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AN EXAMINATION OF MAN-MADE RADIO NOISE AT 37 HF RECEIVING SITES

by

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January 2005

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ABSTRACT *(maximum 200 words)*. Man-made radio noise was examined at 37 HF receiving sites spaced at wide intervals around the world. The measurements were made with the goal of understanding the temporal and spectral structure of each example of man-made noise, determining the sources involved, and developing procedures to minimize the impact of man-made noise on signal reception. All measurements were made at the input terminals of receivers at each site as contrasted to the more traditional field-strength measurement of radio noise collected by a monopole antenna.

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SUMMARY

This document provides a summary of more than two decades of the field investigation of man-made radio-noise problems at U.S. Naval and other receiving sites. The primary goal was to improve the ability of each site visited to receive radio signals. The findings from thirty-seven receiving sites are presented.

Emphasis was placed on determining the adverse impact of man-made radio noise on the ability of the sites to receive radio signals, finding the location of each noise source, identifying the specific item of hardware generating noise, and mitigating each noise source. This emphasis dictated that the antennas normally used for signal reception be used to obtain signal and noise data rather than the standard antennas normally used to collect conventional radio-noise data.

Sources on overhead distribution power lines operated by the electric utilities were the primary origins of radio noise. Only a few sources were traced to overhead electric-power transmission lines. Power-conversion devices such as variable-speed motor drives, uninterruptible power supplies, and other such devices also were found to be major sources. Such sources introduced noise current into their associated overhead power lines, thus the overhead distribution lines were a component in the radiation of noise from such sources.

Harmful levels of radio noise were also identified from sources internal to many of the sites. Since the level of noise from these sources was lower than that from external sources and since the internal sources were under the control of site personnel, the mitigation of these sources is not covered in this document. Mention is made of them only because they will be the dominant source if all external sources are eliminated.

A new model to estimate the adverse impact of man-made radio noise at receiving sites is suggested. The model is based on the number of electric distribution-line power poles within line of sight of the uppermost part of the antennas at each receiving site.

ACKNOWLEDGEMENTS

A large number of individuals participated in the conduct of the radio-noise surveys summarized in this report. The surveys were initiated more than two decades ago by Dr. Stephen Jauregui of the Naval Postgraduate School, Monterey, CA. Dr. Jauregui had a long and distinguished career as a naval intelligence officer, and he joined the staff of the Naval Postgraduate School on his retirement from active duty. Dr. Jauregui recognized that the signal-reception capability of many naval receiving sites had deteriorated over the years, and he sought answers for the reasons for the deterioration. He was joined by LCDR Eugene Cummins of the Naval Security Group during the early part of this effort. Dr. Jauregui and LCDR Cummins then organized the Signal-to-Noise-Enhancement Program (SNEP) teams to investigate the problem. On the retirement of LCDR Cummins from the Navy, overall program management was provided by Ms. Teresa Keefe and later by Ms. Jackie Sherry of the Naval Security Group for Naval matters and by Ms. Anne Bilgihan of INSCOM for US Army matters.

Staff members and students of the Naval Postgraduate School supported the program as the lead technical organization. Additional support was provided by the SPAWAR Activity Pacific at Pearl City, HI and by the SPAWAR System Center at Charleston, SC. Several commercial organizations have also supported the SNEP teams. The first was Engineering Research Associates of Vienna, VA. Engineering Research Associates was absorbed by E-Systems who was absorbed by Raytheon. The SNEP team support followed this succession of corporate changes with no interruption in operation. Personnel from the SouthWest Research Institute in San Antonio, TX and Delfin Inc. of Sunnyvale, CA also participated in early surveys.

A number of individuals in the listed government and commercial organizations have provided significant long-term technical support to the SNEP program. The individuals providing key support from these organizations are:

LCDR Eugene Cummins; Naval Postgraduate School, Monterey CA, USN Student
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LT John O'Dwyer; Naval Postgraduate School, Monterey CA, USN Student
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Mr. William Briotta; Engineering Research Associates, E-Systems, and Raytheon
Mr. Orion Larsen, Delfin
Mr. Ken Cummins, Delfin

Many additional individuals from the above mentioned organizations and from other key organizations also supported the SNEP teams. They are too numerous to list, but their support was appreciated.

Wilbur R. Vincent
Richard W. Adler
George F. Munsch

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1. INTRODUCTION

Man-made radio noise appearing at the input terminals of receivers has been examined at a large number of high-frequency (HF) receiving sites, and this paper presents a summary of the results obtained from thirty-seven widely-separated HF sites. The task was conducted over a period of more than two decades. The objectives were limited to:

(a) Obtain sufficient information about man-made noise to understand its impact on the reception of radio signals.

(b) Locate and identify each source of man-made noise affecting signal reception.

(c) Devise mitigation actions to eliminate each source of man-made noise and implement these actions, starting with the strongest one that affects signal reception and proceeding to the next strongest until all are eliminated.

Instrumentation was used at each site that provided detailed information about the temporal and spectral structure of each case of man-made noise appearing at the input terminals of the receivers. Such information allowed operators of the instrumentation to identify the kind of each noise appearing at the input terminals of a receiver and to assess its adverse effect on the reception of various types of signals. In addition, knowledge of the temporal and spectral structure of each noise allowed the team to pass accurate information to field teams to locate the specific sources observed at the receiving site. In most cases the dominant noise was determined to be from sources on overhead distribution lines which distribute electric power from substations to customers and/or from power-conversion devices operating from overhead distribution lines.

Peak and average noise-power measurements were made within a stated Gaussian-shaped bandwidth at the 50-Ohm impedance of the signal-distribution system at each site. Most measurements were made from the antennas used by the receivers at each site. In a few cases measurements were made from substitute antennas similar to those intended for use at a new or modified site.

Each site survey usually consisted of two teams. One team observed, measured, and documented man-made noise at the receiving site. The second team was equipped with portable instrumentation to locate sources and identify the exact hardware causing the noise. Noise properties were passed from the receiving site to source-location teams in real time by radio. If a specific noise became inactive at the site, the field teams terminated attempts to locate that source and proceeded to another source. In this manner, the strongest sources at the site at any time could be given highest priority. This procedure allowed the internal and external teams to efficiently function as sources became active and inactive.

2. INSTRUMENTATION

Figure 1 shows a block diagram of the site measurement instrumentation. It consisted of a bank of band-pass filters, used one at a time, to limit the total signal and noise power into the preamplifier and the spectrum analyzer to low enough levels to avoid saturation and the deleterious effects of nonlinear operation. At later times it was necessary to replace the filters with a preselector to cope with the dense signal environment in the HF band. A high dynamic range preamplifier was used to obtain a signal- and noise-detection sensitivity about equal to that of a standard HF receiver. A spectrum analyzer (HP-141) was used as a scanning or fixed-tuned receiver to observe signals and noise within the pass band of each filter. This particular model of spectrum analyzer was chosen because of its short dead time between scans compared to more modern analyzers, and its ability to be quickly adjusted to cope with time-changing noise conditions. A time-history display (ELF Engineering Inc. Model 7200B) was used to portray a succession of 60 analyzer scans in a 3-axis format and provide the operator with a visual view of all signals and noise in the band under observation. An oscilloscope camera was used to photograph any desired time-history view.

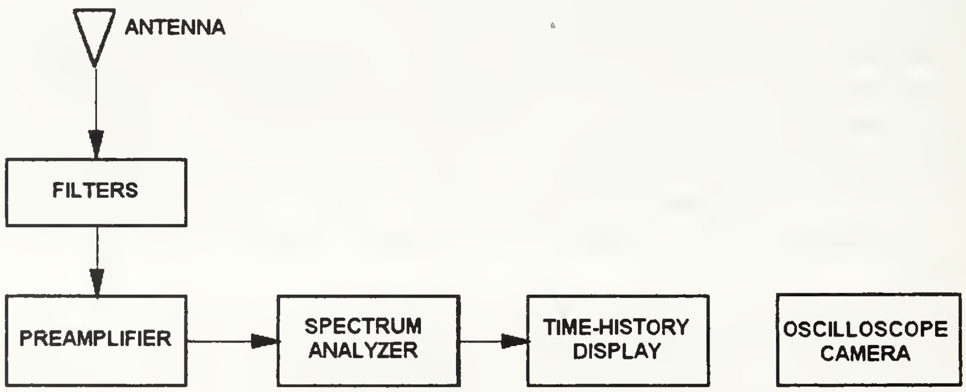

Figure 1 Block Diagram of the Instrumentation

The site instrumentation is described in detail in another publication, as is the source-location and source-identification instrumentation[1]. All examples of noise data collected at all sites were fully calibrated in frequency, amplitude, and time. Site and measurement system parameters are provided in a line under each item of data where each item is separated by a comma. The information in this line is:

Site Identification, Date in yymmdd format, Local Time, Center Frequency, Frequency Span, IF Bandwidth, Scan Time, Antenna ID, Filter ID, PreAmp Gain, RF Attenuation, IF Setting*

* (LS) is appended to the scan time when line synchronization is used.

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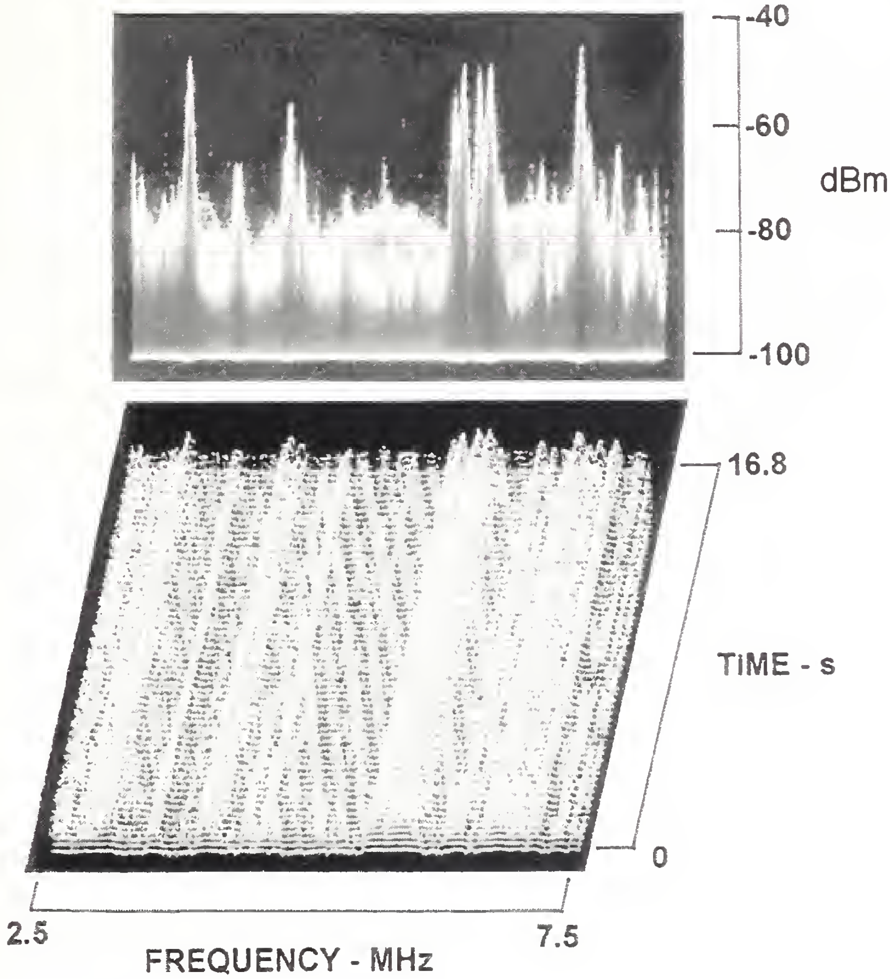
[1] Wilbur R. Vincent and George F. Munsch, ***Power-Line Noise Mitigation Handbook for Naval and other Receiving Sites,*** 5th edition, Report No. NPS-EC-02-002, Signal Enhancement Laboratory, Department of Electrical and Computer Engineering, Naval Postgraduate School, Monterey, CA, January 2002

3. FIELD SURVEY RESULTS

3.1 Example of Temporal and Spectral Structure of Noise

Figure 2 shows a typical case of modest to severe radio noise from a source on a power line pole where the pole was about 2 km from the site. Two views of the same data are shown where the upper view is similar to the amplitude-vs-frequency presentation of a spectrum analyzer. The lower view shows 60 successive scans of the analyzer where amplitude is severely, but not completely, compressed. The slanting lines across the time-history view are caused by repetitive groups of impulsive noise interacting with the scan process of the spectrum analyzer. Strong signals exceed the noise and can be received without interference, but the weaker signals of high interest were covered up by the noise, and they could not be received.



