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MEASUREMENT AND ANALYSIS OF RADIOFREQUENCY INDIGENOUS NOISE

by G. Anzic
Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at
Electromagnetic Compatibility Symposium sponsored by the
Institute of Electrical and Electronics Engineers
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Summary

The results of two surveys of radiofrequency noise in two urban areas are presented.

A limited survey of rf noise in the greater Cleveland, Ohio area was undertaken during the summer and winter of 1967. The noise measurements were made at 480 and 950 megahertz. A portable, self-powered rf noise measuring system was developed to measure and record the root-mean-square (rms) noise voltage at various urban sites. These sites included residential areas, apartment buildings, heavy and light industry, major street intersections, and low and high voltage distribution stations. A total of 40 recordings were made. The noise observed was characteristically impulsive and random in occurrence. The noise levels obtained during this survey indicate that the extrapolation of noise levels from high frequency and very high frequency data would yield valid ultrahigh frequency noise data. Although many sources contribute to the overall rf noise environment, the principal source was found to be automobile ignition.

A combined aerial and ground rf noise survey was conducted in Phoenix, Arizona during the summer of 1968. The air and ground measurement systems was essentially the same. Noise measurements were made at 0.3, 1, and 3 gigahertz clear channels with a bandwidth of 2.7 MHz. Simultaneous air measurements were made while conducting ground measurements at three of the ground locations. Five parallel paths were flown over the city; one path was flown normal to the above paths passing over the center of the city. Ground location measurements were made at six points on the center flight line and the flight line normal to it.

The rms noise level and average noise envelope voltage were measured. Ten 3-dB-step comparators were also used to provide data on noise amplitude distributions, noise pulse width, and frequency of occurrence. Survey results indicate that an aerial survey of an urban area can be performed in 5 to 10 percent of the time required for a ground survey, and that high urban noise areas are easily identified from noise data taken from aircraft.

Introduction

One of the major problems in the design of a communication system which is to serve a large area is the rf interference or "electromagnetic smog." The "smog" introduced into the desired signal incurs severe cost and power penalties in a system if the original signal has to be recovered without impairment. One source of this unwanted interference in the near earth environment is man-made noise.

The UHF portion of the rf spectrum represents a region where a space to earth comminication system is feasible. Very little interference data exists for this region of the spectrum. Most previous man-made rf noise investigations were limited to narrow voice communication channels in the lower region of the UHF spectrum.[1,2] To better characterize rf noise in future wide bandwidth data channels, all surveys described in this paper employed a channel bandwidth of 1 MHz or more.

In systems where many receiving terminals are used and large area coverage is desired, the design is based on the high noise levels of the area to be served. Since indigenous UHF noise closely follows the activity of man, large populated areas exhibit high noise levels and therefore must be investigated.

The main objective of the investigations reported was to identify and characterize noise in urban areas in order to effectively design a space to earth communication link at UHF frequencies. It was desirable that the task of surveying a city be done in a relatively short time and in a manner that is economically attractive. The plan to characterize a city's rf noise environment was implemented in three phases as follows:

1. A limited survey of rf noise in the Cleveland, Ohio area was undertaken during the summer and winter of 1967.[3] The entire survey, including the data reduction, was performed by NASA-Lewis Research Center. Details of measurements and complete survey results are forthcoming in a NASA Technical Memorandum. An obvious limitation that manifested itself during the Cleveland survey was the large amount of time required to conduct a ground survey. It quickly became apparent that this method would not be suitable for an extended survey because of long duration of measurement and high cost.

2. A follow-on effort was undertaken to determine if an aerial survey is a feasible approach to obtain the desired data. An aerial survey is economically more attractive and faster than a ground survey. Large urban areas can be surveyed with one aircraft in a matter of hours, while during the same amount of time the noise characteristics of only one ground location can be determined. Although an aerial rf survey yields only data varying in limited time, prudently chosen survey times within 1 day yield an area's daily noise levels. To develop the technique of an aerial noise survey, a combined aerial and ground rf noise survey was conducted in Phoenix, Arizona during the summer of 1968. The objectives of the

survey were to determine the correlation between noise measurements taken from the air and from the ground, and to demonstrate the ability to identify high urban noise areas from aerial data. Details of measurements taken during the survey, conducted for NASA-Lewis Research Center by General Dynamics/Convair are given in the contractor's final report.[4] The contractor performed the aerial and ground surveys; all data tapes were forwarded to NASA-Lewis Research Center for data reduction and correlation calculations.[5] Complete results of the combined survey will be published in a future NASA Technical Memorandum.

3. An rf noise survey of an older, heavily industrialized city is planned for the summer of 1970. The city of Akron, Ohio has been chosen. A number of measuring system modifications have been incorporated to improve the quality of data. The actual ground and air surveys will again be performed under contract for NASA by General Dynamics/Convair and all data will be analyzed by Lewis Research Center.

This paper discusses the data reduction techniques employed and presents the results obtained from the survey already performed.

Radiofrequency Noise Survey of the City of Cleveland, Ohio

Equipment and Procedure

System Description. Figure 1 presents a block diagram of the rf noise measuring system used in this experiment. To effectively sample the different types of rf noise at a variety of locations, a portable, self-powered noise measuring system was developed.

The root-mean-square (rms) voltage output of an amplitude modulation receiver was the noise parameter measured. This parameter is the measure of noise power commonly used in noise calculations. The rms noise data was recorded for 900-second periods at each location. Two 4-MHz channels were used throughout the survey with center frequencies at 480 and 950 MHz.

The receiver used was a solid state, self-powered instrument with a noise figure of 10 dB at 480 MHz and 12 dB at 950 MHz. The detected output of the receiver was measured by a calibrated rms voltmeter which also provided a dc output voltage proportional to meter deflection. This voltage was then used as the input to a voltage controlled oscillator which will be referred to as the noise oscillator.

The noise oscillator output was recorded on one channel of a portable, self-powered, good quality, stereo tape recorder. The output of a fixed frequency oscillator, the reference oscillator, was recorded on the other channel. During playback, this channel then enabled correction for recorder wow and flutter. All recording and playback was done at 7.5 inches per second tape speed.

The receiver detected output was also processed through an audio amplifier to drive a speaker. Since different types of noise (e.g., ignition, arcing, etc.) are easily distinguishable by ear, noise identification presented no problems.

The antenna used was a frequency and polarization adjustable corner reflector with a 10 dB gain over a dipole. A telescoping mast was used to raise the antenna to a height of 12 feet above ground. The console consisted of the rms voltmeter and signal and power conditioning with associated monitor meters as shown in Figure 1.

The system power supply consisted of a 28 V battery and a dc to ac inverter to supply the ac power for the rms voltmeter.

System Calibration. An impulse generator was chosen as a portable system calibration source for field use since the excessive power requirement of a laboratory standard made its use in the field impractical. Prior to the field measurements, a known value of noise was fed from the laboratory standard into the receiver and monitored on the rms voltmeter. The output of the impulse generator was attenuated to match the noise standard by adjusting a calibrated attenuator. This procedure calibrated the impulse generator in dB above KTB. During the field measurements, a portable oscilloscope was used to monitor the receiver output and detect signal clipping.

Data Reduction. Data reduction was accomplished in two parts. These were the laboratory data processing and the final computer data reduction.

Figure 2 presents the schematic diagram of the system used for laboratory data processing. Each survey run (900 sec) was divided into 30 equal time segments. The total number of cycles from each channel was counted for each time segment. The corresponding noise and reference oscillator frequency counts, which then corresponded to a time average over the segment, were printed out for use in the final computer data reduction. All print and count commands were generated by a dual preset counter. Graphic noise and reference channel data was also obtained for a visual check of the tape recorder operation.

In the computer program, the noise count, corrected by the reference count was converted to the noise power (dB above KTB). The noise power which was already averaged over each 30-second segment of the run was also averaged over the entire 900-second run.

Results and Discussion

Survey Sites. Forty recordings of rf noise were made at various urban and suburban sites in the greater Cleveland area. To provide a better sample of different types and levels of rf noise, the sites included residential areas, apartment buildings, low and high voltage distribution stations, heavy and light industry, and major street intersections.

Although many sources contribute to the overall rf noise environment, the examination of data in this survey indicates that the principal source is the automobile ignition. Out of 13 different sites visited, only two could be identified where, in addition to automobile ignition noise, other types of rf noise were clearly present. These two sites were a heavy industry site and a congested intersection near a hospital, where in addition to ignition noise strong arcing and possibly spurious emissions from diathermy were recorded. Automobile ignition noise was easily identified by ear. The corresponding rise and fall of noise level with the approach and leaving of cars was very evident.

