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TECHNIQUES FOR ESTIMATING THE EFFECTS OF MAN-MADE RADIO NOISE ON DISTRIBUTED MILITARY SYSTEMS

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SUMMARY

This paper reviews techniques available for estimating th effects of man-made radio noise on distributed military systems using empirical man-made noise models. The models given in CCIR Report 258 are reviewed along with the empirical data base upon which they are based. Results of measurements of man-made noise are presented for six Pacific Ocean sites and for three Atlantic Ocean/Europe sites. Accumulative probability distribution models of increasing complexity are reviewed. Tests of fit of these distributions are presented for select samples of measured man-made noise data.

1. INTRODUCTION

Increased utilization of electrical and electronic devices for man's well being and security has also increased the amount of undesired electromagnetic energy in telecommunication systems. This man-made radio frequency interference is characteristically impulsive in form and random in occurrence and originates from such common sources as automobile ignition systems, high voltage transmission lines, electrical power generating stations, and electrical applicances and machinery. Man-made noise predominates over noise of natural origin[1] at many locations especially during the daytime.

In the solution of telecommunication problems, it is highly desirable to be able to estimate the radio noise at any location, frequency, or time of day caused by these different sources. One approach to solving the problem has been the development of empirical models of man-made noise. The empirical models available today are based on an empirical data base acquired by the Institute for Telecommunication Sciences(ITS)[2]. Data exist on man-made radio noise available power levels in the U.S. and on the time and location variabilities of those levels for specific environmental categories: rural,residential and business. These models have been adopted by the CCIR in Report 258-5[3]. These levels are presented as F_a, the effective noise figure, in dB(kT_o)[3] or dB(kT_ob)[1]; however, these are essentially equivalent units[4]. The distribution of F_a is needed to calculate the distribution of SNR(defined as the ratio of average signal power to average noise power) and hence the probability of successful communication or the loss of circuit reliability due to interference.

This paper presents empirical models of man-made noise that can be used in the solution of telecommunication problems for distributed military systems. First, the empirical data for which the CCIR models are based is discussed. Then the CCIR Report 258 models are described. Four models for the probability distribution of the short-term(1 min.) mean values of man-made radio noise available power levels for the specific environmental categories are given(these models are not amplitude probability distributions(APD)). The extension to frequencies above 250 MHz, based on data measured in Canada, is described[5-7]. Results of recent measurements of man-made noise made on a circular disposed antenna array(CDAA) by the Naval Electronics Engineering Activity, Pacific are discussed[8]. Results of these measurements for Guam are compared to measurements made near the CDAA antenna in Guam during 1974 on a short vertical rod[9].

2. EMPIRICAL DATA BASE

In 1974 the Institute for Telecommunication Sciences(ITS) reported the use of a measurement system with a 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.[2]. Over 300 hours of data were obtained simultaneously on ten frequencies over a period from 1966 through 1971 in six states(Colorado, Maryland, Texas, Virginia, Washington and Wyoming) and in the District of Coluumbia. Data were obtained for three environmental categories: rural, residential, and business. Data were measured in 31 rural areas, 38 residential areas, and 23 business areas. At each location the area sampled varied from a few square blocks in the business areas to few square miles in the rural areas. In the noise measurement method used, 10-sec samples of the running average(time constant about 50 sec.) of F_a were recorded. Thus, 360 samples of F_a were obtained each hour for a given measurement location and frequency. These results were analysed statistically at ITS. The least-suares fit for F_{am}, the median value of F_a, given in [2-3] for each environmental category is reproduced as Figure 1 and are given here as Table 1 for each of the frequencies. The slope with frequency was found to be -27.7 dB/decade for each environmental category.

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 local time, and between 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 lightning; and the man-made levels cannot be observed. The diurnal 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.

An indication of the variation encountered from location to location within each environmental category is given by Spaulding and Disney[2]. An example distribution of local median values of man-made noise at 20 MHz in residential areas is given as Figure 2. The values σ_T is the standard deviation of all measured medians for all frequencies combined about the regression line of Figure 1. The authors quote values of 7.00 dB, 5.00 dB, and 6.45 dB for business, residential, and rural areas, respectively. A better estimate of the location variability of Fam for these environmental categories for a specific measured frequency may be obtained from the standard deviations σ_{NL} given in Table 1.

Once the best estimate of the location variability has been found, the variation of F_a at that location with time should be considered. Figure 3 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, CO. The median and the upper and lower deciles are indicated. The time variability for the different environmental categories has been estimated by ITS for each of ten measurement frequencies in terms of the upper and lower deciles, D_u and D_l(in dB, relative to the median value). These values, summarized in Table 1, are the root-mean-squares of all the location values for each frequency and environmental category.

Table 1. Summary of selected measured noise parameters for business, residential and rural environmental categories

Environmental Category	Freq. (MHz)	F_{am} (dB(kT$_o$))	D_u (dB)	D_l (dB)	σ_{NL} (dB)
Business	0.25	93.5	8.1	6.1	6.1
	0.50	85.1	12.6	8.0	8.2
	1.00	76.8	9.8	4.0	2.3
	2.50	65.8	11.9	9.5	9.1
	5.00	57.4	11.0	6.2	6.1
	10.00	49.1	10.9	4.2	4.2
	20.00	40.8	10.5	7.6	4.9
	48.00	30.2	13.1	8.1	7.1
	102.00	21.2	11.9	5.7	8.8
	250.00	10.4	6.7	3.2	3.8
Residential	0.25	89.2	9.3	5.0	3.5
	0.50	80.8	12.3	4.9	4.3
	1.00	72.5	10.0	4.4	2.5
	2.50	61.5	10.1	6.2	8.1
	5.00	53.1	10.0	5.7	5.5
	10.00	44.8	8.4	5.0	2.9
	20.00	36.5	10.6	6.5	4.7
	48.00	25.9	12.3	7.1	4.0
	102.00	16.9	12.5	4.8	2.7
	250.00	6.1	6.9	1.8	2.9
Rural	0.25	83.9	10.6	2.8	3.9
	0.50	75.5	12.5	4.0	4.4
	1.00	67.2	9.2	6.6	7.1
	2.50	56.2	10.1	5.1	8.0
	5.00	47.8	5.9	7.5	7.7
	10.00	39.5	9.0	4.0	4.0
	20.00	31.2	7.8	5.5	4.5
	48.00	20.6	5.3	1.8	3.2
	102.00	11.6	10.5	3.1	3.8
	250.00	0.8	3.5	0.8	2.3

3. CCIR REPORT 258 MODELS

The environmental categories for which predictions are available in CCIR Report 258-5 include: business, residential, rural, and quiet rural[3]. Business areas are 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.). Residential areas(urban or suburban) are defined as any area used predominately for single or multiple family dwellings with a density of at least two single family units per acre and no large or busy highways. Rural areas are defined as locations where land usage is primarily for agricultural or similar pursuits, and dwellings are no more than one every five acres. Quiet rural areas are defined as locations chosen to ensure a minimum of man-made noise.

In all cases results are consistent with a linear variation of the median value of F_a, F_{am}, with frequency of the form:

$$F_{am} = c - d \log f, \qquad (1)$$

where f is the frequency expressed in MHz. The constants c and d are given in Table 2. As these results are based on the work of Spaulding and Disney[2], equation (1) is valid only in the range 0.25 to 250 MHz for all the environmental categories except quiet rural and galactic noise. The formula for galactic noise from radio stars which is incident on the ionosphere is included here for comparison only. Note that Table 2 also contains data from Spaulding and Disney for parks and university campuses and for inter-state highways.

Table 2. Values of the Man-made Noise Constants c and d[2]

Environmental category	c	d
Business	76.8	27.7
Inter-state highways	73.0	27.7
Residential	72.5	27.7
Parks and university campuses	69.3	27.7
Rural	67.2	27.7
Quiet rural	53.6	28.6
Galactic noise	52.0	23.0

Skomal has reviewed man-made noise data collected in a range of countries at various distances from metropolitan areas[10-11]. Results cover the frequency range 500 kHz to 1 GHz. In the frequency interval 100 t0 800 MHz, he showed that the frequency decrement moderates from that given in Table 1 to -10 to -15 dB/decade. This is consistent with the presence of a localized maximum in the UHF-band emission spectrum of vehicular ignition interference.

At four sites in downtown Ottawa, Canada, measurements of the VHF-UHF radio environment were carried out over a 17-day period in November 1976[5]. A linear regression equation of the frequencies 200 to 500 MHz was given as $F_{am} = -15.8 \log f + 48.4$(f in MHz). In the frequency range from 200 to 300 MHz, the results using this equation compare favorably with those using the business area equation of [2].

Man-made noise level measurements were made of the UHF radio environment over a four-month period(1982-1983) in and around

Ottawa, Canada by Lauber and Bettrand[6]. The antenna noise temperature T_a was measured at sites typical of business, residential, and rural areas at frequencies from 600 to 950 MHz. For each of these areas, a minimum of 1800 one-second measurements were combined to form a cumulative probability distribution, which shows the time and location variability of the noise. The highly skewed shape of the distribution, especially those from the business areas, showed that the UHF radio environment is composed of a background noise level upon which is superimposed a highly variable man-made noise level from vehicle ignition noise.

4. NOISE LEVEL DISTRIBUTION MODELS

Hagn and Sailors[12] have presented four statistical models of increasing complexity(simple Gaussian, composite Gaussian, chi-suare, Gaussian from chi-square) which utilize the time and location variability of F_a to predict the accumulative probabilities of man-made radio noise available power levels for short, vertically-polarized antennas located near the ground. These models, which have now been included in CCIR Report 258, are useful in predicting the probability that the short-term signal-to-noise ratio for a given communication system equals or exceeds a value required for successful communication.

For the simple Gaussian model, the mean is approximated by F_{am} from Table 1, and the standard deviation σ_N is given by

$$\sigma_N = (\sigma_{NL}^2 + \sigma_{NT}^2)^{\frac{1}{2}} \quad (2)$$

assuming that the temporal and spatial variabilities are uncorrelated. The parameter σ_{NT} is the standard deviation of the temporal variability and values are obtained from D_u and D_l of Table 1 using

$$\sigma_{NT} = \frac{1}{1.28}\left[\frac{(D_u^2 + D_l^2)^{\frac{1}{2}}}{2}\right] \quad (3)$$

The location variability σ_{NL} is given in Table 1.

The composite Gaussian model is the simplest model which takes into account skewness in the distribution. For this model the standard deviations for the upper and lower halves of the distribution are given by σ_{Nu} and σ_{Nl}, respectively, and the mean is given by F_{am}. The corresponding upper and lower deciles for these distributions are obtained from σ_{Nu} and σ_{Nl}, respectively, using the equations

$$D_{Nu} = 1.28\ \sigma_{Nu} \quad (4)$$

$$D_{Nl} = 1.28\ \sigma_{Nl} \quad (5)$$

The standard deviations themselves are computed

$$\sigma_{Nu} = \left[\left(\frac{D_u}{1.28}\right)^2 + \sigma_{NL}^2\right]^{\frac{1}{2}} \quad (6)$$

$$\sigma_{Nl} = \left[\left(\frac{D_l}{1.28}\right)^2 + \sigma_{NL}^2\right]^{\frac{1}{2}} \quad (7)$$

The chi-suare model also takes into account skewness. In the chi-square model the parameter ν is the number of degrees of freedom. The chi-square model satisfies the relationship $F_a = a + b\ \chi^2$. The mean noise is $\langle F_a \rangle = F_{a\chi}^2 = a + b\ \nu$, and its standard deviation is $\sigma_{N\chi}^2 = b(2\ \nu)^{\frac{1}{2}}$. The parameters $a, b, \nu, F_{a\chi}^2$, and $\sigma_{N\chi}^2$ are given in Table III of CCIR Report 258-5[3] for the ten discrete frequencies between 0.25 and 250 MHz. These parameters were found using a method developed by Zacharisen and Crow[13].

A second Gaussian model using parameters can be estimated from the chi-square approximations. For this model the mean is given by $F_{a\chi}^2$ and the standard deviation $\sigma_{N\chi}^2$.

Figure 4 shows the predictions for 20 MHz in a residential environment. All four models predict very similar values between the deciles. In the tails of the distribution(beyond the deciles), the simple Gaussian model predicts the lowest levels; and the chi-square model predicts the highest levels.

Hagn and Sailors[12] also made a preliminary comparison of the models with measured data. Figure 5 is a plot of the model predictions of Figure 4 superimposed on the data of Figure 3. Since there was no location variability data for this sample, σ_{NL} was set to zero for the comparison. By inspection, the best fit over the interval 1% to 80% is given by the Gaussian model with parameters estimated from the chi-square. The simple Gaussian model predictions are consistently too low; and, in the more interesting upper half of the distribution, the chi-square model predictions are good over the interval 10% to 80% but too high for the upper tail of the distribution. The shape of the measured distribution in the lower tail is most closely approximated by the chi-square.

Hagn and Sailors applied a Kolmogorov-Smirnov(K-S) goodness-of-fit test[14-16] to examine more rigorously how well distributions of sample man-made noise data conform to the hypothesized distributions. The results for data and model predictions of Figure 5 show that the chi-square model is accepted for a significance level of 5% for values of probability of exceeding the ordinate up to 90 percent, whereas, the simple Gaussian model does not fit well throughout the entire distribution. The K-S test was also applied to 20 MHz data obtained for 31 minutes in a Boulder, CO, business area. This particular distribution sample was the only one available which was not used to develop the model. The distribution was slightly skewed as can be seen in Figure 6. As the mean for this sample was 49.7 dB(kT_o) compared to 40.8 dB(kT_o) from Table 1; clearly, all the model predictions would be too low. In this case the authors set σ_{NL}= 0 and adjusted the median of the simple Gaussian model to 49.2 dB(kT_o) for the comparison. For a significance level 5%, the Gaussian model with parameters estimated using the chi-square was overwhelmingly rejected. At this significance level, it was found that it would be incorrect to reject the simple Gaussian, composite Gaussian, and chi-square models. The final conclusions were that the models were most useful in the probability interval 0.1 to 0.9, but further checks against measured data are needed to determine the limits of their applicability.

5. OTHER EMPIRICAL MODELS

There are other useful empirical models that either supplement the CCIR Report 258 models or in one case replace it. This includes: (1) A model developed for use at frequencies in the VHF and UHF bands; (2)A model known as the quasi-minimum atmospheric noise model; and (3)An airborne man-made radio noise model.

The first of these is a model that was developed for use at VHF and UHF by Hagn et al.[7]. For frequencies between 1 MHz and 200 MHz, the model given in CCIR Report 258-8 is used. However, at frequencies above 200 MHz, the following equations for F_{am} in dB(kT_o) are used:

$$F_{am} = 49.4 - 15.8 \log f \quad (8)$$

$$F_{am} = 45.2 - 15.8 \log f \quad (9)$$

$$F_{am} = 39.2 - 15.8 \log f \quad (10)$$

for business, residential, and rural environments, respectively, where the frequency f is in MHz. At 200 MHz, this model and CCIR Report 258-5 produce identical results. Equation (8) differs only 1 dB from that of Lauber and Bertrand[5] at 200 MHz for business areas. The slope of these curves is identical to that of Lauber and Bertrand at these higher frequencies. The above equations extend the noise models upward in frequency until the man-made and/or galactic noise drops into the internal noise of the receiving system. Lauber and Bertrand[6] have compared this model along with one due to Skomal[11]. The results are presented in Figure 7. The Hagn et al.[7] results are within ± 3 dB with the exception of the higher frequencies for the rural areas.

