B. This, combined with traffic engineering estimates of future highway usage, may provide the best estimate of future radio noise levels at many locations.

Relatively good correlation was found between power consumption in an area and the radio noise power below 20 MHz. Unfortunately, in most areas, statistics on power consumption are very difficult, if not impossible, to obtain. Statistics on population density are readily available for small areas (called a standard location area or SLA for the 1960 census) from the Census Bureau. Population density in a SLA, however, shows very poor correlation with the noise level measured in the SLA (Spaulding et al., 1971).

4. MAN-MADE RADIO NOISE ESTIMATES

4.1 Available Noise Power, F_a

In determining the expected man-made radio noise power and its variation for any given location from measurements made at other locations, several factors must be taken into consideration. The main factor, of course, is the similarity between the areas where the measurements were made and the area in question. For any particular location the noise level may be due to particular sources, such as factories in which a large number of arc welders are employed, power lines, etc. The estimates given here are in terms of business, residential, and rural areas, and a physical examination of the area in question should determine which of these types of areas will most closely correspond to the selected area. In addition to these three basic types of areas, estimates are also given for interstate highways and parks and university campuses. Estimates for power lines are also given.

4.1.1 Estimates of F_a for Typical Areas

Using all accumulated data in the data base, the areas where measurements were made were divided into the business, residential, and rural classifications. These divisions were chosen because they can be easily defined and recognized. All data used in this report were measured at ground level. The man-made noise may be quite different at some elevations above ground level or in areas that cannot be logically placed in one of the three classes of areas chosen due to peculiar local conditions. Since the data given are intended for estimating the noise conditions at average locations, data containing these strictly local, unusual effects have not been used.

After the division of the data into the various classes, each set of data was analyzed using the recorded values of F_a. Using the individual median values of the sets of mobile runs (see Appendix A) for each type of area, a linear regression line was found by a least squares fit for F_a, in decibels versus the logarithm of the frequency, for each area. The three regression lines were quite close in slope, showing less than 2 dB per decade of frequency difference. The data for all cases and all frequencies were then combined to find the slope giving the best fit to all the data. A standard statistical test for significance in the differences of the various slopes (one for each of the three types of areas and one for all data) showed that the slopes could all be considered equal to -27.7 dB per decade at the 95 percent confidence level. Linear regression, with the slope constrained to this value, was then used to obtain figure 1. Figure 1 provides an estimate of the median radio noise power spectral density that will be found at that type of location as a function of frequency.

At 250 MHz, at rural locations especially, the system noise figure (Appendix A) was close to the available external radio noise. Since a value related to system noise is recorded (by taking a meter reading of F_a with the input connected to a dummy antenna in place of the recording antenna) at the time of calibration, a means of approximately determining the system noise factor for any run is available. When the system noise factor and the recorded values were close to the same level, the values were discarded or corrected to remove the effect of system noise on the value of F_a. If the recorded value was within 0.5 dB of system noise, the recorded values were discarded. If the recorded value was more than 0.5 dB but less than 6 dB above system noise, the reading was corrected by converting the reading from a decibel value to a power value, subtracting the system noise power and converting the difference back to a value of F_a. Because of this loss of the lowest values at 250 MHz, there is still an unresolved question of whether the - 27.7 dB/decade rate of charge of F_a with frequency is valid to 250 MHz, since all 250 MHz measured medians (and in some cases, the lower decile values) are above the estimated median value line.

In addition to the expected values of man-made radio noise at business, residential, and rural areas, a value for quiet rural areas from CCIR (1964) is also shown on figure 1. These values were obtained from measurements at rural locations chosen with great care to insure low levels of man-made radio noise and probably represent a lower limit of levels to be found. Galactic noise levels are also shown on figure 1 for frequencies above 10 MHz. The level of the galactic noise will vary greatly between 10 and approximately 30 MHz, depending upon the behavior of the ionosphere. Above these frequencies, though, the levels will remain quite constant (Crichlow et al., 1955).

Since the figure 1 estimates for business, residential, and rural locations represent the average values of all similar locations, the variation about the average must be determined next. This variation from location to location in similar areas is indicated by the standard

Table 1. Expected Variation of Median Values about Estimates for Business, Residential, and Rural Locations.