HUM, Pasteup, 930518, 1435, 5, 5, 30, 200, H42, NF, 0, 0, -20

Figure 2 Coarse-Scale Example of Modest to Severe Power-Line Noise

Figure 3 shows an example of severe radio interference from a source on a power pole located 1 km from the receiving site. The noise covered up all signals over the frequency range of 2 to 8 MHz. The amplitude reduction of the noise at the low end of the frequency range is from a band-pass filter used to limit the total signal and noise power received by the instrumentation. Three sources of noise can be identified in the amplitude-vs-frequency view along with peaks and nulls in amplitude with frequency. The temporal structure shown in the time-history view indicates all sources are on the same phase of the power line.

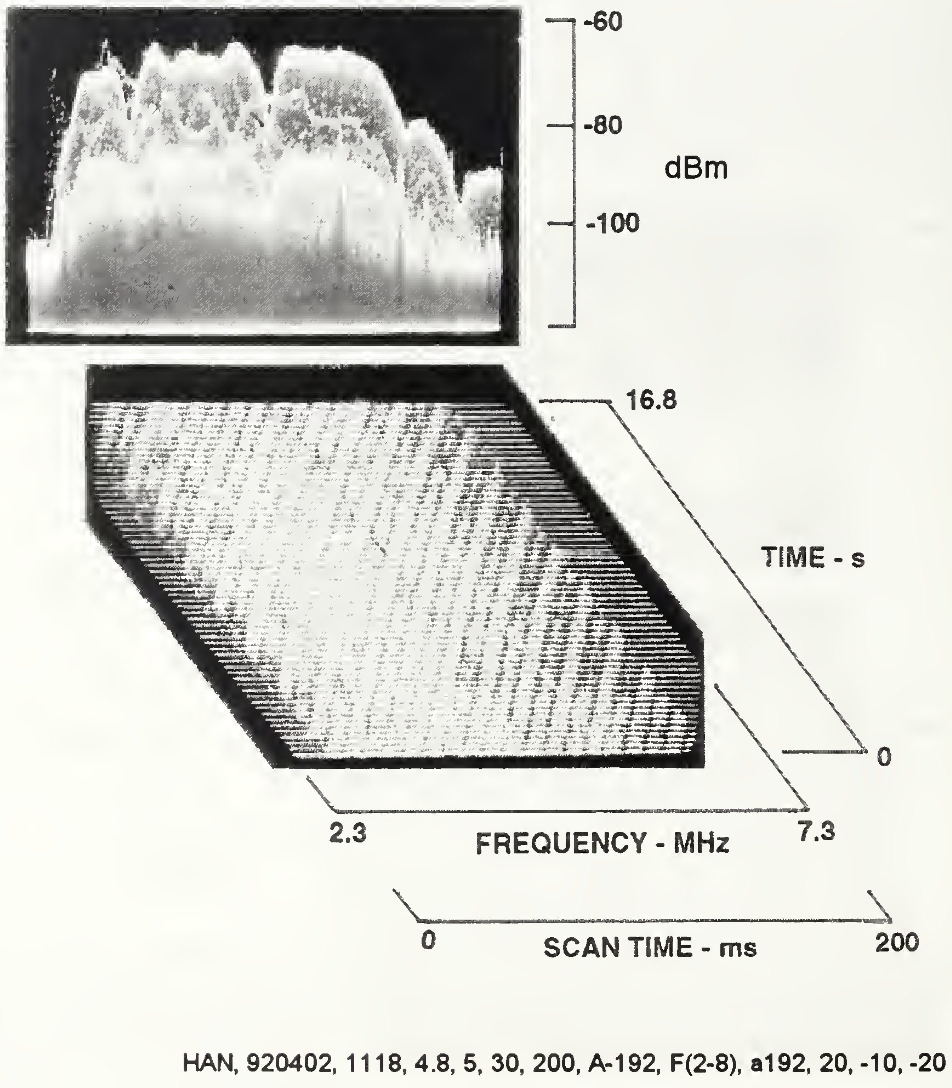


Figure 3 Coarse-Scale Case of Severe Power-Line Noise

The section of distribution line with the onerous sources causing the noise in Figure 3 was rebuilt according to the noise-free procedures in Reference 1. This completely eliminated these particular sources, and this section of distribution line remains free of noise today, more than a decade after the line overhaul.

The time-history view of Figure 4 shows the noise is from a source that is erratic in operation. This is typical of many sources of man-made noise, and the time-varying operation of such sources complicates the task of providing simple descriptions of such noise. In the bottom half of the time-history view the amplitude was fairly constant across the HF band, but it then increased in amplitude up to about 80 MHz. In addition narrow peaks and nulls in the amplitude of noise along the frequency axis made it impossible to provide a single value for noise amplitude for this case and other similar cases.

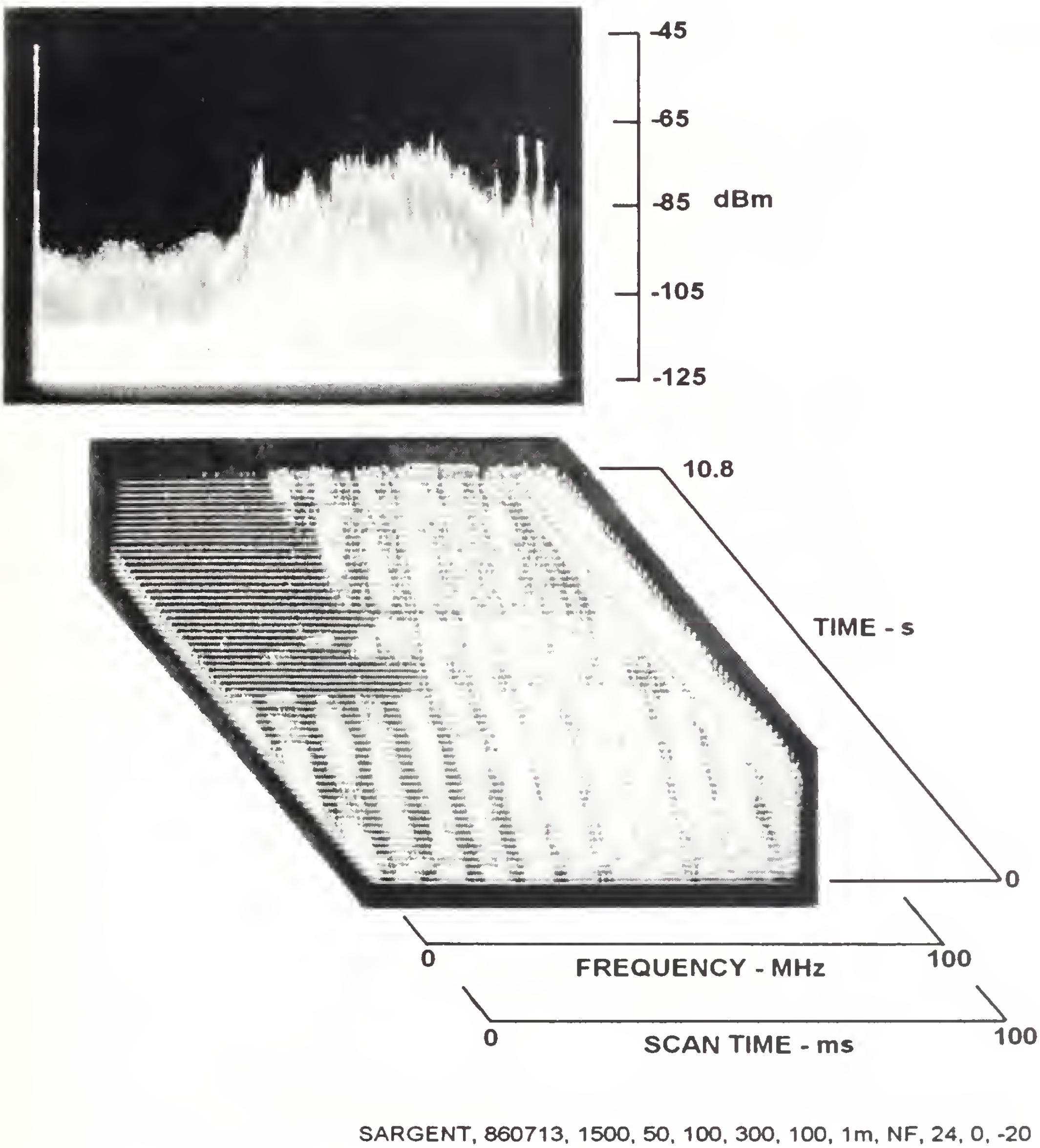


Figure 4 Coarse-Scale Presentation of Intermittent Noise

Figure 5 shows another case of intermittent noise from a source on a power pole. In this case the noise extended from the low end of the HF band up into the VHF and UHF bands. The noise in the upper part of the VHF band is shown in the example. The intermittent activity of the source resulted from the slight movement of the pole hardware from wind. This source was active only on clear days with low humidity. Source activity stopped in the late afternoon when humidity increased slightly and remained off during most of the nighttime, resuming again in the mid-morning hours. The source was inactive during rain and fog while other sources within line of sight became active as humidity increased.

In this example, the source was on a distribution line pole feeding power to the site, and the pole was located only about 100 m from the receiving antenna.

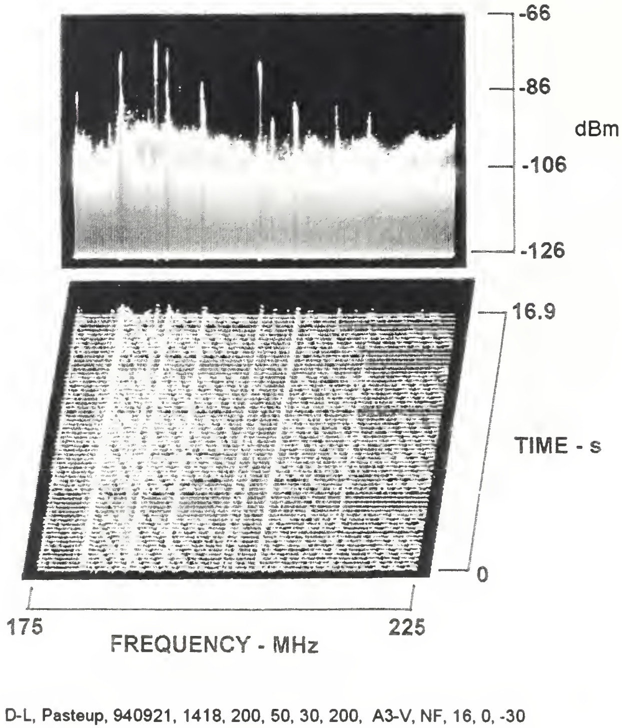
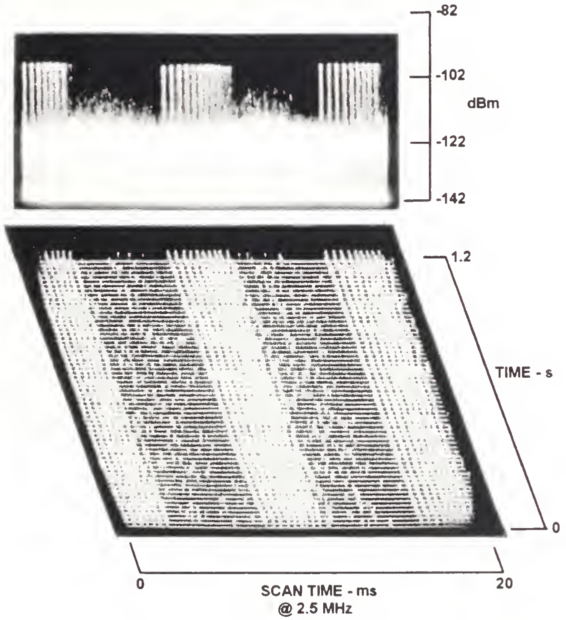


