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THE MITIGATION OF RADIO NOISE FROM EXTERNAL SOURCES

at

RADIO RECEIVING SITES

6TH EDITION

May 2007

by

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13. ABSTRACT

Procedures to locate radio-noise sources, identify source hardware, and mitigate noise problems are provided where the sources are external to a receiving site. In addition, procedures to assess the impact of man-made radio noise on signal reception are included. These procedures were developed over three decades of radio-noise investigations at more than 45 radio-receiving sites.

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PREFACE

This is the sixth edition of this handbook. Periodic updates are necessary to cope with new sources of radio noise, new source-location and source-identification techniques, and improved procedures for mitigating sources. In past years the dominant noise at receiving sites was from sources on power lines. In more recent time, radio noise from power-conversion devices operated by customers of electric utilities has become a significant source, and a section on such sources is included in this edition.

The title of this edition has been slightly changed to better accommodate new noise-mitigation information and the new sources. In addition, the title limits the content of this handbook to sources external to receiving sites. A companion handbook covering sources of radio noise internal to a receiving facility is in preparation.

Editions 1 and 2 of this document were published and distributed by the Southwest Research Institute of San Antonio, Texas in 1993. These two early editions formalized hand written notes on power-line noise mitigation, and they were provided to US Navy Signal-to-Noise Enhancement Teams to aid in their task of minimizing the adverse impact of power-line noise on the reception of radio signals at US Navy radio-receiving sites. The procedures provided in the handbook proved to be highly effective when the teams were adequately trained and when the procedures were strictly followed. All copies of the first two editions were quickly distributed to interested parties. Since there was an ongoing demand for additional copies, a second printing of Edition 2 was provided by the Naval Postgraduate School, Monterey, CA. Engineering Research Associates of Vienna, Virginia provided a third printing of Edition 2.

The second edition was translated into Japanese to support mitigation programs in Japan, into Spanish for use in Spain and Puerto Rico and into Korean for use in Korea. The first two translations were provided by Engineering Research Associates, and the third translation by the Mission Support Activity (MSA) of USA INSCOM. Argon Engineering of Vienna, Virginia has produced a Japanese translation of the fifth edition for use in Japan.

This edition adds considerable information about radio noise from power-conversion devices, a new source of radio noise that has appeared from the use of modern solid-state switching devices to alter and control electric power supplied to various kinds of loads.

The authors are grateful to the Signal Enhancement Laboratory of the Electrical and Computer Engineering Department of the Naval Postgraduate School for their ongoing interest in keeping this handbook up to date.

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1. INTRODUCTION

Radio noise from sources associated with hardware on distribution power lines was the primary kind of radio noise affecting the signal-reception capability of radio receiving sites for many years. Only a very few remote sites that did not obtain power from overhead distribution lines and did not have distribution lines within line of sight of the uppermost part of antennas were free from the noise problems described in this document.

In recent years radio-noise from power-conversion devices has appeared, and it is now an additional problem at many HF through UHF radio-receiving sites. This edition of the handbook adds information about this relatively new source of radio noise. The handbook has been reorganized to add information about new sources and other new material, but the extensive information about sources associated with electric-power-distribution lines in the earlier editions is retained.

A five-step program is described to eliminate external sources of man-made noise from a receiving site. They are:

Step 1—Understand and define the noise problem at a receiving site.
Step 2—Understand sources and source mechanisms.
Step 3—Locate sources.
Step 4—Identify the hardware which is generating noise.
Step 5—Specify and execute an effective mitigation action for each source.

The presentation in this edition of the handbook follows the above steps. Typical noise problems at a receiving site are described in Section 1. Typical sources, source mechanisms and the temporal and spectral properties of noise from a variety of common sources are described in Section 2. Section 3 presents effective ways to locate sources of noise affecting the reception of signals at a site. Section 4 provides techniques to identify the specific items of hardware which generate noise. Section 5 presents effective and ineffective noise-mitigation actions.

Appendix A provides a convenient summary of techniques to build noise-free electric-power distribution lines. Sections of distribution lines constructed in accordance with these techniques and procedures have remained completely free of sources of radio noise during more than a decade of monitoring.

Appendix B describes a realistic method of calculating the loss of signal-reception capability from sources of man-made radio noise, and this technique is often used at the completion of a site survey. An example of signal-reception loss is provided from man-made radio-noise problems at a major receiving site, primarily noise from sources on power lines. The example employs measured noise data, measured site parameters, and is for a specific site, year, and season.

The power-line material in this handbook is directed at the mitigation of noise sources associated with overhead distribution power lines (the lines providing electric power to customers). Sources on transmission lines (the lines interconnecting power plants, interconnecting transmission-line substations, and providing power to transmission substations) are usually more remote from receiving sites and such lines usually have fewer sources. In addition, the safety requirements associated with the higher voltages of transmission lines (69kV to 1MV) are critical and beyond the scope of this handbook.

The planners, managers, and staff of receiving sites have historically given a low priority to radio-noise problems. This is because effective and practical instrumentation to identify and document radio-noise problems in meaningful terms is rarely available at a site. In addition a means to determine its impact on the reception of radio signals at a site is seldom available. Radio-noise problems are often perverse, and they take special techniques and considerable practical field experience to resolve. This handbook fills some of the gaps in the process of resolving radio-noise problems.

Shortcuts to the procedures provided in this handbook are not advised since they almost always lead to incorrect results, excessive expenditures of manpower and money, and ineffective noise-elimination actions. Detailed knowledge of the procedures in this handbook and the strict adherence to the procedures will result in the elimination of noise sources. The reader is cautioned that extensive field experience is a necessary aspect of the successful and complete mitigation of the noise sources described in this handbook. There is no quick and easy way to successfully undertake the tasks of radio-noise mitigation.

Many sites have additional radio-noise problems from sources internal to a site. This handbook does not cover this additional aspect of sources of noise affecting the reception of radio signals. A companion document that deals with this important problem is in draft form.

2. Step 1—THE SITE NOISE PROBLEM

2.1 Background and General Approach

Considerable background information is required to understand whether a receiving site has experienced harmful interference from external sources of noise. A few sites encounter no noise from external sources, thus they have no need for this handbook. Other sites encounter severe levels of radio noise from external sources along with the associated loss of signal-detection capability. Generalized comments about radio noise and radio interference are not sufficient to determine if harmful levels of noise are present, to determine is noise is from internal or external sources, to locate sources, and to undertake effective noise-mitigation actions. This section of the handbook is intended to familiarize the reader with some of the background information needed to investigate and solve site noise problems.

It is useful to first understand the general signal population in the HF band and to relate signals of primary interest to the general signal population. Figure 1 shows an example of the signal levels received in the 8- to 18-MHz portion of the HF band. The signal amplitudes were obtained at 1600 local time, a time of day when the general signal population and signal levels were lowest. Only a few low-level signals were present above and below the frequency range shown due to propagation conditions. The groups of highest-level signals in Figure 1 are signals from transmitters in the International Broadcast Service. They represent signals in the 31-, 25-, 22-, 19-, and 16-meter bands internationally allocated to that service. At nighttime when ionospheric absorption is low, signals in these groups will be 30- to 50-dB higher in amplitude than shown in this figure.

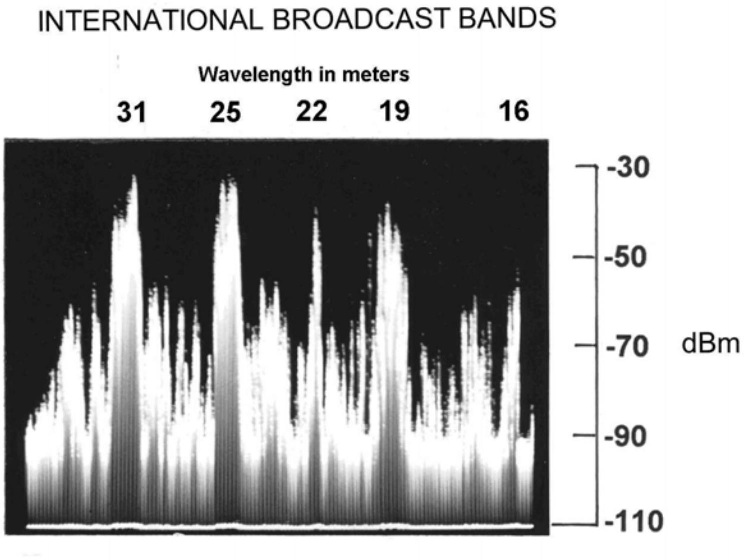

Figure 1 Example of Daytime Signal Levels in the HF Band

Most signals of primary interest will be located at frequencies between, above, and below signals in the International Broadcast Bands shown in Figure 1. The level of most signals of concern will be much lower in amplitude than those in the International Broadcast service, and they will generally range from a peak of about -80 dBm down to the minimum detectable level of about -130 dBm for a receiver with a 3-kHz bandwidth. Radio receivers and noise-measurement instrumentation must be capable of coping with high-level signals in the International Broadcast Bands while also receiving signals and noise at the minimum signal-detection level of about -130 dBm.

All broadband components of the RF path from the antenna to a receiver must be capable of coping with the total signal power delivered by the antenna without becoming saturated. In addition, the receivers and noise-measurement instrumentation at a site must also be able to cope with the total signal and noise power delivered to them. To obtain general information about the nature of signals in the band, the total signal and noise power delivered by an omni-directional antenna to a 50-Ohm load was measured at a number of HF receiving sites over one- to four-day periods with a broadband rms. voltmeter. A bandpass filter of 2- to 30-MHz was used between the antenna and the voltmeter to prevent signals lower and higher in frequency from contaminating the results. This measurement was completed at several sites to understand the maximum power levels presented to the input terminals of site receivers and at the input terminals of the noise instrumentation.

Figure 2 shows an example of the total power delivered from an omidirectional antenna to a 50-Ohm load over a 4-day period. This example was obtained from a European location, but almost identical examples were obtained from all other locations. As shown, daytime power levels are reduced by signal absorption in the propagation path. Nighttime absorption levels are lower, resulting in higher signal levels and higher total power delivered by an antenna.

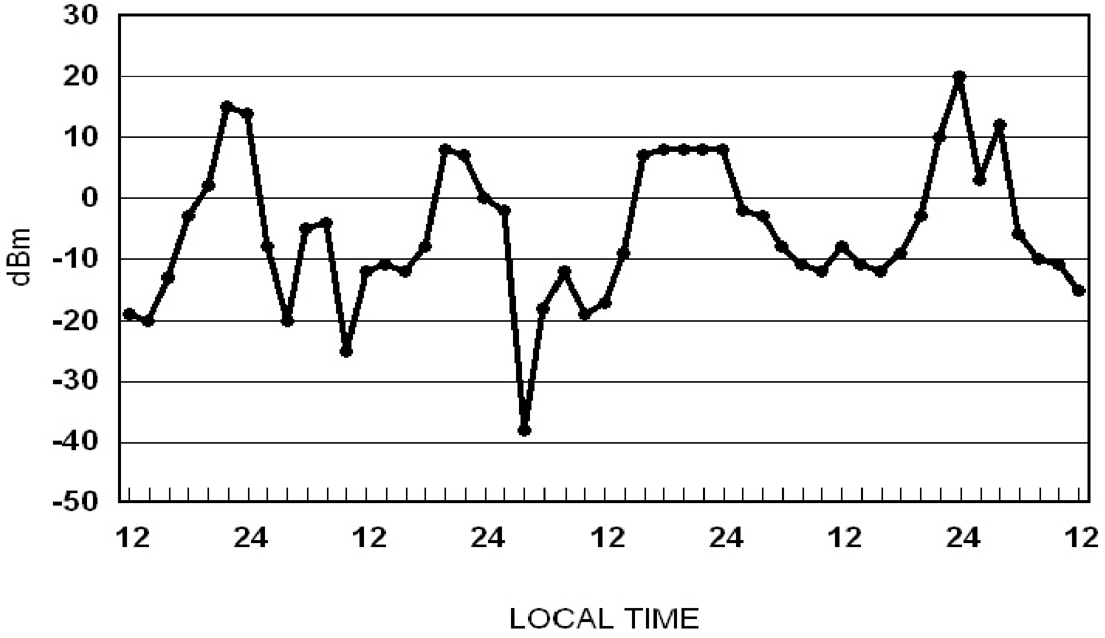

Figure 2 Total Signal Power Delivered from an Antenna

The noise floor of a typical HF receiver is about –130 dBm for a 3-kHz bandwidth. This indicates that the broadband dynamic range of components in the RF path from the antenna to a receiver, and in the front-end portion of a receiver or noise instrumentation, must be about 100 dB for the daytime measurement of noise at a receiving site. A broadband dynamic range of about 140 dB is required to ensure that nighttime noise data will not be contaminated by inter-modulation products or inter-modulation noise generated by components in the RF path between the antenna and the receiver. Alternatively, filters can be used to reduce the level of the broadcast band signals. Daytime noise measurements can usually be made by the careful use of conventional instrumentation. While some care must be made to ensure that instrumentation has sufficient dynamic range to handle the daytime signal power, much greater care must be taken to cope with the increased nighttime signal power.

Yet another problem exists for the measurement of man-made radio noise in the HF band. Such noise is often highly impulsive. The spectral components of impulses are generally much wider than the measurement bandwidth of a conventional HF receiver or the bandwidth of noise-measurement instrumentation. Since little information about the impact of measurement bandwidth on noise amplitude was available, Hodge[1] investigated the problem and developed a plot for bandwidth conversion.

Figure 3 shows how the amplitude of power-line noise changes with instrumentation bandwidth. A similar plot of the amplitude of time-stable Gaussian noise as bandwidth is changed is added to the figure for reference purposes. The amplitude of a discrete-frequency signal does not change with bandwidth.

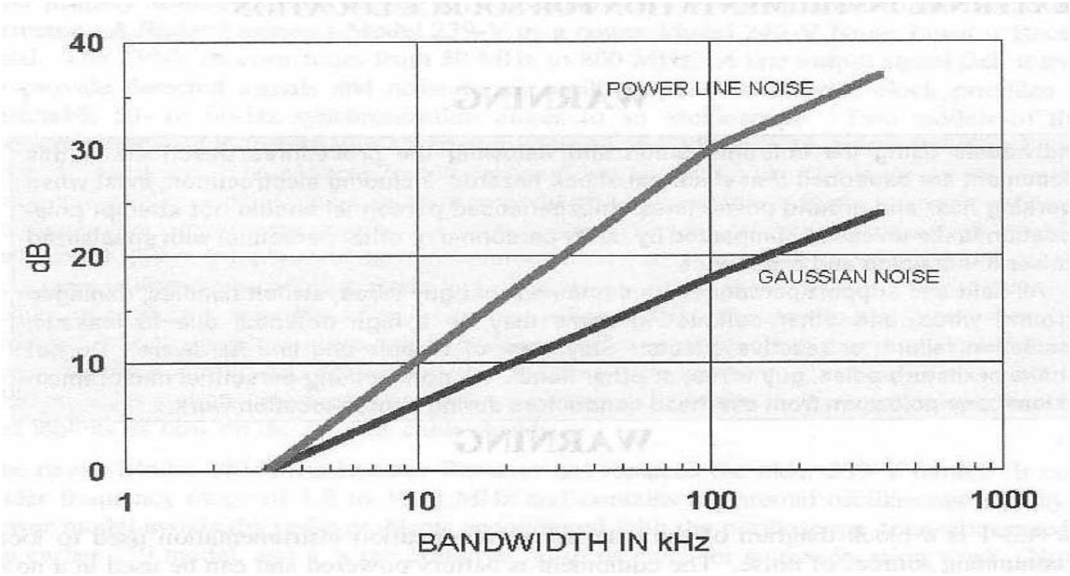

Figure 3 Bandwidth Scaling Curve for Power-Line Noise

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

Preliminary data about the amplitude of noise from a few power-conversion devices has been collected as receiver bandwidth was changed. Figure 4 shows plots of data from two types of motor controllers. Again a line representing variation in the amplitude of time-stable Gaussian noise with bandwidth is added to the plot for reference purposes.

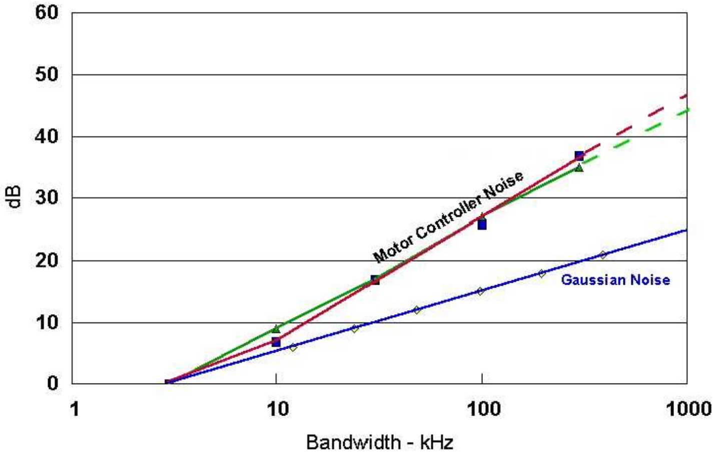


Figure 4 Preliminary Bandwidth Scaling Curve for Power-Conversion Noise

Because of measurement bandwidth implications on noise amplitude, the actual measurement bandwidth for each example of data shown in this document is provided. In addition, all measurements were made with a Gaussian-shaped bandwidth to minimize pulse-distortion effects. Considerable care was taken to ensure that all measurements were made under linear conditions to avoid contamination from intermodulation products and broadband intermodulation noise.

Occasionally one will encounter a nonlinear device during noise measurements at a receiving site. The term "Intermodulation Products" is often used to describe the resulting spectral components generated by a nonlinear device. However, "Intermodulation Products" is commonly used to define the result of mixing multiple discrete-frequency signals together in a nonlinear component where the original and the additional spectral components generated are all discrete in frequency. Intermodulation products are highly useful for many laboratory measurements where clean signals are generated by signal generators, but it does not describe the intermodulation results found at a receiving site. A receiving site encounters many signals that are wide in spectral content (examples are FM, SSB, spread spectrum, repetitive impulses, random impulses, etc.). The intermodulation products of such signals are spectrally wide and change in amplitude and occurrence as signals fade, come and go. The term "Intermodulation Noise" is used in this document to distinguish the additional wideband spectral components generated in a nonlinear device while the term "Intermodulation Components" is used in its conventional sense.

2.2 Site Instrumentation

Instrumentation is required inside the receiving site to verify that radio noise and interference from power lines is present at the input terminals of receivers and to document the technical properties of such interference. Special importance is given to this instrumentation since it must present the investigator with sufficient information to determine the adverse impact of noise on signal reception, differentiate power-line noise from power-converter noise, and define noise from other sources. The instrumentation must also be able to cope with, and define, the highly erratic and time-changing operation of individual sources as well as multiple sources.

The site instrumentation must be capable of accomplishing a variety of measurement tasks. Examples of these tasks are:

- Identify and measure the ambient noise floor presented to the input terminals of a receiver in the absence of man-made radio noise.
- Identify and sort power-line noise and power-conversion noise from a variety of other kinds of noise.
- Identify and describe multiple cases and types of noise.
- Identify the primary spectral and temporal properties of each source of noise.
- Identify brief bursts of noise and sort them from other noise bursts, signal bursts, transients, and other ambient signals and noise.
- Cope with and define highly erratic time-varying noise.
- Identify, sort, and distinguish between cases of non-stationary noise and non-stationary signals.
- Document the technical characteristics of each case of harmful radio noise.
- If possible, provide directional information toward each source of noise to external source-location teams.
- Coordinate the observed temporal structure of each case of power-line noise with that observed by external source-location teams in real time.

This handbook does not include instrumentation to obtain long-term statistical measures of man-made radio noise. That is a separate matter that is beyond the scope and objectives of this handbook. The information and the instrumentation described in this handbook are limited to the objectives stated in Section 1.

Figure 5 shows a block diagram of the primary site-located instrumentation used to obtain the data presented in this document.

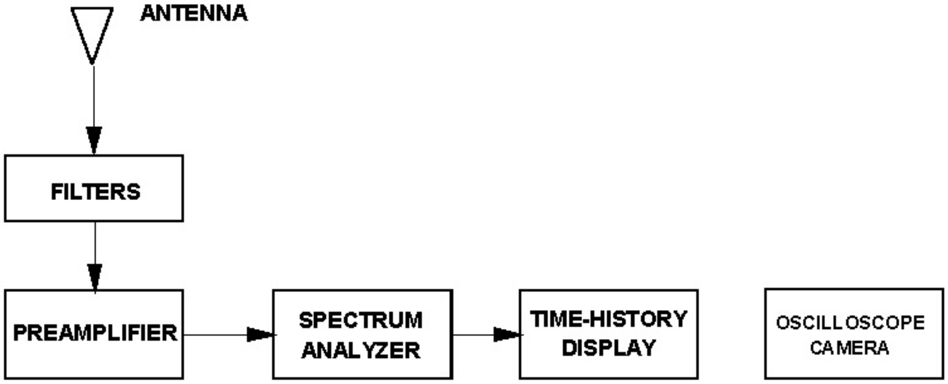


Figure 5 Block Diagram of Site Instrumentation

The antenna should be the one normally used for signal reception at a site. Furthermore, the instrumentation should be connected to the antenna at a location near the receiver. This will allow the instrumentation to examine the same radio-noise conditions which the receiver encounters.

Banks of band-pass filters are used to avoid the high signal strengths found in the International Broadcast Bands. Unfortunately, it is not possible to design conventional discrete-component filters to completely avoid all of the high-level signals in the HF band. The filters were often supplemented with a narrow-band preselector of the kind popular in the early days of radio. Between the filters and a preselector it is possible to obtain sufficient information about low-level signals and noise to achieve the program objectives.

High dynamic range preamplifiers were used to set the noise floor of the instrumentation about equal to that of a standard HF/VHF/UHF receiver.

The spectrum analyzer is the critical part of the instrumentation. A scanning analyzer is preferred, but many new digital scanning analyzers are unsuitable for two reasons. First, the dead time between scans is far too large, resulting in excessive missed information along with their inability to define cases of erratic and intermittent noise. Second, it is impossible to alter their adjustments fast enough to define many cases of intermittent and short-term noise. For these reasons hand-selected units of the older HP-141 type Spectrum Analyzers were used to collect the data shown in this document. The dead time between scans for the older analyzer is minimal, and its controls can be rapidly adjusted to cope with changing conditions. Newer models of scanning spectrum analyzers are desired to replace the older model used for noise measurements, but suitable models were not available at the time this document was prepared. However, presently available newer models were preferred for laboratory measurements of time-stable signals and noise.

An ELF Engineering Model 7200B 3-Axis Display was interfaced to the HP 141 Spectrum Analyzer to provide a real-time time-history display of the temporal and spectral properties of signals and noise in any portion of the HF, VHF or UHF bands. The time-history presentation of the display provides its operator with comprehensive information about the time-changing signals and noise as well as those of more stable sources of signals and noise. The time-history view is often optimized by adjusting the spectrum analyzer scan-time control to a value considerably longer than the repetitive period of power-line noise (8.3 or 16.6 ms for a 60-Hz line and 10 or 20 ms for a 50-Hz line). A scan time of 100 or 200 ms allows several bursts of wide-band impulsive noise to occur during each scan. This provides an excellent view of the coarse-scale temporal and spectral structure. The interaction of repetitive bursts of power-line or power-converter noise with the slower scan time results in slanting lines across the time-history view. This provides an effective means to quickly determine the primary properties of each case of noise and to distinguish power-line noise from other types of signals and noise.

In past years the time-history views were photographed with oscilloscope cameras using Polaroid film. This camera has been replaced with a digital oscilloscope camera, and the resulting digital files are stored on a laptop computer.

Figure 6 Photograph of Typical Site Instrumentation

Some sites may not have suitable real-time instrumentation for source-location, source-identification, and source-mitigation tasks. For such sites, the spectrum analyzer can be replaced with the Radar Engineers, Inc. Model 240 or 242 RFI Locators described in Section 3.

2.3 *Coarse-Scale Properties of Power-Line Noise*

This section of the handbook describes the primary properties of radio noise from sources on power poles. Several examples of the coarse-scale temporal and spectral properties of power-line noise obtained at receiving sites are provided to illustrate its impact on signal reception. The fine-scale temporal properties of such noise are highly useful in identifying sources, and several examples are provided in the following section.

Figure 7 shows an example of the coarse-scale temporal and spectral structure of noise from a source on a power line. This example of severe noise from sources on a distribution line was obtained at a large receiving site and from an operational antenna at that site. The distribution line poles containing the sources were more than 1 km from the site.

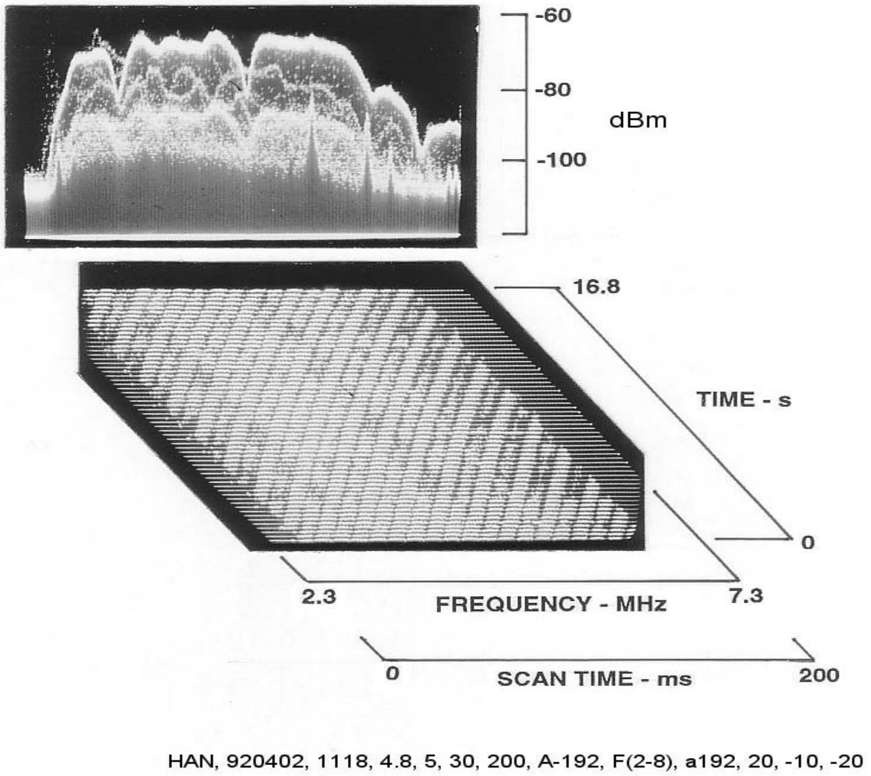


Figure 7 Coarse-Scale Properties of Power-Line Noise, Example 1

Two views of the same data are provided in Figure 7. The top view shows noise amplitude vs. frequency. Noise amplitude can be obtained from the scale on the right end of the view. This scale provides the peak noise power within the bandwidth of the measurement system that is delivered to a 50-Ohm receiver. Multiple sources of noise (at least 4) with differing spectral shapes are shown in this view. The frequency scale shown below the bottom view also applies to the top view.

Deep nulls and high peaks in amplitude across the 5-MHz frequency band are shown in Figure 7. These peaks and nulls are caused by the non-frequency-flat characteristics of the source and spectral distortion from items in the path between the source and a receiver. The peaks and nulls make it impossible to define noise amplitude by a single number except at a specific frequency. The rather sharp fall in amplitude at the lower end of the frequency scale was caused by the use of a band-pass filter (band pass of 2 to 8 MHz) to limit the total signal and noise power fed to the instrumentation. The reduction in amplitude at the upper end of the frequency scale is associated with the spectral content and shape of the noise.

A close inspection of the upper view shows a few discrete-frequency signals near the upper end of the frequency scale, but the noise level exceeded all signal levels. Signal reception was not feasible with the presence of this noise.

The lower view provides a time-history picture of the activity of the sources. In this case the sources were active for the full 16.8 seconds duration of the example. