NPS-EC-05-003

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

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

by

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

January 2005

Approved for public release; distribution is unlimited

NAVAL POSTGRADUATE SCHOOL
Monterey, California 93943-5000

RDML Patrick W. Dunne, USN
President

Richard Elster
Provost

This report was prepared for the Naval Security Group. Any opinions, findings, and conclusions or recommendations expressed in this document are those of the authors and do not necessarily reflect the views of the United States Government.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE January 2005	3. REPORT TYPE AND DATES COVERED Technical Report

4. TITLE AND SUBTITLE AN EXAMINATION OF MAN-MADE RADIO NOISE AT 37 HF RECEIVING SITES	5. FUNDING NUMBERS
6. AUTHOR(S) Vincent, Wilbur R., Adler, Richard W., and Munsch, George F.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Signal Enhancement Laboratory Department of Electrical and Computer Engineering Naval Postgraduate School Monterey, CA 93943	8. PERFORMING ORGANIZATION REPORT NUMBER NPS-EC-05-003
SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Security Group	10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense, or other U.S. Government agency.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.	12b. DISTRIBUTION CODE

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.

14. SUBJECT TERMS Radio interference, radio noise	15. NUMBER OF PAGES 34
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFI- CATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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
CPT James Hodge, Jr.; Naval Postgraduate School, Monterey CA, USMC Student
LT John O'Dwyer; Naval Postgraduate School, Monterey CA, USN Student
Mr. Hugh Myers; SPAWARSYSACT PAC, Pearl City HI
Mr. Steve Kelly; SPAWAR Systems Center, North Charleston SC
Ms. Pamela Denoon, SPAWAR Systems Center, North Charleston SC
Mr. Carlo Melnick; Engineering Research Associates, E-Systems, and Raytheon
Mr. Roy Bergeron; Engineering Research Associates, E-Systems, and Raytheon
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

CONTENTS

LIST OF FIGURES

LIST OF TABLES

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.

