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# Man-Made Noise Power Measurements at VHF and UHF Frequencies

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# MAN-MADE NOISE POWER MEASUREMENTS AT VHF AND UHF FREQUENCIES

Robert J. Achatz and Roger A. Dalke*

Man-made noise generated by automotive ignition, power distribution and transmission, industrial equipment, consumer products, and lighting systems degrades the performance of radio systems. Man-made noise models, derived from measurements made in the 1970s, may be inaccurate due to changes in these technologies. For example, recent man-made noise measurements performed by ITS in the 136 to 138 MHz meteorological satellite band indicated that man-made noise power in residential areas is lower than predictions by these models. However, these same measurements indicated that man-made noise in business areas has not changed. UHF man-made noise has not been comprehensively measured and modeled. This report describes UHF man-made noise measurements conducted in the Denver, CO metropolitan area in 1999. Measurement data is analyzed and results are compared to other measurements and models. These results showed that 402.5 MHz UHF noise levels in business areas were high enough to adversely affect communication system performance some of the time.

Key words: radio channel, man-made noise, impulsive noise, non-Gaussian noise, simulation of communication systems, noise measurement, noise modeling

## 1. INTRODUCTION

Man-made noise power was measured comprehensively 25-35 years ago [1]. These measurements, conducted from 0.25 to 250 MHz, were used to develop the CCIR [2] and current ITU-R [3] man-made noise model commonly used in radio link design to this day. Since that time no comprehensive man-made noise power measurements have been made, in spite of the fact that technological changes may have made this model inaccurate. In 1996 the Institute for Telecommunication Sciences (ITS) conducted man-made noise power measurements at 137 MHz for the National Oceanic and Atmospheric Administration (NOAA) [4] which had been tasked with converting space-to-earth VHF analog-modulated radio links to digital modulation. The measurements showed that VHF man-made noise power has decreased in residential areas and has remained constant in business and rural areas.

Predicting whether UHF frequencies would follow the same trend as VHF frequencies is difficult. For example, noise due to automotive ignition systems may have also decreased in UHF frequencies as it did at VHF frequencies; however, modern electronic devices such as personal computers and pulse-width modulated motor drives may have increased noise. All these factors point to the need for a comprehensive man-made noise measurement and analysis campaign.

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As a beginning, ITS has performed a limited set of noise power measurements at VHF and UHF frequencies in business and residential settings at 137.5 MHz, 402.5 MHz, and 761.0 MHz. These measurements were collected between April and August of the year 1999 in the Denver, CO metropolitan area. Instantaneous and long term noise power statistics were included in the measurement data analysis.

## 1.1. Background and Terminology

### 1.1.1 Noise Voltage Representations

A noise voltage is a random function of time whose behavior can only be described statistically. The time-varying noise voltage, *v(t)*, is represented as a *passband* signal centered about a carrier frequency, $f_c$,

$$v(t) = Re\left\{\hat{v}(t)e^{j2\pi f_c t}\right\}, \tag{1.1}$$

where $Re\{\}$ denotes the real part and $\hat{v}$(t) is the noise voltage *complex baseband* signal centered about 0 Hz that can be represented in Cartesian or polar form as follows:

$$\hat{v}(t) = x(t) + j\,y(t) = \sqrt{x(t)^2 + y(t)^2}\, e^{j \arctan\left(\frac{y(t)}{x(t)}\right)}, \tag{1.2}$$

where *x(t)* and *y(t)* are the baseband signal real and imaginary components, respectively. Both *v(t)* and $\hat{v}$(t) are random processes defined by one or more random variables. For example, if *v(t)* is *white Gaussian noise,* the real and imaginary components are independent and identically distributed zero-mean Gaussian random variables whose *power spectral density* (PSD) is flat. The corresponding amplitude is *Rayleigh distributed* while the phase is *uniformly distributed*.

### 1.1.2 Instantaneous Noise Power

We define the *instantaneous noise power* as

$$w = |\hat{v}(t)|^2 = x(t)^2 + y(t)^2. \tag{1.3}$$

In this report the instantaneous noise power is normalized by the average noise power due to black body radiation and thermal noise that is present in all radio systems. This average noise power is $kT_0b$ where $k = 1.38 \times 10^{-23}$ W/Hz/K is Boltzman's constant, $T_0 = 288$K is the absolute temperature, and $b$ is the receiver *noise equivalent bandwidth*.

### 1.1.3 Statistics of Instantaneous Noise Power

The *cumulative distribution function (CDF)* of instantaneous noise power describes the probability that the noise power will not exceed a value

$$P(W_{RV} \le w) = \int_{0}^{w} p(x)dx \ , \tag{1.4}$$

where $W_{RV}$ is the noise power random variable, $w$ is the noise power independent variable, and $p(w)$ is the *probability density function (PDF)* of the noise power random variable. Radio engineers are concerned with the probability that the noise power will exceed a value. This probability is expressed as

$$A(w) = P(W_{RV} > w) = \int_{w}^{\infty} p(x)dx \tag{1.5}$$

and is customarily referred to as the *amplitude probability distribution* function (APD).

For white Gaussian noise, the amplitude PDF, expressed in $w$, is

$$p(w) = \frac{1}{w_0} e^{-\frac{w}{w_0}} \ , \tag{1.6}$$

where $w_0$ is $F_x^2 + F_y^2$ which is equivalent to the average power of $w$. The amplitude CDF, expressed in $w$, is

$$P(W_{RV} \le w) = 1 - e^{-\frac{w}{w_0}} \ , \tag{1.7}$$

and the APD, expressed in $w$, is

$$A(w) = P(W_{RV} > w) = e^{-\frac{w}{w_0}} \ . \tag{1.8}$$

Receiver performance can be predicted from the APD [5,6]. The APD, in turn, is dependent on the bandwidth of the measurement, bandwidth of the noise, and time intervals between noise pulses. The APD of zero-mean, white Gaussian noise is completely described by its mean power; therefore the performance of a receiver in white noise can be predicted from mean noise power alone.

In this report APD's are plotted on a *Rayleigh probability graph* whose axes represent the amplitude in dB above $kT_0b$ and the percent-of-time the amplitude is exceeded. On a Rayleigh probability graph, noise with a Rayleigh amplitude distribution forms a straight line with slope -1/2 . Impulsive noise is represented by amplitudes that exceed this line at low probabilities. Continuous wave interference is represented by an approximately straight line with a slope that approaches zero as the signal-to-noise ratio increases.

Mean, median, and peak statistical functions are commonly used to characterize noise power. The mean power statistic is described in the next section. Median is the power which is exceeded 50% of the time and peak is somewhat arbitrarily defined to be the power that is exceeded 0.01% of the time. For white Gaussian noise with Rayleigh distributed amplitudes, the mean lies on the 37.0 percentile and the median and peak are 1.6 dB below and 9.6 dB above this mean value, respectively.

### 1.1.4 Average Noise Power

Zero-mean Gaussian noise is completely described by its variance, which is equivalent to the average noise power. The average noise power does not completely describe non-Gaussian noise but is vitally important. The *average noise power* is defined as

$$w_0 = E\{w\} \tag{1.9}$$

where $E\{\}$ denotes the expected value of its argument. The *average noise power* relative to $kT_0b$ is called the *noise factor* and is given by

$$f = \frac{w_0}{kT_0b} , \tag{1.10}$$

and the *noise figure* in dB is

$$F = 10\log_{10} f. \tag{1.11}$$

Noise sources are often specified in terms of temperature, t. Temperature in K and noise factor is related by

$$f = \frac{t}{290K}. \tag{1.12}$$

### 1.1.5 Antenna Average Noise Power

The noise collected by the antenna originates, presumably, from widely scattered directions at or near the horizon and is therefore altered by the receiving station antenna directional gain. If $S(2,N)$ is the power density coming from elevation $2$ and azimuth $N$; and $g(2,N)$ is the antenna directional gain relative to isotropic, the total noise power received by an antenna is

$$w_a = \frac{\lambda^2}{4\pi} \int_0^{2\pi} \int_{-\pi/2}^{\pi/2} S(\theta,\phi) g(\theta,\phi) \cos(\theta) \, d\theta \, d\phi \tag{1.13}$$

where $8$ is the wavelength. The corresponding antenna noise factor is

$$f_a = \frac{E\{w_a\}}{kT_0 b} \ . \tag{1.14}$$

A noise power measurement system consists of an antenna, antenna matching circuit, transmission line, and receiver. If the antenna matching circuit and transmission line are assumed to be lossless and operating at a temperature $T_0$, the measured noise factor is related to the antenna noise factor and receiver noise factor by

$$f_a = f - f_r + 1 \tag{1.15}$$

where $f$ is the measured noise factor and $f_r$ is the receiver noise factor.

### 1.1.6 Noise Power Statistics

Man-made noise power statistics are non-stationary in that they have been found to vary over time and location. The statistical behavior of noise power can be shown by plotting the distribution on a *normal probability graph* where random variables that are Gaussian distributed form a straight line with a slope equal to its standard deviation and a median equal to its mean. The normal probability graph can be used to display *within-the-hour*, *hour-to-hour*, and *location-to-location* noise power statistics.

### 1.2 Predicted Noise Power

Noise power present for 50% of the time and 50% of the locations is predicted as a function of frequency by

$$F_{am} = c - d\log_{10} f \tag{1.16}$$

where $c$ and $d$ are constants and $f$ is frequency in MHz. $F_{am}$ is derived from an ensemble of $f_a$ defined in Equation 1.15. Below 200 MHz, the longstanding ITU-R model provides values of 76.8, 72.5, and 67.2 dB for $c$ for business, residential, and rural environments and 27.7 dB/MHz for $d$. Above 200 MHz, Hagn [7] provides values of 49.2, 45.2, and 39.3 dB for $c$ for business, residential, and rural environments and 15.8 dB/MHz for $d$. These values were based on the extrapolation of a number of lower UHF frequency spot measurements reported in the literature. Lauber [8] analyzed man-made noise power measurements obtained in 5 business, 10 residential and 2 rural environments at 600, 700, 800, and 900 MHz with a 100 kHz bandwidth. These measurements agreed well with Hagn's predictions.

Natural noise is produced by extraterrestrial and atmosphere sources. The total power is dependent upon the directionality of the source and receiving antenna. The omnidirectional antenna used in these measurements effectively attenuates the noise power of directional sources.

The sun, galactic center, cosmos, and atmospheric water vapor all have insignificant noise powers when measured with an omnidirectional antenna. Galactic noise may not be insignificant. Figure 1 summarizes noise power trends over a wide frequency range. Table 1 provides an estimate of natural and man-made noise power at the measurement frequencies.

Table 1. Natural and Man-made $F_{am}$ (dB above $kT_0b$) at Measurement Frequencies

| Environment/type | Frequency (MHz) | | |
|---|---|---|---|
| | 137.5 | 402.5 | 761.0 |
| Business | 17.6 | 8.1 | 3.7 |
| Residential | 13.2 | 4.1 | -0.3 |
| Rural | 8.0 | -1.9 | -6.3 |
| Galactic | 2.8 | -7.9 | -14.3 |

For comparison, values of previous ITS measurements at 137.5 MHz are 18.0, 6.0, and 6.3 dB for business, residential, and rural environments. These measurements showed that recent business and rural noise powers are similar to older measurements but residential man-made noise may have decreased. Measurements and analysis for this report will attempt to estimate corresponding values for business and residential man-made noise power at 402.5 and 761.0 MHz.

