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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

INTERNATIONAL CENTRE FOR SCIENCE AND HIGH TECHNOLOGY
c/o INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS 34100 TRIESTE (ITALY) VIA GRIGNANO, 9 (ADRIATICO PALACE) P.O. BOX 586 TELEPHONE 040-224572 TELEFAX 040-224575 TELEX 460449 APH I

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Man-made radio noise

A. D. Spaulding
Institute for Telecommunication Sciences
U.S. Department of Commerce
Boulder, Colorado

MAN-MADE RADIO NOISE

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1. INTRODUCTION

Electromagnetic noise can be defined as "all electromagnetic energy from both intentional and unintentional radiators, except the desired signal for a specific system of interest" (Hagn 1975, 1977a)[1,2] Such noise (a cause) should not be confused with interference (an effect), which is the degradation that the noise can cause to the performance of a telecommunications or an electronic system (CCIR, 1979).[3] Other terms used in the literature for man-made radio noise include: incidental noise, unintentionally generated radio noise, etc.

There is a large body of literature on man-made electromagnetic noise. The International Union of Radio Science (URSI) has produced summaries triennial review (e.g., Herman, 1971; Rivault, 1972; Hagn 1973,1975,1978),[4-7] and the International Special Committee on Interference (CISPR) has given considerable attention to the allowable radiation limits for specific sources of noise (Stumpers, 1970,1971,1973,1975).[8-12] The International Radio Consultative Committee (CCIR) has produced a report on environmental noise (CCIR, 1980).[13] The Joint Technical Advisory Committee of the Institute of Electrical and Electronics Engineers (IEEE) and the Electronics Industries Association (EIA) considered radio noise as it impacts on the use of the spectrum (JTAC, 1968).[14] Spaulding has discussed the problems associated with man-made noise and recommended steps for solutions in the U.S. (Spaulding, 1976).[15] Two recent books have been devoted almost entirely to man-made noise (Skomal, 1978; Herman, 1979).[16-17] These publications, and the references therein, when combined with a bibliography by Spaulding, Disney and Hubbard (1975),[18] cover the major work on man-made noise published through 1978.

The composite electromagnetic noise environment observed (or observable) by a given receiving system at a given time and location can arise from various categories of natural and man-made source (see Figures 1 and 2). This chapter will discuss the noise from man-made sources.

2. SOURCES OF MAN-MADE NOISES

The intended coherent radiation from intentional radiators produces the largest electromagnetic fields. The density of international radiators is highly correlated with population density (JTAC, 1968; Herman, 1979).[14,12] Janes, et al (1977, 1979),[19,20] have measured the integrated power density levels (including that of sub-bands) were log-normally distributed with a median of 0.03μW/cm^2. The FM band (88-108 MHz) had the largest median (1.3 x 10^{-2}μW/cm^2), the high VHF-TV band (174-216 MHz) was next highest (2.9 x 10^{-3}μW/cm^2), followed by the UHF-TV band (470-806 MHz) with 2.1 x 10^{-3}μW/cm^2, the low VHF TV band (54-88 MHz) with 1.7 x 10^{-3}μW/cm^2; whereas; the land mobile bands (150-182 MHz, and 450-470 MHz) were the lowest with 2.8 x 10^{-5}μW/cm^2. In addition to their desired emissions, such powerful transmitters can radiate broadband noise (Shepherd and Smith, 1958),[21] harmonics and other unintended radiation, and they can cause problems to nearly receivers such as desensitization and intermodulation products (Lustgarten, et al., 1975; CCIR, 1979).[22,23]

Unintentional man-made radiators also contribute to the composite electromagnetic environment. Table 1 summarizes some of the primary categories of such radiators. The level of radiation from these equipments and devices is typically much less than the levels from intentional radiators. Figure 3 is an example of the relative contributions to the composite noise environment at 155 MHz as observed with a scanning receiver with memory.[24] Notice the relative contributions of the land-mobile transmitter and the ignition noise. This 3-dimensional display of amplitude versus frequency and time is a useful way to observe the short-term variability and complexity of the environment (see also Vincent, 1977 and Herman, 1979 for numerous other examples of the 3-dimensional "signatures" of specific sources).[25,17] Let us now consider the sources that contribute to the ambient noise levels.

The list of potential incidental radiators (Table 1) which can cause interference is very great (see also Skomal, 1978, Herman, 1979). Frequently, the closest noise source to your receiving antenna will dominate the ambient while it is operating, but it is possible to identify specific sources which make major contributions to the noise background by noting complaints (e.g., Robertson, 1971)[25] or by correlating their characteristics with observed ambie levels. Since we are dealing with man-made noise, let us first consider the correlation of the composite man-made noise level with population density befo addressing its measured correlation with specific electromagnetic sources. Because of the attenuation of noise field strength with distance from the source, it seems reasonable that man-made noise levels should correlate, at least broadly, with population in urban areas (Skomal, 1978).[16] Allen (1960)[27] presented data relating quasi-peak field strength values measured at street level to urban population. He computed the probability of various levels being exceeded at 1 MHz as a percentage of locations in an urban area. This was done over a population range from 10^3 to 10^6 persons. Although Allen reported a gross correlation between population and noise levels, attempts to correlate average noise power levels with population density, as measured o a finer scale, in U.S. Census Bureau standard location areas (SLAs)--of 1 to 5 square miles--have not been successful (SPAULDING et al., 1971).[28] SPAULDING (1972)[29] investigated the relationship between population density and average noise power spectral density, F_a, in decibels above kT_o, in signal-free channe in the band 250 kHz to 48 MHz. In the population density range of 1,000 to 25,000 per square mile, in San Antonio, Texas, he found no significant correlation between the average population density of an SLA and the average values of noise level taken at several locations within the SLA (see Figure 4). Correlation on a finer scale (down to an individual city block) has not been attempted.

SPAULDING, et al. (1971),[28] DISNEY (1972),[30] SPAULDING (1972),[29] and SPAULDING and DISNEY (1974)[30] did find significant correlation between vehicular traffic density and average noise power spectral density (Figure 5), especially for frequencies above 20 MHz (Figure 6). Data taken later than those in Figure 6 indicate that the correlation remains high between 50 and 250 MHz. Therefore, it seems reasonable to conclude that vehicle ignition systems will be potentially important sources of interference to radio systems operating above 20 MHz, especially near roads. In rural areas remote from power lines and other sources, automobiles may be dominant noise sources below 20 MHz.

Overhead power lines are known to be an important source of man-made noise below 15 to 20 MHz. SPAULDING and DISNEY (1974)[31] reported relatively good correlation between electrical power consumption in an area and the root mean square (rms) value of the radio noise below 20 MHz. They noted, however, that information on local power consumption in the United States is difficult to obtain. Overhead lines also can be important above 15 MHz (WARBURTON, et al., 1969),[32] and the interference to television from power lines has been discussed (e.g., LOFTNESS, 1970; JUETTE, 1972 and March 19).[33-35] Let us now consider in more detail the technical characteristics of the noise from power lines and automobiles and some other specific sources.

Power lines operating on ac can be categorized by their function (power transmission or distribution), which determines their operating voltage and the mechanisms by which they produce radio noise under normal operating conditions. In general, the lower-voltage distribution and transmission lines (below about 70 kV) produce noise from various types of discharges in gaps, while the higher-voltage transmission lines (110 kV and higher) generate noise by various kinds of corona (PAKALA, et al., 1968).[36] The high rate of current

rise transforms to a broader spectrum for gap noise than for corona noise, as observed with peak detectors (PAKALA and CHARTIER, 1971)[37] and with quasi-peak detectors (see Figure 7). The low-voltage lines may also radiate noise resulting from switching transients and other effects from devices connected to the lines.

High-voltage dc transmission lines are coming into use (KAUFERLE, 1972).[38] ANNESTRAND (1972)[39] points out that noise is generated at the converter stations, which then propagates on the lines. Vincent (1980)[40] has been studying this noise, and he has observed that corona from the measurement antenna can be a problem (see Figure 8). This only adds to the problems regarding noise measurements already noted by Hubbard (1972).[41]

The noise from power lines is greatly influenced by the weather (and the state of maintenance of the line. Fair-weather noise levels measured by using peak and quasi-peak detectors have been reported in the literature of the IEEE Power Engineering Society.

Indeed, most of the measurements of power-line noise reported in the literature have been made by using quasi-peak detectors, although some data on power-line noise measured with peak and average detectors are available (THOMPSON, W. I., III, 1971). Measurements made with an rms detector are not generally available in the literature (Hagn and Shepherd, 1977),[42] but some data of this type were given by DISNEY and LONGLEY (1973)[43] and SPAULDING and DISNEY (1974).[31] Figure 9 presents median values of average noise power spectral density data obtained in the near field by several investigators at MF, HF, and VHF with rms detectors. Vertical monopole antennas were used; the antennas were positioned directly under the line, with the exception of the 15-kV/16.67-Hz line. One of the most interesting observations is that the 115-kV lines were noiser than the lines with higher or lower operating voltage. The absolute calibration is only approximate, however the relative calibration is ±3dB At any given frequency, the difference between measured medians for the noisiest and the quietest line was about 30 dB. PAKALA and CHARTIER (1971)[37] stated that noise increases of 17 dB were likely during rain. They observed that, in 60 percent of their measurements, those made with horizontally polarized dipoles produced greater noise than those made with vertically polarized dipoles. The differences ranged from 0 to 10 dB over the frequency band 15 kHz to 10 GHz. The IEEE (1965)[45] indicated increases of 15 to 25 dB during foul weather and also (1971)[46] indicated increases of 20 dB during bad weather. Data on radio interference (RI) levels taken on a Bonneville Power Administration 345-kV line between May 1965 and May 1966 (Figure 10) show an average RI level during rain of approximately 20 dB above that shown during clear weather, while during snow the average level was nearly 26 dB higher than the clear-weather level (BAILEY and BELSHER, 1968).[47] FORREST (1969)[48] pointed out that "defect" noise on lower-voltage (11- to 66-kV) lines, caused by sparks and microsparks, tended to determine the fair-weather RI levels above 10 MHz. He noted that wet weather could cause RI increases of 5 to 15 dB in the band 100 kHz to 10 MHz, due to corona, while causing RI levels above 10 MHz to decrease, due to the shorting out of arcing gaps. Lauber (1976)[49] and Lauber and Bertrand (1979)[50] have reported on power line APDs (see also Shepherd and Hagn, 1976).[51] The IEEE (1980)[52] has just completed an excellent summary of the technical aspects of power line noise pertinent to establishing limits on this important noise source.

Ignition noise is generally found wherever automobiles or other vehicles using spark-initiated power systems (e.g., trucks, boats, aircraft, and snowmobiles) are used. The sources of ignition noise include the distributor, spark plugs, generator. Typically, in a given band, one of these is the dominant source. This noise is highly impulsive and spreads over much of the frequency spectrum. At the low end of the spectrum (below about 20 MHz), ignition noise is generally believed to be exceeded by power-line noise when both sources are present. The actual lower limit will, of course, be determined by specific situations, including the density of automobile traffic and the proximity of power lines. The high frequency limit to the automobile ignition noise spectrum has not been as well studied. Generally, instrumentation capability or investigator interest tapers off before the establishment of a clear upper limit. Increased traffic intensity associated with the rush hour commonly produces noise spikes 30 to 40 dB above the receiver noise in a 100-kHz bandwidth at 1.2 and 2.9 GHz for a 30dB noise figure receiver (spectrum analyzer).

The APDs of three vehicles measured in an 8 kHz bandwidth (Shepherd, 1974),[53] are shown in Figure 11 and single-vehicle APDs (averaged over 4 vehicles) are shown in Figure 12 (Schulz, et al., 1973-1974).[54,55] Note the change in the shape of the APD in Figure 11 as a function of engine speed. Shepherd, et al. (1975) have also surveyed a vehicle population using a spectrum analyzer (peak detector) to measure impulse field strength (see Figure 13). This survey was extended at 50 MHz and 153 MHz to include over 10,000 vehicles in the U.S. (Shepherd, et al., 1977).[57] Figure 14 shows the distribution of noise levels observed at 10m using the procedures of the Society of Automotive Engineers (SAE)[58] as applied to passing vehicles. Figures 15 and 16 show similar distributions versus vehicle type and country of origin (for non-US vehicles) respectively. Other sources of noise have also been studied (e.g., Vincent and Ellison, 1974),[59] but they will not be discussed further here (see references 16, 17 and 44.)

3. EXAMPLE MEASURES OF MAN-MADE NOISE

Due to the variability of man-made noise it is necessary to treat it statistically. The noise envelope statistics discussed in Chapter 6 are equally applicable to describing atmospheric and man-made noise. These statistics include the rms voltage, the average voltage (and the dB difference between rms and average, V_d) and the various distributions (e.g., APD). The quasi-peak voltage, measured by passing noise envelope waveform through a circuit with a very short charging time and a long discharge time and averaging the output, has been used by CISPR workers and others. For power line noise the gp meter typically reads about 10-15 dB higher than an rms meter (Lauber, 1980). Under certain circumstances the relationship between quasi-peak and rms values of a given envelope can be computed for random noise (Cook, 1979),[60] but in the general case no analytical relationship exists. Another measure used in the peak voltage (for the period, T).

Examples of the APD, ACR, PDD and PSD (see Chapter 6 for definitions) for the magnetic field strength of man-made noise in a coal mine are given in Figures 17-20 (Kanda, 1974, 1975)[61,62] for comparison with Figures 10-13 in Chapter 6.

As previously mentioned, the 3-dimensional display of amplitude versus frequency and time is most descriptive of the details of the noise variation. The scanning receiver approach used by Vincent (1977)[25] and the Fourier transform approach of Bensema (1977)[63] are both most useful.

4. EMPIRICAL PREDICTIONS OF THE COMPOSITE NOISE ENVIRONMENT FROM INCIDENTAL RADIATORS

Spaulding and Disney (1974)[31] have discussed two methods of predicting man-made radio noise average power levels. One method is based directly on past measurements in specified environments; the other depends on the correlation of past noise measurements with some predictable parameter(s) of the environment (e.g., traffic density for frequencies above 20 MHz). Skomal (1978)[16] has developed empirical formulas for noise level versus frequency and distance from the center of a metropolitan area measured along or above the earth's surface. Vincent (1980)[64] observed "hot spots" and "cold spots" in the Los Angeles area at 100 kHz and observed that noise levels in the downtown area (with mostly underground power lines) were lower than in the surrounding area--in contrast to Skomal's model which predicts contours of levels decreasing with distance from the city's center. In some cities it is difficult to specify a central reference location in order to use Skomal's model at the shorter distances.

Let us consider now Spaulding and Disney's first prediction method which assumes that the behavior patterns noted at "typical" locations will be the same at similar locations in the future. Analysis of the available data base for each category of location will then provide the estimates of the man-made radio noise conditions to be found in future locations in the same category. The user must determine the category that best describes the location for which he desires to predict the noise level, and he must make modifications if he uses a different antenna or detector.

Spaulding and Disney (1974)[31] used the same measurement system with an rms detector to obtain data in the band 250 kHz to 250 MHz with a short vertical antenna near ground at various sites in the U.S. Over 300 hours of data were

obtained simultaneously on ten frequencies over the period from 1966 through 1971 in six states and in the District of Columbia. Three environmental categories were defined: rural, residential, and business. Rural areas were defined as locations where land usage is primarily for agricultural or similar pursuits, and dwellings are no more than one every five acres. Residential areas (urban or suburban) were defined as any area used predominantly for single or multiple family dwellings with a density of at least two single family units per acre and no large or busy highways. A business area was defined as any area where the predominant usage throughout the area is for any type of business (e.g., stores and offices, industrial parks, large shopping centers, main streets or highways lined with various business enterprises, etc.

These results were analyzed statistically, and the least-squares fit for F_{am}, the median values of F_a, for each environmental category is reproduced as Figure 21. The slope with frequency was found to be -27.7 dB/decade for each environmental category (at the 95% confidence level). The equations for F_{am} in dB(kT_o) for each category are: rural, $F_{am} = -27.7 \log_{10} f_{MHz} + 67.2$; residential, $F_{am} = -27.7 \log_{10} f_{MHz} + 72.5$; business, $F_{am} = -27.7 \log_{10} f_{MHz} + 76.8$. The other man-made noise prediction shown is for a quiet rural location (CCIR, 1964):[65] $F_{am} = -28.6 \log_{10} f_{MHz} + 53.6$. These quiet rural predictions are typical of the lowest levels at sites chosen to ensure a minimum amount of man-made noise. Data are also given for urban parks and college campuses: $F_{am} = -27.7 \log_{10} f_{MHz} + 69.3$. For comparison, the curve for galactic noise is $F_{am} = -23.0 \log_{10} f_{MHz} + 52.0$. These results have been adopted by the International Radio Consultative Committee (CCIR, 1980)[13] as the best available estimates.

These man-made noise data are daytime values. At night these 20-50 MHz levels can drop 5-10 dB to a minimum around 0400 hours, and at 100 MHz and 250 MHz they can drop 3-5 dB. At the lower frequencies in the HF band the night levels are frequently controlled by atmospheric noise from lightining, and the man-made levels cannot be observed (see Figure 21). The dirunal variation decreases for the MF band and is again only 3-5 dB at 0.25 MHz, with values at night being slightly higher than during the day.

Let us now consider the variability about these median values due to location within a given generic environmental category and with time while at a given location.

An example distribution of local median values of man-made noise at 20 MHz in residential areas is given as Figure 22. The value σ_T is the standard deviation of all measured medians about the regression line for F_{am} versus frequency (5.0 dB for residential areas and 6.5 dB and 7.0 dB for rural and business areas, respectively). σ_{NL} is the standard deviation for location variability at each of the measurement frequencies. Values for σ_{NL} are given in Table 1 for each frequency and environmental category.

Figure 23 gives the distribution of F_a values obtained on 20 MHz during an hour (0839-0939 hours local time) in a residential area in Boulder, Colorado. The median and the upper and lower deciles are indicated. The time variability for the different environmental categories has been estimated by Spaulding and Disney (1974)[31] for each of the ten measurement frequencies in terms of the upper and lower deciles, D_u and D_ℓ (in dB, relative to the median). These values, summarized in Table 1, are the root-mean-squares of all the location values for each frequency and environmental category. Let us now consider the models derived from this empirical data base.

Hagn and Sailors (1979)[66] presented four models for the probability distribution of the short-term ($\hat{\approx}$1 minute) mean values of man-made radio noise available power levels based upon the data of Spaulding and Disney (1974):[31] a model based upon a single Gaussian distribution (simple Gaussian), a slightly more complicated model based upon two Gaussian distributions (compound Gaussian), a more complex model based upon the Chi-square distribution, and a Gaussian model with the parameters estimated using the Chi-square results. These models assume that the mean value is given by the F_{am} expressions for the appropriate environmental categories. Approximate expressions for the standard deviations are given in Table 2 (see Figure 24 for an example at 20 MHz of a comparison with data). When the skew is negligible and the distribution between the deciles is required, the simple Gaussian model (or the Gaussian derived from the Chi-square) is often adequate; whereas the two-part Gaussian model or the Chi-square model is needed when there is significant skew. These model distributions should not be confused with the amplitude probability distribution (APD) of the envelope of the noise waveform at the output of the predetection filter of a communication receiver.

5. ANALYTICAL MODELS OF THE COMPOSITE ELECTROMAGNETIC NOISE ENVIRONMENT

Spaulding (Chapter 6) has reviewed noise models for the envelope statistics of atmospheric noise, and Skomal (1978)[16] has summarized the theory of envelope statistics of man-made radio noise developed by Middleton (1972, 1973, 1977 1979, 1980).[67-71]

A truly comprehensive statistical-physical model of the composite electromagnetic environment has been developed by Middleton (1977, 1979). Analytical first-order probability densities and distributions, as observed at the output of the initial (linear) stages of typical narrow-band receivers (of bandwidth Δf_R), are obtained for three basic classes of electromagnetic noise. These are, respectively: (i), Class A noise, characterized by input bandwidths Δf_N less than Δf_R; (ii), Class B noise, where Δf_N is larger than Δf_R; and (iii), Class C noise, which is a linear combination of Class A and Class B components. These models combine statistical and physical structures: the noise sources are assumed to be independently, randomly distributed in space and emit arbitrary waveforms randomly in time, so that the basic statistics are Poisson. The emitted waveforms obey appropriate propagation laws (e.g., the wave equations) and explicitly include the effects of source and receiver antenna patterns, relative doppler effects, source distributions in space, and other geometrical factors. The results are highly nongaussian, as would be expected, but they are analytically tractable and canonical (i.e., the form of the probability structures are essentially invariant of the waveform and of kinematic and geometric details). This is strongly true of Class A noise (such as some man-made noise and communications signals), but only moderately so for Class B noise (such as atmospheric noise and automobile ignition noise) whose statistics are sensitive to the source distribution and propagation laws. Excellent agreement

of the statistical-physical model with experiment is found for the relative APDs both basic Classes A and B (see Figure 25). These quantitative models, appropriately calibrated to reality by simple experiment, are useful for: (1) the assessment of EM environments, for the purposes of spectrum management; (2) the evaluation of receiver performance and the design of optimum receivers in these strongly nongaussian situations; and (3) determination of system performance.

Techniques have been developed to estimate the Middleton model parameters from experimentally measured APDs (Middleton, 1979). It should be noted that this is not simply curve fitting. The model, once the parameters are determined, is capable of predicting the APD quite well in dB relative to the rms value (see Figure 25). Currently, an empirical model (e.g., Hagn and Sailors, 1979)[66] is still required to predict the probability of occurrence of a given rms value for a given environmental category (e.g., business, residential or rural).

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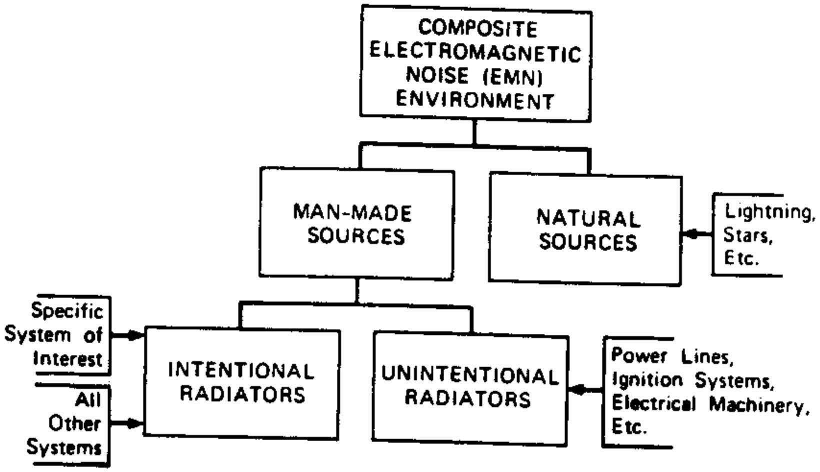
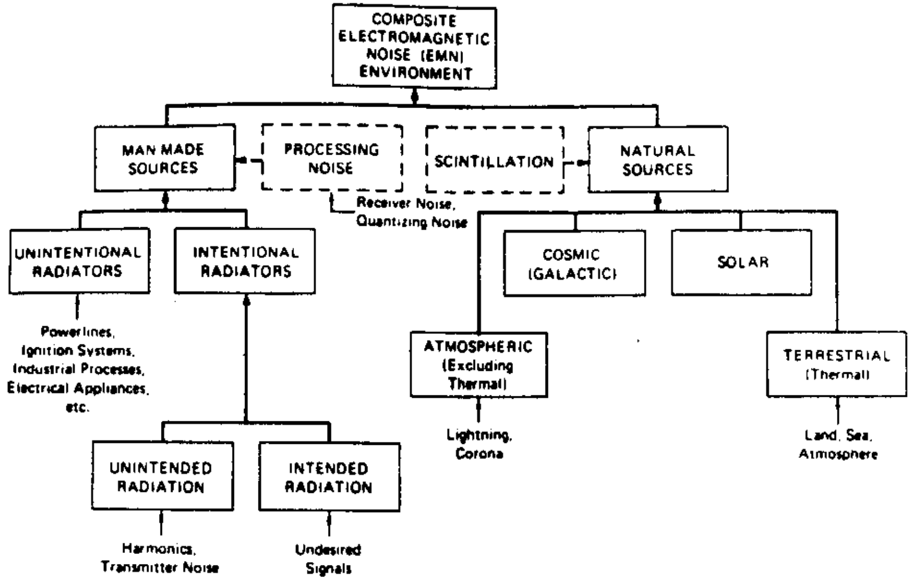
FIGURE 1



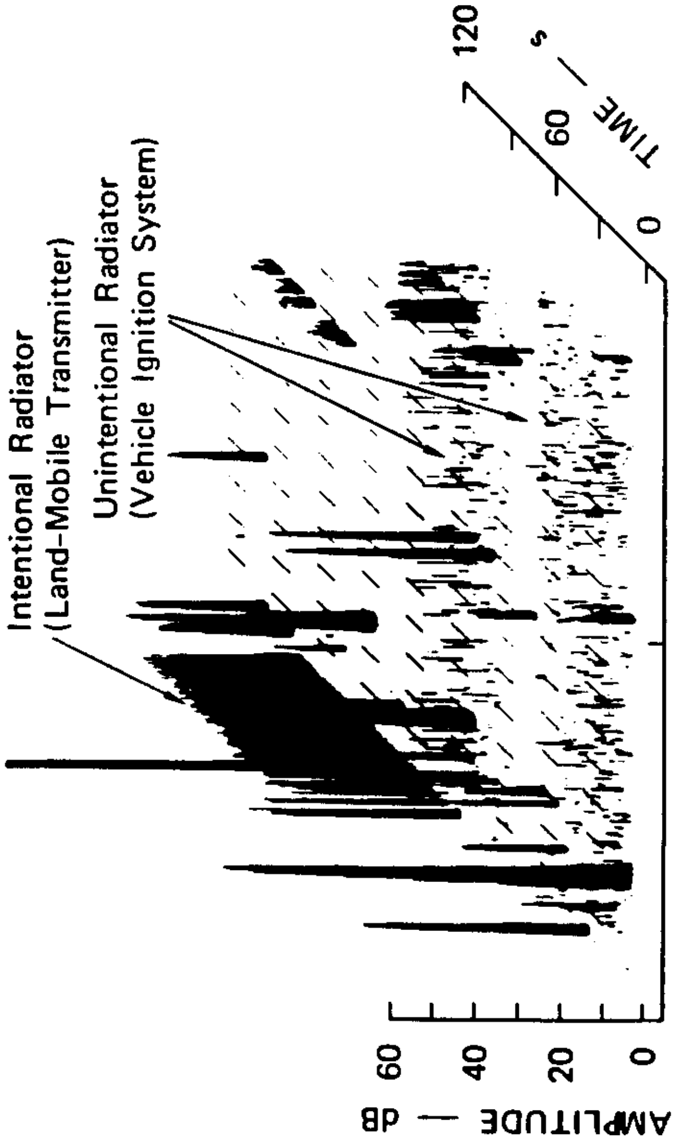
CATEGORIES OF SOURCES CONTRIBUTING TO THE COMPOSITE ELECTROMAGNETIC NOISE ENVIRONMENT

FIGURE 2



SOURCES OF THE COMPOSITE ELECTROMAGNETIC NOISE (EMN) ENVIRONMENT

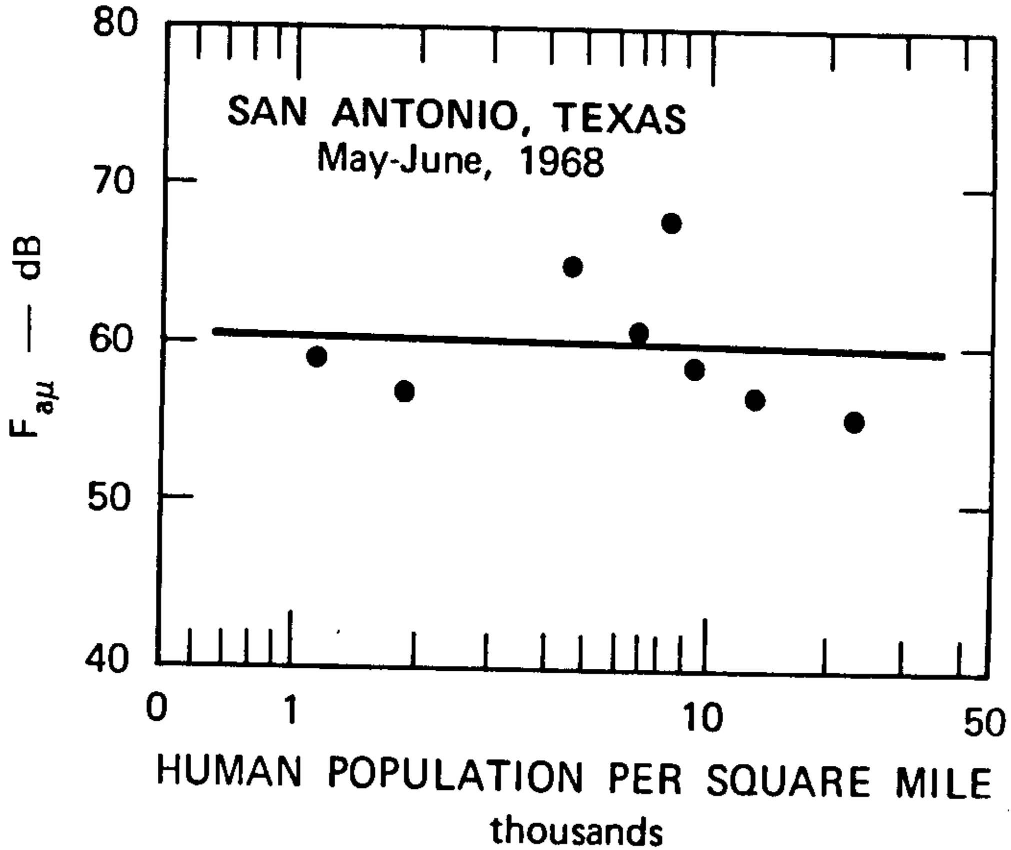
FIGURE 3



EXAMPLES OF CONTRIBUTIONS TO THE COMPOSITE ELECTROMAGNETIC ENVIRONMENT BY INTENTIONAL AND UNINTENTIONAL RADIATORS – AS OBSERVED WITH A SCANNING RECEIVER (AFTER VINCENT, W. R., AND DAYHARSH, T. I., 1969)

FIGURE 4

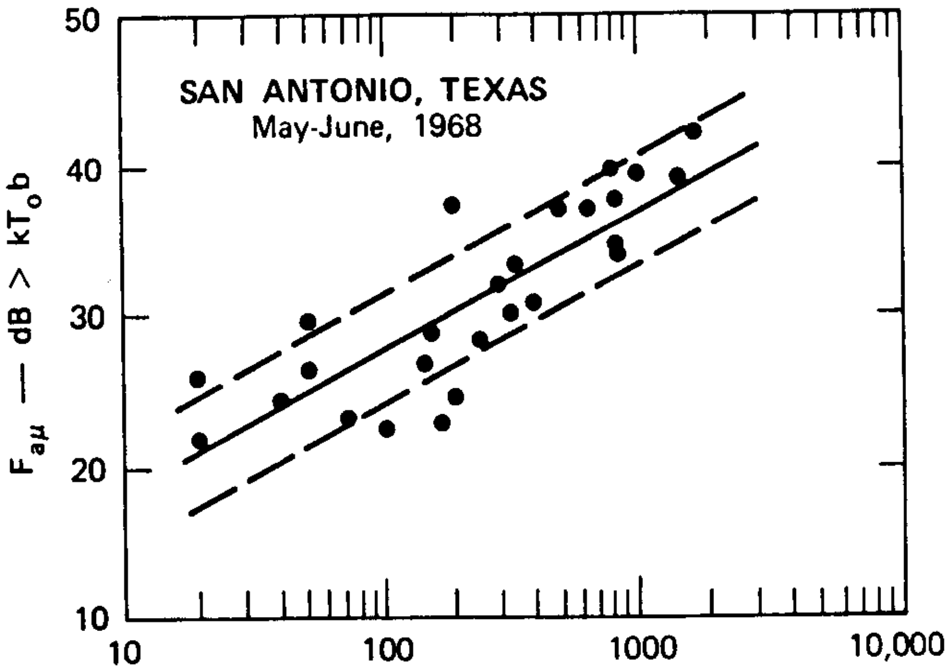
REGRESSION OF 5.0 MHz $F_{a\mu}$ WITH LOG POPULATION DENSITY OF SLA's



SOURCE: Spaulding, A. D., 1972.

FIGURE 5

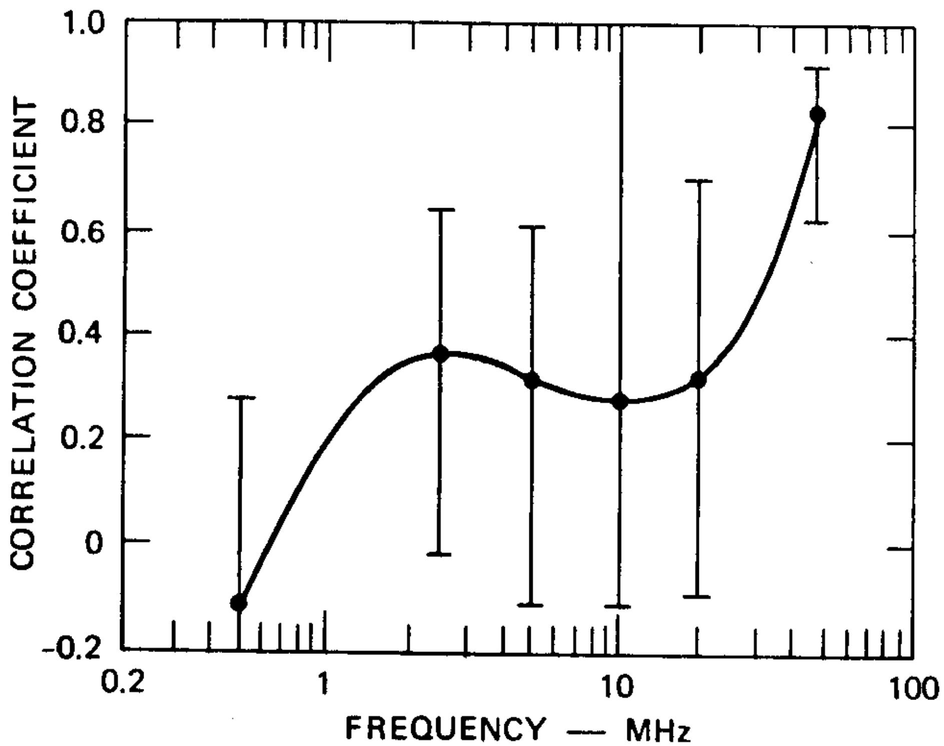
LINEAR REGRESSION OF THE MEAN OF F_a VALUES ALONG A THOROUGHFARE ($F_{a\mu}$) VERSUS LOG HOURLY TRAFFIC COUNT ALONG THE THOROUGHFARE AT 48 MHz (26 THOROUGHFARES)



SOURCE: Spaulding, A. D., 1972.

FIGURE 6

CORRELATION COEFFICIENTS ALONG WITH THE 95-PERCENT CONFIDENCE LIMITS FOR EACH OF THE MEASUREMENT FREQUENCIES, $F_{a\mu}$ VERSUS LOG HOURLY TRAFFIC COUNT



SOURCE: Spaulding, A. D., 1972.

FIGURE 7

LATIVE FREQUENCY SPECTRA FOR DIFFERENT NOISE TYPES (THE NUMBERS IN PARENTHESES ARE THE ABSOLUTE VALUES MEASURED AT 0.150 MHz) (AFTER JUETTE, G. W., 1972)

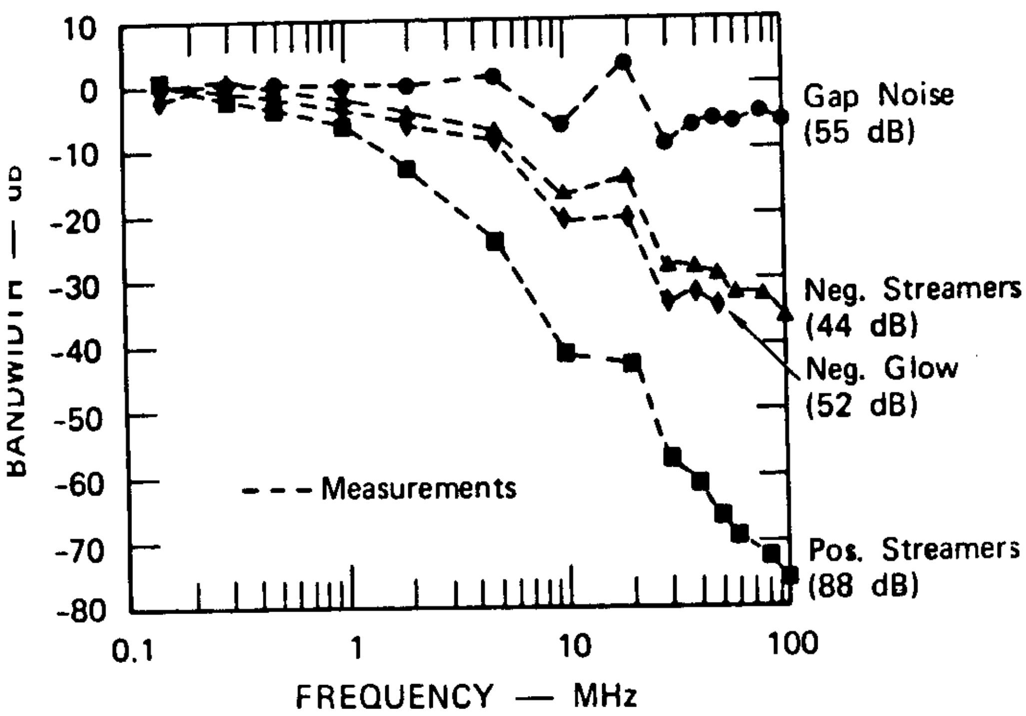
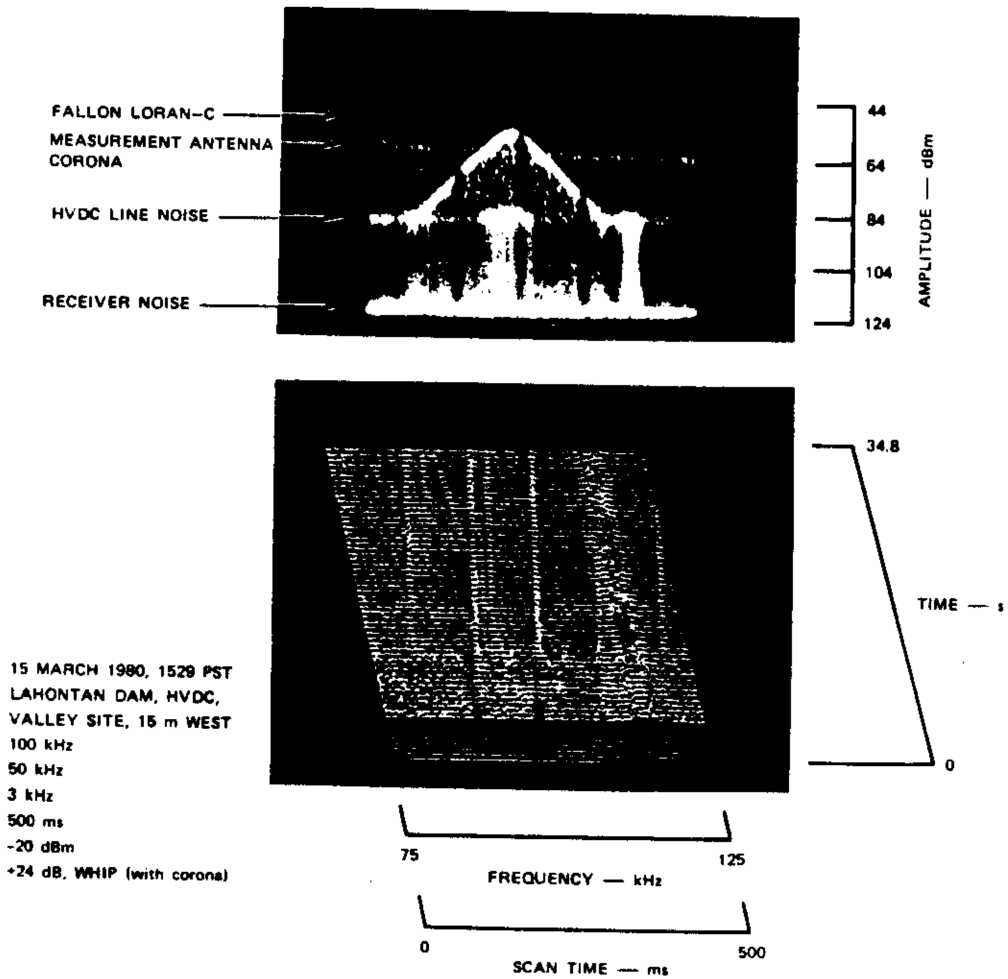


FIGURE 8

(Source: W.R. Vincent, 1980)



HVDC LINE NOISE, ANTENNA BREAKDOWN NOISE, AND LORAN-C SIGNALS

FIGURE 9

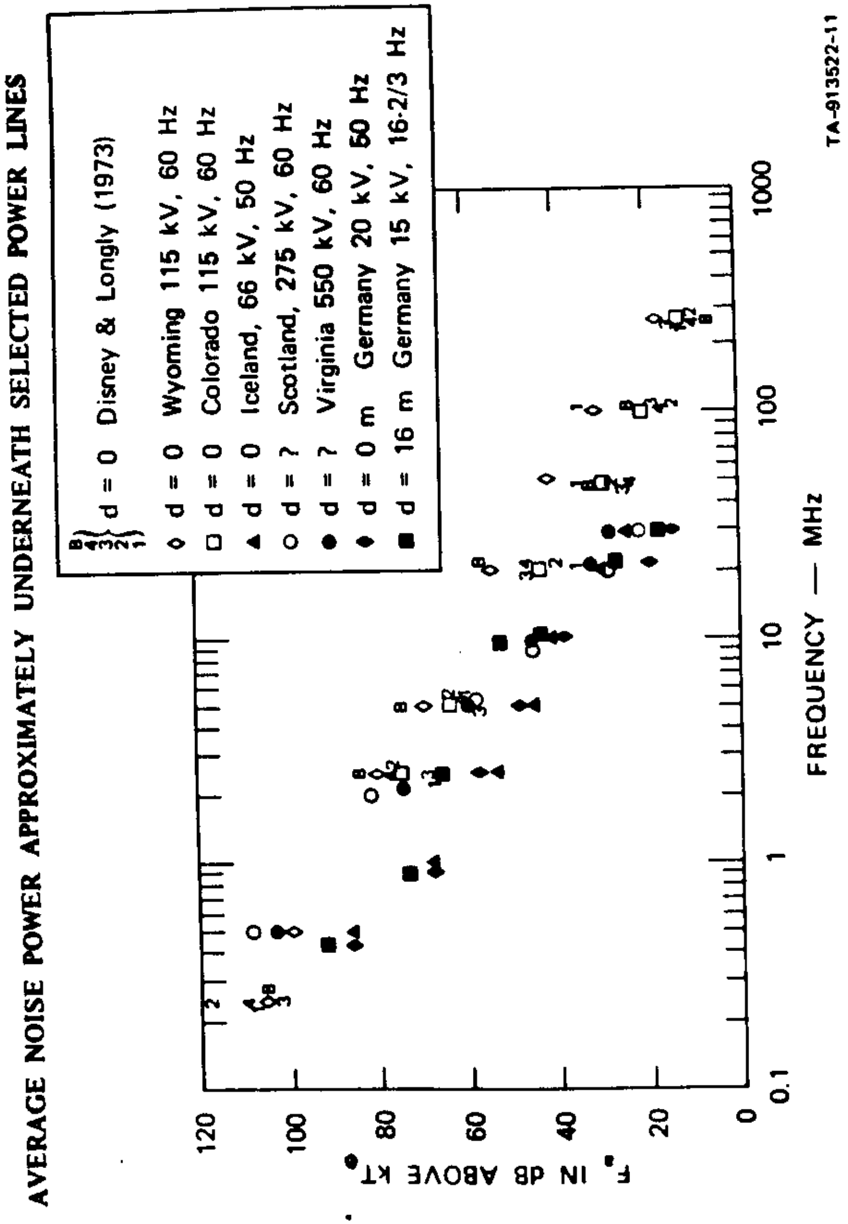
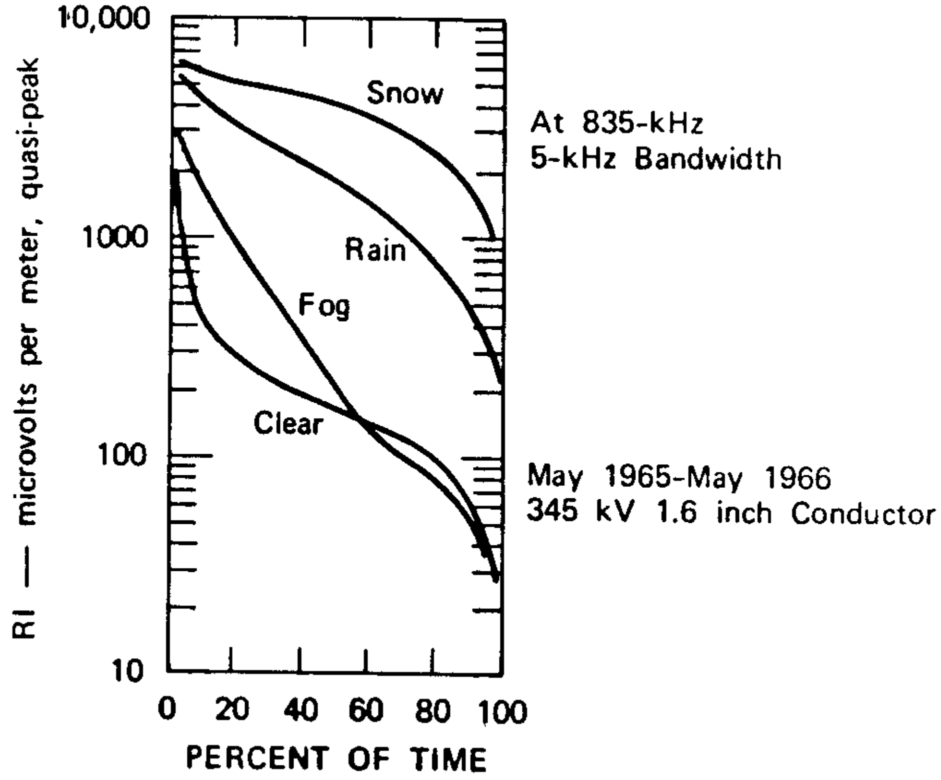


FIGURE 10

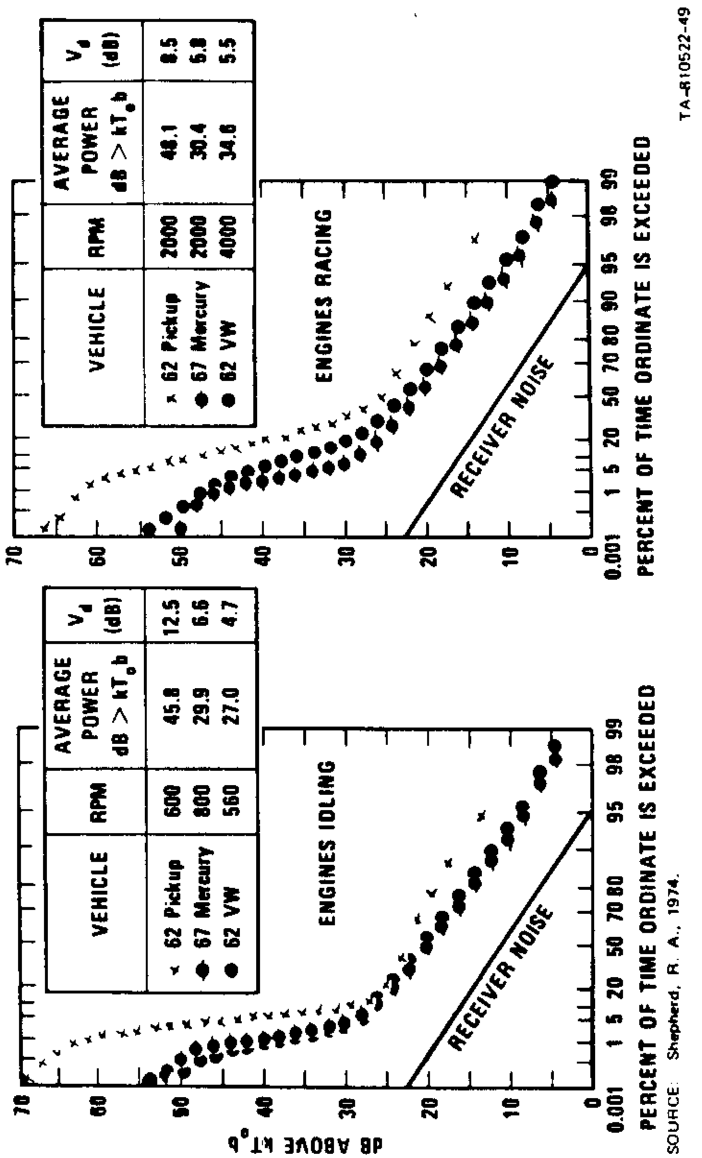
RI DISTRIBUTION, PERCENT OF TIME
RI LEVEL EQUALS OR EXCEEDS ORDINATE



SOURCE: Baily, B. M. and Belsher, M. W., 1968.

FIGURE 11

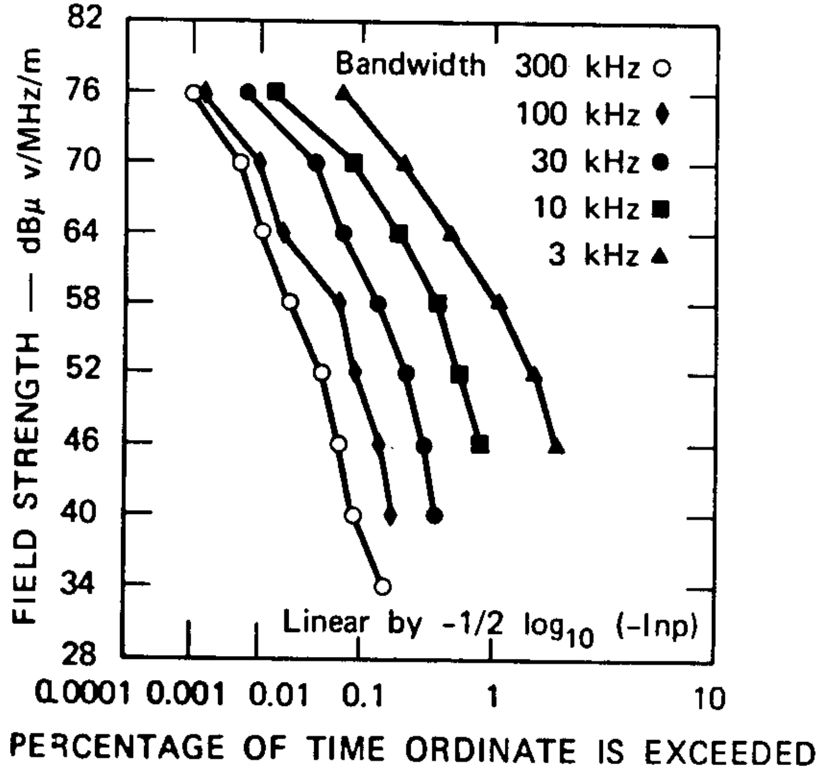
APDs OF THREE VEHICLES, RIGHT SIDE AT 10 m, 24.11 MHz, 8 kHz NOISE BANDWIDTH



SOURCE: Shepherd, R. A., 1974.

FIGURE 12

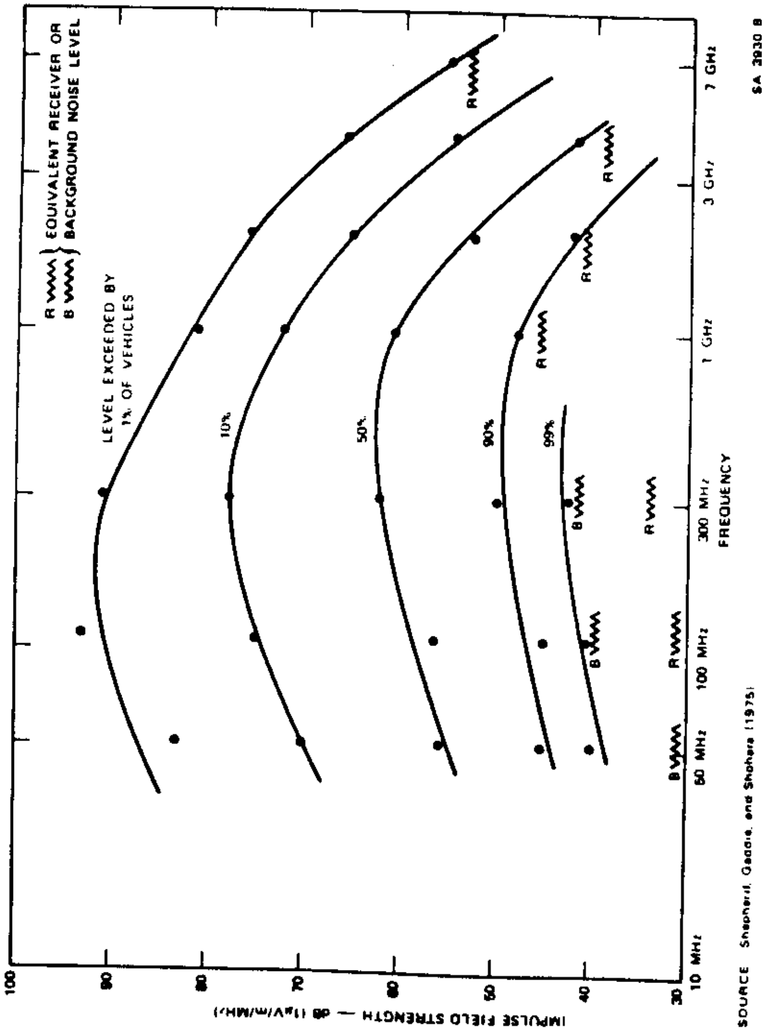
SINGLE-VEHICLE APD DATA (AVERAGE OF FOUR VEHICLES)



SOURCE: Schulz, R. B. et al., 1973.

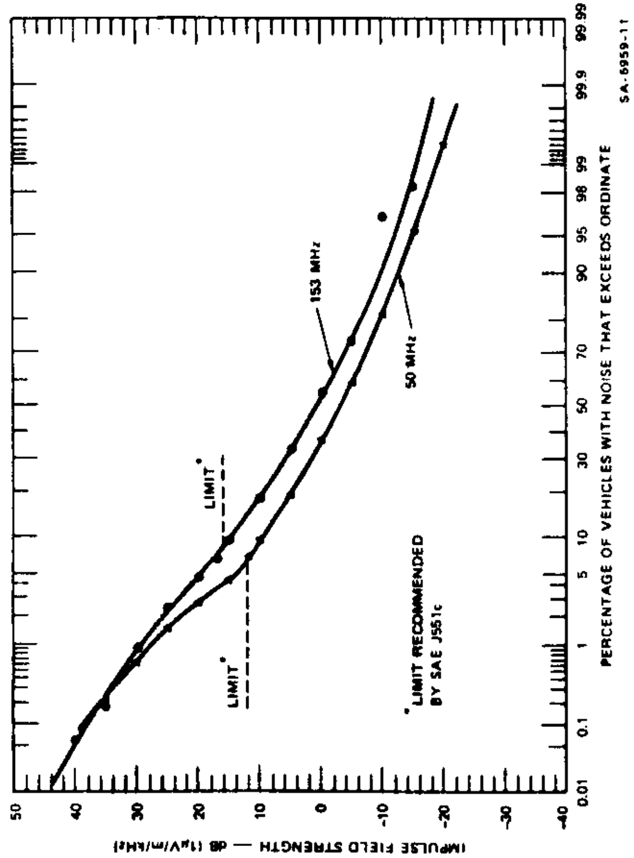
TA-913522-13

FIGURE 13



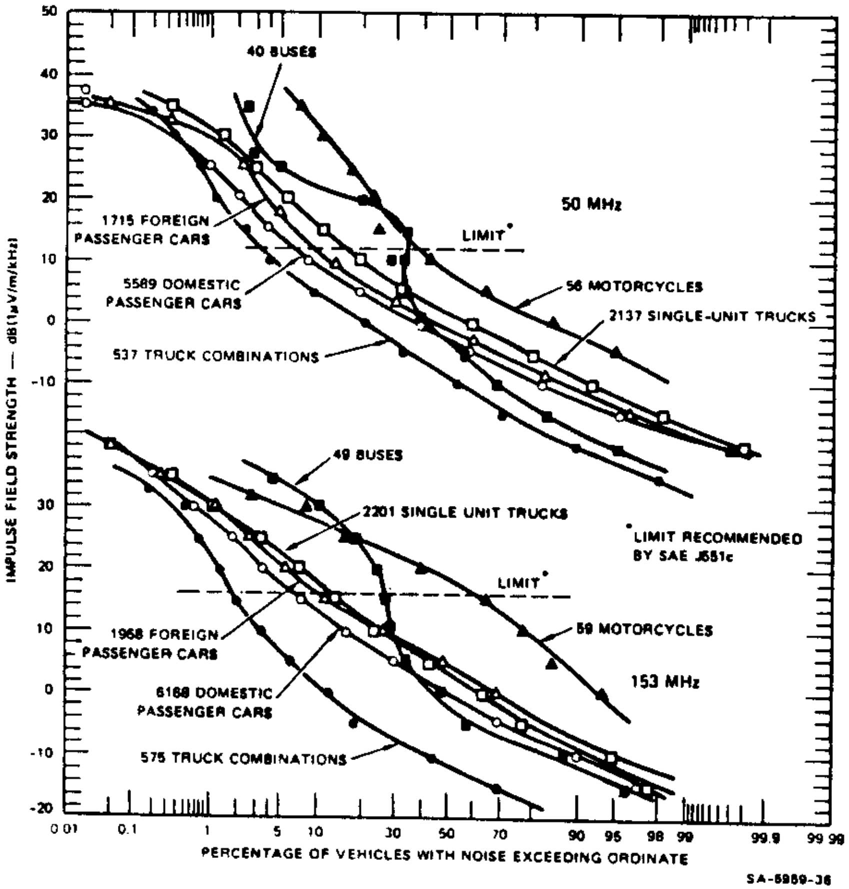
IGNITION NOISE FROM INDIVIDUAL MOVING VEHICLES AT ABOUT 13 METERS

FIGURE 14



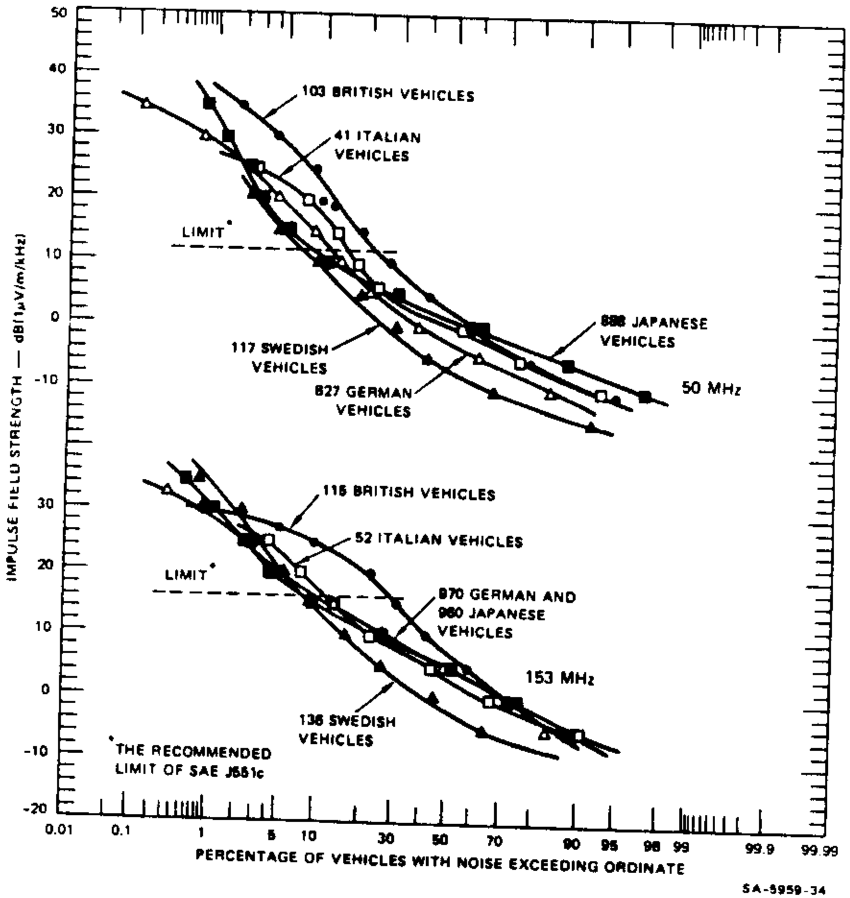
IGNITION NOISE DISTRIBUTIONS OF THE UNITED STATES VEHICLE POPULATION IN MID-1977 — DEVELOPED FROM REGIONAL DISTRIBUTIONS

FIGURE 15



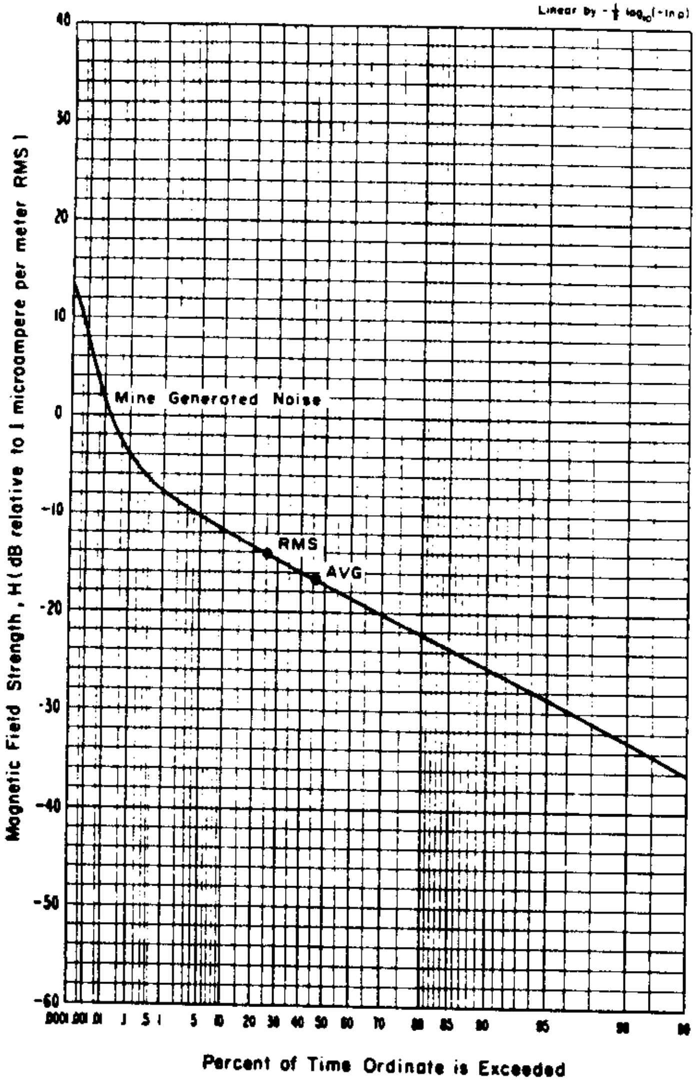
IGNITION NOISE DISTRIBUTIONS FOR VARIOUS VEHICLE TYPES

FIGURE 16



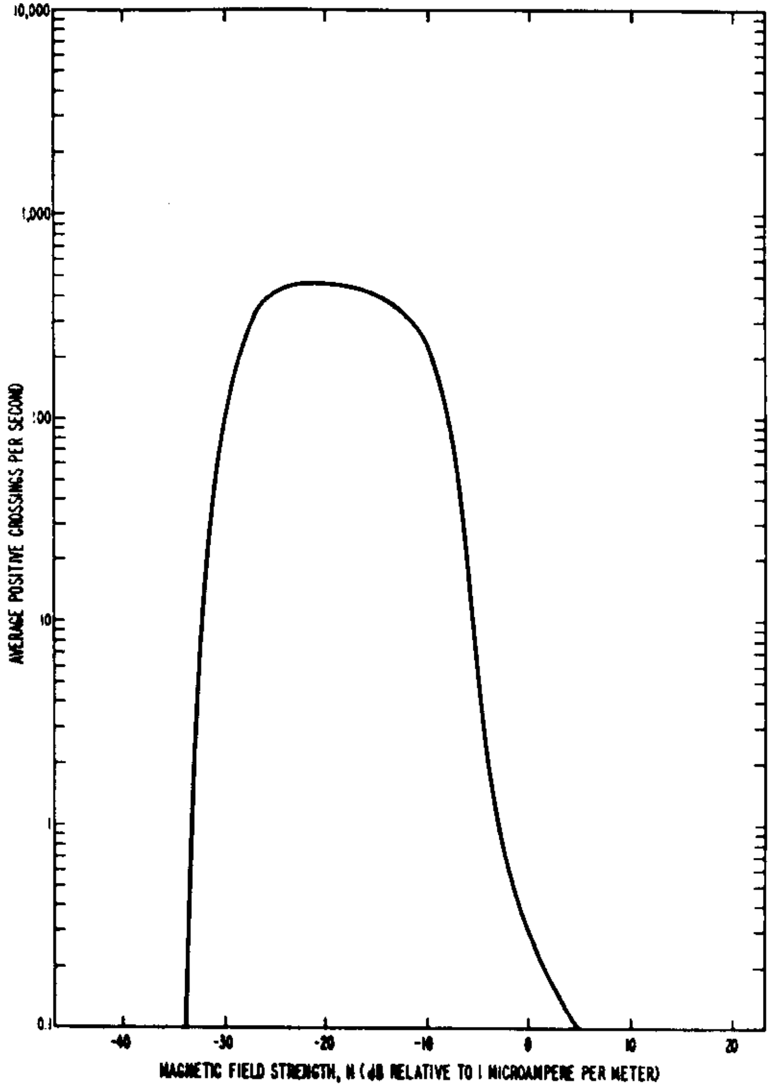
IGNITION NOISE DISTRIBUTIONS FOR VEHICLES SEPARATED BY NATIONAL ORIGIN

FIGURE 17



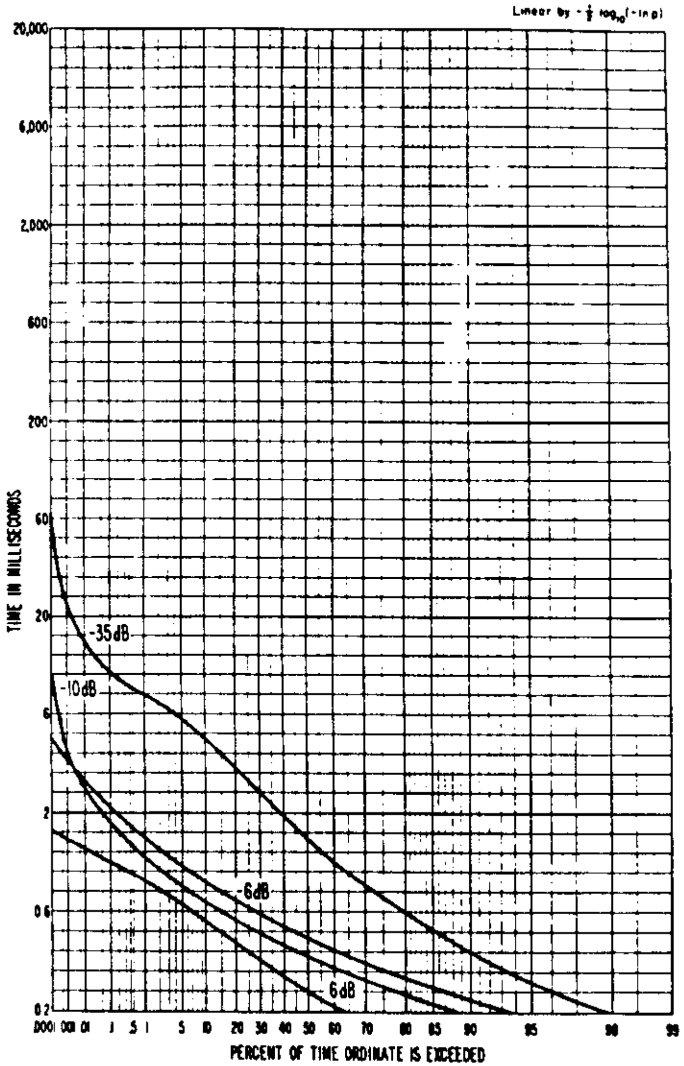
APD, 1 MHz, vertical component, 1.2 kHz predetection bandwidth, April 17, 1973, 12:20 p.m., Itmann No. 3. (After Kanda, 1974)

FIGURE 18



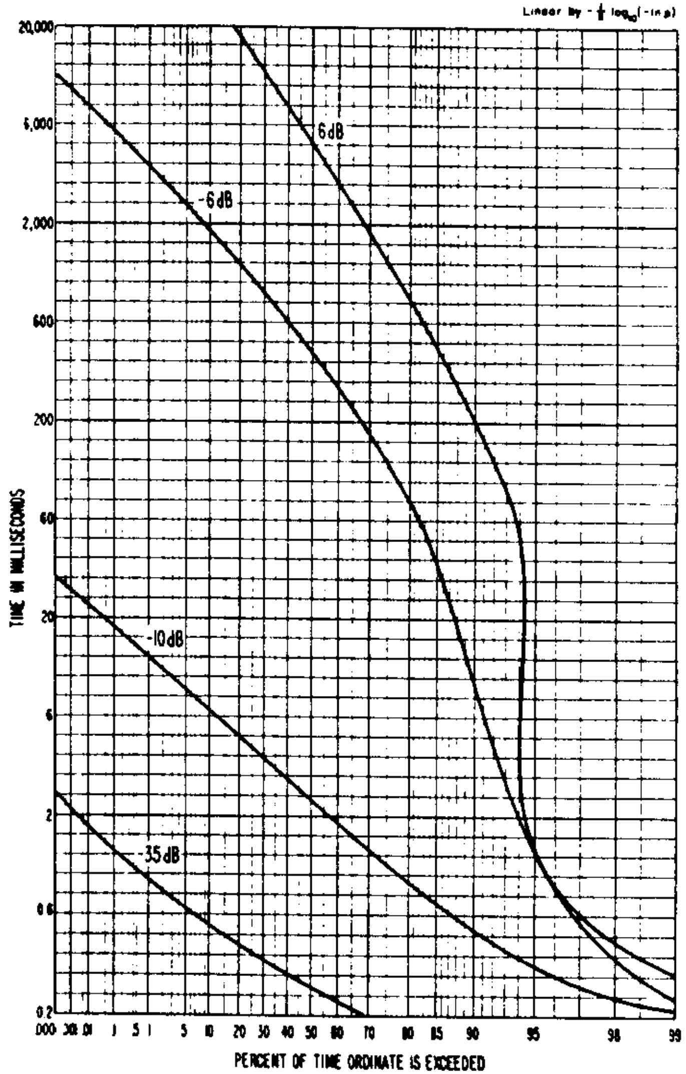
ACR, 1 MHz, vertical component, 1.2 kHz predetection bandwidth, April 17, 1973, 12:20 p.m., Itmanr. No. 3. (After Kanda, 1974)

FIGURE 19



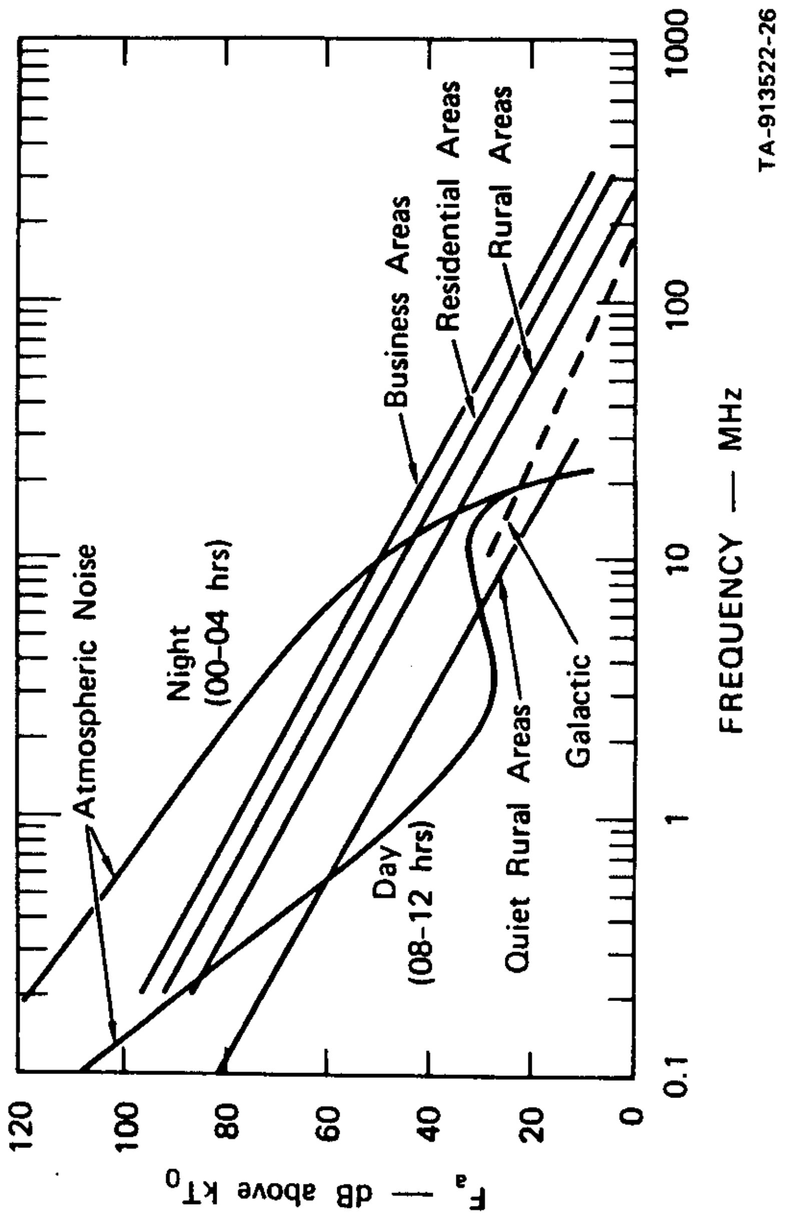
PDD, 1 MHz, vertical component, 1.2 kHz predetection bandwidth, April 17, 1973, 12:20 p.m., Itmann No. 3. (After Kanda, 1974)

FIGURE 20



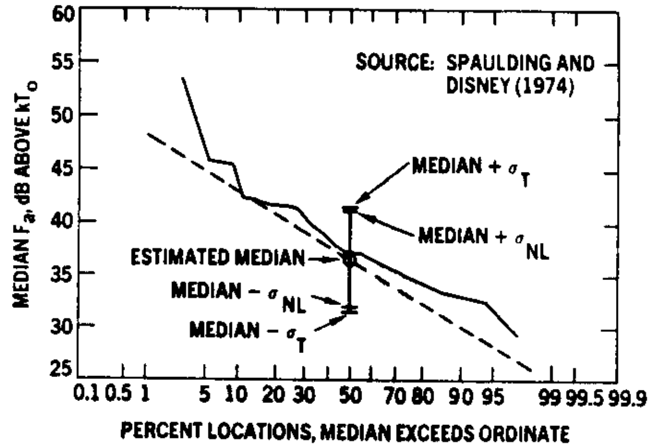
PSD 1 MHz, vertical component, 1.2 kHz predetection bandwidth, April 17, 1973, 12:20 p.m., Itmann No. 3. (After Kanda, 1974)

FIGURE 21



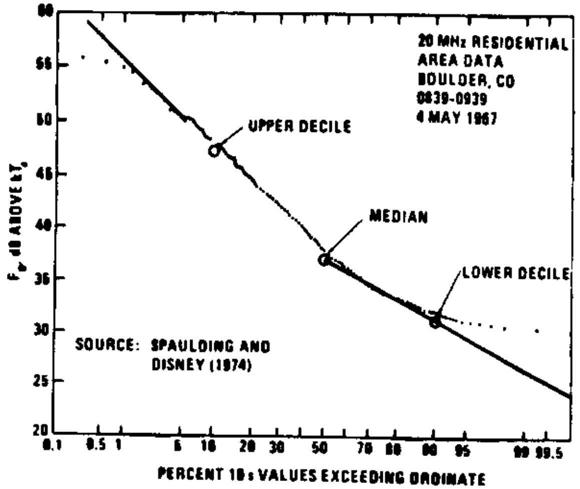
ESTIMATES OF MEDIAN VALUES OF MAN-MADE ATMOSPHERIC AND GALACTIC NOISE EXPECTED NEAR WASHINGTON, D.C. DURING SUMMER (AFTER SPAULDING AND DISNEY, 1974, AND CCIR, 1964)

FIGURE 22



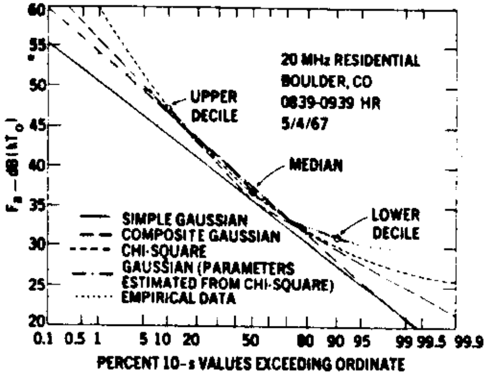
EXAMPLE DISTRIBUTION OF LOCAL MEDIAN Fa VALUES
(20 MHz, RESIDENTIAL)

FIGURE 23



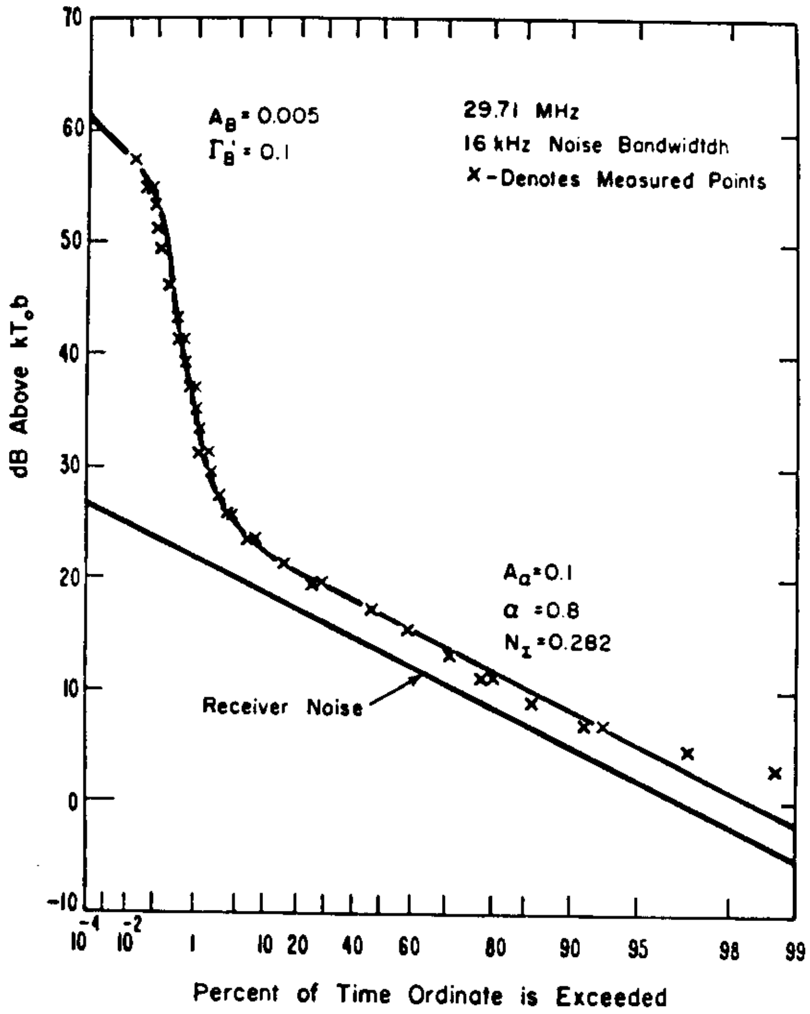
EXAMPLE DISTRIBUTION OF SHORT-TERM LOCAL MEDIAN AVERAGE NOISE POWER SPECTRAL DENSITY (20 MHz, RESIDENTIAL AREA)

FIGURE 24



COMPARISON OF HAGN AND SAILORS' MODEL PREDICTIONS WITH MEASURED DATA AT 20 MHz IN A RESIDENTIAL AREA

FIGURE 25



Comparison of measured envelope distribution, $P_1(\mathcal{E}>\mathcal{E}_0)_B$, of automotive ignition noise from moving traffic with full Class B model. [Data from Shepherd, 1974]

TABLE 1 CATEGORIES OF UNINTENTIONAL RADIATORS

Overhead power transmission and distribution lines.
Ignition systems (e.g., automotive, aircraft, small engines, etc.).
Industrial fabrication and processing equipment (including arc welders).
Electric motors and generators.
Electric busses and trains (excluding their power lines).
Contact devices (e.g., thermostats, bells, and buzzers).
Electrical control, switchings, and converting equipment (e.g., SCRs, and ac/dc converters).
Medical and scientific apparatus.
Lamps (e.g., gaseous discharge devices and neon signs).
Various electrical consumer products.

APPROXIMATE FORMULAS FOR THE
STANDARD DEVIATIONS, IN dB

Environmental Category	Simple Gaussian and Chi-Square	Composite Gaussian
Business	for $0.25 \le f_{MHz} < 2.5$ $\sigma_N \cong \sigma_{N\chi^2} \cong 9.0$	for $0.25 \le f_{MHz} < 100$ $\sigma_{Nu} \cong 10.5$, $\sigma_{N\ell} \cong 8.0$
	for $2.5 \le f_{MHz} < 10$ $\sigma_N \cong \sigma_{N\chi^2} \cong 8.0-4 \log_{10}\left(\frac{f_{MHz}}{10}\right)$	for $100 \le f_{MHz} \le 250$ $\sigma_{Nu} \cong 9.5$, $\sigma_{N\ell} \cong 7.5$
	for $10 \le f_{MHz} \le 100$ $\sigma_N \cong \sigma_{N\chi^2} \cong 8.0 + 4 \log_{10}\left(\frac{f_{MHz}}{10}\right)$	
Residential	for $0.25 \le f_{MHz} \le 250$ $\sigma_N \cong \sigma_{N\chi^2} \cong 8.0$	for $0.25 \le f_{MHz} < 100$ $\sigma_{Nu} \cong 9.0$, $\sigma_{N\ell} \cong 6.0$
		for $100 \le f_{MHz} \le 250$ $\sigma_{Nu} \cong 8.0$, $\sigma_{N\ell} \cong 4.0$
Rural	for $0.25 \le f_{MHz} \le 2.5$ $\sigma_N \cong \sigma_{N\chi^2} \cong 9.0 + 4 \log_{10} f_{MHz}$	for $0.25 \le f_{MHz} < 100$ $\sigma_{Nu} \cong 9.0$, $\sigma_{N\ell} \cong 6.0$
	for $2.5 \le f_{MHz} \le 250$ $\sigma_N \cong \sigma_{N\chi^2} \cong 8.0-4 \log_{10}\left(\frac{f_{MHz}}{10}\right)$	for $100 \le f_{MHz} \le 250$ $\sigma_{Nu} \cong 6.3$, $\sigma_{N\ell} \cong 3.5$