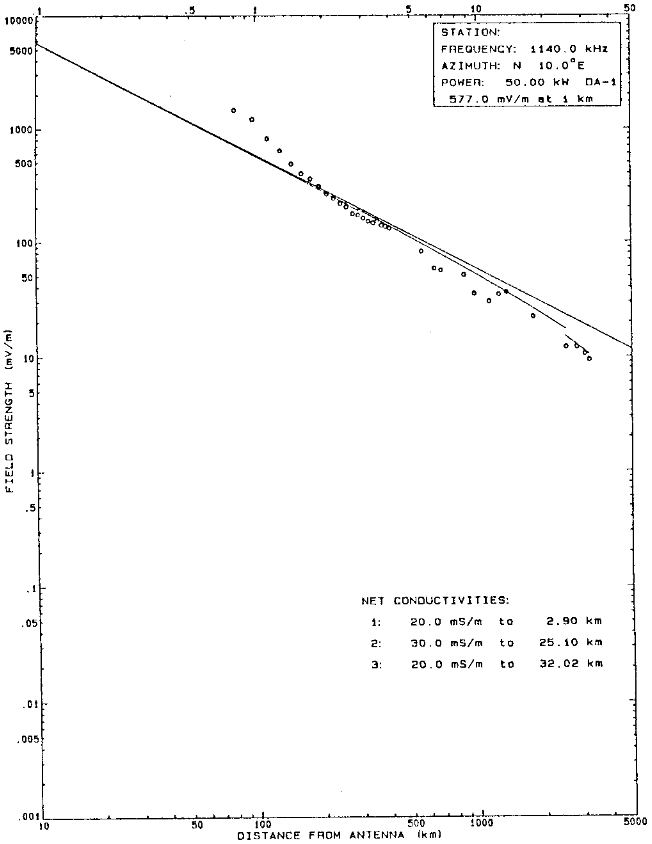

Fig. 9. Computer analysis of DA measurement data.
Manual analysis: 579 mV/m at 1 km.

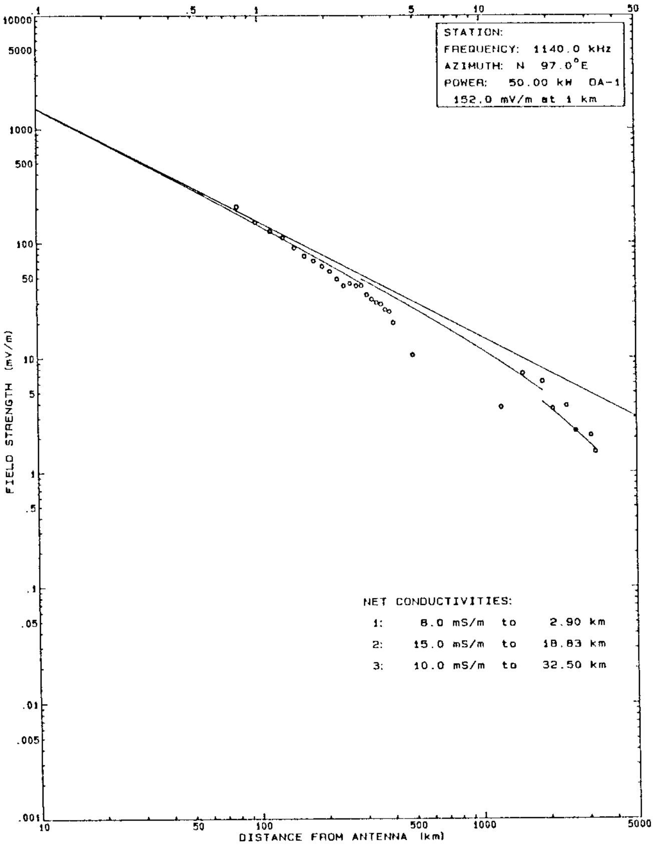

Fig. 10. Computer analysis of DA measurement data.
Manual analysis: 88.5 mV/m at 1 km.

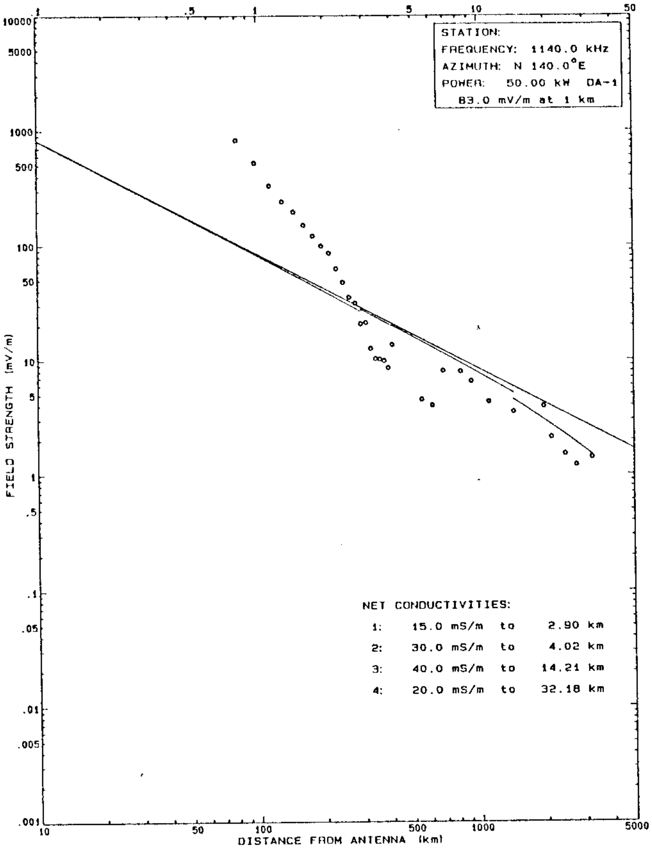

Fig. 11. Computer analysis of DA measurement data.
Manual analysis: 65.7 mV/m at 1 km.