Figure 5 Intermittent Noise from a Source Close to a Receiving Site

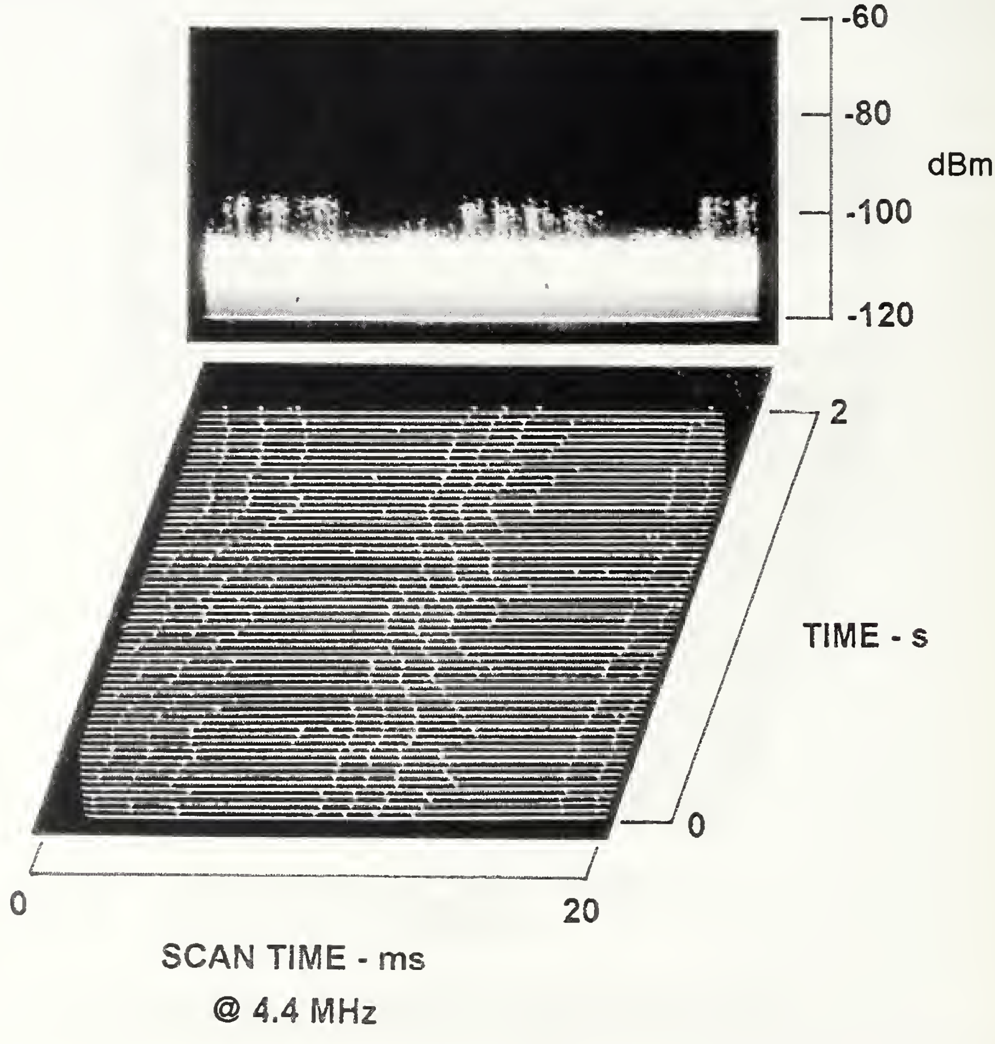
Figure 6 shows an example of the fine-scale temporal structure of noise emanating from a frequently observed type of source. In this case the frequency-scanning process was set at zero with the spectrum analyzer frequency control set to 2.5 MHz. The scan process of the analyzer was synchronized to the frequency of the power source for this example. With these settings the output data is similar to the presentation on an oscilloscope operating in its line-sync mode. The noise consists of groups of close-spaced impulses which occur every 8.3 ms, one half the period of the power-line frequency. The uniform amplitude of each impulse is shown in the upper view, and the distinctive temporal pattern of the impulses in each group is shown in the lower view. The unique temporal pattern of this example identifies the most likely source of the noise as a bell insulator on a nearby overhead distribution line. The signatures of this and many other sources of noise are illustrated and described in Reference 1.



NPS BEACH, 931123, 1033, 2.5, 0, 10, 20LS, 3m, F(2-8), 22, 0, -40

Figure 6 Fine-Scale Temporal Structure of Power-Line Noise, Example 1

Figure 7 shows another example of noise from a source on a power pole. The distinctive temporal structure is entirely different from that of the previous example. In this example the source was a small arc between two metal pieces of hardware on a power pole. Neither piece of metal was connected to the hot line. The metal pieces were close enough to the line to be charged to a potential difference sufficiently high to breakdown the air gap between them, a distance of about ¼ inch. Three and occasionally four breakdowns occurred at the peaks of the voltage waveform on the power line. Current surges caused by each individual breakdown resulted in a strong electromagnetic field surrounding the objects and the impulse current was inductively coupled onto the power-line conductors. The pole was located several miles from the receiving site.



NW, Pasteup, 970429, 1608, 4.4, 0, 30, 20LS, BPF 1, 20, 0, -20

Figure 7 Fine-Scale Temporal Structure of Power-Line Noise, Example 2

Figure 8 shows an example of the erratic temporal structure of noise from multiple sources on power poles. Three dominant sources of noise are present along with low-level noise from other sources. The site instrumentation operator was able to sort the sources and concentrate on the location of the highest level source. When the highest level source was located, attention could then be given to the next highest source.

This example was obtained at the high end of the HF band. Similar structure was found throughout the entire HF band and up into the lower end of the VHF band although the amplitude of the noise changed significantly with frequency, exhibiting peaks and nulls across the HF and VHF bands.

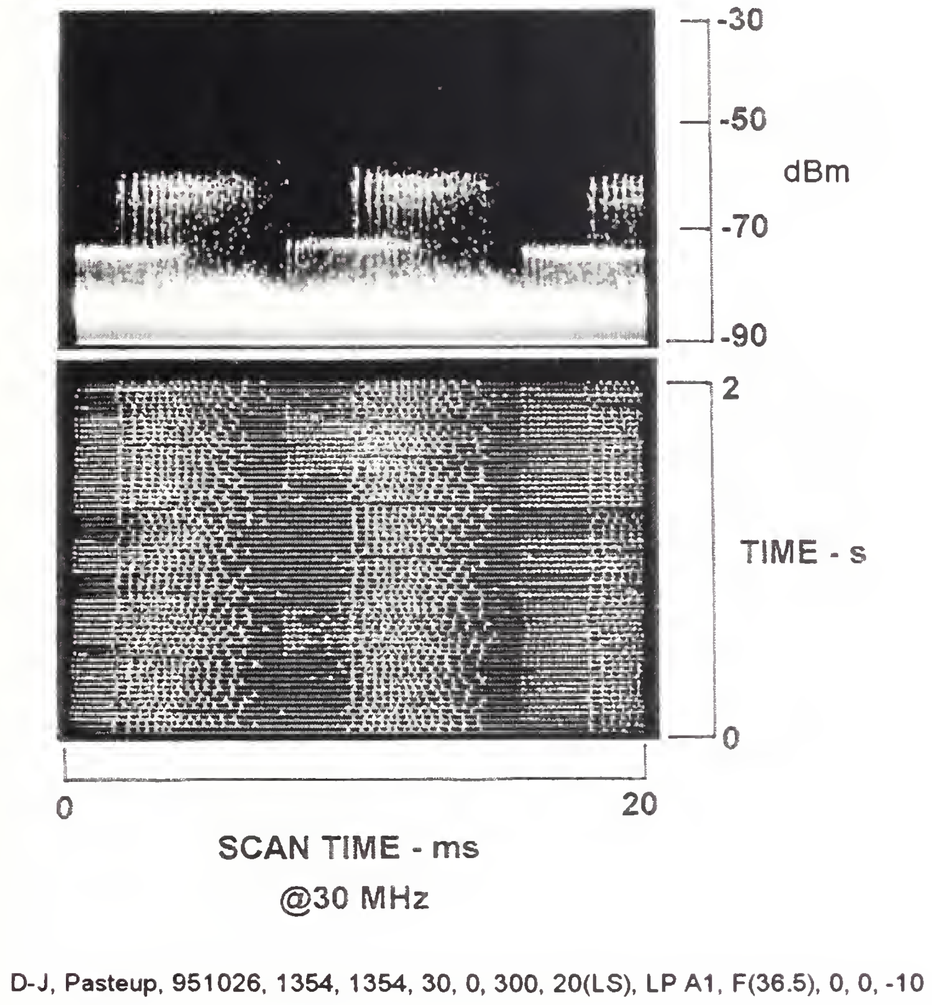
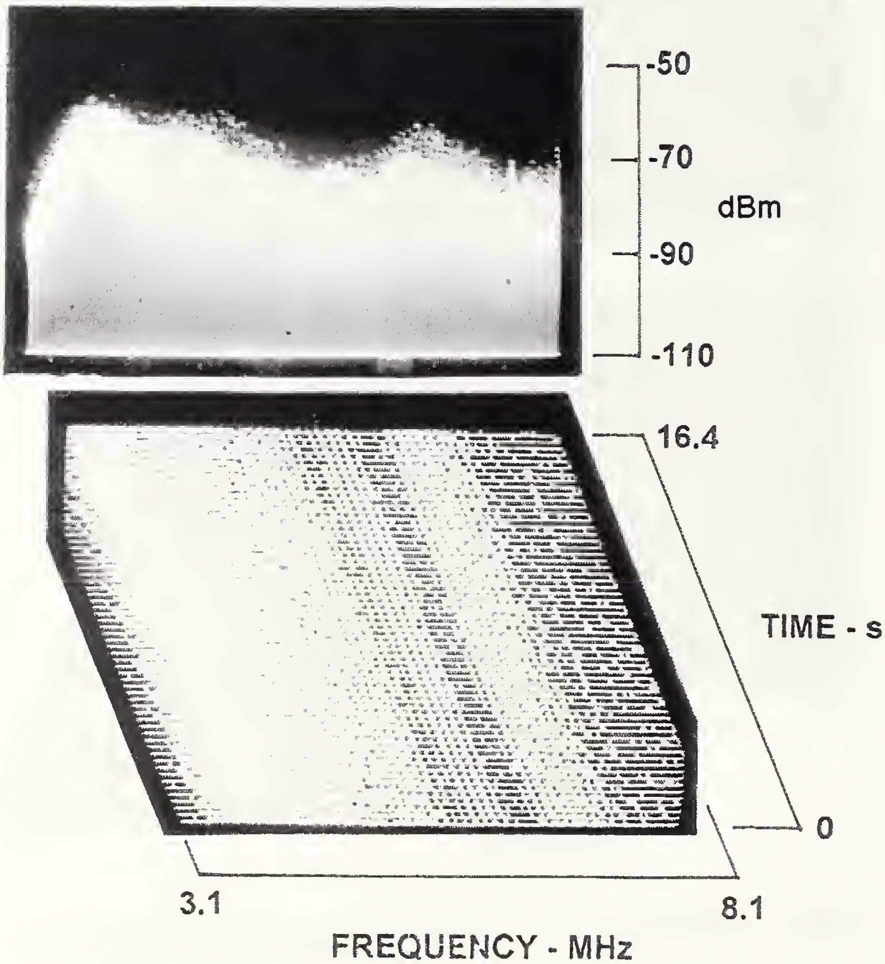


Figure 8 Fine Scale Structure of Multiple Erratic Sources

Power-conversion devices also have been identified as a source of harmful interference at a number of receiving sites. Figure 9 shows the coarse-scale temporal and spectral structure of noise emanating from an Uninterruptable Power Supply (UPS) feeding a satellite terminal. The UPS introduced harmful interference into a HF receiving site located more than 2 km away.

Figure 9 shows the spectral and temporal structure of the UPS noise when examined with a 3-meter whip antenna located 8 meters from the UPS facility. In this case the UPS was installed in a small metal hut located on a cement pad and separated from the satellite facility about 5 meters. The noise originated from high levels of EMI current flowing on the surface of the hut housing the UPS, on the power cables from the hut to the satellite facility, and on ground cables associated with the UPS.