For ease of data tabulation the survey sites were grouped into urban noisy and urban quiet areas, the selection criteria being the subjective evaluation of the receiver audio channel. Typical urban noisy locations were

a. Congested intersections

b. Shopping centers

c. Downtown areas

d. Heavy industry

where at 480 MHz the 900-second average noise power was approximately 28 dB above KTB and the noise level remained below 35 dB above KTB for 90 percent of the time. At 950 MHz the average noise power was approximately 11 dB above KTB, and the noise remained below 14 dB above KTB for 90 percent of the time. Figures 3 and 4 show the noise deviation about average power levels and noise probability distribution for the two frequencies monitored at all noisy locations. The noisiest location encountered was a congested intersection where ignition noise predominated. The average noise levels recorded were 33 and 12 dB above KTB for 480 and 950 MHz, respectively.

Typical urban quiet locations were:

a. Light industry

b. High voltage distribution stations

c. Apartment houses

d. Suburban residential area

where the average noise level at 480 MHz was 11 dB above KTB and remained below 13 dB above KTB for 90 percent of the time. At 950 MHz the average noise level was 6 dB above KTB. The quietest area visited was a typical suburban residential street located about 1 mile from the nearest major traffic route, where the noise levels measured at both frequencies were below the 6 dB above KTB. The accuracy of the urban quiet noise levels at 950 MHz is questionable because of the relatively high noise figure of the measuring system.

Correlation with Other Surveys. The rf noise obtained during this survey is compared in Figure 5 to the recent data obtained by three other rf noise surveys in the high frequency (HF) and very high frequency (VHF) regions of the spectrum for urban, suburban, and rural areas. Narrow bandwidth receivers (BW < 400 kHz) were used for the other three surveys. The urban quiet noise level at 480 MHz of the Cleveland survey agrees with the extrapolated value of noise obtained from the suburban data of references 6 and 7.

The noise levels obtained at noisy sites during the Cleveland survey exhibit a somewhat steeper slope than the values extrapolated from the HF and VHF data would indicate. Such variations may be due to differences in measurement techniques and survey site selection. In general, the noise levels obtained in this survey indicate that extrapolation of noise levels from HF and VHF data would yield acceptable UHF noise data.

Noise Discrimination Due to Antenna Elevation and Polarization. Most noise data recorded was done with the antenna at horizontal polarization and 0° elevation. A few noise recordings were made with the antenna at vertical polarization and 45° elevation above the horizon. Due to the relatively low antenna height (12 ft) and insufficient number of data points, no conclusion could be drawn as to the noise discrimination due to antenna polarization or elevation.

Radiofrequency Noise Survey of the City of Phoenix, Arizona

Equipment and Procedure

Ground Survey. The ground measurements were conducted at six city locations as shown in Figure 6. Radiofrequency noise was measured in clear channels at or near 0.3, 1.0, and 3.0 GHz. The receiving system, housed in a generator equipped van, consisted of three low noise (NF < 4 dB) receivers (Fig. 7) followed by a data processing and recording system (Fig. 8). Ground noise data was measured as a function of antenna azimuth, polarization, elevation above the horizon and time of day. Six antennas, mounted on a 40-foot collapsible tower, were used to receive rf noise. The characteristics of the antennas were as follows:

Frequency, GHz	Type	Gain, dBi	Polarization
0.3	Quad Dipole	11	Circular
.3	Corner Reflector	10	Vertical or Horizontal
1.0	Helical	11	Circular
1.0	Horn	9	Vertical or Horizontal
3.0	Helical	13	Circular
3.0	Horn	19	Vertical or Horizontal

The noise measurements were made during the morning, noon, and evening hours. No measurements were made on weekends.

To properly characterize the noise and its effect on wide-band channels, a noise bandwidth of 2.7 MHz was used in all three survey channels. The noise parameters measured were:

rms Noise

Average Noise Envelope

60 Hz Noise Component

15.75 kHz Noise Component

Ten 3-dB-step comparators were also used to provide data on noise amplitude distributions, pulse width and frequency of occurrence. Simultaneous air measurements were made while conducting the ground measurements at three of the ground locations.

Aerial Survey. A DC-3 aircraft, equipped with an interference suppressed ignition system and suitable electrical power generators, was used in the aerial survey. An air speed of 100±10 knots, at altitudes of 1000 and 4000 feet, was used for all survey flights. The aircraft, frequently used in scientific experiments of similar nature, proved ideal for this task, since the pilots were familiar with precise flying requirements.

The receiving system used for the airborne survey was essentially the same as the ground system, except that only circularly polarized antennas were used. The antennas were mounted on removable panels on the underside of the aircraft fuselage.

Five parallel paths were flown over the city. One path was also flown normal to the above paths passing over the center of the city (Fig. 9). Simultaneous ground measurements were made at three ground locations while conducting the air measurements. Like the ground measurements, the air measurements were also made during morning, noon, and evening hours. An automatic sequence camera was used to provide the photographic record of ground area covered by the antenna pattern. The sequence photos were used for noise source identification and air data correction factor calculation.

Survey Results

Ground and Aerial Noise Correlation. As shown in Figure 10, the ground system received noise from the following sources: sky (T_s), ground (T_g), the receiver itself (T_r), and the indigenous noise sources (T_i) in the subtended angle θ. Figure 11 presents the weighting factor, G_i, which was calculated from the integration of the antenna gain as a function of angle θ, subtended by the noise source. This angle is estimated from the photographs taken at each ground site. The noise temperature received at a ground site (T_{gr}) can then be expressed as:

$$T_{gr} = 0.5(T_s) + 0.5(T_g) + T_r + G_i T_i \qquad (1)$$

The noise power received by the airborne system is shown in Figure 12. The airborne noise temperature (T_{ar}) consists of the ground temperature (T_g), receiver system temperature (T_r), and the indigenous noise temperature (T_i). The weighting factor (A_i), representing the percentage of ground area covered by indigenous noise sources, was selected from the examination of aerial photographs. The noise temperature received by the airborne antenna is:

$$T_{ar} = 1.0\ T_g + A_i T_i + T_r \qquad (2)$$

Assuming that T_g, T_s, and T_r are negligible, above equations yield the following correlation expression:

$$\frac{T_{ar}}{T_{gr}} \cong \frac{A_i}{G_i} \qquad (3)$$

Results of the air and ground data correlation for 0.3 and 1.0 GHz are shown in Figures 13 and 14, respectively. It is evident that the aircraft altitude and ground site selection greatly affect the degree of correlation. As an example, the correlation data for two ground sites is presented in Table I. Air data collected at a 1000-foot altitude tends to correlate better with the ground data since the aircraft antenna becomes more selective of noise sources in its narrower coverage pattern.

In general, ground sites well immersed in noise yielded better correlation data. On the average, the air-ground correlation data indicates that an estimate of the ground noise levels can be obtained by subtracting 5 to 7 dB from the noise level obtained at a 4000-foot altitude.

Aerial and Ground Noise Data. The air and ground data was collected by a periodic sampling of rf noise at each of three frequencies. The large quantity and variety of data recorded made a computer data reduction almost mandatory. All data tapes were first digitized. A computer program was written to accept the digitized data and either plot or print out the desired parameters.

Typical aerial noise data obtained during the survey are presented in Figures 15 and 16. Radio-frequency noise, seen from the aircraft flying at 4000 feet from west to east over the center of the city is presented in Figure 15. Figure 16 shows the results from another flight path, crossing the center of town in a north-south direction.

In general, all airborne noise data indicates that the noon and late evening average urban noise levels are 2 and 6 dB, respectively, below the noise during the morning rush hour traffic flow. The average rf noise power levels at 0.3 GHz obtained at an altitude of 4000 feet during the morning, noon, and late evening hours were 19, 17, and 13 dB above KTB, respectively. This daily cyclic variation is typical of man-made rf noise.

Peak rush hour noise levels were near 30 dB above KTB.

Figure 17 shows the 0.3 GHz noise probability distribution data of the city of Phoenix as seen from a 4000-foot altitude for all flights. Typical 1.0 GHz noise levels during morning rush hour were 5 to 6 dB below the 0.3 GHz values. It is interesting to note that a 3 dB difference in the satellite power exists between the systems designed to serve 60 percent of the area (average noise power) and 90 percent of the area.

Figures 18 and 19 show computer presentations of time comparators for 0.3 and 1.0 GHz channels, respectively, indicating the percentage of time the noise value exceeded the 3 dB steps ranging from the receiver threshold to 30 dB above the threshold. The rms value of noise, also plotted above the comparator data, illustrates the relatively high peak to rms ratio typically exhibited by all noise data.

The noise data, recorded at each ground site, was reduced as a function of frequency, antenna azimuth, antenna polarization, and antenna elevation above the horizon. Typical noise predominating in most cases was the automobile ignition noise. Normally, the highest noise levels recorded at a ground site occurred during morning rush hour, while the lowest levels were recorded during the late evening hours. Noonday noise levels were somewhat below the rush hour levels. On the average, the ground noise followed the same daily cyclic behavior exhibited by aerial data. This daily cyclic nature of rf noise level is directly dependent on the activity of man.

Noise data was found to be insensitive to polarization during the ground measurements. No 3.0 GHz data is presented since most data obtained is questionable because of receiving system limitations. The small quantity of valid data obtained indicates that the rf noise was near the system threshold for the majority of the time (<4 dB above KTB).

Radiofrequency Noise Survey of the City of Akron, Ohio

A combined ground and aerial rf survey of an older, heavily industrialized city is planned for the summer of 1970. The city of Akron, Ohio has been selected. A number of measuring system modifications have been incorporated to reduce the quantity and improve the quality of data. The contractor, General Dynamics/Convair, will again perform the combined aerial and ground noise survey. All data will be reduced by NASA-Lewis Research Center.

Conclusions

The following conclusions were reached from examination of aerial and ground survey data:

1. The major source of man-made radio interference was automobile ignition.

2. The noise levels obtained during the Cleveland survey indicate that the extrapolation of noise levels from high frequency and very high frequency data would yield valid ultrahigh frequency noise data.

3. The average radiofrequency noise levels (dB above KTB) obtained during the Cleveland survey were as follows:

	Noisy Sites	Quiet Sites
480 MHz	28	11
950 MHz	11	6

4. An aerial survey of an urban area can be performed in 5 to 10 percent of the time required for the ground survey.[4]

5. An aerial survey can be used to identify high urban noise areas.

6. Cyclic behavior of noise is easily determined from aerial data.

7. Ground noise levels are 5 to 7 dB below the noise levels calculated from measurements at a 4000-foot altitude.

8. Ground sites well immersed in noise yielded good correlation with air data.

9. Antenna polarization did not noticeably affect the noise data obtained.

References

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2. "Man-Made Noise," Report to Technical Committee of the Advisory Committee for Land Mobile Radio Services from Working Group 3, Federal Communications Commission.

3. Anzic, G., "Radiofrequency Noise Measurements in Urban Areas at 480 and 950 Megahertz," NASA TM X-1972, 1970.

4. Mills, A. H., "Measurement and Analysis of Radio Frequency Noise in Urban, Suburban and Rural Areas," General Dynamics/Convair Report GDO-AWV68-001, NASA CR-72490, Feb. 1969.

5. Anzic, G., and May, C., "Results and Analysis of a Combined Aerial and Ground UHF Noise Survey in an Urban Area," Proposed NASA Technical Memorandum.

6. "Voice Broadcast Mission Study," Radio Corp. of America Report AED-R-3187, NASA CR-95491, May 1967.

7. "Voice Broadcast Mission Study. Vol. 2: Study Report," General Electric Co. Report GE-67SD4330, vol. 2, NASA CR-98711, July 1967.

TABLE I. SAMPLE AIR-GROUND NOISE CORRELATION (REF. 5)

[f = 300 MHz, BW = 2.7 MHz.]

Ground site number	No. 3 Open Field		No. 10 Near Highway	
Aircraft altitude, ft	4000		1000	
T_{ar}	-89 dBM$\pm$2		-92 dBM$\pm$2	
Ground antenna azimuth	North	East	South	East
T_{gr}	-102 dBM$\pm$2	-102.5 dBM$\pm$2	-97 dBM$\pm$2	-98 dBM$\pm$2
A_i	-1 dB	-1 dB	0 dB	0 dB
G_i	-8 dB	-10 dB	-3.5 dB	-5 dB
T_{ar}/T_{gr} Calc.	7 dB	9 dB	3.5 dB	5 dB
T_{ar}/T_{gr} Exp.	13 dB	13.5 dB	4.5 dB	5.5 dB
θ	10°	5°	45°	25°

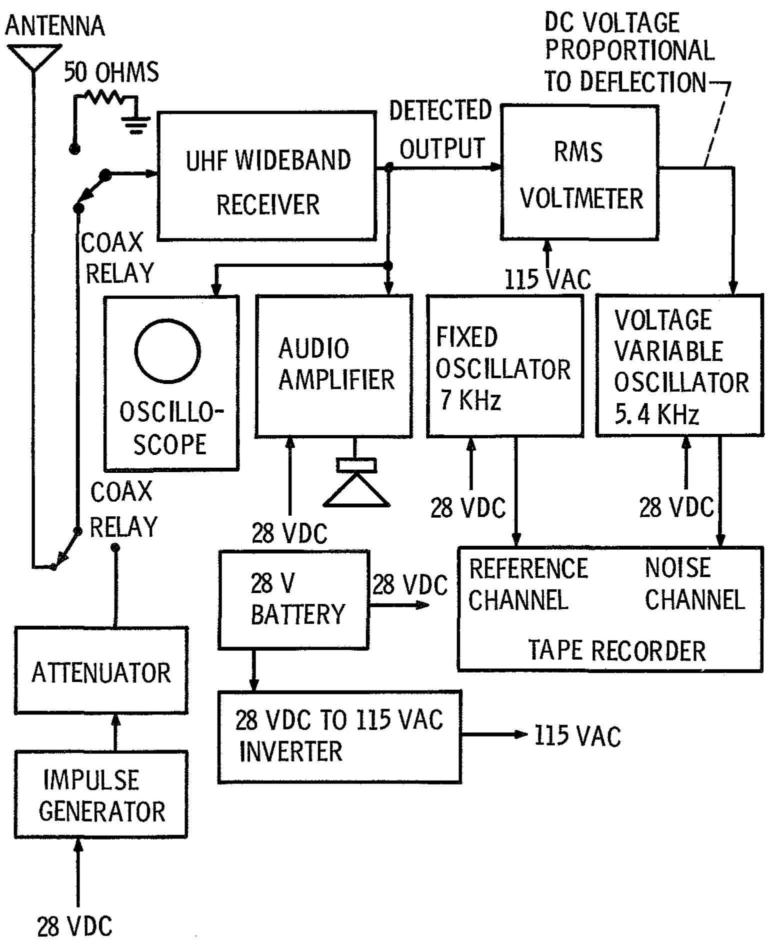


Figure 1. - UHF noise measuring system (ref. 3).