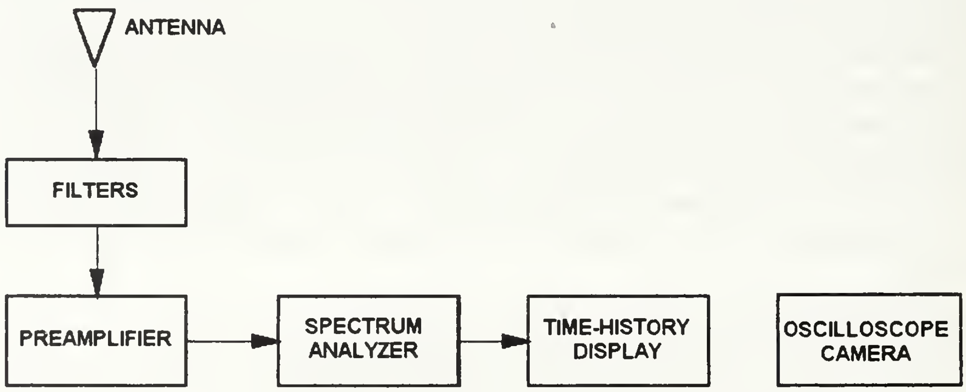


Figure 1 Block Diagram of the Instrumentation

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*

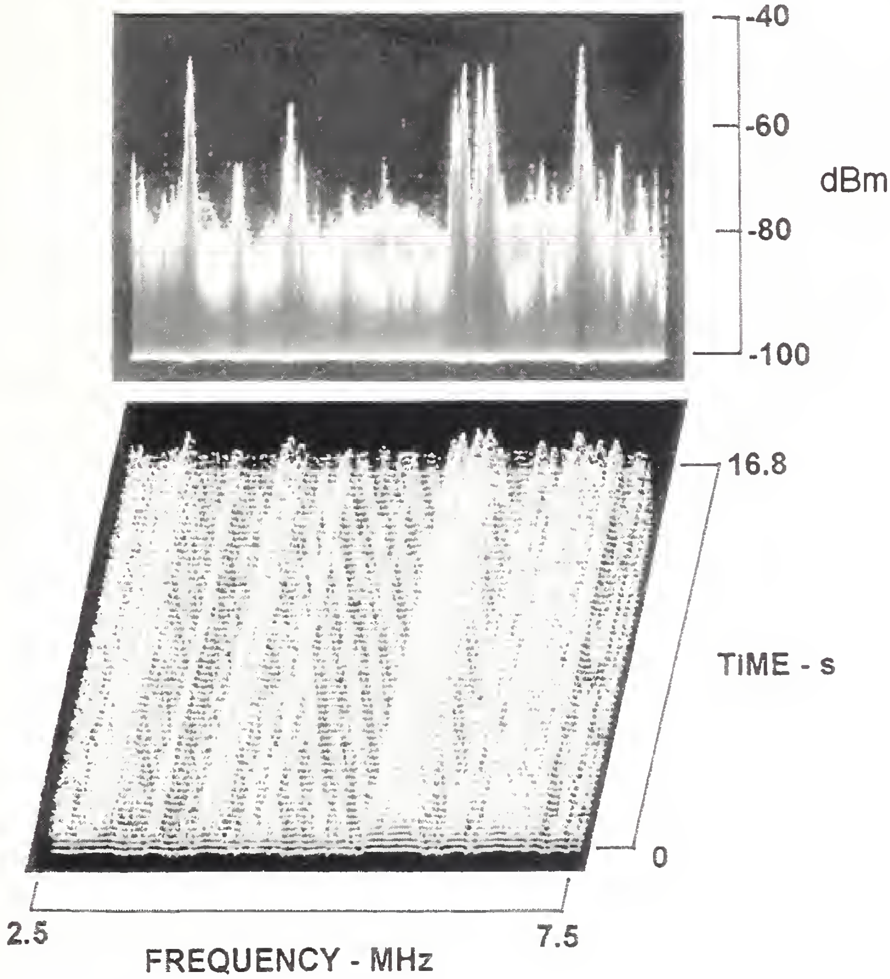
* (LS) is appended to the scan time when line synchronization is used.

[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.

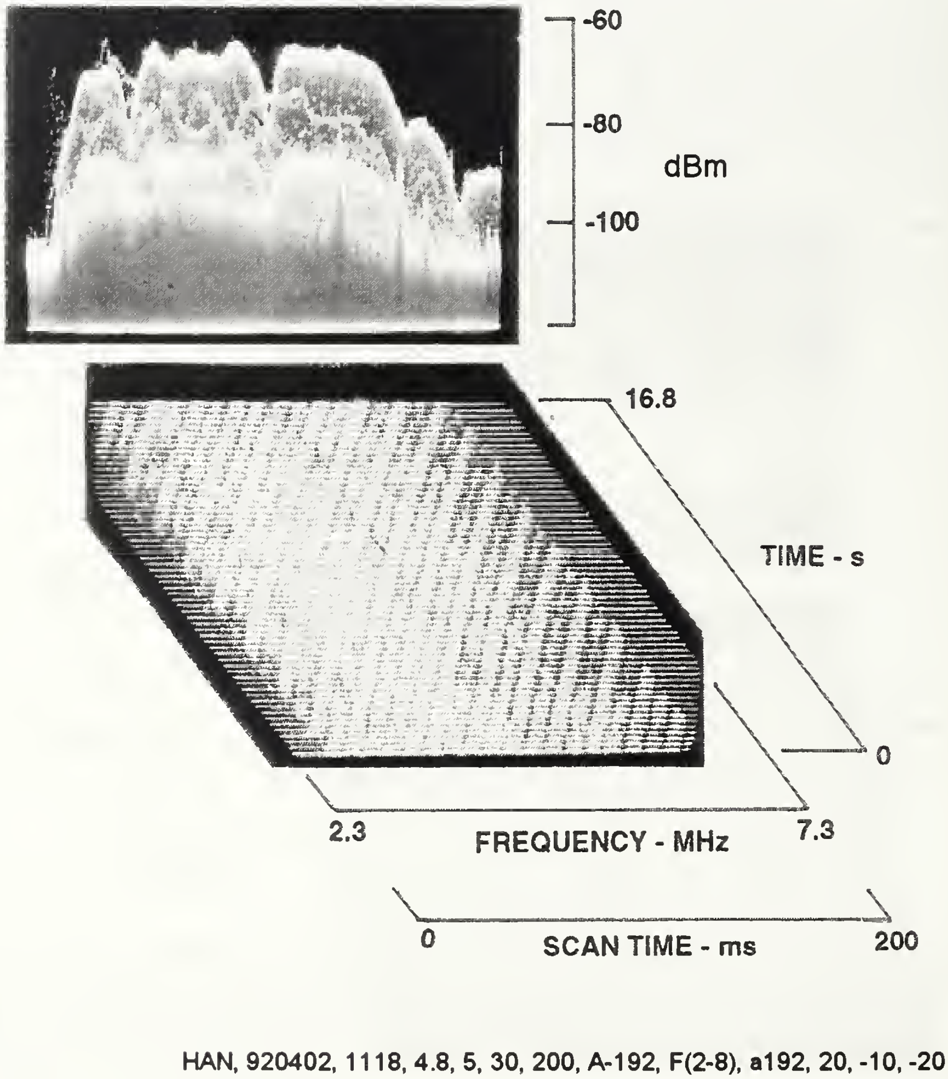


Figure 3 Coarse-Scale Case of Severe Power-Line Noise

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.