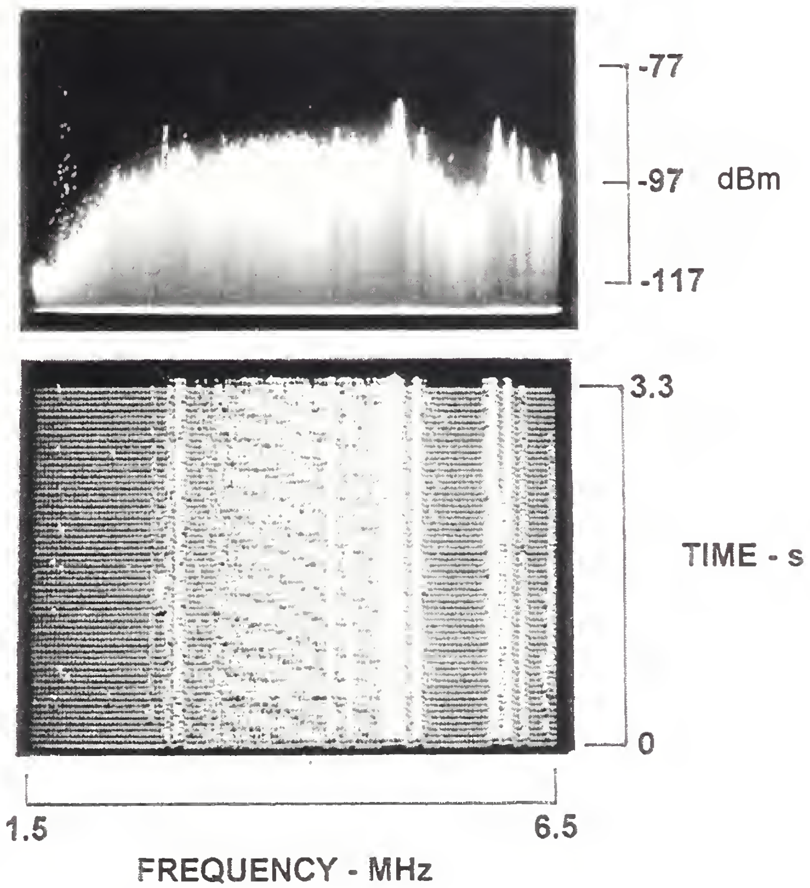


NW, 970507, 1450, Pasteup, 5.6, 5, 30, 200LS, 3m, NF, 0, 0, -30

Figure 9 Coarse-Scale Properties of Noise from a UPS

Controllers for variable-speed drives for electric induction motors convert power from the line frequency to a variable frequency with switching techniques. These devices feed switching transients back onto overhead power lines with little loss through the distribution line transformer and switch gear used to supply electric power to the controller.

Variable speed drives are used for a variety of purposes such as controlling air flow, the speed of conveyer belts, the flow of liquids, and many other similar tasks. Figure 10 shows noise received at a receiving site from a motor controller located 11 km from the site. The variable speed drive in this example controlled the flow of enriched water to tomato plants in a hydroponics farm.



HAN, 960319 0950, Pasteup, 4, 5, 30, 50, PS, BPF-1, 20, 0, -20.

Figure 10 Coarse-Scale Properties of Motor Controller Noise

Three additional motor controllers with similar temporal and spectral characteristics were located at the same site where the example for Figure 10 was obtained. The low cost and effective performance of controllers for variable-speed-motor drives suggest they will be an ongoing source of harmful radio interference at many receiving sites.

Figure 11 shows the fine-scale temporal structure of noise from a variable-speed motor controller. This noise was found at a receiving site. In this case the frequency of the spectrum analyzer was set at 13.4 MHz, the frequency of maximum amplitude of the noise, and the frequency span was set to zero.

Two sets of impulsive noise appear in the time-history view. One set is associated with the conversion of the electric power to direct current and the other set is associated with the frequency of the power applied to the electric motor. Note that the temporal structure changes significantly of one set as the load on the variable speed drive is varied. This changing pattern continued throughout the working day, but it turned off during the noon hour and at the end of the working day. Other controllers such as those on air-handling system often operate continuously with only very small changes in temporal structure.

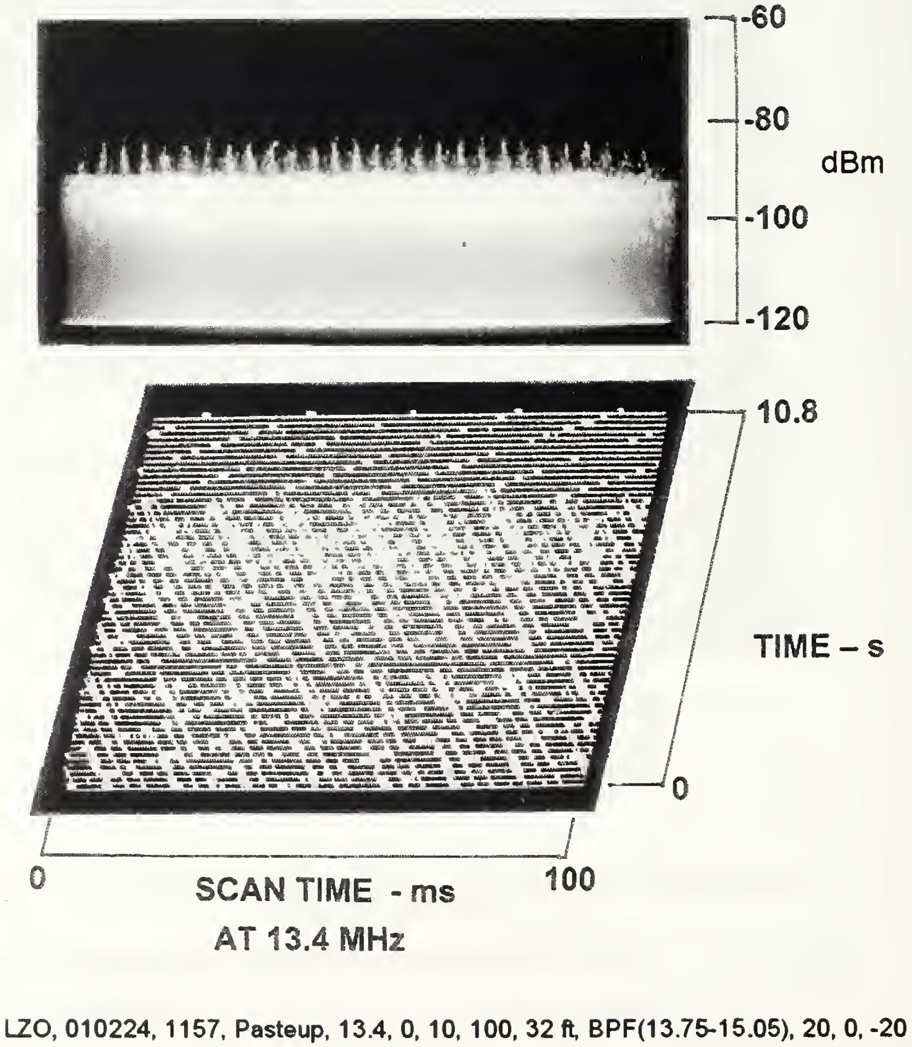


Figure 11 Fine-Scale Temporal Structure of Noise from a Motor Controller

3.2 Bandwidth Issues

Early measurements employed the 3-kHz bandwidth Gaussian-shaped IF bandwidth of spectrum analyzers since it was close to the 2.4-kHz bandwidth used for classical radio-noise measurements, but bandwidth problems were encountered. It was found that the 3-kHz bandwidth did not permit the collection of enough information about the temporal structure of noise for many signal-detection analyses or to define noise properties sufficiently for source-location and source-identification tasks. Wider measurement bandwidths did provide sufficient information about the temporal structure of each source for these purposes.

One of the bandwidth problems was with the measurement of the amplitude of man-made radio noise. Most man-made radio noise is impulsive, and the spectral width of impulsive noise is often wider than 3 kHz. Thus, the amplitude of impulsive noise changes significantly with bandwidth while the amplitude of signals with spectral content less than the measurement bandwidth does not change with bandwidth. In addition, the shape of the impulses of noise changes with bandwidth. Thus the statistical properties of man-made radio noise are also a function of bandwidth.

Hodge examined the amplitude problem at a number of sites and empirically derived a useful bandwidth-scaling plot.[2] His plot to convert the amplitude of impulsive noise from one bandwidth to another is reproduced in Figure 12. The Hodge plot was derived from a large number of measurements at a number of receiving sites located around the world. A reference line for Gaussian noise is included in his plot.

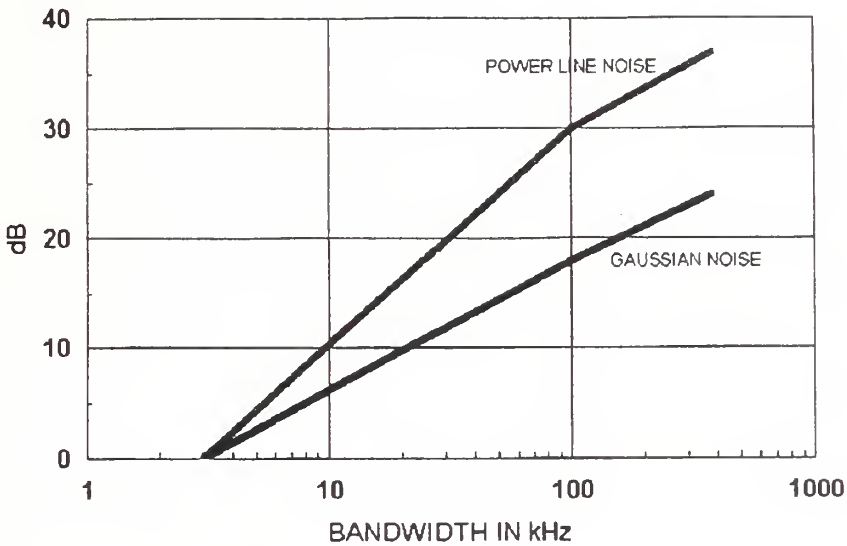


Figure 12 Bandwidth Scaling Curve for Power-Line Noise

The bend in the upper end of the curve in Figure 12 where the slope approaches that of Gaussian noise suggests that most of the spectral components of power-line noise are contained

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[2] James W. Hodge, Jr., ***A Comparison Between Power-Line Noise Level Field Measurements and Man-Made Radio Noise Prediction Curves in the High Frequency Band***, MS Thesis, Naval Postgraduate School, Monterey, CA, December 1995

within a 100-kHz bandwidth. At some low bandwidth the slope of the line for power-line noise should also approach the slope of the Gaussian noise curve, but this has not been adequately examined. The lower end of the plot is under further investigation.

Initial attempts have been made to examine the amplitude-vs-bandwidth properties of noise from variable-speed motor controllers. Figure 13 shows the result of measurements on two examples of such noise. In one case the slope of the curve at the low-frequency end of the plot appeared to approach that of Gaussian noise in the vicinity of 3 kHz, but the other case did not show this change. The data also indicate that the slope did not change at the widest measurement bandwidth available as found for power-line noise. This implies that the maximum available bandwidth of the instrumentation (300 kHz) was not sufficient to include the major spectral components of noise from power-conversion devices.

While the initial data shows the primary features of the amplitude-vs-bandwidth plot, additional data is needed to understand the finer details at both the lower end and the upper end of the bandwidth scale. Since noise from various power-conversion devices does not have the same spectral and temporal structure, multiple curves may be needed to present the amplitude-vs-bandwidth correction factors.

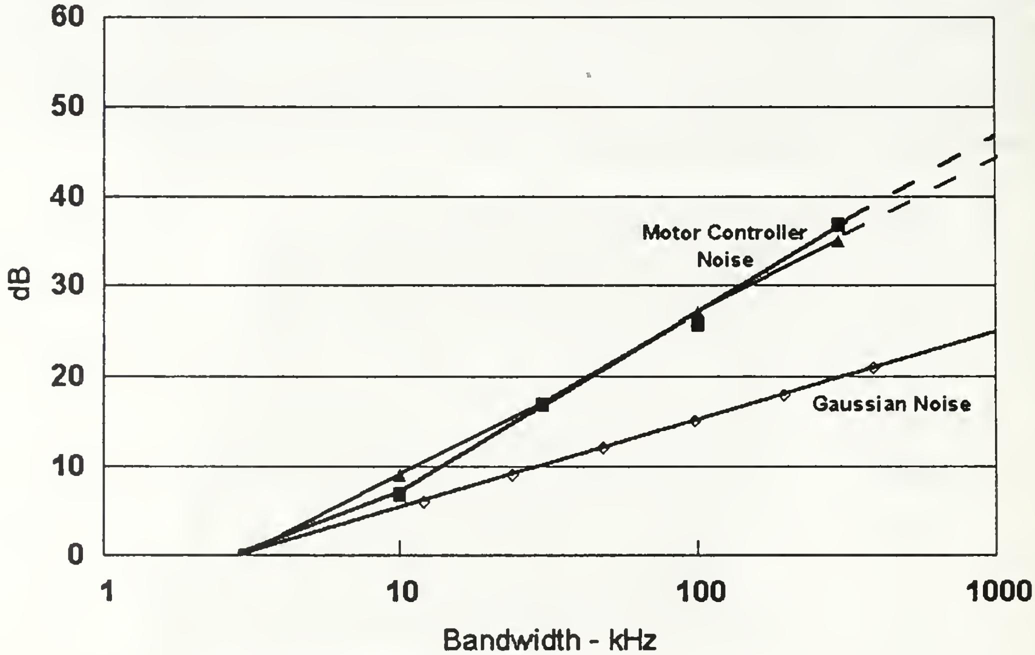

Figure 13 Initial Bandwidth Scaling Curve for Power-Conversion Devices

3.3 Time-Varying Aspects of Noise

The time-varying aspects of noise caused considerable difficulty in all aspects of the site noise investigations. The activity of most sources changed with time in many ways, thus the noise properties at the input terminals of a receiver varied with time. Noise sources turned on and off as well as exhibiting significant time-varying alterations in both the temporal and spectral characteristics while on. Brief bursts of noise were often noted lasting from a fraction of a second to minutes. The simultaneous erratic operation of multiple noise sources was often observed. Additional erratic noise from sources within a site had to be sorted from erratic noise from other sources external to sites.

