An Investigation of Radiofrequency Radiation Exposure Levels on Cougar Mountain Issaquah, Washington May 6-10, 1985

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EXECUTIVE SUMMARY

During May 1985, the Electromagnetics Branch (formerly the Nonionizing Radiation Branch) of the Environmental Protection Agency's (EPA) Office of Radiation Programs (ORP) conducted a radiofrequency (RF) radiation investigation on Cougar Mountain, Washington, in response to a request from the Federal Communications Commission (FCC). EPA found that FM radio broadcast antennas are the only significant sources of RF on Cougar Mountain. The majority of EPA's measurements were made at publicly accessible locations relatively far from FM antennas, i.e., at distances greater than 100 meters. The measured values are relatively low when compared to the limits developed by various standards-setting organizations. These limits fall into the range 100 to 1,000 microwatts per square centimeter ($\mu W/cm^2$) for FM radio frequencies.

Two types of results are presented, spatially averaged values and maximum localized values. The spatially averaged values are most representative of an individual's typical whole-body exposure. The maximum values are normally associated with areas of limited extent wherein only partial-body exposures might occur. The greatest spatially averaged power density measured in a publicly accessible location is 700 $\mu W/cm^2$ within 25 feet of a tower which supports an FM antenna. Near residences, the greatest spatially averaged power density found was 117 $\mu W/cm^2$. Measured localized maximum power densities in two publicly accessible areas exceeded the 1,000 $\mu W/cm^2$ ANSI radiation protection guide adopted by the FCC. These include areas near the unfenced KMGI/KZOK/KMPS tower, where one measurement exceeded 2,000 $\mu W/cm^2$, and locations near one residence where a maximum of 2,350 $\mu W/cm^2$ was found. Indoors, highly localized power densities reached 350 $\mu W/cm^2$, while spatially averaged values did not exceed 23 $\mu W/cm^2$.

Because power density values are likely to increase with height above ground on Cougar Mountain, and because the conducting objects normally found in structures tend to enhance ambient RF fields, the siting of new multistory dwellings near the high power antennas on Cougar Mountain should be approached with care. Also, cooperation among broadcasters will be needed to prevent tower climbers in the Ratelco North Lot from exposure to power densities exceeding the ANSI radiation protection guide.

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Background

Cougar Mountain lies approximately 12 miles east-southeast of Seattle with its summit 1400 to 1500 feet above Seattle (Figure 1). The mountain's elevation above Seattle has made it a popular location for broadcasters to place their antennas. Twenty-two towers sit atop the mountain today, supporting 10 FM antennas, several microwave point-to-point dishes, and a myriad of other low-power communications antennas (Table 1). Twenty years ago, when few residents and fewer antennas resided on Cougar Mountain, there was little concern about the levels of electromagnetic radiation there. As more people moved to the mountain for its magnificent views, as more broadcast and communications companies chose Cougar Mountain for its advantageous position over the Seattle area, and as questions arose in the popular and scientific press about the biological effects of radiofrequency (RF) radiation, many residents developed a concern about the possible hazards of being so close to an "antenna farm". They wrote to their county government, to the Federal Communications Commission (FCC), to the Environmental Protection Agency (EPA), and to their Congressional representatives seeking information on the levels of RF radiation on the mountaintop, inquiring about the possibility of any associated health consequences, and requesting relief from the addition of more antennas to the area.

The FCC responded to citizens' concerns by requesting an EPA study of the RF levels on Cougar Mountain. The Electromagnetics Branch (formerly the Nonionizing Radiation Branch) within the EPA Office of Radiation Programs, assisted by personnel from the FCC Seattle and Washington, DC offices, conducted the study during the week of May 6, 1985. This report describes that study and is provided by EPA to the FCC under the terms of Interagency Agreement number RW27931344-01-0.

Equipment

The strength of RF fields is commonly measured using broadband isotropic electric or magnetic field meters, or antennas connected to tunable field strength meters. Broadband equipment is used to provide an indication of the total RF field at a point while narrowband equipment provides detailed information on the RF intensity at any particular frequency. This study employed both types of equipment.

The Fiber Optic Isolated Spherical Dipole (FOISD) was used for narrowband or frequency specific measurement of frequencies up to 700 MHz. The FOISD's small size (a sphere about 10 cm in diameter) allowed us to calibrate it in a small calibration apparatus in our facility at frequencies of major interest before leaving for Seattle. The FOISD's size and the fact that it does not need to be adjusted to each frequency individually also make it far more convenient to use in the field than the larger and more cumbersome half-wave tuned dipoles, which require readjustment at each frequency of interest. The FOISD was calibrated in a transverse electromagnetic (TEM) cell in the Electromagnetics Branch laboratory in the Las Vegas Facility. The report, An Automated TEM Cell Calibration System (1), describes this calibration facility.

Between 700 and 1000 MHz, a Singer Model DM-105A-T3 half-wave tuned dipole was used. We have experimentally determined the antenna factor for this narrowband Singer system.

Above 1000 MHz we used an AEL Model APX-1293 crossed log periodic antenna (1-13 GHz), and a Watkins Johnson Model WJ 8549 vehicle-mounted omnidirectional bicone antenna (1-18 GHz). We determined the calibration factor for the AEL and Watkins Johnson antennas based upon manufacturer-supplied data for the frequency range that would be of primary interest to us as we used that antenna. For example, our antenna factor curve for the Watkins Johnson omnidirectional bicone antenna (see Appendix) is based upon a 2dBi gain figure supplied by Watkins Johnson for a frequency of approximately 15 GHz, a frequency which is within the range (2-18 GHz) for which we used that antenna.

All these antennas were linked to a Hewlett Packard 8566A spectrum analyzer to measure RF electric field strengths. The analyzer was interfaced to a Hewlett Packard 9845B desktop computer which controlled the analyzer, processed, and stored the frequency-specific electric field data. We used the internal calibrator in the spectrum analyzer to verify the calibration of the analyzer itself in the field. We verified the accuracy of the internal calibrator signal with a power meter upon our return to Las Vegas. All calibrations referenced in this report are traceable to the National Bureau of Standards.

Upon arrival at Cougar Mountain, we checked the response of the Holaday 3001 broadband electric field strength meter and the Narda 8616 (8631 probe) broadband magnetic field strength instrument. It was apparent that the Narda would be of limited usefulness on Cougar Mountain because of a serious zero-drift on its lowest (most sensitive, i.e., 0 to 200$\mu W/cm^2$) scale - the scale where most of the Cougar Mountain values would be read. However, the Narda's next scale (0 to 2000 $\mu W/cm^2$) did not exhibit a significant zeroing problem and was used in a few of the higher exposure sites.

The Holaday meter does not suffer from a zero drift problem because it self-zero's many times each second. However, the Holaday fulfilled its manufacturer's predictions that it would overrespond in the presence of multiple FM fields of similar intensity. Despite these problems, we decided to use the Holaday because its stability (i.e. lack of zero drift) allowed us to compare it to more accurate, narrowband FOISD values at several sites and power densities. For further information on calibrations and the equipment used in this study, see the Appendix.

Procedures

Two months before the study, the Puget Power Company sent us a notebook of maps, photos, contacts, and very detailed information concerning the engineering characteristics of antennas on Cougar Mountain. Puget Power, which owns two towers on Cougar Mountain, had gathered information on the RF environment there in response to inquiries from the residents. The information contained in the Puget Power book saved us days of long-distance telephone investigation. After verifying items of interest and adding details that we learned from the FCC, FM station engineers, and the owners of the towers, EPA predicted the maximum RF levels that all the antennas were likely to create on the mountaintop. (The modeling techniques we used are described in reference 2.) These calculated power density values shown in Figure 2, helped determine the scope of the investigation, and suggested areas where detailed mapping of fields would be warranted. The contours on Figure 2 are located at the greatest distance from the towers at which power density values as high as the stated values were predicted to exist. According to the model, much of the mountaintop would be above 100 $\mu W/cm^2$ with a few locations on Cougar Mountain exceeding 1000 $\mu W/cm^2$. It should be noted that due to particular antenna characteristics, the field strength does not decrease monotonically with distance from the antenna. Therefore, there can be multiple contours for a single power density value. Figure 2 displays only the most conservative (i.e., furthest from the antenna) contours for the three exposure values.

Using the modeling results, we considered how we should investigate the mountaintop in order to present the most complete picture of the RF environment there. We decided to collect spatially averaged values (typical measurements which exist over a vertical planar area of about 70 square feet) and maximum values (maximum measurement values normally associated with areas of limited extent wherein only partial body exposures might occur) both outdoors and indoors. While frequency specific measurements, using the dipole antennas and the spectrum analyzer, provide the most detailed and most accurate information, the size of the Cougar mountain area and time constraints dictated that broadband meters be used to collect the majority of the data.

In general we tried to obtain spatially averaged or typical values wherever people might be located - inside and outside homes, along roads, and even around fenced areas. Because there were so many locations at which to measure such spatially averaged values, over 400, we used a broadband instrument that could be handcarried and that allowed us to collect data rapidly.

We searched for maximum values in order to characterize some areas more thoroughly. Areas that we believe warranted this extra attention included residences and locations close to FM antennas. We used the same broadband meters to find maximum power density locations that we had used for the collection of spatially averaged values because those meters are lightweight, and can be quickly and easily maneuvered to search for peak values.

We used narrowband equipment at several sites to determine the contribution of each FM station to the total power density at a given point and to estimate the error associated with the less accurate broadband measurements. We chose sites for narrowband measurements which were: (a) near homes, since narrowband readings permit more accurate exposure assessments and allow the development of correction factors for the more numerous broadband data; and which were (b) at various distances from clusters of FM antennas. We chose several distances from the FM towers because we wanted to learn the actual exposure values at those points in order that we could assess the broadband instrument errors under different combinations of FM signal strengths. The Holaday manual predicts over-responses in the presence of multiple signals which are strong and approximately equal in magnitude.

· Frequency Specific Electric Field Data

Frequency specific data enhance the usefulness of any study not only by providing accurate standard values against which broadband data can be evaluated, but also by identifying the contribution of emissions at various frequencies to the total power density at a point in space. The approach for these measurements was (a) to seek sites at various distances from the different frequency band antennas on the mountain, (b) to sample at a group of sites where a wide range of field intensities existed, and (c) to measure the fields near residences. Eight sites were chosen. All but one are accessible to the public. A quick survey with the Holaday would locate a point in space where the field was strong for that particular site. The FOISD was then placed at that point in space, and collection of frequency-specific data commenced.

The computer processed electric field data from three orthogonally aligned FOISD measurements at each site, and saved the resulting spectra. After each set of three FOISD measurements, the FOISD was removed from its gimbals. We then centered the Holaday probe in the gimbals and measured the field through a 360° rotation of the probe about the axis of its handle. An average field intensity from that rotation was recorded for comparison with the FOISD value for the FM band. Every value was corrected for the frequency response of the instrument and converted to plane wave equivalent power density units. The power density comparisons are listed in Table 2 for the eight sites. Figure 3 (the attached large fold-out map) displays the locations of the comparison sites and identifies each with its site number inside a triangle. (Note that in Table 2 and Figure 3 there is no comparison site No. 1.) The other values on Figure 3 are the power density values which are discussed in the next section of this report.

Magnetic field data were collected to determine if electric field values could be used to reliably predict equivalent plane wave power densities. We used the Narda 8631 broadband magnetic field probe for these measurements. At three sites where the RF fields were great enough, we measured the maximum magnetic field in the vicinity of the site where the electric field values were taken, but we were unable to obtain reliable values at 5 other comparison sites due to the zero drift problem.

After collecting the FM band data with the FOISD, we returned to three of the comparison points to collect information on the electric fields at non-FM frequencies. We collected data at one site (No. 10), which was not an FM comparison point, because it was near residences and it overlooked all the antennas on the mountaintop. Table 2 lists these data by site number and by the instrument used to make each measurement. Some non-FM frequencies were sampled by taking three orthogonal FOISD measurements. When half-wave tuned dipoles were used, we oriented them in the azimuth such that the field produced the greatest amplitude signal on the spectrum analyzer, and then collected data from horizontal and vertical orientations. To collect data with the crossed log periodic antenna, we directed it at a tower which supported antennas of interest and which was visible from the measurement point. To redirect the antenna toward towers which were not visible from the measurement point, we took angles from our maps and rotated the antenna accordingly. At higher frequencies we sometimes sampled only a single polarization. In some cases we were forced to collect peak values rather than average, because of the duty cycles and low powers of the transmitters. The omnidirectional antenna samples in the horizontal plane, hence it requires no azimuthal orientation. It is mounted in a fixed vertical position on our vehicle and thus collects data from only vertically polarized fields. Unlike the FM band data which were collected at a height of 7 feet or less because we could not reach higher with the broadband probe or place the FOISD higher on its tripod, the non-FM band data were collected at heights which ranged between 5 and 10 feet because the non-FM band antennas were placed atop our truck.

• Broadband Spatially Averaged Values

Our intention was to find spatially averaged values in areas accessible to the public (i.e. in areas that were not fenced). Although we had considered taking data at intersecting gridpoints on the mountain, the dense vegetation over much of the area did not allow us to establish gridlines, much less physically move to intersection points. So we collected data every 20 to 25 feet along each road in the area, around the exterior of fenced areas, and near homes. (One exception to this plan was that values were taken just inside the Ratelco North lot fence in a defoliated area in order to speed data collection.) The areal extent of the Cougar Mountain survey was determined by our ability to obtain on-scale indication of the ambient field strengths on the most sensitive range of the Holaday meter (the equivalent of 1-2 $\mu W/cm^2$). At each measurement point, we surveyed over the point in a vertical plane about 7 feet high by 10 feet wide with the Holaday probe. We deliberately avoided locations where the field might be affected by nearby conducting objects (see "Maximum Values" below). We recorded our best estimate of the spatially averaged square of the electric field value (V^2/m^2) throughout the plane that was surveyed. Through repeated measurements at the same location, but at different times, we became confident that our estimated spatial averages were within approximately 30 percent of the actual spatially averaged value.

• Maximum Values

Despite the fact that they may be quite localized, maximum power density values are important for hazard assessment and compliance monitoring. Maximum values are of two varieties. The first results from unperturbed fields in space which happen to sum to a high value. These would be at points of standing waves. The second variety is caused by perturbation of an electromagnetic field by a conducting object. This can dramatically enhance the field intensity over a small area. We set out to locate the maxima by searching near the strongest sources of RF energy (the FM antennas) and by searching for field perturbing situations in areas that are likely to be frequented by people. In some cases those two criteria led us to the same area.

Near most of the FM antennas we recorded maximum values as we moved along the four compass radials (referenced to true North) from the base of the tower. At ten-foot intervals from the base of the tower, we searched for the maximum field value within our reach using the Holaday broadband instrument. The elevated levels inside the North Ratelco lot called for a more exhaustive series of measurements, while the relatively low levels and dense vegetation near the KQKT tower argued against radial measurements there. After completing the radials, we searched in areas where the radial data suggested high field strengths would be found, and recorded those values.

The approach for areas that would be frequented by people was to survey the area generally but emphasize locations near conducting objects such as fences, swing sets, etc. We did not search for maximum values that might have occurred near transient structures like automobiles.