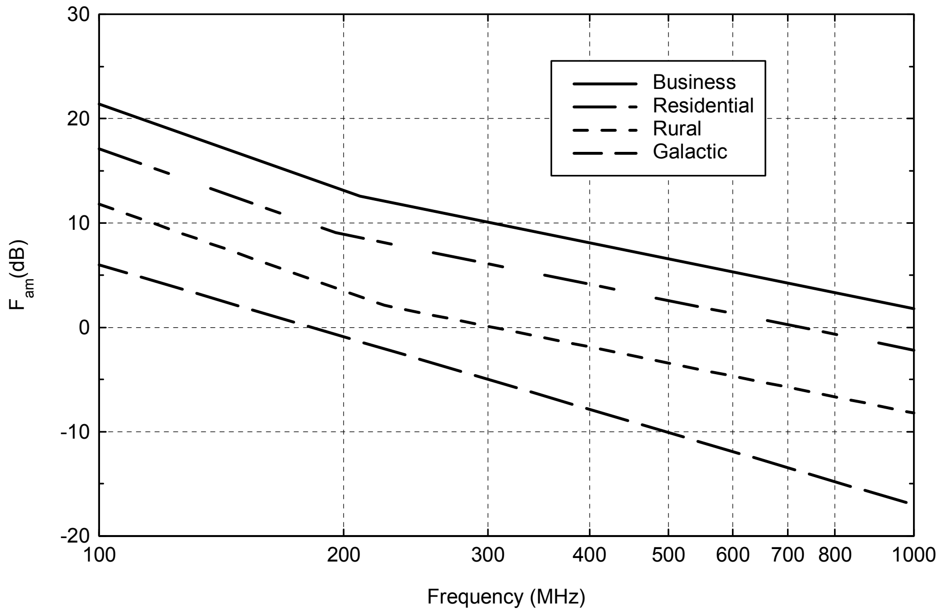


Figure 1. Natural and man-made antenna noise figures.

## 2. MEASUREMENTS

### 2.1 Frequencies

Three frequencies, 137.5 MHz, 402.5 MHz, and 761.0 MHz, were measured. The 137.5 MHz frequency is a VHF meteorological satellite space-to-earth allocation. This is the same frequency measured in the NOAA work described earlier. The 402.5 MHz frequency is in the UHF meteorological aids band extending from 400 to 406 MHz. No intentional signals at this frequency were detected at any of the measurement locations. The 761.0 MHz frequency is the center of a 6 MHz UHF television broadcast band channel. No television signals were found in this television channel or in adjacent television channels during the measurements.

### 2.2 Measurement Sites and Duration

Measurements were conducted in the Denver metropolitan area between April and August of the year 1999. They were acquired continuously over time periods lasting several days. This is a prudent approach for initial measurements since it allows trends in noise power statistics to be correlated with cultural patterns such as working hours and weekdays.

Two residential and two business locations in two cities were chosen to assure spatial independence. The first residential measurement was performed at a residence in Lakewood, CO approximately 10 miles west of downtown Denver, CO. The second residential measurement was performed at a residence in Boulder, CO approximately 3 miles south of downtown Boulder, CO. The business measurements were performed in downtown Boulder, CO and downtown Denver, CO.

### 2.3 Equipment

Man-made noise power measurements were acquired with the system depicted in Figures 2 and 3. The equipment specifications are detailed in the Appendix. The quarter-wave monopole antenna was mounted on a ground plane to assure an omnidirectional pattern whose gain is maximum at or near the horizon. The signal captured by the antenna was preselection-filtered to attenuate out-of-band power and preamplified to increase system sensitivity. The spectrum analyzer, tuned to the measurement frequency, down-converted the signal to the final intermediate-frequency where it was resolution bandwidth-filtered and log amplified. Noise power samples were obtained by digitizing the output of the envelope detector.

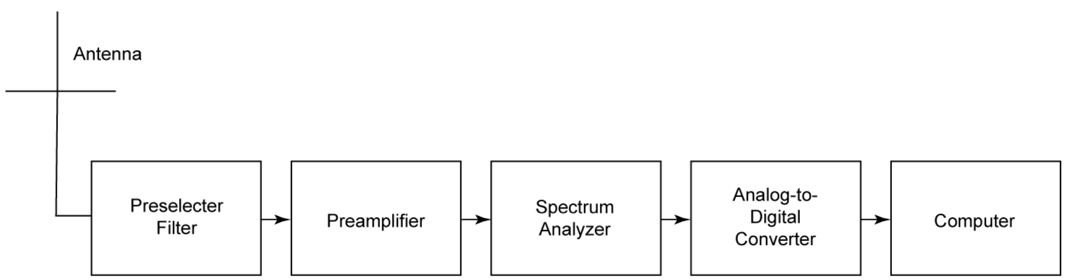


Figure 2. Block diagram of noise measurement system.

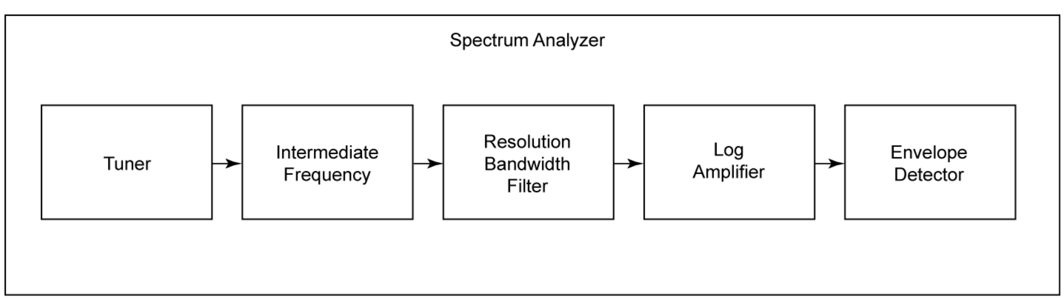


Figure 3. Block diagram of spectrum analyzer shown in Figure 2.

The resolution bandwidth filter was Gaussian shaped and had a 3-dB bandwidth of 30 kHz and a corresponding noise equivalent bandwidth of 36 kHz. The thermal noise floor, $kT_0b$, was approximately -128 dBm and the 1-dB compression point at the preselection filter input was approximately -55 dBm.

The slope of the log amplifier calibration curve in units of dB/volt was constant from -100 to -10 dBm spectrum analyzer input power. These input powers correspond to 0.1 to 1.0 volt direct current at the output of the log amplifier. Gain from the preselection-filter input to the spectrum analyzer input was adjusted so that noise below $kT_0b$ was measurable and the 1-dB compression point was never exceeded. A gain of 44 dB provided a dynamic range extending from -144 dBm to -54 dBm. This range corresponds to 16 dB below $kT_0b$ to 74 dB above $kT_0b$.

For business measurements the spectrum analyzer, preamplifier, and preselection filter were installed in a van. The antenna was attached to a rectangular 1.5 m by 3.0 m (5 ft by 10 ft) ground plane welded to the van roof. In this configuration the cable from the preamplifier output to the spectrum analyzer input was 3 m (10 ft) long. For residential measurements the spectrum analyzer was sheltered by a garage while the preselection filter and preamplifier were housed outside in a waterproof container. The antenna was attached to a 1.2-m (4-ft) diameter, circular ground plane. In this configuration the cable from the preamplifier output to the spectrum analyzer input was 7.6 m (25 ft) long.

Gain was accurately measured by applying a strong sinusoidal signal to the preselection-filter input and then to the spectrum analyzer input. System noise was measured by replacing the antenna with a 50-ohm load. A system noise APD is shown in Figure 4. The straight APD demonstrates that the system noise is Gaussian. System noise statistics for all other frequencies and configurations also were Gaussian distributed. Corresponding measured noise figures are reported in the following table.

Table 2. System Noise Figures (dB above $kT_0b$)

| Configuration | Frequency (MHz) | | |
|---|---|---|---|
| | 137.5 | 402.5 | 761.0 |
| Business | 1.8 | 0.8 | 3.2 |
| Residential | 1.8 | 1.9 | 2.9 |

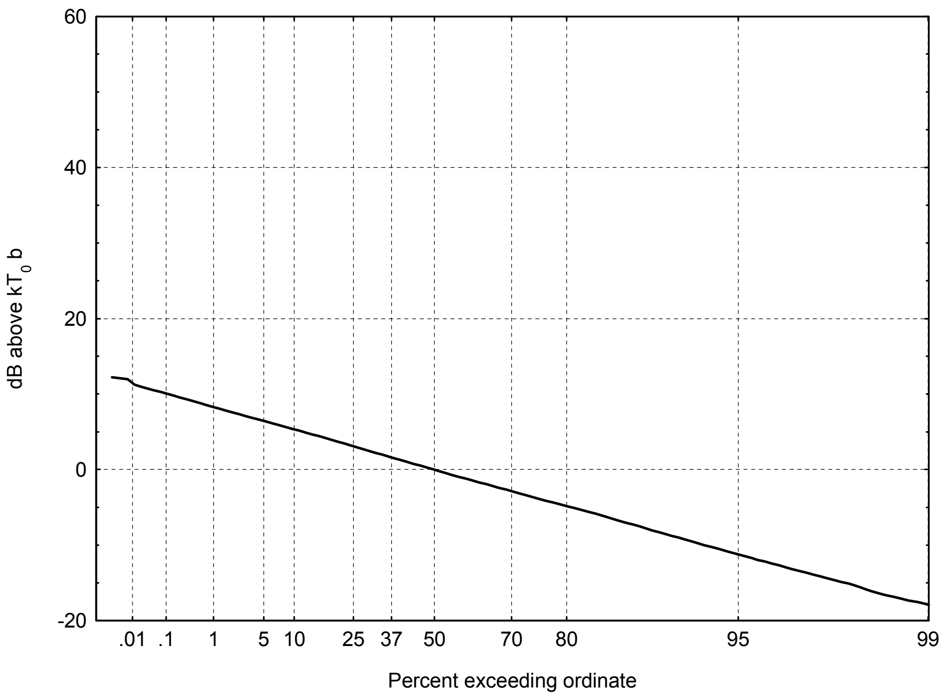


Figure 4. APD of system noise power at 137.5 MHz with residential equipment configuration. Gain and noise figure are 44.7 dB and 1.8 dB respectively.

## 2.4 Data Acquisition

The voltage at the output of the log amplifier was digitized with a 12-bit analog-to-digital converter (ADC). The ADC amplified the log amplifier output voltage by a factor of ten and then sampled it. The samples were converted to dBm and the gain in dB from the preselector input to the spectrum analyzer input was subtracted.

The basic noise power measurement contains 60,000 samples acquired at a rate of 1,000 samples/sec in 1-second bursts. The entire 60,000 samples were acquired in less than 3 minutes. The measurement system was not moved during this time and the noise statistics were assumed to be stationary over this time interval. Statistics of the samples were archived in a measurement histogram. The histogram bins range from -154 to -54 dBm, or 26 dB below $kT_0b$ to 74 dB above $kT_0b$ in 0.1-dB steps.

# 3. DATA

## 3.1 APD

Representative man-made noise APDs, shown in Figures 5-16, characterize short term noise behavior. Of particular interest are the median, mean, and peak power, the percentage where the APD deviates from the straight Gaussian APD, and the shape of the low probability non-Gaussian component.

Figures 5 and 6 are representative of 137.5 MHz residential noise. The APD departs from Gaussian at 1% or less. The low probabilities are rectangular shaped, indicating little variation in amplitudes of the non-Gaussian component. Figures 7 and 8 depict 137.5 MHz business noise. Median, mean, and peak powers are high compared to system noise. The Denver, CO APD non-Gaussian component departs from Gaussian at 5%. This is high in comparison to the other representative APDs.