The erratic nature of noise in the examples shown in Figures 4, 5, 8, and 11 is typical of many cases of man-made noise from external sources. Such variations are not shown by the other examples since the other examples were purposely taken when the structure of the noise was relatively stable. Time variations on the order of a fraction of a second, to minutes, to hours were common, and source activity could change on a time scale of days.

Table 1 provides an example of a log of noise activity over a five-day portion of a survey at a large receiving site. The dominant kinds of noise encountered are tabulated in this table along with the time of each record, and the bearing to each source. Unfortunately, this table shows the only the cases observed while the instrumentation was operated. The times when noise was not being observed such as during breaks, noon hours, after normal working hours, and other interruptions are not contained in this log. Nevertheless it does show the significant time-varying nature of source activity.

In Table 1 the term "Classic Gap" and "Gap" refer to sources generating a temporal structure similar to that shown in Figures 6 and 8.

It was impossible to describe the important short-term properties of noise in conventional statistical terms such as average value, root-mean-square value, amplitude-probability distributions, amplitude-spacing distributions, or other such descriptors. These descriptors of noise are valid only for noise whose temporal properties are stable over a time period of interest or for very long periods of time compared to the sudden and large-scale changes in noise. The noise properties at all sites, most of the time, were statistically non-stationary. Thus deterministic ways to describe and use the noise data were found necessary.

Table 1 Log of Noise Activity

DATE	TIME	BEARING	COMMENTS
920331	0828	144/156	Classic gap
	0830	132	Classic gap
	0831	180	2 or 3 pulse gap
	0832	168	Close-spaces gap, 10-15 impulses
	0906	192/180	Classic gap
	1008	132	Classic gap
	1710	216	Classic gap
920401	1002	132	Classic gap
	1005	144	Erratic gap
	1705	168	Gap noise
	1713	168	Gap noise
920404	0830	240/252	Intermittent Gap
	0845	180	Classic gap
	1145	060/072	7 pulse classic gap
	1146	096	2 pulse gap
	1147	108	10 pulse gap
	1148	144	10 pulse gap, 15 pulse classic gap, 2 pulse gap
	1200	168	6 pulse gap
	1205	132	4 pulse gap
	1331	288/276	1 pulse discharge
	1345	060	4/5 pulse intermittent gap noise
	1530	168	1 pulse discharge
	1530	132	2 pulse and 4 pulse gap
	1535	012	SCR
	1536	024	SCR
	1540	132	2 pulse and 4 pulse gap
	1544	144/156	13 pulse classic gap
	1615	180/192	15 pulse classic gap
	1616	168	4 and 5 pulse gap
	1618	132	16 pulse classic gap
920405	0800	132/148	2 pulse gap
	0801	144	Mixed pulse gap
	0810	288/300	1-pulse gap
	0812	048	Multiple mixed pulse gap
	0820	072	4 pulse gap
	0822	096	4 pulse gap, Mixed pulse gap
	0845	180/192	1 pulse gap
	0850	060	8 pulse classic gap
	0930	192	8 pulse gap
	1045	144/156	2/3 pulse gap
	1050	132/144	4/5 pulse gap
	1055	276/288	6 pulse Intermittent gap
	1100	024	SCR
	1101	048	Mixed pulse gap
	1102	072	5 pulse gap
	1103	132/144	multiple gap sources - pulse gap noise, 5/7 pulse gap noise, 4/6 pulse gap noise, Intermittent 4 pulse gap
	1350	192	11 & 12 pulse classic gap
	1432	240/228	12 pulse classic gap
	1508	108/120	14 pulse classic gap
	1542	060	SCR noise and low level, power related
	1555	264	Classic gap noise, one phase solid, one intermittent
920406	0810	132/144	4 and 5 pulse gap, 3 pulse gap, Mixed pulse gap
	0814	072	2/4 pulse (varies) gap
	0855	168	3 pulse gap
	0856	144/156	1 pulse gap
	0857	132	2 and 3 pulse gap
	0859	024	Weak SCR noise (-90 dBm)
	0915	144	11 pulse classic gap

3.4 Example of 24-Hour Noise Measurement

In order to obtain some information about the long-term implications of external sources of man-made noise on signal reception, noise amplitude data was collected at intervals of time (usually hourly or bi-hourly) and at intervals of frequency (usually 1 or 2 MHz) across the 2- to 30-MHz high-frequency band.

Figure 14 shows an example of noise amplitude from a site that had modest to severe radio-noise problems.

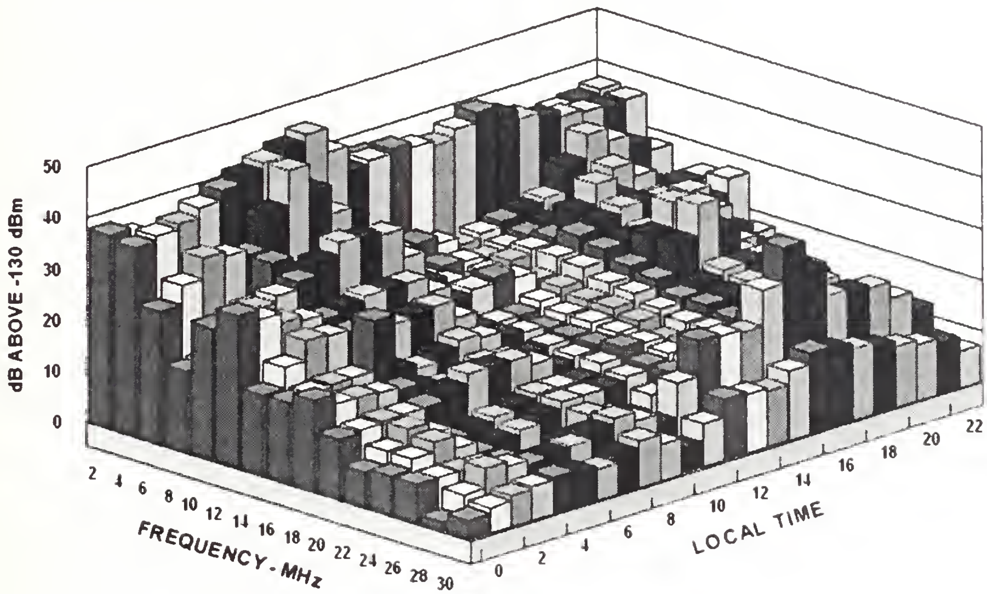

Figure 14 Example of 24-Hour Noise Measurement

Several aspects of the 24-hour example must be considered. First, noise amplitude was sampled only at the beginning of the measurement period of the example shown. Noise could and did change in amplitude between measurements. Figures 4, 5, 8, and 11 show such time variations. Thus, Figure 14 shows samples of noise amplitude for each frequency increment. Additional fine-scale measurements are needed to show the short-term viariations. This was done for special analysis tasks, but the above example will demonstrate general trends over a 24-hour period

Next, noise amplitude often changed within the frequency increments used to obtain the data in Figure 14. Fine-scale measurements were again required to define these changes. Figures 2, 3, 4, 5, and 10 show such variations

In addition, many such measurements of noise amplitude were accomplished while obtaining data for source-location and source-identification tasks, a primary reason for these surveys. The bandwidth used for each measurement was recorded and the measured amplitude value was adjusted for bandwidth in accordance with the plots provided in Figures 12 and 13. The example in Figure 14 shows the amplitude adjusted for a bandwidth of 3 kHz. Other bandwidths were used as needed for specific analysis tasks.

3.5 Site-to-Site Results

As expected, noise from external sources varied significantly from one site to another site. A general overall assessment of noise conditions at the thirty-seven HF receiving sites is tabulated in Table 2. This table is divided into two portions where the left portion provides general information about each site. A number was assigned to each site (see Column 1) for convenience in keeping track of the data from the various site visits. This is followed by a column identifying the general location of each site to illustrate the wide geographic extent of the collection of data. The third column in the left portion of Table 1 provides a crude representation of the power-pole density within line of sight of each site. Five levels are used to rate the density of power-line poles where "5" represents a large number of poles (more than 500) and decreasing numbers represent fewer poles. This number is followed by the letters "OD" representing "overhead distribution lines", and the letters "OT" representing "overhead transmission lines". The letter "B" was used for sites where all distribution lines within line of sight were buried underground.

The right portion of Table 2 provides a summary of noise conditions found at each site along with the identification of the primary and secondary sources of noise. The first column of the right portion of the table provides the noise-level information. The noise from external sources was divided into the four levels with "H" representing a high level of noise, "M" a medium level of noise, "L" a low level, and "VL" a very low level including cases of no external noise.

Letters are used the second column of the right portion of Table 2 to identify the primary and secondary types of sources of noise appearing at the input terminals of each receiver. The letter "P" represents power-line sources, and the letter "R" represents one major source encountered from an electric-powered rail system. The number "Ø" indicates the complete lack of external sources of man-made noise. The letter "S" also appears in the second of the two columns at the right side of Table 2. This letter represents sites that exhibited man-made noise from sources located within the site that significantly exceeded the noise floor of receiving systems. The order of the letters indicates the relative magnitude of the noise. In most cases, the noise from site sources was lower in amplitude than the noise from external sources.

Table 2 Site Noise Summary

SITE PARAMETERS			NOISE	
Site No.	Site Location	PL Status	Noise Level	Noise Source
1	North Pacific	B	VL	S
2	Polar	B	VL	S
3	Polar	4,OD	H	P,S
4	Europe	4,OD	M	P,S
5	Europe	B	VL	P
6	Europe	4,OD	H	P,S
7	Europe	1,OD	VL	P,S
8	Caribbean	4,OD	H	S
9	North America	B	VL	P,S
10	North Asia	4,OD	H	P,S
11	North Asia	4,OD	H	P,S
12	North Asia	4,OD	H	P,S
13	Europe	3,OD	M	P,S
14	North Asia	5,OD	H	P,S
15	North Atlantic	3,OD	M	P,S
16	Pacific	4,OD	H	P,S
17	Pacific	4,OD	H	P,S
18	Pacific	4,OD	H	P,S
19	North America	5,OD,OT	H	P,S
20	North America	5,OD	H	P,S
21	North America	4,OD	VL	Ø
22	North America	B	VL	Ø
23	North America	1,OD	L	P
24	Asia	3,OD	H	P,S
25	North America	5,OD	H	P,S
26	North America	5,OD	H	P,S
27	North America	4,OD	M	P,S
28	Europe	5,OD	H	P,S
29	Caribbean	5,OD	H	P,S
30	North America	3,OD	H	R,P
31	South Asia	B	VL	Ø
32	South Asia	B	VL	Ø
33	South Asia	B	VL	Ø
34	South Asia	B	VL	Ø
35	South Asia	B	VL	Ø
36	North America	5,OD,OT	H	P,S
37	North America	4,OD	H	P,S

A summary of the information in Table 1 follows:

High-Noise Sites: Twenty sites had high levels of noise from external sources, and eighteen of these sites had a power-line pole-density rating of four or five. Two sites had a power-line pole-density rating of three. None had a lower rating.

Medium-Noise Sites: Four sites with a medium-noise rating all had distribution-line densities of three or four.

Low-Noise Site: The one site with a low-noise rating had only a single distribution line within line of sight. That site was located in a region of high rainfall, a condition that minimizes the activity of most sources of noise on distribution lines.

Very-Low-Noise Sites: Twelve sites fell into the very-low-noise category. Ten of the sites were surrounded only by underground distribution lines. Two sites had overhead distribution lines within line of sight. Of these two, Site 7 had one overhead distribution line that was constructed to noise-free standards, and Site 21 had a power-line density rating of four. Site 21 was a special site where all sources of noise on all overhead lines within line of sight had been eliminated in accordance with the noise-mitigation procedures provided in Reference 1. These lines remained completely noise free for the 12 years of operation of that site.

A direct relationship between man-made noise levels from external-site sources and the density of overhead distribution lines is clearly established from the data. All sites surrounded by overhead distribution lines (except one special case) had high or medium noise levels and all sites without overhead distribution lines had low noise levels. Insufficient data was obtained to understand the impact of overhead high-voltage transmission power lines on man-made noise at the sites since by design only two sites were located within line of sight of such lines.

Man-made noise from site-related sources was found at twenty-seven of the thirty-seven sites. This was considered a separate problem that should be completely under the control of site personnel, and it is a direct indicator of poor site engineering and/or maintenance.

Sites in the "S" category also do not fit into the International Telecommunications Union (ITU) noise categories discussed later since their categories apply only to external noise sources. For these reasons site-related sources of man-made radio noise are mentioned but are excluded from the primary analysis. The sites with such sources are listed to better understand the extent of this additional but slightly less pervasive problem. Of interest is that sites with the lowest level of internal noise were older sites not yet updated with modern signal distribution and modern digital electronic devices. The older sites did not have excessive noise leakage from internal sources such as: poorly installed digital and RF cables, Uninterruptible Power Supplies, variable-speed motor controllers (often used in air-handling systems), poorly designed switching power supplies, and other modern power-control devices based on switching processes. The measurement teams concluded that a serious internal-noise problem is lurking just below the external-source problem at most of the sites examined, and internal sources will be recognized as a major problem adversely affecting signal reception as the external sources are eliminated.

3.6 Comparison with ITU Noise Categories

The model for man-made noise provided by the ITU[3] is used for a wide variety of purposes. For example, the ITU model is used in most HF propagation prediction programs, in many communication performance models, and for site planning tasks. The basis for the ITU model was derived many decades ago from measurements of man-made noise levels at a large number of locations around the world. These measurements were made from a specific short monopole antenna and the results are provided in terms of field strength impinging on the monopole.

The data presented in this paper was obtained from the actual antennas used at each site where the antennas varied from dipoles to various versions of monopoles to large directional arrays. Also, our data was based on noise power measured at the input terminals of 50-Ohm receiving systems. It is not feasible to accurately convert our noise-power data into comparable field-strength data primarily because of major differences between the radiation pattern of the various antennas at each receiving site and that of the ITU monopole. Nevertheless, two simple but pertinent comparisons can be made.

First, the ITU model uses four categories to describe results obtained at their noise-measurement sites that are Business, Residential, Rural, and Quiet Rural. The thirty-seven receiving sites were sorted into these categories as shown in Table 3. The sorting process required some judgement since some sites had residential or business areas remote from a site but still within line of sight. In order to be placed into a residential or business category, a site had to be located adjacent to or reasonably close to such an area (within one km). In most cases significant noise sources could not be attributed to the residential or business activities themselves, but hardware items on overhead power lines associated with these residential and business areas were found to be major sources of noise. At three sites, noise originating from industrial uses of RF-stabilized arc welders was noted. Such noise was significant, but it was less onerous than power-line noise. Noise from RF-stabilized arc welders affecting these three sites radiated from overhead lines, thus the overhead lines were a primary aspect of such sources.

In addition, it was difficult to allocate sites to the Rural or Quiet-Rural categories. Sites in these two categories were combined into a single Rural category. Several such sites had electric utility distribution lines within line of sight that served rural area farming activities and/or provided power to the sites.

In Table 3 the noise at each site is shown using the noise-level designations of Table 1.

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[3] CCIR, ***Man-made radio noise***, Report 258-5, International Radio Consultative Committee, International Telecommunications Union, Geneva, Switzerland, 1990

Table 3 Sites by ITU Classification

Site No.	Estimated ITU Classification		
	Business	**Residential**	**Rural**
1			VL
2			VL
3			H
4			M
5	VL		
6			H
7			VL
8			H
9		VL	
10			H
11			H
12			H
13			M
14		H	
15			M
16			H
17			H
18			H
19			H
20		H	
21		VL	
22	VL		
23			L
24			H
25		H	
26			H
27			M
28			H
29			H
30		H	
31			VL
32			VL
33			VL
34			VL
35	VL		
36			H
37			H

Sites Placed in the ITU Rural Category: A total of twenty-eight of the thirty-seven sites fell into the Rural categories. Of these sixteen had high noise levels, four had medium noise levels, one had a low level, and seven had very-low noise levels.

All of the sixteen sites with high noise levels had numerous overhead electric-utility distribution lines within line of sight of the antennas.

The three sites with medium noise levels had a modest number of overhead lines within line of sight.

The one low-noise site (Site 23) had a single distribution line. It was located in an area of high rainfall, a weather condition that prevents most radio noise sources on overhead power lines from functioning.

Of the seven sites that had very-low noise levels, five were located in areas with no overhead distribution lines. One had a single overhead power line constructed in accordance with noise-free standards, and the other had a single overhead distribution line operating at less than 1200 Volts, a type of line that seldom generates radio noise.

Sites Placed in the ITU Residential Category: Six sites fell into the Residential category. Four of these sites had high noise levels and two had very-low noise levels. The four sites with high-noise-level were surrounded by overhead distribution power lines. Of the two sites with very-low noise levels, only buried distribution lines were in the area around one site, and the other was a special case (Site 21) which was surrounded by overhead distribution lines. All noise sources on lines surrounding Site 21 had been eliminated by mitigation actions taken in strict accordance with the procedures provided in Reference 1.

Sites Placed in the ITU Business Category: Three sites fell into the Business category. All had very-low noise levels. All facilities near these sites were fed from underground power lines, and no overhead lines were within line of sight of the receiving sites. In addition, none of the buildings in the areas around the sites contained radio-noise-radiating devices.

3.7 The 1/f Relationship

The fall in noise amplitude with frequency in accordance with the 1/f relationship developed from the data used to establish the ITU noise model was examined and crudely compared to data collected at the 37 sites. Caution must be used in this comparison since the measurements described in this document were made to obtain noise power at the input terminals of a receiver using antennas at each site. The 1/f rule was derived from field strength measurements of Volts/meter impinging on a standard collection antenna.

The 1/f rule was generally met when all external noise sources were located more than about 2 km from a site. The exception for such cases was a consistent fall in amplitude at frequencies below 4 MHz. This fall was attributed to the reduction of radiated noise power from sources on power lines below about 4 MHz. This was confirmed by additional measurements in the close vicinity of such sources.

The 1/f rule failed when sources were very close to a site. An example of this finding is provided in Figure 4. In this example several active sources of power-line noise were located on a distribution line providing power to the site and on poles less than a km from the site. The elimination of nearby sources by effective mitigation actions allowed the man-made noise at such sites to more closely fit the 1/f relationship.

One further complication with the 1/f relationship was noted. Sharp spectral nulls and peaks, closely separated in frequency, were always noted. These peaks and nulls caused amplitude variations of 10 to 30 dB. A measurement of noise amplitude at one frequency could not be used to determine noise amplitude at other nearby frequencies. The source of these peaks and nulls was attributed to resonance characteristics of the noise radiation mechanisms. It appears that variations with frequency of the radiation patterns of noise emanating from power lines due to the complex physical shapes of the conductors might also be involved in the production of the peaks and nulls of signal power at the receiver input terminals.

3.8 Impact of Noise on Signal Reception

While the examples shown earlier in the document imply that radio noise degrades the ability of an affected site to receive radio signals, quantitative numbers for signal loss are not provided directly from such data. A means to assess the adverse impact of man-made noise on signal reception is needed to fully understand the loss in signal reception.

A program named the Performance Evaluation Technique (PET) was developed over several years of conducting radio-noise surveys at receiving sites, eventually developing into version PET-2A[4]. This is a relatively simple program using a radio propagation prediction program (PROPHET) and a spreadsheet (Lotus 123). Any similar propagation prediction program or spreadsheet can be used.

PET-2A is a flexible program that can accommodate a number of HF communications signal formats including conventional signal formats such as frequency-shift-keyed, spread-spectrum, single sideband, amplitude modulation, Morse Code, and other signal formats. It is also useful for use with short-duration signals as long as the input data is collected over the short times of interest.

Figure 1 shows a block diagram of the PET-2A process. Six types of input data are required:

1. Signal level at the output port of a receiving antenna from PROPHET.
2. The signal-to-noise ratio required for the reception of a chosen modulation format.
3. The loss of signal (if any exists) in the RF-Distribution System (RFD) of a site.
4. Any increase in the noise floor at the input terminals of a receiver due to RFD components. This is expressed in dB over the design noise floor of the site, and usually measured in a 3-kHz Gaussian-shaped bandwidth.
5. The level of man-made noise, expressed in dB over the design noise floor of the site, usually measured in a 3-kHz Gaussian-shaped bandwidth.
6. Attenuation at the input stage of a receiving system introduced to limit receiver saturation caused by strong signals.

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[4] Wilbur R. Vincent and Richard W. Adler, *A Method of Evaluating the Ability of Naval Receiving Sites to Detect and Process Data from Signals of Interest*, Technical Memorandum PET9608, Signal Enhancement Laboratory, Electrial and Computer Engineering Department, Naval Postgraduate School, Monterey, CA, August 1996

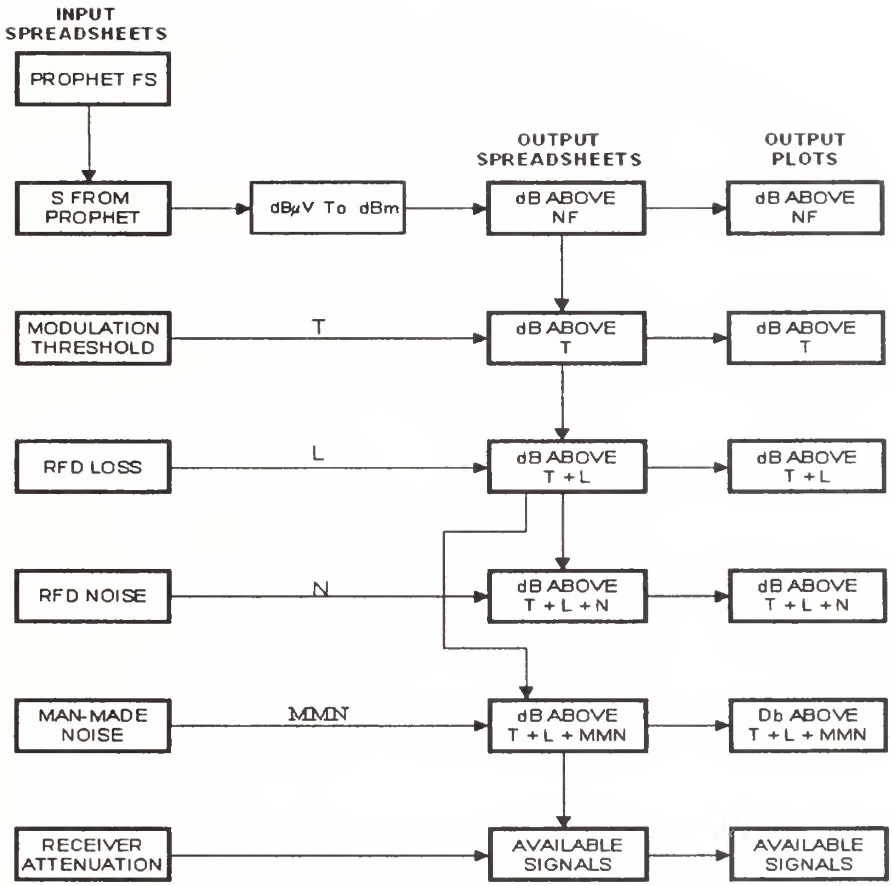

Figure 15 Block Diagram of PET-2A

Figure 15 uses a number of abbreviations to minimize the amount of text in each block. These abbreviations are:

FS	Signal Strength module of PROPHET.
S	Signal strength at the antenna output in dBμV.
RFD	Radio-Frequency Distribution System of a site.
NF	Noise floor in dBm.
T	Detection threshold of the modulation of the signal of interest.
L	RFD loss.
N	Noise added by RFD components.
MMN	Man-made noise in dB above the NF.

For the primary use of PET-2A, these parameters are provided at each hour of the day and in frequency increments of 1 or 2 MHz over the 2- to 30-MHz band. Closer frequency and time intervals can be used for special analysis cases. All of the listed parameters must be obtained to evaluate the impact of each on signal reception.

The operation of PET-2A is described by a number of sequential steps.

Step 1.

Obtain the operating parameters and location of the SOI and the receiver site. Enter these parameters into the FS module of PROPHET Version 5.1 along with the desired date and the sunspot number or other equivalent measure of radiation from the sun. Compute the strength of the SOI at the output terminals of the receiving site's antenna in dBμV. Convert the dBμV values into dBm and enter the dBm values into the spreadsheet labeled "S" from PROPHET.

This will produce Output 1. The values in Output 1 represent signal levels at the output port of the antenna. The values shown are signal strength above the site's design noise floor for a 0-dB (S+N)/N ratio. The 3-axis view shows signal levels for a 24-hour period.

Step 2.

Enter the modulation threshold required to obtain good reception of the particular type of modulation employed. PET will automatically produce the second output. Output 2 shows the signal level above the threshold level for the type of modulation used by the SOI. This plot represents the best the site can accomplish. The values of Maximum Usable Frequency (MUF) and the Lowest Useful Frequencies (LUF) are established by the propagation path, and site parameters will not significantly affect these values.

Step 3.

Enter the signal loss between the antenna and the receiver. In a well designed site this value will be very low. The signal loss can be significant in a modified site. Signal loss values will probably not change with time of day. Enter the measured values in the first column of the spreadsheet and copy these values to all other times of the day.

Step 4.

Enter the amount of noise appearing at the input to a site's receiving system that exceeds the design noise floor of the site. A 3-axis plot will appear at Plot 4. This plot will show the signal level at the input to a site's receiver after RFD loss and RFD noise floor effects are considered.

Step 5.

Enter the man-made noise levels. These levels will change from hour to hour, from frequency to frequency, and with the activity of the noise sources. Erratic jumps in noise can occur. Just enter the actual data.

Step 6.

Some receivers have an attenuator prior to their first stage. This attenuator is used to reduce strong signals to harmless levels and to avoid excessive intermodulation production. If the receiver of interest has such an attenuator, record its value at hourly intervals and enter the values into the spreadsheet labeled "Receiver Attenuation." A 3-axis plot will appear as Plot 6. This plot will show all detectable signals that exceed the modulation threshold, RFD loss, man-made noise, and receiver attenuation.

Select the output plots desired. Usually Plots 2 and 5 or 6 will be sufficient for an overall analysis of the ability of the site to receive SOI. Prior to printing the plots, manually remove all negative values of signal from each output spreadsheet. Negative values represent signals below the detection threshold which cannot normally be received.

Should the impact of a specific factor, i.e. RFD loss, be of interest, then Plot 2 and 3 will provide the degradation in signal detection from that factor. Other combinations of output plots will provide information about the extent of degradation in receiving capability from other factors.

A numerical evaluation of the loss in receiving capability can be obtained by counting the frequency-time blocks in each view. While the 3-axis plots provide an excellent overall view of the operation of a receiving site, the data in some frequency-time blocks can obscure data in other blocks. The maximum value of the amplitude scale of any plot can be manually increased to a higher value up to 999 dB. This compresses the amplitude-time blocks and allows them to be viewed and counted.

Keep in mind that the source of signal levels, the FS module in PROPHET Version 5.1, calculates the average monthly signal values. Signals that are both above and below the calculated values will appear at the antenna output terminals. In addition, Pet-2A should be used to evaluate signal reception only during periods of low magnetic-storm activity, and no solar flares. This can be determined by monitoring the magnetic activity and sunspot values provided by WWV and other time-standard stations. In addition, the same information is available from the Internet[5].

Several examples of the input and output plots from a PET-2A evaluation of signal reception at a site are provided. Figure 16 shows the output of the propagation-prediction program. The maximum usable frequencies (MUF) and the lowest useful frequencies (LUF) are shown based the use of a 1 kW transmitter coupled to a ¼-wave vertical transmitting antenna and with a lossless transmission line from the transmitter to the antenna. The distance from the transmitter to the receiver is 3894 km.

The signal-strength numbers in Figure 16 must be converted into dBm and then into signal above receiver noise in dB where receiver. In this case we assume a phase-shift-keyed signal is transmitted, and it is received with a 3-kHz wide Gaussian-shaped receiver bandwidth. Furthermore, a HF receiver with a noise floor of -130 dBm in a 3-kHz bandwidth is assumed. Figure 17 shows all signals received by the antenna that are above the noise floor of the receiver, again assuming the receiver is located at the antenna terminals.

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[5] http://wdc-c2.crl.go.jp.ISD/index-E.html or http://solar.spacew.com/www/realtime.html

```
                    SIGNAL STRENGTH  (DB ABOVE 1 MICROVOLT)

                                   FREQUENCY
TIME 2        8          16          24          32          40 LF MF
00  20 26 26 29 32 33  5                                         2 12
01  20 26 26 29 32 18-17                                         2 11
02  20 26 26 29 24-12                                            2 10
03  20 26 26 29 14                                               2  9
04  20 26 26 29 32 33 34 35 35  9                                2 18
05 -17 11 20 22 26 30 32 33 34 35 31 14-17                       2 23
06        4 16 22 25 27 31 32 34 29 25 19 -8                     4 26
07           1 16 21 23 26 30 32 28 24 21 14-14                  5 28
08          -9 10 16 20 24 26 31 27 23 21 20  0                  6 29
09             -1 13 18 22 24 30 26 22 20 20  9-18               6 29
10             -4 11 16 20 23 26 25 21 19 19 12-24               7 30
11             -5 10 15 20 23 25 25 21 19 19 12-14               7 30
12             -5 11 16 20 23 26 25 21 19 19  8-18               7 29
13             -2 12 17 21 24 29 26 22 20 19  1                  6 29
14         -11  9 15 19 23 25 30 26 22 20 20-10                  6 28
15          -2 14 19 22 25 30 32 28 23 21  3                     5 27
16       -1 13 20 23 25 30 32 33 29 24 11-17                     4 25
17    -7 17 20 25 29 31 32 33 35 30 15-15                        3 23
18  12 24 25 28 31 32 33 34 35 36 11                             2 21
19  20 26 26 29 32 33 34 35  5                                   2 16
20  20 26 26 29 32 33 34  9                                      2 14
21  20 26 26 29 32 33 21-10                                      2 13
22  20 26 26 29 32 33 20-11                                      2 13
23  20 26 26 29 32 29 -3                                         2 12
FS>
```

Figure 16 Signal Level Delivered by the Receiving Antenna

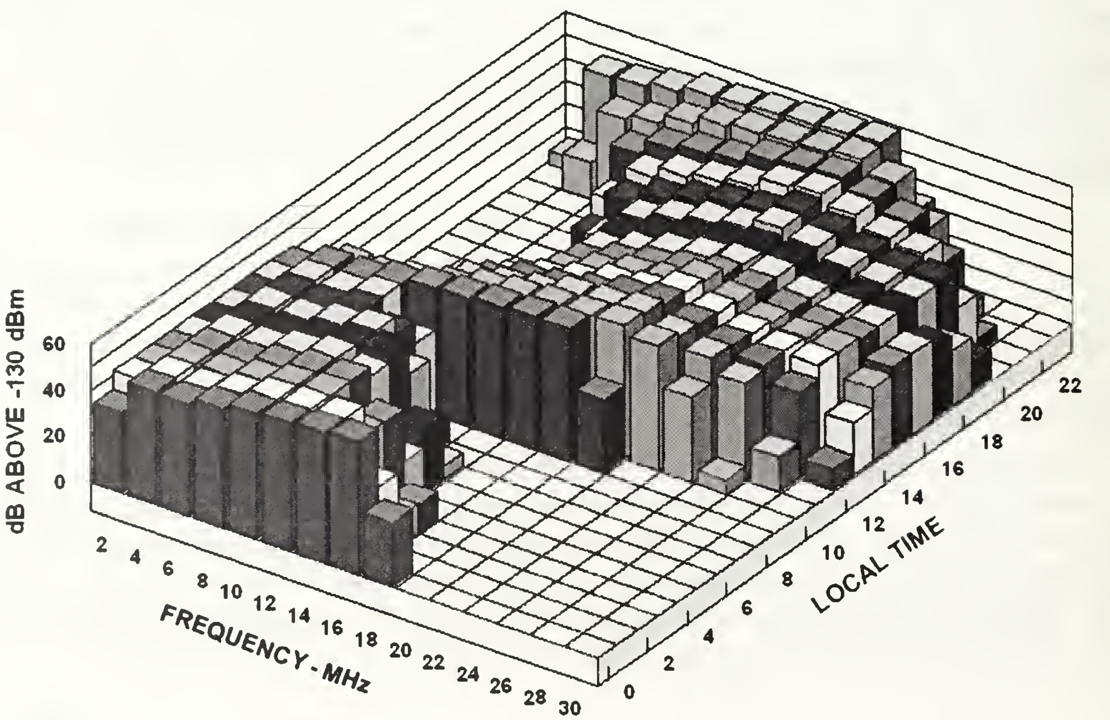

Figure 17 Signals Exceeding Receiver Noise Floor at the Antenna Terminals

Most receiving sites have some signal gain or loss between the antenna and the receiver. In addition, other components in the RF path from the receiving antenna to the receiver may introduce noise that is higher than the noise floor of the receiver. Because of these, the measurement of gain/loss and noise floor of the RF path from the antenna to a receiver is often required. Figure 18 shows the result of the gain/loss measurement of the RF path for this example. The gain/loss of each primary component of the RF path is measured, and the total gain/loss values are provided on the bottom line of the example. This example was obtained from a two-band system, resulting in two columns for 8 MHz.

Freq.(MHz)	2	3	4	5	6	7	8	8	9	10	11	12	13	14
Dirc.Cou.Loss	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2
Pri MC Gain	-1.6	-1.3	-1.3	-1.3	-1.3	-1.4	-1.4	1.7	1.7	1.8	1.7	1.8	1.8	1.8
Total Cable Loss	0.8	1.0	1.0	1.3	1.4	1.6	1.6	2.1	1.7	2.3	2.3	2.3	2.2	2.5
Dist MC Gain	1.3	1.6	1.6	2.7	1.7	1.8	1.7	2.1	1.8	1.6	1.8	1.9	2.0	1.8
OmniBeam Gain	-0.3	-2.2	-1.8	-0.4	-2.6	-3.2	-2.9	-4.8	-4.8	-4.1	-4.6	-4.4	-4.9	-4.9
SR RF Seg Loss	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Omni G/L	-1.7	-3.2	-2.8	-0.6	-4.8	-4.6	-4.5	-3.4	-3.4	-3.3	-3.7	-3.3	-3.6	-4.1

Freq.(MHz)	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Dirc.Cou.Loss	0.2	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3
Pri MC Gain	1.8	1.9	1.9	1.9	2.0	2.0	2.0	2.1	2.1	2.2	2.3	2.4	2.4	2.6	2.8	2.9
Total Cable Loss	2.0	2.7	2.6	2.8	2.8	3.4	2.6	3.0	3.2	3.5	3.4	3.5	3.5	3.5	3.8	3.8
Dist MC Gain	1.5	1.7	1.4	1.5	1.4	2.1	1.4	1.9	2.1	2.3	2.2	2.5	2.5	2.4	2.6	2.6
OmniBeam Gain	-4.3	-4.5	-5.4	-6.6	-5.4	-5.8	-6.3	-6.1	-6.5	-5.9	-5.9	-7.0	-7.7	-6.9	-7.2	-8.5
SR RF Seg Loss	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Omni G/L	-3.2	-4.1	-5.1	-6.3	-5.1	-5.4	-5.9	-5.4	-5.8	-5.2	-5.0	-5.9	-6.6	-5.8	-6.0	-7.2

Figure 18 Gain/Loss Values

Noise added by components in the RF path between the antenna and the receiver is shown in Figure 19. The noise level is expressed as dB above the receiver noise floor. In this case additional noise is added by components in the RF path at frequencies up to 12 MHz. Above that frequency the noise was below the receiver noise floor.

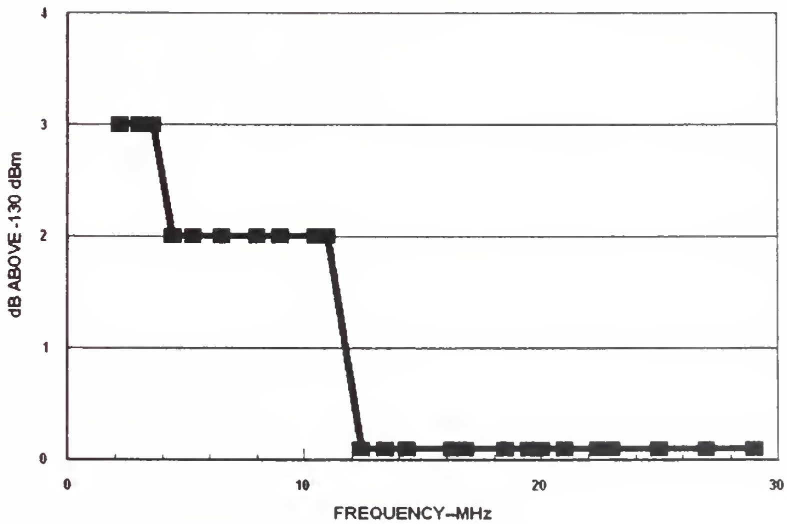

Figure 19 Noise Added by Components in the RF Path

The path loss and the noise decrease the signal population applied to a receiver. In addition, one must have a signal margin of about 12 dB to detect a PSK signal. These factors are taken into account to determine the best signal-detection capability of the receiver site. Figure 20 shows best signal-reception of the test signal by the receiving site. This plot can be compared with Figure 17 to obtain a general understanding of the impact of the combination of site parameters and signal-detection threshold on the ability of the site to detect a signal.

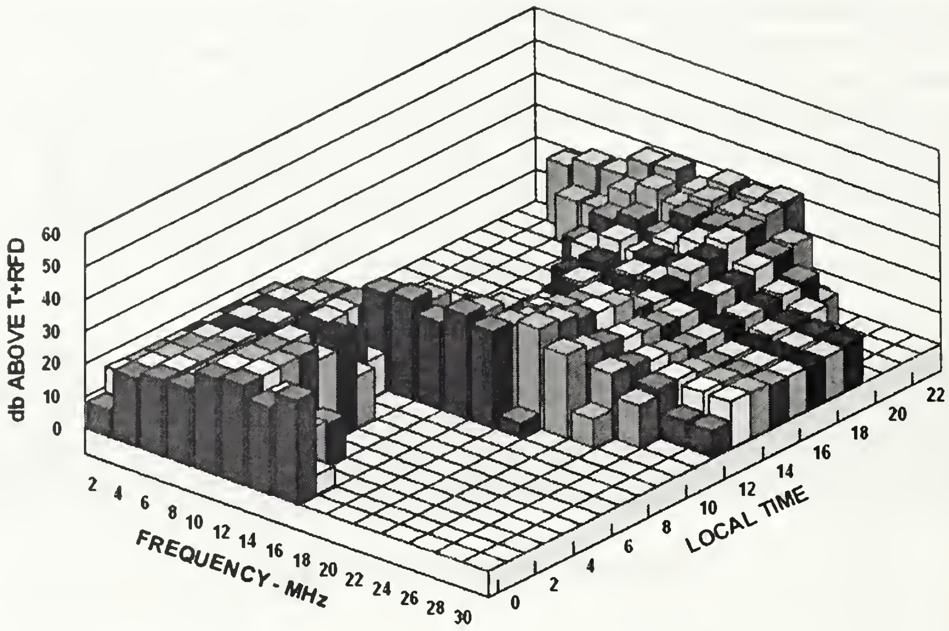

Figure 20 Useful Signals Available at the Receiver

One is left only with the need to determine the additional adverse impact of man-made noise on the reception of signals from the selected source. Figure 21 shows the added impact of man-made radio noise from external sources on signal reception. A significant decrease in the number of time-frequency blocks resulted from the addition of the impact of man-made noise as noted by comparing Figures 20 and 21.

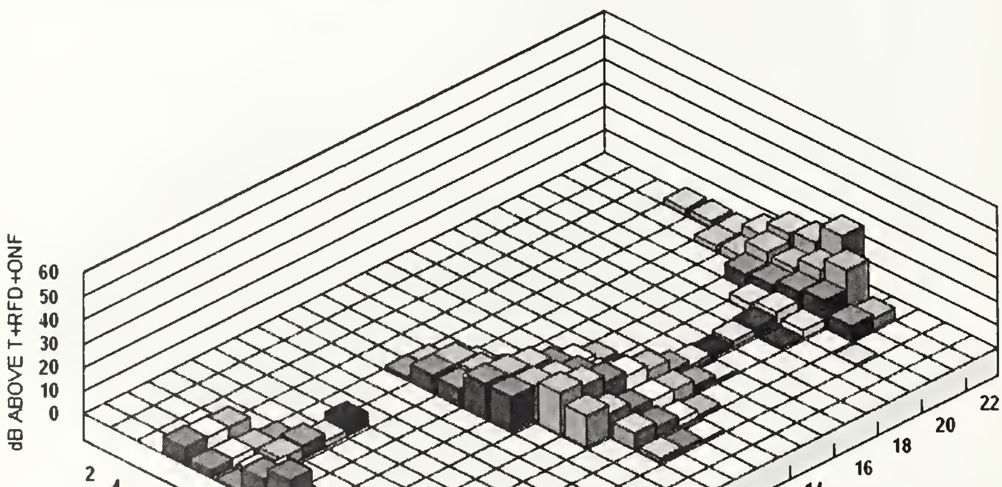

Figure 21 Signals Available after Man-made Noise is Added

In this particular example 64% of the useful signals from the selected source are lost due to man-made radio noise and 12% are lost from undesired site parameters. It is clear the major problem for this particular site is radio noise from a variety of sources of noise external to the receiving site. While minor signal-reception performance increases can be achieved by making improvements in the RF path from the antenna to a receiver, no amount of money spent at the site itself will correct the man-made radio noise problem. Only the mitigation of those off-site noise sources that produce radio noise at the input terminals of the site's receivers will improve the ability of the site to receive the low-level signals of primary interest.

The results of PET-2A analyses varied considerably from site to site. Some sites with low or no external noise only experienced signal-reception loss from site-related problems. Other sites with many distribution-line poles within line of sight of the site's antenna experienced significant signal-reception loss from external sources of man-made radio noise.

In most cases the sources were located on distribution power lines operated by the electric utilities. Only a few cases of radio noise from transmission lines were encountered.

The PET-2A program as described above relies on standard models of the ionosphere. This is sufficient for many general signal-reception-analysis tasks, but other tasks sometimes can benefit from real-time results. Near real-time ionospheric parameters are now available from the Internet, and they can be imported into most propagation-prediction programs to replace the standard models of the ionosphere. In addition, near real-time noise data can be also be used although this implies a site has sophisticated noise-measurement equipment that is sufficiently accurate and flexible for analysis purposes.

4. DISCUSSION

4.1 General Comments

The examples showing the temporal and spectral properties of radio noise provided in Section 3 are representative of massive amounts of data accumulated over a period of more than two decades of conducting noise surveys at receiving sites. The examples and the data were obtained from many visits to both large-scale and small-scale receiving sites located throughout the world. In all cases multiple visits were made to each site, and noise-measurement and noise-mitigation procedures were conducted at some sites several times each year. In addition, numerous auxiliary measurements of man-made noise were made at many other locations including amateur radio stations, commercial radio sites, electric utility sites, and research sites. The results of the auxiliary measurements are not provided in this document, but the results from these additional measurements are consistent with those reported in this paper.

The data collected by this program and the examples provided in this document were not a part of a large-scale radio-noise collection program. The total effort was focused on practical receiving-site operating issues such as:

- Obtain measures of noise-power at the input terminals of receivers at each site, the information needed to assess performance degradation.
- Provide the information needed to locate, identify, and mitigate all sources of man-made radio noise regardless of their origin.

These limited objectives, while different from classical radio-noise measurements, provided site managers with the information they needed to improve the operational performance of their sites and secondarily produced a catalog of real-world noise examples and their distribution.

4.2 Instrumentation Comments

Several features of the instrumentation used for the measurements described in this document proved highly useful in the conduct of the surveys. Examples are:

- The ability to cope with and define rapidly and erratically changing noise characteristics and to define the time-varying temporal and spectral structure of each example of noise.
- The provision of noise characteristics needed to assess the amount of signal-detection loss, if any, from man-made noise and from other factors.
- The provision of noise data over short time frames consistent with the evaluation of its impact on short-duration signals or the collection of data over longer periods.
- The real-time identification of the kinds of noise affecting signal reception.
- The supply of accurate and real-time information to outside source-identification teams.
- The stipulation of the information needed to implement accurate and effective mitigation actions.

4.3 Site Performnace

At the beginning of the site surveys, no means was available to assess the impact of man-made noise, or from other factors, on a site's ability to receive and detect radio signals. The PET-2A program provided site managers with this capability and the information needed to conduct cost-effective site-improvement actions.

The recent extension of this program to take advantage of near real-time ionospheric data has further expanded the analysis capability of the program.

5. CONCLUSIONS

Undesirable levels of man-made radio noise from a combination of external and internal sources were encountered at most of the thirty-seven sites examined. Noise from external sources was the dominant problem at most of the sites. It was severe enough to significantly degrade the ability of these sites to receive the typically weak signals of primary interest, allowing only occasional strong signals of interest to be received.

Several primary conclusions were reached from the data accumulated at the thirty-seven sites. They are:

1. A very close relationship was found between the presence of man-made radio noise at HF receiving sites and the presence or absence of overhead distribution lines located within line of sight of the uppermost part of the receiving antennas at each site. Only one exception to this finding was noted. In this exception, all noise sources on all overhead lines within line of sight had been eliminated by effective mitigation actions. Sites with no overhead power lines within line of sight were all free from sources of external noise.

2. The dominant sources of noise were found to originate from hardware on power poles and from power-conversion devices powered from overhead distribution lines. Noise from these sources was usually highly erratic and highly impulsive. Stable noise conditions were seldom encountered, and source activity would often change over short periods of time.

3. Because the noise was impulsive, it was necessary to employ wider than normal measurement bandwidths to define the impulse properties. Since noise amplitude and its temporal structure changed with measurement bandwidth, it was necessary to develop a procedure to cope with and provide an amplitude-vs-bandwidth scaling capability. In addition, other measures of man-made radio noise such as amplitude probability distributions, rms levels, average levels, and other measures are a function of measurement bandwidth. This greatly complicated the measurement and definition of man-made radio noise.

4. The ITU categories for man-made noise at HF sites (Business, Residential, Rural, and Quiet Rural) are widely used in communication performance models, for site selection, and for planning purposes. The sites were grouped into these categories, and the noise level from only external sources was examined to ascertain how well they fit into each category. Our results show the ITU categories no longer provide useful guidelines for noise levels and noise conditions at the 37 receiving sites, and attempts to use the ITU guidelines produced misleading results.

5. While the 1/f relationship of noise amplitude with frequency was crudely followed at several of the sites, significant exceptions to this relationship were found (e.g. see Figure 4). Also, significant fine-scale nulls and peaks in the spectral structure of noise were found at most sites that are not taken into account by the 1/f relationship unless data is averaged over time, frequency, or multiple sites. The relatively old data used to define the ITU man-made-noise model urgently needs to be updated.

6. The results suggest that a new model for man-made noise based on the number of power poles within line of sight of the uppermost part of a receiving site's antenna would provide more realistic results than the ITU model. Should all sources of noise emanating from power lines be eliminated by effective mitigation actions at some future time, this suggested model also will be ineffective.

7. Many of the receiving sites experienced significant levels of man-made noise at receiver input terminals from sources within the sites. This is a separate problem that may become the primary problem as external sources are eliminated. Internal noise was traced to a variety of sources. Examples are poorly-designed power-control devices (e.g switching power supplies, variable-speed motor drives, light-dimmer controls, faulty or improperly installed ballasts for internal and external lights), improperly installed cables carrying digital signals, improperly installed RF cables, leakage into single-shielded coaxial cables used to carry low-level RF signals, new high-efficiency lighting systems, intermodulaton products from current flowing through welded joints in galvanized metal, and intermodulation products generated by overloaded components in RF distribution systems.

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