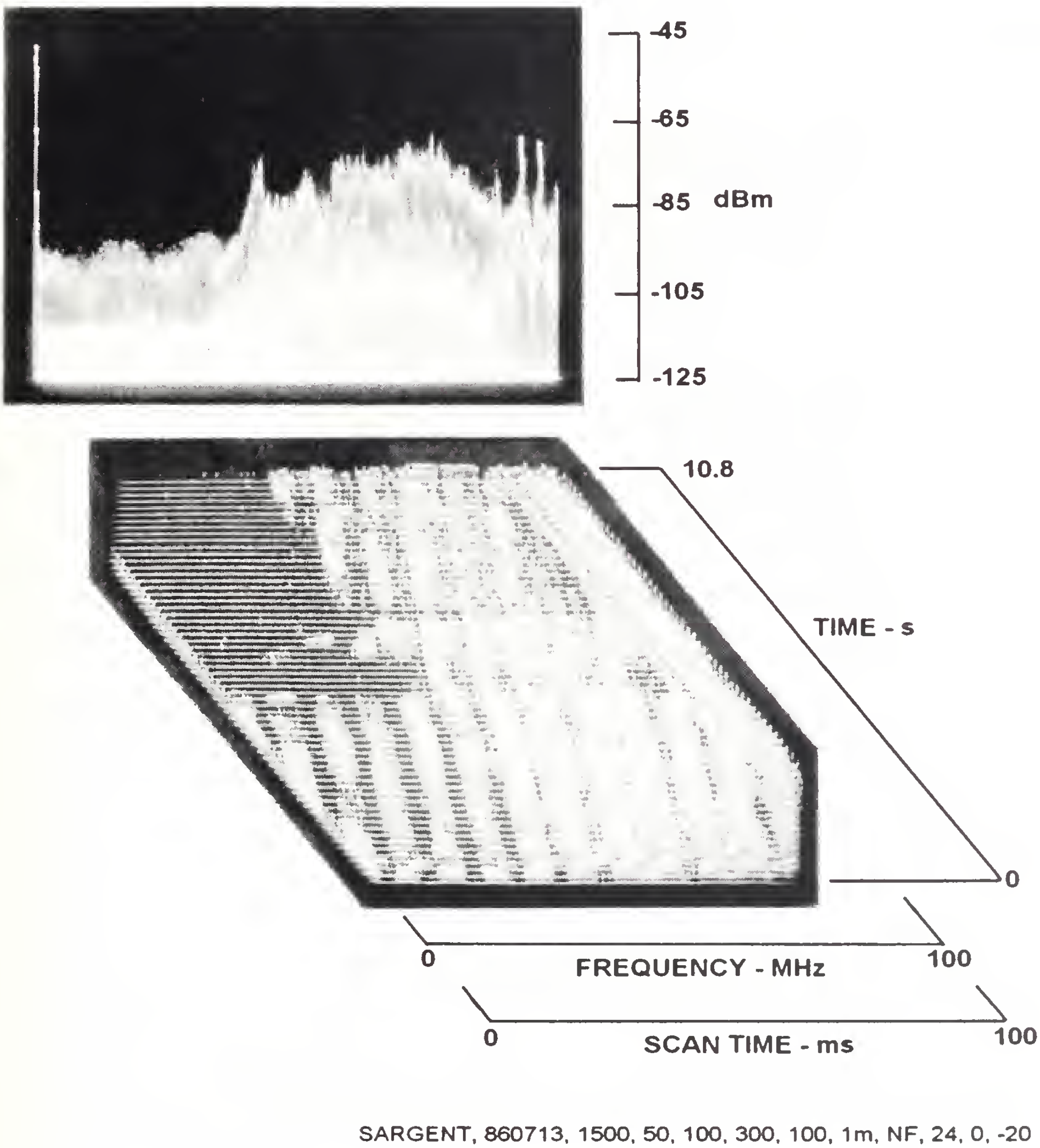


Figure 4 Coarse-Scale Presentation of Intermittent Noise

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.

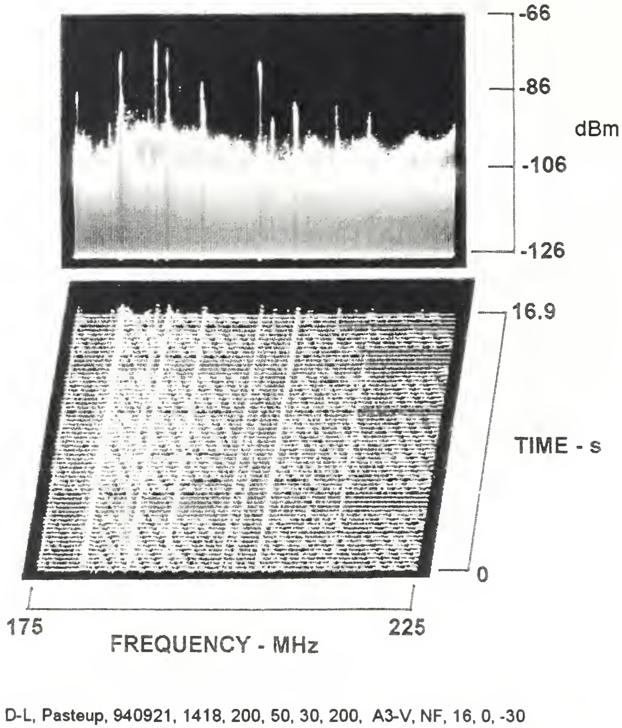
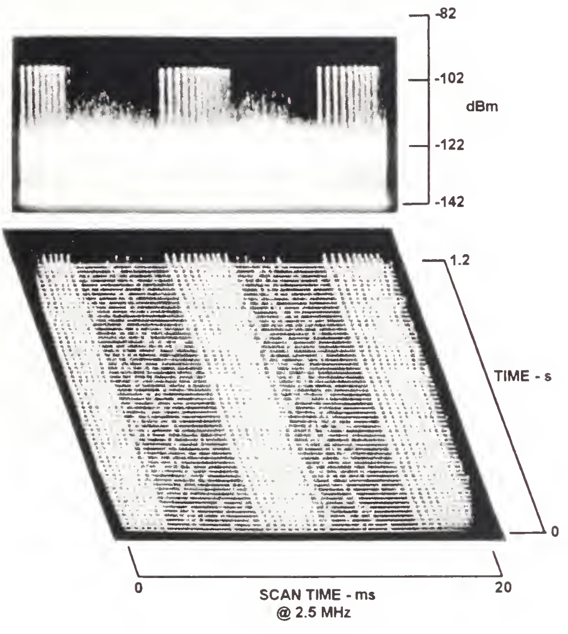


Figure 5 Intermittent Noise from a Source Close to a Receiving Site

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