• Indoor Measurements

The purpose of this study was to estimate the potential for human exposure to RF fields on Cougar Mountain. Measurements inside residences were therefore included. Three homes near the Ratelco North lot were surveyed, room by room. In each house, spatially averaged as well as maximum values were recorded. The residents were helpful, not only by allowing us access, but also by directing us to locations at which previous surveys had found elevated field intensities. Interior electric field data were collected with the Holaday.

Results and Discussion

The data collected in this study are primarily electric field strength values supplemented with a few magnetic field strength measurements. The data that we report, however, are in power density units of microwatts per square centimeter ($\mu W/cm^2$). We converted the electric field strength values to power density values, assuming equivalent plane wave conditions. All the values reported here are corrected for the frequency response of the instrument.

• Frequency Specific Values

Table 2 displays the frequency specific measurements for 9 sites on Cougar Mountain. The corresponding FM band spectra and individual station power density contributions are shown in Figures 4 thru 11. The data show that power densities from FM band sources far exceed those from non-FM band sources. Figure 12, a spectrum taken near site 7, highlights this distinction between FM (88 to 108 MHz) and other frequency bands. The spectrum plot in Figure 12, in conjunction with the data for Site 7 in Table 2, show that the contribution to power density from frequencies outside the FM band constitutes only one to two hundredths of a microwatt, or less than one percent of the FM power density at this site. Hence the non-FM band sources contribute such low power densities that they may be neglected for practical purposes.

A more subtle distinction than that between FM and other frequencies is that between the FOISD and Holaday values at the 8 comparison points (Table 2). The ratios of the FOISD to the Holaday values range from 0.53 to 1.14 for the sites we sampled. Using the FOISD as our standard for measuring field strength, these data imply that the Holaday typically read high and its values should be multiplied by some factor to correct for its multiple-frequency response. Unfortunately, the only way to know what factor is appropriate for a particular point is to take frequency specific data at that point. Of course, if frequency specific data were available for every point, there would be no need for Holaday readings. The dilemma: very accurate data that require an inordinate collection time or less accurate data which can be collected in a reasonable period of time and whose error range can be estimated. We opted for the latter.

Each of the Holaday values presented in this report, while corrected for the frequency response of the meter, should nevertheless be considered to represent a range of values whose boundaries are about 0.53 and 1.14 times the stated value. This correction is necessary to account for the Holaday's erroneous response in the presence of multiple, strong, and approximately equal strength signals. Realizing that the Holaday's error, and hence the appropriate correction factor, can change over short distances as the contributions from various antennas change, we nevertheless feel comfortable using a particular correction factor over a limited area (radius of 50' to 100') centered on the actual comparison site. We arrived at this conclusion after comparing the FOISD/Holiday ratios at sites 8 and 9. The comparison values are similar at these two nearby sites.

The Narda magnetic field meter operated well at three of the sites where the Holaday and FOISD were used (see Table 2). At these sites, the equivalent plane wave power density that corresponds to the measured magnetic field (corrected for the meter's frequency response) is approximately equal to that predicted by the electric field value obtained with the FOISD. The ratios of the FOISD to Narda values at the three sites are 0.97, 1.20, and 1.09. These data indicated to us that electric field values could be used to reliably predict power densities on Cougar Mountain in the absence of measured magnetic field values.

- Broadband, Spatially Averaged Values

Figure 3 shows the spatially averaged power densities on Cougar Mountain as well as the correction factors for the Holaday which were found at various points. As expected, the spatially averaged values decrease rapidly as distance increases from FM antennas. Interestingly, the values are far lower than those predicted by our modeling. We attribute this discrepancy to three causes. First, the model is designed to avoid underpredicting, so some overprediction is likely. Second, the model is designed for level terrain. As one moves away from the towers on Cougar Mountain, the distance from the antenna is greater and the elevation angle from the point to the antenna is steeper than what would be predicted if the area were level. Hence the actual power densities are lower than predicted. Finally, the dense vegetation atop Cougar Mountain attenuates the RF fields. The trees also help to increase the inhomogeneity of the field. For these reasons, the ratio of the actual power densities to the calculated power densities can be anywhere from about one-twentieth to one.

Figure 13 shows a probability plot of the over-400 spatially averaged values which were measured on Cougar Mountain where the equivalent power density exceeded 1-2 $\mu W/cm^2$, the practical lower limit of detection for the Holaday instrument. The highest of these values exceeded 700 $\mu W/cm^2$. Although there are many points that exceed 200 $\mu W/cm^2$, about 95 percent of the values are less than 200 $\mu W/cm^2$, 88 percent are less than 100 $\mu W/cm^2$, and 75 percent are less than 50 $\mu W/cm^2$. Although the method of data presentation used is sensitive to the selection of measurement locations, Figure 13 provides a convenient means for summarizing the spatially averaged data. In off-road areas, we checked the fields in the pasture to the east of the Ratelco North lot and in the park at the old Nike site. In the pasture, the values were remarkably uniform at about 45-50 $\mu W/cm^2$. At the park, common values were about 2 $\mu W/cm^2$, with the highest levels routinely reaching no more than 5 $\mu W/cm^2$. In the most uniform field we found, the variability over the vertical plane surveyed was a factor of 4 from the greatest to the lowest value. It was not unusual to see a factor of 2 in horizontal variability and a factor of 8 to 10 vertically.

To place these data in perspective, it is helpful to know that the least stringent standard in existence for FM frequencies is 1000 $\mu W/cm^2$, published by the American National Standards Institute (ANSI) and recently adopted by the State of New Jersey and triggering environmental reviews by the FCC. The National Council on Radiation and Measurements (NCRP) has prepared a draft standard at the 200 $\mu W/cm^2$ level (3). The International Radiation Protection Association (IRPA), the State of Massachusetts, and Multnomah County Oregon have all adopted the same limiting value for exposures in the FM band (200 $\mu W/cm^2$). The City of Portland, Oregon, has chosen a 100 $\mu W/cm^2$ limit for FM frequencies within its borders. EPA estimates that the average power density in urban areas of the United States is about 0.005 $\mu W/cm^2$, with fewer than 1 percent of the urban population exposed to levels greater than 1 $\mu W/cm^2$ (4). Figure 13 portrays the Cougar Mountain spatially averaged values, several standards, and EPA data on urban RF power densities. It also shows that while none of the <u>spatially averaged</u> values at measured locations in accessible areas on Cougar Mountain exceeds 1000 $\mu W/cm^2$, about 5 percent exceed 200 $\mu W/cm^2$ and about 11 percent exceed 100 $\mu W/cm^2$. However, one of the spatially averaged values found just inside the fence at the Ratelco North lot does exceed 1000 $\mu W/cm^2$.

• Maximum Values

Figure 14 locates maximum values that we found along several radials in the fenced Ratelco North lot. Several of the values inside the North lot exceed 1000 μW/cm^2, with a few surpassing even 2000 μW/cm^2. In order to obtain a general impression of the RF environment inside the Ratelco North lot, we combined the maximum values (Figure 14) with the spatially averaged values (Figure 3) and plotted the resulting collection of data on a probability scale. Figure 15 is the result, and shows that in the mixture of maximum and spatially averaged values, a few percent of the points exceed 2000 μW/cm^2, about 20 percent exceed 1000 μW/cm^2, and 98 percent exceed 100 μW/cm^2. After correction of these values for the Holaday's multiple-frequency response, the ANSI limit will be exceeded inside the Ratelco North lot.

The levels inside the KUBE fenced enclosure (Figure 16) are far lower than those inside Ratelco North, with maximum values of about 375 μW/cm^2 along the radials.

Moving to unfenced areas, just outside the Ratelco North lot west gate, (Figure 14) are two locations where the Holaday reading approximated 1000 μW/cm^2. The maximum value in the area between the KUBE enclosure and the North Ratelco lot (Figure 16) was about 470 μW/cm^2. Near the unfenced KMGI/KZOK/KMPS tower (Figure 17), power densities at several locations approach or exceed 1000 μW/cm^2, with one nearly 1700 μW/cm^2 and one exceeding 2000 μW/cm^2. It is apparent from the data in Figures 14, 16, and 17, that the power densities decrease rapidly with increasing distance from the tower.

The search for maximum outdoor values near residences was concentrated just east of the Ratelco North site in a backyard play area behind the Percival residence, the nearest residence to any of the broadcast towers. On Figure 14 this play area is located about 100 feet east of the eastern fence of the Ratelco North Lot, and due east of towers 4 and 5. While the spatially averaged power density in this area was about 117 μW/cm^2, the greatest unperturbed field value we found corresponded to a power density of about 350 μW/cm^2. In perturbed fields, the values were much higher. Near a fence, the power density rose to 1174 μW/cm^2. At the end of the swing set the maximum value was about 1450 μW/cm^2, and near the chinning bar the equivalent power density exceeded 2350 μW/cm^2. Despite the fact that these perturbed field values are very localized, they are real and can result in relatively high partial body exposures.

• Indoor Measurements

Spatially averaged equivalent power density values for the interior of three homes near the Ratelco North site ranged from negligible values to 23 μW/cm^2. However, Table 3 shows that the maximum, apparently unperturbed fields inside the homes occurred in the bedrooms along the south side of the Percival residence and were approximately 300 μW/cm^2. These values exceed all existing exposure guidelines except the ANSI radiation protection guide level. (While it is possible that these fields were "perturbed" by the house wiring acting as an antenna, it is unlikely that the elevated RF fields are due to 60 Hz current in the house wiring. We have found that the Holaday does not respond to 60 Hz fields of the intensity that is found near common electrical wiring.) The metal lamps in the homes are examples of conductive objects near which elevated fields could be found. The highest perturbed field equivalent power density was 352 $\mu W/cm^2$ along a curtain rod in one of the bedrooms in the Sparks residence. Towel racks, metal door and window frames, and curtain rods proved to be good indicators of areas where the local electric fields would be elevated.

• Miscellaneous

At site 3 the Holaday meter did not experience the multiple-frequency error evident at other sites, because there was a single dominant FM signal at this point (24 dB above the next highest peak). The FOISD and Holaday agreed very well in the comparison at this point, their ratio being 1.04. The Holaday was a good indicator of actual field strength at site 3; therefore, we decided to look at the FOISD support structure's effect on the FOISD values by using the Holaday to measure the electric fields with and without the support structure present. The structure consists of a wooden tripod topped by a 10 cm diameter flat metal plate, and a metal adapter which supports a wooden post and platform on which the plastic gimbals sit. The distance from the flat metal plate to the center of the FOISD antenna is about 51 cm. Data were taken with this 51 cm structure both in place, and removed. The point of measurement in both cases was the center of the FOISD's gimbals, with the FOISD removed, of course. With the support structure in place the Holaday meter read 330 V^2/m^2 (87.5 $\mu W/cm^2$). Without that structure perturbing the field, the value was 380 V^2/m^2 (100.8 $\mu W/cm^2$).

These data suggest that the FOISD values, and also the Holaday's multiple-frequency correction factors, should be altered. Using these new data, the Holaday correction multipliers would range from 0.61 to 1.31 over the entire mountaintop. However, a few considerations caution against this change. First, when the FOISD was calibrated at the Las Vegas facility, it was calibrated while resting in its gimbals. Hence the effects of a part of the field-perturbing structure are already included in the calibration. Second, we performed this check only once on Cougar Mountain, in part because there were only a few sites where the Holaday meter corresponded well with the FOISD values, and in part because there was no time to pursue the question. The Holaday meter's multiple-frequency response and the gimbals' effect upon the FOISD response underscore the fact that not only the Cougar Mountain RF environment, but also the techniques by which that environment might be measured are quite complex. We will study the influence of the FOISD antenna support structure in the Electromagnetics Branch laboratory and during future field studies.

<u>Summary</u>

1. With the exception of the data collected at the nine points noted in Table 2, all data in this study were taken using a Holaday 3001 meter

with an electric field probe. In this document, all power density values which were derived from the Holaday values, incorporate the instrument's frequency response correction and have been converted to units of equivalent plane wave power density. We have not altered the power density values to correct for the Holaday's multiple-frequency error, but have estimated the correction factor to be between 0.53 and 1.14. We believe these factors may be used to a distance of 50 to 100 feet from the actual measurement site without introducing significant error.

2. Non-FM band antennas are insignificant contributors to the power densities that exist on Cougar Mountain. For hazard and compliance purposes, FM antennas are the only significant sources on the mountain.

3. Vegetation, coniferous trees in particular, appears to be a good RF radiation shield.

4. The greatest spatially averaged power density that we found in a publicly accessible area was about 700 $\mu W/cm^2$. No spatially averaged value in a publicly accessible area exceeds the American National Standards Institute (ANSI) radiation protection guide. The selection of measurement locations will influence the distribution of power densities found in any investigation of environmental RF exposures. If one considers the set of locations at which we chose to make spatially averaged measurements (Figure 3), about 5 percent of the locations in publicly accessible areas have spatially averaged values exceeding 200 $\mu W/cm^2$, the value chosen as a limit for continuous exposure of the public by the International Radiation Protection Agency, the National Council on Radiation Protection and Measurement (in draft) (3), the State of Massachusetts, and Multnomah County, Oregon. Spatially averaged values at approximately 11 percent of the locations exceed 100 $\mu W/cm^2$, a guideline that the City of Portland, Oregon, has proposed for public exposure to RF radiation. Virtually all values exceed 1 $\mu W/cm^2$, the actual upper range of the exposures most people in the nation experience (4).

5. Localized unperturbed maximum power densities exceed the ANSI radiation protection guide in publicly accessible areas near the KPLZ tower, the KMGI, KZOK, KMPS tower, and in the backyard play area near the Percival residence.

6. Many of the maximum values at ground level inside the Ratelco North lot exceed 1000 $\mu W/cm^2$; a few exceed 2000 $\mu W/cm^2$. These values represent only potential occupational exposures. Although no measurements were taken at elevated locations on the towers, there is no question that a worker who ascends any of the FM towers (inside or outside the Ratelco North lot) will encounter fields that exceed the ANSI radiation protection guide.

7. All spatially averaged values near the residences we surveyed were below 100 $\mu W/cm^2$. Spatially averaged values inside the homes did not exceed 23 $\mu W/cm^2$. The maximum unperturbed value inside any home was 305 $\mu W/cm^2$, while outside it was about 350 $\mu W/cm^2$. The maximum

perturbed field inside a home was about 350 μW/cm^2 near a towel rack. The maximum outdoor perturbed field was 2350 μW/cm^2 near a "chinning bar" in the playground near the Percival residence.

8. Calculated exposure values exceed the actual measured values by wide margins in some cases. These discrepancies are caused by: (a) the use of a model which prudently avoids underpredicting, (b) the terrain at Cougar Mountain which presents greater elevation angles and distances from any given measurement location to an FM antenna than would be encountered if the terrain were level, and (c) the dense vegetation which acts as an RF attenuator.

9. In addition to potential health effects, residents on Cougar Mountain are concerned about radio frequency interference (RFI). Their electronic equipment, televisions, recorders, etc., do not function as expected. It should be noted that FCC Rules and Regulations, Vol. 3 Part 73, Radio Broadcast Services, Section 73.318 specifies limitations on FM radio "blanketing." Blanketing refers to a condition caused by high field strengths, which degrades FM radio reception because of receiver overload. The blanketing field strength defined by the FCC is 0.562 V/m which is equivalent to 0.0838 μW/cm^2. The data contained in this report (see Figures 3 and 13) illustrate that the RF levels on virtually the entire mountaintop exceed the blanketing value. We experienced what we believe to be an RFI problem when we were taking data along S.E. 173rd Road near the Ratelco North lot. Despite the fact that it was surrounded by a steel vehicle with conductive film covering most of the window surfaces, our computer ceased to function until we moved further from the KPLZ tower. It is understandable that interference problems would arise in nearby unshielded homes.