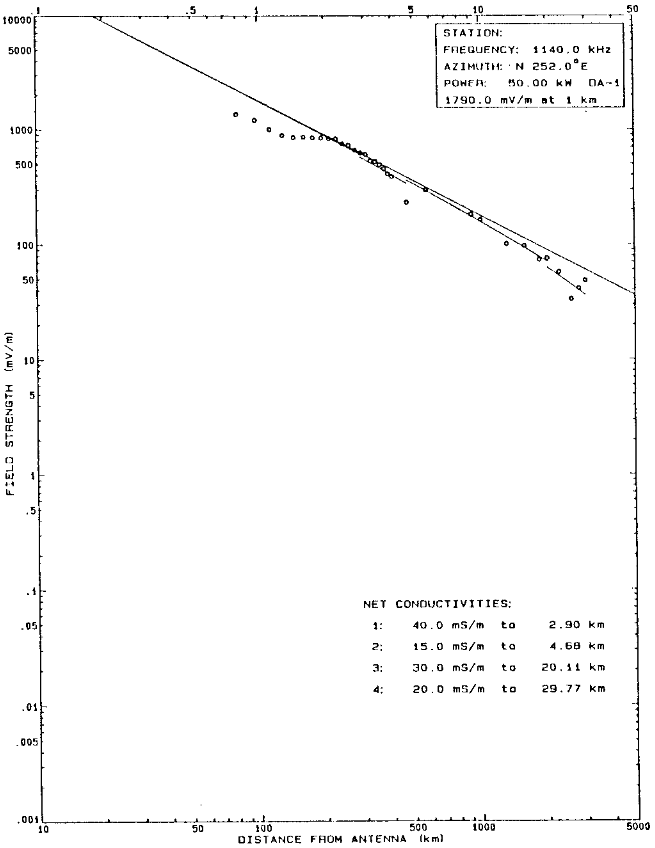

Fig. 12. Computer analysis of DA measurement data.
Manual analysis: 1769 mV/m at 1 km.

5.0 Conversion to "M3 Map" Conductivities

The conductivities determined by the foregoing analysis are net conductivities; that is, the effective total conductivity to a measurement location taking into account all preceeding conductivity changes. Since there is currently an interest in using AM measurement data in the FCC files to update the M3 conductivity map of the United States, it would be worthwhile to devise a way to extend the automated method described in this paper to create equivalent M3 map or zone conductivities from the net conductivities along measurement radials.

The appropriate set of map conductivities on a radial is that set which yields the measurement point data when the equivalent distance method for calculating field strengths described in the FCC Rules is applied. If only one conductivity zone (i.e., the first) is involved, the problem is trivial since this conductivity *is* the map conductivity. For subsequent conductivities, the equivalent distance method must be involved.

In using the equivalent distance method, a distance correction factor is computed for each conductivity zone which takes into account the effect of preceeding conductivities and must be used to modify a field strength value found on that section of conductivity curve. If the distance correction to a particular point is positive due to higher preceeding conductivities, the distance to a contour in that zone would be extended by the correction distance. For a negative correction, the distance would be reduced.

In order to apply the distance correction method, each zone along a particular radial must be defined in terms of starting distance and ending distance. A reasonable set of zone distance definitions are those established by the running average technique described in Section 3.0, since these are identically based on apparent shifts in measured signal strength.

Starting with the first conductivity as a valid map conductivity, the distance correction factors to each of the other 16 possible conductivity curves is computed at the ending distance of the first zone, following the usual equivalent distance method. These distance corrections are then applied to each conductivity curve over the next distance section. This is equivalent to shifting the piece of a curve farther out or closer in. Each section of curve in its shifted position is then compared with the measurement points for that section to select the shifted curve which most closely matches the measurement points using a minimum squared error process like that described earlier in Section 2.0.

Once the second zone is established, the composite correction factor is computed using the usual equivalent distance technique, and the whole evaluation repeated to find a third zone. The process can be repeated until all the net conductivity zones identified on a radial are converted to M3 map zones.

Using conductivity sections established along radial lines to define conductivity *areas* is more speculative. An approach for completely defining the conductivity around a station would involve dividing the area into pie-shaped sections, each of which would contain a measurement radial. The boundaries of each pie section would be the azimuth midway between two measurement radials. A measurement radial would then occur in each pie section, but not necessarily at the center unless the measurement azimuths were uniformly spaced.

With the edges of each pie section defined, the sections can then be further subdivided radially according to the conductivity zones defined by the measurement radial passing through that section.

Applying such a procedure to updating the M3 map would result in highly refined conductivity definition around stations, and relatively little definition elsewhere. Existing measurement data in the FCC files could be applied to the updating process if some convenient limitations were applied on the type of data which would be used; i.e., only non-directional measurement data collected using modern instrumentation and measurement techniques.

6.0 Conclusions

A technique has been presented which systematically analyzes AM field strength measurement data to establish inverse distance field strength at 1 km and associated conductivity zones out to the limit of the measurement data. A computer program incorporating this method produces non-directional radiation calculation results which are typically within 3% of the radiation value determined by an independent manual analysis. Extending the method to directional antenna arrays produces radiation computations which can account for near-field effects and yield results which reasonably match the measurement points when applying the conductivity zone data established in the corresponding non-directional case. The technique is a useful tool which can be applied to automating and standardizing the use of AM field strength measurement data to determine radiation from AM broadcast stations.

A procedure for possibly extending the analysis technique to define equivalent M3 map conductivities was also presented. The automated method could use field measurement data in the FCC files to create high resolution conductivity zones around stations included in the study.