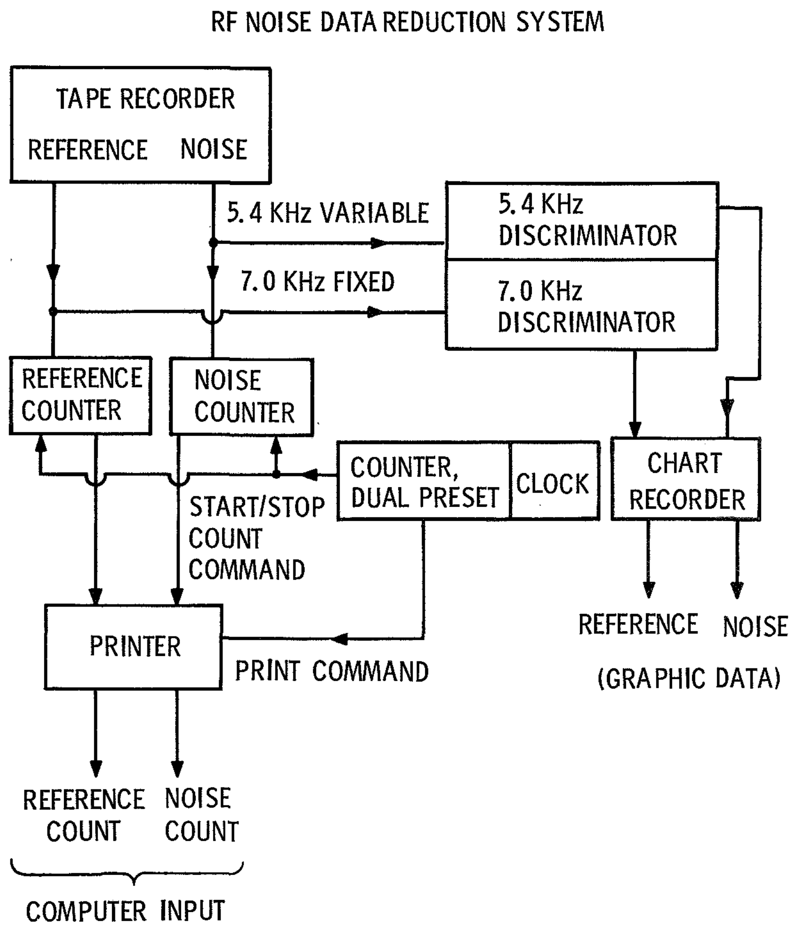
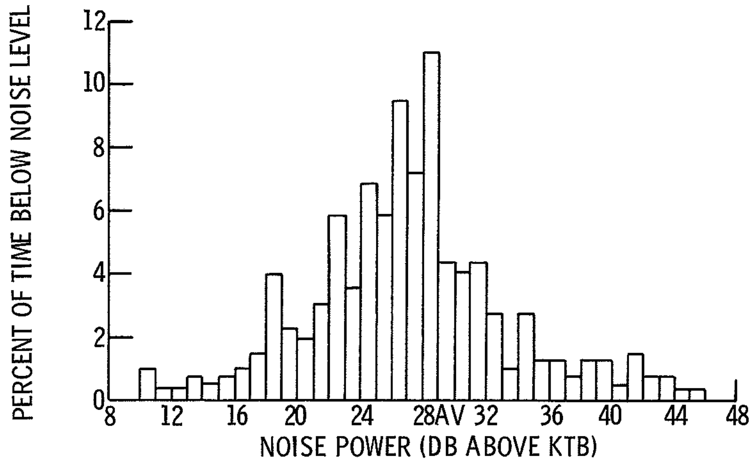
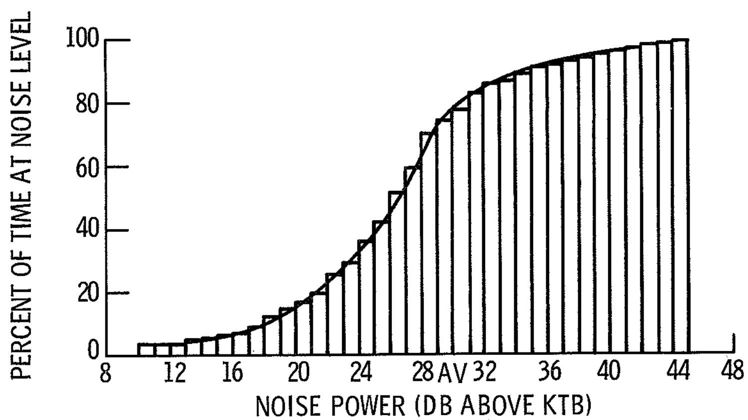


Figure 2. - RF noise data reduction system (ref. 3).

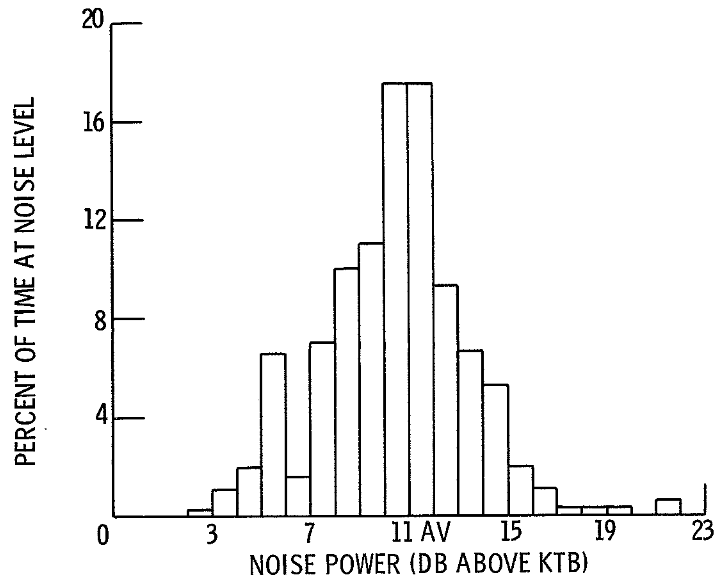


(A) NOISE DISTRIBUTION ABOUT AVERAGE LEVEL.

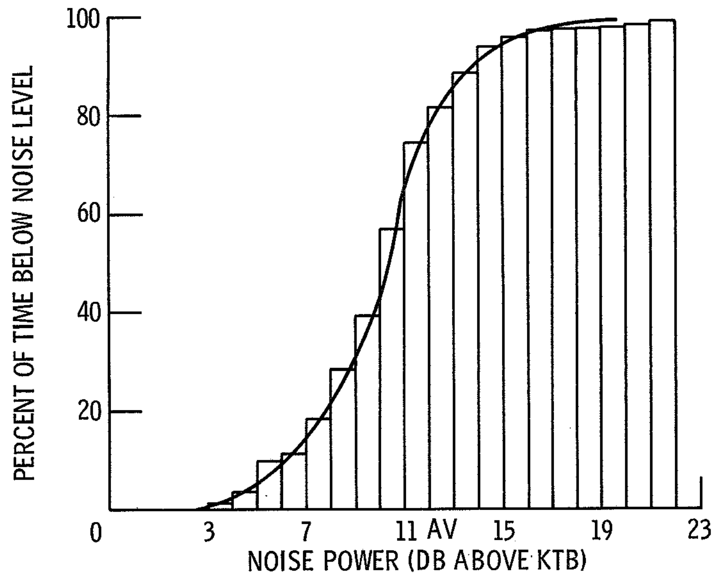


(B) NOISE PROBABILITY DISTRIBUTION.

Figure 3. - Radiofrequency noise at 480 megahertz (13 recordings at urban noisy areas) (see ref. 3).



(A) NOISE DISTRIBUTION ABOUT AVERAGE LEVEL



(B) NOISE PROBABILITY DISTRIBUTION.

Figure 4. - Radiofrequency noise at 950 megahertz (12 recordings at urban noisy areas) (see ref. 3).

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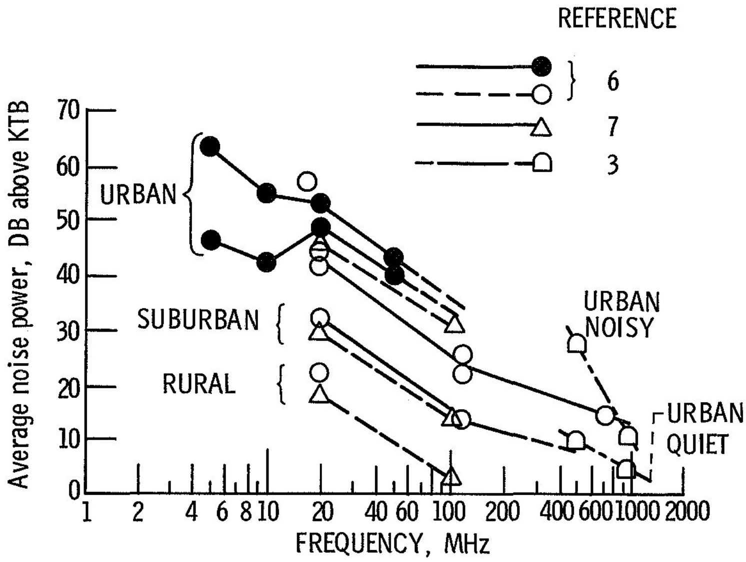

Figure 5. - Radio frequency noise (ref. 3).

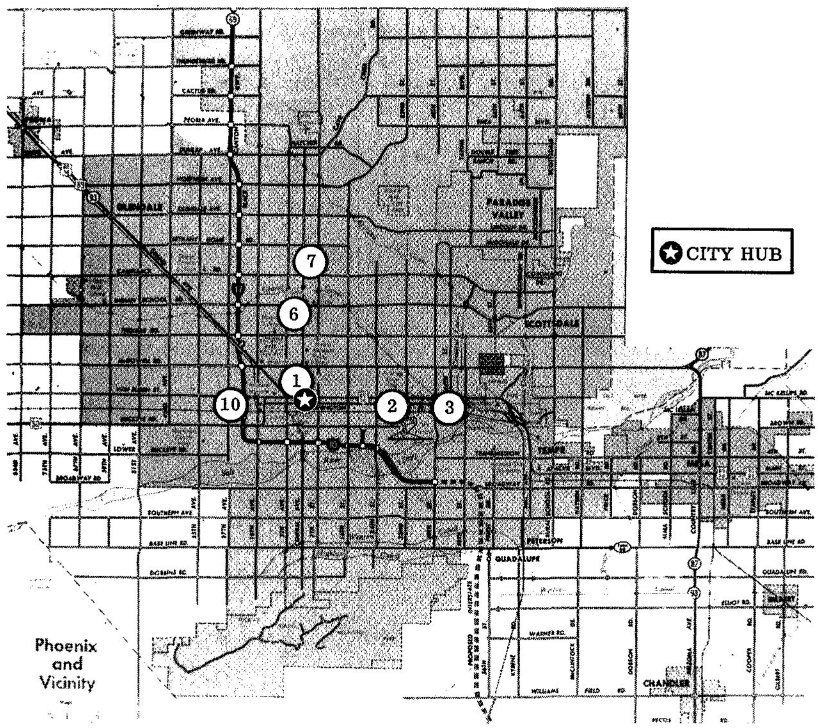

Figure 6. - Map showing ground measuring sites (ref. 4).

