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# TELECOMMUNICATIONS
## Research and Engineering Report 14

# URBAN RESIDENTIAL MAN-MADE RADIO NOISE ANALYSIS & PREDICTIONS

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(c) Conduct research and analysis on radio systems characteristics, and operating techniques affecting the utilization of the radio spectrum in coordination with specialized, related research and analysis performed by other Federal agencies in their areas of responsibility;

(d) Conduct research and analysis in the general field of telecommunication sciences in support of other Government agencies as required; and

(e) Develop methods of measurement of system performance and standards of practice for telecommunication systems.

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# URBAN RESIDENTIAL MAN-MADE RADIO NOISE ANALYSIS AND PREDICTIONS

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During May and June of 1968, OT/ITS conducted a man-made radio noise survey of San Antonio, Texas. The results of part of this survey of residential urban man-made radio noise are given, along with the correlations of the measured values of noise power density with population density and vehicular count (traffic density). Also given are various detailed amplitude and time statistics of man-made noise recorded in the vicinity of Grand Coulee Dam, Washington, and in an urban area of Boulder, Colorado.

## 1. INTRODUCTION

A survey of man-made radio noise in certain areas within the city of San Antonio, Texas, was made by OT/ITS* during the months of May and June 1968. The survey was made for the U.S. Air Force, Electronic Systems Division, Hanscom Field, Bedford, Massachusetts, and the Air Force Security Service, Kelly Field, San Antonio. The results of this survey of urban man-made noise are given, along with the correlation of the measured values with population density and vehicular count. During the same time period, noise surveys were also made of the various military installations in the San Antonio area, and the results of these measurements will be covered in a separate report.

Recordings of noise parameters were made simultaneously on 500 kHz and on 2.5, 5, 10, 20, and 48 MHz with a bandwidth of 10 kHz. In addition, a 15-level detector was used on one of the channels at a time. The 15-level detector records either the fraction of time the noise envelope is above each of the levels or the number of envelope crossings of each level. This equipment, therefore, measures either

*Formerly ESSA/ITS.

the amplitude probability distribution (APD) of the noise envelope or the average crossing rate characteristic. It was used in the APD mode for these measurements.

For both stationary and mobile operation, the above data are recorded on digital tape every 10 seconds for direct computer analysis. Logistic data, such as the location of the van and time, are also recorded, resulting in the capability of noise contour mapping.

The noise parameters (in addition to the APD) that are recorded are as follows:

(1) $F_a$: This parameter is the noise power density referred to the terminals of a lossless antenna.

This parameter is the most useful single description of the noise. It is easily related to rms field strength or antenna noise temperature and is a basic requirement for determining system performance. The definition of $F_a$ (CCIR, 1966) is given by

$$F_a = 10 \log_{10} f_a \tag{1}$$

where

$$f_a = \frac{p_n}{k t_o b} :$$

$p_n$ is the noise power (watts) available from an equivalent lossless antenna,

k is Boltzmann's constant = $1.28 \times 10^{-23}$ joules/$^{\circ}$K,

$t_o$ is the reference temperature in $^{\circ}$K, taken as 288$^{\circ}$K, and

b is the noise power bandwidth in Hz.

If we use capital letters to denote the ratio in decibels, then $P_n$ expressed in dB above 1 watt becomes

$$P_n = F_a + B - 204 \quad \text{dBW}. \tag{2}$$

The noise in terms of its rms vertical electric field strength, $E_n$, is simply related to $F_a$ for a short vertical lossless antenna by

$$E_n = F_a + 20 \log_{10} f_{MHz} + 10 \log_{10} b - 95.5 \tag{3}$$

where

$E_n$ is the rms field strength for a bandwidth, b (Hertz), in dB referred to $1 \mu V/m$, and

$f_{MHz}$ is the frequency in megahertz.

Another method commonly used to express the noise power is in terms of an equivalent antenna temperature, $t_a$, of a loss-free antenna. The value of $t_a$ is simply related to $f_a$ by

$$f_a = t_a/t_o. \tag{4}$$

(2) $V_d$: This parameter, in dB, is the ratio of the rms envelope voltage to the average envelope voltage $\left(20 \log \frac{V_{rms}}{V_{ave}}\right)$.

The rms envelope voltage is directly related to $F_a$, and the average voltage is then indicated by $V_d$ in dB below $F_a$. The parameter $V_d$ provides a measure of the impulsive nature of the noise, and it has been found that for atmospheric noise, $V_d$ can be used to obtain the amplitude probability distribution, APD, of the noise envelope (Crichlow et al., 1960; Spaulding, et al., 1962). It has not yet been determined how the parameter $V_d$ relates to the APD for man-made noise, but the distributions for urban man-made noise are similar to those for atmospheric noise. The APD is of great interest, as it is almost always required for the determination of system performance.

(3) $L_d$: This parameter, in dB, is the ratio of the rms envelope voltage to the average of the logarithm of the envelope voltage $\left(20 \log \frac{V_{rms}}{V_{a\ell m\ell}}\right)$, where $V_{a\ell m\ell}$ is the anti-log of the mean logarithm of the noise envelope.

The logarithmic moment of the noise envelope has been found to be useful in further defining the APD for atmospheric noise and gives another well defined moment of the noise envelope (in addition to the mean and mean square moments above).

The noise measurements were made under mobile conditions on most of the thoroughfares within specified areas called SLA's (standard location area). SLA's are areas defined by the Census Bureau for counting population. Figure 1 shows the SLA's for the San Antonio area. The eight circled SLA's were those areas surveyed and were chosen because they represented a widely varied sampling of population densities within the urban residential area. The mobile van made two separate runs within each specified SLA. One run was routed in a predominantly east-west direction, while the other run completed the pattern by covering the thoroughfares in a north-south direction. The noise recordings were made during the working week days, Monday through Friday, and within the time period from 0900 - 1500 with most of the data compiled in the morning hours to limit the amount of atmospheric noise interference. The time period was also chosen to avoid the heavy rush hour traffic.

Since the man-made noise process is not time independent, time statistics of the process are important, as well as the amplitude statistics, for detailed system analysis and design purposes. For completeness, samples are included of time statistics for man-made noise obtained at other locations. These statistics were obtained from wide-band, high dynamic range tape recordings of the predetection noise process. These recordings were digitized and then computer analyzed to obtain the statistics. The statistics given are for noise recorded in the downtown Boulder business area and high noise locations in Washington state. This work was performed with Air Force SAMSO support (Spaulding et al.; unpublished ESSA Technical Memorandum, ERLTM-ITS 184, 1968, ITS Final Reports to Space and Missile Systems Organization, Project 672A, Contract No. F07401-68-F-0072, ESSA, CPRL Items 7 and 19, 1968) and with ITS support (Disney and Spaulding, 1970). The statistics given are the APD, the average crossing rate characteristic, pulse interval distributions and pulse duration distributions.

The noise parameter, $F_a$, that was obtained from the San Antonio survey was correlated with the population densities for the SLA's and with vehicular densities in the SLA's. The population densities were obtained from the 1960 Census figures and the vehicular densities from traffic counter charts made available to ITS by the Department of Traffic and Transportation in San Antonio. Estimates of the average total traffic along given throughfares (for each one hour time block during which measurements were made) were obtained from all available traffic counts for points along the throughfares from 1963 through 1968. Using these values and the 1968 traffic flow charts, reasonable values for the average traffic flow in the vicinity of a given thoroughfare as well as the traffic flow for each individual point along the thoroughfare (intersections, for example) were obtained.

The correlation study shows essentially no correlation between the population density of a given SLA and the average noise level recorded for that SLA. Good correlation at the higher frequencies was found between the average vehicular density along any given thoroughfare and the average noise level measured along that thoroughfare.

## 2. SAN ANTONIO URBAN RESIDENTIAL MAN-MADE NOISE MEASUREMENTS AND ANALYSIS

### 2.1 Analysis for Surveyed Standard Location Areas

Tables 1 through 8 give a summary for each of the surveyed SLA's, while figure 2 gives the mean value of $F_a$ for all the measurements made as a function of frequency. Tables 1 through 8 give the mean and standard deviation for values of $F_a$, $V_d$, and $L_d$ measured throughout each SLA. Also given are the median value and the dB difference between the median and upper decile ($D_u$) and the dB difference between the median and the lower decile ($D_\ell$) for the distribution of each parameter. The upper decile is the value exceeded by only 10% of the measurements and the lower decile is the value exceeded by 90% of the measurements. Figure 2 can be used as a prediction of urban residential area man-made noise levels. Predictions previously prepared for and summarized by JTAC (1968) compare quite closely at the lower frequencies (up to and including 10 MHz), but the JTAC predictions for urban man-made noise are approximately 8 dB higher for 50 MHz. Predictions of urban business area man-made noise, as well as rural and quiet rural receiving site predictions, are given by Disney and Spaulding (1970). The business area predictions are based on measurements made by ITS in Washington, D.C., in 1960 and 1966. The San Antonio measurements (figure 2) are 8 to 10 dB lower than the predicted values given by Disney and Spaulding. This probably indicates a considerably higher noise level in urban business areas than in urban residential areas, though measurements for both areas in a single city the size of Washington, D.C., or San Antonio are not available for direct comparison.

## 2.2 Measured Noise Profiles Along Thoroughfares

Section 2.1 gave a summary of the mean values measured throughout the 8 SLA's, along with statistics that indicate the range of the measurements. To indicate the variations in $F_a$ that can occur at closely spaced locations (or times) in an urban area, figures 3 through 15 have been included. The figures show the variations of $F_a$ for each designated frequency along two particular mobile runs. Figure 3 shows the route taken on a particular run in SLA 59, while figures 4 through 9 show the variations in $F_a$ along this route for each of the designated frequencies. Figures 10 through 15, similarly, show the results for a particular run in SLA 83. Also shown on these figures is the hourly vehicular count for the same time of day at various points along the route obtained from past traffic engineering records. The lower frequencies (less than 20 MHz) are generally strongly affected by power lines, while the higher frequencies are generally more dependent on vehicular density.

## 3. AMPLITUDE AND TIME STATISTICS OF URBAN MAN-MADE NOISE

During the survey, the amplitude probability distribution (APD) of the noise envelope was recorded along with the statistical moments mentioned above. The percentage of time the noise envelope exceeded each of 15 levels was recorded by the digital data system in a 10-kHz bandwidth. An APD was obtained every 10 seconds; however, this is not sufficient time, generally, to obtain a good sample of the envelope distribution, 10 seconds being of insufficient length to obtain statistically meaningful counts of the high level, rarely occurring events. Meaningful APD's were obtained by combining successive 10-second counts to obtain an APD for approximately a five-minute period. In this way several hundred APD's were obtained on the four frequencies (2.5, 10, 20, and 48 MHz) at which these recordings were made. All APD's were normalized to the rms voltage, $V_{rms}$, that is, plotted with the ordinate in dB relative to $V_{rms}$. The APD's were then grouped by frequency. Typical (average) APD's were then found for each group. These are shown on figures 16 through 19, along with the average value of $V_d$ for each group. The range of values of the individual APD's used to obtain the typical values is indicated by the dotted APD's. The normalization to $V_{rms}$ for plotting purposes causes the crossing of the curves, and in one case (figure 17) the typical value appears to fall outside the limit of the individual APD's from which it was obtained. This is not the case as would be shown if the plots were in terms of absolute values instead of values relative to $V_{rms}$. Little variation was noted as far as the dynamic range or shape of the APD's for the different SLA's.

A capability of wide band, high dynamic range analog tape recording of the predetection noise process (Disney and Spaulding, Final report to SAMSO, Project 672A, ESSA, Item 19, CDRL, 1968) is now available. These analog recordings can be used for testing of systems or for obtaining more detailed statistics of the noise process. To provide an indication of the time statistics of the man-made noise process figures 20 through 31 give examples of some statistics obtained from recordings of man-made noise in a 4-kHz bandwidth. The statistics were obtained by digitizing the envelope of the recordings and using computer techniques.

The statistics obtained and shown on the figures are the APD, the average number of envelope crossings as a function of envelope level, and the distributions of pulse intervals (PID) and pulse durations (PDD) for various envelope levels.

Figures 20 through 23 give these statistics for a sample of noise recorded in the vicinity of Grand Coulee Dam in Washington. As before, all envelope levels are given relative to the $V_{rms}$. Figures 20 and 21 give the APD and the average positive crossing rate characteristic. Figure 22 gives the pulse duration distribution (PDD) for seven envelope voltage levels. The seven levels are spaced 10 dB apart, except for the highest interval which is 8 dB, and cover the significant portion of the dynamic range of the noise envelope. The distributions give the percentage of pulse durations (widths) which exceed various times (in milliseconds) at each of the seven levels. Figure 23 gives the pulse interval distributions (PID) for these seven levels and gives the percentage of pulse intervals (time intervals when no noise is present) which exceed the various times shown.

The statistics show that the urban man-made noise is a complicated statistical process with significant dependence on the time behavior of the process. If the noise were composed of independently occurring events (e.g., events occurring according to a Poisson distribution) the pulse intervals would be essentially exponentially distributed, especially at the higher envelope levels. Some slight deviation might be expected due to the receiver response characteristic. The measurements given show that we are not dealing with independently occurring events, since an exponential distribution plots as a straight line of slope -1 on the coordinates used for plotting the pulse interval and pulse duration distributions (Rayleigh coordinate paper).

One sees from the measured statistics that for the lower voltage levels, where we have many events from many sources, the pulse interval distributions are reasonably close to being exponentially distributed. However, a great deal of correlation exists at the longer time periods and the high envelope levels as reflected by the much greater steepness of the pulse interval distributions. These high-level events contain most of the energy in the noise process and have the greatest effect on communication systems.

# 4. CORRELATION OF MEASURED MAN-MADE NOISE WITH VEHICULAR TRAFFIC FLOW AND AREA POPULATION DENSITY, SAN ANTONIO, TEXAS

## 4.1 Correlation Parameters

In an attempt to determine parameters which could serve as predictors for man-made noise levels, the degree of correlation between the noise power measurements, $F_a$, and vehicular density and population density has been determined for the San Antonio measurements. Two averages of the individual $F_a$ measurements have been used: $F_{am}$ is the median of a number of $F_a$ values used in the analysis, and $F_{a\mu}$ is the mean of the $F_a$ values.

The hourly vehicular traffic count, C, was obtained directly from traffic counter charts made available to ITS by the Department of Traffic and Transportation in San Antonio. These chart records covered a 24-hour period and were recorded during the normal work days of Monday through Friday. Four traffic counters were generally placed at a 4-way intersection to record the one-way traffic flow in units per time interval towards the intersection. The traffic counters recorded cumulative counts and were generally set to record (within their maximum range) the count for 15 min., 30 min., and 1-hr. intervals (depending on traffic density) before resetting and recounting. Traffic counts were tabulated according to hourly time blocks from these charts, and sufficient information was obtained to cover all periods of time during which noise recordings were made. All traffic count chart records from 1963 through 1968 covering intersections within the designated SLA's were used. From these data and the 1968 traffic-flow chart for San Antonio, reasonable values for the average traffic flow along given thoroughfares were determined.

The population density was obtained by using the 1960 population census figures for San Antonio, which were available for each SLA. The area of each SLA was determined and the population density in people/sq. mile obtained. Another method for determining area population density was by using a topological ring method. In this method, rings of known radii (in miles) with centers at the SLA centroids were used, and population densities were computed from mapping techniques. The ring population densities computed for areas centered on each SLA used in the analysis were based on rings having a radius of two miles. The SLA population density is designated as $P_s$ and the ring population density as $P_r$.

## 4.2 Correlation of $F_{a\mu}$ with Vehicular Hourly Count Along Thoroughfares

A linear regression line analysis was performed to relate the mean noise factor ($F_{a\mu}$) of noise data to hourly vehicular count measured along 26 selected thoroughfares ranging from an hourly (bidirectional) vehicle count of 20 units to 1750 units per hour. The $F_a$ values along each particular thoroughfare chosen for the analysis were averaged to determine $F_{a\mu}$. The hourly vehicle count, C, for the particular thoroughfare was matched according to the hourly time block during which the noise measurements were made. Care was taken to include only the $F_a$ data points along the thoroughfare free from the influence of heavy traffic flow density at certain intersections. All $F_a$ values, time of measurement, and location data were obtained directly from computer printouts. The thoroughfares were chosen within the SLA's surveyed and for which traffic flow information was available. The following were used to solve for the linear regression line, variances, and correlation coefficients for the $F_{a\mu}$ values versus hourly vehicle count for each of six frequencies:

(a) The assumed regression line

$$F_{a\mu} = a + b \log C \ , \qquad (5)$$

where

$$b = \frac{n\Sigma(\log C)(F_{a\mu}) - \Sigma(\log C)\Sigma(F_{a\mu})}{n\Sigma(\log C)^2 - (\Sigma \log C)^2}$$

and

$$a = \frac{\Sigma(F_{a\mu}) - b\Sigma(\log C)}{n} \ ,$$

(b) The standard error of estimate

$$S^2_{y/x} = \frac{(n-1)}{(n-2)} (S_y^{\,2} - b^2 S_x^{\,2}) \ , \qquad (6)$$

where

$$S_y^{\,2} = \frac{n\sum(F_{a\mu})^2 - (\sum F_{a\mu})^2}{n(n - 1)}$$

and

$$S_x^{\,2} = \frac{n\sum(\log C)^2 - (\sum \log C)^2}{n(n - 1)} .$$

(c) Finally, the correlation coefficient,

$$r = b \frac{S_x}{S_y} \quad . \tag{7}$$

The calculated regression line along with the standard error of estimate is given in figures 32 through 37 for each frequency. The correlation coefficients were plotted as a function of frequency and shown in figure 38. As was indicated by the previous noise profile charts, the highest positive correlation between measured noise and hourly vehicle count occurred at 48 MHz with no significant correlation at the lower frequencies.

## 4.3 Correlation of $F_{a\mu}$ and $F_{am}$ with SLA and Ring Population Densities

Using a linear regression analysis technique which allows all parameters to be subject to error (statistical variation) to obtain the correlations (Norton, 1957), the correlation of $F_{a\mu}$ and $F_{am}$ with SLA population and also with ring population was calculated.

Figures 39 through 43 show the results for each of the frequencies for $F_{a\mu}$ versus SLA and ring population density. The results for $F_{am}$ were quite similar and, therefore, are not shown.

We note that no significant correlation was obtained at any of the frequencies, indicating the population density in a small area is a very poor noise level predictor for that limited area.

## 4.4 Multiple Correlation of $F_{a\mu}$ with SLA Population Density and SLA Hourly Vehicular Count

A multiple correlation analysis was also performed. The correlation of $F_{a_\mu}$ with both SLA population density and SLA hourly vehicular count was calculated. Since essentially no correlation was obtained between population density and $F_{a_\mu}$ when the population density was the only independent variable, one cannot expect the addition of this variable to improve correlation in a multiple correlation analysis. This is indeed what happened. No improvement in correlation (i.e., predicting ability) was obtained by considering population density and vehicular count jointly over that obtained by considering vehicular count alone.

## 5. CONCLUSIONS

The urban man-made noise process has been shown to be quite complex. However, the APD does not seem subject to great variations throughout an urban area. Since the APD is always required, and is sometimes sufficient, for systems performance analysis and for system design, this is an encouraging find. By using the average APD for the frequency of concern given in figures 16-19, one cannot be too far off for the APD for urban residential man-made noise. This lack of great variation in the APD (for a given bandwidth and frequency) is somewhat surprising. It probably indicates that for the types of areas surveyed, there are a sufficient number of sources so that a few individual sources of various kinds seldom predominate. Also, as any predominant sources move away, they are generally replaced by similar sources, resulting in the variations in the noise envelope (about its rms level) remaining reasonable constants. The APD's of data recorded in the urban business areas of Boulder also are similar to the APD's from the San Antonio urban residential areas shown in this report. The time behavior, as given by the PID's and PDD's, is subject to greater variations, with varying degrees of time dependence in the process noted.

While the APD seems to remain fairly constant, one must predict its level, i.e., average power. The most likely value for $F_{am}$ given in figure 2 is based on all the San Antonio measurements. It compares quite closely with the predictions prepared for JTAC but is consistently 10 dB lower than measurements taken in Washington, D. C. It appears that while one could now use all the available measurements to prepare a reasonable prediction of $F_{am}$ for urban areas, there would still be a large statistical variation about these median values. This indicates that the area definitions (urban, suburban, and rural) chosen for the JTAC report can represent too gross a variation in areas. A more definitive designation of areas has therefore been attempted here by dividing urban into urban residential areas and urban business areas. As additional data become available, even finer gradation may be desirable. Zoning practices, for example, might provide useful descriptions of areas, although, at frequencies above HF, the noise power is probably based primarily on traffic density.

An attempt to determine prediction parameters so that a finer prediction of $F_{am}$ for various urban areas could be obtained was carried out. The results, using population density and vehicular count, were varied. Population density in an SLA appears to have very little to do with the urban noise level at any frequency in the SLA.

It appears that for the higher frequencies the average vehicular count is a good predictor, although this needs further testing, especially at frequencies above 48 MHz ( the highest used in this measurement program). The average hourly vehicular count in a given urban area (along thoroughfares) shows very good correlation with the average noise level along thoroughfares at frequencies of above 20 MHz. Very little correlation exists at the lower frequencies. Very good correlation at the higher frequencies was also noted between the noise power measured at particular points along a route and the traffic flow at that point, but this was to be expected. Here also, the same lack of correlation with vehicular count at the lower frequencies was noted.

No significant difference was noted between the median and mean value of the noise power. Also, no improvement was obtained by considering population density and vehicular count jointly.

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Table 1. Analyzed Data,* Mobile Run in SLA 15, San Antonio, Texas, June 17, 1968

| | $F_a$(dB > $kt_o$) | $V_d$(dB) | $L_d$(dB) |
|---|---|---|---|
| Frequency 2.5 MHz | | | |
| Mean of dB | 82.1 | 9.6 | 18.1 |
| Standard Deviation | 14.0 | 3.9 | 8.3 |
| Median of dB | 76.9 | 8.8 | 16.7 |
| $D_u$ | 29.3 | 6.7 | 13.2 |
| $D_\ell$ | 5.1 | 3.6 | 8.3 |
| Frequency 5 MHz | | | |
| Mean of dB | 64.2 | 8.7 | 15.6 |
| Standard Deviation | 12.2 | 3.9 | 7.9 |
| Median of dB | 58.6 | 7.9 | 13.8 |
| $D_u$ | 25.3 | 6.7 | 13.2 |
| $D_\ell$ | 4.8 | 3.8 | 7.3 |
| Frequency 10 MHz | | | |
| Mean of dB | 54.8 | 10.0 | 14.9 |
| Standard Deviation | 13.2 | 4.8 | 6.8 |
| Median of dB | 49.6 | 8.8 | 13.5 |
| $D_u$ | 24.7 | 8.3 | 11.2 |
| $D_\ell$ | 6.2 | 4.1 | 6.4 |
| Frequency 20 MHz | | | |
| Mean of dB | 44.4 | 8.1 | 13.6 |
| Standard Deviation | 7.8 | 3.0 | 4.7 |
| Median of dB | 42.1 | 7.7 | 12.9 |
| $D_u$ | 14.4 | 4.8 | 7.5 |
| $D_\ell$ | 5.4 | 3.0 | 4.8 |
| Frequency 50 MHz | | | |
| Mean of dB | 33.9 | 8.9 | 13.9 |
| Standard Deviation | 8.3 | 3.0 | 4.4 |
| Median of dB | 32.3 | 8.6 | 13.3 |
| $D_u$ | 13.1 | 4.6 | 6.9 |
| $D_\ell$ | 8.1 | 3.3 | 4.8 |

*2 1/6 hours of data

Table 2. Analyzed Data,* Mobile Run in SLA 19, San Antonio, Texas, June 24, 1968

| | $F_a(dB > kt_o)$ | $V_d(dB)$ | $L_d(dB)$ |
|---|---|---|---|
| Frequency 2.5 MHz | | | |
| Mean of dB | 75.0 | 3.2 | 5.2 |
| Standard Deviation | 4.7 | 1.3 | 2.9 |
| Median of dB | 74.2 | 2.9 | 4.4 |
| $D_u$ | 4.4 | 1.8 | 3.0 |
| $D_\ell$ | 2.4 | 0.6 | 0.9 |
| Frequency 5 MHz | | | |
| Mean of dB | 57.5 | 3.9 | 6.1 |
| Standard Deviation | 6.2 | 1.7 | 3.5 |
| Median of dB | 56.1 | 3.3 | 5.0 |
| $D_u$ | 4.7 | 2.4 | 3.9 |
| $D_\ell$ | 1.9 | 0.8 | 1.0 |
| Frequency 10 MHz | | | |
| Mean of dB | 47.2 | 4.4 | 6.4 |
| Standard Deviation | 5.8 | 2.6 | 3.4 |
| Median of dB | 45.9 | 3.6 | 5.3 |
| $D_u$ | 6.4 | 4.4 | 5.1 |
| $D_\ell$ | 3.1 | 1.7 | 2.1 |
| Frequency 20 MHz | | | |
| Mean of dB | 39.8 | 4.2 | 7.1 |
| Standard Deviation | 5.9 | 2.3 | 3.8 |
| Median of dB | 37.9 | 3.3 | 5.4 |
| $D_u$ | 8.8 | 4.8 | 8.1 |
| $D_\ell$ | 3.3 | 1.1 | 1.7 |
| Frequency 48 MHz | | | |
| Mean of dB | 27.1 | 5.6 | 8.8 |
| Standard Deviation | 6.3 | 3.1 | 4.4 |
| Median of dB | 24.7 | 4.3 | 6.9 |
| $D_u$ | 12.4 | 6.3 | 8.8 |
| $D_\ell$ | 2.8 | 1.3 | 1.9 |