The Hagn et al. model also provides approximations for the standard deviations for the simple Gaussian model of Hagn and Sailors[12]. For frequencies between 1 MHz and 100 MHz, these standard deviations are given as 10.5, 8.5, 6.5, 4.5, and 1 dB for business, residential, rural, quiet rural, and galactic environments, respectively. For frequencies above 100 MHz, the values are based on the more limited data of Lauber and Bertrand[5]. The standard deviation σ_N, in dB, is given by:

$$\sigma_N = 10.5 - 9 \log(\frac{f}{100}), \text{ or } 2 \text{ dB} \quad (11)$$

$$\sigma_N = 8.5 - 9 \log(\frac{f}{100}), \text{ or } 2 \text{ dB} \quad (12)$$

$$\sigma_N = 6.5 - 9 \log(\frac{f}{100}), \text{ or } 2 \text{ dB}, \quad (13)$$

respectively, for business, residential, and rural man-made noise environments. These equations are useful for $\sigma_N \pm 0$ dB. The standard deviation σ_N is not allowed to go negative at higher frequencies but merely drops to 2 dB and stays constant for higher frequencies until F_{am} decreases to 0 dB(kT_o).

Another noise model often used as a man-made noise model in some applications is one known as the quasi-minimum atmospheric noise model[17]. It is based on a comprehensive examination of expected noise at many locations and for all seasons using data from the National Bureau of Standards noise measurement program, and shipboard measurements made at sea in the San Diego,CA area. Table 3 is a list of the values for this model. A fit to these data is given by

$$F_{am} = 60.0 - 27.5 \log f \quad (14)$$

where f is in MHz. Equation (14) is also given in Table 3. Note that the median rural noise equation is nearly equal to the quasi-minimum atmospheric noise equation. Results for rural noise equation are also presented in Table 3.

Measurements indicate that airborne man-made radio noise from a distant metropolitan area can be detected once an aircraft rises above the local optical horizon. Above 10,000 feet measurements show a broad noise signature representative of an entire metropolitan area. Roy has reported an airborne man-made radio noise model developed to evaluate the effect of man-made radio noise on the operation of meteor burst communication systems[18-19]. Equations developed by Skomal[11] were used to construct the model. Two parametric equations were used to model the height gain of man-made radio noise as a function of distance, 0 to 150 miles, from the source. Coefficients for these equations were calculated from data measured over Seattle[20]. Roy used two hundred of the nation's largest cities and 62 of the largest counties and military installations as sources of radio noise. Day and nighttime contours were produced in the 25 to 75 MHz range for altitudes between 30 and 70 thousand feet. These maps show that very little of the continental United States is free of airborne man-made noise. Minimum noise levels are found during the night at low altitudes for distances greater than 100 miles from most metropolitan areas. As an example Figure 8 shows daytime 45 MHz contours for an altitude of 5 thousand feet. Contours of constant radio noise power in dB above kTb are plotted for values of 15,20, and 25 dB. Shaded areas in the continental United States represent areas containing noise power 3 dB or less above galactic noise.

Table 3. Quasi-minimum atmospheric noise levels in dB above kT_o

Frequency (MHz)	Level Chase & Tirrell[17]	Equ.(14) (Quasi-Minimum)	Equ. (1) (Rural)
2	52	51.72	58.86
4	44	43.44	50.52
6	39	38.60	45.65
8	36	35.17	42.18
10	36	32.50	39.50
12	31	30.32	37.31
15	28	27.66	34.62
20	25	24.22	31.16
25	22	21.56	28.48
30	20	19.38	26.28

6. RECENT MEASUREMENTS

When one uses the models of CCIR Report 258, it is necessary to decide which environmental category a receive site belongs. This author had an opportunity to determine the environmental categories for the receive sites of an HF communication system. For this purpose he acquired man-made noise data measured on CDAA antennas at the receive sites of the communication stations at Adak,AL; Diego Garcia; Guam; Honolulu,HI; San Diego, CA; and Stockton,CA.

These measurements were made by the Naval Electronics Engineering Activity, Pacific(NEEAP) on the Automated AN/FRM-19(v) Test System. This system includes an Automated Noise Measurement System(ANMS). The ANMS allows the site to measure its baseline/strong signal level on a periodic basis. The ANMS acquires data every two hours at seven frequencies over a seven day period. This data is then averaged over this period, and a baseline noise/strong signal level is found. The ANMS acquires data data from a 0.5 MHz window centered on the seven frequencies(usually 2.5,5.0,7.5,10.0,12.5,20.0,30.0 MHz). The ANMS searches for the lowest power level or "hole" in this 0.5 MHz window. This 0.5 MHz window at a frequency of interest is divided into 83 channels of 3.6 kHz. The ANMS then samples the noise waveform in each channel by taking 50 consecutive points. By taking 50 samples, a window is set up in the time domain that will capture time related RFI noise, such as powerline noise. After the ANMS scans the 0.5 MHz window, it returns to the "hole" to measure the system noise level. The average power(true rms voltage) and V_d(voltage deviation) are then calculated from the digitized waveform. After the ANMS has collected the noise data for seven days, an operator can then proceed to plot out the data using different plotting modules to analyze the noise environment.

Baseline noise data was provided by NEEAP for the forenamed communications sites measured by the ANMS for the local noon period. Local noon was chosen as the most likely time of day that man-made noise would most likely be present. The data for Guam, measured from September 17, 1987 through September 24, 1987, was examined first because that was the only site for which there was other measured results available for comparison[9]. Figure 9 shows this data measured by the Stanford Research Institute(SRI) along with the data measured by NEEAP on a CDAA antenna. The SRI data was measured on a short vertical rod. For comparison purposes both quiet rural and galactic noise are included. Clearly there is a large difference between these two measurements part of which is due to the measurements by NEEAP on a CDAA type antenna rather than the standard short vertical rod.

George Hagn of SRI International provided this author with some conversion factors which he obtained while making noise measurements in Iceland[21]. Mr Hagn made noise measurements at the edge of the ground screen of the CDAA antenna with a calibrated nine foot vertical rod and then made noise measurements through the CDAA antenna to compare to the other measurements. He developed a rough set of corrections that could be applied to noise measurements made on the omni-beam output of the CDAA antenna. These are given in Table 4. The way they are used is that first the noise measurements in dBm are converted to dB above 1 micro-volt by adding 107(-107 dBm=0 micro-volts across a 50 ohm resistance). Then the antenna correction factor is added. Finally, the noise field strength is converted to F_a by using the relationship between F_a and noise field strength found in CCIR Report 322-3[1] taking into account the receiver bandwidth, which in this case was 3.6 kHz.

Table 4. CDAA to 9 Foot Rod Conversion Factors

Frequency (MHz)	Antenna Factor dB/1 Meter
2.0 - 2.5	-3,± 6 dB
2.5 - 8.0	-23,± 8 dB
8.0 -13.0	-15,± 8 dB
13.0-30.0	-14,± 8 dB

Figure 10 shows the results of appling these antenna factors to the NEEAP measurements. The curve marked Guam-NEEAP is the result of appling the antenna factor disregarding the error term. The curve marked Guam-NEEAP Adjusted has had the upper limit of the error term added to the antenna factor for 5, 20 and 30 MHz. Although the Guam-NEEAP curve is an improvement over that show in Figure 9 for this case, the Guam-NEEAP Adjusted is an even better improvement. Based on this comparison, the measured noise at the other five sites was adjusted using Table 4; for 5,7.5, 20, and 30 MHz, the upper error, 8 dB, was added to the antenna factor. Figure 11 shows the results of the NEEAP measurements with these antenna factors applied. Curves for rural and quiet rural and galactic noise are show for comparison.

In addition to providing man-made noise measurement data for Guam, Shepard et al.[9] also show the results of measurements made at Keflavik, Iceland; Rota, Spain; and Bremerhaven, Germany. These results are repeated here as Figure 12.

7. DISCUSSION

Engineers and operational analysts who use these CCIR man-made models are faced with the problem of determining whether any environment is most like a U.S. business area, a U.S. residential area, or a U.S. rural area over a decade ago. The only other alternative is to assume the environment is similar to a quiet rural area near one of the quiet stations where the atmospheric noise data were gathered over three decades ago. Hagn has provided additional insight into this problem[22].

One problem already encountered in this paper is the effect of the receive site antenna on the measured or estimated noise values. In fact in the case encountered here additional data is needed comparing CDAA antenna and short vertical rod noise measurements. Hagn and Shepherd[23] have provided some insights into this problem of the effect of different antennas on noise estimation and measurement; however, the problem is not solved.

In the discussion of the simple Gaussian model, it was assumed that the median value of man-made noise Fam was an efficient estimator of the mean. Sailors[24] has reviewed techniques for estimating the mean and standard deviation of a parameter from its quantiles. Results using these techniques were compared to that obtained from estimating the sample means and standard deviations from data samples of man-made noise. For man-made noise modeling, it was determined that the mean could be estimated to an accuracy of 0.1 dB using the expression $F_{am} + 0.237(D_u - D_l)$. In the example given in Figures 4 and 5, the median noise was 36.46 dB. The value of the mean using this expression is 37.43 dB. This compares to 37.5 dB given by the simple Gaussian obtained from the chi-square.

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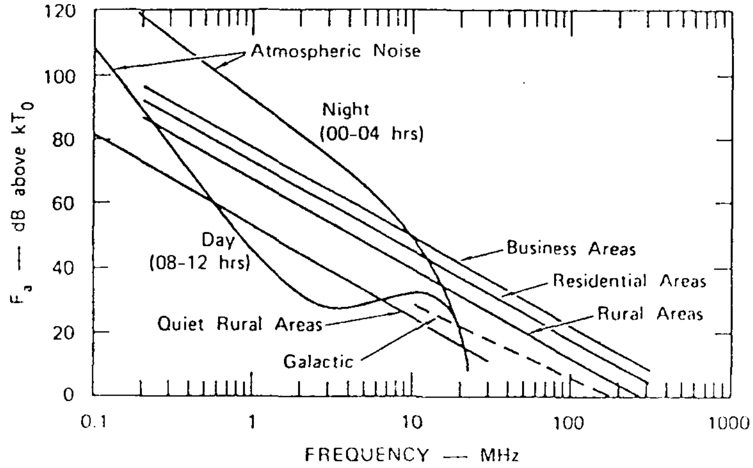

Figure 1. Estimates of median values of man-made, atmospheric, and galactic noise expected near Wshington, D.C. during summer[1-2].

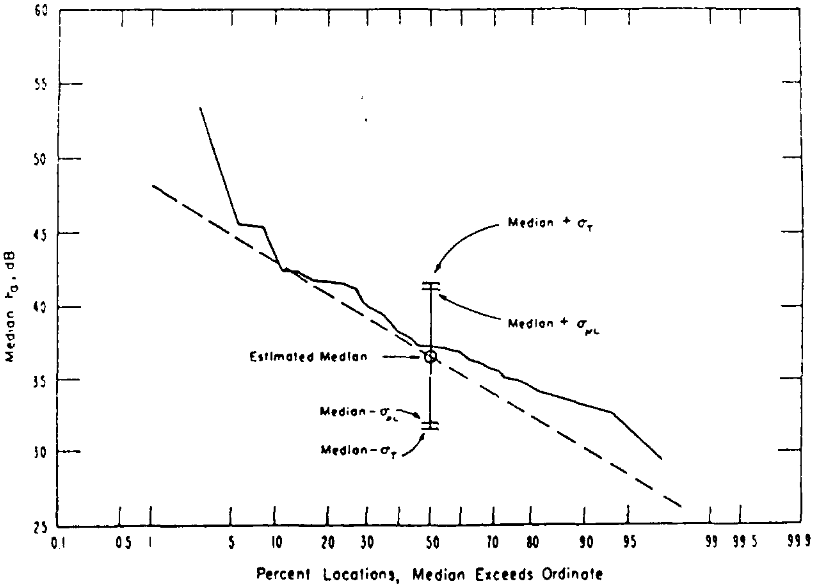

Figure 2. Distribution of location median of F_a values for man-made noise in residential areas at 20 MHz[2].

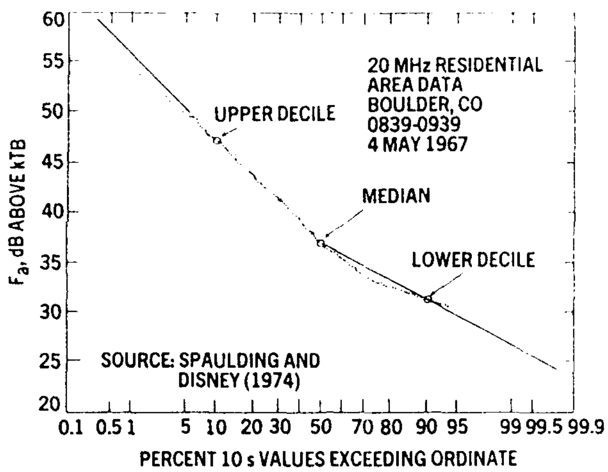

Figure 3. Example distribution of F_a at one location during one hour with short-term median and deciles indicated[2].

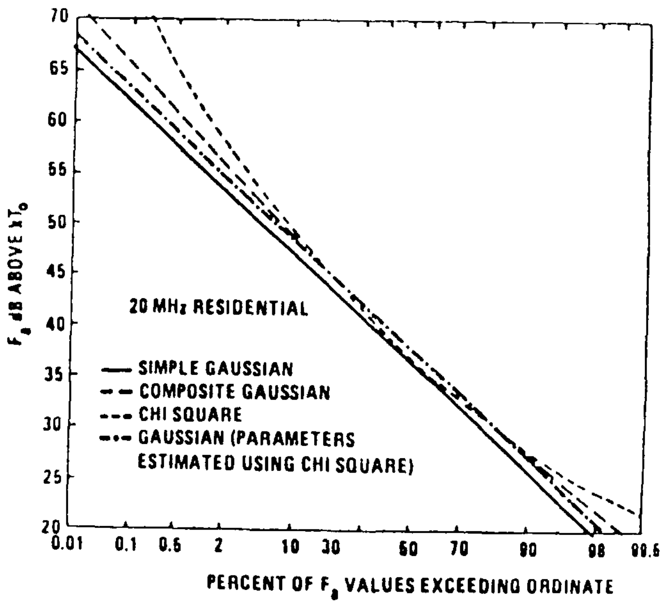

Figure 4. Comparison of model predictions for 20 MHz in a residential area[12].

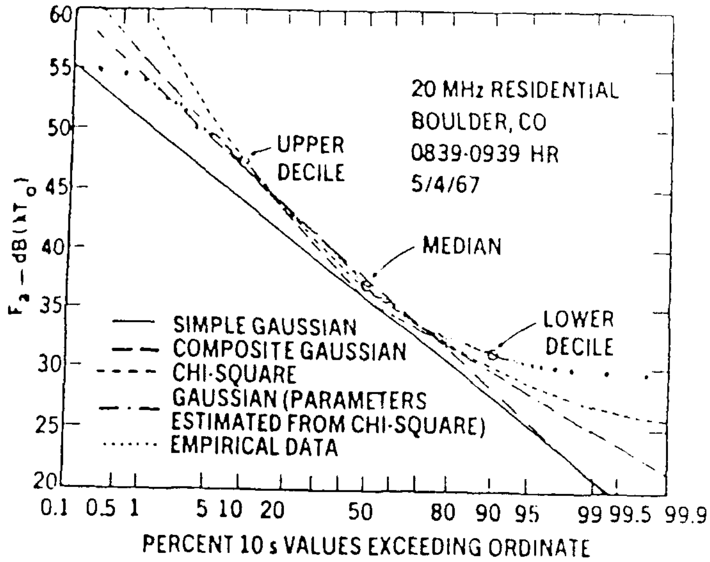

Figure 5. Example comparison of models and data[12].