Figures 9 and 10 are representative of 402.5 MHz residential noise. In Figure 9 the non-Gaussian component departs from Gaussian at approximately the same percentile as 137.5 MHz residential. However, the non-Gaussian component is triangular rather than rectangular. The median is comparable to the system noise median and the peak has little effect on the mean. Figure 10 indicates Gaussian noise statistics. Figures 11 and 12 depict 402.5 MHz business noise. The Denver, CO APD non-Gaussian component departs from Gaussian at 5%. This high probability has a definite effect on mean power.

Figures 13 and 14 are representative of 761.0 MHz residential noise. Both have Gaussian noise statistics with means comparable to those of system noise. Figures 15 and 16 depict 761.0 MHz business noise. The non-Gaussian components depart from Gaussian at 1% or less and have little effect on mean power.

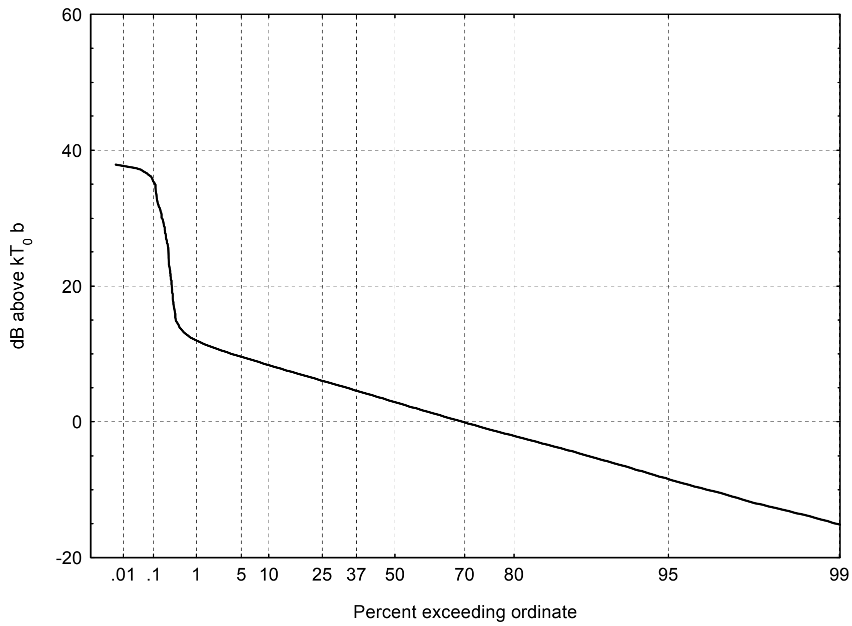


Figure 5. 137.5 MHz noise from measurements at Lakewood, Colorado residence on Tuesday, April 27, 1999 at 10:28:26 AM. Noise figure is 10.0 dB.

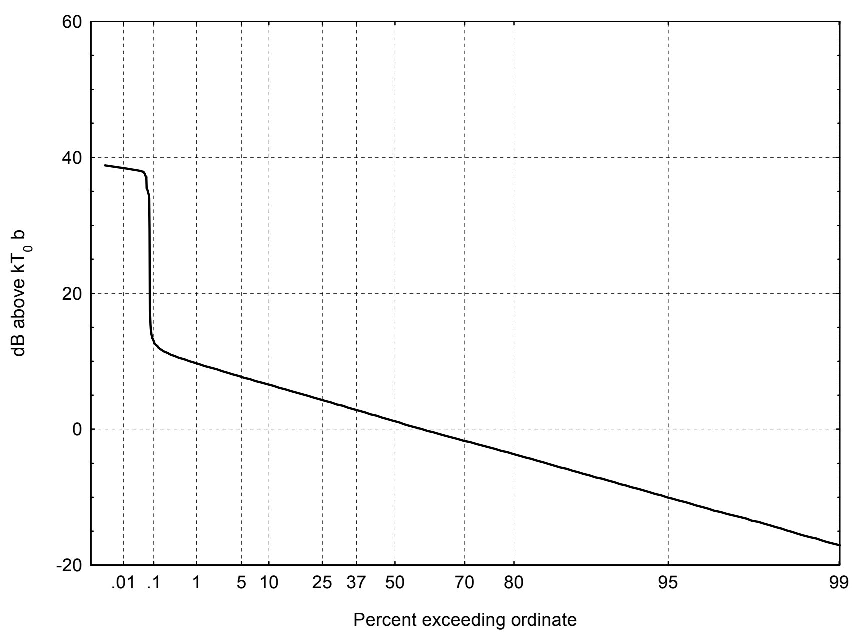


Figure 6. 137.5 MHz noise from measurements at Boulder, Colorado residence on Friday, May 21, 1999 at 03:38:55 PM. Noise figure is 8.1 dB.

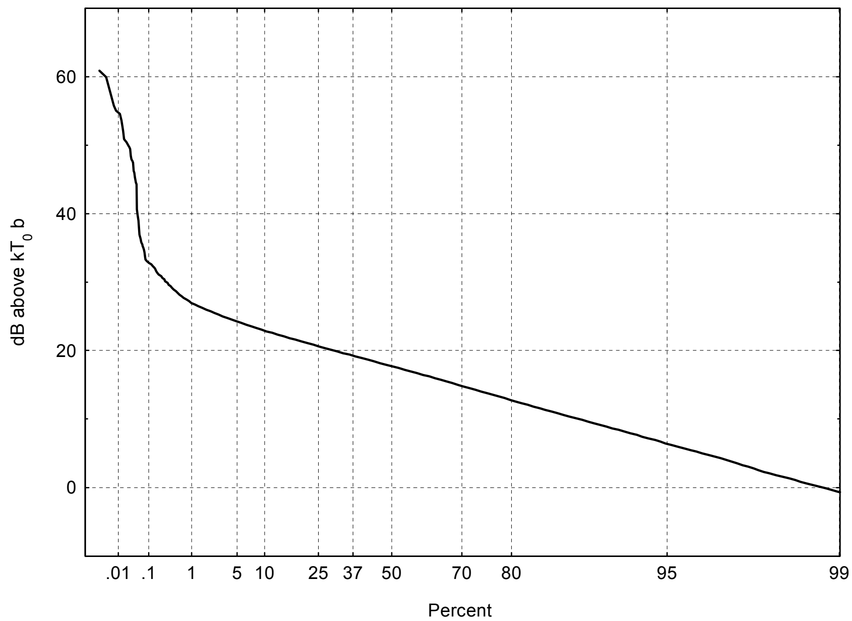


Figure 7. 137.5 MHz noise from measurements at downtown Boulder, Colorado on Friday, July 9, 1999 at 11:06:35 AM. Noise figure is 25.8 dB.

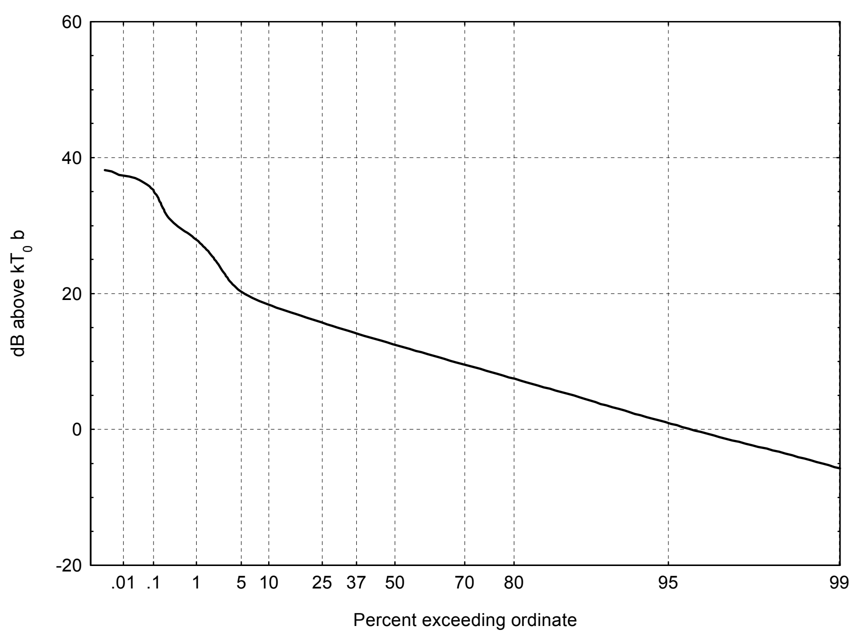


Figure 8. 137.5 MHz noise from measurements at downtown Denver, Colorado on Monday, August 30, 1999 at 10:52:04 AM. Noise figure is 16.7 dB.

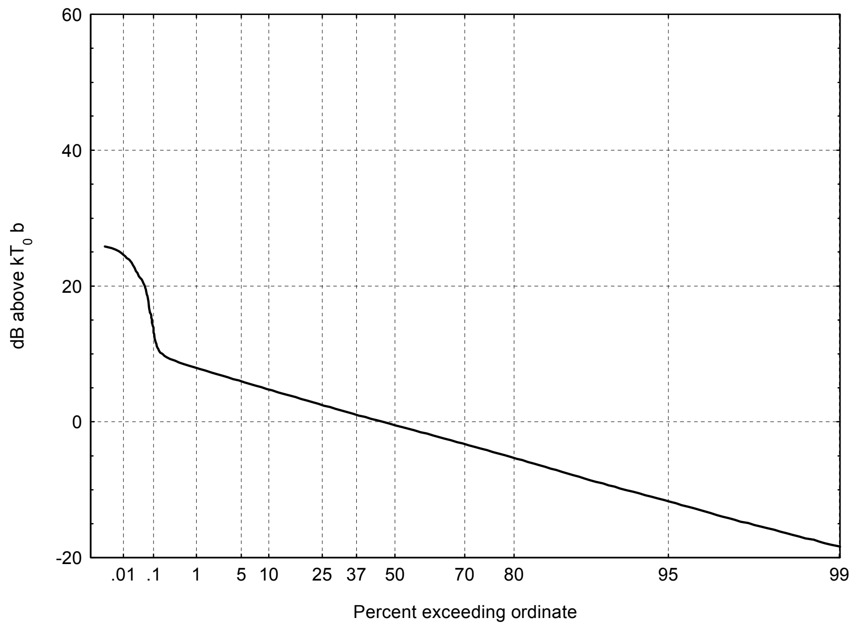


Figure 9. 402.5 MHz noise from measurements at Lakewood, Colorado residence on Wednesday, May 26, 1999 at 12:57:44 PM. Noise figure is 1.7 dB.

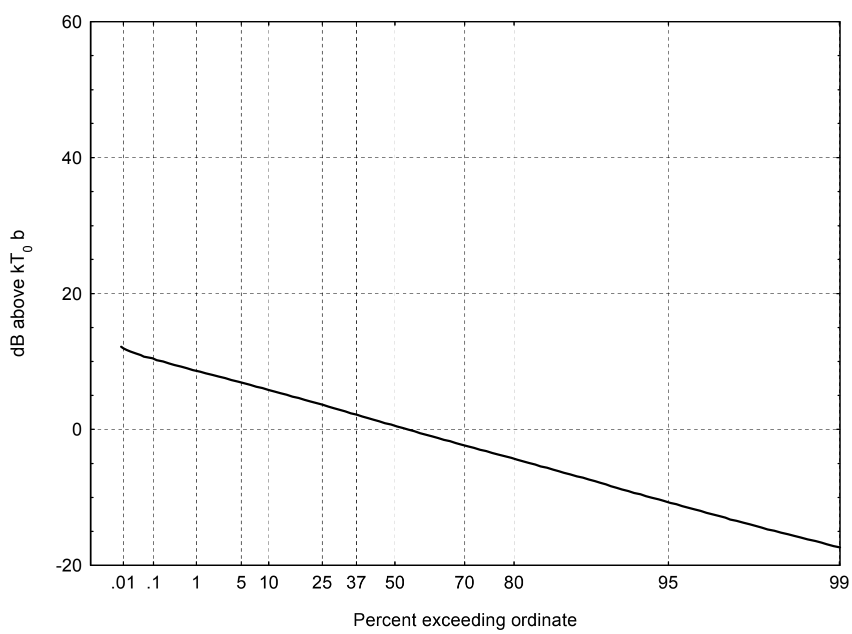


Figure 10. 402.5 MHz noise from measurements at Boulder, Colorado residence on Thursday, May 13, 1999 at 12:58:50 PM. Noise figure is 2.3 dB.

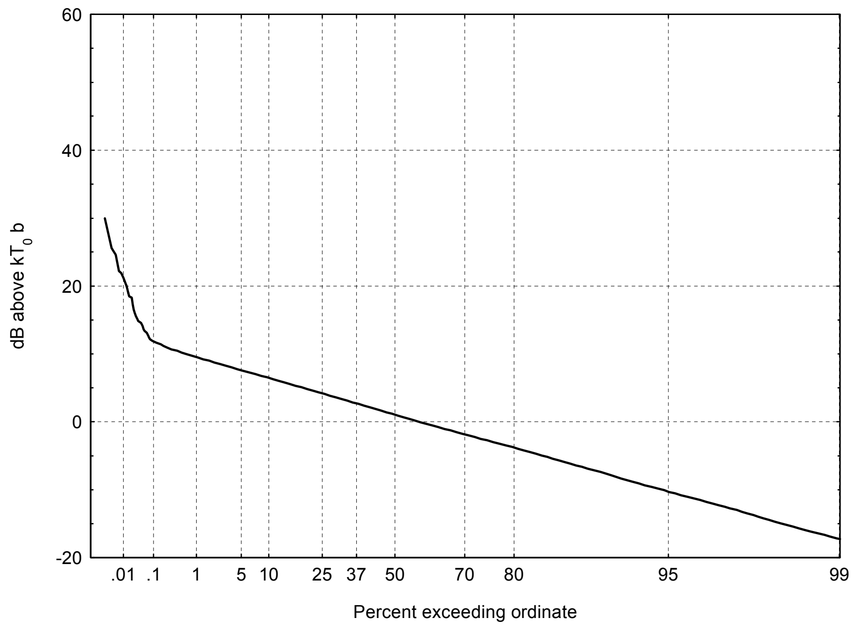


Figure 11. 402.5 MHz noise from measurements at downtown Boulder, Colorado on Thursday, July 1, 1999 at 12:51:52 PM. Noise figure is 3.1 dB.

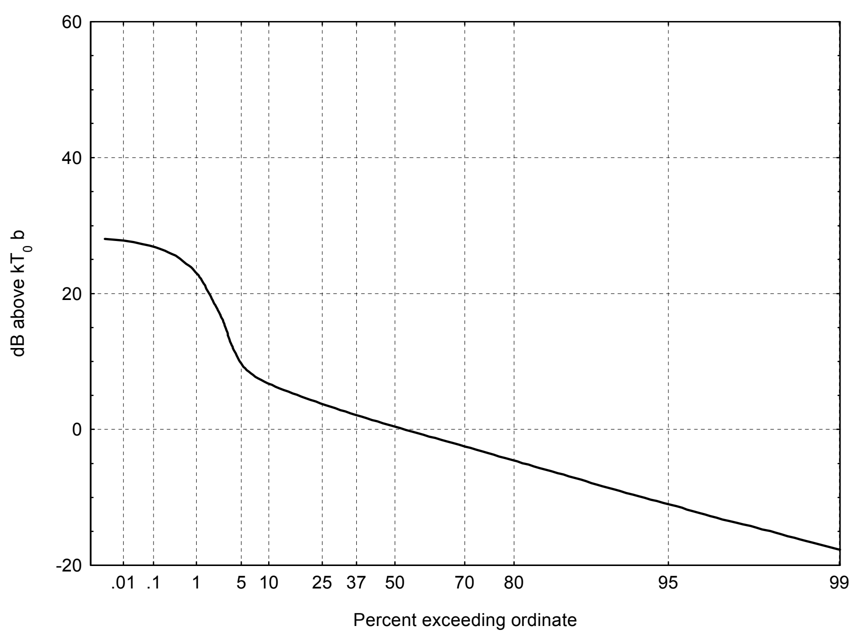


Figure 12. 402.5 MHz noise from measurements at downtown Denver, Colorado on Wednesday, August 25, 1999 at 09:52:57 AM. Noise figure is 8.6 dB.

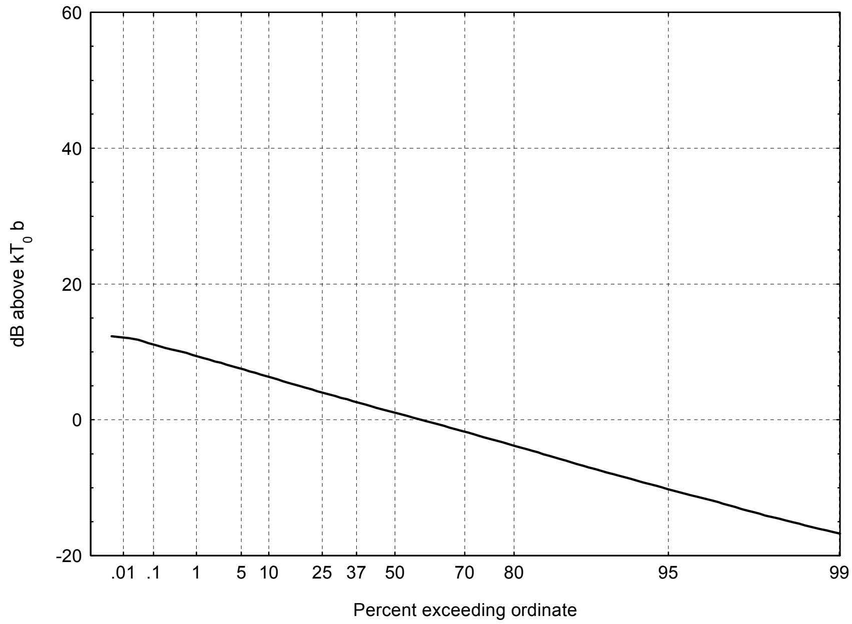


Figure 13. 761.0 MHz noise from measurements at Lakewood, Colorado residence on Thursday, April 29, 1999 at 11:55:15 AM. Noise figure is 2.8 dB.

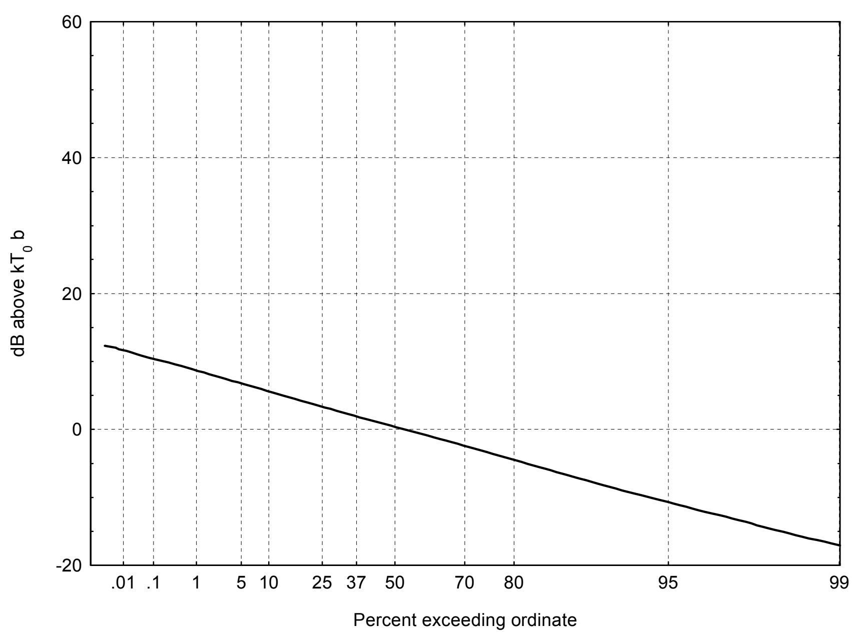


Figure 14. 761.0 MHz noise from measurements at Boulder, Colorado residence on Wednesday, May 19, 1999 at 12:56:22 PM. Noise figure is 2.1 dB.

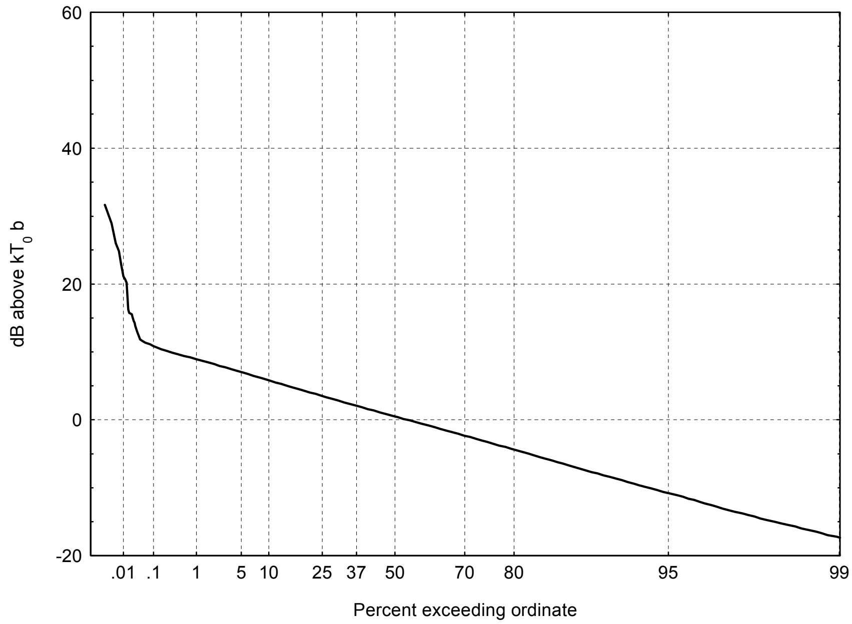


Figure 15. 761.0 MHz noise from measurements at downtown Boulder, Colorado on Monday, July 5, 1999 at 02:55:56 PM. Noise figure is 2.5 dB.

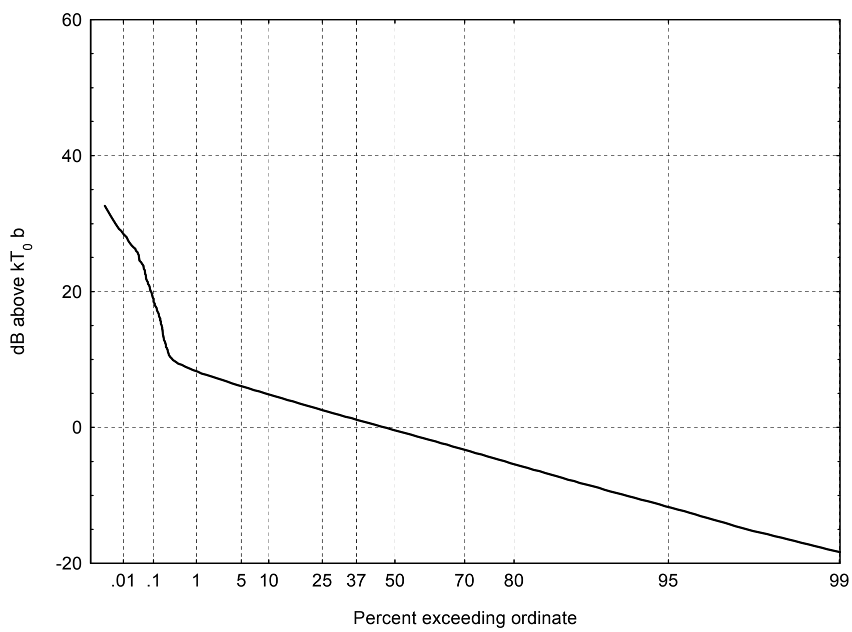


Figure 16. 761.0 MHz noise from measurements at downtown Denver, Colorado on Friday, August 27, 1999 at 07:31:10 PM. Noise figure is 2.5 dB.

## 3.2 24-hour Summaries

Figures 17-28 summarize long term noise behavior by plotting the peak, mean, and median noise power as a function of time. The median, mean, and peak powers are the bottom, middle, and top curves respectively of these graphs. Noise added by the measurement system has not been removed from these values. These graphs show how noise power statistics are correlated with time of day.

The 24-hour summary graphs show that median power varied much less than mean and peak power for all frequencies and locations. The only exception to this was when a weather satellite, which transmits an FM modulated signal at 137.5 MHz, was in view. Several examples of this, noticeable by the large increase in median noise power, can be found between 4:00 a.m. and 10:00 a.m. at the Lakewood, CO residence shown in Figure 17. Median power was typically very close to system noise median power. The main exception to this was the 137.5 MHz business measurements where it is elevated more than 10 dB.

Mean power was higher than system noise mean power for 137.5 MHz business, 137.5 MHz residential and 402.5 MHz business measurements. The increase in 402.5 MHz business mean power is most dramatically demonstrated in the downtown Denver, CO measurement shown in Figure 24.

Peak power variation was evident for all but 761.0 MHz residential measurements. In general, peak power was higher for business than residential and decreased with increasing frequency. Of the three power statistics, only peak power consistently showed higher levels during working hours. This is particularly evident in the downtown Boulder, CO measurements.

Gaussian noise, evident from the approximately 10-dB spread between mean and peak powers, was dominant at most frequencies and environments between midnight and 6:00 a.m. The most significant exception to this is the 402.5 MHz business downtown, Denver, CO measurement where Gaussian statistics were observed between 10:00 a.m. and 2:00 p.m. Gaussian noise was present at 761.0 MHz residential measurements the whole day.

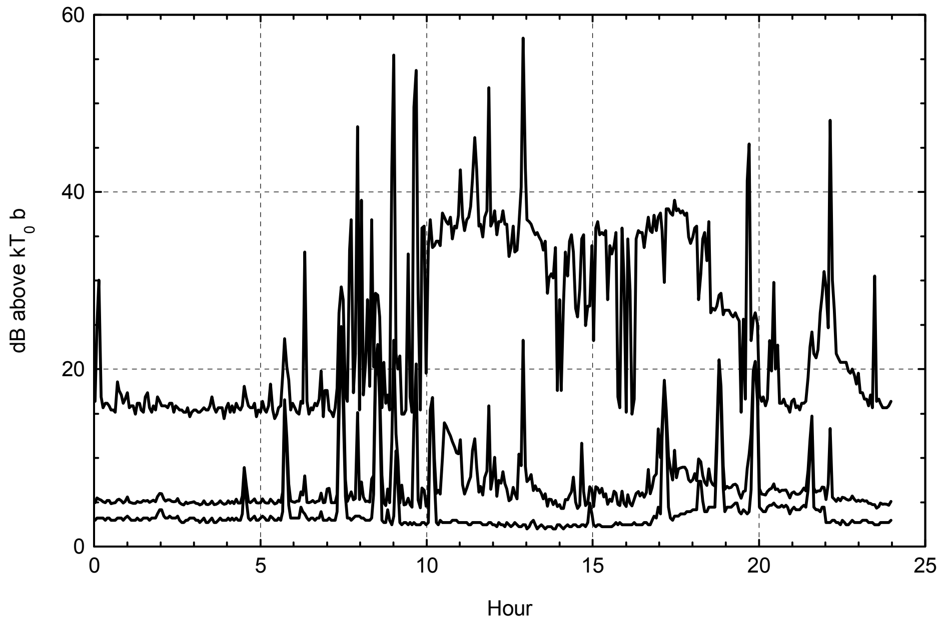


Figure 17. 137.5 MHz median, mean, and peak power at Lakewood, Colorado residence on Tuesday, April 27, 1999.

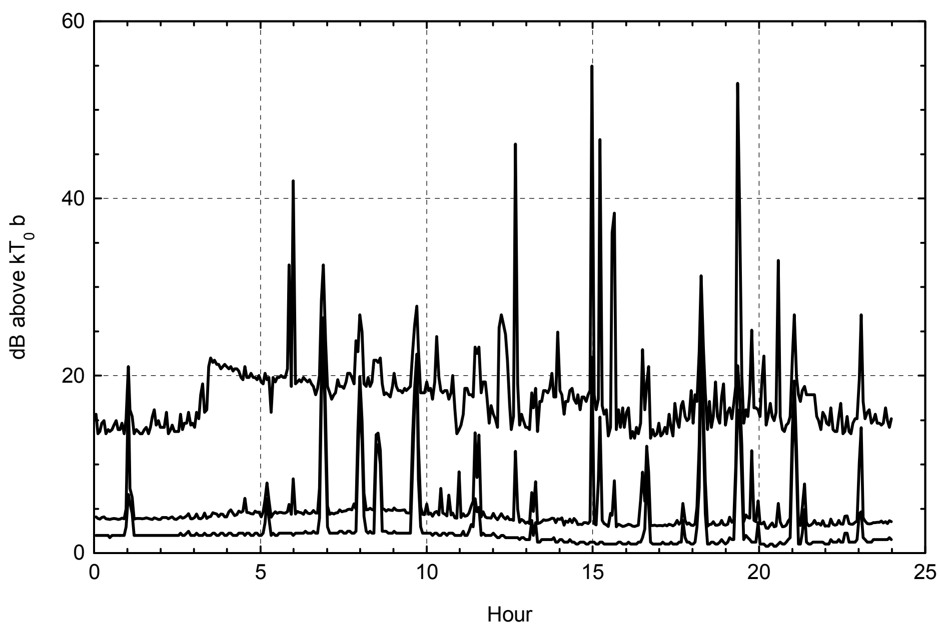


Figure 18. 137.5 MHz median, mean, and peak power at Boulder, Colorado residence on Friday, May 21, 1999.

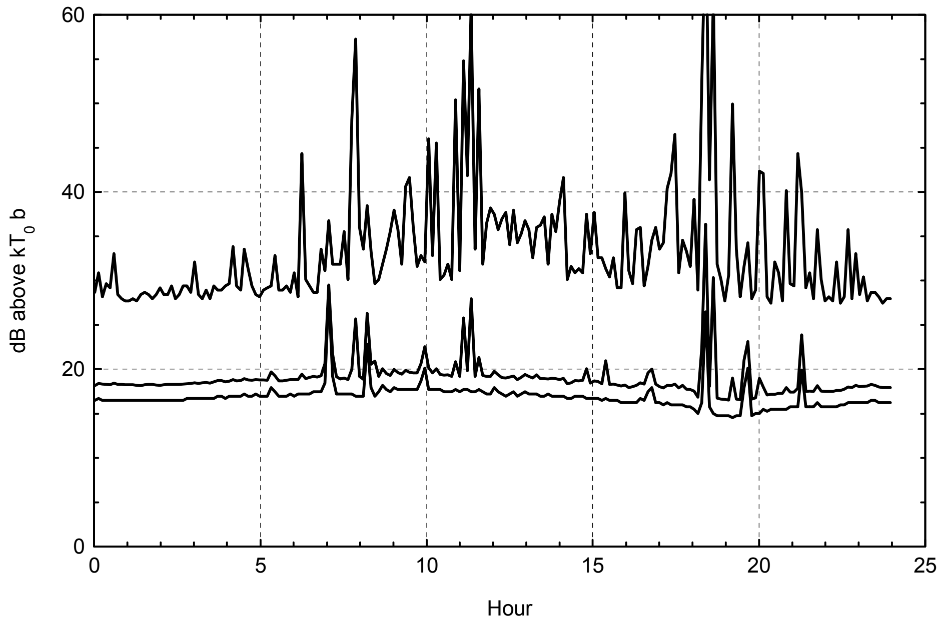


Figure 19. 137.5 MHz median, mean, and peak power at downtown Boulder, Colorado on Friday, July 9, 1999.

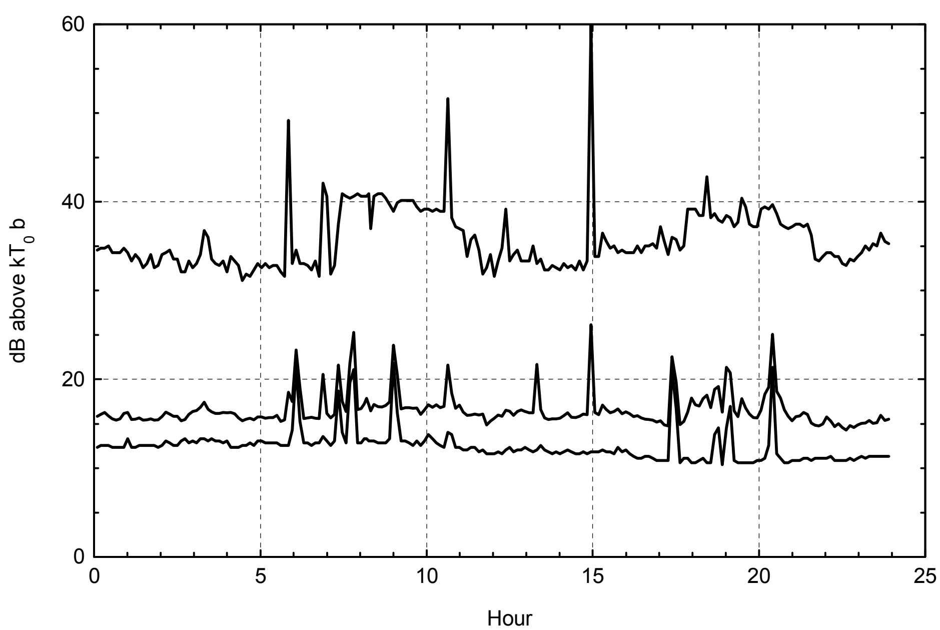


Figure 20. 137.5 MHz median, mean, and peak power at downtown Denver, Colorado on Monday, August 30, 1999.

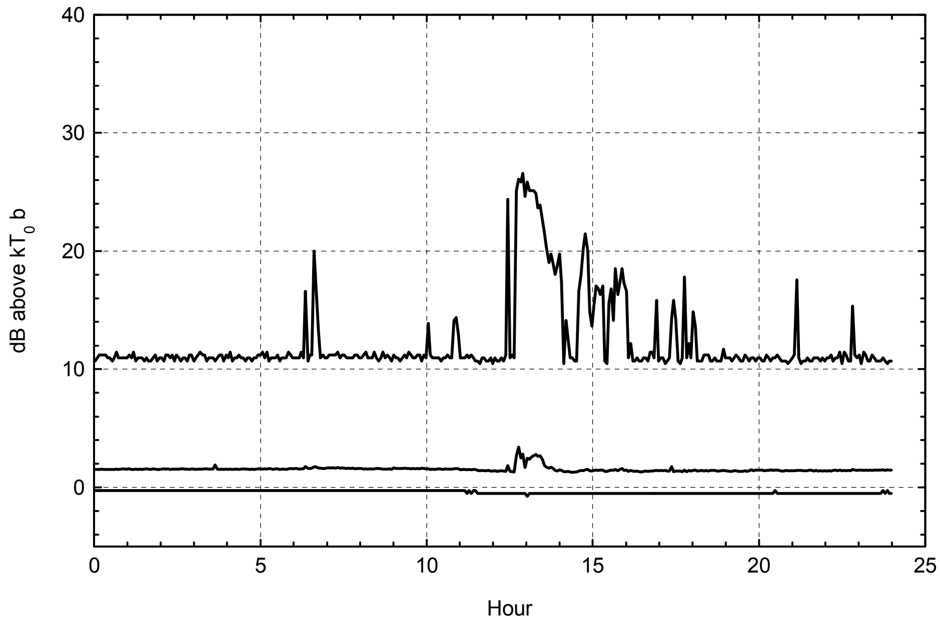


Figure 21. 402.5 MHz median, mean, and peak power at Lakewood, Colorado residence on Wednesday, May 26, 1999.

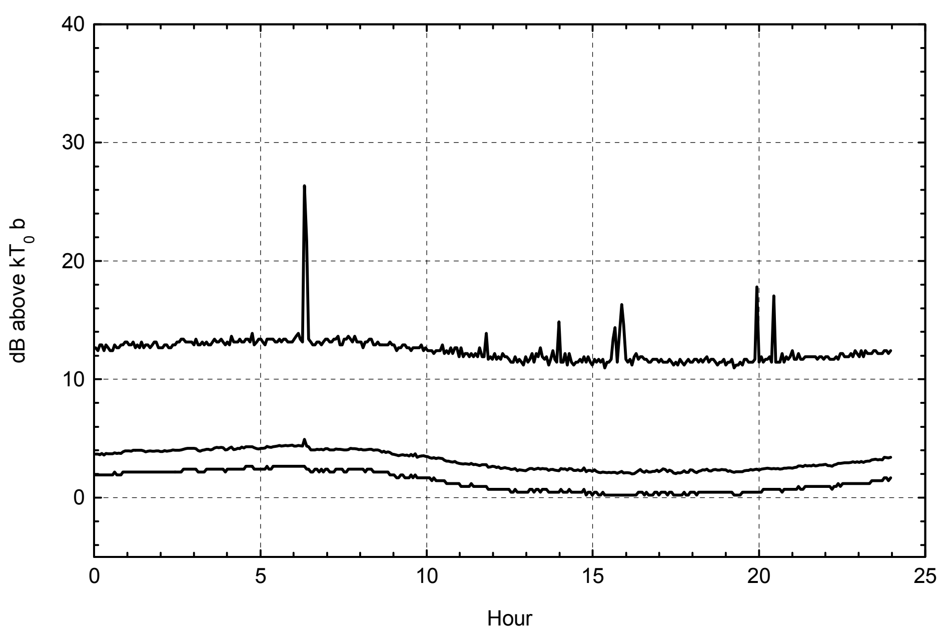


Figure 22. 402.5 MHz median, mean, and peak power at Boulder, Colorado residence on Thursday, May 13, 1999.

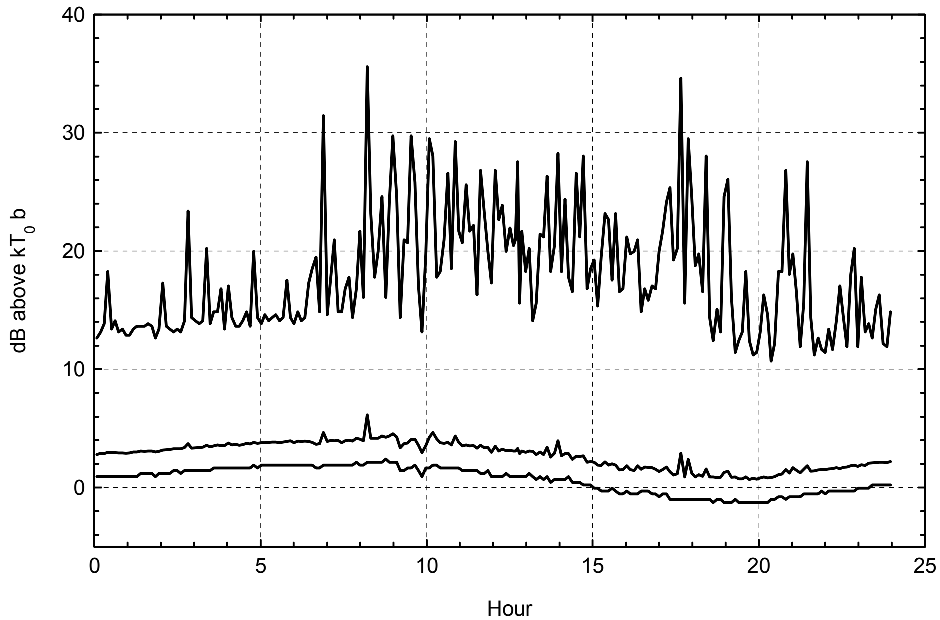


Figure 23. 402.5 MHz median, mean, and peak power at downtown Boulder, Colorado on Thursday, July 1, 1999.

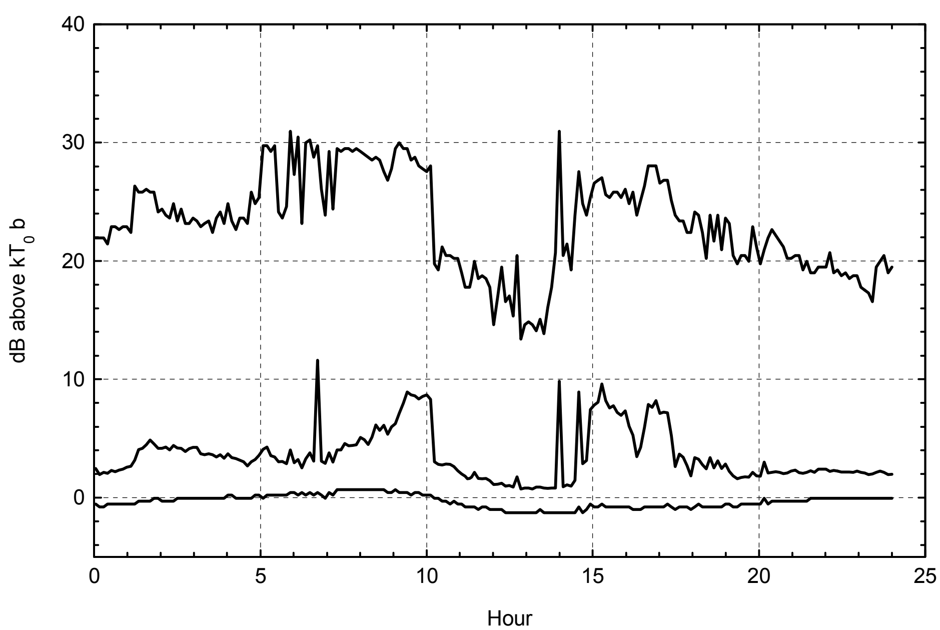


Figure 24. 402.5 MHz median, mean, and peak power at downtown Denver, Colorado on Wednesday, August 25, 1999.

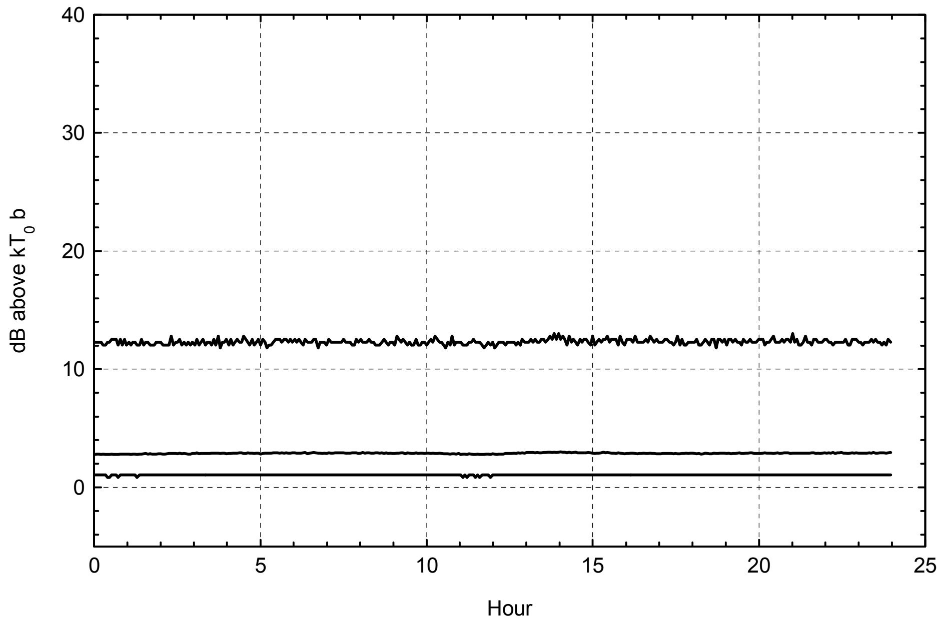


Figure 25. 761.0 MHz median, mean, and peak power at Lakewood, Colorado residence on Thursday, April 29, 1999.

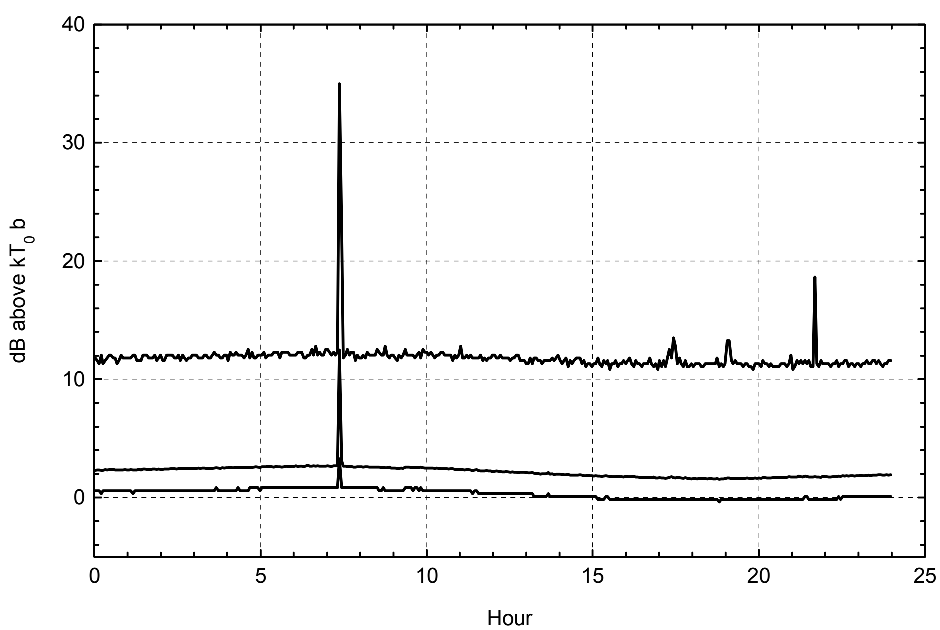


Figure 26. 761.0 MHz median, mean, and peak power at Boulder, Colorado residence on Wednesday, May 19, 1999.