*2 hours of data

Table 3. Analyzed Data,* Mobile Run in SLA 22, San Antonio, Texas, May 20, 1968

| | $F_a(dB > kt_o)$ | $V_d(dB)$ | $L_d(dB)$ |
|---|---|---|---|
| Frequency 0.5 MHz | | | |
| Mean of dB | 93.1 | 4.8 | 8.4 |
| Standard Deviation | 7.7 | 2.2 | 3.2 |
| Median of dB | 91.8 | 5.1 | 8.5 |
| $D_u$ | 11.3 | 2.6 | 4.1 |
| $D_\ell$ | 7.5 | 3.4 | 4.2 |
| Frequency 2.5 MHz | | | |
| Mean of dB | 70.0 | 4.5 | 7.9 |
| Standard Deviation | 9.2 | 2.6 | 5.2 |
| Median of dB | 70.5 | 3.8 | 6.3 |
| $D_u$ | 7.4 | 4.1 | 7.7 |
| $D_\ell$ | 6.7 | 1.6 | 2.4 |
| Frequency 5 MHz | | | |
| Mean of dB | 59.5 | 6.0 | 10.1 |
| Standard Deviation | 5.9 | 2.1 | 4.1 |
| Median of dB | 58.3 | 5.9 | 9.6 |
| $D_u$ | 7.7 | 2.9 | 5.9 |
| $D_\ell$ | 4.4 | 2.5 | 4.1 |
| Frequency 10 MHz | | | |
| Mean of dB | 52.4 | 8.2 | 12.9 |
| Standard Deviation | 7.8 | 2.5 | 5.2 |
| Median of dB | 51.3 | 8.2 | 12.3 |
| $D_u$ | 12.7 | 3.3 | 8.0 |
| $D_\ell$ | 8.1 | 3.4 | 5.7 |
| Frequency 20 MHz | | | |
| Mean of dB | 47.4 | 7.7 | 10.9 |
| Standard Deviation | 7.5 | 4.3 | 5.2 |
| Median of dB | 45.3 | 6.8 | 10.1 |
| $D_u$ | 14.5 | 7.0 | 8.4 |
| $D_\ell$ | 5.9 | 4.0 | 5.3 |
| Frequency 50 MHz | | | |
| Mean of dB | 27.5 | 9.0 | 14.1 |
| Standard Deviation | 7.0 | 3.0 | 4.6 |
| Median of dB | 26.3 | 9.0 | 14.0 |
| $D_u$ | 10.4 | 4.2 | 6.4 |
| $D_\ell$ | 6.5 | 3.8 | 6.3 |

*1 1/2 hours of data

Table 4. Analyzed Data,* Mobile Run in SLA 27, San Antonio, Texas, June 18& 21, 1968

| | $F_a$(dB > $kt_o$) | $V_d$(dB) | $L_d$(dB) |
|---|---|---|---|
| Frequency 0.5 MHz** | | | |
| Mean of dB | 106.4 | 10.3 | 18.6 |
| Standard Deviation | 4.9 | 1.6 | 2.4 |
| Median of dB | 106.9 | 10.7 | 19.2 |
| $D_u$ | 5.9 | 1.2 | 1.9 |
| $D_\ell$ | 6.4 | 2.6 | 3.9 |
| Frequency 2.5 MHz | | | |
| Mean of dB | 80.0 | 4.5 | 6.8 |
| Standard Deviation | 5.0 | 3.0 | 4.5 |
| Median of dB | 79.0 | 2.9 | 4.6 |
| $D_u$ | 7.3 | 6.5 | 9.2 |
| $D_\ell$ | 3.5 | 1.1 | 1.7 |
| Frequency 5.0 MHz | | | |
| Mean of dB | 59.4 | 5.0 | 7.7 |
| Standard Deviation | 4.5 | 2.0 | 3.4 |
| Median of dB | 58.4 | 4.5 | 6.7 |
| $D_u$ | 6.7 | 3.6 | 5.6 |
| $D_\ell$ | 3.4 | 1.6 | 2.2 |
| Frequency 10.0 MHz | | | |
| Mean of dB | 49.0 | 6.5 | 9.4 |
| Standard Deviation | 5.2 | 2.2 | 3.5 |
| Median of dB | 47.7 | 6.0 | 8.6 |
| $D_u$ | 7.5 | 2.9 | 4.5 |
| $D_\ell$ | 3.6 | 1.7 | 2.4 |
| Frequency 20.0 MHz | | | |
| Mean of dB | 44.8 | 4.5 | 6.9 |
| Standard Deviation | 5.3 | 2.5 | 4.2 |
| Median of dB | 43.6 | 3.7 | 5.6 |
| $D_u$ | 9.0 | 4.3 | 6.7 |
| $D_\ell$ | 3.6 | 1.5 | 2.3 |
| Frequency 50 MHz | | | |
| Mean of dB | 28.5 | 7.4 | 11.5 |
| Standard Deviation | 8.3 | 3.8 | 5.8 |
| Median of dB | 25.4 | 6.2 | 9.5 |
| $D_u$ | 16.7 | 7.3 | 11.0 |
| $D_\ell$ | 4.7 | 2.9 | 4.1 |

*9 1/2 hours of data

**The data for 0.5 MHz is mainly atmospheric noise.

Table 5. Analyzed Data,* Mobile Run in SLA 41, San Antonio, Texas, May 21, 1968

| | $F_a(dB > kt_o)$ | $V_d(dB)$ | $L_d(dB)$ |
|---|---|---|---|
| Frequency 0.5 MHz | | | |
| Mean of dB | 85.7 | 5.3 | 8.9 |
| Standard Deviation | 8.2 | 1.7 | 3.0 |
| Median of dB | 83.4 | 4.9 | 7.9 |
| $D_u$ | 15.0 | 2.9 | 5.2 |
| $D_\ell$ | 6.1 | 1.2 | 2.1 |
| Frequency 2.5 MHz | | | |
| Mean of dB | 69.3 | 3.2 | 5.4 |
| Standard Deviation | 5.2 | 1.4 | 3.1 |
| Median of dB | 68.0 | 2.8 | 4.4 |
| $D_u$ | 7.9 | 1.9 | 4.2 |
| $D_\ell$ | 2.9 | 0.8 | 1.2 |
| Frequency 5.0 MHz | | | |
| Mean of dB | 57.4 | 5.3 | 8.5 |
| Standard Deviation | 6.3 | 1.9 | 3.7 |
| Median of dB | 55.8 | 4.9 | 7.4 |
| $D_u$ | 6.8 | 2.8 | 4.8 |
| $D_\ell$ | 3.1 | 1.5 | 1.8 |
| Frequency 10 MHz | | | |
| Mean of dB | 49.1 | 6.4 | 9.1 |
| Standard Deviation | 5.6 | 2.1 | 3.1 |
| Median of dB | 47.7 | 5.8 | 8.3 |
| $D_u$ | 8.8 | 3.6 | 4.7 |
| $D_\ell$ | 4.0 | 1.4 | 2.2 |
| Frequency 20 MHz | | | |
| Mean of dB | 43.9 | 4.1 | 6.9 |
| Standard Deviation | 5.9 | 2.7 | 4.0 |
| Median of dB | 42.4 | 3.0 | 5.3 |
| $D_u$ | 10.8 | 5.7 | 8.2 |
| $D_\ell$ | 4.2 | 1.3 | 2.0 |
| Frequency 50 MHz | | | |
| Mean of dB | 26.1 | 8.5 | 13.2 |
| Standard Deviation | 7.7 | 3.6 | 5.2 |
| Median of dB | 23.4 | 7.7 | 12.2 |
| $D_u$ | 13.8 | 6.4 | 8.7 |
| $D_\ell$ | 4.2 | 3.4 | 4.9 |

*2 hours of data

Table 6. Analyzed Data,* Mobile Run in SLA 43, San Antonio, Texas, May 23, 1968

| | $F_a$(dB >$kt_o$) | $V_d$(dB) | $L_d$(dB) |
|---|---|---|---|
| Frequency 0.5 MHz | | | |
| Mean of dB | 81.7 | 5.4 | 8.7 |
| Standard Deviation | 8.0 | 2.1 | 3.4 |
| Median of dB | 79.1 | 5.0 | 7.8 |
| $D_u$ | 15.7 | 3.4 | 6.2 |
| $D_\ell$ | 4.7 | 1.8 | 2.6 |
| Frequency 2.5 MHz | | | |
| Mean of dB | 64.0 | 5.0 | 7.6 |
| Standard Deviation | 5.7 | 2.0 | 3.5 |
| Median of dB | 63.0 | 4.6 | 6.7 |
| $D_u$ | 8.4 | 3.0 | 4.7 |
| $D_\ell$ | 5.2 | 1.6 | 2.0 |
| Frequency 5.0 MHz | | | |
| Mean of dB | 55.9 | 6.8 | 10.1 |
| Standard Deviation | 5.1 | 2.2 | 3.6 |
| Median of dB | 54.6 | 6.3 | 9.3 |
| $D_u$ | 7.3 | 3.5 | 5.5 |
| $D_\ell$ | 3.2 | 1.8 | 2.7 |
| Frequency 10 MHz | | | |
| Mean of dB | 49.1 | 7.6 | 10.5 |
| Standard Deviation | 5.4 | 2.4 | 3.6 |
| Median of dB | 47.7 | 7.2 | 9.7 |
| $D_u$ | 8.0 | 4.1 | 6.2 |
| $D_\ell$ | 4.1 | 2.4 | 3.0 |
| Frequency 20 MHz | | | |
| Mean of dB | 46.8 | 4.6 | 7.4 |
| Standard Deviation | 6.1 | 2.4 | 3.4 |
| Median of dB | 45.5 | 4.1 | 6.5 |
| $D_u$ | 11.1 | 3.9 | 5.4 |
| $D_\ell$ | 5.4 | 2.2 | 2.6 |
| Frequency 50 MHz | | | |
| Mean of dB | 41.3 | 4.2 | 7.2 |
| Standard Deviation | 8.0 | 2.9 | 5.3 |
| Median of dB | 39.3 | 3.6 | 5.9 |
| $D_u$ | 13.6 | 4.9 | 9.4 |
| $D_\ell$ | 7.0 | 2.7 | 4.6 |

*2 hours of data

Table 7. Analyzed Data,* Mobile Run in SLA 59, San Antonio, Texas, May 17, 1968

| | $F_a$(dB > $kt_o$) | $V_d$(dB) | $L_d$(dB) |
|---|---|---|---|
| Frequency 2.5 MHz | | | |
| Mean of dB | 76.2 | 5.0 | 8.9 |
| Standard Deviation | 5.8 | 1.2 | 2.0 |
| Median of dB | 75.8 | 5.0 | 8.7 |
| $D_u$ | 7.3 | 1.5 | 2.8 |
| $D_\ell$ | 5.7 | 1.6 | 2.3 |
| Frequency 5 MHz | | | |
| Mean of dB | 68.5 | 4.2 | --- |
| Standard Deviation | 5.4 | 1.8 | --- |
| Median of dB | 67.4 | 4.4 | --- |
| $D_u$ | 7.7 | 2.0 | --- |
| $D_\ell$ | 3.8 | 3.0 | --- |
| Frequency 10 MHz | | | |
| Mean of dB | 57.4 | 5.4 | 8.9 |
| Standard Deviation | 7.1 | 1.6 | 2.6 |
| Median of dB | 55.3 | 5.0 | 8.4 |
| $D_u$ | 12.7 | 2.6 | 3.8 |
| $D_\ell$ | 4.7 | 1.2 | 2.1 |
| Frequency 20 MHz | | | |
| Mean of dB | 57.9 | 4.1 | 6.0 |
| Standard Deviation | 7.9 | 1.5 | 2.7 |
| Median of dB | 58.9 | 3.7 | 4.9 |
| $D_u$ | 8.1 | 2.4 | 5.5 |
| $D_\ell$ | 13.5 | 1.0 | 1.2 |
| Frequency 50 MHz | | | |
| Mean of dB | 28.5 | 8.6 | 12.8 |
| Standard Deviation | 5.8 | 2.8 | 3.4 |
| Median of dB | 28.4 | 8.7 | 13.1 |
| $D_u$ | 7.4 | 3.4 | 4.1 |
| $D_\ell$ | 7.3 | 3.5 | 5.1 |

*2 hours of data

Table 8. Analyzed Data,* Mobile Run in SLA 83, San Antonio, Texas, May 27-28, 1968

| | $F_a(dB > kt_o)$ | $V_d(dB)$ | $L_d(dB)$ |
|---|---|---|---|
| Frequency 0.5 MHz | | | |
| Mean of dB | 90.3 | 4.6 | 8.4 |
| Standard Deviation | 10.3 | 2.0 | 3.0 |
| Median of dB | 87.6 | 4.2 | 7.8 |
| $D_u$ | 16.8 | 3.0 | 4.9 |
| $D_\ell$ | 8.3 | 1.8 | 2.8 |
| Frequency 2.5 MHz | | | |
| Mean of dB | 73.0 | 5.4 | 9.7 |
| Standard Deviation | 9.6 | 2.5 | 5.3 |
| Median of dB | 71.3 | 5.0 | 8.6 |
| $D_u$ | 14.4 | 3.8 | 8.0 |
| $D_\ell$ | 8.6 | 2.5 | 4.7 |
| Frequency 5.0 MHz | | | |
| Mean of dB | 61.2 | 6.0 | 9.8 |
| Standard Deviation | 7.6 | 2.2 | 4.0 |
| Median of dB | 59.5 | 5.7 | 9.0 |
| $D_u$ | 10.5 | 3.1 | 5.5 |
| $D_\ell$ | 5.7 | 2.4 | 3.6 |
| Frequency 10 MHz | | | |
| Mean of dB | 50.7 | 5.9 | 9.5 |
| Standard Deviation | 6.7 | 2.3 | 3.3 |
| Median of dB | 50.0 | 5.8 | 9.3 |
| $D_u$ | 9.3 | 3.1 | 4.4 |
| $D_\ell$ | 7.2 | 2.8 | 3.9 |
| Frequency 20 MHz | | | |
| Mean of dB | 52.2 | 2.9 | 5.0 |
| Standard Deviation | 6.7 | 1.5 | 2.1 |
| Median of dB | 53.3 | 2.6 | 4.6 |
| $D_u$ | 6.9 | 2.2 | 3.0 |
| $D_\ell$ | 9.3 | 1.2 | 1.5 |
| Frequency 50 MHz | | | |
| Mean of dB | 30.7 | 8.1 | 12.7 |
| Standard Deviation | 7.1 | 3.6 | 4.9 |
| Median of dB | 29.9 | 8.1 | 12.3 |
| $D_u$ | 9.7 | 5.1 | 7.9 |
| $D_\ell$ | 8.1 | 4.6 | 5.4 |

*2 5/6 hours of data

Table 9. Values of the parameters used in the correlation of noise power with vehicular density and population density

| SLA | Noise Factor Values in dB above $kt_o$ at Frequencies in MHz. Top Line: $F_{am}$ Botton Line: $F_{a\mu}$ | | | | | Population Density: Ring | | Population Density: SLA | |
|---|---|---|---|---|---|---|---|---|---|
| | Frequencies: 2.5 | 5.0 | 10.0 | 20.0 | 48.0 | $P_r$ | 10 log $P_r$ | $P_s$ | 10 log $P_s$ |
| 27 | 79.0 | 58.4 | 47.7 | 43.6 | 25.4 | 889 | 29.49 | 1210 | 30.8 |
| | 80.0 | 59.4 | 49.0 | 44.8 | 28.5 | | | | |
| 19 | 74.2 | 56.1 | 45.9 | 37.9 | 24.7 | 3582 | 35.54 | 1914 | 32.8 |
| | 75.0 | 57.5 | 47.2 | 39.8 | 27.1 | | | | |
| 15 | 76.9 | 58.6 | 49.6 | 42.1 | 32.3 | 5192 | 37.15 | 4720 | 36.7 |
| | 82.1 | 64.2 | 54.8 | 44.4 | 33.9 | | | | |
| 83 | 71.3 | 59.5 | 50.0 | 53.3 | 29.9 | 3821 | 35.82 | 6772 | 38.3 |
| | 73.0 | 61.2 | 50.7 | 52.2 | 30.9 | | | | |
| 59 | 75.8 | 67.4 | 55.3 | 58.9 | 28.4 | 9358 | 39.71 | 8094 | 39.1 |
| | 76.2 | 68.5 | 57.4 | 57.9 | 28.5 | | | | |
| 22 | 70.5 | 58.3 | 51.3 | 45.3 | 26.3 | 7826 | 38.94 | 9091 | 39.6 |
| | 70.0 | 59.5 | 52.4 | 47.4 | 27.5 | | | | |
| 41 | 68.0 | 55.8 | 47.7 | 42.4 | 23.4 | 9754 | 39.89 | 12644 | 41.0 |
| | 69.3 | 57.4 | 49.1 | 43.9 | 26.1 | | | | |
| 43 | 63.0 | 54.6 | 47.7 | 45.5 | 39.3 | 11234 | 40.51 | 21826 | 43.4 |
| | 64.0 | 55.9 | 49.1 | 46.8 | 41.3 | | | | |

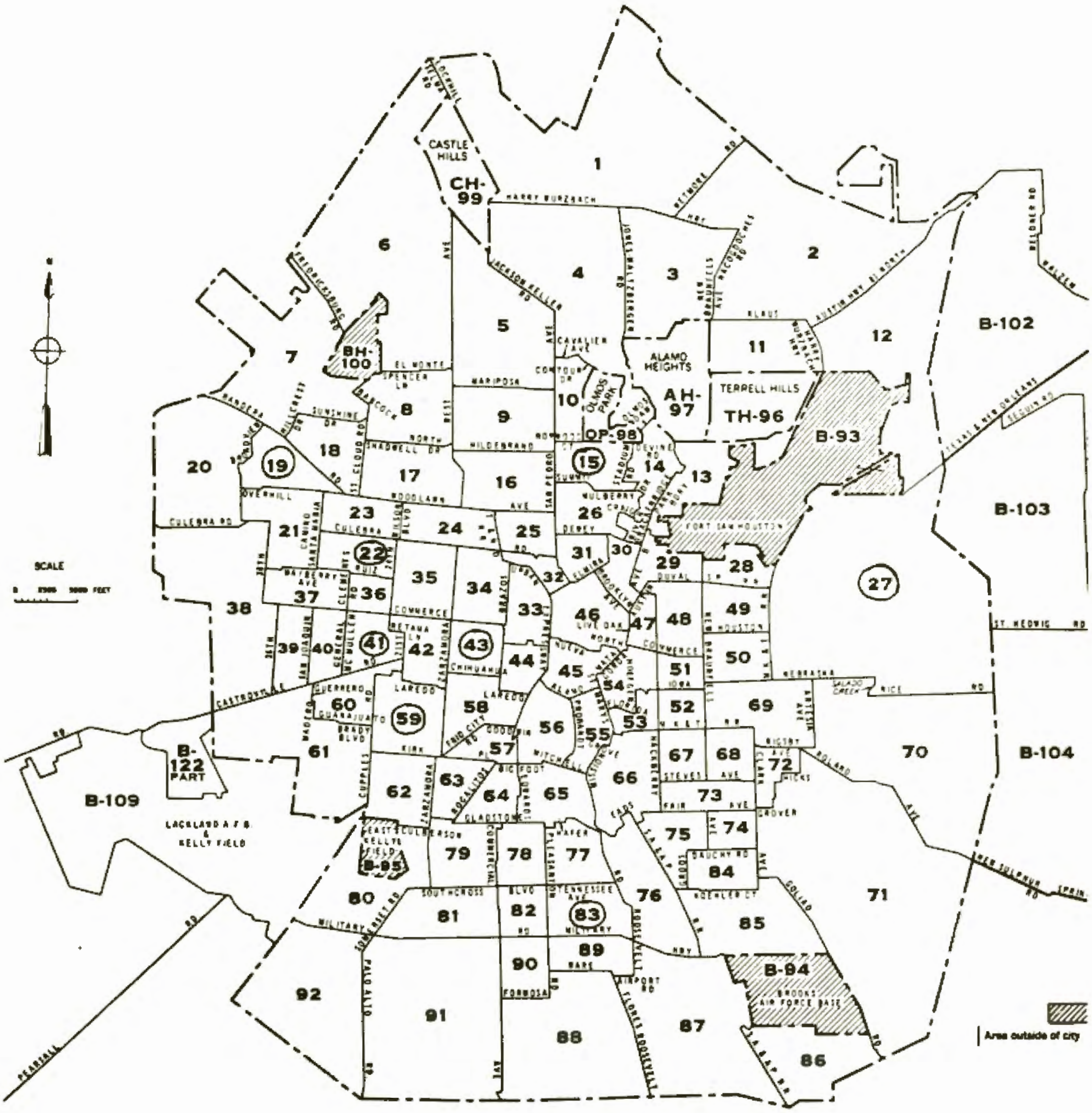


Figure 1. Standard location areas (SLA's) for San Antonio, Texas. Circled numbers are the areas surveyed.

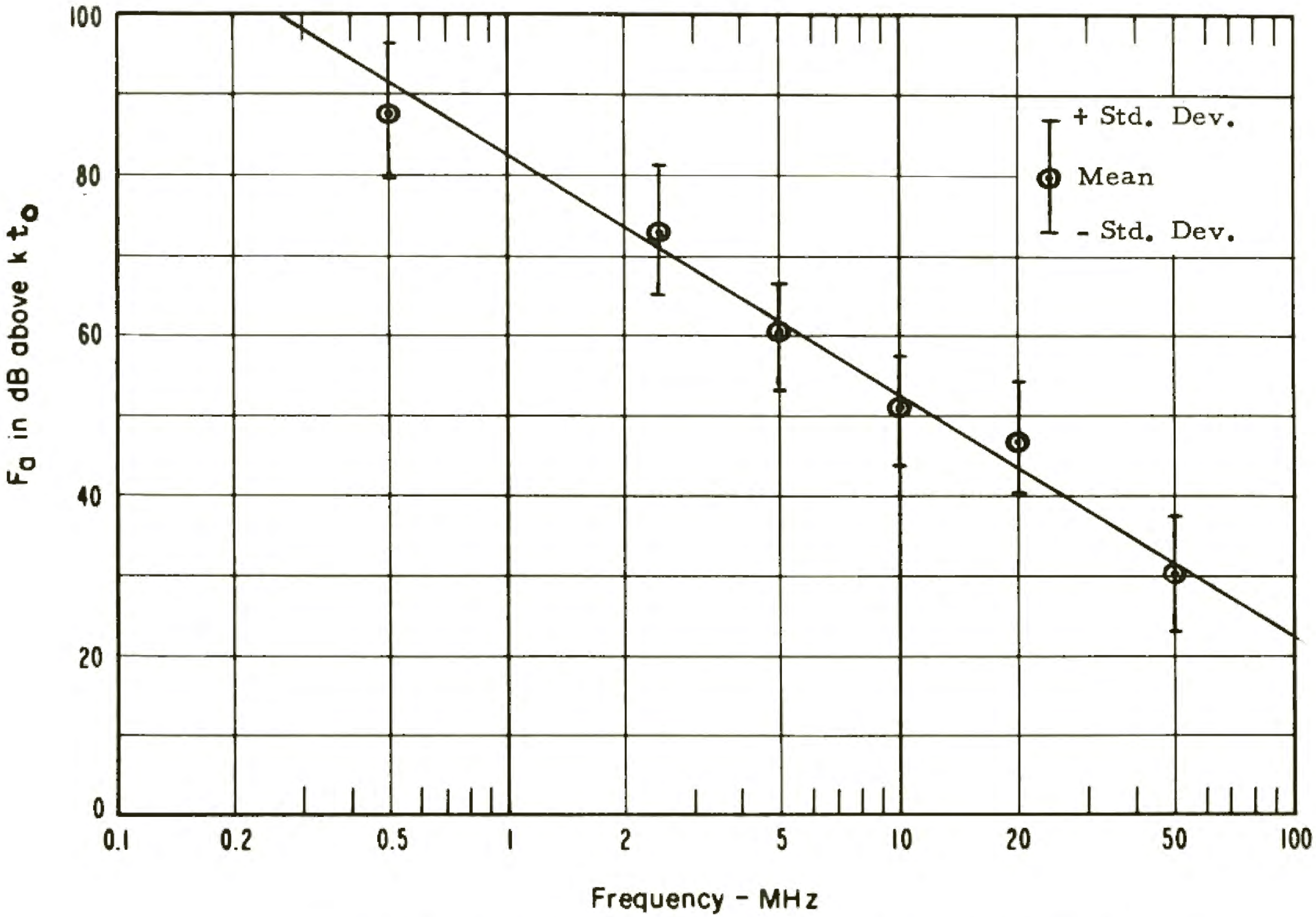


Figure 2. Mean urban residential area man-made noise (all SLA's surveyed)

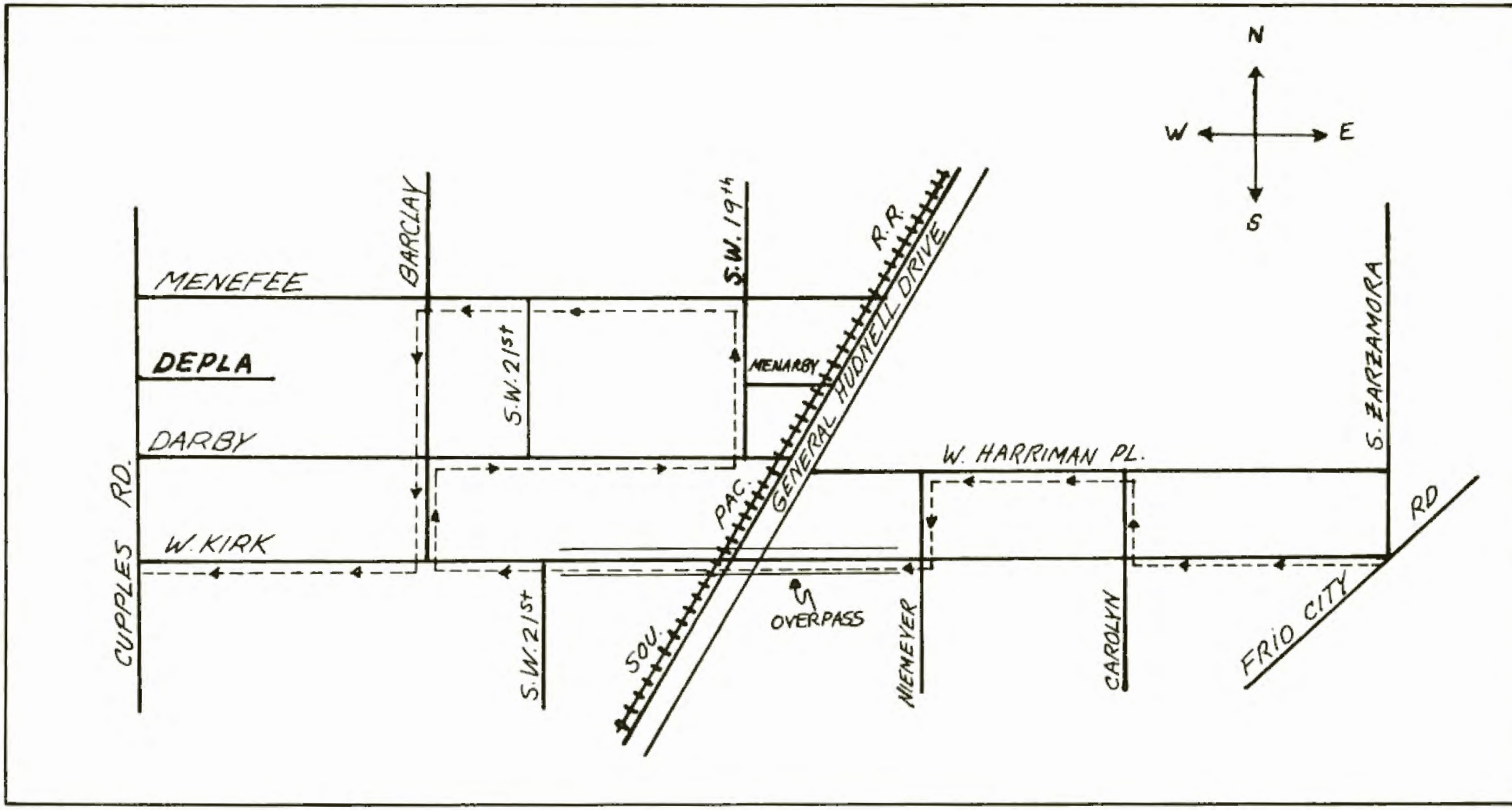


Figure 3. One route taken by mobile radio noise recording laboratory in SLA 59, San Antonio, Texas, on May 17, 1968, 1032 to 1042 CST

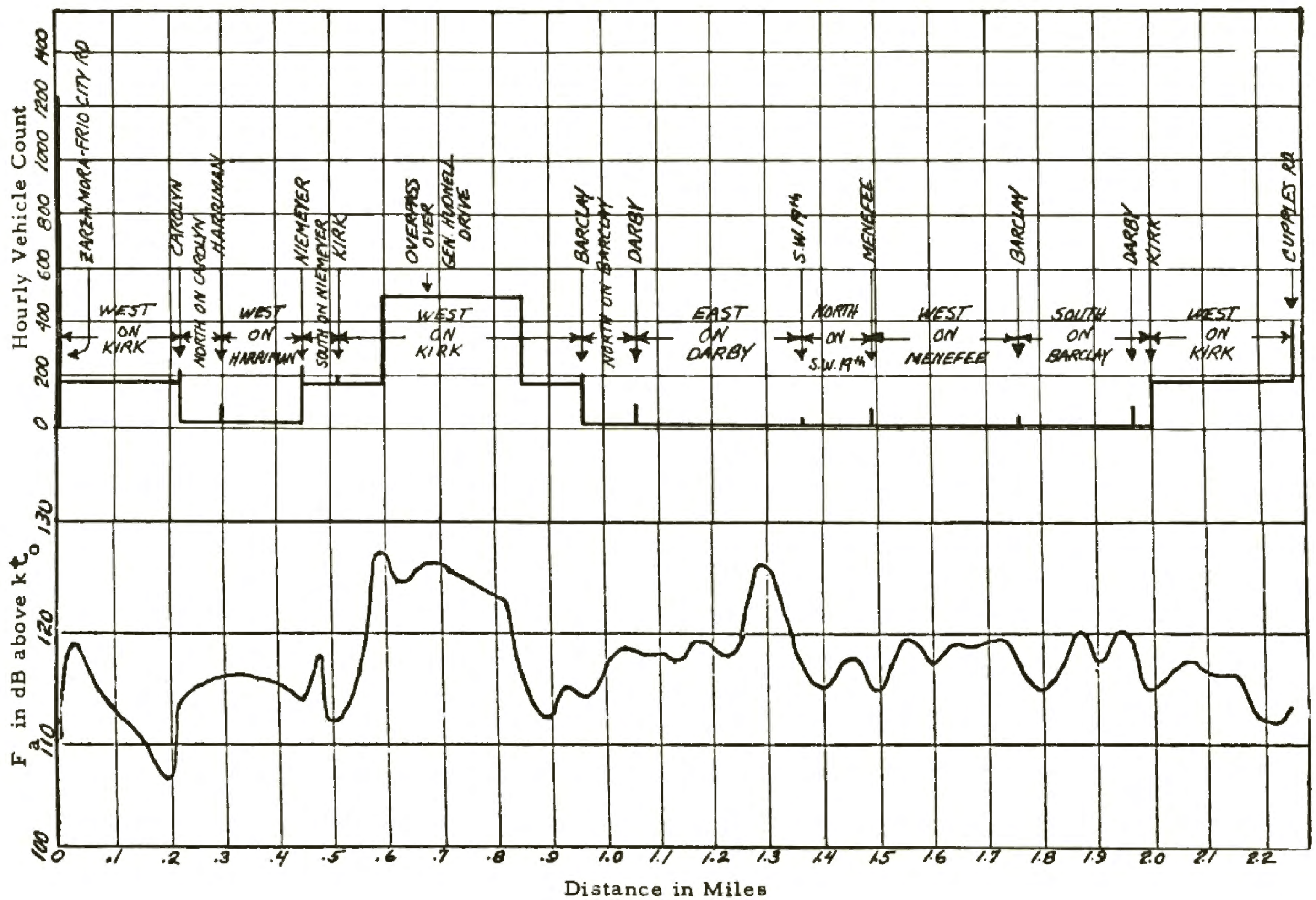


Figure 4. $F_a$ and hourly vehicular count along the route in SLA 59 for 500 kHz

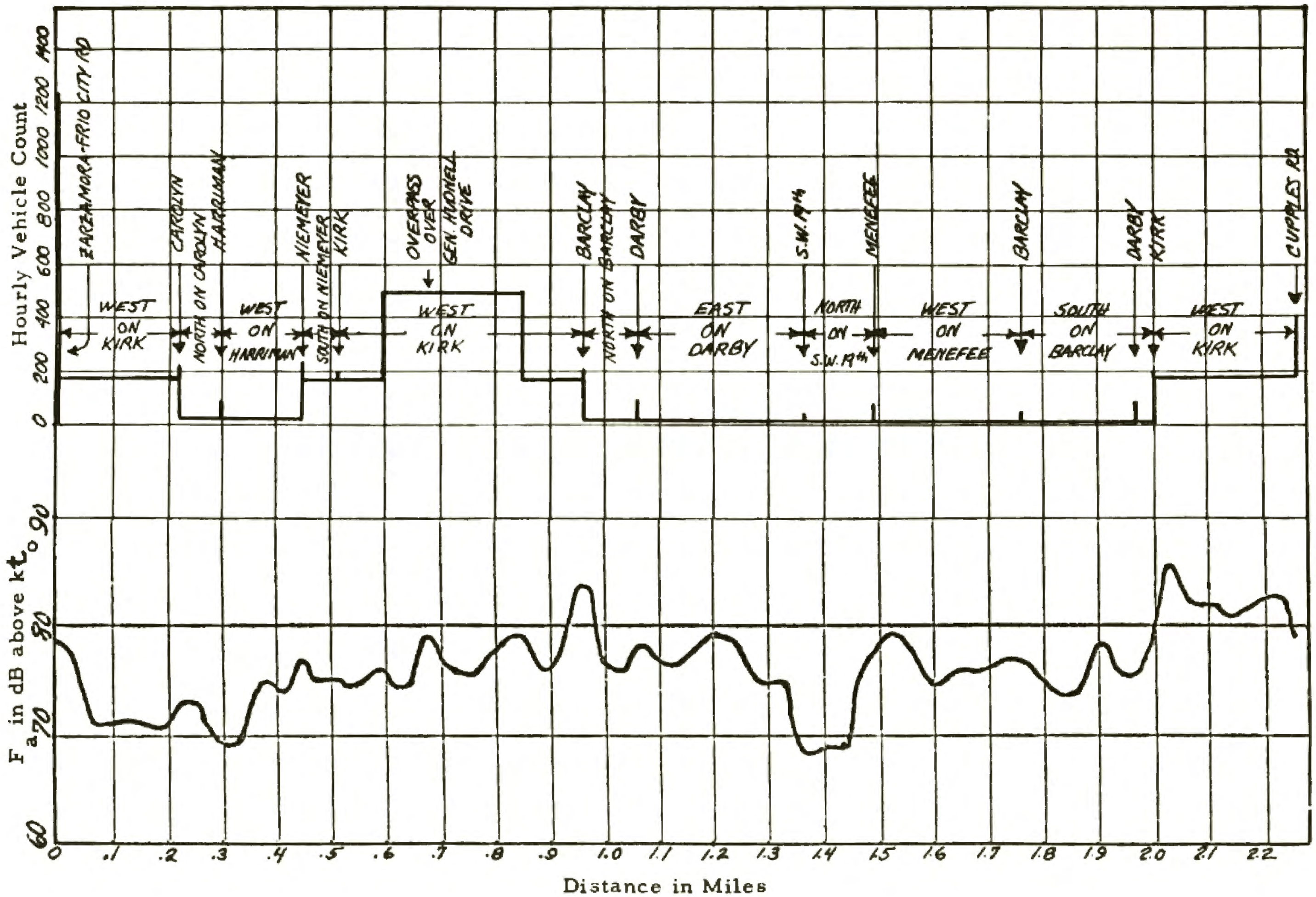


Figure 5. $F_a$ and hourly vehicular count along the route in SLA 59 for 2.5 MHz

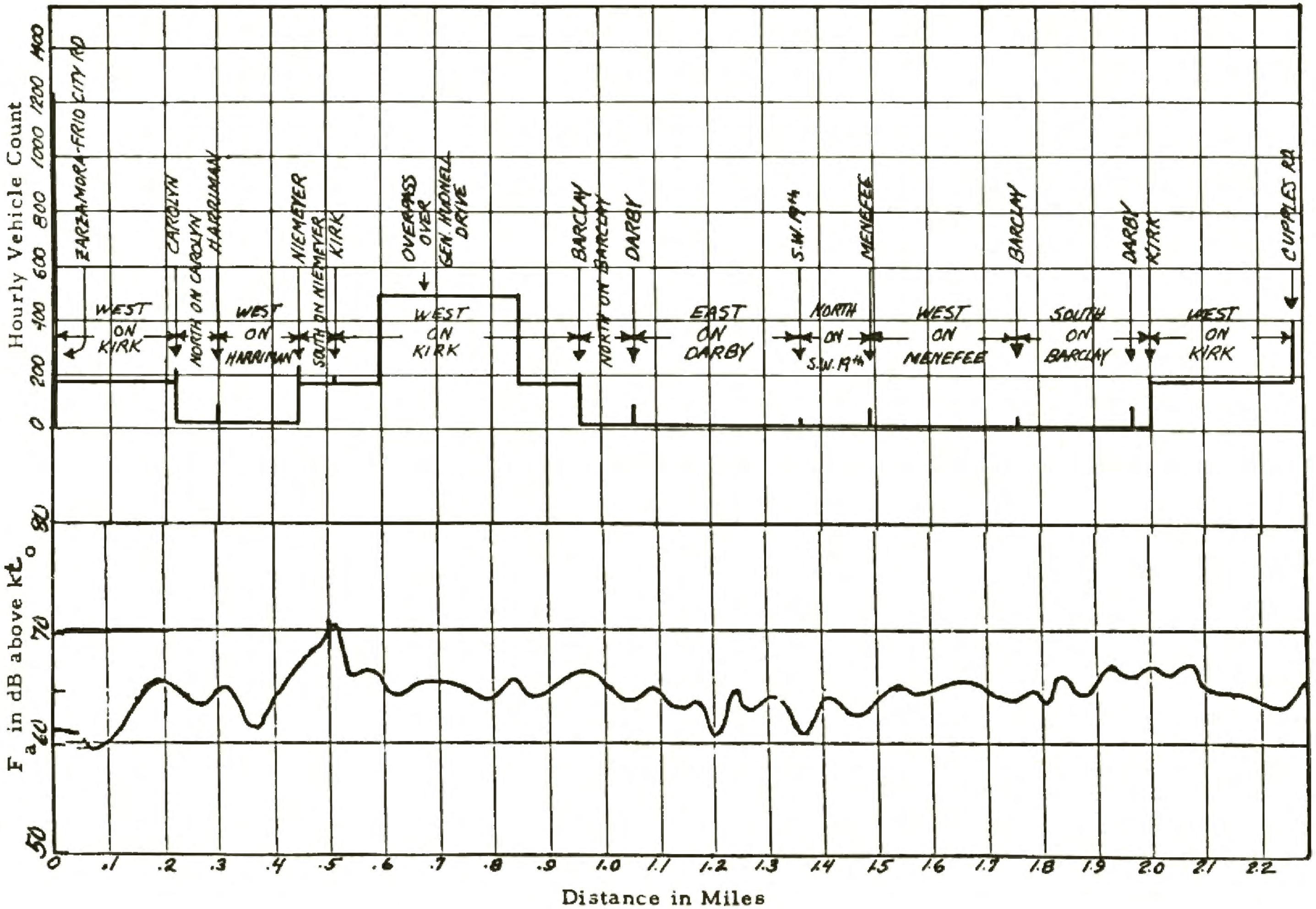


Figure 6. $F_a$ and hourly vehicular count along the route in SLA 59 for 5 MHz

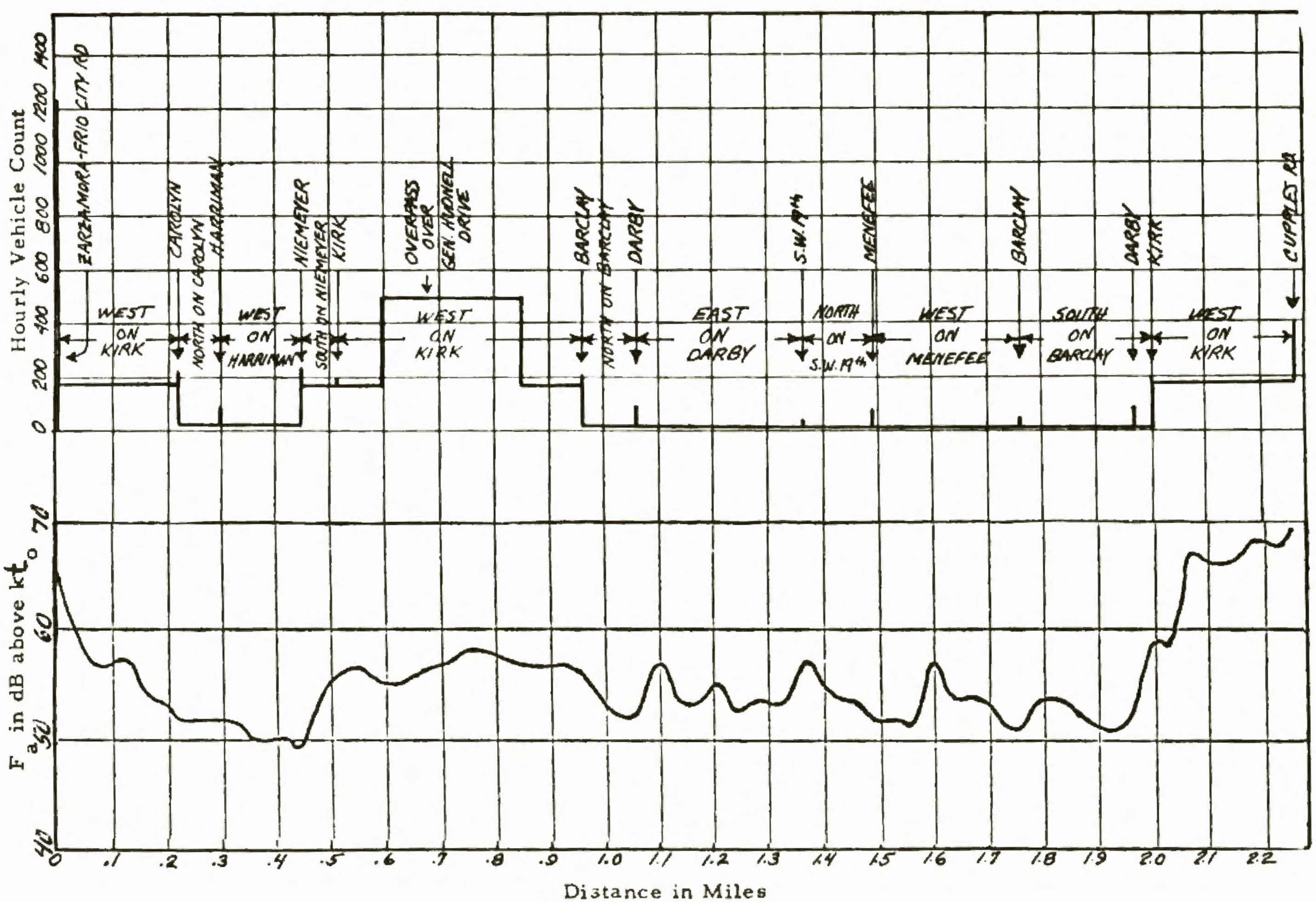


Figure 7. $F_a$ and hourly vehicular count along the route in SLA 59 for 10 MHz

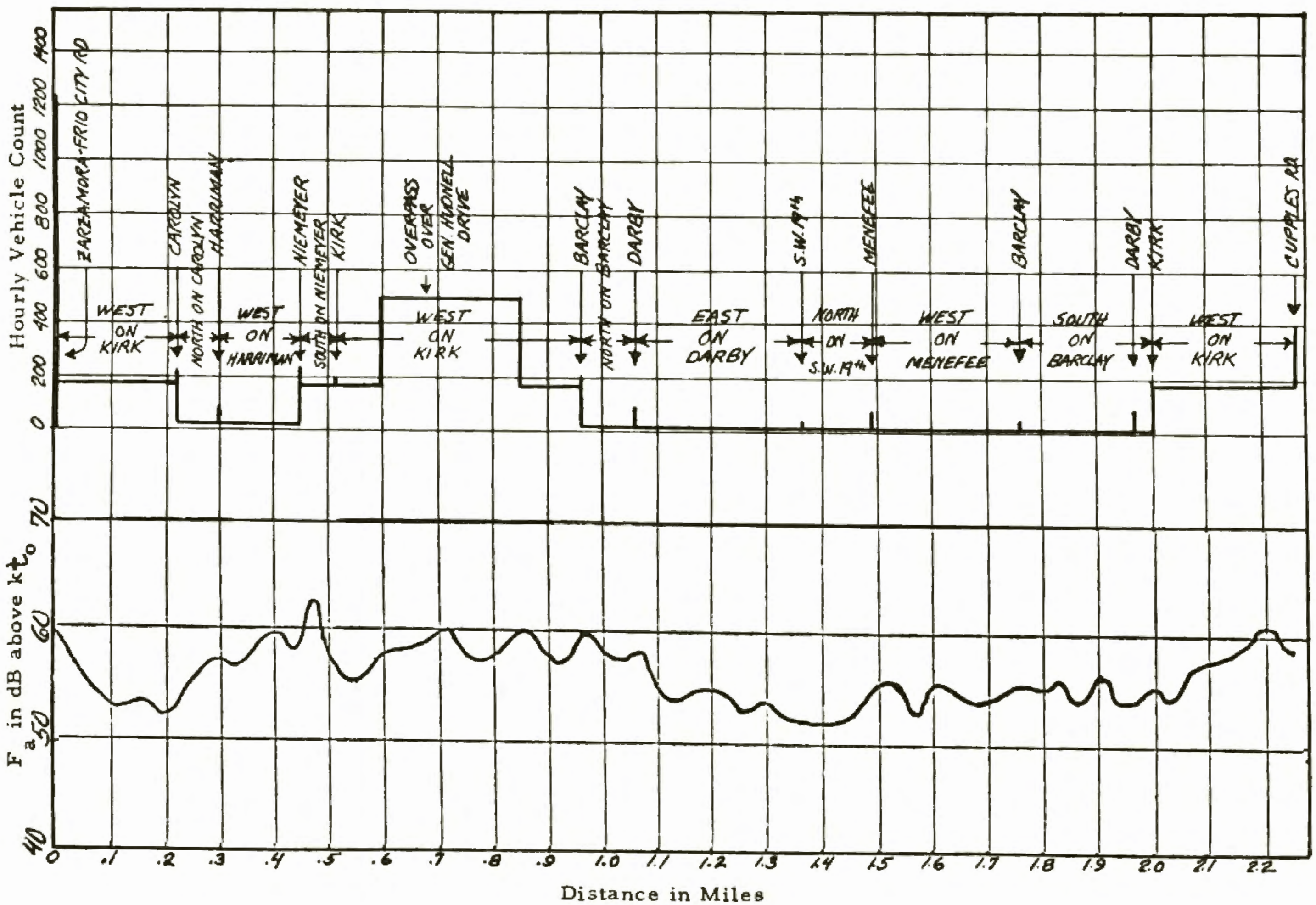


Figure 8. $F_a$ and hourly vehicular count along the route in SLA 59 for 20 MHz

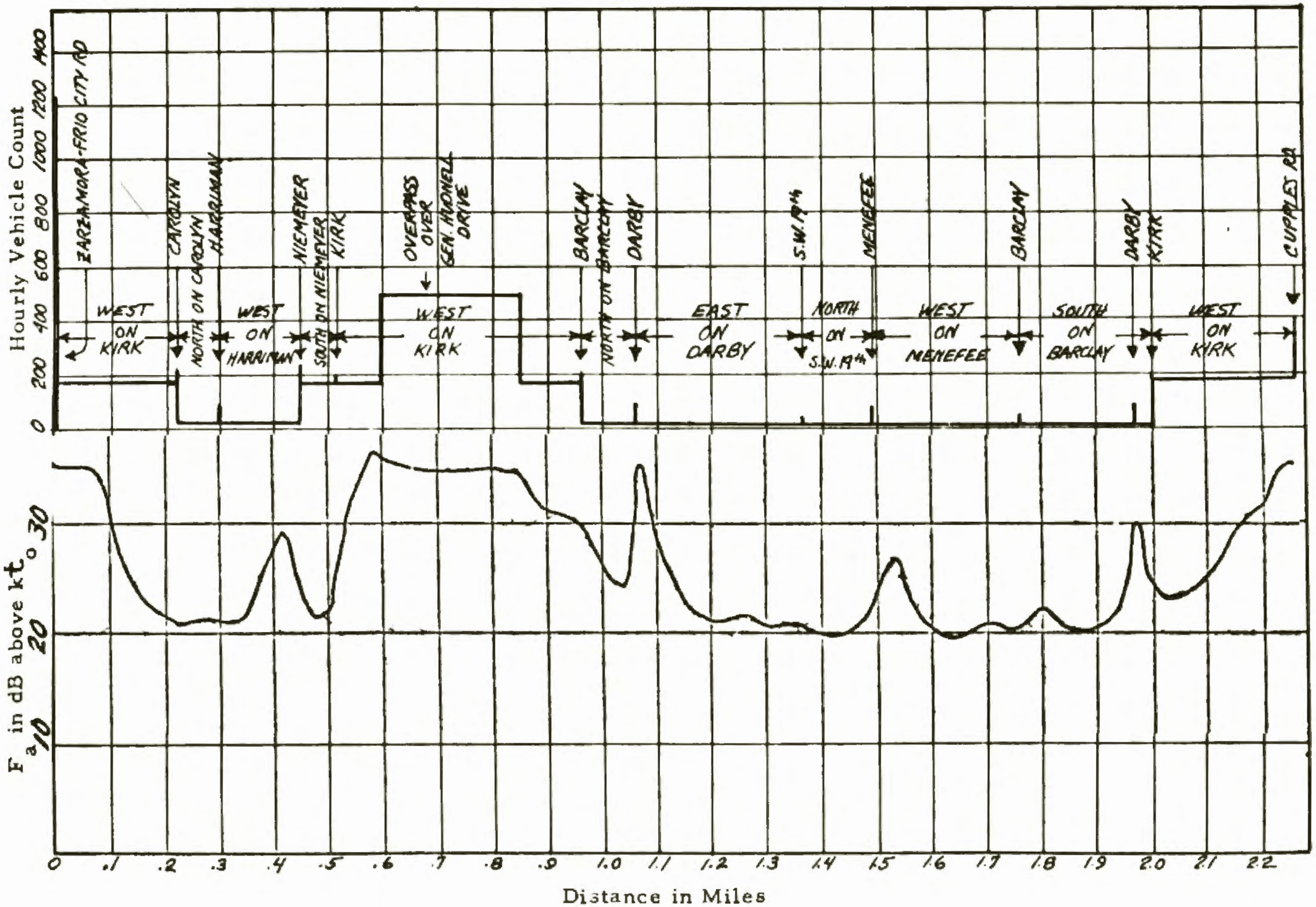


Figure 9. $F_a$ and hourly vehicular count along the route in SLA 59 for 48 MHz

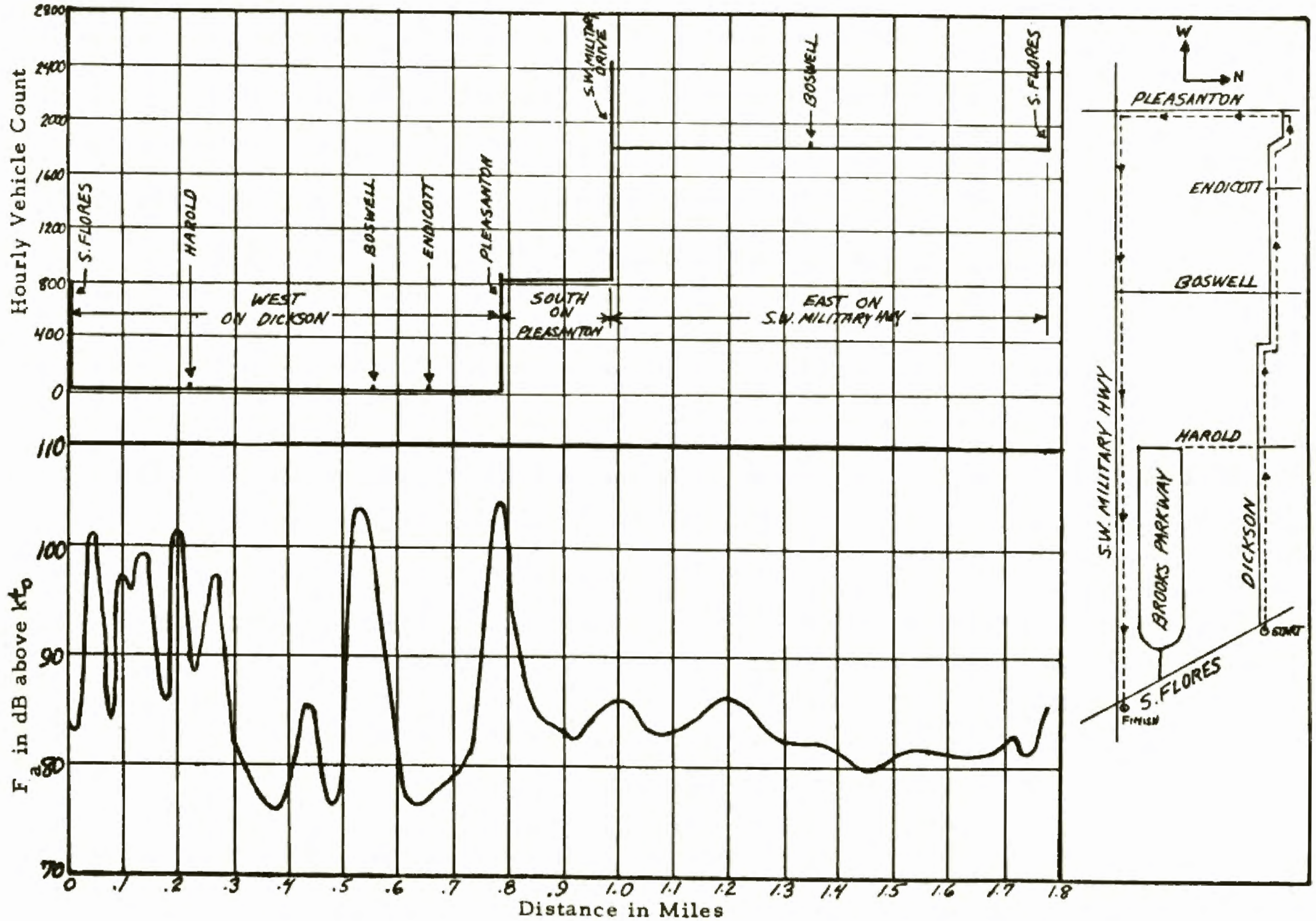


Figure 10. $F_a$ and hourly vehicular count along a route taken in SLA 83 on May 28, 1968, 1059-1110 CST, for 500 kHz