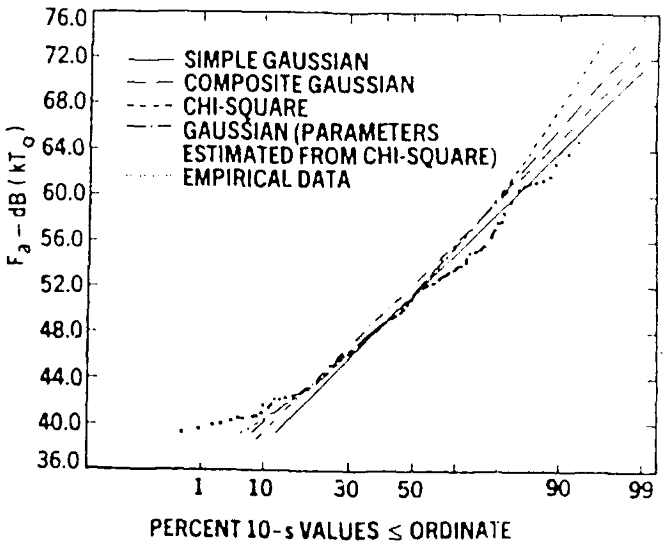

Figure 6. Comparison of models and data: business[12].

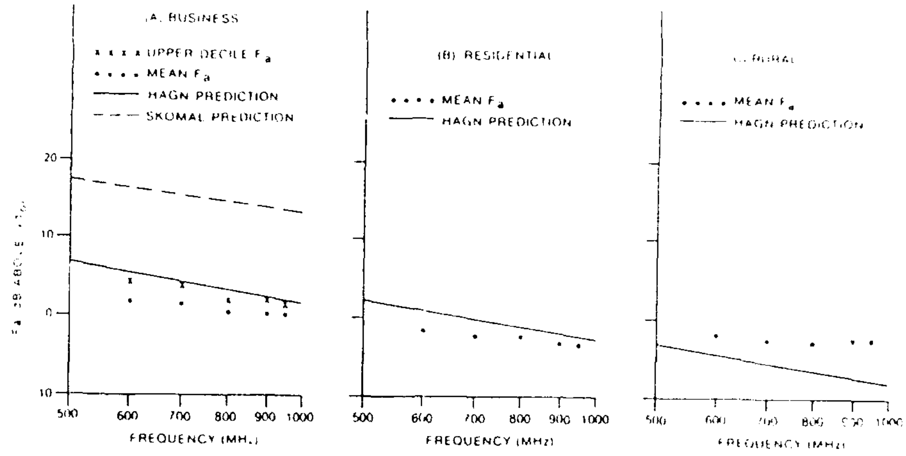

Figure 7. Comparisons of measurements with recent prediction models[6].

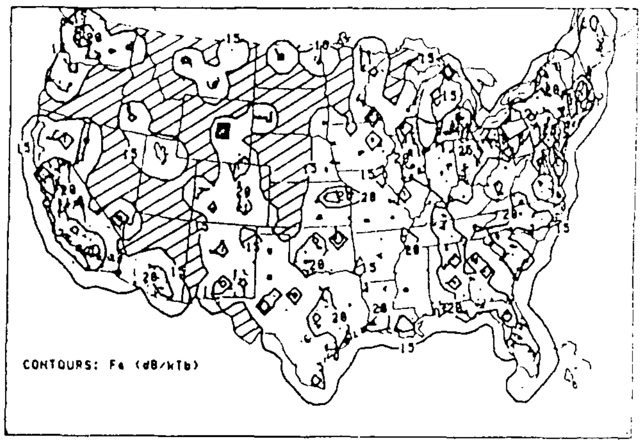

Figure 8. Daytime 45 MHz airborne man-made radio noise map of the continental United States for an altitude of 5 thousand feet[18-19]. Shaded areas represent noise power 3 dB or less above galactic noise.

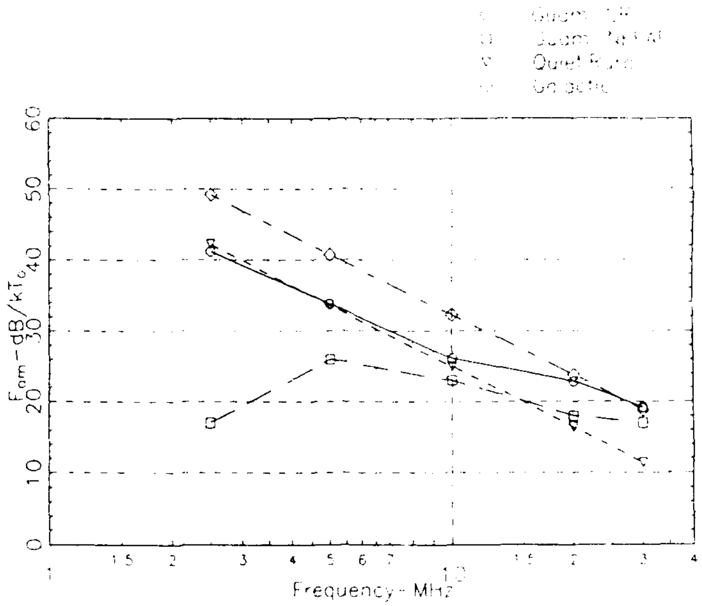

Figure 9. Comparison of man-made noise measurements at Guam made by Stanford Research Institute(SRI) on a short vertical rod with data measured by the Naval Electronics Engineering Activity, Pacific(EEAP) on a CDAA antenna.