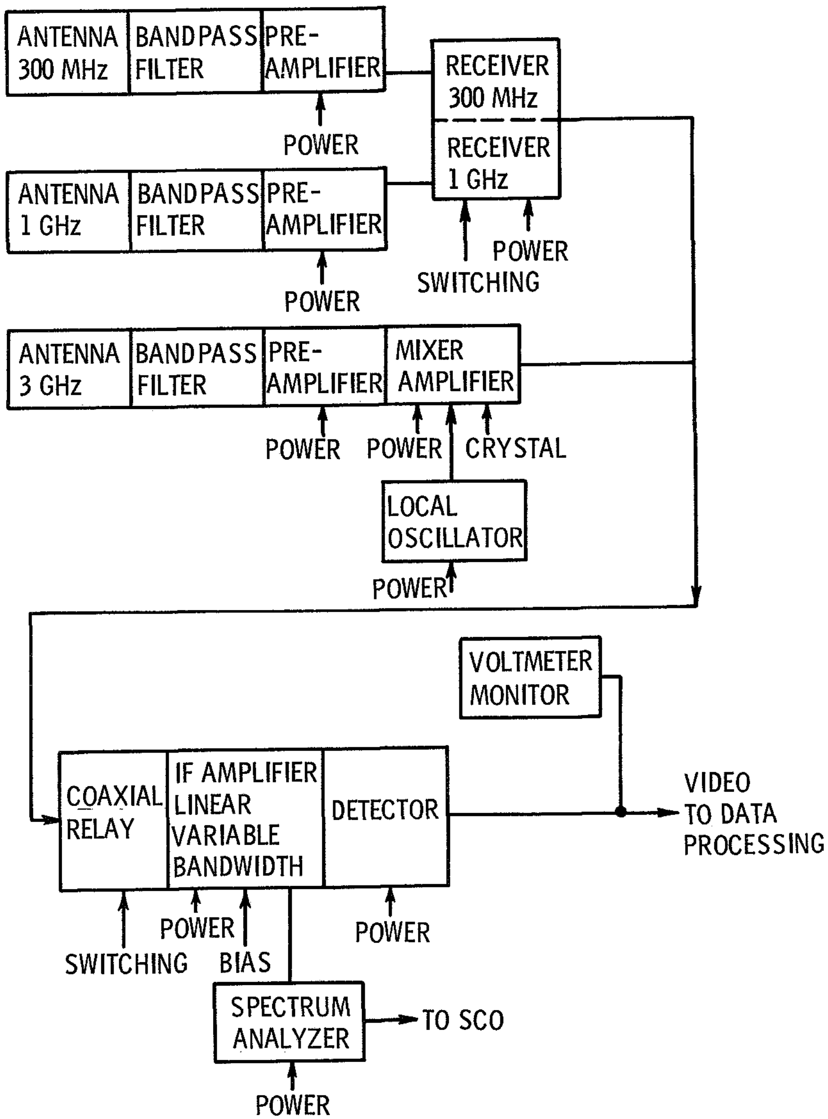

Figure 7. - Receiving system (ref. 4).

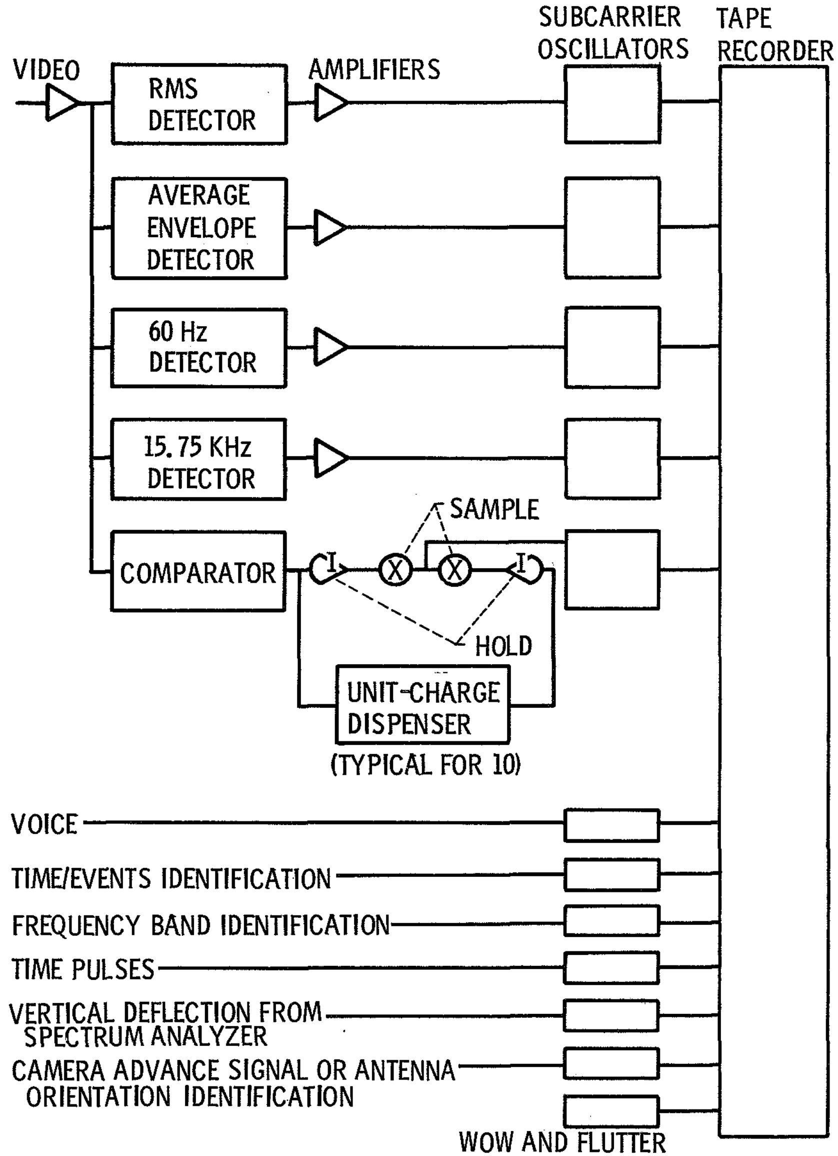

Figure 8. - Data processing and recording subsystem (ref. 4).

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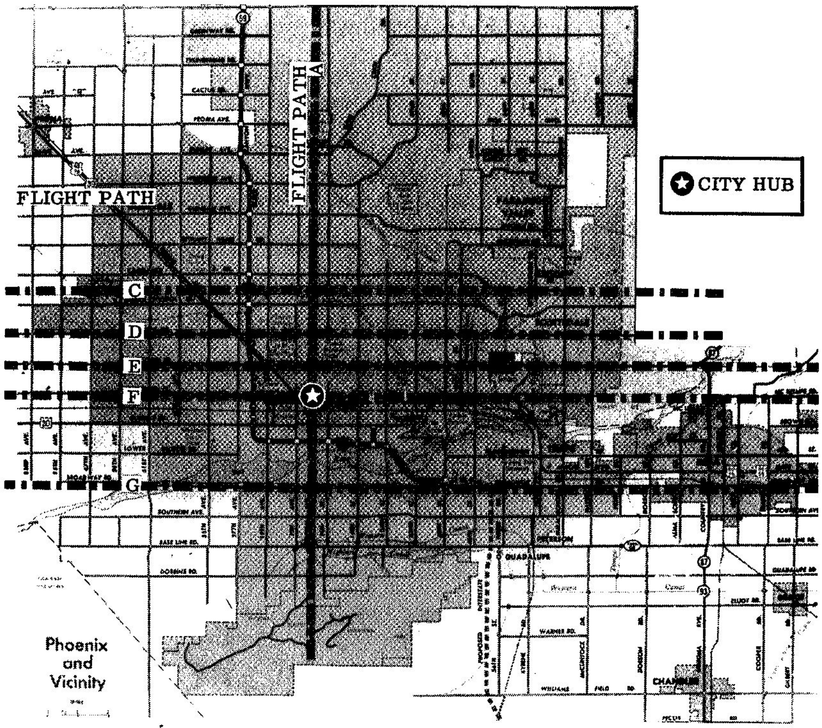
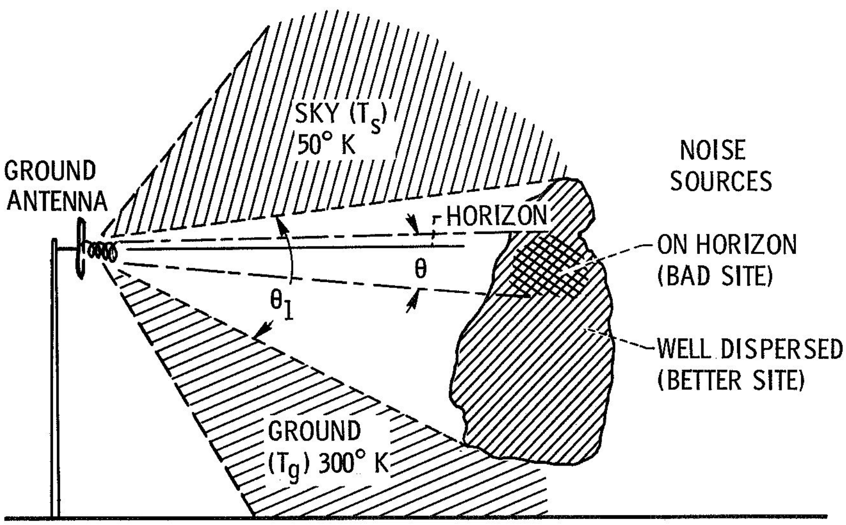


Figure 9. - Map showing flight paths (ref. 4).



$$T_{gr} = 0.5(T_s + T_g) + G_i(T_i) + T_r$$

Figure 10. - Ground RF noise (T_{gr}) (see ref. 5).

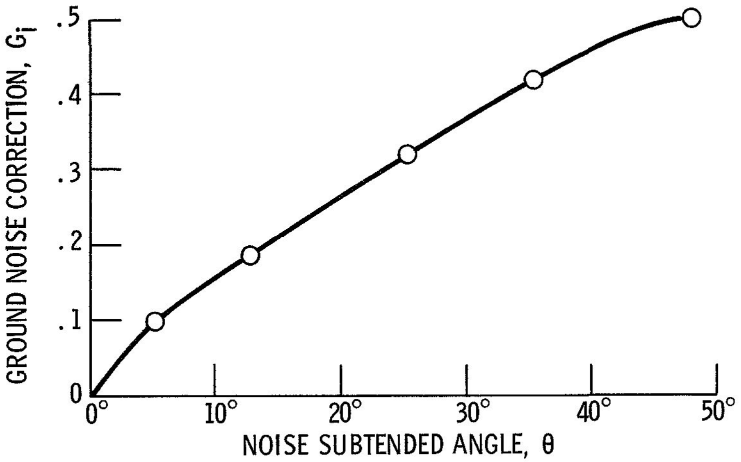


Figure 11. - Ground noise correction factor (G_i); (freq = 300 MHz) (see ref. 5).

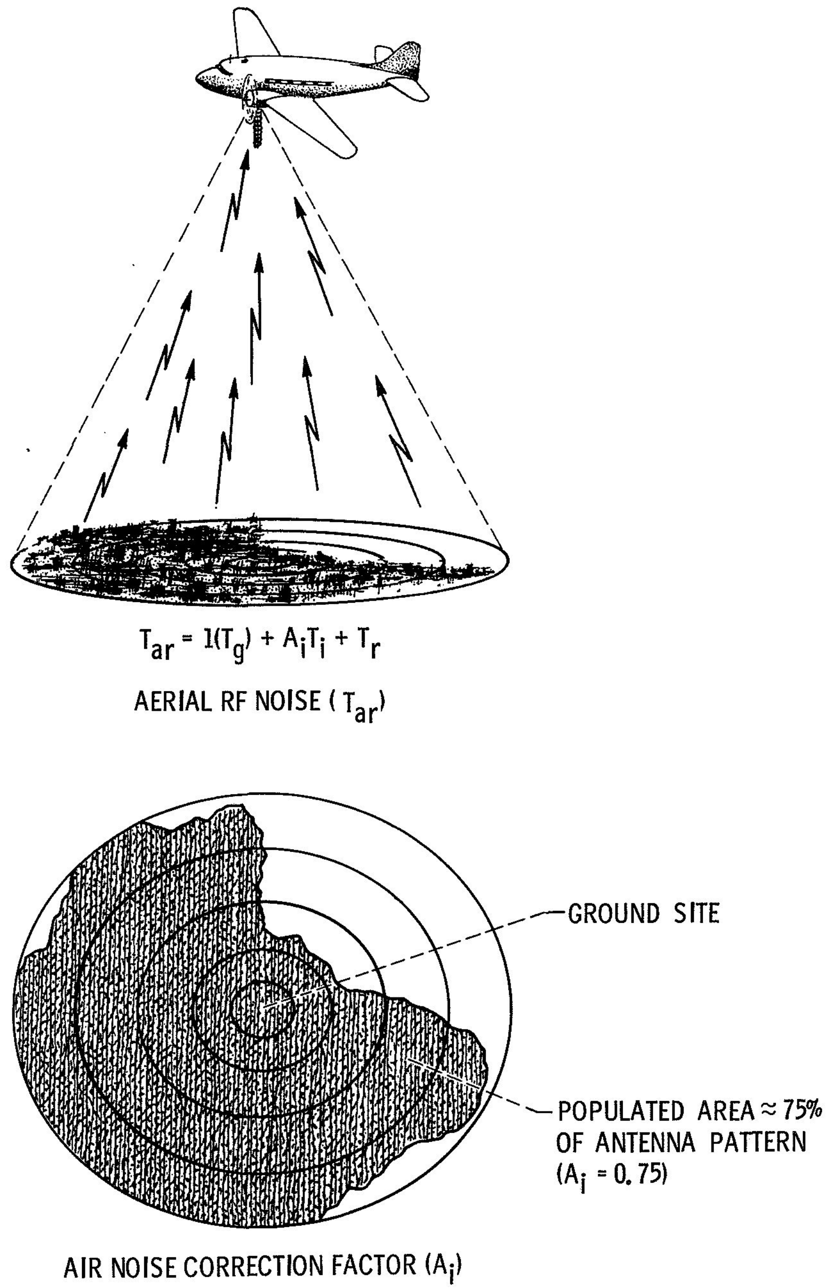


Figure 12. - Aerial RF noise and correction factor (see ref. 5).

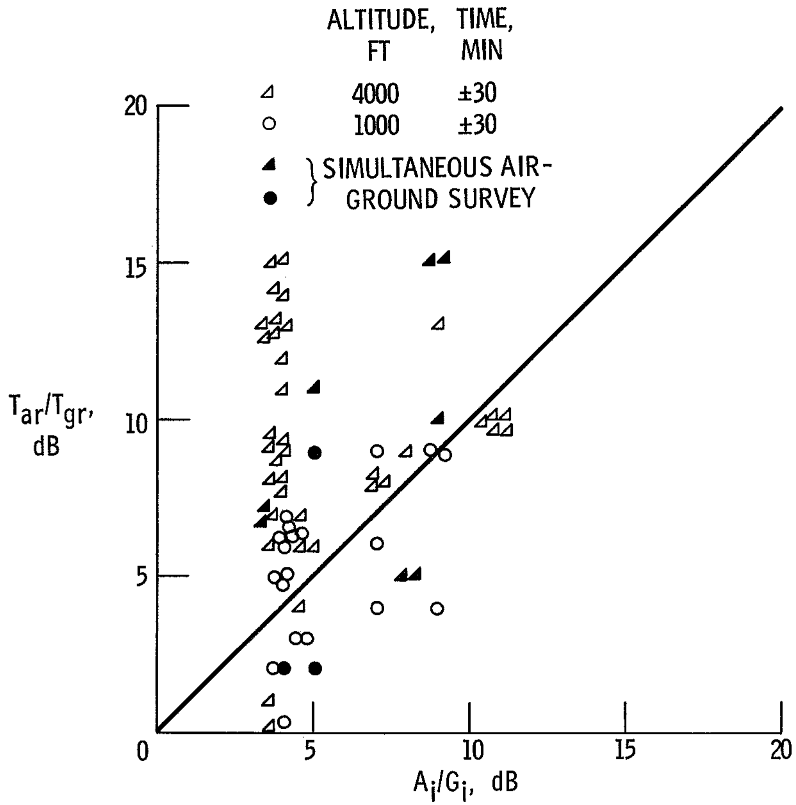


Figure 13. - Air-ground correlation (5 ground sites, 300 MHz) (see ref. 5).