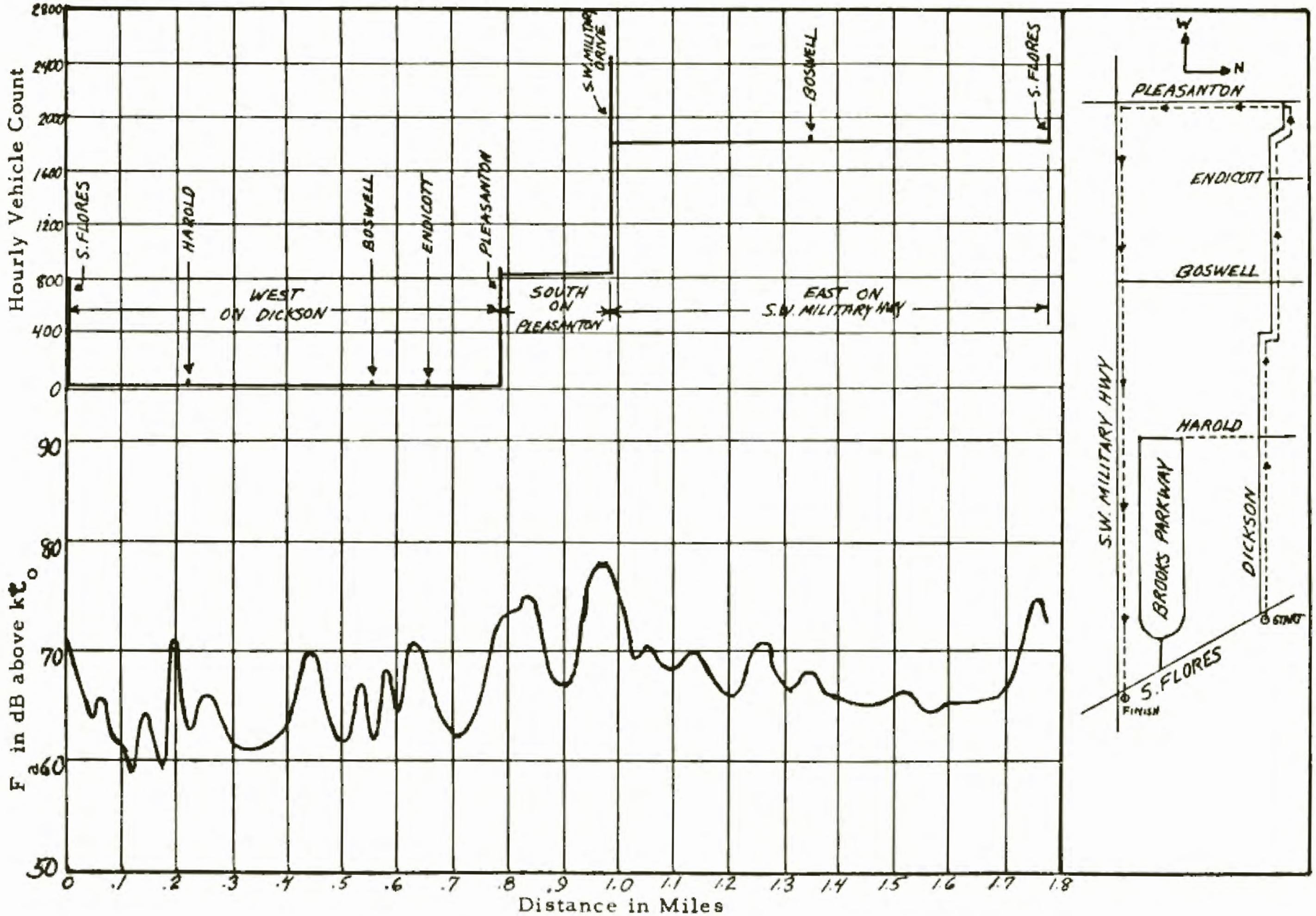


Figure 11. $F_a$ and hourly vehicular count along a route taken in SLA 83 on May 28, 1968, 1059-1110 CST, for 2.5 MHz

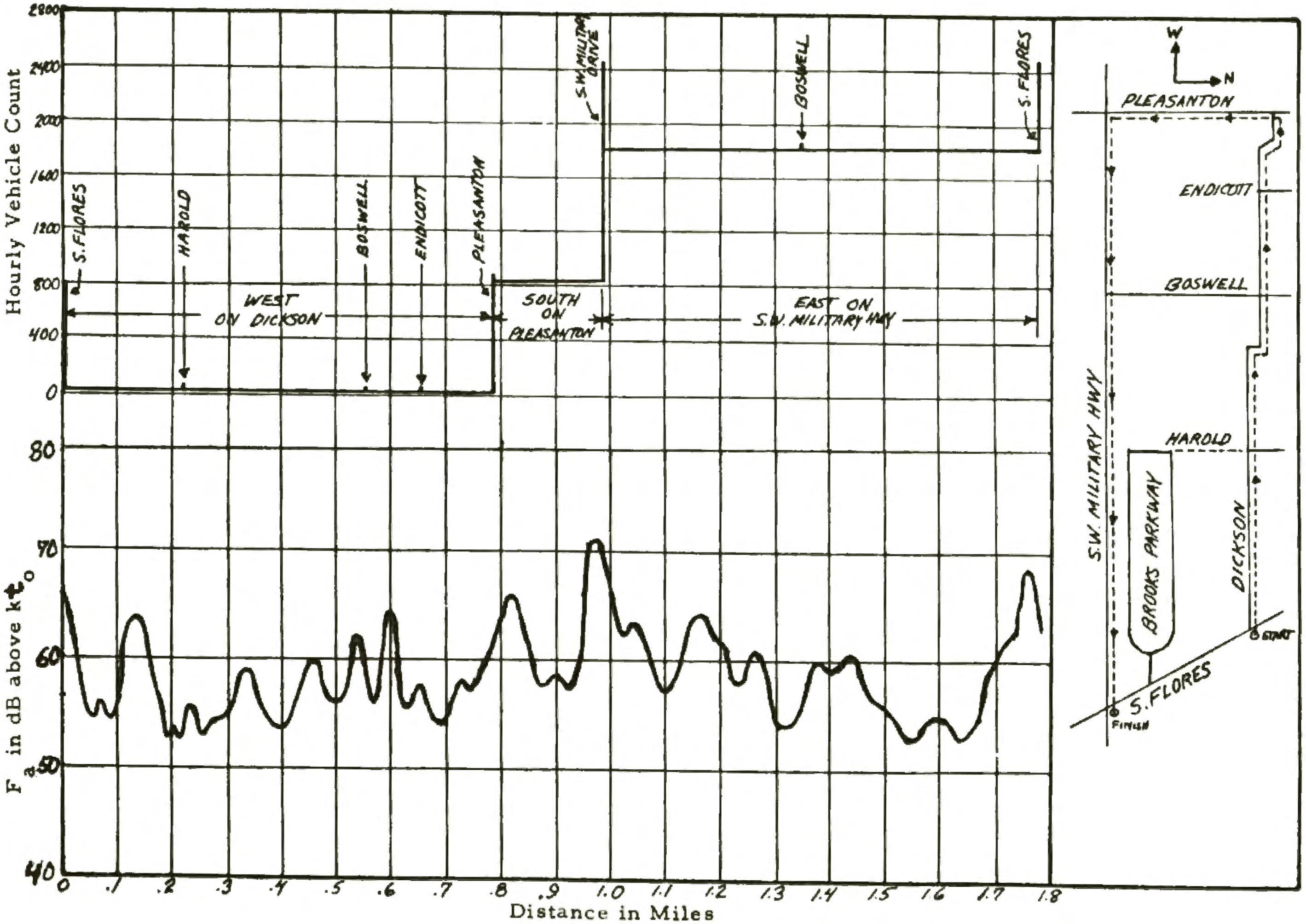


Figure 12. $F_a$ and hourly vehicular count along a route taken in SLA 83 on May 28, 1968, 1059-1110 CST, for 5 MHz

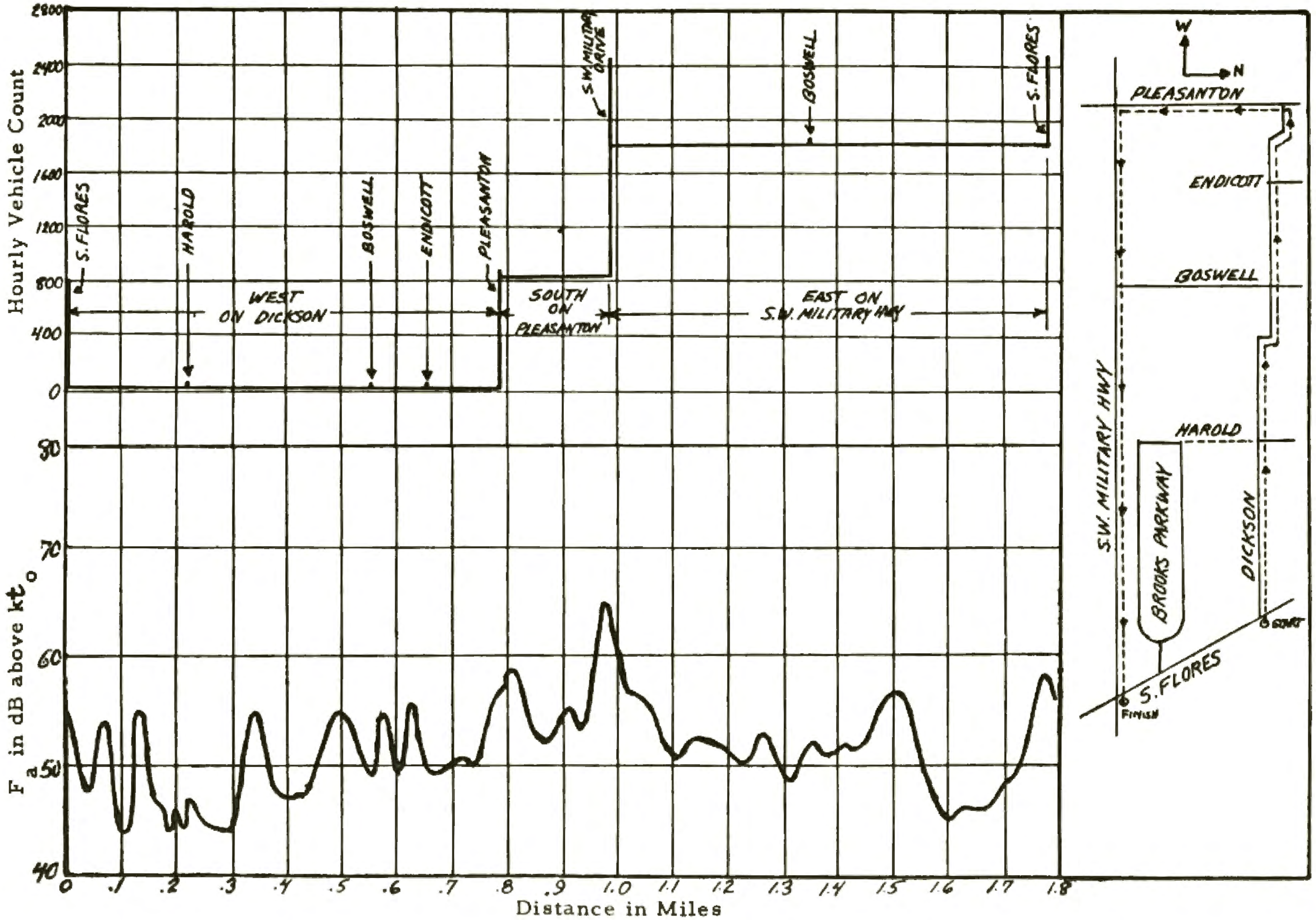


Figure 13. $F_a$ and hourly vehicular count along a route taken in SLA 83 on May 28, 1968, 1059-1110 CST, for 10 MHz

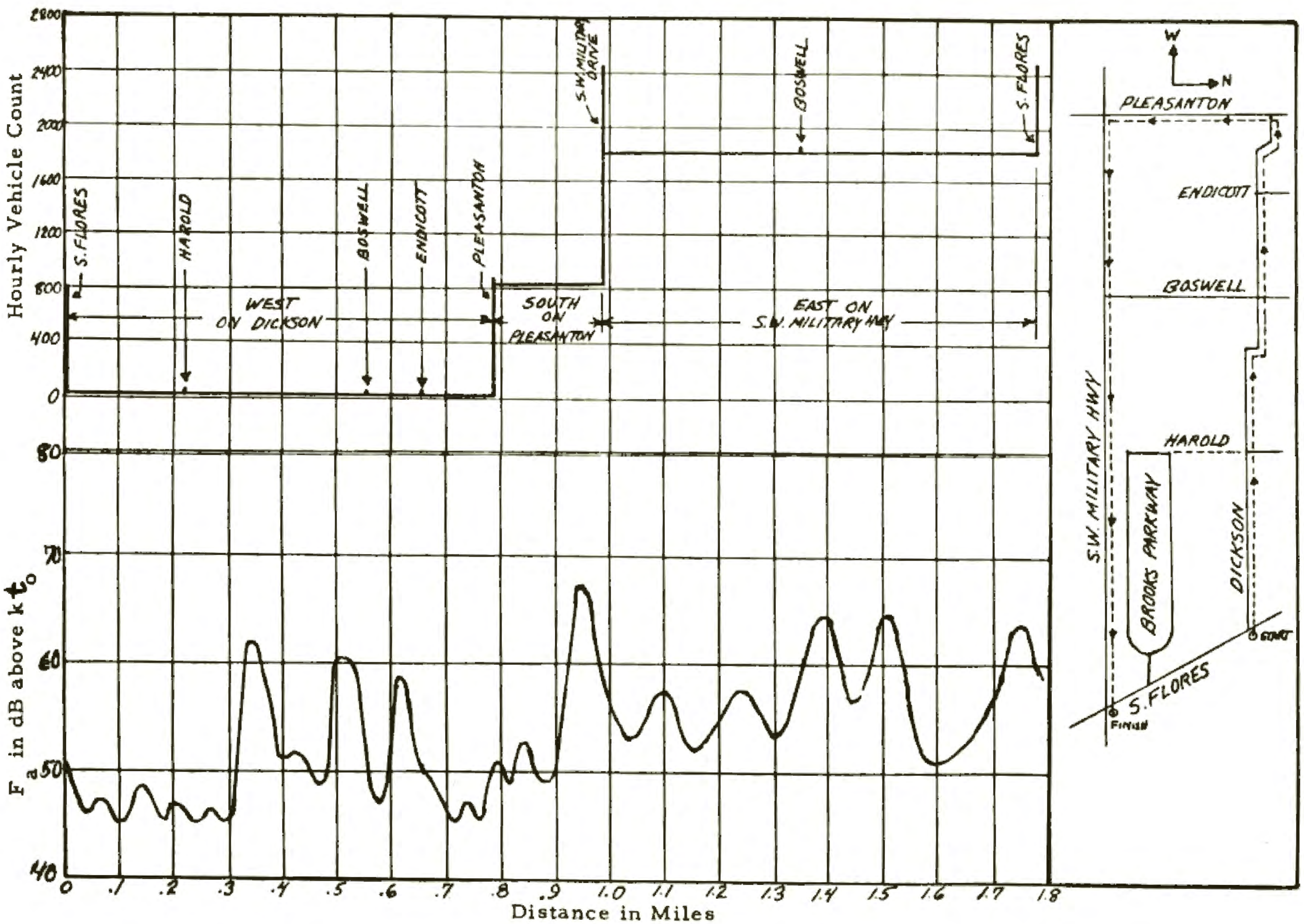


Figure 14. $F_a$ and hourly vehicular count along a route taken in SLA 83 on May 28, 1968, 1059-1110 CST, for 20 MHz

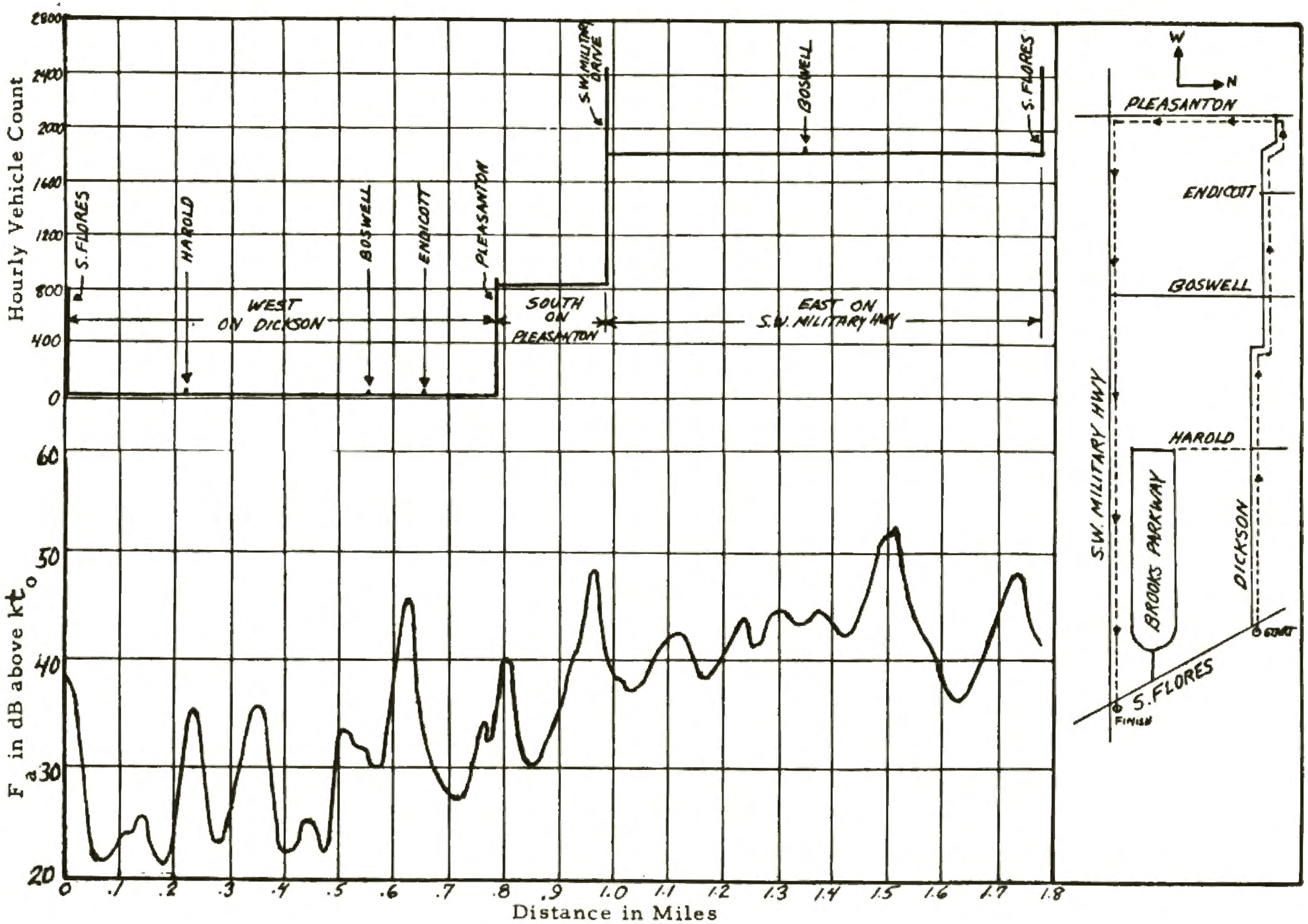


Figure 15. $F_a$ and hourly vehicular count along a route taken in SLA 83 on May 28, 1968, 1059-1110 CST, for 48 MHz

Amplitude Probability Distribution

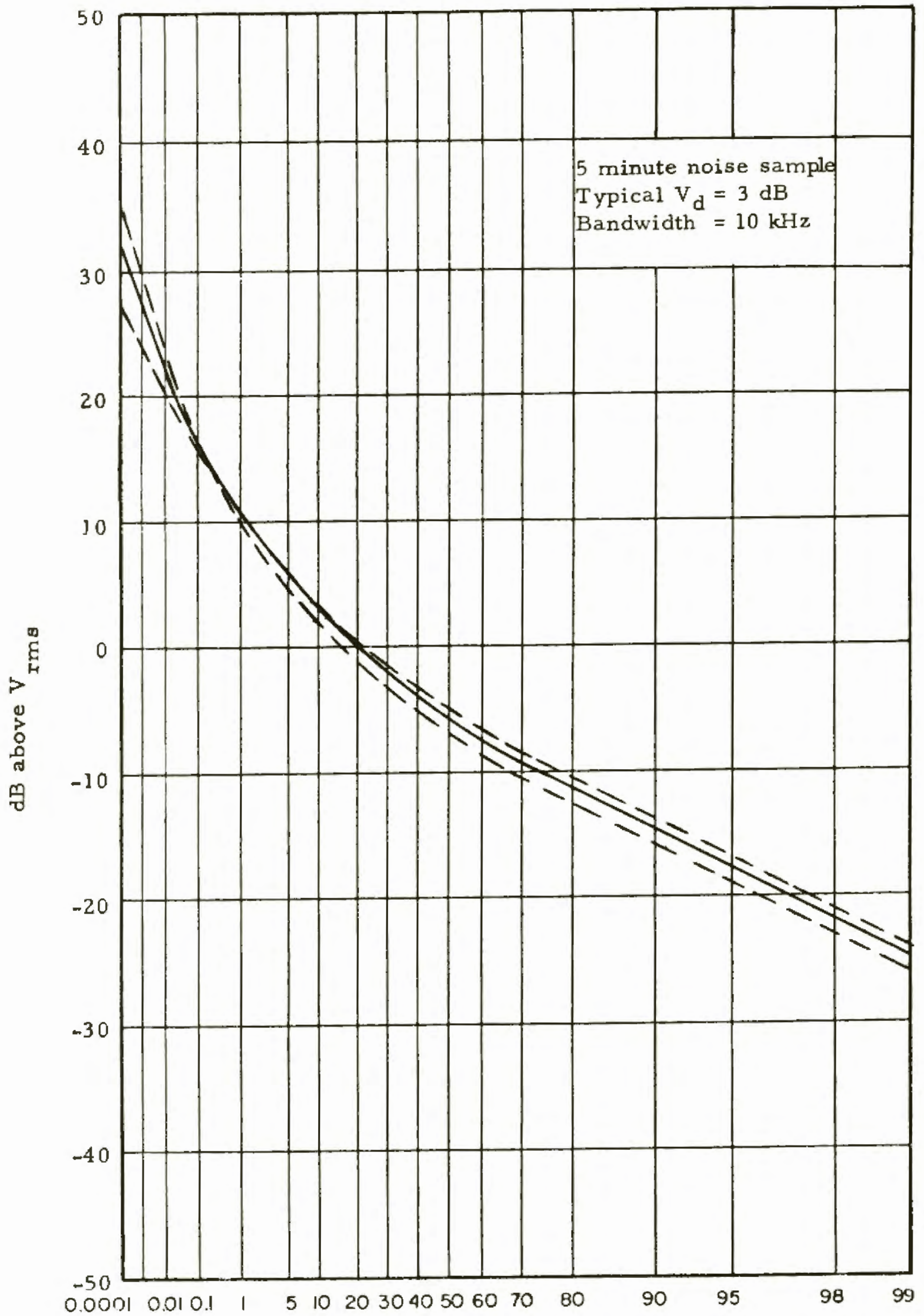


Figure 16. Typical APD and observed variations for urban residential man-made noise for 2.5 MHz at San Antonio

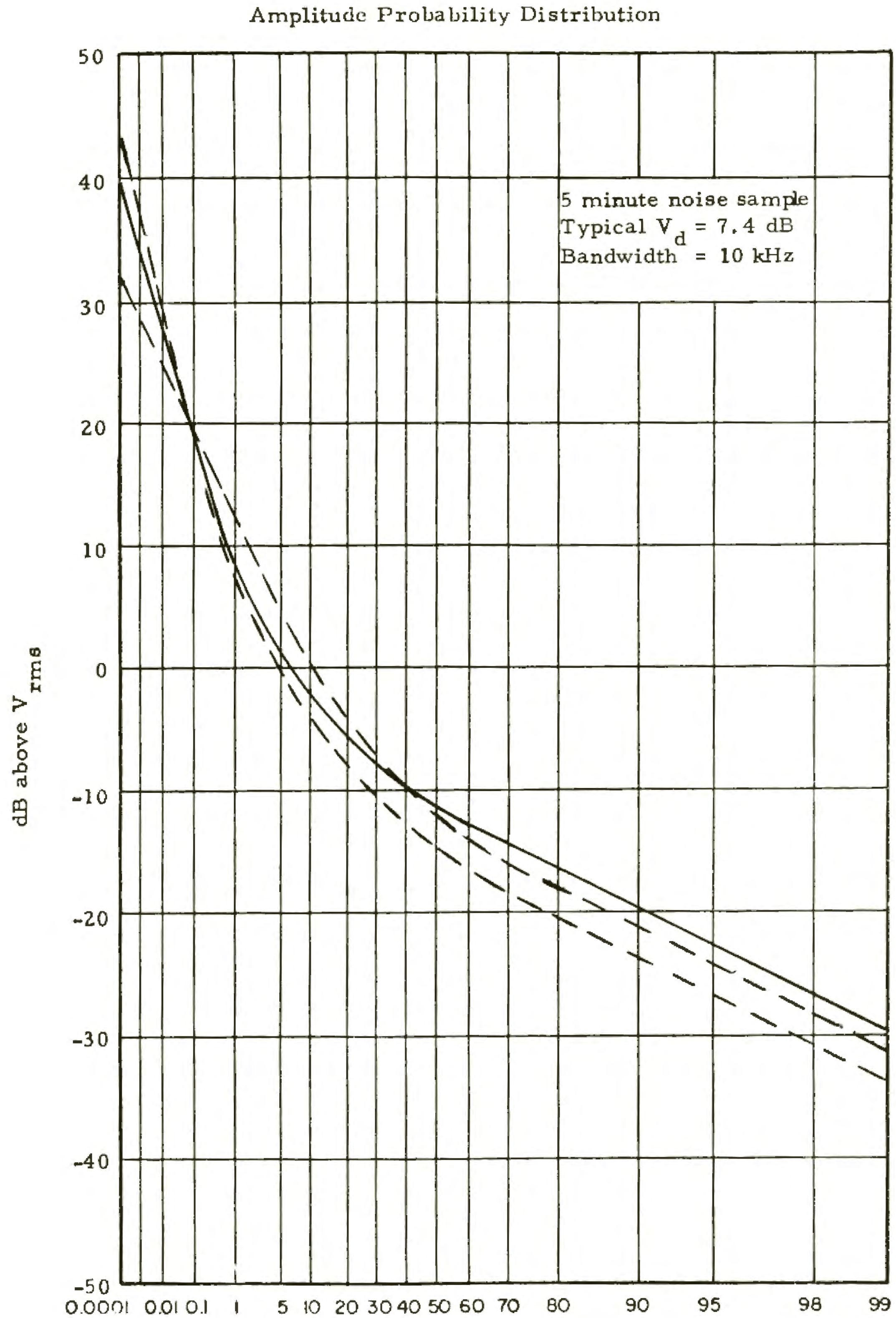


Figure 17. Typical APD and observed variations for urban residential man-made noise for 10 MHz at San Antonio

Amplitude Probability Distribution

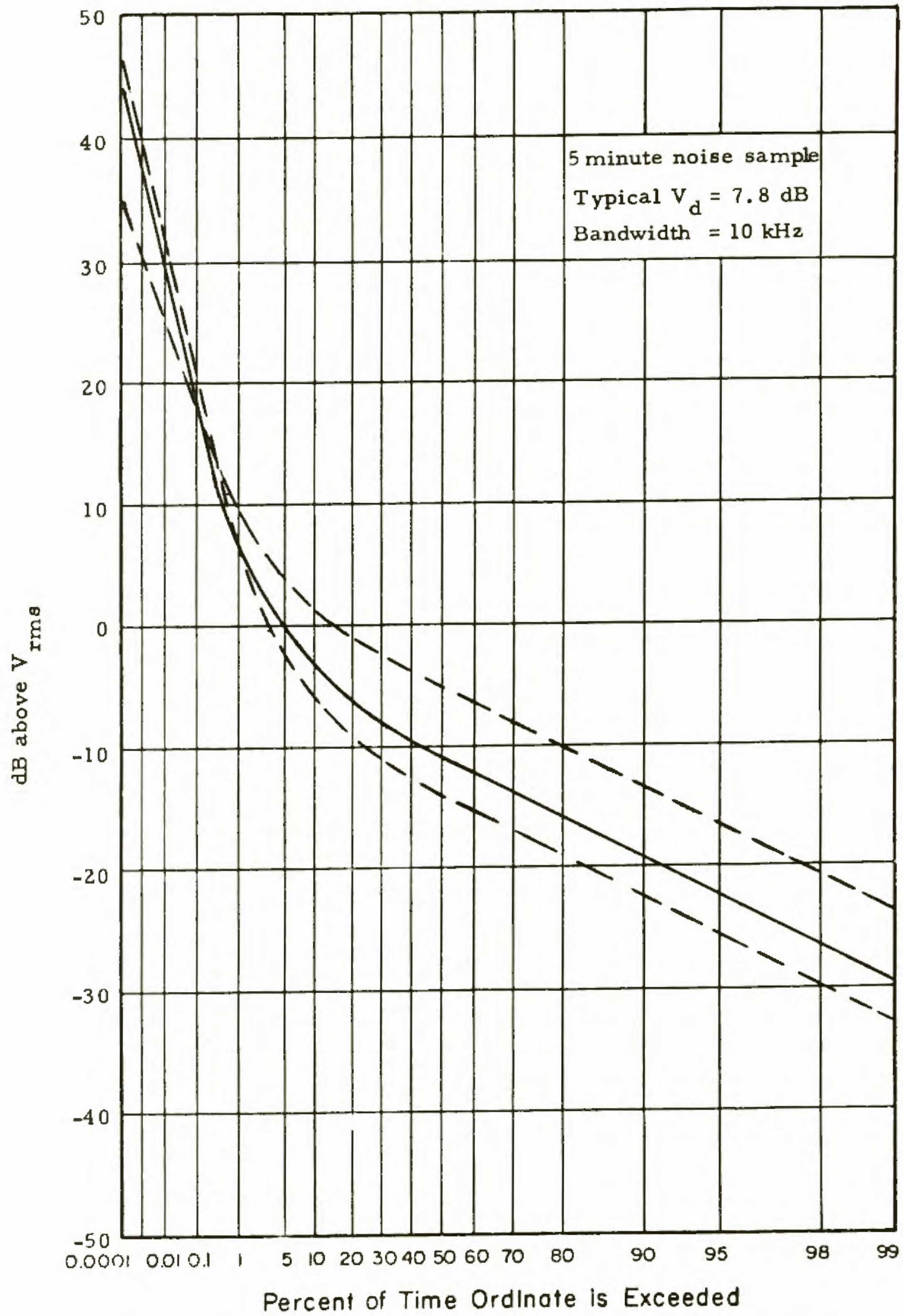


Figure 18. Typical APD and observed variations for urban residential man-made noise for 20 MHz at San Antonio

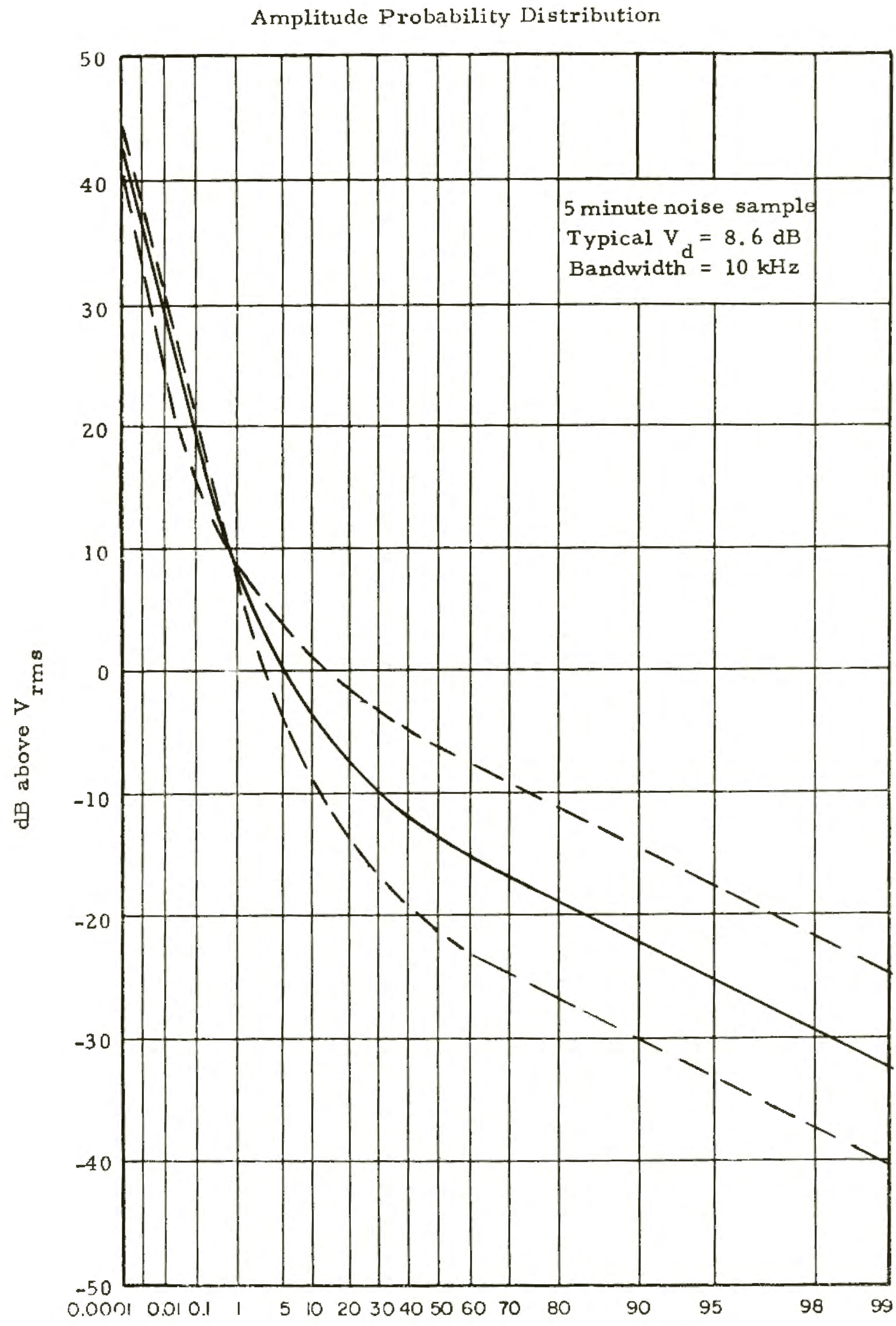


Figure 19. Typical APD and observed variations for urban residential man-made noise for 48 MHz at San Antonio

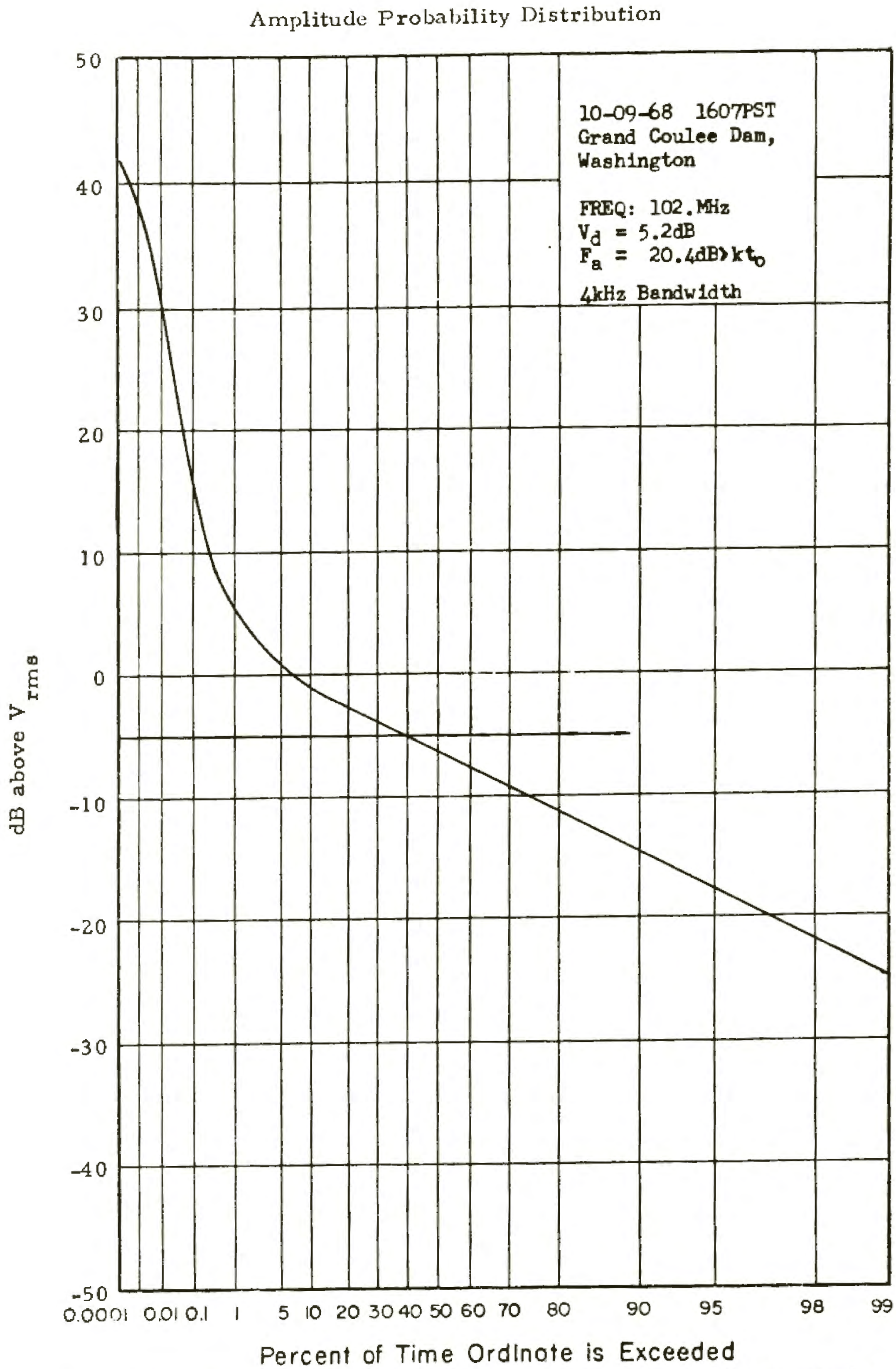


Figure 20. Amplitude probability distribution for a 5-minute sample of man-made noise recorded at Grand Coulee Dam

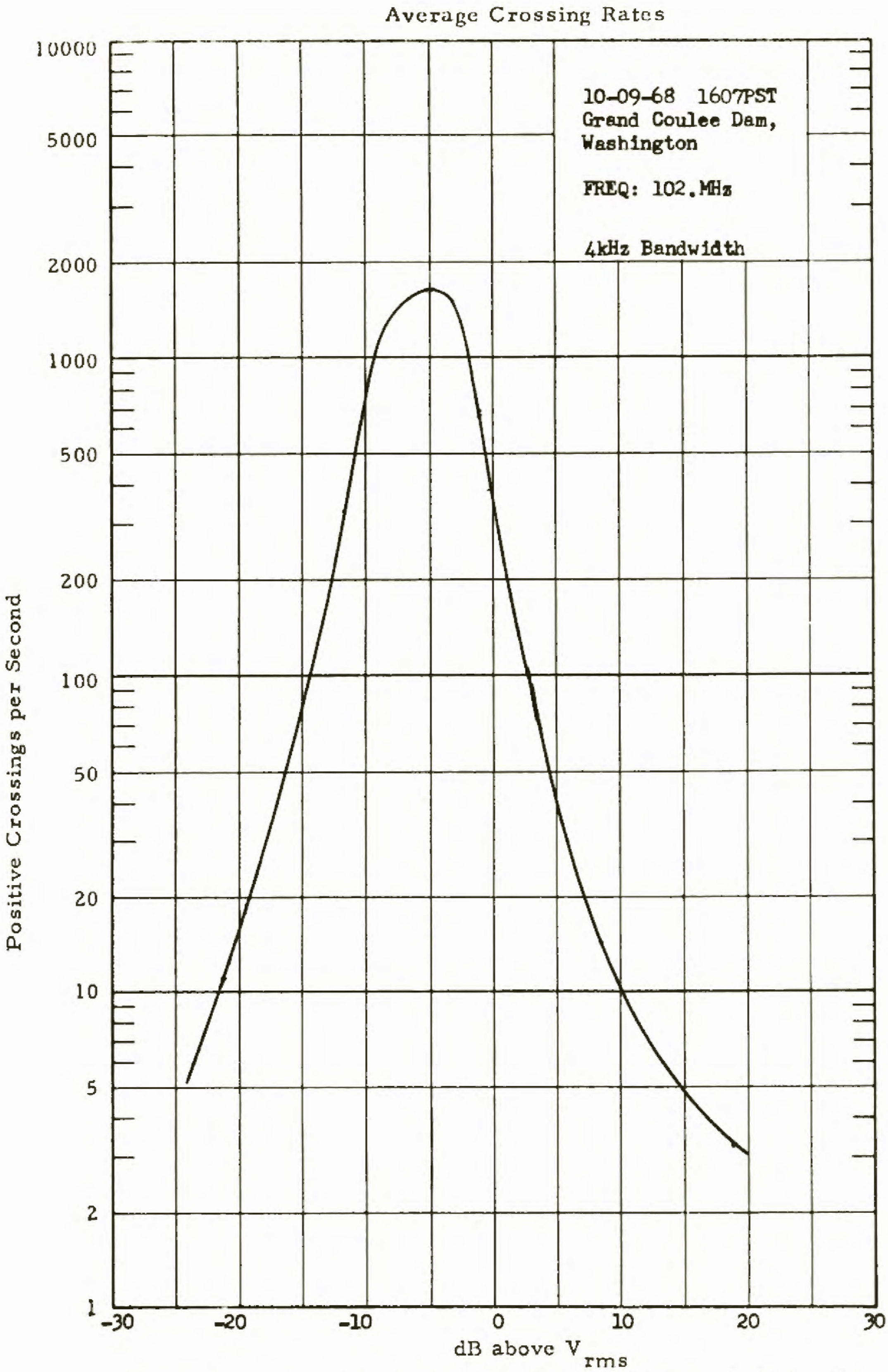


Figure 21. Average positive crossing rate characteristic for the sample of noise of figure 20

Pulse Duration Distributions

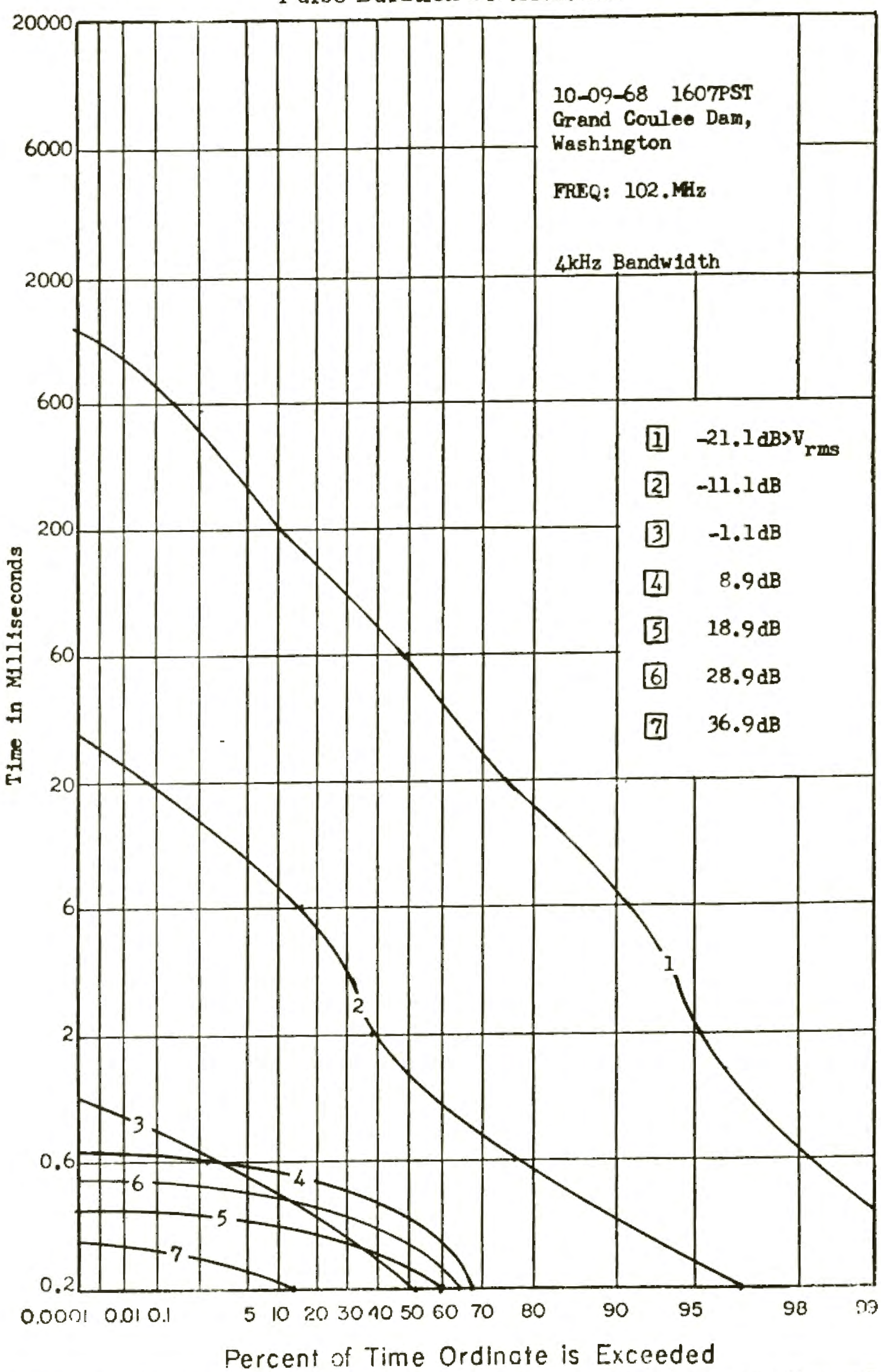


Figure 22. Pulse duration distributions for the sample of noise of figure 20

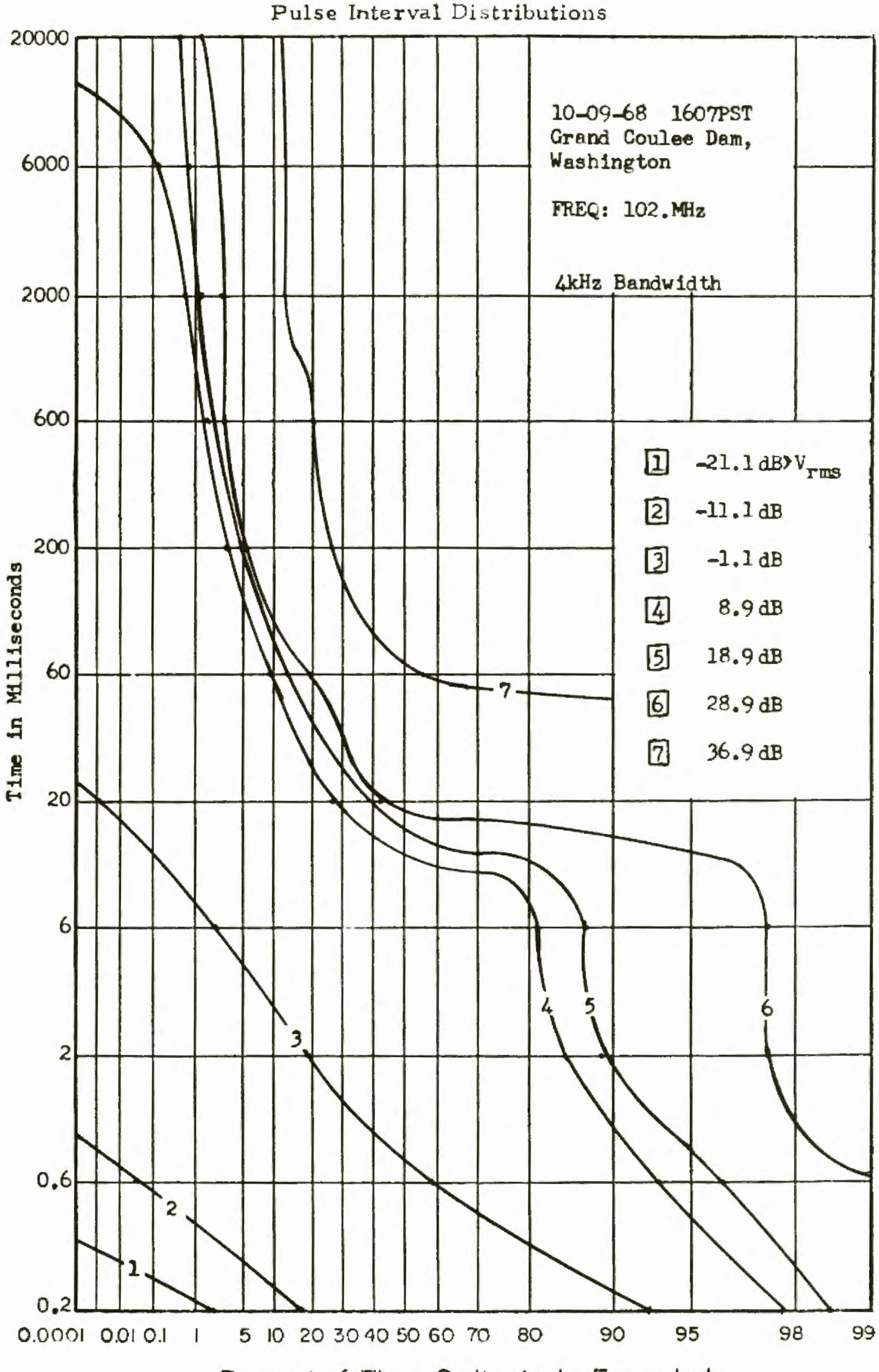


Figure 23. Pulse interval distributions for the sample of noise of figure 20

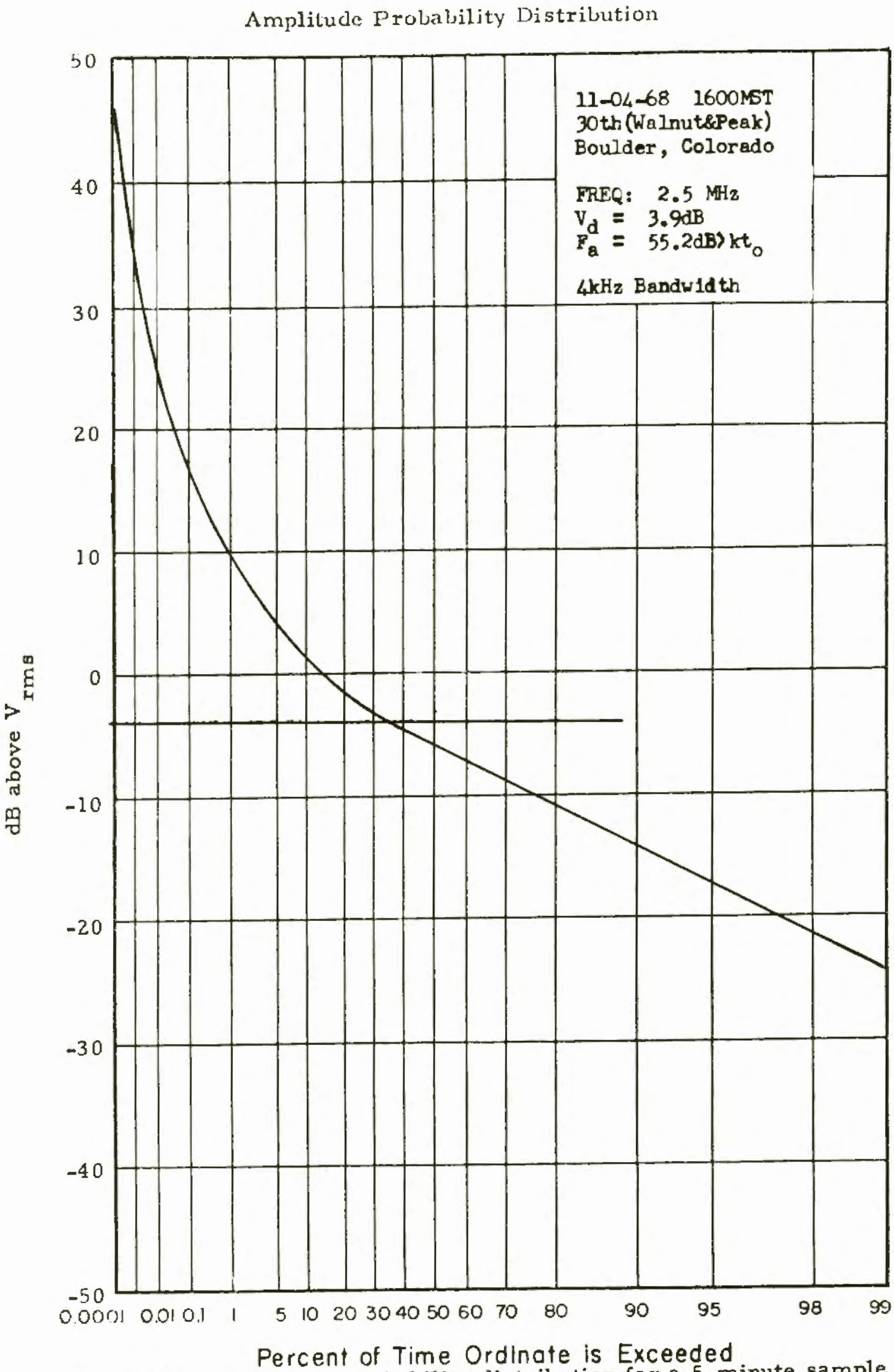


Figure 24. Amplitude probability distribution for a 5-minute sample of man-made noise recorded in Boulder, Colorado

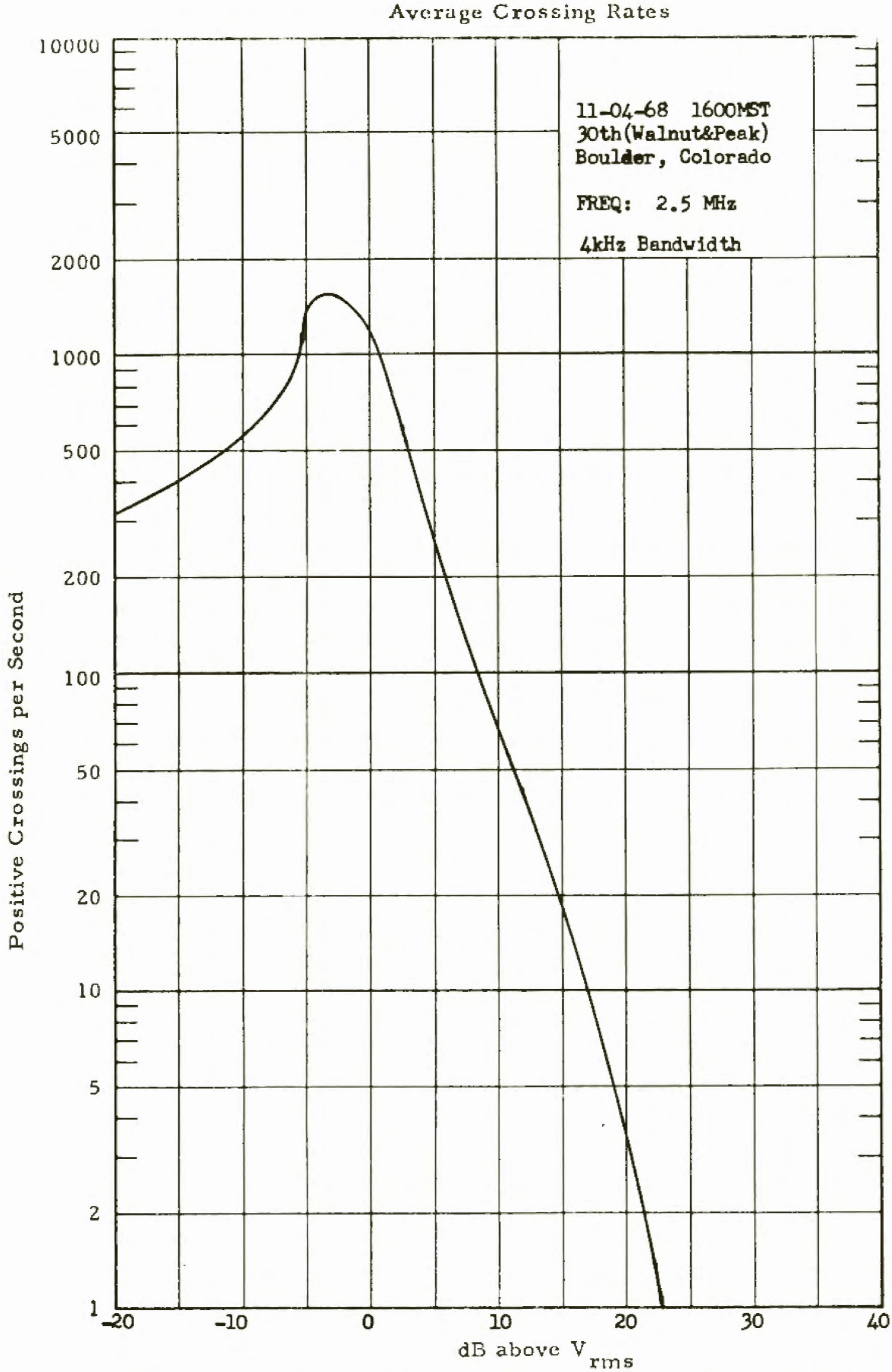


Figure 25. Average positive crossing rate characteristic for the sample of noise of figure 24

Pulse Duration Distributions

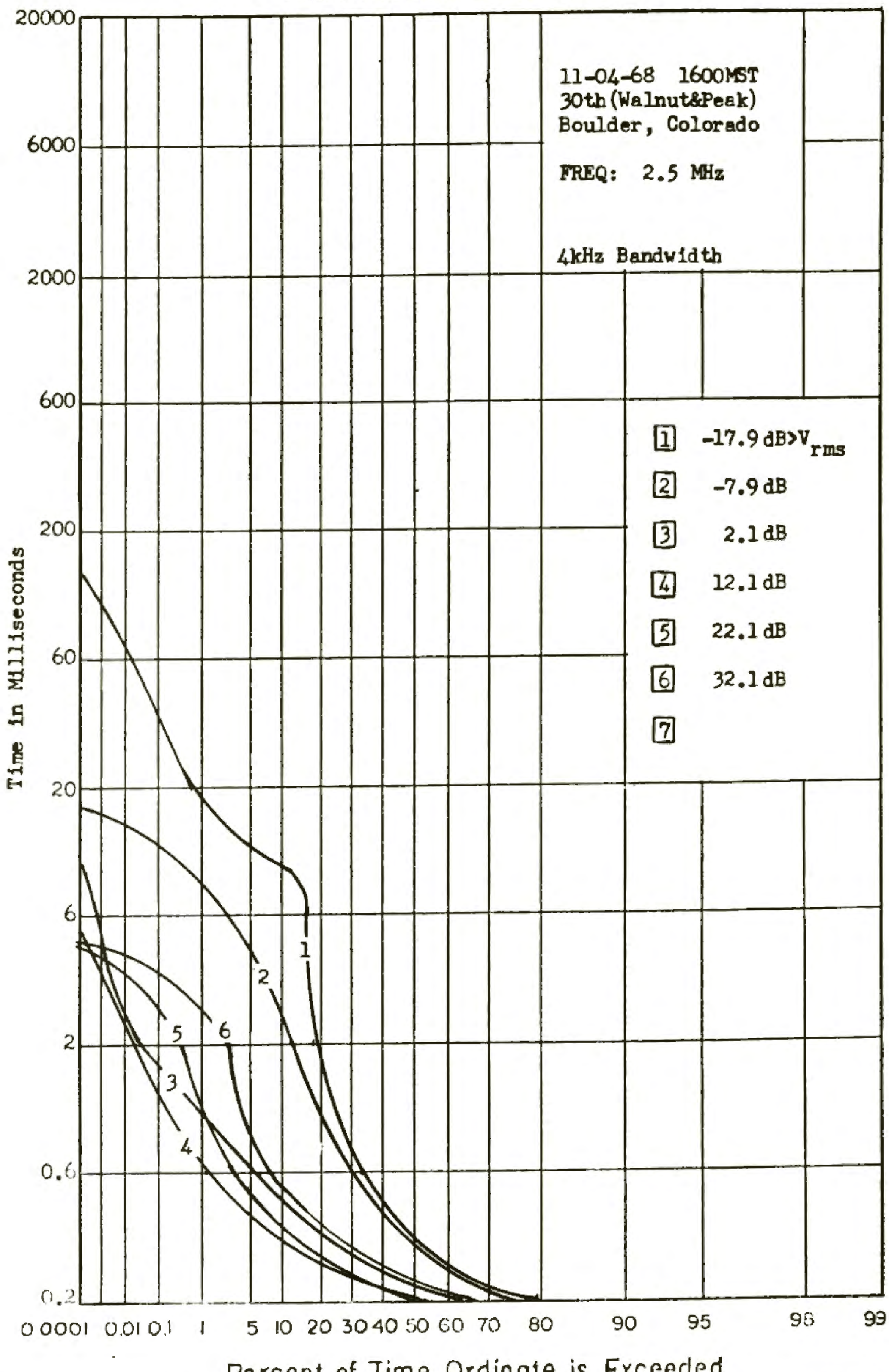


Figure 26. Pulse duration distributions for the sample of noise of figure 24

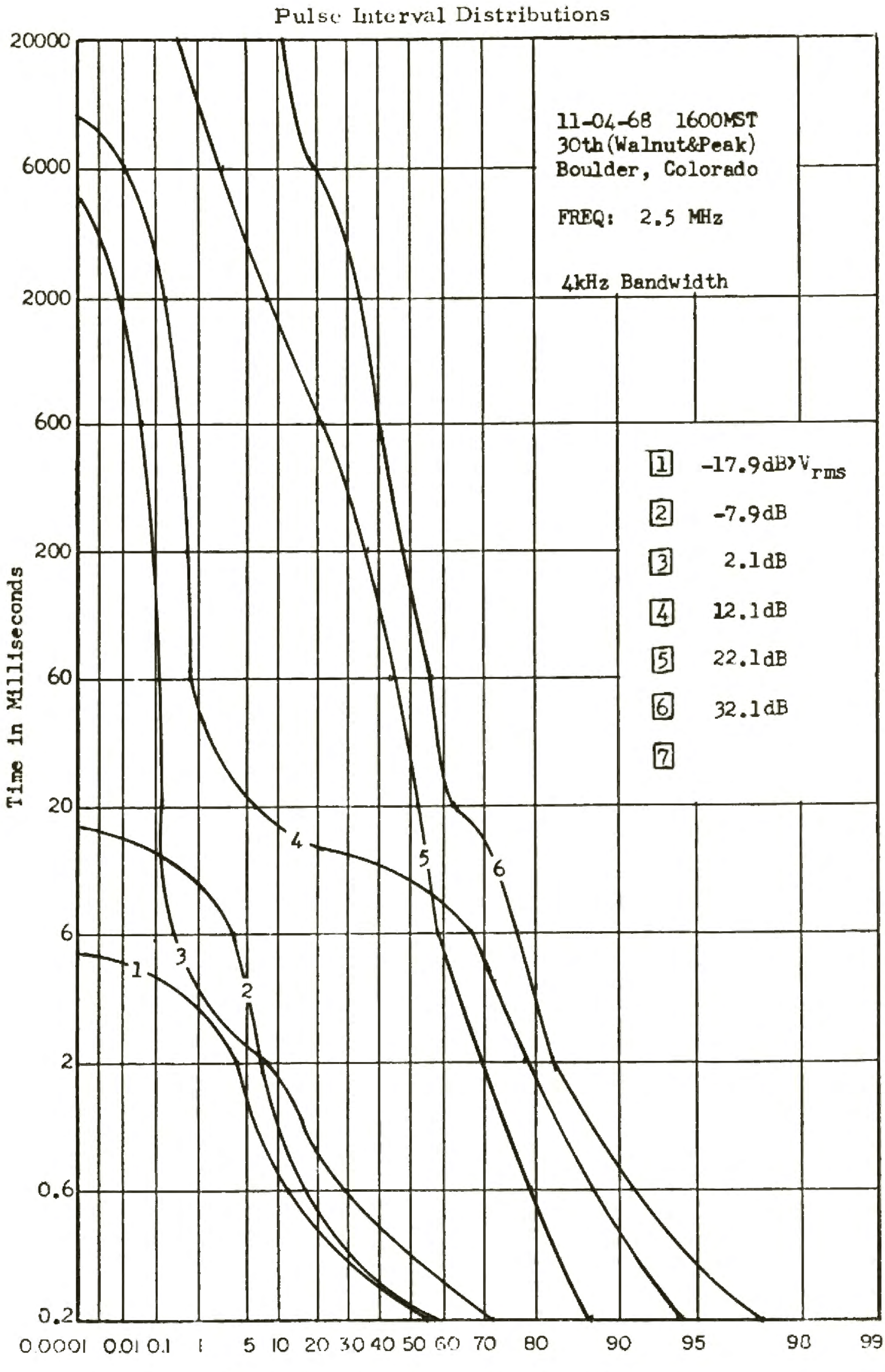


Figure 27. Pulse interval distributions for the sample of noise of figure 24

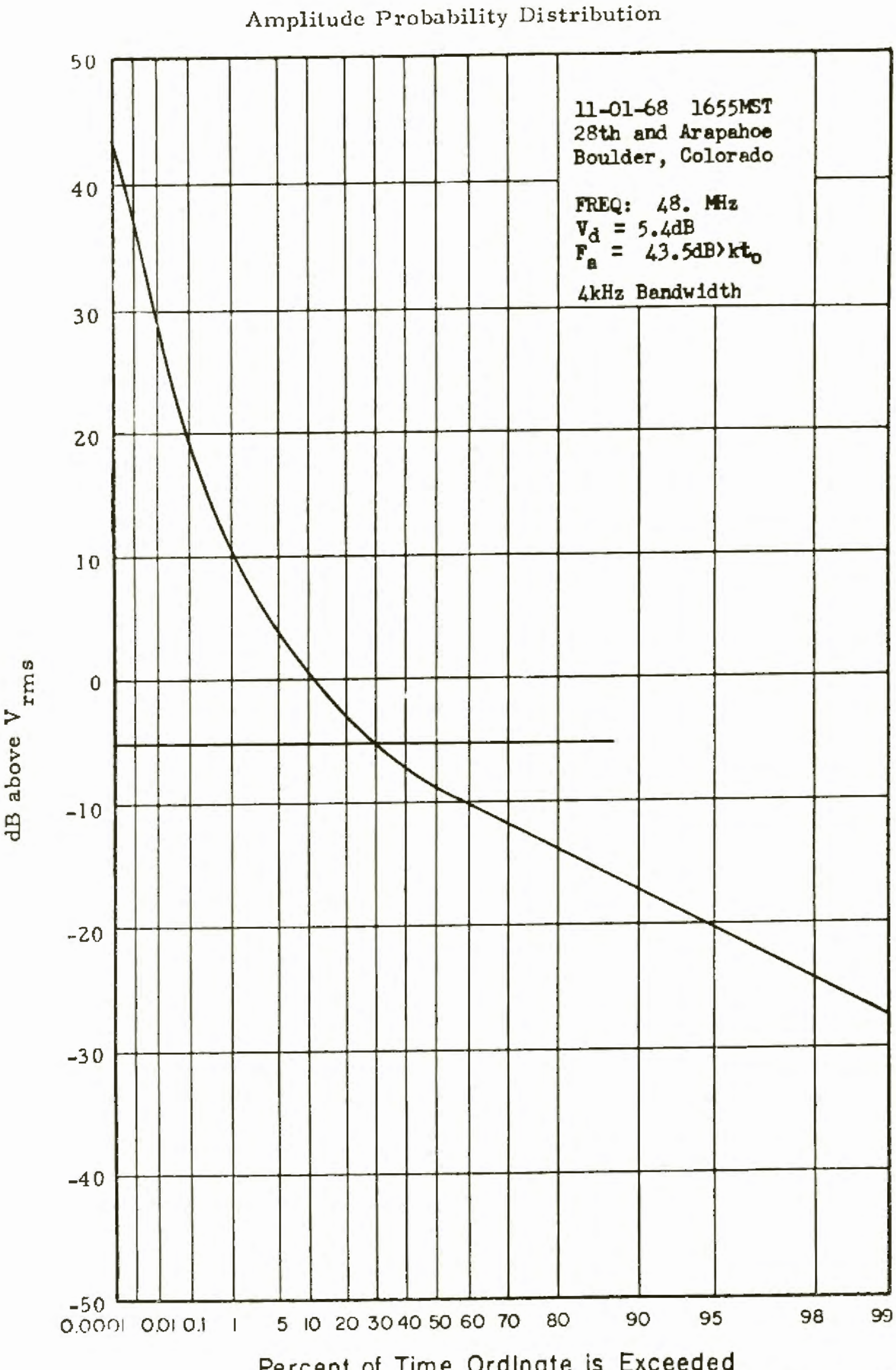


Figure 28. Amplitude probability distribution for a 5-minute sample of man-made noise recorded in Boulder, Colorado.

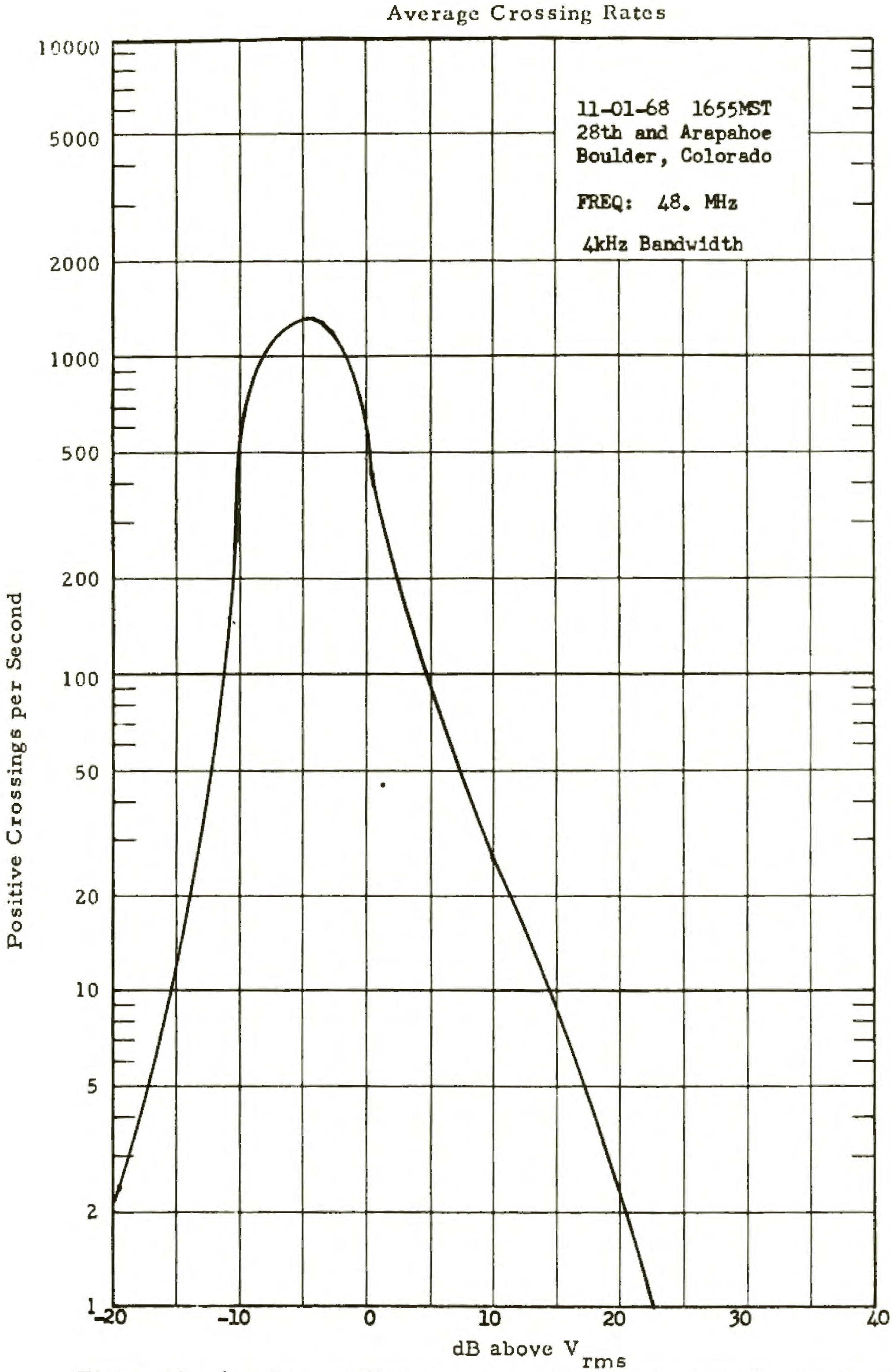


Figure 29. Average positive crossing rate characteristic for the sample of noise of figure 28