Frequency in MHz	Standard Deviation, σ, in dB		
	Business	Residential	Rural
0.25	6.12	3.54	3.89
0.5	8.21	4.28	4.40
1.0	2.33	2.52	7.13
2.5	9.14	8.06	8.02
5.0	6.08	5.54	7.74
10.0	4.15	2.91	4.03
20.0	4.93	4.65	4.53
48.0	7.13	3.98	3.23
102.0	8.76	2.73	3.82
250.0	3.77	2.87	2.26
σ_T*	7.00	5.00	6.45

*σ_T = Standard deviation of all measured medians about regression line of figure 1.

deviation, σ_T, given in table 1. The value of σ_T is given for each of the three types of areas and is the value obtained by using the data at all frequencies to obtain the standard deviations about the regression line shown for each type of location.

Table 1 also gives the standard deviation, σ, at each of the measurement frequencies. A better estimate of the variation of the median values for these typical areas at any given frequency might possibly be obtained by interpolation of the σ's for the measurement frequencies rather than using σ_T.

An example of the location variation for a given frequency and area type is shown on figure 2. Shown on figure 2 is the cumulative distribution of the median values obtained from residential areas at 20 MHz. Also shown is the estimate for a residential area at 20 MHz from figure 1 and this estimate plus and minus σ and σ_T (from Table 1).

Once the best estimate of the median value of F_a for a given location has been found, the next point to consider is the variation of F_a at that location with time. A number of time periods are of concern in determining the temporal variation to be expected. The first is the expected variation within a period up to one hour. In the noise measurement method used, 10-sec samplings of the running average of F_a were recorded where the time constant for the power moment, F_a, was approximately 50 sec. Thus, 360 sample values were obtained for each hour of recording time. Again, using a 20 MHz residential area run, as an example, figure 3 shows a typical cumulative distribution of the individual F_a values measured within an hour at a location. These values were measured May 4, 1967, between 0839 and 0939 local standard time in Boulder, Colorado. Also shown on figure 3 are the upper and lower decile values.

Table 2 and figure 4 show the estimates of the ratios, in decibels, of the upper decile value to the median, D_u, and of the median to the lower decile, D_ℓ. These values can be used to estimate the variation of F_a about the estimated median (from fig. 1) for periods from several minutes up to one hour.

The data were analyzed to obtain the median value of F_a for each measurement location and also the ratio in decibels of the upper and lower decile values to the median. Figure 5 shows the results of this analysis for all measurement locations considered business areas, giving the mean value of the business area location medians and the 27.7 dB per decade regression line (from fig. 1) along with the expected variation within an hour. The root-mean-square of all the business locations D_u's and D_ℓ's for each frequency is given on figure 5 to show the expected variation within an hour. The same information is given on figure 6 for residential areas, figure 7 for rural areas, figure 8 for interstate highways, and figure 9 for parks and university campuses.

Table 2. Expected Variation, Man-Made Radio Noise Levels, about the Median Value for a Location, within the Hour.

Frequency MHz	Business Area		Residential Area		Rural Area	
	D_u(dB)	D_ℓ(dB)	D_u(dB)	D_ℓ(dB)	D_u(dB)	D_ℓ(dB)
0.25	8.1	6.1	9.3	5.0	10.6	2.8
0.5	12.6	8.0	12.3	4.9	12.5	4.0
1.0	9.8	4.0	10.0	4.4	9.2	6.6
2.5	11.9	9.5	10.1	6.2	10.1	5.1
5	11.0	6.2	10.0	5.7	5.9	7.5
10	10.9	4.2	8.4	5.0	9.0	4.0
20	10.5	7.6	10.6	6.5	7.8	5.5
48	13.1	8.1	12.3	7.1	5.3	1.8
102	11.9	5.7	12.5	4.8	10.5	3.1
250	6.7	3.2	6.9	1.8	3.5	0.8

