USING YOUR PC PROPAGATION

The personal computer provides a revolutionary means for propagation studies.

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The widespread use of personal computers (PCs) in the business environment has revolutionized the way in which traditional business activities are accomplished. If your business depends on predicting the coverage areas of base stations, repeater sites, cellular or paging transmitters, or the performance of point-to-point microwave or telemetry links, the PC offers a new resource for engineering work which you may not yet have exploited.

Today, there is PC software available which can perform these coverage and radio path studies, allowing you to get more use out of your computer resources, and at the same time, do a better job of choosing transmitter sites and predicting your service area.

SITE SELECTION

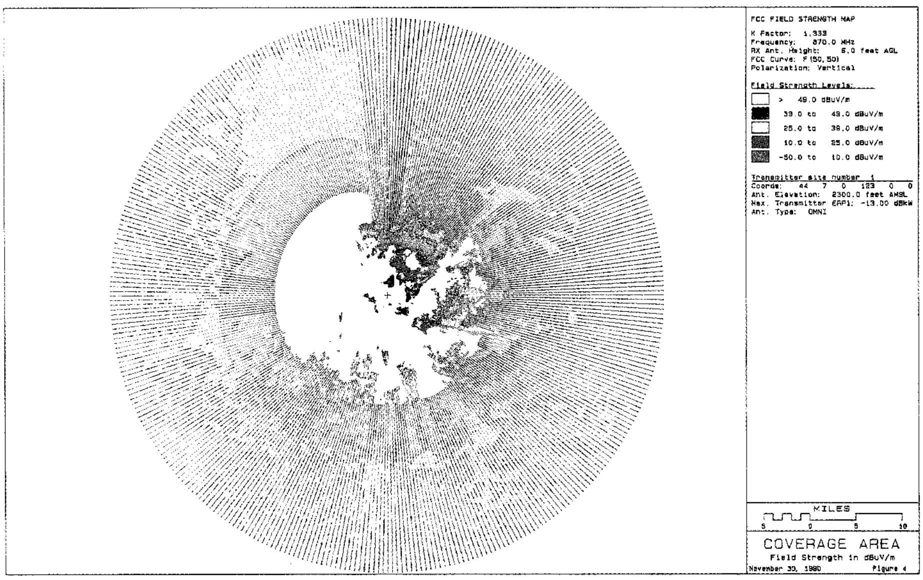
The performance of most radio systems hinges on choosing a site which allows adequate signal strengths in the desired service area, and adequate talk-back signal strengths from mobile units. The field strength at some distance from a transmitter is a function of the transmitter power, the transmission line efficiency, and the gain and directional radiating pattern of the transmitting antenna. The signal strength at the receiver also depends on the transmission path between the transmitter and receiver. The longer the path, the weaker the signal strength. The following equation relates signal or field strength with path length and effective radiated power (ERP) in the direction of the receiver:

Field strength in dBuV/m = 104.77 + ERPi - 20 log(DST) -A dBuV/m where ERPi = transmitter power (kilowatts)- transmission line loss + antenna gain relative to an isotopic radiator, and DST is distance in kilometers.

If the factor A is zero, this equation for field strength applies for free space conditions; i.e. when there are no mountains or signal reflections along the path. When there are mountains or reflections, the field strength is modified by the factor A to take into account these path effects. The loss due to such factors is usually referred to as excess path loss and is added to the normal free space or basic path loss. The excess path loss can also include signal loss due to foliage and buildings.

Before computer techniques were available, the traditional method for determining the amount of excess path loss was to draw the radio path from the transmitter to receiver on topographic maps, then draw a profile of the terrain along the path. This arduous task would result in a drawing showing terrain elevation versus distance, similar to the drawing shown in Figure 2. With this information, it's possible to plot the radio path from the transmitter to the receiver and determine whether terrain obstructions will result in excess path loss. You can then make such technical decisions as:

- How tall do the transmit and receive towers have to be to achieve



Graphic 1. Multi-level field strength map for the transmitter on Coburg Ridge. Low field strength values are due to terrain obstructions.