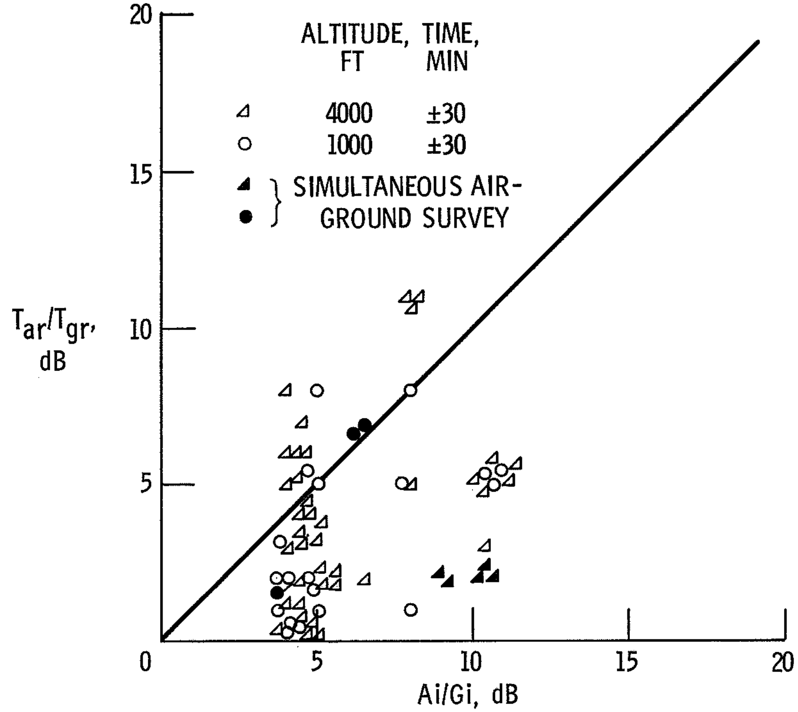


Figure 14. - Air-ground correlation (5 ground sites, 1.0 GHz) (see ref. 5).

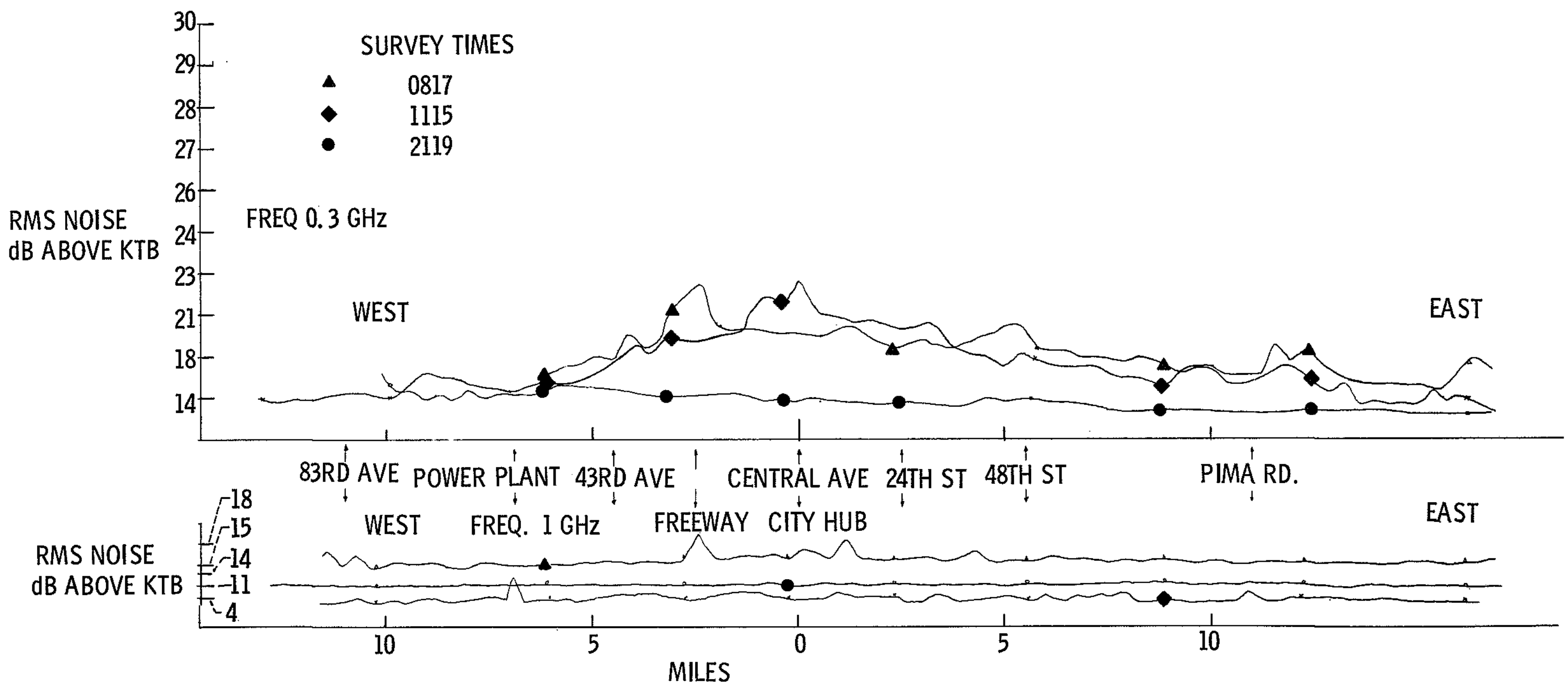


Figure 15. - RMS noise. Altitude = 4000 feet. Flight path "F" (Van Buren St.) (see ref. 5).

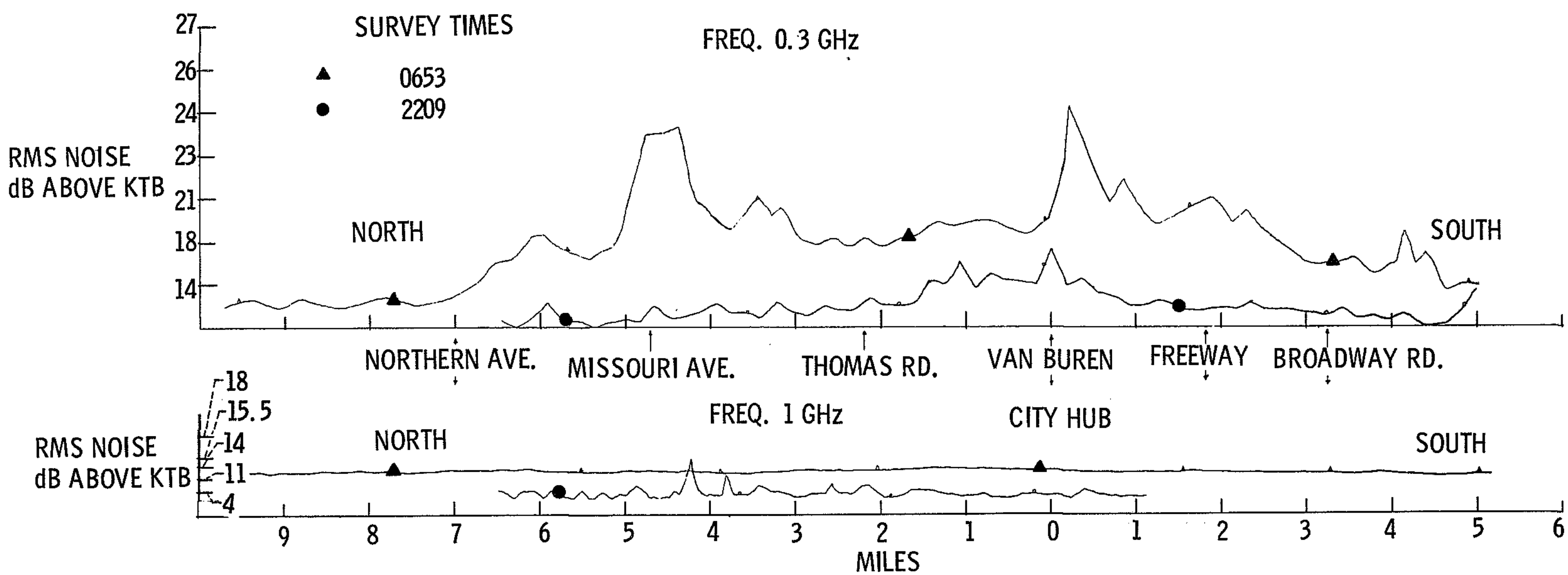


Figure 16. - RMS noise. Altitude = 4000 feet. Flight path "A" (Central Ave.) (see ref. 5).