The next longer time period of interest is the diurnal variation that can be expected. Since the measurements of man-made radio noise consisted of values at MF and HF as well as the higher frequencies, most of the measurements (all the measurements discussed ~~to~~ this point) were taken between about 0830 and 1500 LST. During this period, atmospheric radio noise is at its lowest level and is least likely to affect the readings. The predictions so far presented can, therefore, be considered the values of man-made radio noise for the hours of daylight. Several 24-hour continuous runs have been made on the grounds of the Department of Commerce, Boulder Laboratories. Some of these runs were made at the end of wing 1 near the parking areas. The hourly median values of F_a recorded on April 27-28, 1971, are shown on figure 10. This particular run was started at 0930, LST on April 27 and ended at 0900 LST on April 28. Several items are noteworthy on this figure. First are the relatively high levels caused by atmospheric radio noise between 1800 on April 27 to 0700 on April 28 on the three lower frequencies, and to a lesser degree, present in the 20 MHz values. A peak is observed between 1600 and 1700 on the 2.5 and 5 MHz, but not on the 250 kHz. This would indicate two things. The levels throughout the day on 250 kHz probably are determined by the atmospheric radio noise rather than man-made. The peak on 2.5 and 5 MHz probably is a true man-made radio noise level and was associated with power lines since it was not nearly as predominant (though noticeable) on the four higher frequencies. The low, rather steady levels on 102 MHz at 8 to 10 dB probably were caused by a combination of set noise and galactic noise. Set noise was measured at 7.4 dB, and the expected galactic noise would be 6 ± 2 dB. Combining these two values would give an expected level of 9.8 ± 1 dB. The balance of the values shown on figure 10 probably are all predominantly man-made radio noise. The data shown on figure 10 for 0.25, 10, and 48 MHz are also shown on figure 11 and compared with the data recorded on April 19 and 20, 1967, and on May 11 and 12, 1971. Most of the noise recorded on 250 kHz was atmospheric in origin though the lower values recorded on April 29 and 30, 1967, were from man-made noise. Perhaps the most interesting feature of this figure is the high spike on May 12, 1971, at 48 MHz and the corresponding high reading on 20 MHz. This particular run was started at 1055 LST, but daylight saving time was in effect, and the clock time was 1155 MDST. Since only 5 min of recordings were used to obtain this value, the median was greatly influenced by the heavy traffic density of employees' leaving for lunch. The hourly medians on frequencies of 20 MHz and above are generally influenced by beginning of work, lunch hour, and end of work times, though the effect is somewhat hidden when the median value for the whole hour is considered. The May 12 recording suggests that a 5-min median could be expected to increase by some 15 dB near a parking lot during a peak traffic period. The expected galactic noise level is shown for 20 and 48 MHz. The lowest levels on both of these frequencies were greatly influenced by this type of noise. While it appears that the 1967 data are generally lower than the 1971 data, no significant yearly trends can be established on this basis. It is interesting to note that the day-to-day variation shown here is considerably less than that predicted within the hour as indicated by the decile values for business areas, figure 5, and residential areas, figure 6.

A continuous three-day run was made with the mobile radio noise laboratory parked on the DOC Boulder Laboratories grounds near Broadway (a main highway on the east side of the Laboratories). The diurnal variation of the noise measured at this location is shown on figure 12. The days shown are Wednesday afternoon, October 25, 1967, through Saturday morning, October 28, 1967. The levels recorded are greatly influenced by traffic patterns at this location, as is discussed in greater detail in Appendix B. The repeatability of the diurnal variation from such a location can be seen from figure 12. The 24-hr pattern shows little variation on the three work days--Wednesday, Thursday, and Friday. It is especially interesting to note the same pattern is repeated on Saturday after 0800, but that the "morning rush hour noise," between 0600 and 0800, is not present on Saturday, a nonworkday for most. Comparing figures 11 and 12, quite good agreement is found for the measurements between 0100 and 0400 when traffic on Broadway is at the lowest. For the rest of the day, the noise near the highway is 5 to 10 dB higher than the noise at the end of wing 1, which is several hundred feet from the highway.