10. All values presented in this report were the result of measurements within about 10 feet of the ground. It is likely that the power densities increase as one moves to greater heights, becoming closer to the antennas, and encountering more of the main beams. Public access to such elevations would be possible with the erection of multistory buildings.

11. Introducing conducting objects to a relatively weak electromagnetic field can cause local power densities that are many times as great as what would be measured in the absence of the conducting object. Exposure to such enhanced power densities is likely to occur for significant periods of time only inside a dwelling or business. This field enhancing effect that conducting objects, which are commonly found in inhabited structures, have on generally weak fields, should admonish the FCC and land use planners as they rule on high power antenna, industrial, and residential siting.

Table 1. TRANSMISSION FREQUENCIES ON COUGAR MOUNTAIN BY TOWER NUMBER

Tower Number	FM Broadcast (MHz)	FM Effective Radiated Power (kW)	Frequency (MHz)
1	-	-	35.700 48.180 173.375 455.025 455.125
2	KIXI 95.7 KISW 99.9	(200) (200)	43.580 12,410.
3	KLSY 92.5	(200)	43.2
4	Not in use		
5	KEZX 98.9	(200)	-
6	KPLZ 101.5	(200)	-
7	KUBE 93.3	(200)	72.640
8	KQKT 96.5	(162)	-
9	KMGI 107.7 KZOK 102.5 KMPS 94.1	(126) (200) (196)	461.000 461.375 862.6375 863.3875 864.1375 864.8875 865.6375
10	-	-	43.26 151.985
11	-	-	12,470. 12,490. 12,510. 12,530. 12,670. 12,690.
12	-	-	72. 150.920 150.935 159.720 454.050 457.5375 457.5625

(continued)

Table 1 (continued)

Tower Number	FM Broadcast (MHz)	FM Effective Radiated Power (kW)	Frequency (MHz)
12 (cont.)	-	-	457.5875
			461.050
			461.100
			461.450
			461.600
			461.625
			461.9375
			462.175
			462.8625
			462.9125
			463.2375
			463.800
			464.400
			464.700
			464.7625
			861-865 15 transmiters on a trucking system
			960.
13	-	-	72.
			44.
			152.21
14	-	-	49.520
			49.580
			140.050
			150.920
			150.950
			151.595
			154.040
			156.500
			157.590
			158.700
			159.660
			415.050
			418.950
			450.6125
			452.300
			452.625
			452.675
			461.650
			461.975
			462.150
			462.774

(continued)

Table 1 (Continued)

Tower Number	FM Broadcast (MHz)	FM Effective Radiated Power (kW)	Frequency (MHz)
14 (cont.)	-	-	462.925 463.225 463.425 463.600 463.675 464.175 862.6125 862.6625 862.8125 862.9375 862.9875 863.3625 863.4125 863.5625 863.6875 863.7375 864.1125 864.1265 864.3125 864.4375 864.4875 864.8625 864.9125 865.0625 865.1875 865.2375 865.6125 865.8125 865.9375 865.9875
15	Not in Use		
16	Not in Use		
17	-	-	159.990
18	-	-	152.090
19	-	-	1,855. 1,915. 6,745. 6,775.
20	-	-	1,885. 1,895.

(continued)

Table 1 (Continued)

Tower Number	FM Broadcast (MHz)	FM Effective Radiated Power (kW)	Frequency (MHz)
21	-	-	47.02 47.10 147.08
22	-	-	33.160 43. 72. 150.845 152.240 159.525 159.840 462.550

) MEASUREMENTS AND BROADBAND COMPARISONS
n Microwatts Per Square Centimeter)

Site	88-108 MHz (FM) Narda	Holaday	FOISD	FOISD/Holaday s	1-2.5 GHz AEL Crossed Log Periodic	2.5-13 GHz AEL Crossed Log Periodic	2-18 GHz WJ Ominidirectional Vehicle Mount
2. South Gate area of Ratelco North Lot		81.0	56.7	0.70			.006 peak, 1 polarization
3. Near KQKT	83.1	77.5	80.8	1.04			
4. Near Ratelco South Lot		12.2	9.0	0.74			
5. Near KMGI, KZOK, KMPS	760	1268	914	0.72			
6. Near Percival Residence		50.5	45.6	0.90			
7. Near Lennox Residence		4.9	5.6	1.14 eak,	0.0003 peak, 2 polarizations (0.000003 for 1.84-1.87 GHz averaged, 2 polarizations) (0.00000007 for 2.178 GHz peak, 1 polarization)	no frequency exceeding noise level on wide band scan (0.000007 for 6.775 GHz peak, 1 polarization)	
8. Near West Gate of Ratelco North Lot		599	370	0.62			
9. Inside Ratelco North	760	1561	830	0.53			
10. Near Sparks Residence					0.00002 for 1.85 to 1.92 GHz peak, 2 polarizations 0.006 for 0.86 to 0.87 GHz peak, 1 polarization		

Table 3. INDOOR MEASUREMENT DATA

LENNOX RESIDENCE	Plane-wave Equivalent Power Density ($\mu W/cm^2$)	
	Spatially Averaged	Maximum
Living Room	2	11
Kitchen	2	-
Bedroom	7-9	-
Chinning Bar	-	117
Microscope eyepiece	-	35
Office area	2	-
Chair	5-12	-
Second Floor Storage	4-5	-
Lamp	-	14
Over table	7	-
Shower	2	-
Basement	2-12	-
Near radial arm saw	-	129

PERCIVAL RESIDENCE	Spatially Averaged	Maximum
Living Room	5-12	-
Near sliding door to deck	-	23
Door to Kitchen	12	-
Door frame between kitchen and deck	-	70
Kitchen	7-23	-
Near corner of woodstove	-	23
Entry Way	12-23	-
Master Bedroom	12	-
Over bed near ceiling	-	59
Southwest corner	-	305
Near swag lamp	-	235
Daughter's Bedroom		
Over bed	23	-
Near bed with electric blanket	-	70
Near south wall	-	282
Bathroom	8-12	-
Deck	12	23
West end	21	-
East end	4	-

Table 3 (continued)

SPARKS RESIDENCE	Plane-wave Equivalent Power Density ($\mu W/cm^2$) Spatially Averaged	Maximum
Living Room	7	15
Kitchen	1-2	-
Window frame	-	26
Family Room	1-2	-
Sliding glass door frame	-	7
Master Bedroom	1-2	-
Metal door frame	-	7-21
Dressing room	1-2	-
Shower stall	-	95
Bedroom No. 2	2-7	-
Along curtain rod	-	352
Office	2-5	-
Filing cabinet	-	16-23
Window	-	16
End of curtain rod	-	117
Bathroom	1-4	-
End of towel bar	-	33
End of shower curtain rod	-	129
Entry Way	2-5	-
Utility Room	1-4	8
Garage	8	-
metal bar surface on door	-	59-70
Basement	1-2	-
Bedroom downstairs	0-1	-
window frame	-	20
Furnace room	1-2	-
Bathroom Downstairs	0-1	-
end of towel rack	-	8

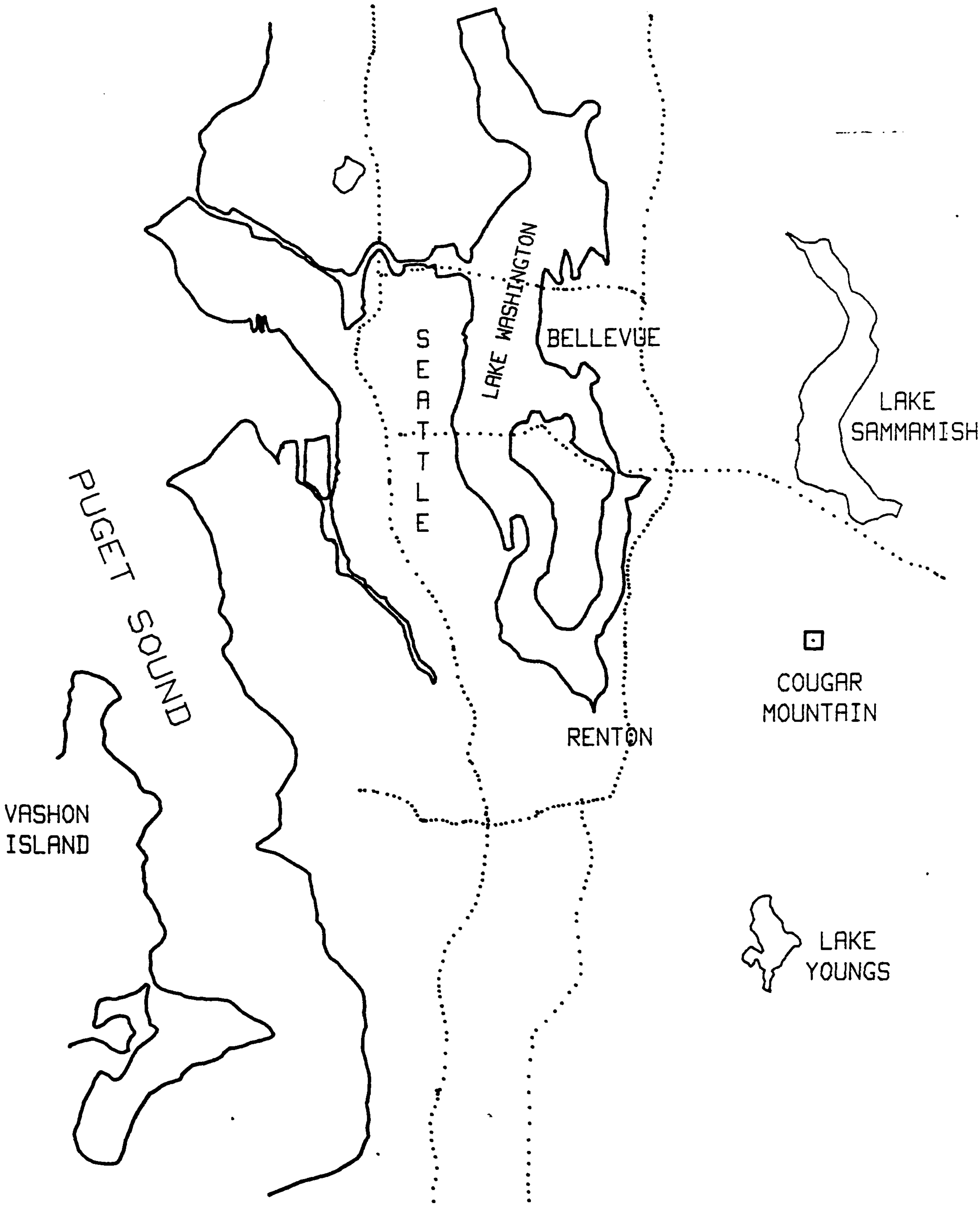


Figure 1. Map of Seattle Area Showing Location of Cougar Mountain.

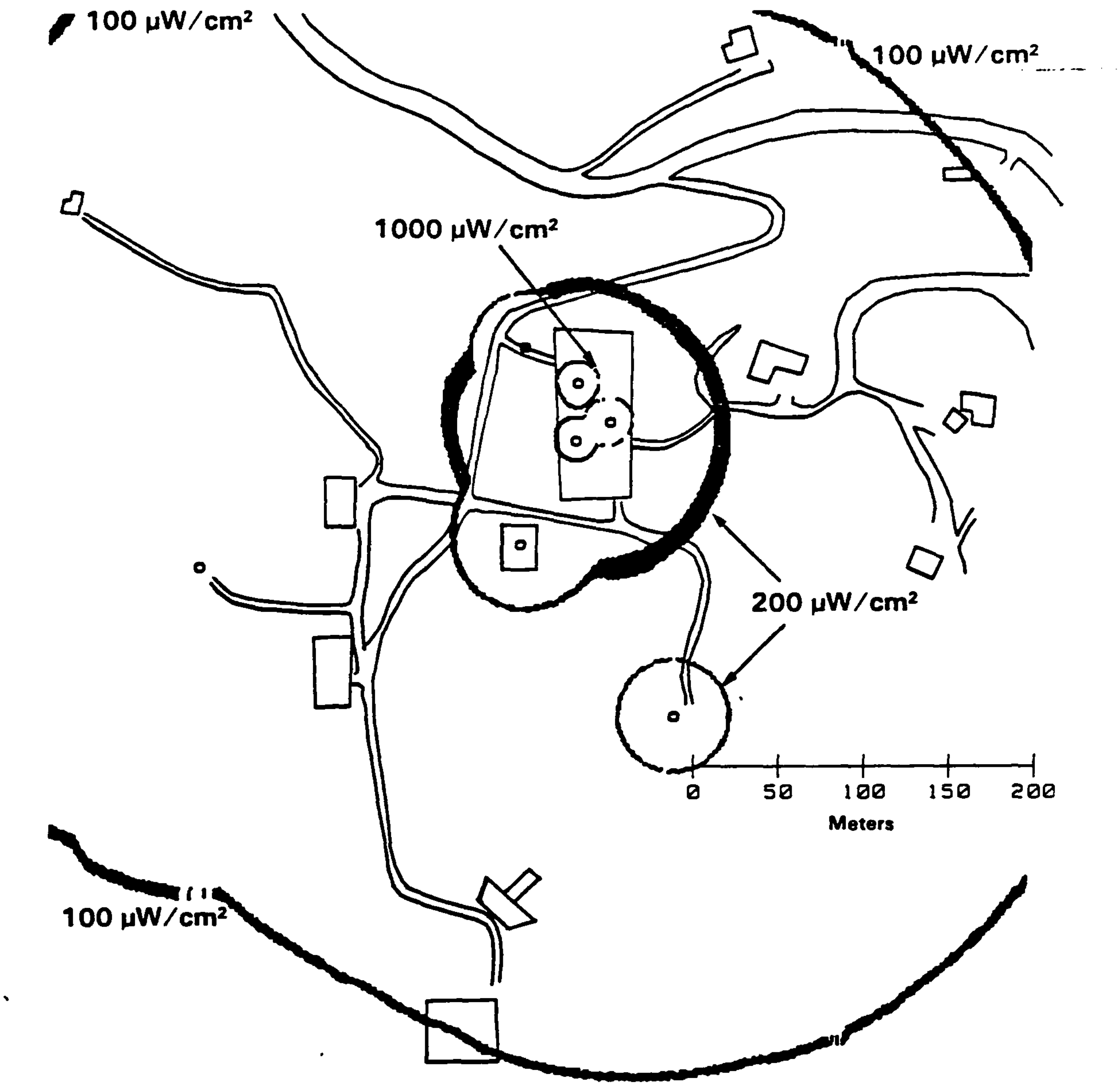
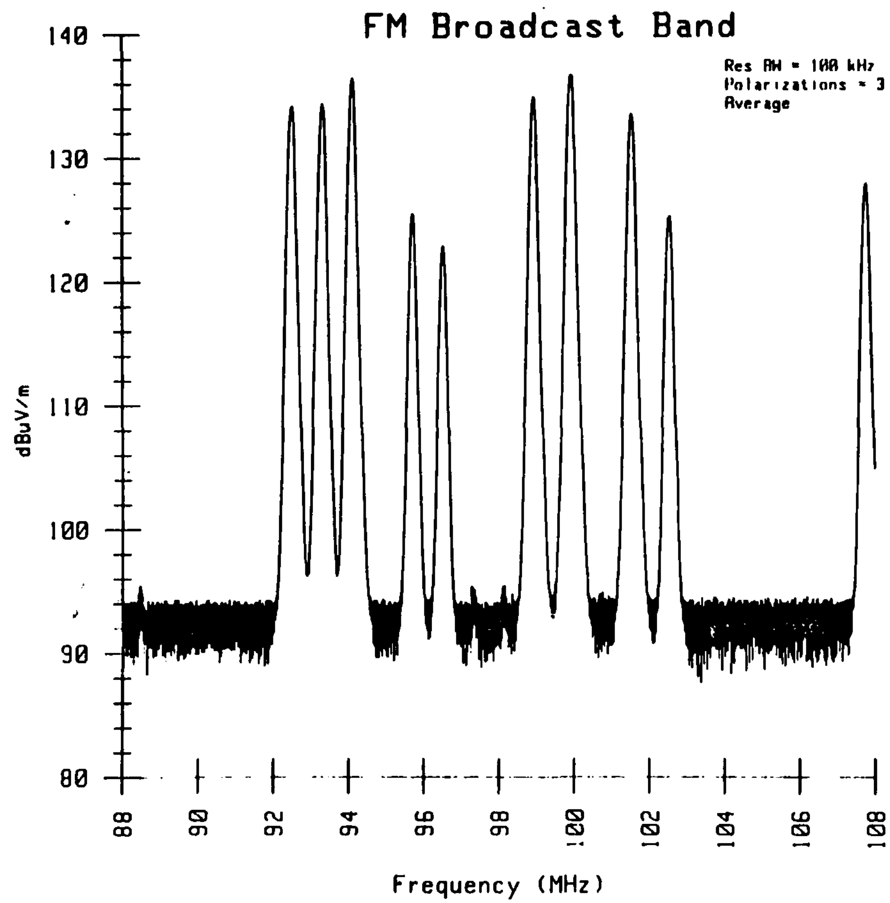


Figure 2. Computer Plot of Calculated Power Density Values for Cougar Mountain.