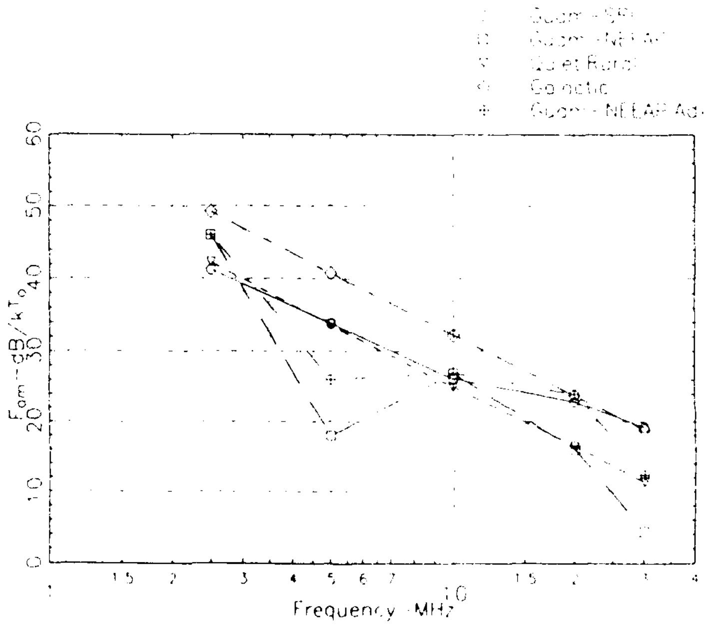

Figure 10. Comparison of man-made noise measurements at Guam made by Stanford Research Institute(SRI) with data measured by the Naval Electronics Activity, Pacific(NEEAP).

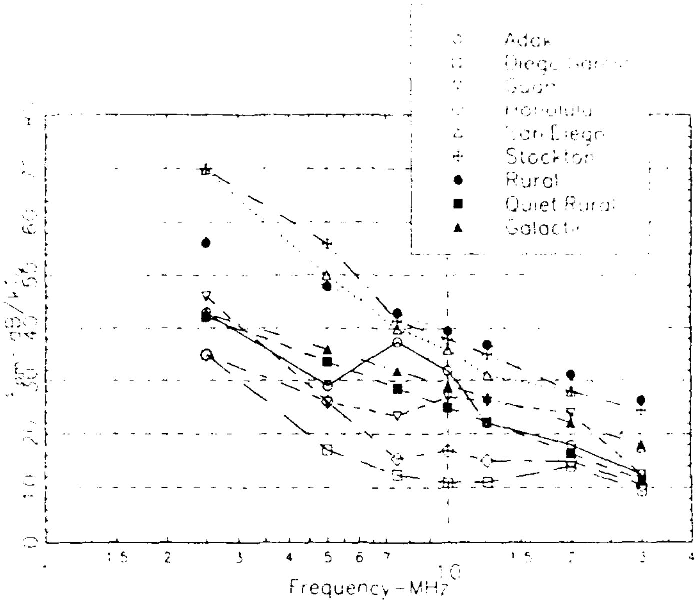

Figure 11. Man-made noise environment at sites in the Pacific Ocean.

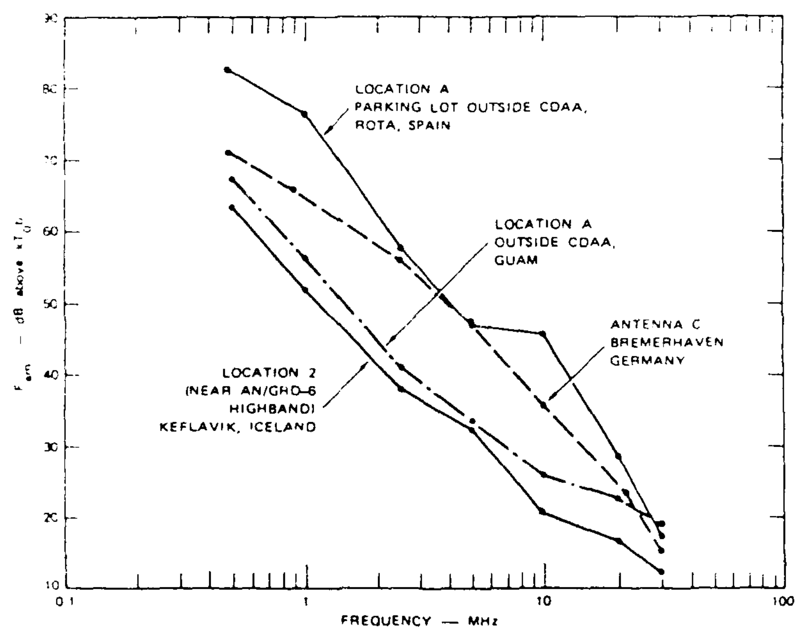

Figure 12. A comparison of F_{am} at quiet locations[9].