For certain areas where activities are seasonal (resort areas, industrial areas where the work is seasonal such as canneries, etc.), an estimate of the seasonal variation of the man-made radio noise levels may be required. In some areas this variation can be estimated on the basis of a change in the type of area. The area may be considered a business area if the increased activity causes an increase in the business or industrial activity during a given season and essentially a residential or rural area during the balance of the year. Since this seasonal variation is so dependent on actual location usage, no general estimates of seasonal variation can be given.

The longest time period of interest is the change of noise levels from year to year. Here again, growth in a given area may change the general nature so that the area may go from rural to residential or residential to business (or in a few cases, the reverse) in a period of one year or more. Therefore, long-range estimates can to some extent be predicated on growth potentials in the area. Trends in the increase in electric power consumption and the number of registered automobiles (both possible predictors of man-made noise) are given for the United States as a whole in JTAC (1968). This type of information indicates that the total man-made interference is increasing in the United States but does not provide data helpful in estimating the noise environment at a given location. In a well established business area where streets are already crowded with vehicles, the annual change will be very small. For example, measurements were made by ITS in downtown Washington, D.C., in 1960 and repeated in 1966. The comparison of the two sets of recordings showed that the change in man-made radio noise was negligible over the 6-yr period. The level at a given location in the area varied by as much as 8 dB between the two sets of measurements, but the median value for the area increased by less than 2 dB in the 6-yr period. Since variations of these magnitudes are found on a day-to-day basis, even in a single area, they cannot be considered significant over the 6-yr period. During this same period, the number of automobiles registered in and near Washington, D.C., increased considerably as did the population. The measured radio noise was predominantly from power distribution lines at the lower frequencies and from vehicle ignition systems at the higher frequencies. Over the 6-yr period, no major change was made to the power distribution system and only minor changes in types of business and amount of power supplied in the area. It probably is reasonable, therefore, to expect little change in the man-made radio noise levels at the lower frequencies. Improvement in ignition noise suppression techniques used by the manufacturers over this period would explain some of the lack of increase in the measured levels at the higher frequencies. Since the streets were already crowded in 1960, vehicle density in that particular area was not changed to any large extent by the greater number of cars in the larger areas. This does not imply that the man-made radio noise remained constant in surrounding areas. Areas that were rural in 1960 and were developed into residential or business areas by 1966, areas where traffic density showed large increases, and areas that changed in character and/or where power consumption increased drastically probably would have shown an increase in the man-made noise levels.

All of the measurements used in obtaining the above estimates were made using a vertical omnidirectional antenna and, therefore, strictly speaking can be considered only as estimates of the vertical component of the radio noise. Very few data are available on the relationship between the vertically and horizontally polarized components. The information that is available indicates that on the average there probably is very little difference in the rms level of the two components. The AMA (1971) and Doty (1971) show peak voltage measurements on individual automobiles and an array of automobiles using a log periodic antenna in a horizontal and vertical configuration with the center line of the antenna at a height of 10 ft and measuring over a frequency range from 20 MHz to 1 GHz. These measurements indicate that the vertical component may be higher than the horizontal component between 30 and 36 MHz and between 210 MHz and 1 GHz, and there may be as much as 10 dB difference at certain frequencies. Doty also shows the horizontal component as much as 5 dB higher in the frequency range from 63 to 210 MHz. The spectrum was swept from 20 MHz to 1 GHz in approximately 6 min with the antenna in a horizontal position for one sweep and then in a vertical position for the next.

The results of a small sample of measurements made recently by ITS at 250 MHz using two halfwave dipoles in corner reflectors 10 ft above ground are given in figure 13. Two short runs were made with one antenna in a horizontal and the other in a vertical configuration. The measurements were made simultaneously on the two configurations. During one run, the antennas were separated by a distance of 10 ft, while antenna separation was 50 ft during the other run. The offset of 0.559 dB in the equation for the linear regression line is no doubt due to a slight difference in gain settings in the two channels. Even though a fair amount of spread about the regression line is noted, the best estimate of the difference between the vertical and horizontal components is less than 1 dB. Admittedly, both of these samples are relatively small and, therefore, may or may not be representative of the effects of polarization.

All of the above can be used either in a quantitative or qualitative way to assess the best estimate of the level of the average power of the man-made radio noise for a given location and its variation within various time frames.