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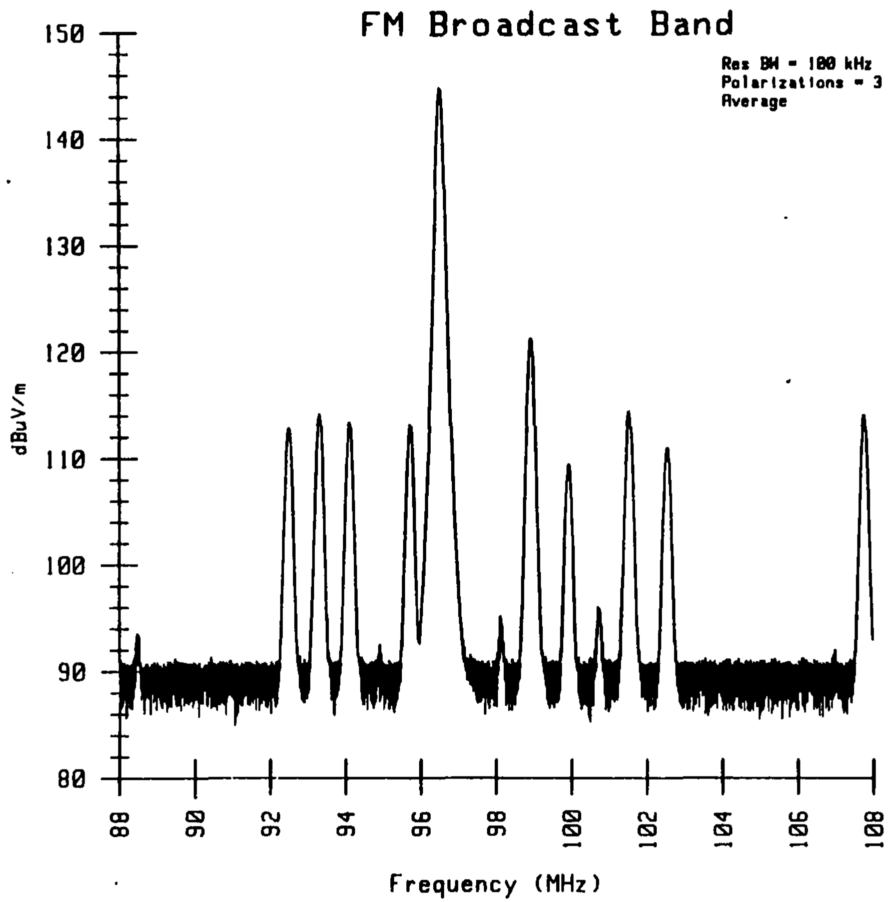
Location: SITE 2
Antenna Used: Fiber Optic Isolated Spherical Dipole

Frequency (MHz)	Amplitude (dBuV/m)	Power Density (uW/cm^2)
92.5 (KLSY)	134.20	6.97
93.3 (KUBE)	134.39	7.29
94.1 (KMPS)	136.47	11.76
95.7 (KIXI)	125.53	0.95
96.5 (KOKT)	122.91	0.52
98.9 (KEZX)	134.94	8.27
99.9 (KISW)	136.72	12.46
101.5 (KPLZ)	133.53	5.98
102.5 (KZOK)	125.30	0.90
107.7 (KMGI)	127.91	1.64

Total Band Exposure: 56.74 uW/cm^2

10 Frequencies included in the integration.

Figure 4. Site 2 FM Spectrum.



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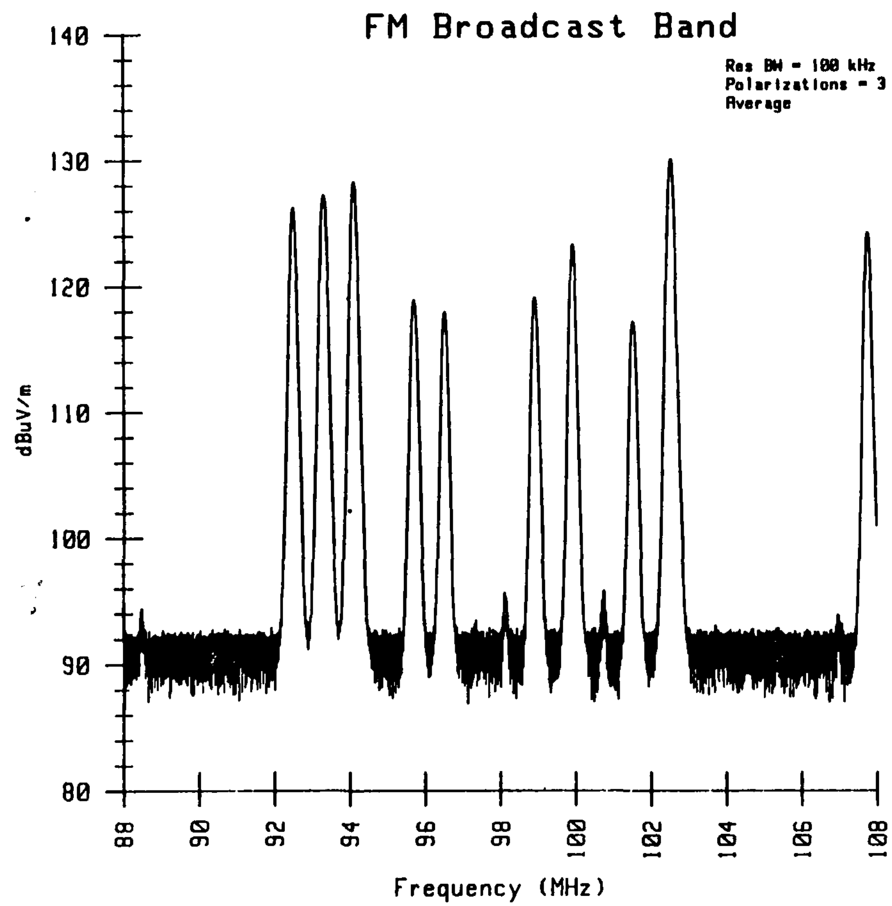
Location: SITE 3
Antenna Used: Fiber Optic Isolated Spherical Dipole

Frequency (MHz)		Amplitude (dBuV/m)	Power Density (uW/cm^2)
92.5	(KLSY)	112.86	0.05
93.3	(KUBE)	114.17	0.07
94.1	(KMPS)	113.44	0.06
95.7	(KIXI)	113.16	0.05
96.5	(KQKT)	144.80	80.03
98.9	(KEZX)	121.20	0.35
99.9	(KISW)	109.41	0.02
101.5	(KPLZ)	114.37	0.07
102.5	(KZOK)	110.96	0.03
107.7	(KMGI)	114.02	0.07

Total Band Exposure: 80.81 uW/cm^2

10 Frequencies included in the integration.

Figure 5. Site 3 FM Spectrum.



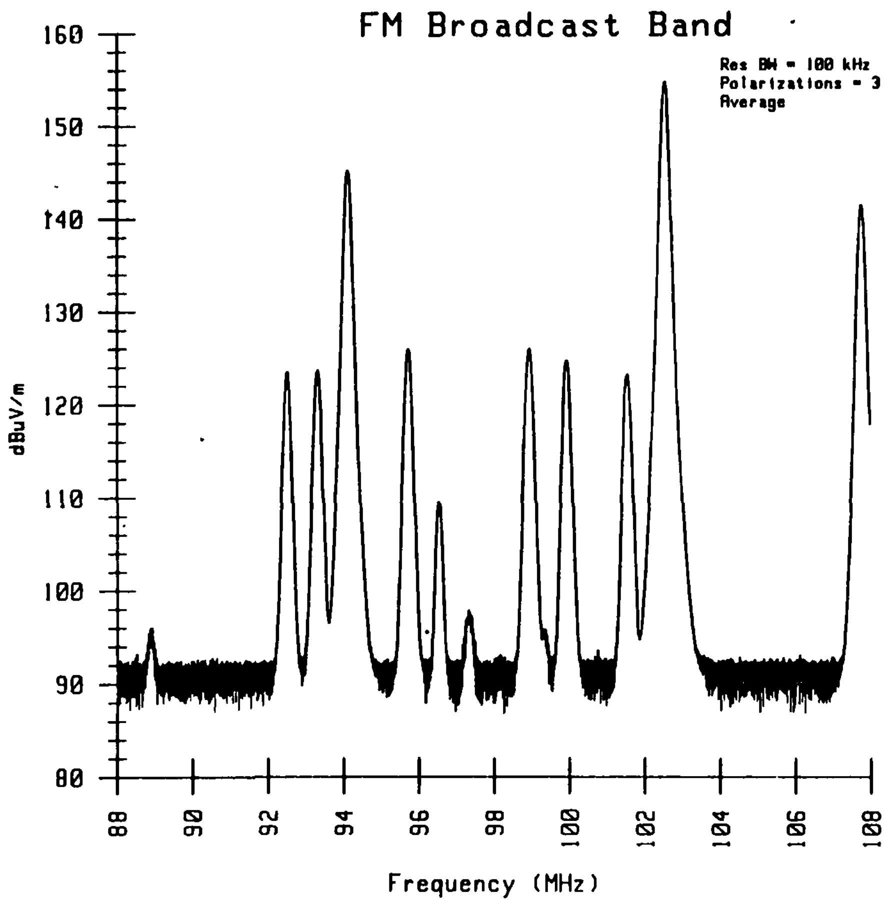
05/08/85. 5:14 PM 20 Scans Processed

Location: SITE 4
Antenna Used: Fiber Optic Isolated Spherical Dipole

Frequency (MHz)	Amplitude (dBuV/m)	Power Density (uW/cm^2)
92.5 (KLSY)	126.24	1.12
93.3 (KUBE)	127.27	1.41
94.1 (KMPS)	128.31	1.80
95.7 (KIXI)	118.94	0.21
96.5 (KOKT)	117.97	0.17
98.9 (KEZX)	119.09	0.22
99.9 (KISW)	123.30	0.57
101.5 (KPLZ)	117.20	0.14
102.5 (KZOK)	130.09	2.71
107.7 (KMGI)	124.23	0.70
Total Band Exposure:		9.03 uW/cm^2

10 Frequencies included in the integration.

Figure 6. Site 4 FM Spectrum.



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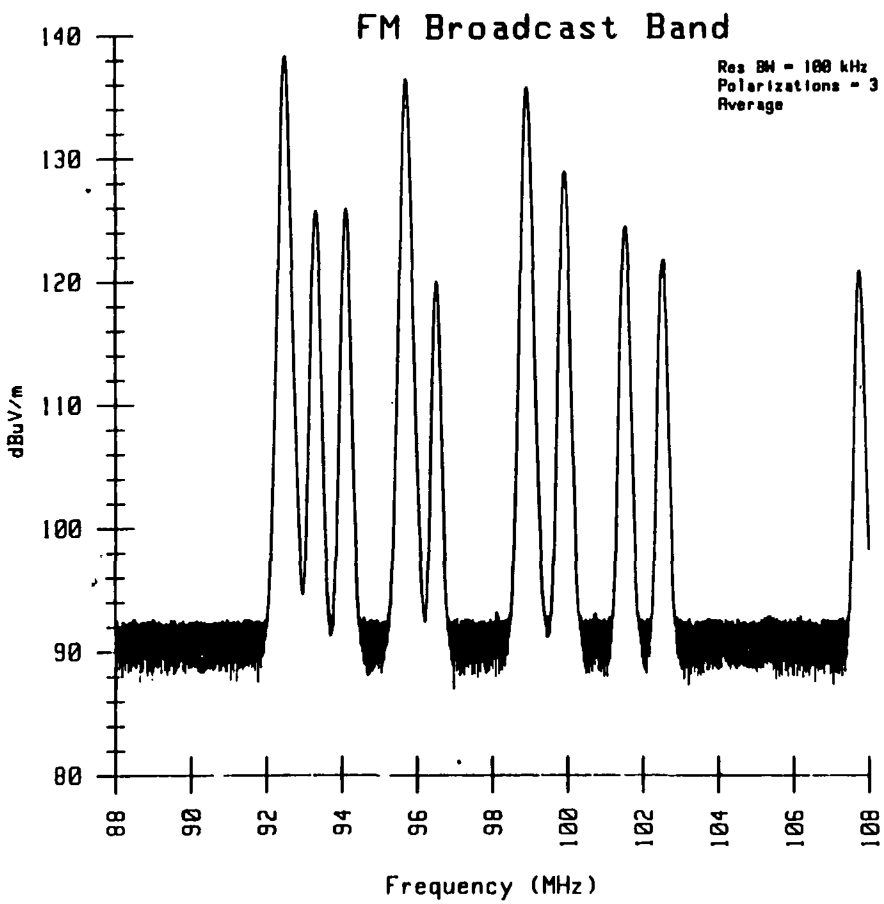
Location: SITE 5
Antenna Used: Fiber Optic Isolated Spherical Dipole

Frequency (MHz)	Amplitude (dBuV/m)	Power Density (uW/cm^2)
92.5 (KLSY)	123.40	0.59
93.3 (KUBE)	123.67	0.62
94.1 (KMPS)	145.10	87.36
95.7 (KIXI)	125.92	1.04
96.5 (KOKT)	109.46	0.02
98.9 (KEZX)	125.90	1.05
99.9 (KISW)	124.70	0.78
101.5 (KPLZ)	123.19	0.55
102.5 (KZOK)	154.72	785.69
107.7 (KMGI)	141.40	36.65
Total Band Exposure:		914.36 uW/cm^2

10 Frequencies included in the integration.

Figure 7. Site 5 FM Spectrum.