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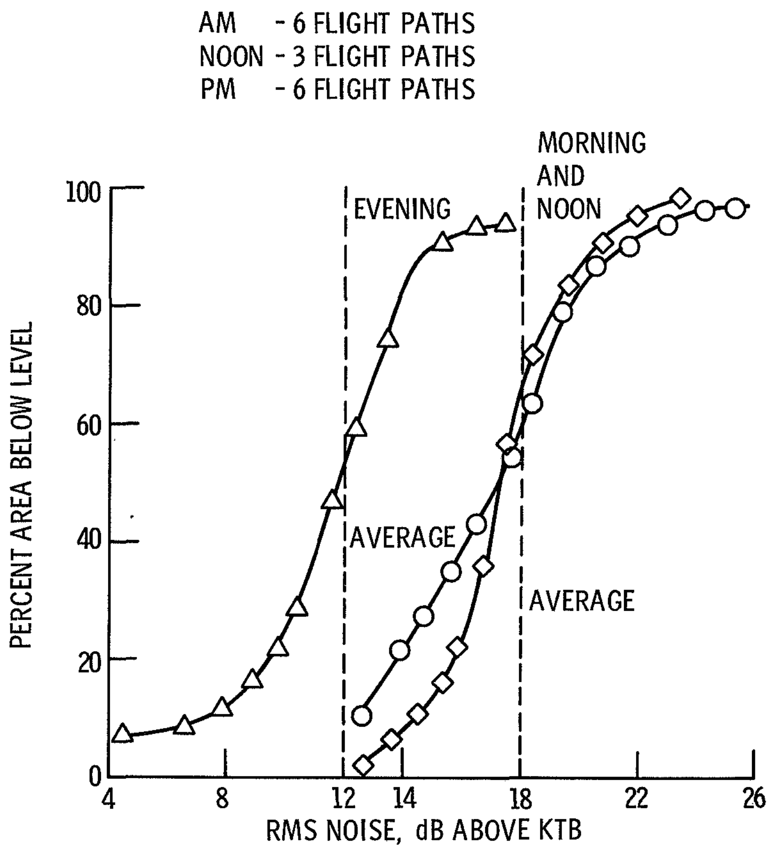

Figure 17. - Noise probability distribution (frequency = 300 MHz, altitude = 4000 feet) (see ref. 5).

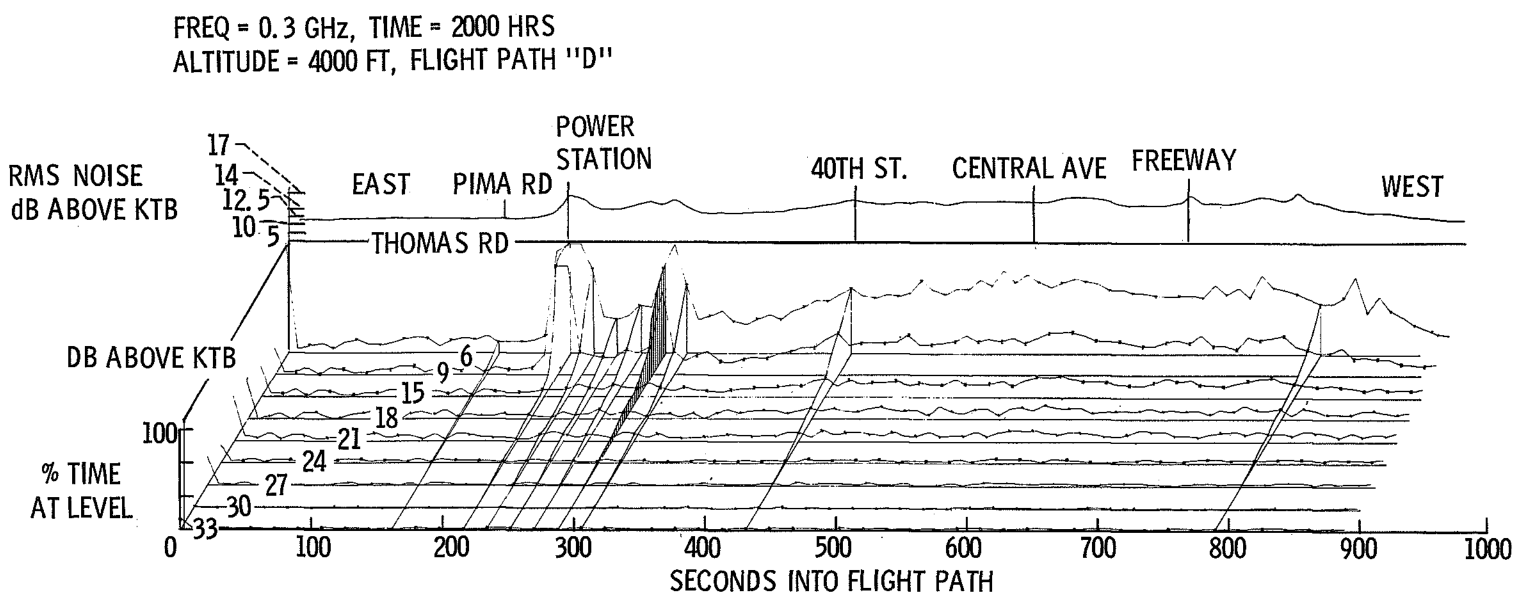

Figure 18. - RMS noise and time comparator data (ref. 5).

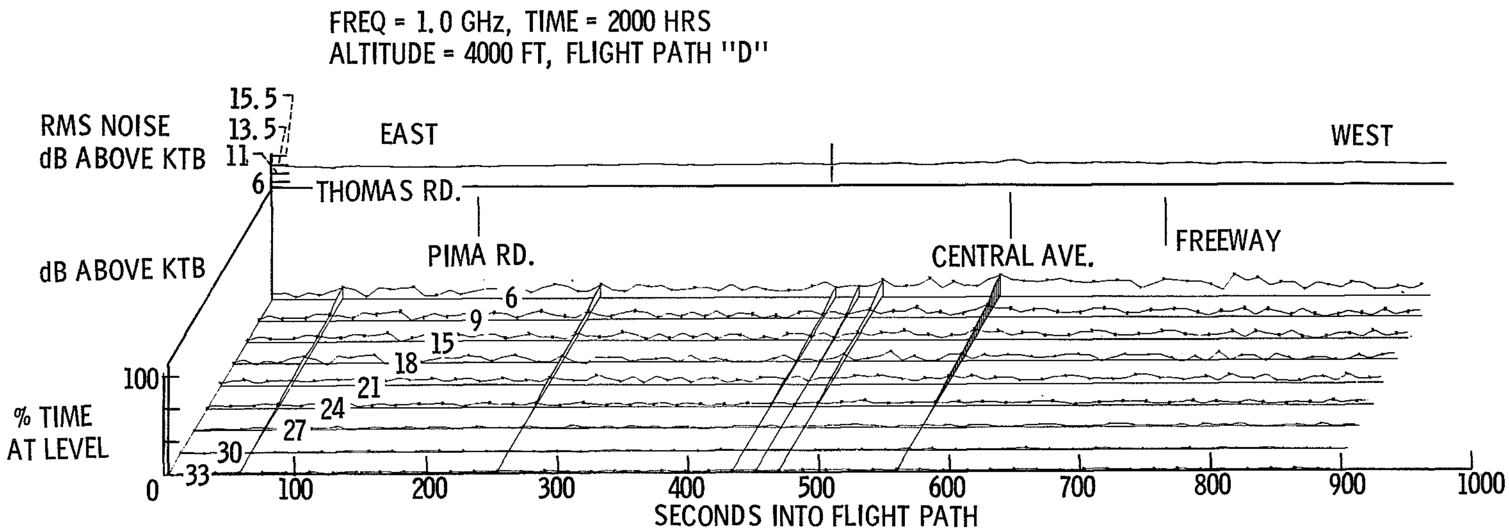

Figure 19. - RMS noise and time comparator data (ref. 5).