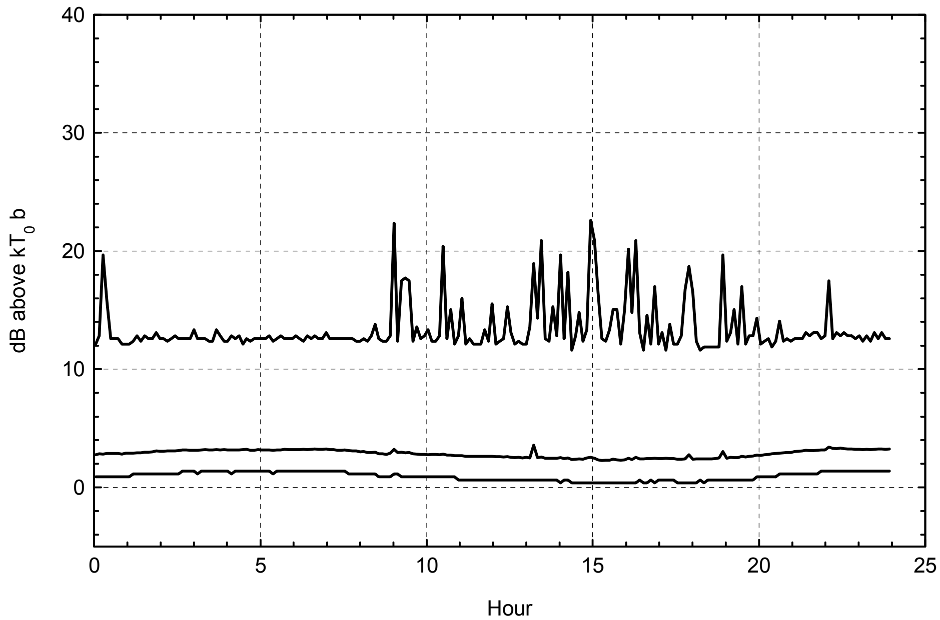


Figure 27. 761.0 MHz median, mean, and peak power at downtown Boulder, Colorado on Monday, July 5, 1999.

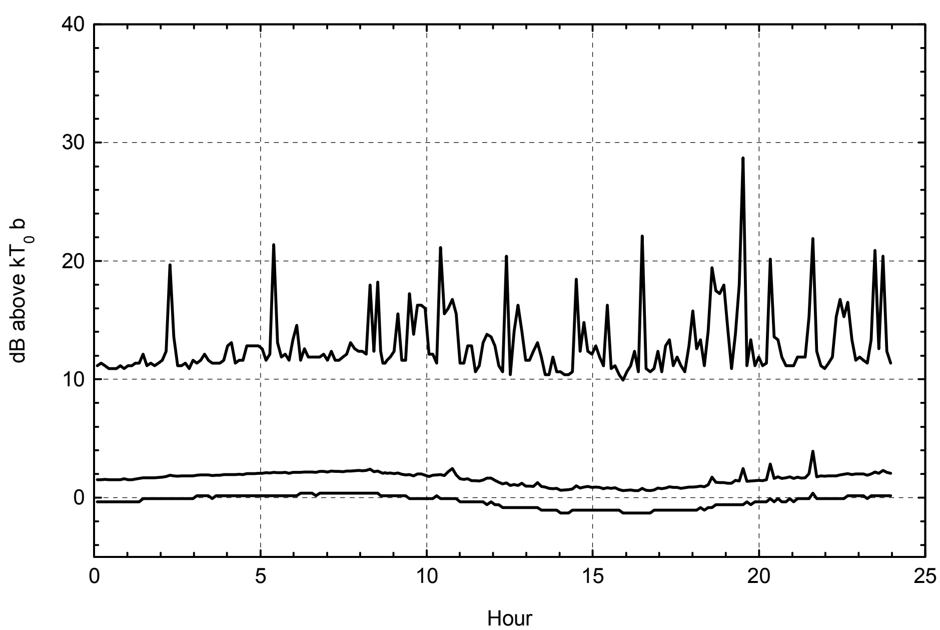


Figure 28. 761.0 MHz median, mean, and peak power at downtown Denver, Colorado on Friday, August 27, 1999.

## 4. RESULTS

The statistics of man-made noise power typically vary over time and between locations and hence, in general are non-stationary. Analysis of the non-stationarity was determined by calculating hourly median values from the median, mean, and peak power statistics of the measured APDs. These hourly median values were then sorted into CDFs, as shown in Figures 29-34. The median, mean, and peak powers are the bottom, middle, and top curves respectively of these graphs. Noise added by the measurement system has not been removed from these values.

The CDFs were plotted on a normal probability graph where a Gaussian distributed variable is represented by a straight line whose mean lies on the 50th percentile and the slope is the standard deviation. The statistics of the means are approximately Gaussian for most frequencies and environments if the lowest 5% are not included. Similarly the medians are also approximately Gaussian. However, the peaks are clearly non-Gaussian.

Of particular interest is the mean-power CDF median. In principle, this value represents the mean power exceeded for 50% of the time and 50% of the locations. These values denoted as $F_m$ are tabulated in Table 3. For clarification, $F_m$ is derived from the f in Equation 1.15 while $F_{am}$ is derived from $f_a$. In other words $F_m$ includes system noise power while $F_{am}$ does not. $F_{am}$ for 137.5 MHz business and residential are 17.5 dB and 3.6 dB respectively. These results agree with earlier 137.5 MHz measurements that showed a decrease in residential noise and no change in business noise from the ITU model.

The 402.5 MHz and 761.0 MHz $F_m$ are all within one standard deviation of system noise. As a result, we could not determine $F_{am}$ with any reasonable accuracy. This result is significant since this means man-made noise power is less than that predicted by the Hagn model.

Table 3. Measured $F_m$ for All Frequencies and Environments

| Environment/type | Frequency (MHz) | | | | | |
|---|---|---|---|---|---|---|
| | 137.5 | | 402.5 | | 761.0 | |
| | $F_m$ (dB) | F (dB) | $F_m$ (dB) | F (dB) | $F_m$ (dB) | F (dB) |
| Business | 17.6 | 1.5 | 2.2 | 1.4 | 2.6 | 0.9 |
| Residential | 4.5 | 1.6 | 2.6 | 1.4 | 2.9 | 0.4 |

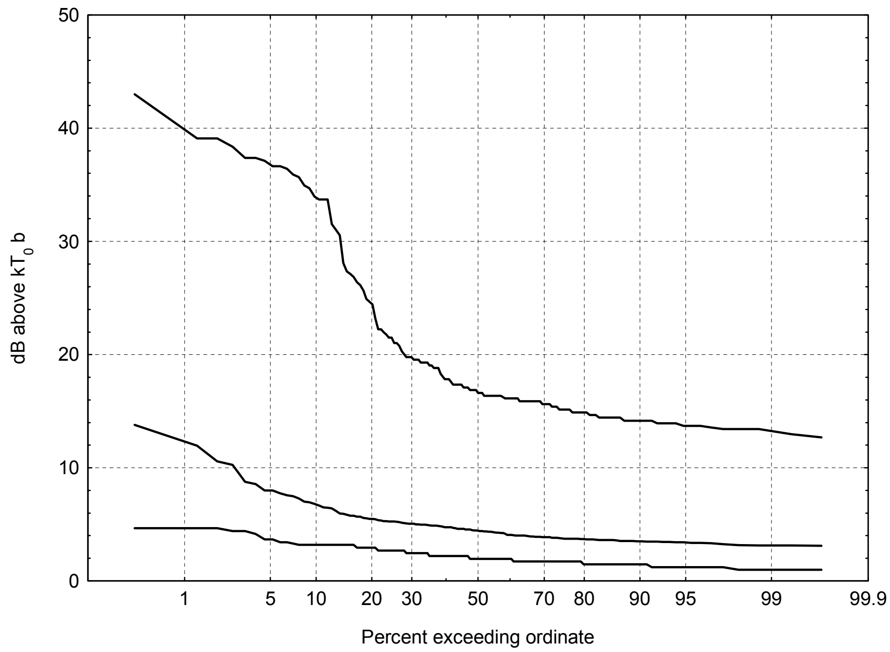


Figure 29. Cumulative distributions of 137.5 MHz residential median, mean, and peak power.

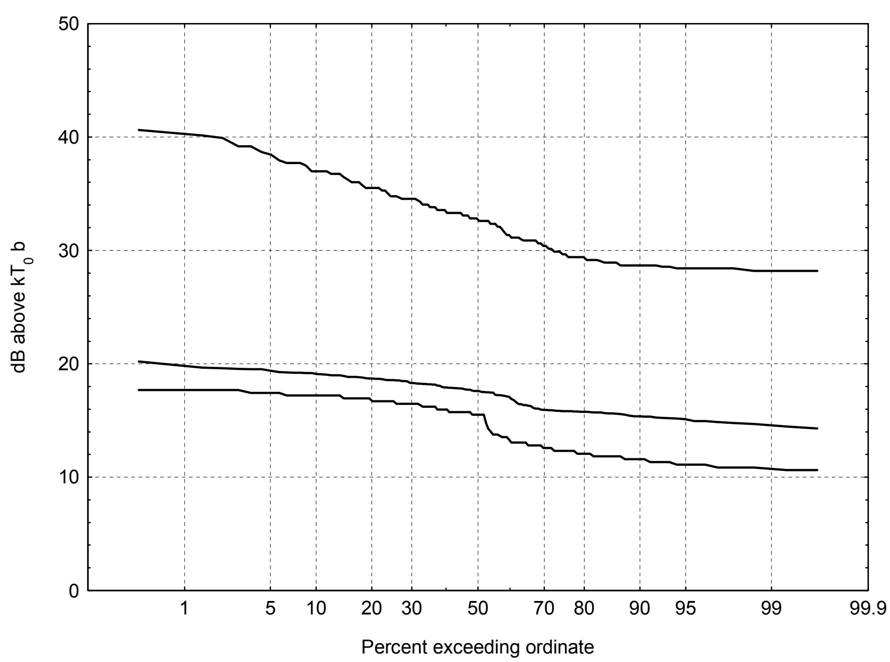


Figure 30. Cumulative distributions of 137.5 MHz business median, mean, and peak power.

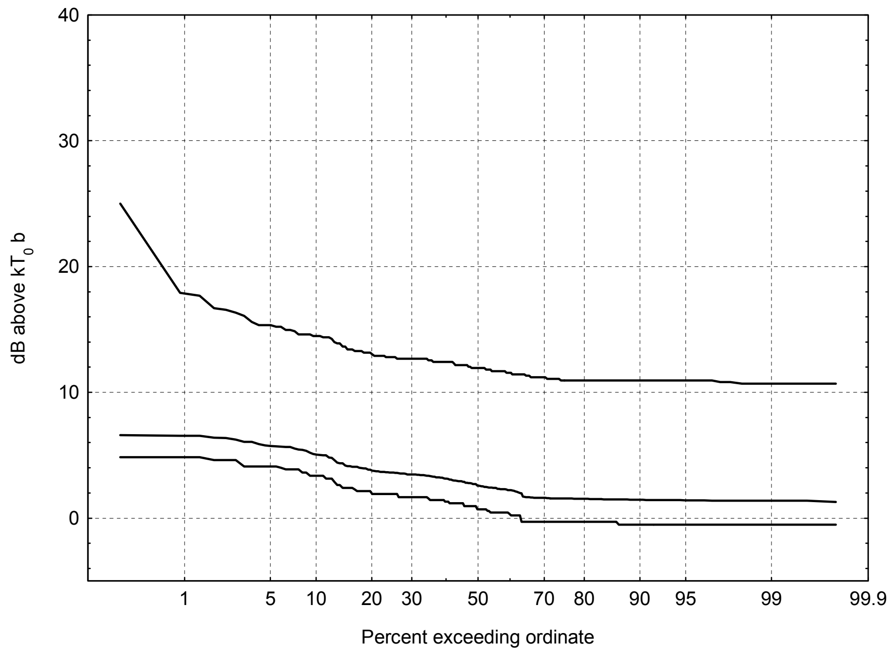


Figure 31. Cumulative distributions of 402.5 MHz residential median, mean, and peak power.

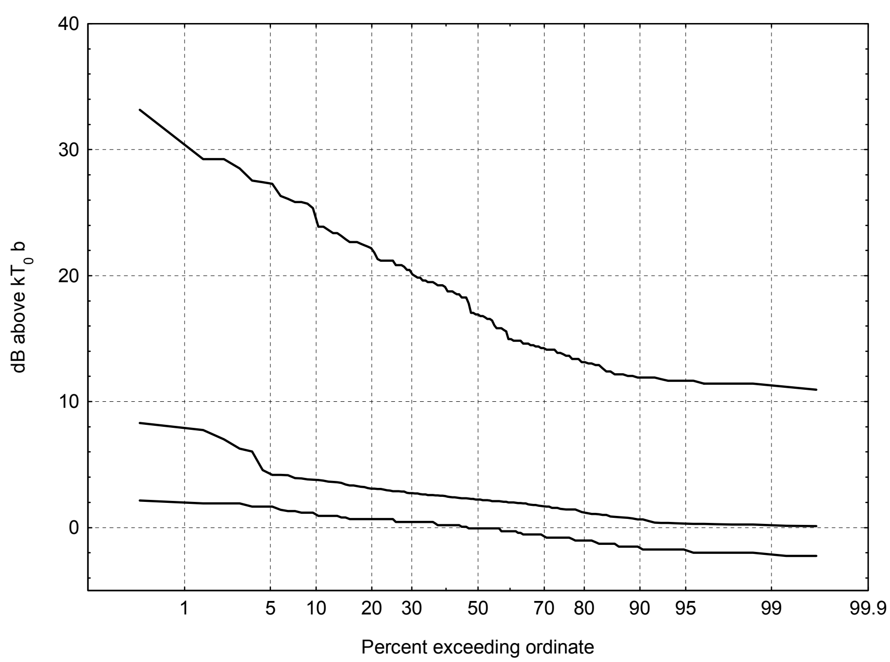


Figure 32. Cumulative distributions of 402.5 MHz business median, mean, and peak power.

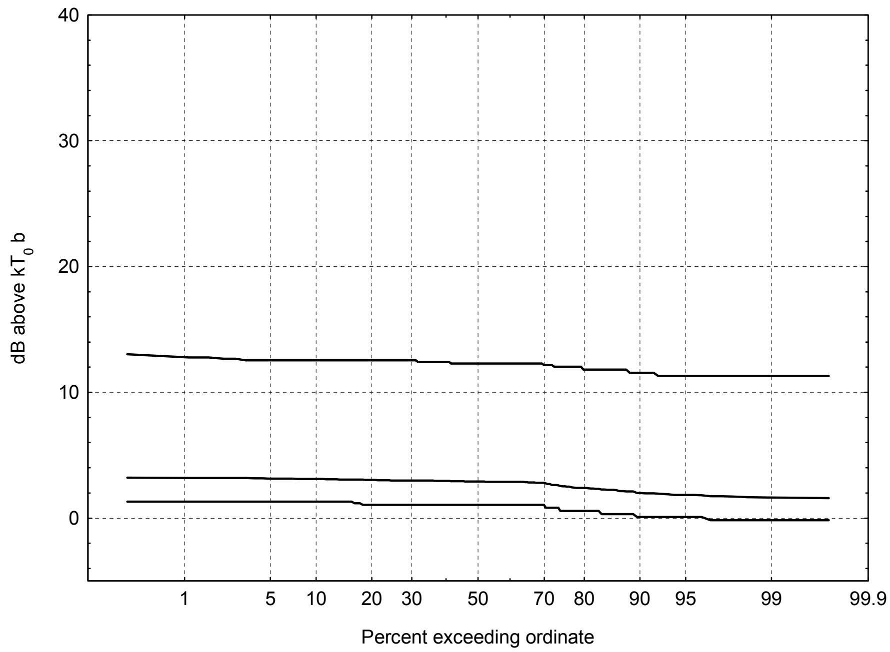


Figure 33. Cumulative distributions of 761.0 MHz residential median, mean, and peak power.

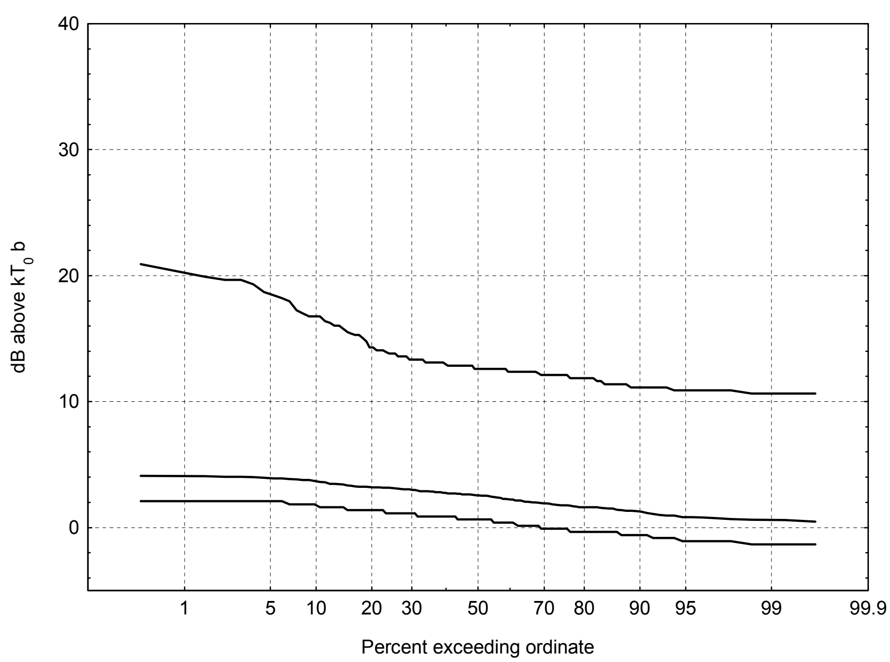


Figure 34. Cumulative distributions of 761.0 MHz business median, mean, and peak power.

# 5. CONCLUSIONS

Man-made, non-Gaussian noise was observable in all 137.5 MHz and 402.5 MHz business and residential measurements. It was also found at 761.0 MHz in business measurements but absent, for all practical purposes, at 761.0 MHz in residential measurements. VHF measurements were found to be consistent with previous measurements [4]. As in the previous study, 137.5 MHz residential $F_{am}$ seems to have decreased from levels measured 25-30 years ago, while 137.5 MHz business $F_{am}$ has remained constant.

The UHF measurements showed that median mean power at 402.5 MHz and 761.0 MHz is comparable to system noise, indicating that $F_{am}$ may be less than those predicted by Hagn's model [7]. It should be noted, however, that the 402.5 MHz business noise cumulative distribution shown in Figure 32 is peaked. Noise levels at low percentiles are high enough to adversely affect some communication systems. Figure 24 characterizes the long term statistics of this noise. Noise levels are correlated to working hours in that they rise in the morning and fall in the afternoon. However, it is noteworthy that high noise levels are not present during the middle of the day.

Further measurements are needed to determine the extent of these high noise levels. Sources for this noise, such as modern electronic devices, are more likely to be used within buildings and vehicles. Hence, it is important to make future measurements inside of buildings and vehicles.

## 6. REFERENCES


[1] A.D. Spaulding and R.T. Disney, “Man-made radio noise, part 1: Estimates for business, residential, and rural areas,” Office of Telecommunications Report 74-38, Jun. 1974.

[2] CCIR, “Man-made radio noise,” Report 258-5, International Radio Consultative Committee, International Telecommunication Union, Geneva, Switzerland, 1990.

[3] ITU-R Recommendations, “Radio Noise,” ITU-R P.372-6, Vol. 1997, P Series-Part 1, pp. 49-124.

[4] R.J. Achatz, R.A. Dalke, G.A. Hufford, and Y. Lo, “Man-made noise in the 136-138 MHz VHF meteorological satellite band,” NTIA Report 98-355, Sep. 1998.

[5] A.D. Spaulding, “Digital system performance software utilizing noise measurement data,” NTIA Report 82-95, Feb. 1982.

[6] R.J. Achatz and R.D. Dalke, “VHF space-to-earth radio link performance in various man-made noise environments,” in *Proc. of the 1998 Radio and Wireless Conf.*, Colorado Springs, Co., Aug. 9-12, 1998, pp. 257-260.

[7] G.H. Hagn, “Man-made radio noise and interference,” in *Proc. of the 1987 AGARD Conf.*, No. 420, Lisbon, Portugal, Oct. 26-30 1987, pp. 5.1-5.15.

[8] W.R. Lauber and J.M. Bertrand, “Man-made noise level measurements of the UHF radio environment,” in *Proc. of the 1984 IEEE National Symposium on EMC*, San Antonio, TX, Apr. 1984.

# APPENDIX: NOISE MEASUREMENT SYSTEM SPECIFICATIONS

## A.1 Component Specifications

Antenna: Quarter-wave monopole
Preselection Filter:
    137.5 MHz, insertion loss: 1.2 dB, 3-dB bw: 4.1 MHz, 40-dB bw: 24.6 MHz
    402.5 MHz, insertion loss: 0.5 dB, 3-dB bw: 20.0 MHz, 40-dB bw: 68.0 MHz
    761.0 MHz, insertion loss: 0.3 dB, 3-dB bw: 30.0 MHz, 40-dB bw: 102.0 MHz
Preamplifier (cascaded component specifications)
    Amplifier: gain: 37 dB, noise figure: 1.4 dB, 1 dB compression point: 10 dBm
    Attenuator: loss: 6 dB
    Amplifier: gain: 24 dB, noise figure: 4.5 dB, 1 dB compression point: 25 dBm
    Attenuator: loss: 10 dB
Cable, RG 58/U
    137.5 MHz, insertion loss: 0.055 dB/ft.
    402.5 MHz, insertion loss: 0.10 dB/ft
    761.0 MHz, insertion loss: 0.145 dB/ft
Spectrum Analyzer
    Attenuation: 0 dBm
    Reference level: -10 dBm
    Resolution filter noise equivalent bandwidth: 36 kHz
    Resolution filter bandwidth: 30 kHz
    Video filter 3-dB bandwidth: 3 MHz
    Single sweep mode
    Zero span mode
    Noise figure: 35 dB
    1 dB compression point: -5 dBm
    Log amplifier output: 0.1 volt DC to 1.0 volt DC output corresponding to -100 dBm to -10 dBm input
Analog-to-Digital Converter
    Resolution: 12 bit
    Gain: 10

## A.2 Receiver Specifications

Noise floor: -129.2 dBm
Noise figure: 2.2 dB
1 dB compression point: -50.8 dBm
3rd order intercept: 14.9 dBm
Gain: 43.5 dB
Linear dynamic range: 78.4 dB
2nd order dynamic range: 43.5 dB
3rd order dynamic range: 65.9 dB