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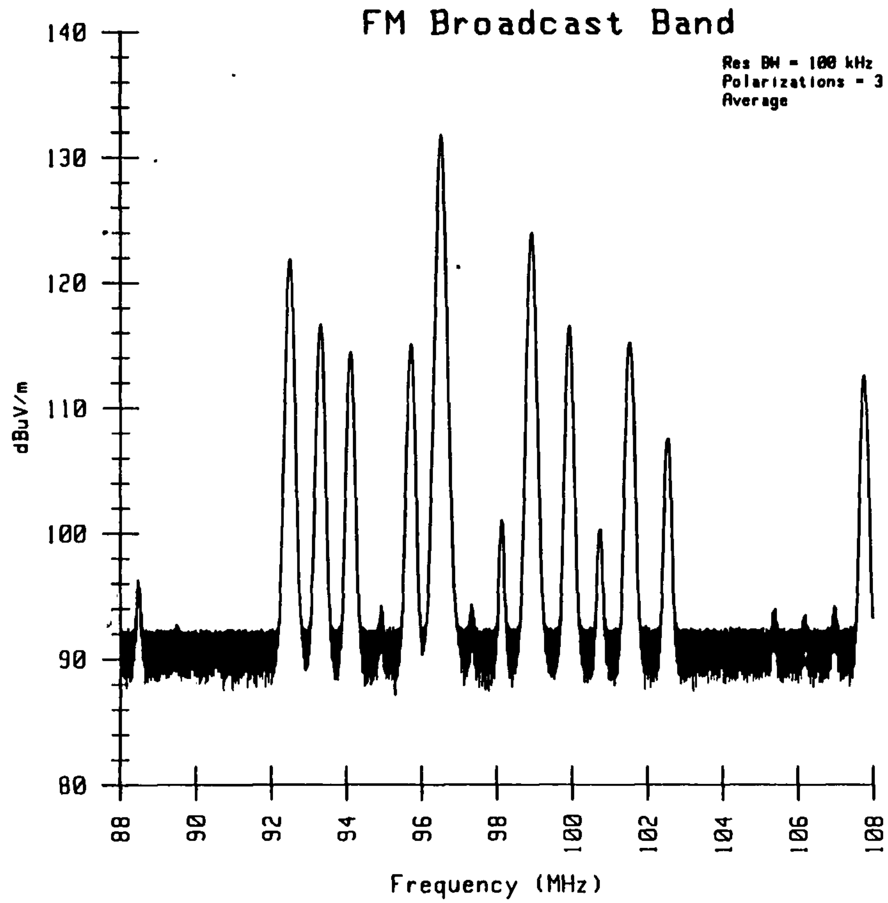
Location: SITE 6
Antenna Used: Fiber Optic Isolated Spherical Dipole

Frequency (MHz)		Amplitude (dBuV/m)	Power Density (uW/cm^2)
92.5	(KLSY)	138.34	18.09
93.3	(KUBE)	125.77	1.00
94.1	(KMPS)	125.91	1.03
95.7	(KIXI)	136.45	11.72
96.5	(KQKT)	120.06	0.27
98.9	(KEZX)	135.73	9.92
99.9	(KISW)	128.94	2.08
101.5	(KPLZ)	124.43	0.74
102.5	(KZOK)	121.76	0.40
107.7	(KMGI)	120.08	0.32
Total Band Exposure:			45.57 uW/cm^2

10 Frequencies included in the integration.

Figure 8. Site 6 FM Spectrum.



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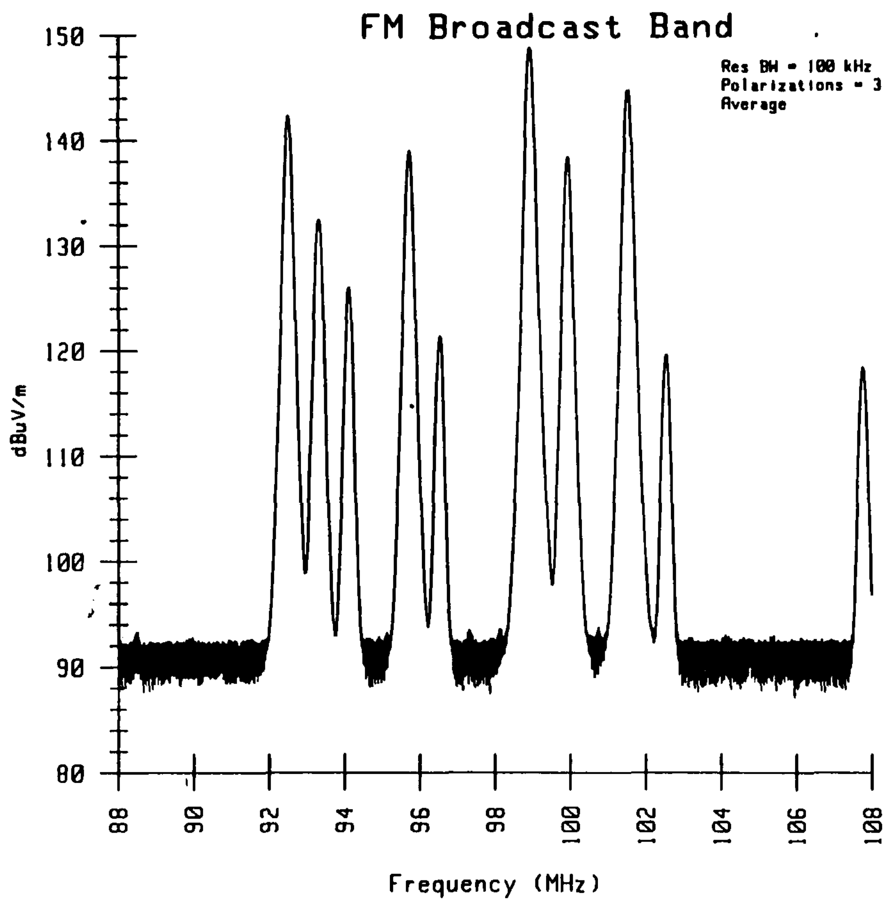
Location: SITE 7
Antenna Used: Fiber Optic Isolated Spherical Dipole

Frequency (MHz)	Amplitude (dBuV/m)	Power Density (uW/cm^2)
92.5 (KLSY)	121.87	0.41
93.3 (KUBE)	116.69	0.12
94.1 (KMPS)	114.45	0.07
95.7 (KIXI)	115.10	0.09
96.5 (KQKT)	131.75	3.97
98.9 (KEZX)	123.97	0.66
99.9 (KISW)	116.52	0.12
101.5 (KPLZ)	115.10	0.09
102.5 (KZOK)	107.51	0.01
107.7 (KMGI)	112.54	0.05

Total Band Exposure: 5.59 uW/cm^2

10 Frequencies included in the integration.

Figure 9. Site 7 FM Spectrum.



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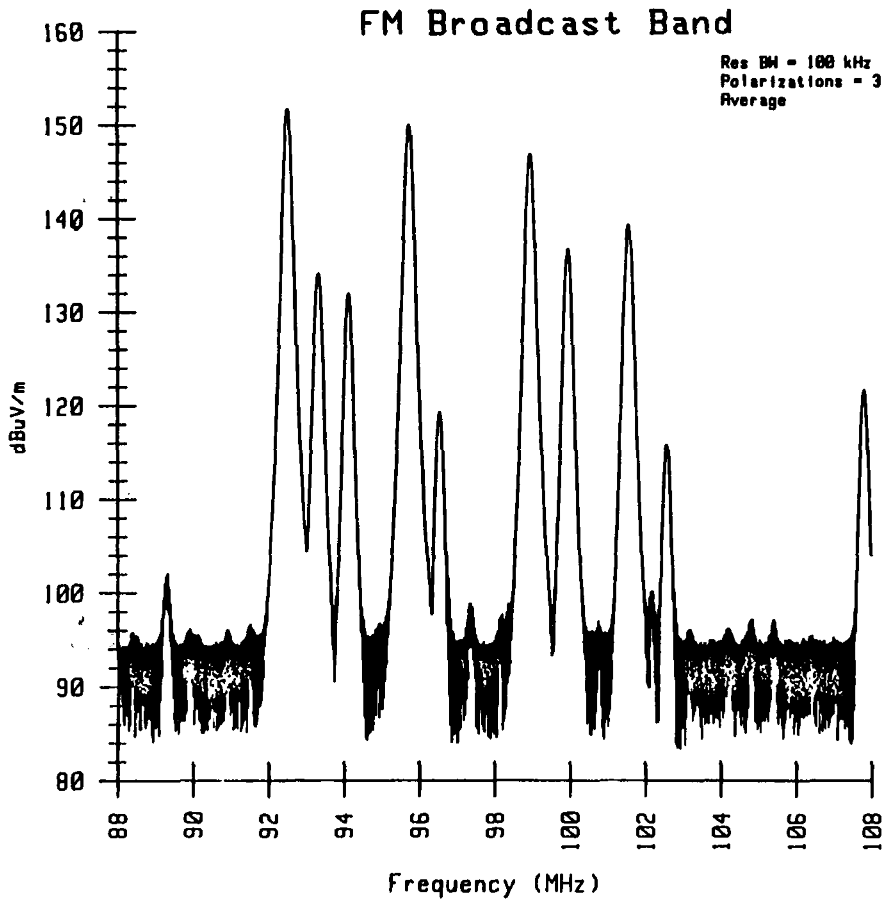
Location: SITE 8
Antenna Used: Fiber Optic Isolated Spherical Dipole

Frequency (MHz)		Amplitude (dBuV/m)	Power Density (uW/cm^2)
92.5	(KLSY)	142.34	45.44
93.3	(KUBE)	132.51	4.73
94.1	(KMPS)	126.04	1.07
95.7	(KIXI)	139.01	21.10
96.5	(KQKT)	121.40	0.37
98.9	(KEZX)	148.76	199.34
99.9	(KISW)	138.44	18.50
101.5	(KPLZ)	144.74	79.04
102.5	(KZOK)	119.57	0.24
107.7	(KMGI)	118.39	0.18

Total Band Exposure:			370.01 uW/cm^2

10 Frequencies included in the integration.

Figure 10. Site 8 FM Spectrum.



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Location: SITE 9
Antenna Used: Fiber Optic Isolated Spherical Dipole

Frequency (MHz)		Amplitude (dBuV/m)	Power Density (uW/cm^2)
92.5	(KLSY)	151.67	389.64
93.3	(KUBE)	134.09	6.79
94.1	(KMPS)	131.97	4.10
95.7	(KIXI)	149.99	264.84
96.5	(KQKT)	119.20	0.22
98.9	(KEZX)	146.86	120.84
99.9	(KISW)	136.73	12.50
101.5	(KPLZ)	139.29	22.52
102.5	(KZOK)	115.00	0.10
107.7	(KMGI)	121.62	0.39

Total Band Exposure: 830.02 uW/cm^2

10 Frequencies included in the integration.

Figure 11. Site 9 FM Spectrum.

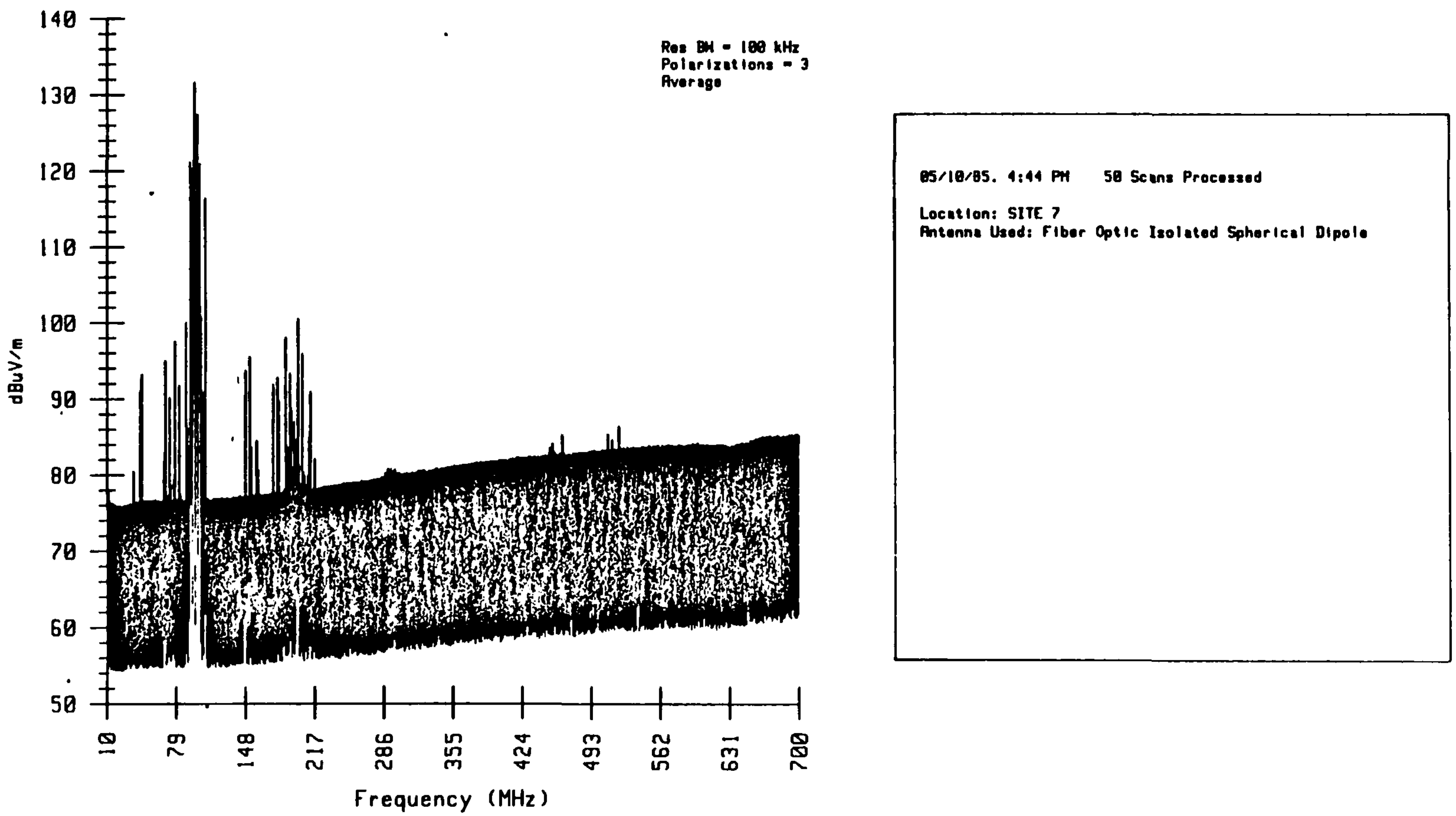

Figure 12. Site 7 Wideband Spectrum.