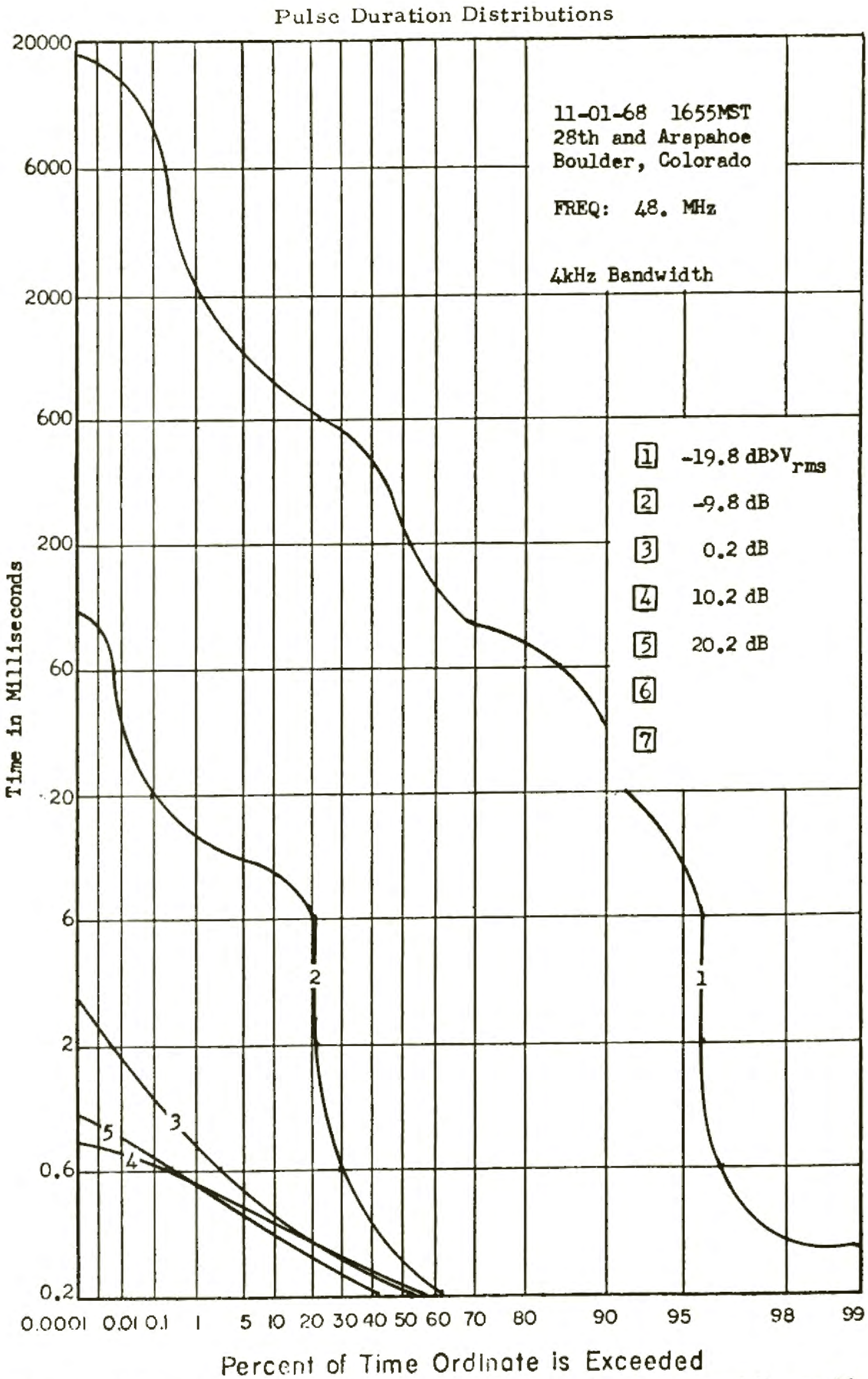


Figure 30. Pulse duration distributions for the sample of noise of figure 28

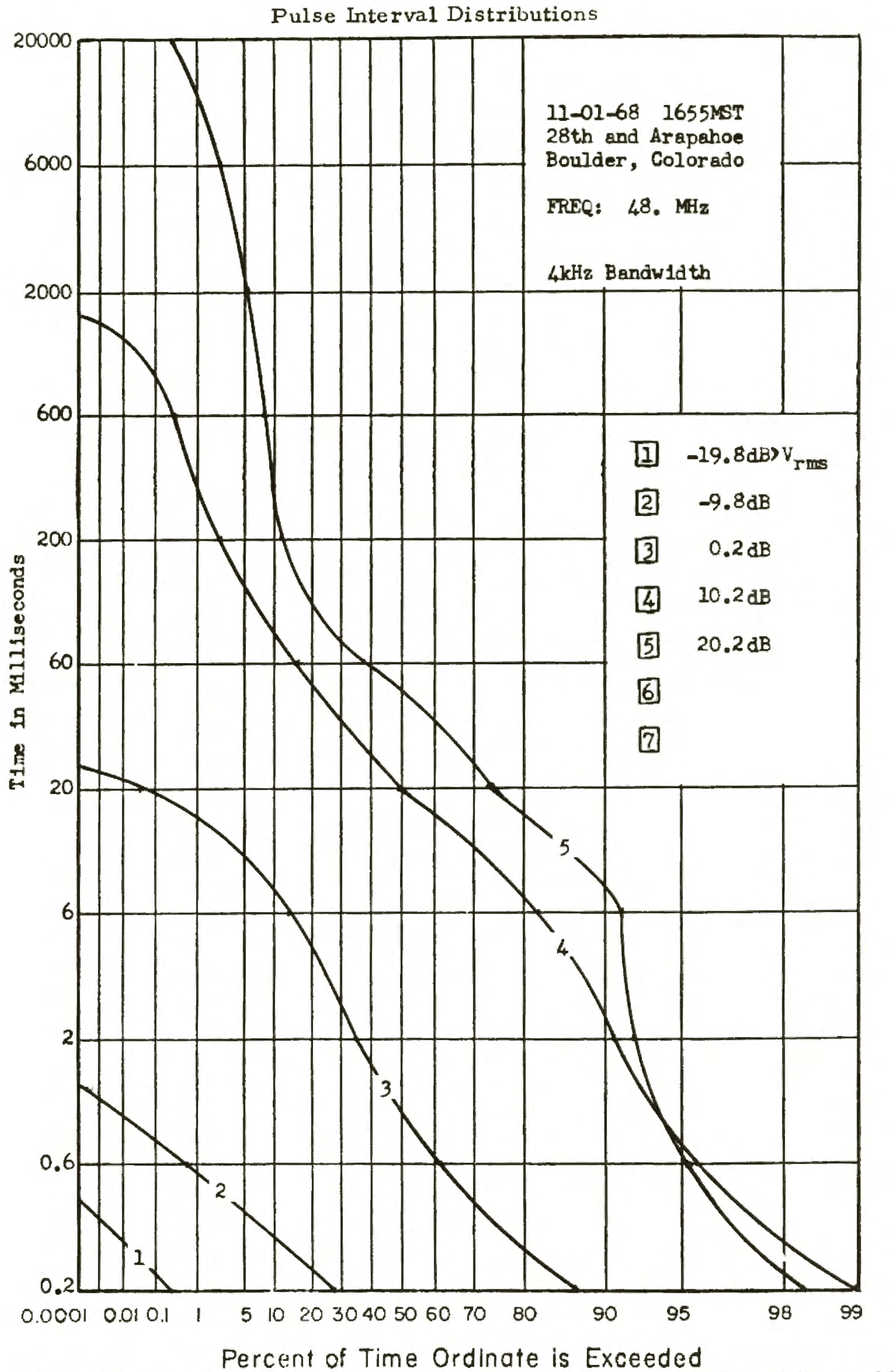


Figure 31. Pulse interval distributions for the sample of noise of figure 28

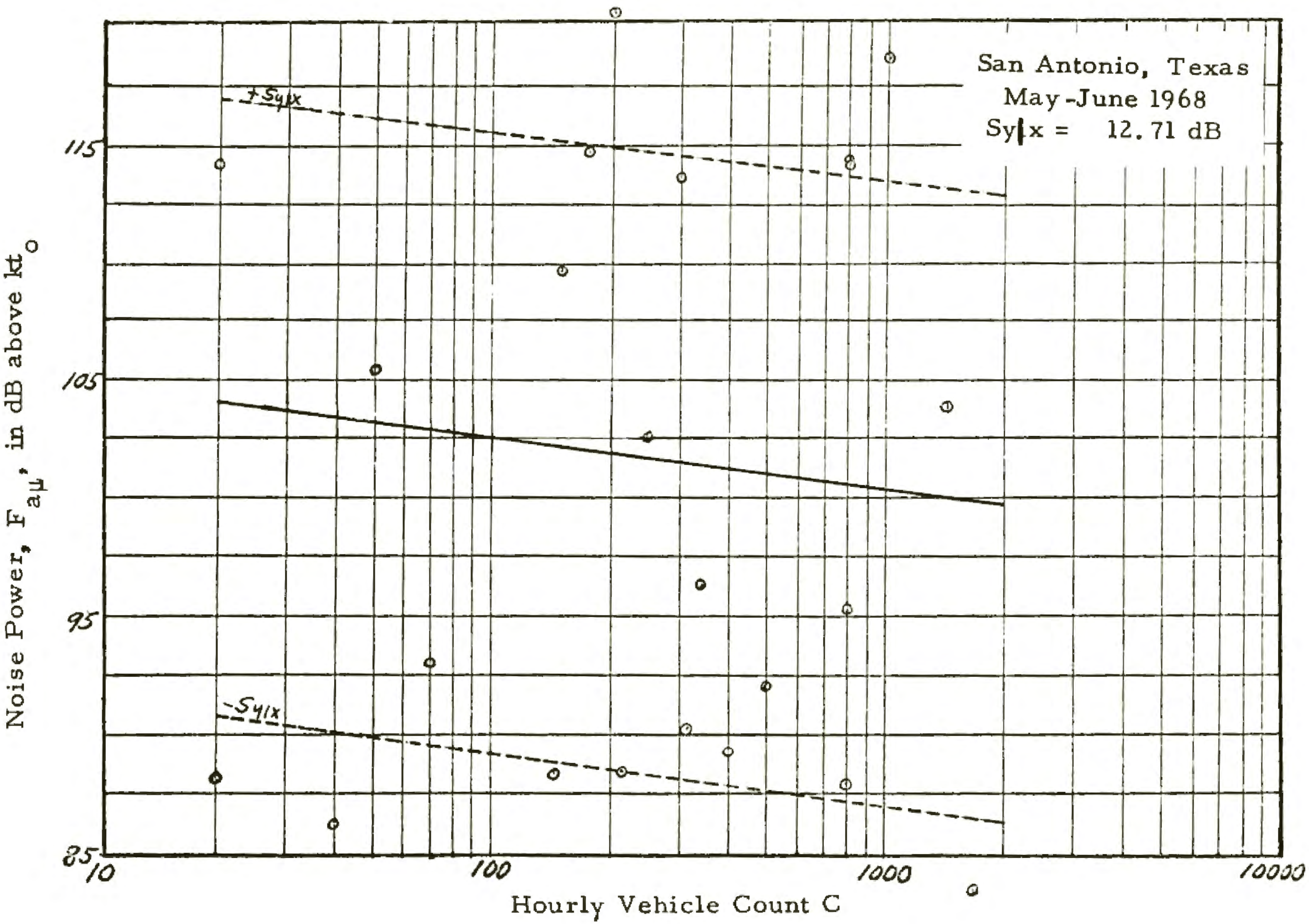


Figure 32. Linear regression of $F_{a\mu}$ versus log C at 500 kHz along 26 thoroughfares

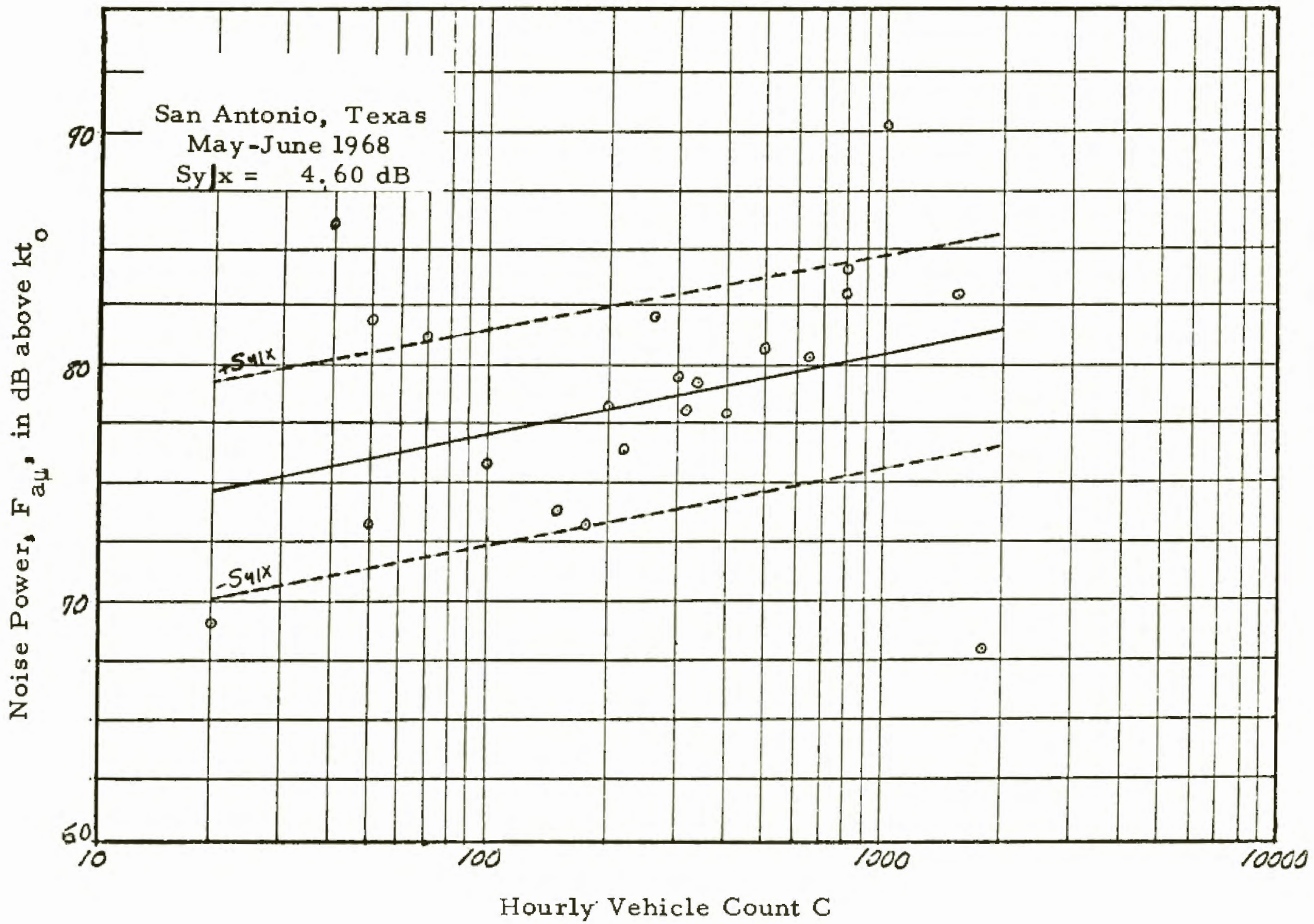


Figure 33. Linear regression of $F_{a\mu}$ versus log C at 2.5 MHz along 26 thoroughfares

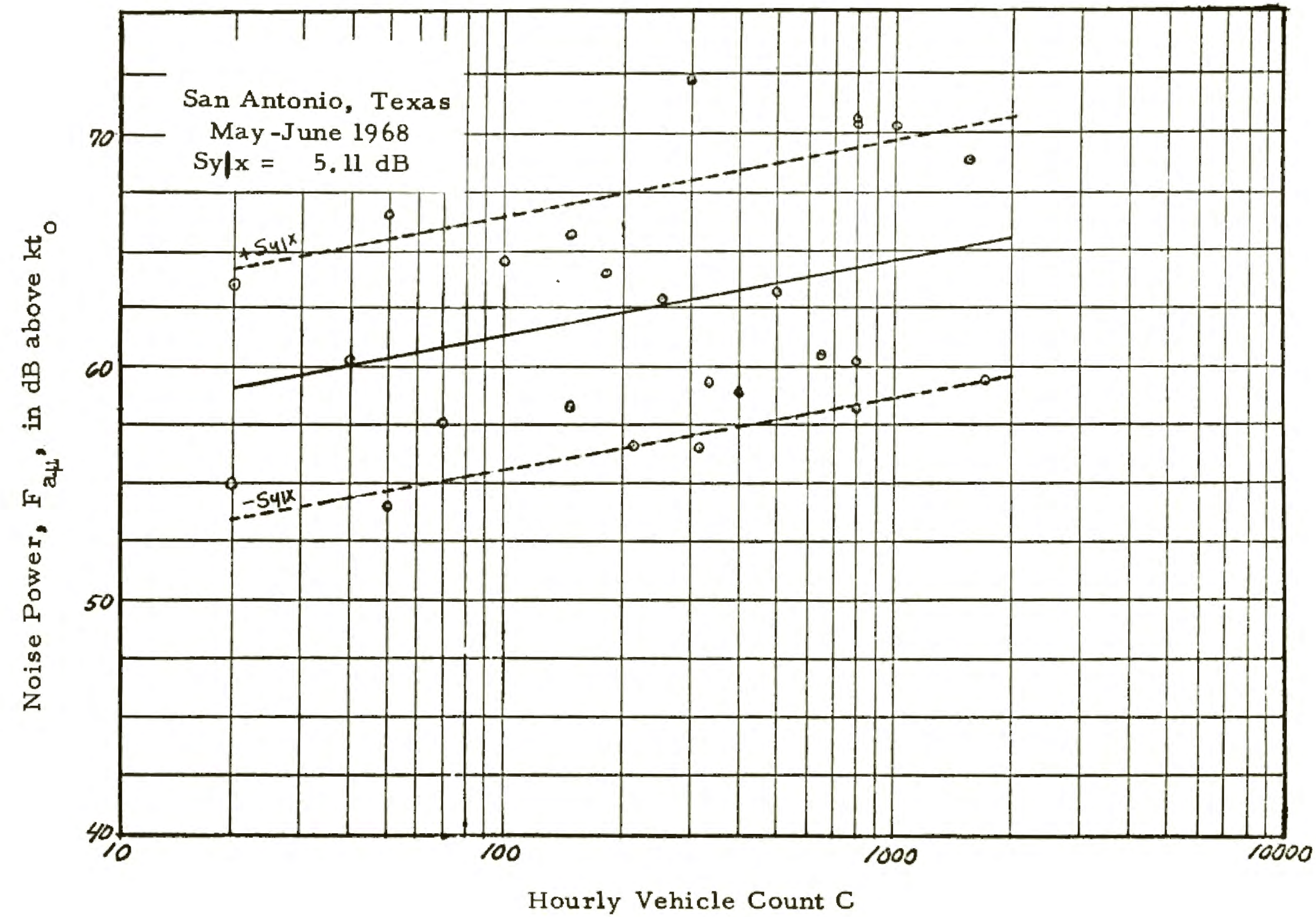


Figure 34. Linear regression of $F_{a\mu}$ versus log C at 5.0 MHz along 26 thoroughfares

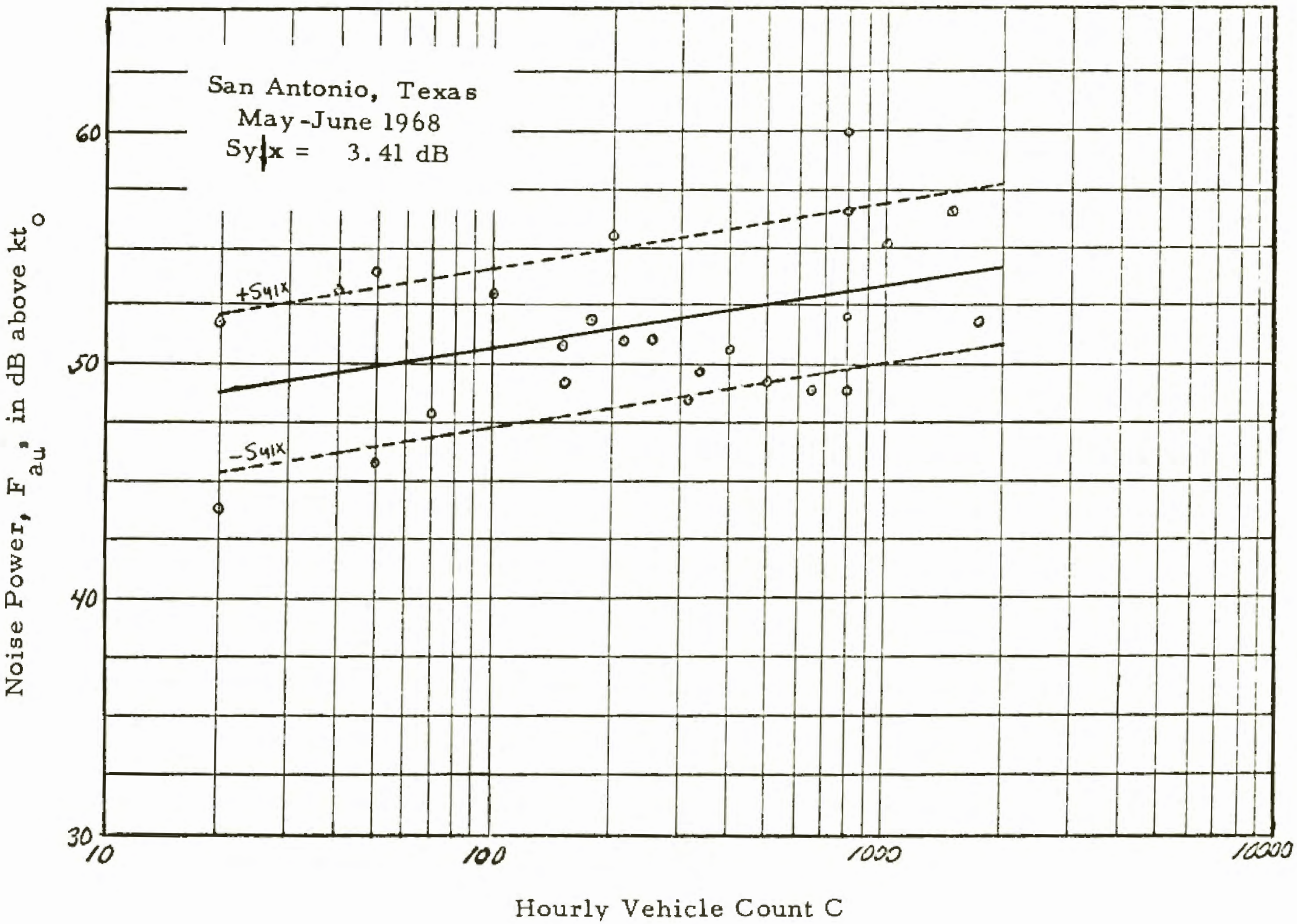


Figure 35. Linear regression of $F_{a\mu}$ versus log C at 10 MHz along 26 thoroughfares

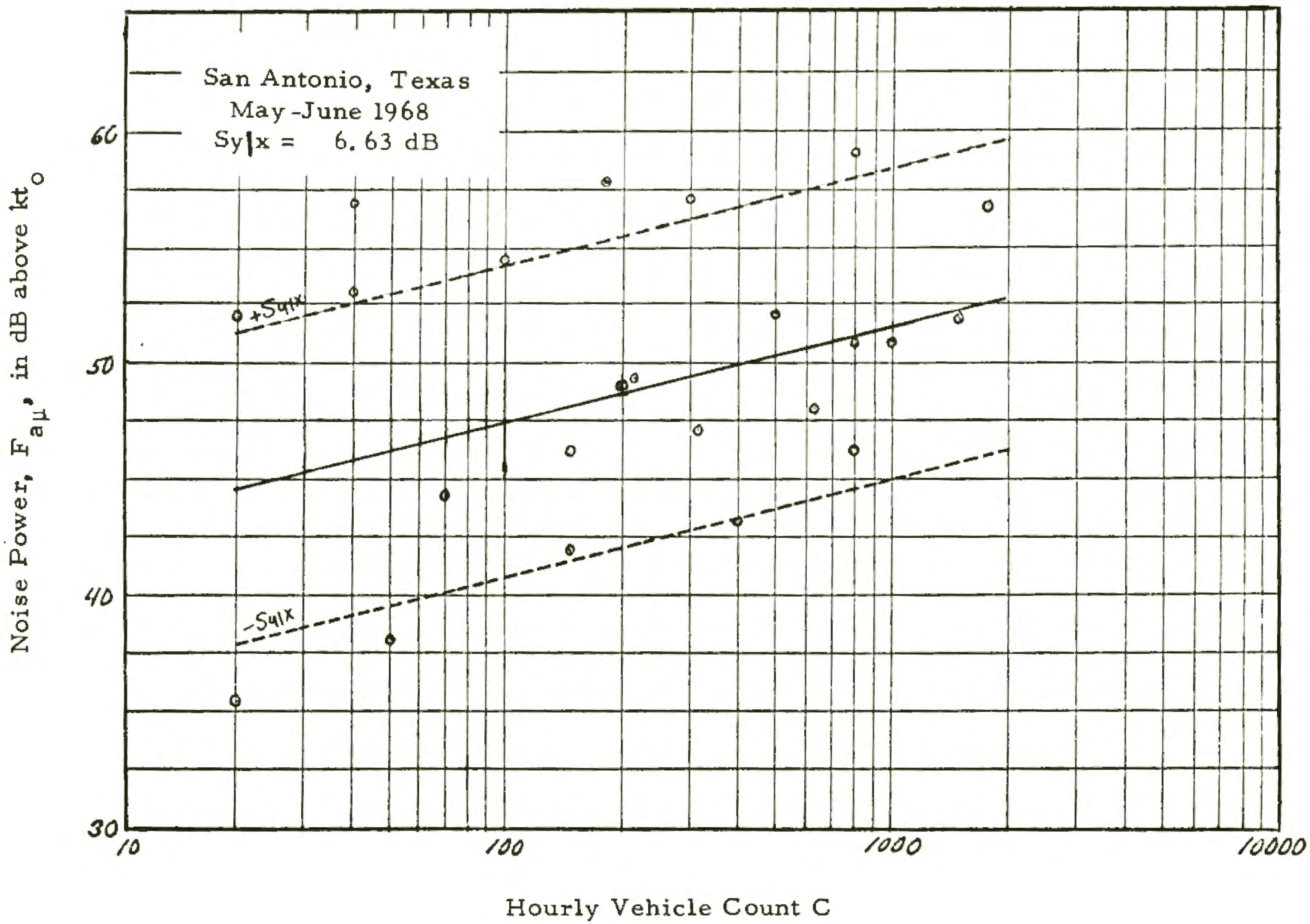


Figure 36. Linear regression of $F_{a\mu}$ versus log C at 20 MHz along 26 thoroughfares

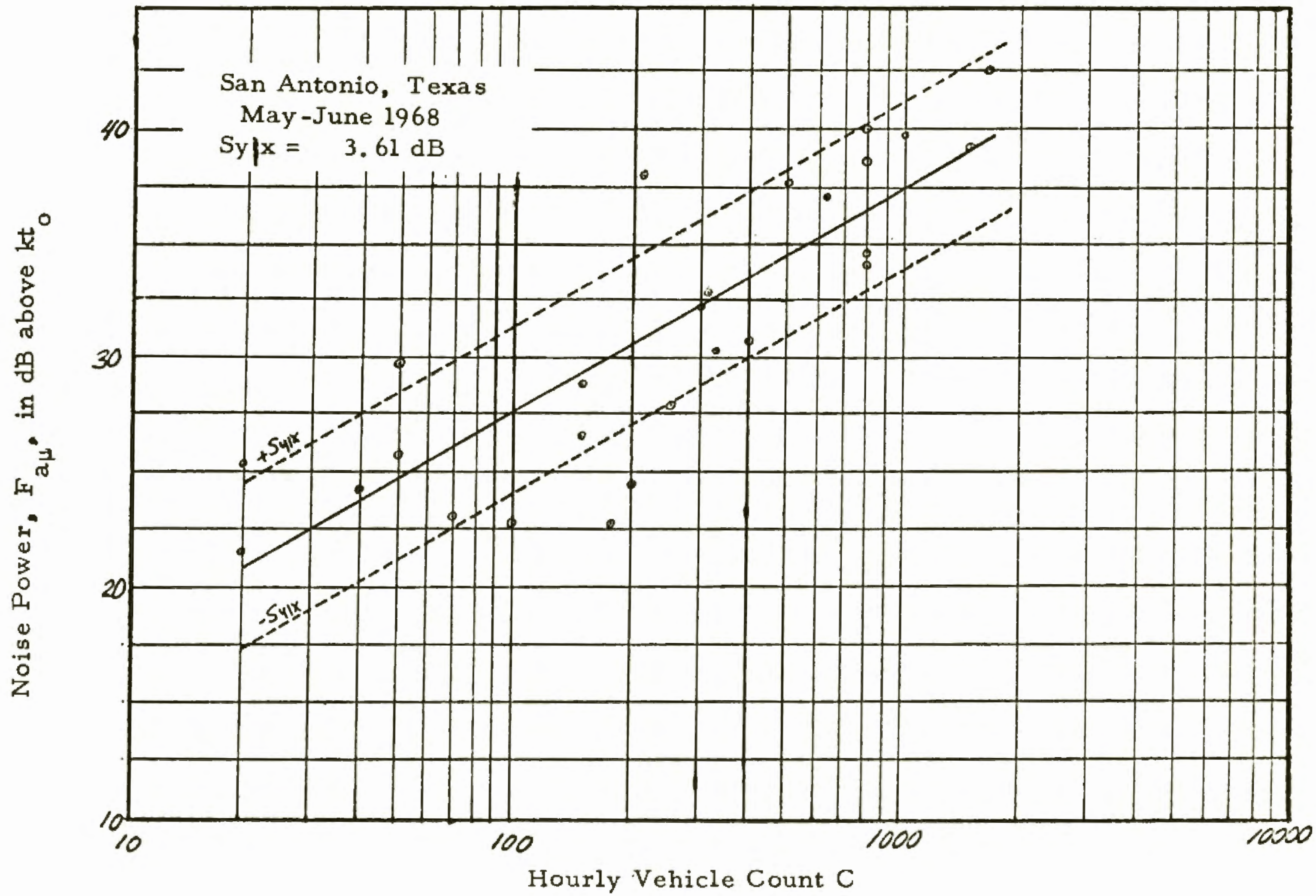


Figure 37. Linear regression of $F_{a\mu}$ versus log C at 48 MHz along 26 thoroughfares

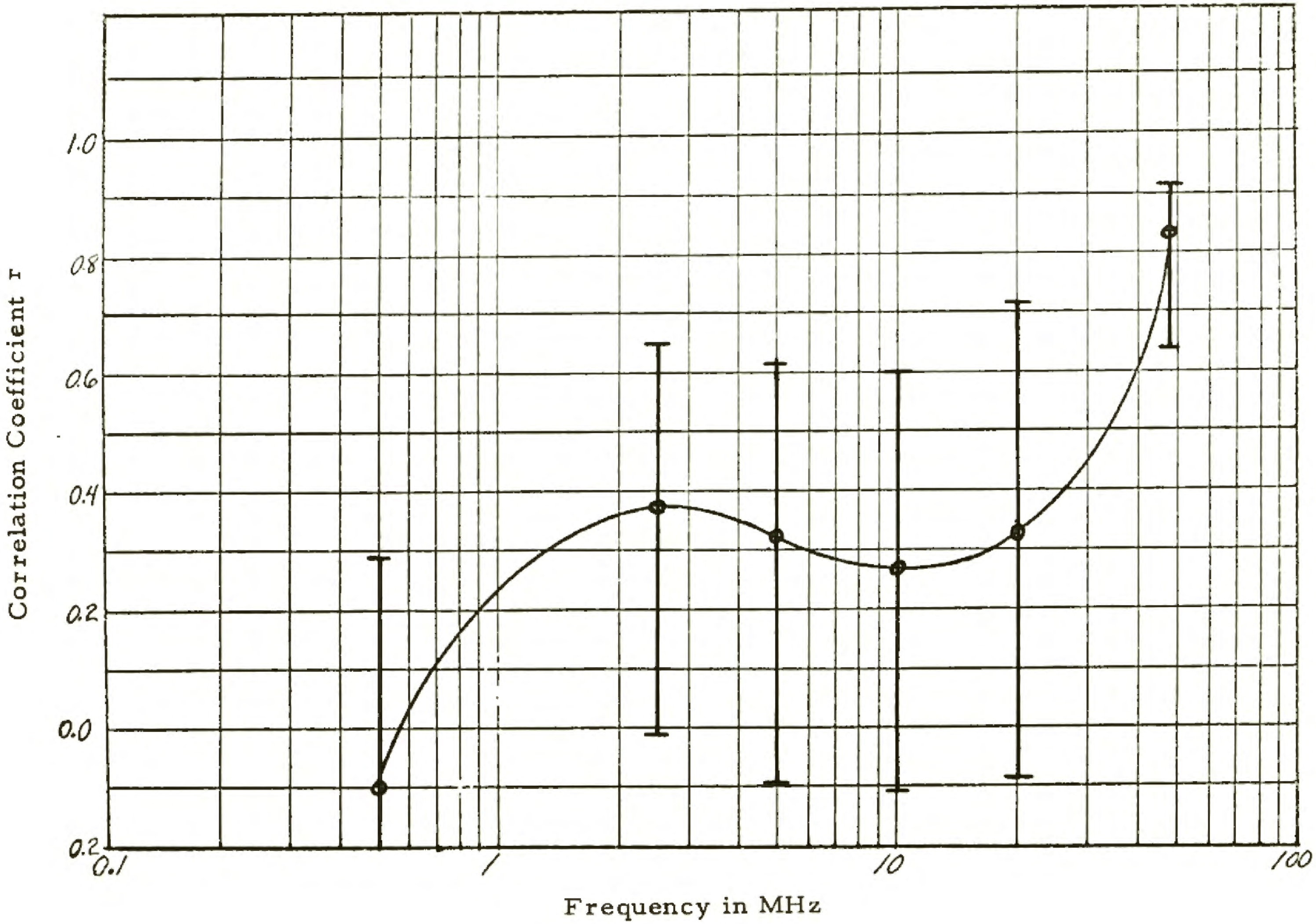


Figure 38. Correlation coefficient for each of the measurement frequencies, $F_{a\mu}$ versus log C, along with their 95% confidence limits.

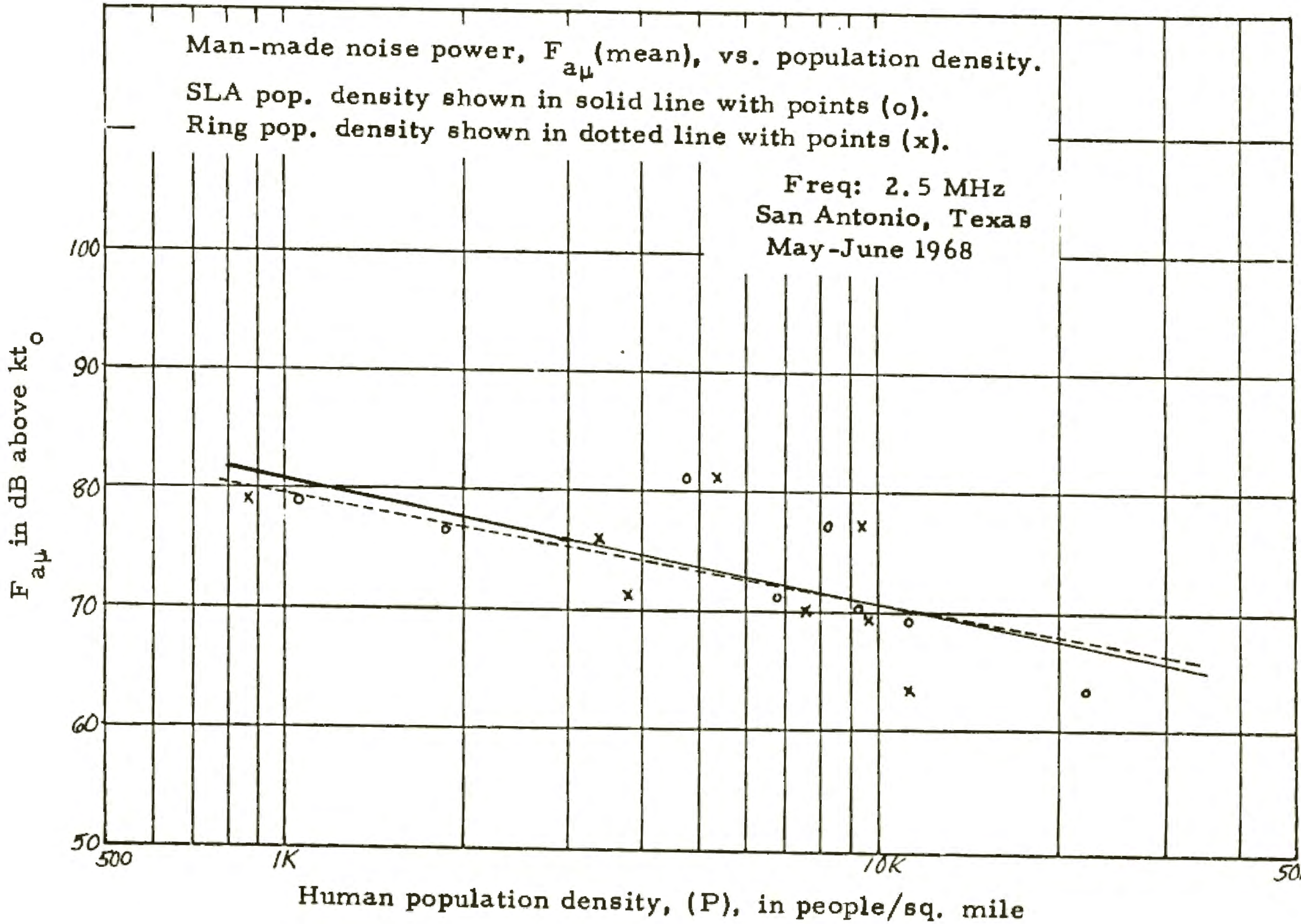


Figure 39. Regression of 2.5 MHz $F_{a\mu}$ with log population density of SLA and ring

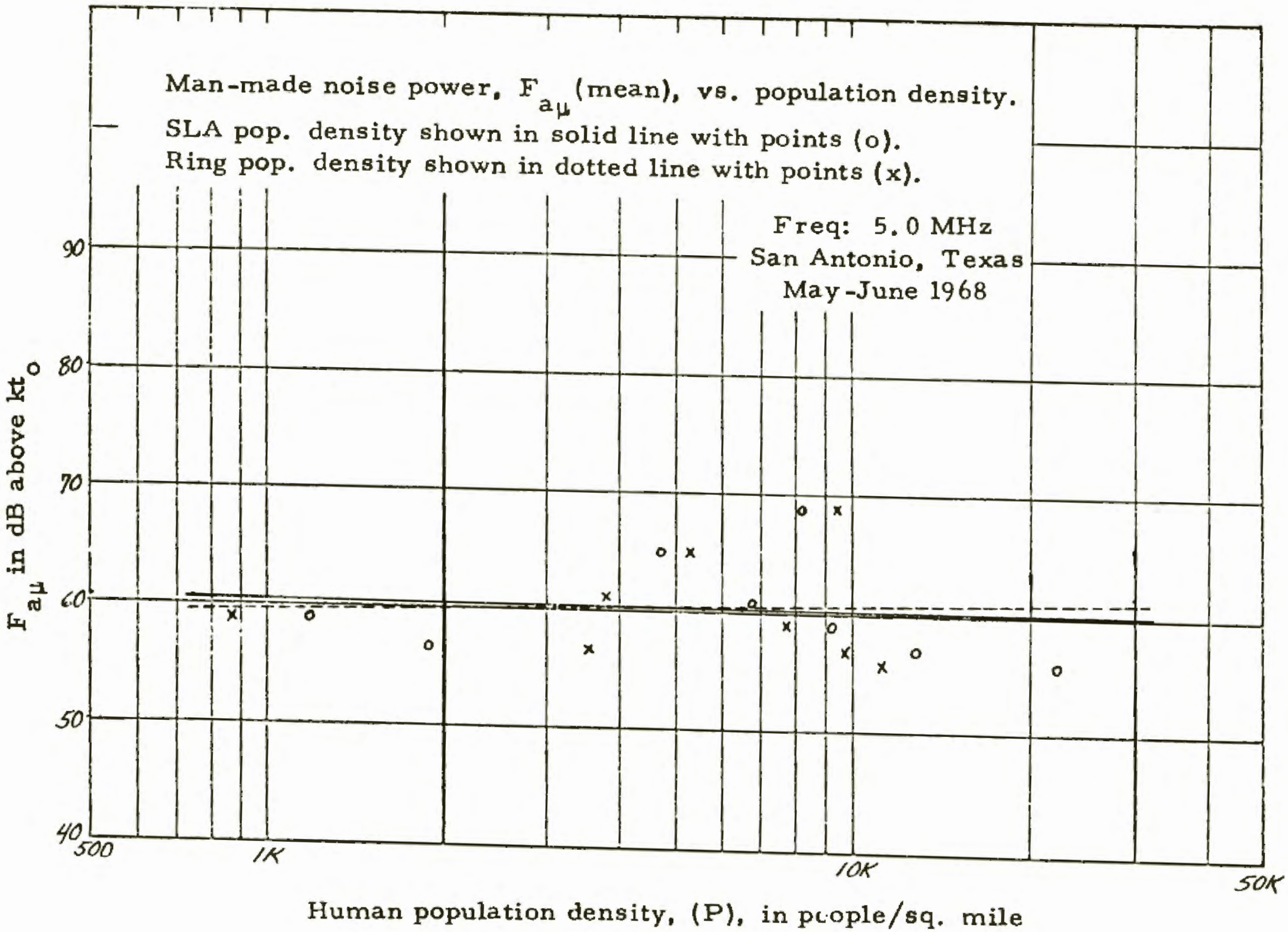


Figure 40. Regression of 5.0 MHz $F_{a\mu}$ with log population density of SLA and ring

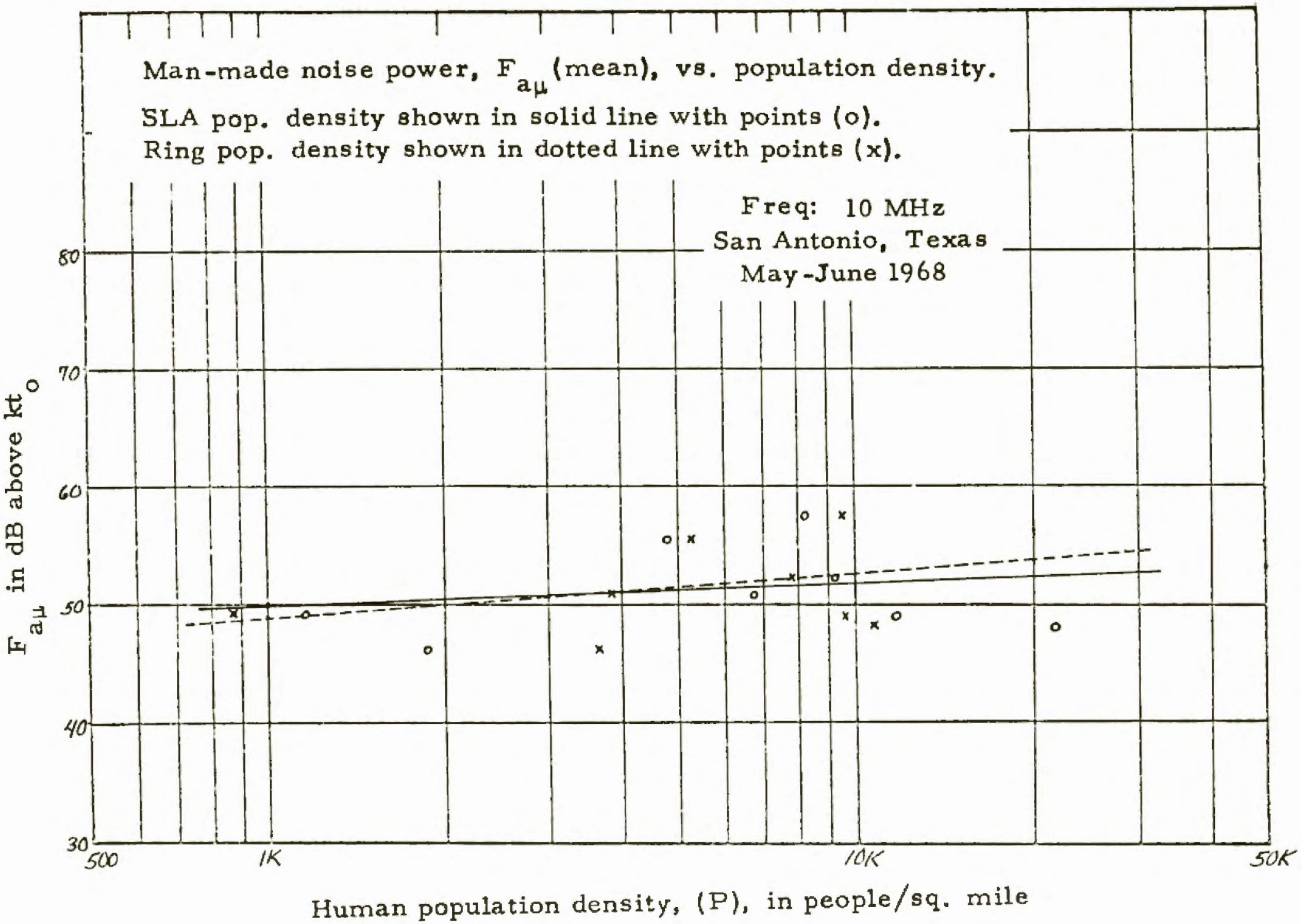


Figure 41. Regression of 10 MHz $F_{a\mu}$ with log population density of SLA and ring

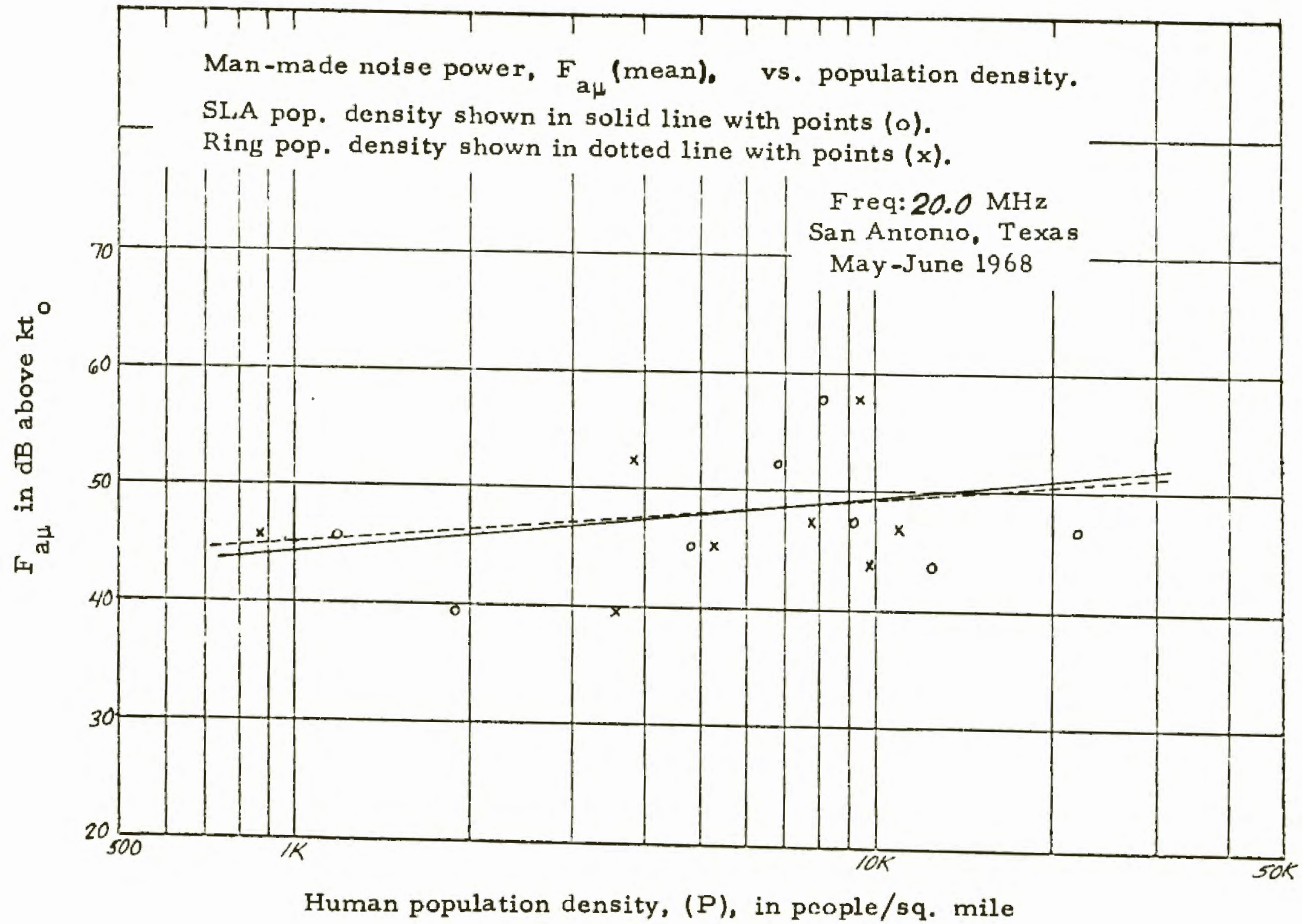


Figure 42. Regression of 20 MHz $F_{a\mu}$ with log population density of SLA and ring

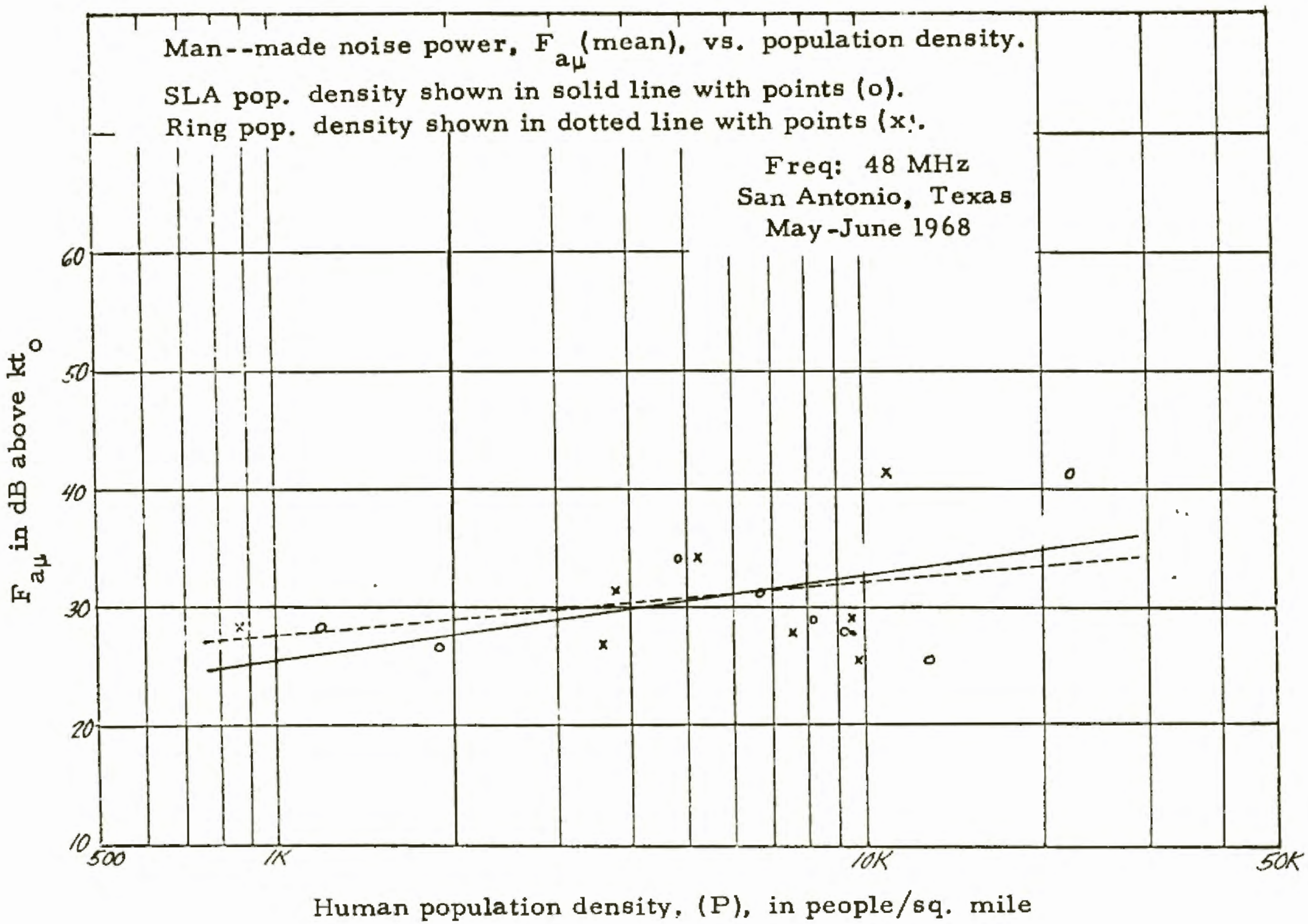


Figure 43. Regression of 48 MHz $F_{a\mu}$ with log population density of SLA and ring



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