FOR SIGNAL PREDICTION

adequate clearance over the intervening mountains?

- If several candidate transmitter sites are available, which is the best to serve the desired area?
- Given the total path loss, will the signal strength be adequate to achieve acceptable performance in the receiver?

EXCESS PATH LOSS

If there is a mountain obstructing the path, how much excess path loss occurs due to the obstruction? In the 1950s, Kenneth Bullington developed a set of nomographs which could be used along with the geometry of the path over the obstruction to determine the excess path loss. Like reading the terrain data from the topographic map, using the nomographs was also a time-consuming graphical task when done by hand.

The example we discussed is a single path study. With the manual method, you have already spent a lot of time hunched over topographic maps and drawing lines on nomographs. What happens when the objective is to determine area-wide coverage in which literally thousands of receive locations, and thousands of propagation paths, are involved? Obviously, the manual approach would become totally impractical. Such calculations, however, can readily be done by computer programs. And with the availability of digitized terrain data describing the elevations throughout the country, the entire task of site selection, path and coverage analysis, and making other system engineering decisions, can all be done from the keyboard of your PC.

DIGITIZED TERRAIN DATA

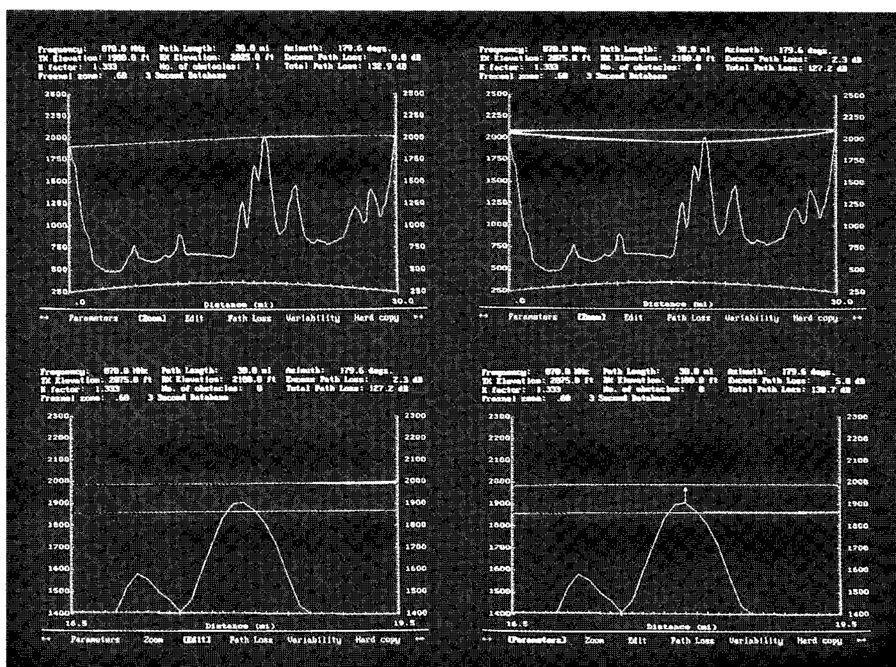
For the United States, there are two terrain elevation databases commonly used—the 30 arc second and the 3 arc second. The names refer to the grid spacing of the points in the database. The 30 arc second database has an elevation point spacing of 30 seconds in latitude and longitude; that is, there is a point every 30 seconds across the surface of the country, while the 3 arc second database has 10 times the resolution, i.e. a grid data point spacing of 3 seconds in latitude and longitude. This is equivalent to a spacing of about 300 feet in a north-south direction, and 250 feet in the east-west direction at a latitude of 35 degrees.

The 3 arc second data was originally digitized from the 1:250,000 series maps by the Defense Mapping Agency, and supplemented with more detailed information from USGS benchmarks, stream beds, ridgelines, and other identified elevation points. This ensemble of data was then used with sophisticated interpolation algorithms to arrive at the elevation points at 3 arc second intervals.

The 30 arc second database was derived during the development of the 3 arc second database by taking every 10th point. It obviously lacks some of the resolution found in the 3 second database so that it can completely miss, or more inaccurately represent, mountain peaks and other terrain features which are included in the 3 second data. Nonetheless, the 30 second data is still useful for calculating height above average terrain (HAAT), and Carey coverage and interference contours for FCC purposes.

PC TERRAIN DATABASES

While these terrain databases are



Clockwise from uper left: Figure 1a. Terrain profile and radio path with mountain peak obstruction at 18 miles. Figure 1b. Transmit and receive antenna heights have been raised to clear the peak. The 0.6 Fresnel zone and reflection point are also shown. Figure 1c. Zoomed in presentation accurately shows amount of clearance over the peak. Figure 1d. Addition of a 75 foot tree on the peak greatly reduces path clearance.

available from the government, in the case of the 3 second data it is only available on 1/2 inch 9 track magnetic tape, an impossible and unwieldy format to deal with in most PC environments. However, the database is now commercially available in 1 x 1 degree blocks on 3 1/2 inch or 5 1/4 inch diskettes, or for those who do studies in many areas of the country, the data is available on CD-ROM (compact disk read-only memory).

A CD-ROM is the same size as an audio CD, but instead of containing digitized music, it contains the data bits representing terrain elevations. You make use of it by connecting a CD-ROM drive to your PC. Once installed, the CD-ROM drive looks like another disk drive on your computer, the only difference being that you can't write to it, and it contains more than 600 Mbytes of data! This large data capacity makes it ideal for high resolution databases such as the 3 second terrain which contains nearly 1.4 billion elevation points covering the entire United States, including Hawaii and Puerto Rico. Through the use of advanced data compression techniques, the entire 3 second database, along with the 30 second database, has been reduced to fit on a single CD-ROM.

With the terrain elevation databases available for use on your PC, you have the data necessary to replace the manual path studies you did using topographic maps. The process first consists of identifying the path endpoint coordinates to the computer program, having the program extract the appropriate elevation data points along the path from the terrain database, and then analyzing the radio path to determine total path loss. The computer software for doing this analysis generally falls into two categories—those for point-to-point analysis, and those for area-wide coverage analysis.

POINT-TO-POINT

Figure 1a shows a photograph of the screen display for an obstructed path for a 30 mile radio link between two points in Oregon. The computer program has extracted the elevation points from the 3 second database every 0.1 miles along the path, and

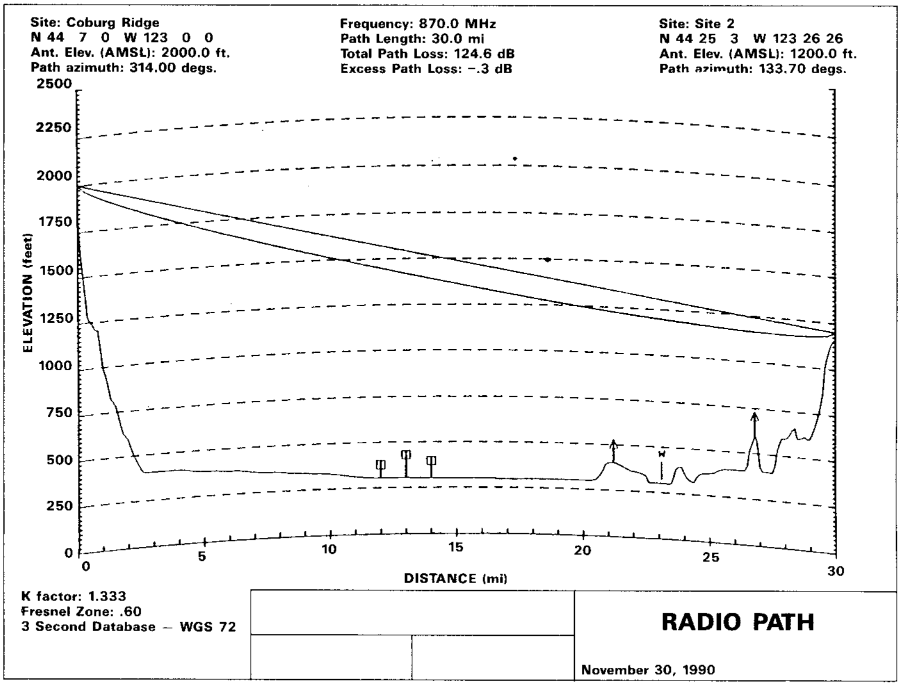


Figure 2. Terrain profile with radio path and 0.6 Fresnel zone. Building, trees, obstacles, and water are identified.

plotted them using a 4/3 (1.333) earth radius (K factor) which was an input variable to the program. The radio path is shown in red.

One important virtue of such path analysis on your PC is that once you have the terrain profile on your screen, you can *interactively* adjust any of the path parameters, including the transmit and receive antenna elevations. The old manual method of using a straight edge on 4/3 or 2/3 earth paper to establish optimum tower heights is now replaced using a few key strokes.

The screen display in Figure 1a also shows a calculated value for excess path loss due to the terrain obstructions. The nomograph methods of Bullington have been replaced with more accurate and efficient models as described in National Bureau of Standards (NBS) Technical Note 101, and in the Terrain Integrated Rough Earth Model (TIREM). These models are readily adapted for use in PC programs and provide for comprehensive consideration of over-the-horizon multiple obstacle diffraction loss as well as reflection point and partial Fresnel zone obstruction loss for line-of-sight conditions.

The screen display in Figure 1b shows the path after the antenna elevations have been increased on the transmit and receive ends to achieve line-of-sight conditions between the transmitter and receiver. Note also that the computer program has drawn the Fresnel zone radius around the path—in this case it's the 0.6 Fresnel zone, but again this value can be interactively changed to 1 or 1.5 or 2 or whatever value might be appropriate for a particular study. Note that a red tic mark also appears on the display (at about 14.3 miles) indicating the location of the reflection point. With computer analysis, the program can rapidly calculate the geometry to determine the location of a reflection point. Using this grazing angle, and ground conductivity and dielectric constant (input parameters), the program can calculate the magnitude and phase of the reflected signal, vectorially add that contribution to the directly received signal, and then calculate the net signal magnitude at the receive location.

Having an interactive computer display of the terrain profile and path opens the door to many other useful capabilities. For example, the display in Figure 1b shows that although the path is line-of-sight, it is close to being obstructed by a mountain peak at about 18 miles. Using the Zoom function selected by the prompt line at the bottom of the screen, the vertical and horizontal scales and minimum display elevation can be adjusted to zoom in on the path clearance at this point, as

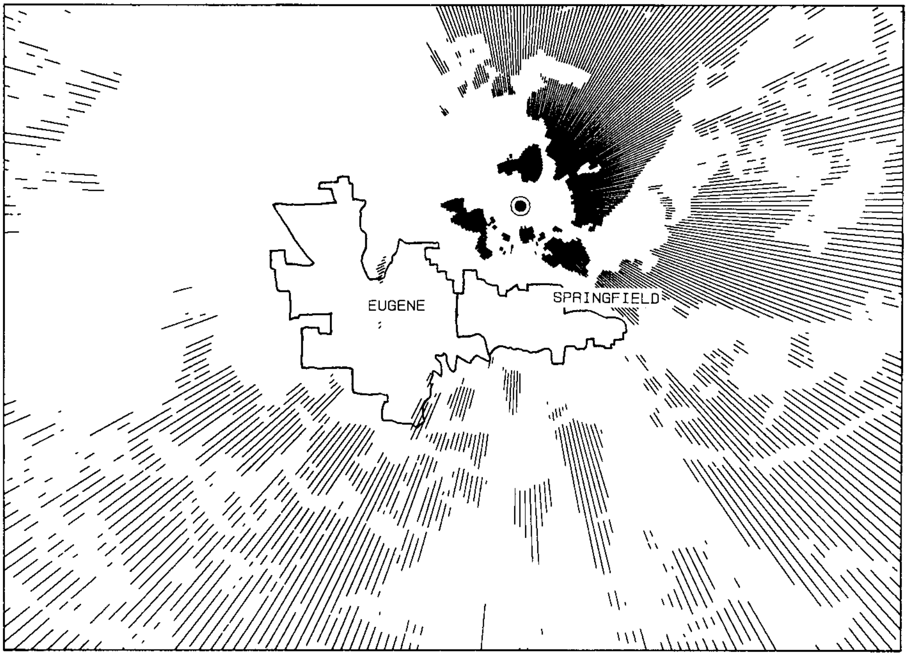


Figure 3a. Shadow map for the transmitter site on Coburg Ridge. The cross-hatched areas are shadowed.

shown in Figure 1c.

The terrain database itself only contains information about terrain elevations, not buildings or trees. Sometimes buildings or trees will represent the critical element in determining the performance of the path. Computer analysis conveniently gives you the ability to interactively edit the profile to add elevation augmentations at selected points. For example, if you knew there were trees 75 feet high on the peak shown in Figure 1c, you could simply select the Edit function to modify the path elevation to include a 75 foot increase. The resulting path, with a 75 foot ''spike'' to represent the trees, is shown in Figure 1d. The presence of the trees significantly reduces the path clearance at this point. This editing technique could be repeated to add trees and buildings, and identify water, anywhere along the path. Symbolic annotations are added to the path to distinguish these edited features, as shown in Figure 2. And, a computer program can save the edits to a file so that the edited path can be re-analyzed, or further enhanced, later.

This example shows that the color screen graphics and interactive keyboard control available on PCs offers distinct path engineering advantages over manual path analysis, and over path analysis done on a time-share service where such screen graphics are not available, or through companies which specialize in preparing path profiles or coverage maps where you have no interactive control. These same advantages can also be exploited for area-wide coverage analysis for repeater or base station design.

The point-to-point analysis discussed above can be extended to thousands of points to yield a picture of signal strength over a wide area. Using the terrain elevation databases as before, this type of analysis can be used to select the best site for a repeater, to determine the overall coverage or service area for marketing purposes, or select tower heights and make other system design decisions.

The simplest form of area-wide analysis is a shadow map. A shadow map shows areas which are line-of-sight or obstructed based on the path geometry and the terrain. An example of shadow maps for three sites around Eugene, Oregon are shown in Figures 3a—3c. These shadow maps were drawn using the 3 arc second database, and 360 radials spaced every degree extending out to a distance of 30 miles, with points spaced every 0.1 miles along each radial.

By comparing these maps, the choice of transmitter site can be made based on the desired service area. Of the three, Coburg Ridge has the least shadowed area in the Eugene-Springfield city limits, but its desirability may be mitigated by other factors which affect the selection process.

Assuming that Coburg Ridge is the best choice for our station, the coverage area can be further analyzed by drawing a multi-colored map of

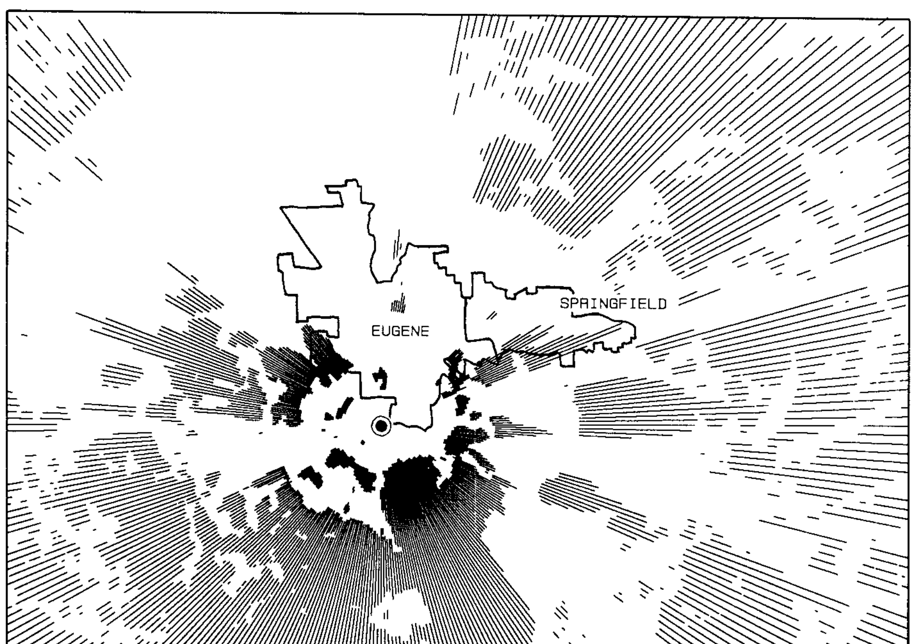


Figure 3b. Shadow map for the transmitter site on Blanton Heights. Shadow areas extend into Eugene and Springfield city limits.

field strengths (Graphic 1). For this illustration, it was assumed that a transmitter operating on 870 MHz with an effective radiated power of 50 watts was in use along with an omnidirectional transmitting antenna. The map shows excellent coverage through a wide arc, but with low field strengths in the areas north and east of the site where the Cascades begin.

Computer analysis of field strengths or received power can also be done at evenly spaced grid points rather than along radial lines. Such an x,y,z grid of data can then be used with three-dimensional plotting utility programs available for the PC which can produce interesting and useful depictions of coverage around a site. A three-dimensional plot of field strengths for the same hypothetical station on Coburg Ridge is shown in Figure 4. The view in this case is from the northwest of the site. The smooth monotonic decrease of signal strength versus distance in the line-of-sight regions west and northwest of Coburg Ridge are quite apparent, as are the deep ''canyons'' of low field strength northeast of the site.

In all cases, the calculated field strengths for these coverage maps make use of the same propagation path loss algorithms that were used for point-to-point analysis, so that reflection points, diffraction loss, urban loss and foliage loss can all be included.

The PC has opened up a wide range of capabilities to the engineer, technician, or manager who is designing new repeater sites or point-to-point links, or who simply wishes to better assess the coverage of existing systems and prepare accurate presentations of the service area. All the figures in this article were prepared using commonly available PC hardware, an inexpensive pen plotter, and commercially available propagation software and terrain databases. The PC environment offers distinct engineering and cost advantages for path and coverage analysis when compared to time-share services or companies which specialize in preparing path profiles or coverage maps. More thorough and cost-effective system designs on your PC can contribute to the success of any company engaged in radio communications. □

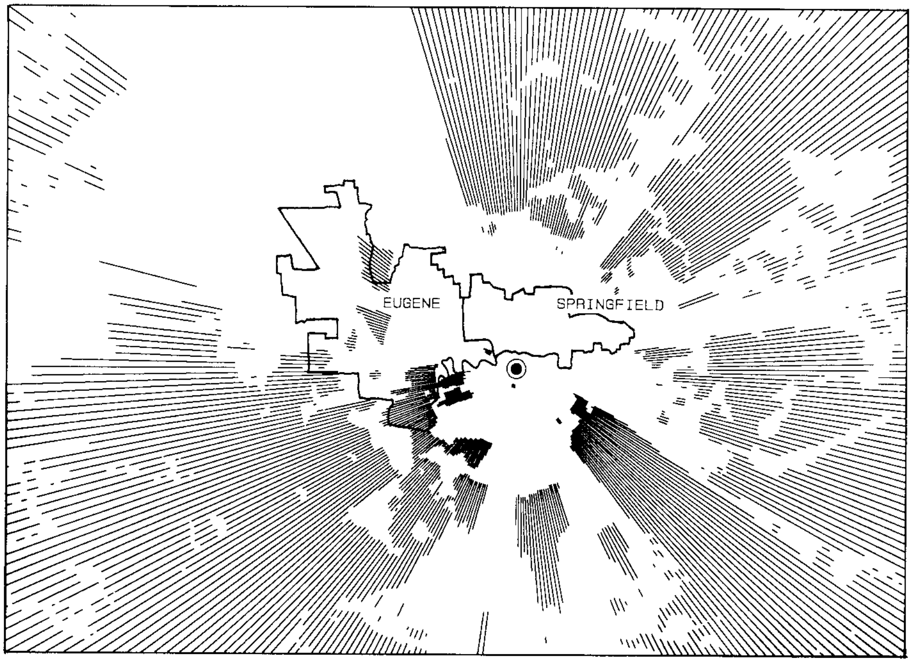


Figure 3c. Shadow map for the transmitter site on Quarry Hill. Shadow areas large over parts of Eugene.

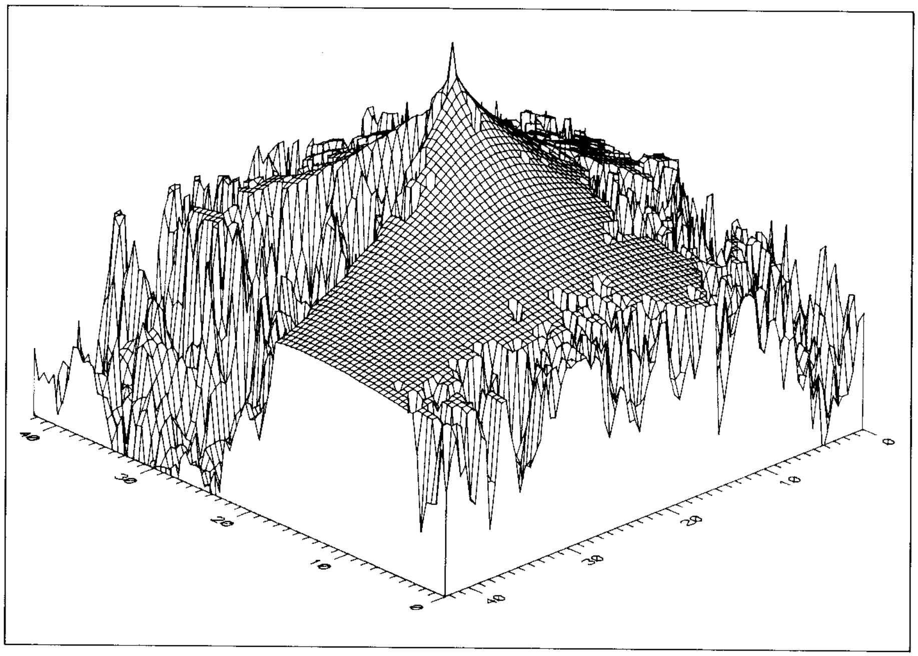


Figure 4. Three-dimensional plot of field strength for Coburg Ridge transmitter viewed from the northwest. Line-of-sight region shows smooth decrease in field strength versus distance; mountainous regions to the northeast and east show low signal levels.

About the Author

Harry Anderson is the president of EDX Engineering Inc., located in Eugene, Ore.