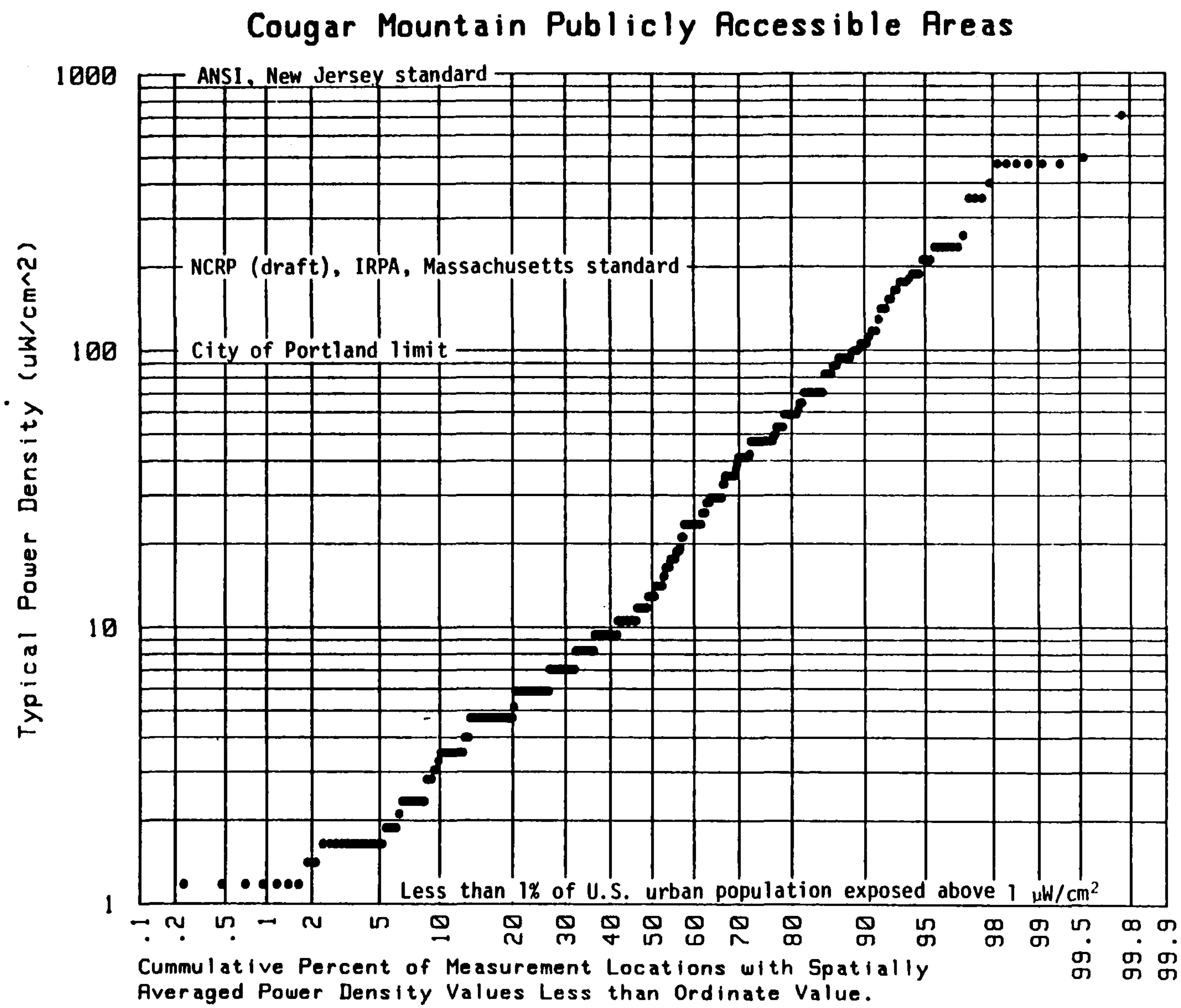

Figure 13. Probability Plot for Cougar Mountain Spatially Averaged Power Density Values in Accessible Areas.

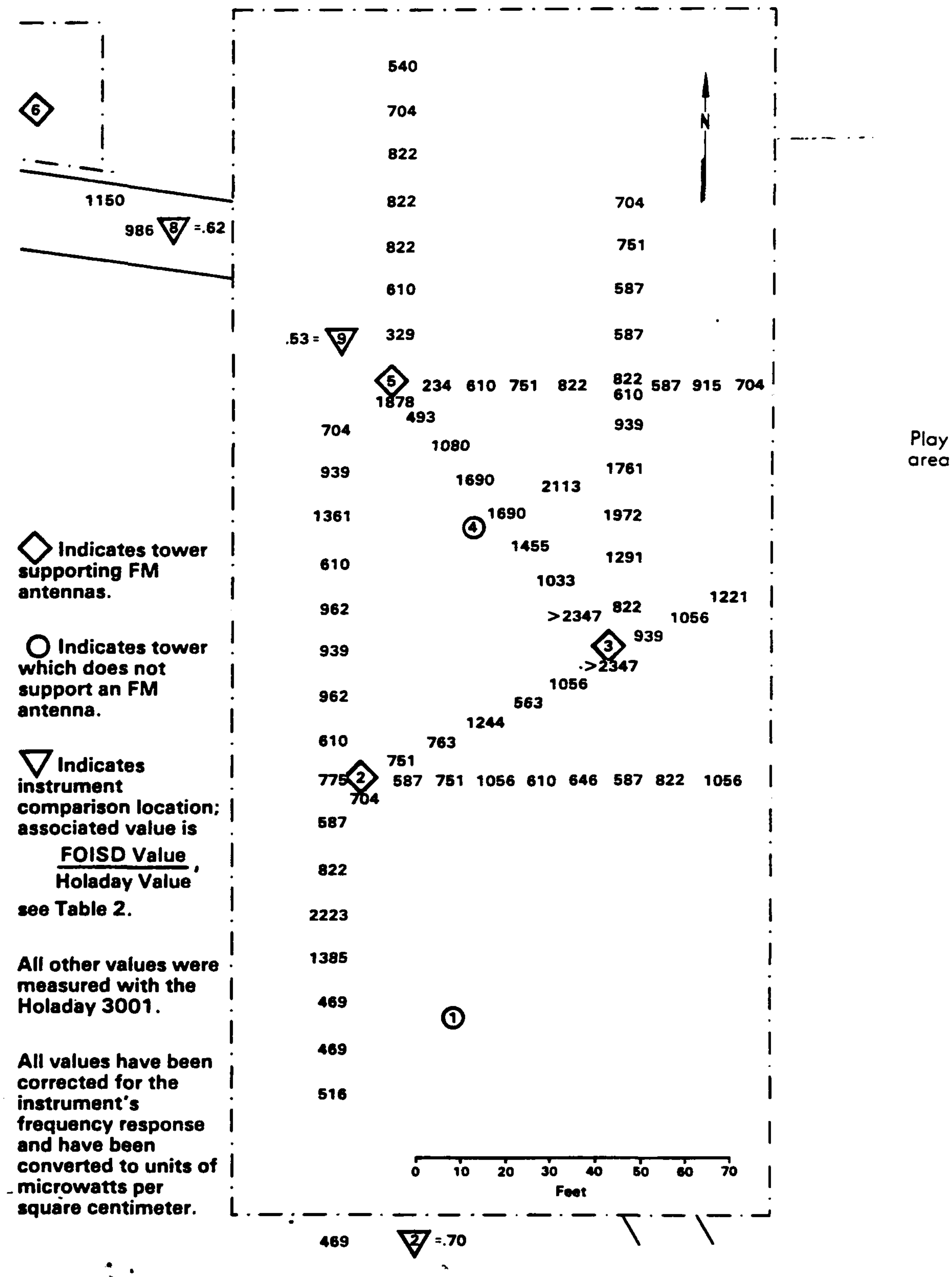

Figure 14. RATELCO North Lot Maximum Values.

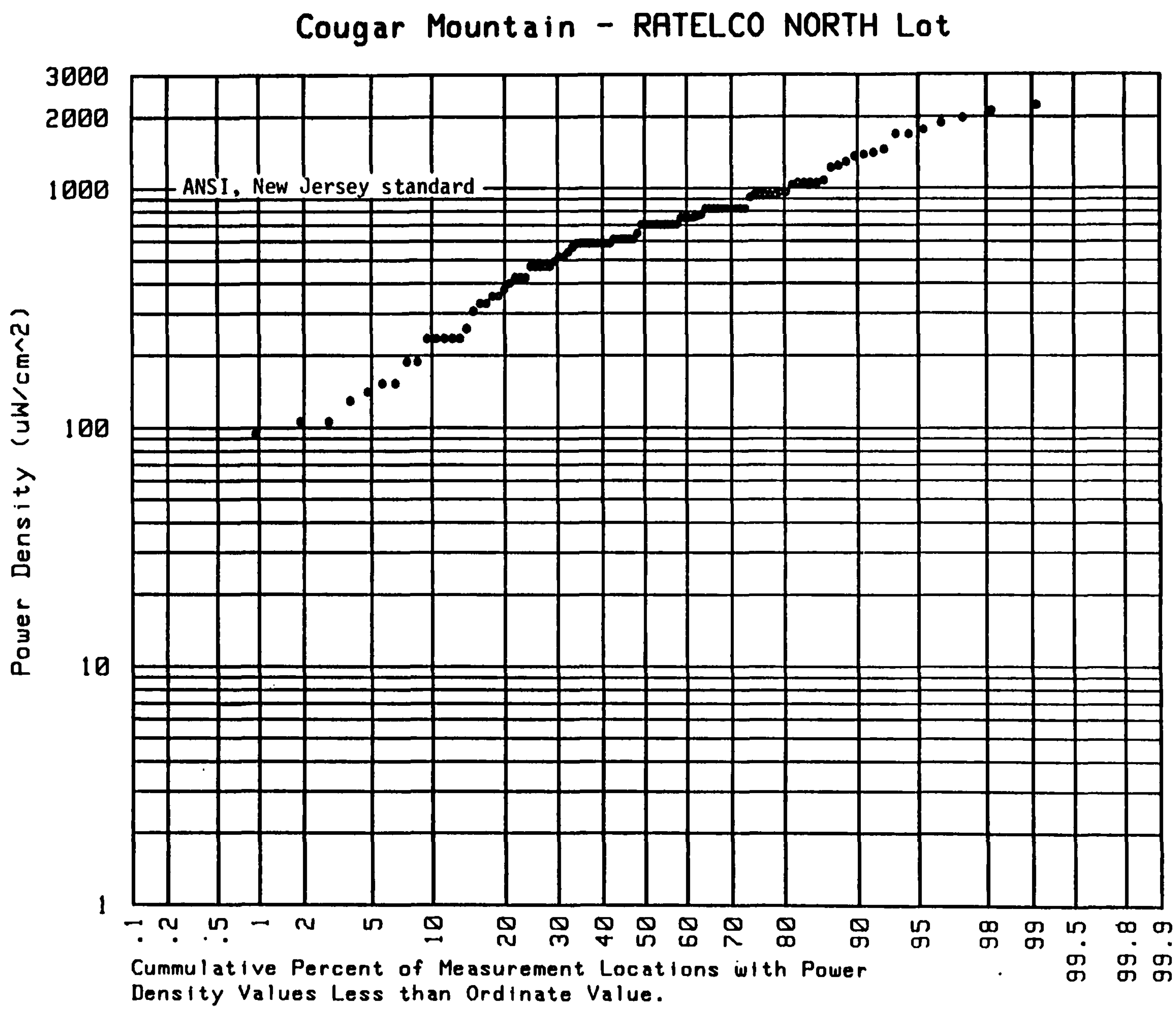

Figure 15. Probability Plot of Power Density Values at All Measured Points Inside RATELCO North Lot.

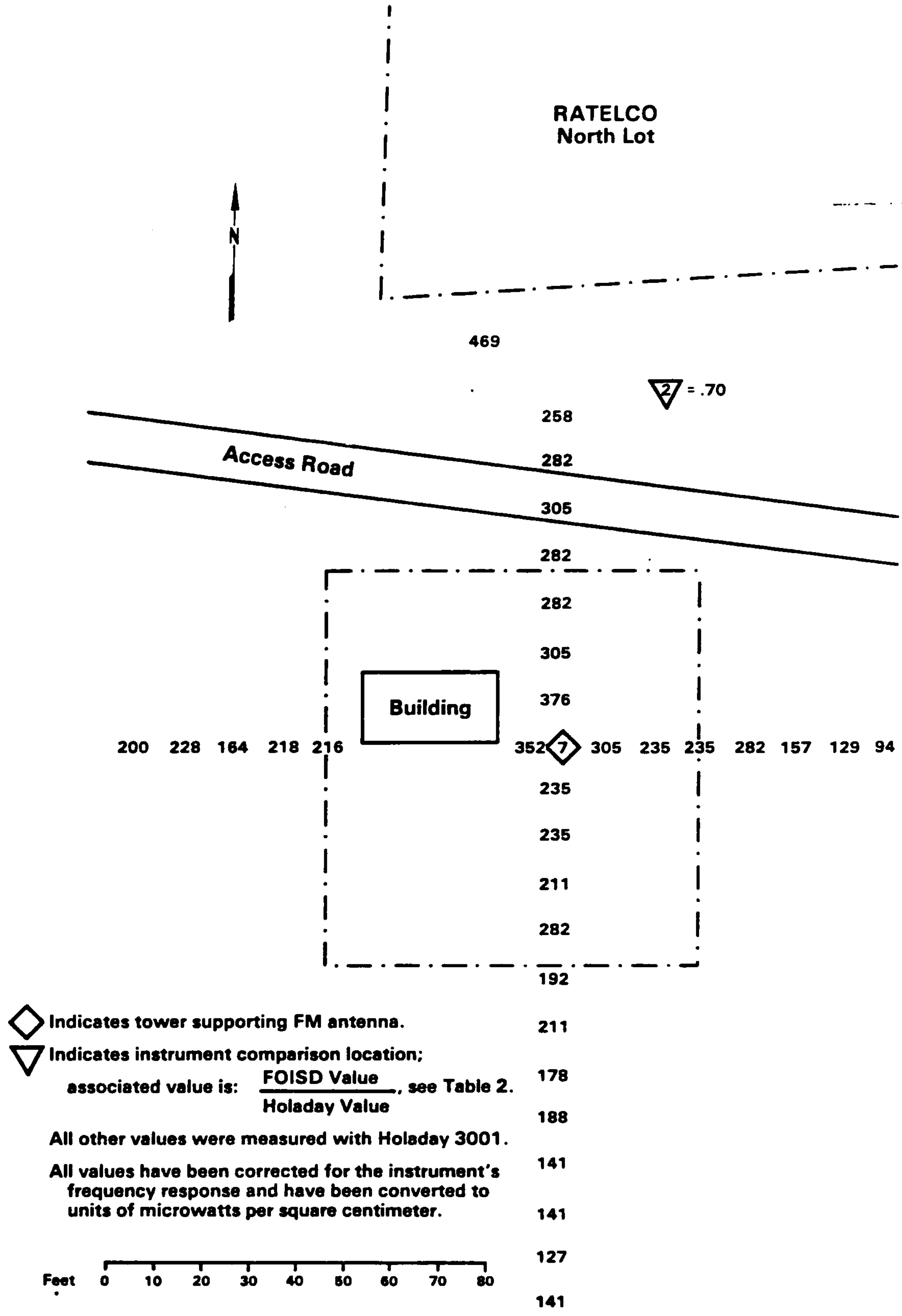

Figure 16. RATELCO KUBE Enclosure Maximum Values.

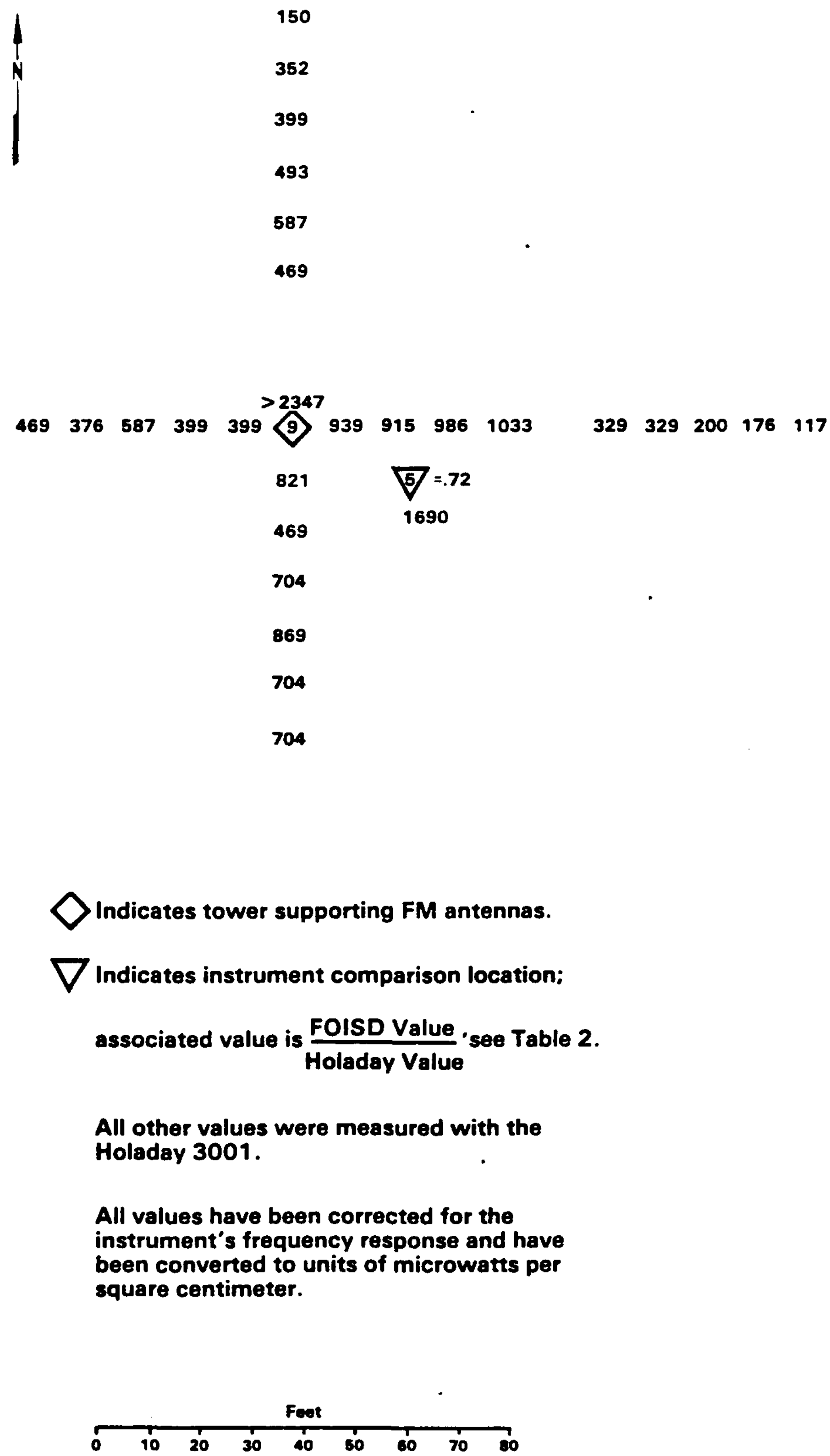

Figure 17. Maximum Values Near KMGI/KZOK/KMPS Tower.

REFERENCES

1. An Automated TEM Cell Calibration System, E. D. Mantiply, EPA 520/1-84-024, October 1984.

2. An Engineering Assessment of the Potential Impact of Federal Radiation Protection Guidance on the AM, FM, and TV Broadcast Services, P. C. Gailey, R. A. Tell, EPA 520/6-85-011, April 1985.

3. Presented at the Annual Meeting of NCRP, Washington, D.C., April 1984.

4. Population Exposure to VHF and UHF Broadcast Radiation in the United States, R. A. Tell, E. D. Mantiply, Proceedings of the IEEE, Vol. 68, No. 1, January 1980.

GLOSSARY

Gigahertz (GHz); 1 GHz equals 1,000,000,000 Hz.

Hertz (Hz) is a unit for expressing frequency equivalent to cycles per second, i.e., one Hertz is defined as one cycle per second.

Kilohertz (kHz); 1 kHz equals 1000 Hz.

Maximum Value refers to the highest power density value that can be found in a given area based on electric field measurements, normally associated with areas of limited extent wherein only partial body exposures might occur.

Maximum Value in a Perturbed Field refers to the maximum power density value which we believe is caused by the convergence of electric field lines at a conducting object. While these elevated levels are artifacts of the conducting objects in the field and are highly localized in volume, they are real, measurable fields.

Maximum Value in Unperturbed Field refers to that maximum power density value which exists in the absence of any conducting object in the immediate vicinity (i.e. a few feet). These are the maximum values found in "free space."

Megahertz (MHz); 1 MHz equals 1,000,000 Hz.

Microwatt per Square Centimeter ($\mu W/cm^2$); an expression for the power density of an electromagnetic field, 1000 $\mu W/cm^2$ = 1 mW/cm^2.

Milliwatts per Square Centimeter (mW/cm^2); an expression for the power density of an electromagnetic field, 1 mW/cm^2 = 1000 $\mu W/cm^2$.

Power Density is a term to describe the intensity of incident electromagnetic radiation fields.

Spatially Averaged Value refers to our best estimate of the average power density or typical power density that exists in a given location. (i.e. the average value that exists over a vertical area of about 70 square feet.)

Ratelco refers to Ratelco Incorporated. a company which owns several towers atop Cougar Mountain and leases tower space to broadcasters, point to point users, land mobile users, etc.

Volts per Meter (V/m) is an expression for the strength of an electric field.

APPENDIX

EQUIPMENT AND CALIBRATION INFORMATION

The equipment used during the Cougar Mountain study is listed below. Calibration data are detailed for each instrument in the following pages.

Broadband Equipment

Holaday Industries	Model 3001, S/N 26026	Meter
	S/N 056	Electric Field Probe
Narda	Model 8616, S/N 05016	Meter
	Model 8631, S/N 03026	Magnetic Field Probe

Narrowband Equipment

NanoFast Fiber Optic Isolated Spherical Dipole Model EFS-2, S/N 2927

Ailtech Singer Dipole Antenna Set Model DM-105A-T3, S/N 95414-13

American Electronic Laboratories (AEL) Crossed Log Periodic Antenna Model APX 1293, S/N 108

Watkins Johnson Omnidirectional Antenna Model 8549, S/N 17

Hewlett Packard 8566A Spectrum Analyzer, S/N 1918A00731 (display)
S/N 1918A00220 (analyzer)

Hewlett Packard 9845B Desktop Computer, S/N 1838A02156

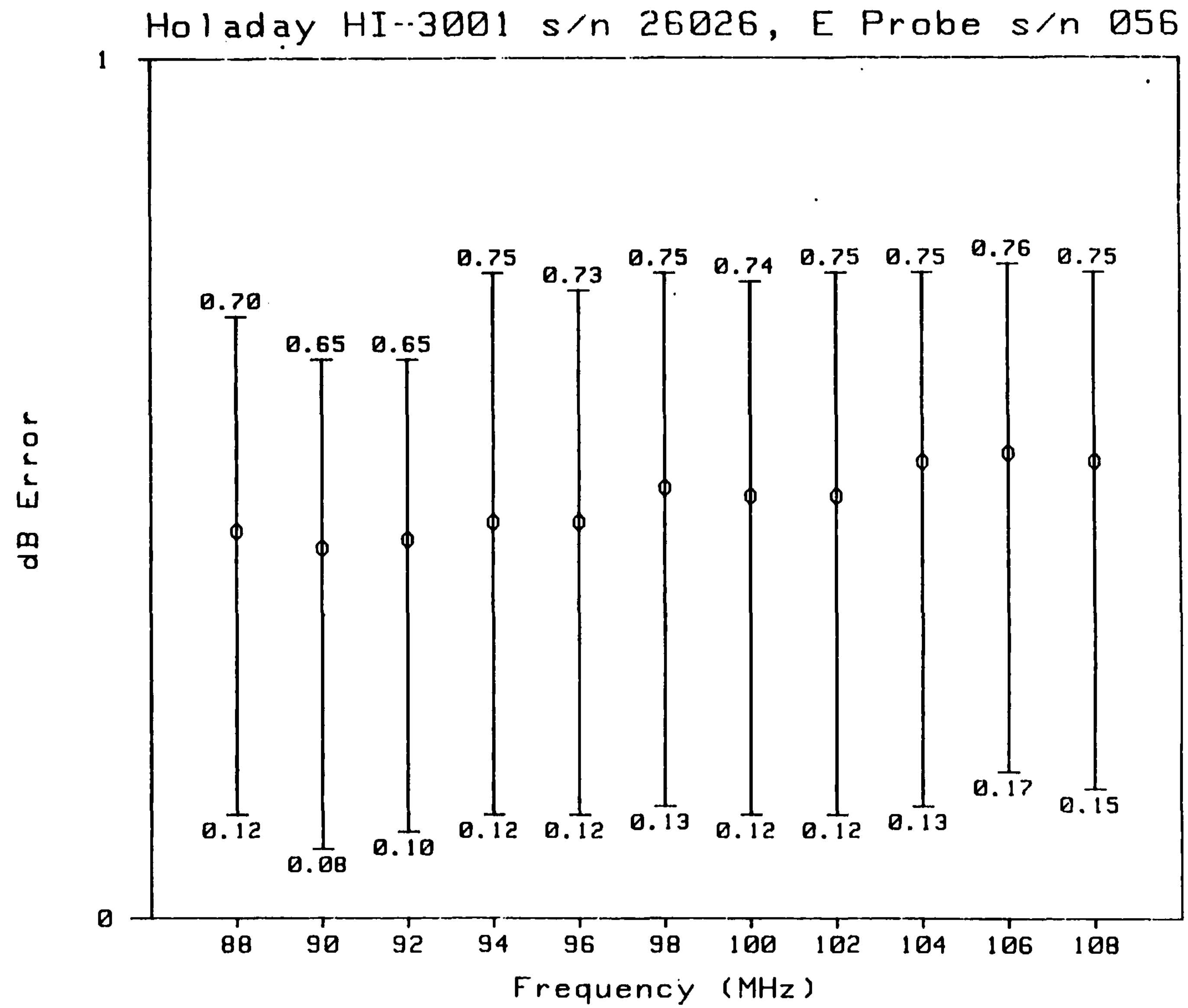

Figure A1. Holaday Model 3001 Electric Field Calibration in FM Frequency Band.

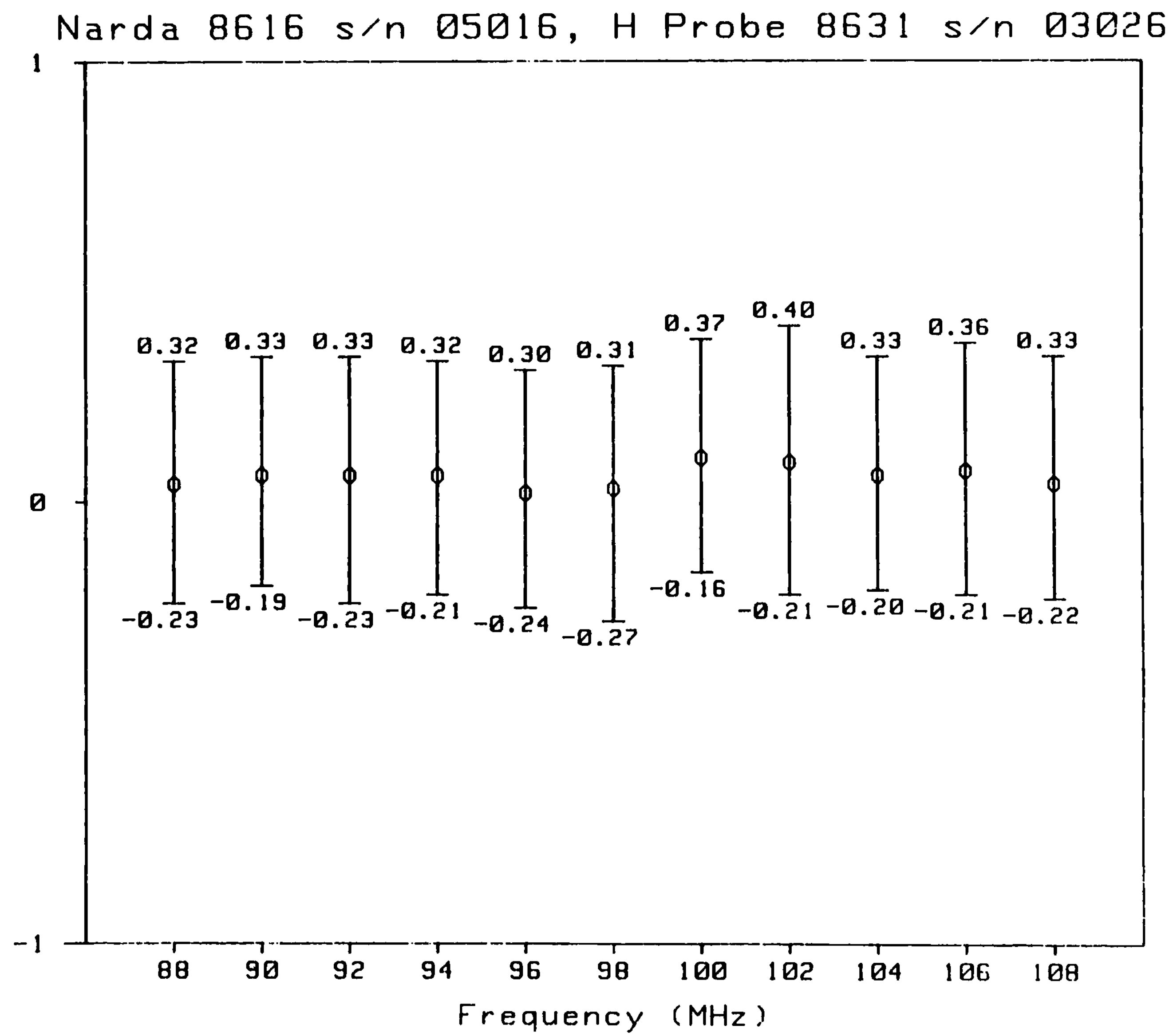

Figure A2. Narda Model 8616 (8631 Probe) Magnetic Field Calibration in FM Frequency Band.

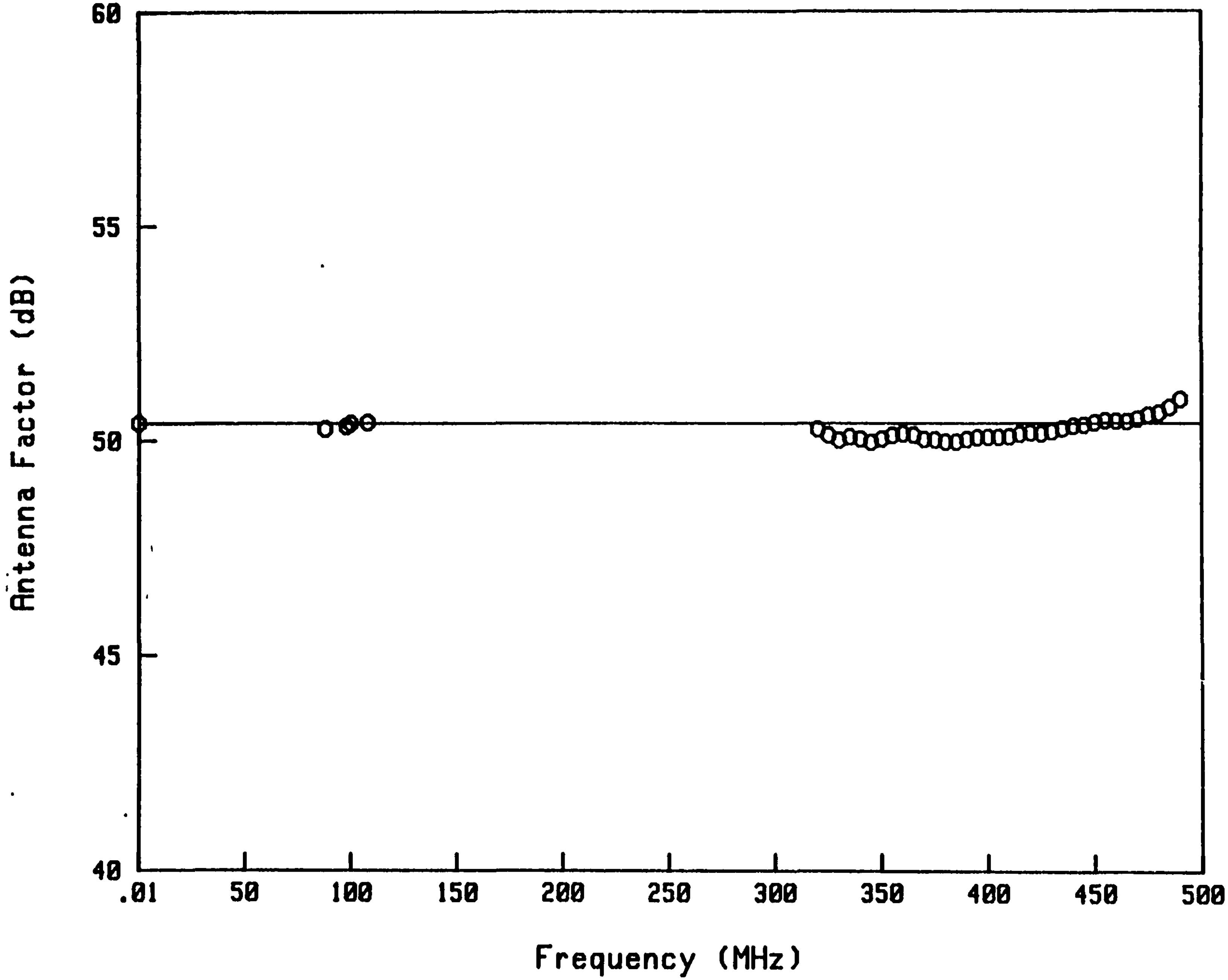

Figure A3. NanoFast Model EFS-2 Fiber Optic Isolated Spherical Dipole Antenna Factor.

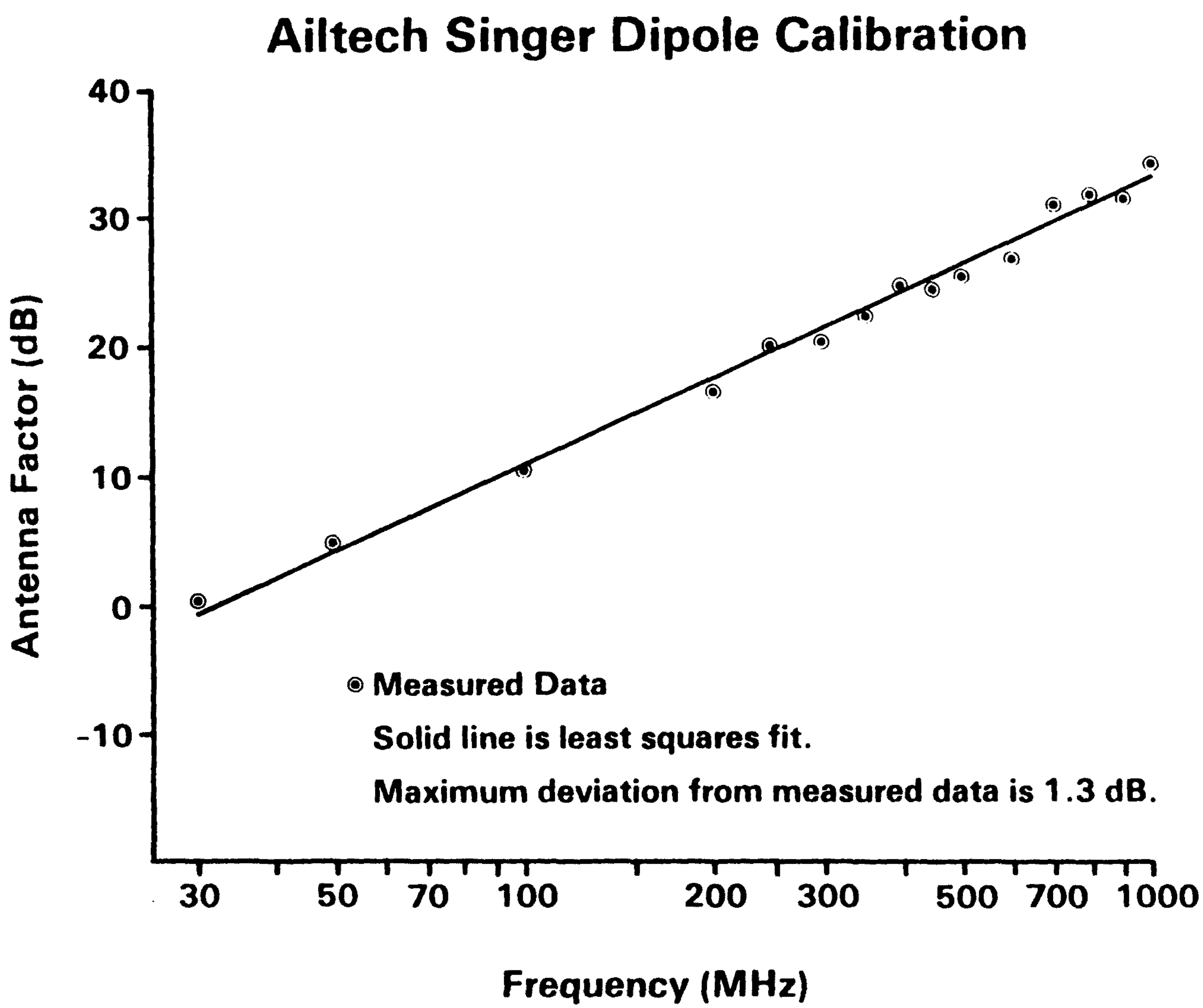

Figure A4. Antenna Factor Graph for the Tunable Dipole with 20 Feet of RG-55 Cable.

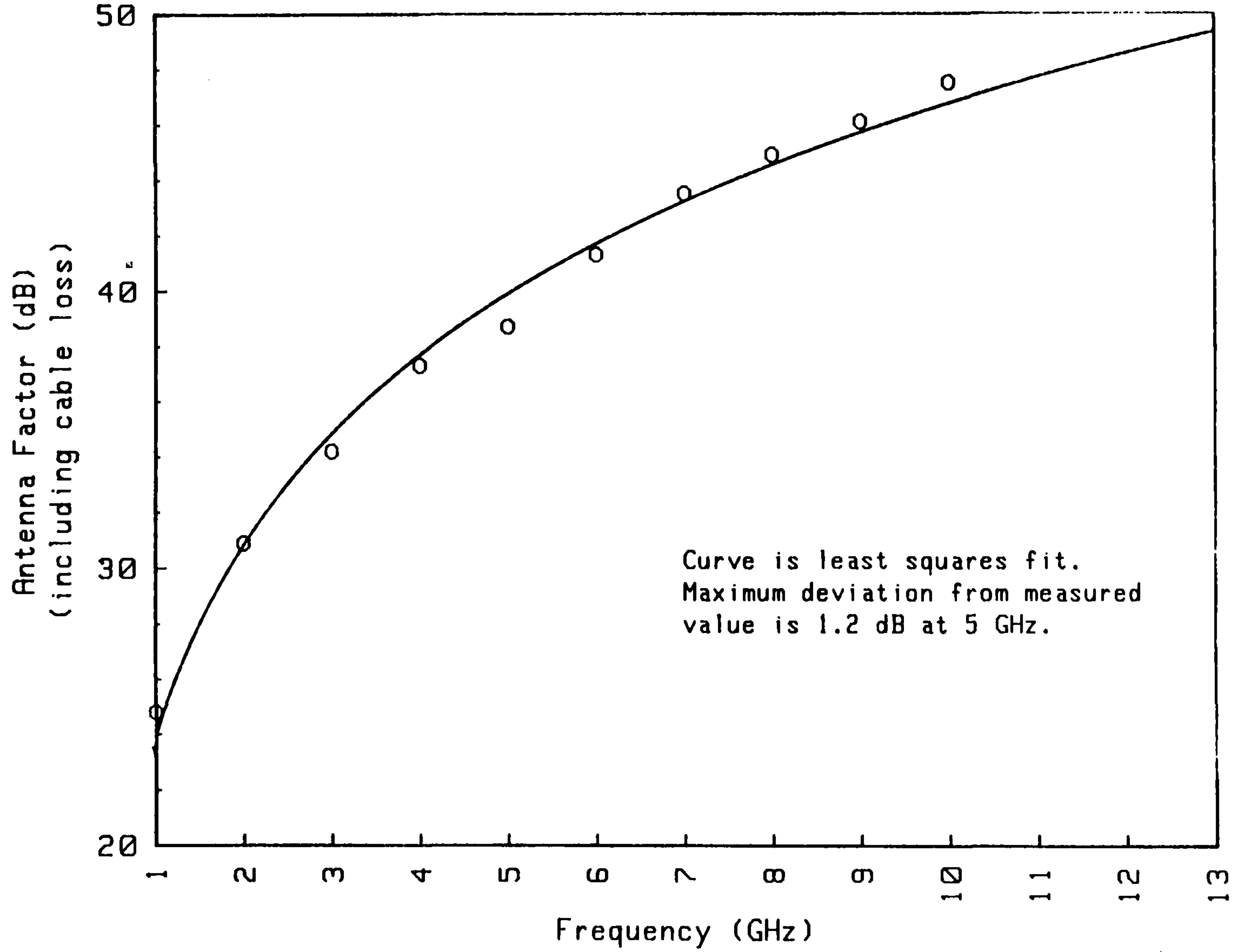

Figure A5. AEL Model APX 1293 Crossed Log Periodic Antenna Factor for 1-13 GHz.

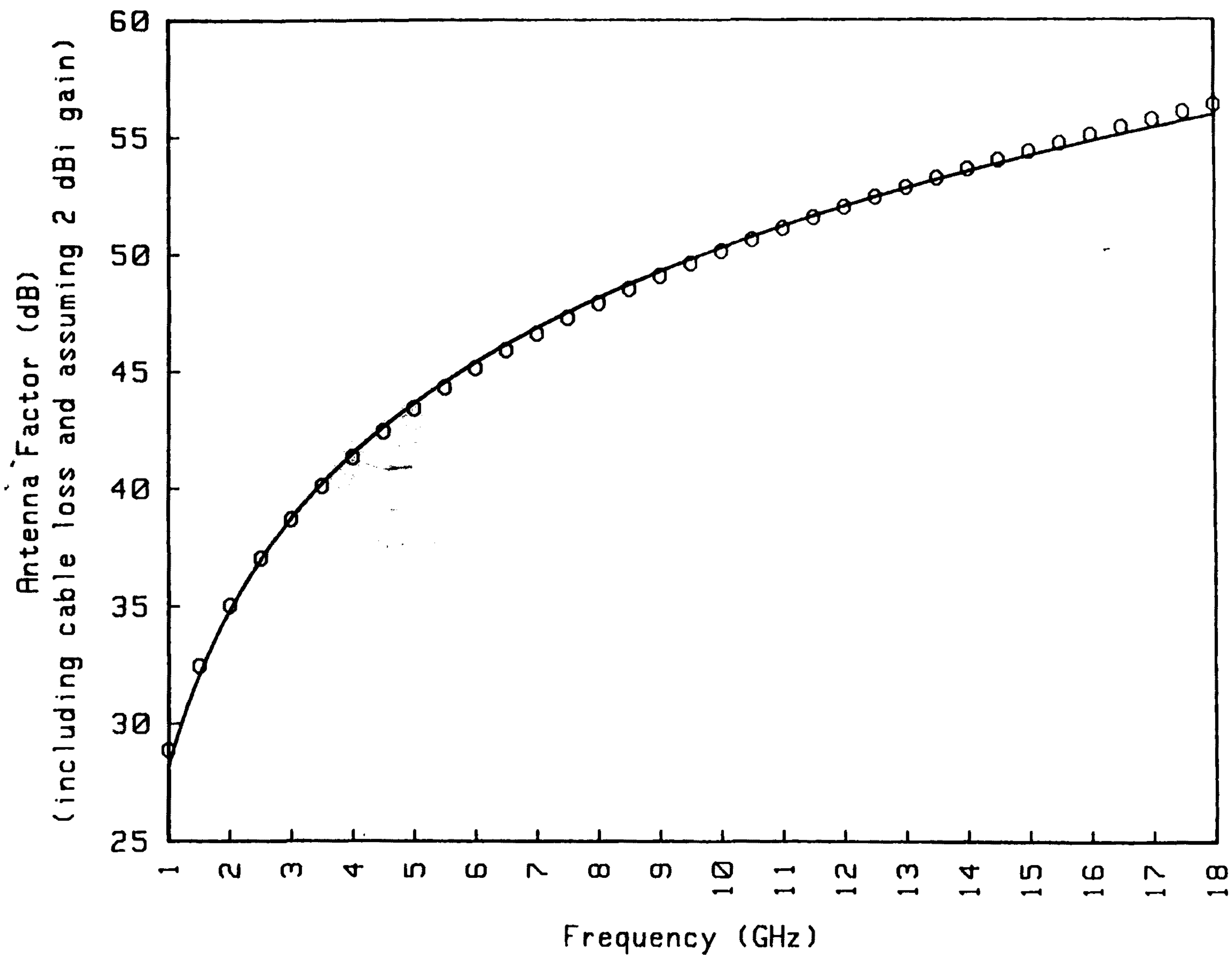

Figure A6. Watkins Johnson Model WJ 8549 Antenna Factor for 1-18 GHz.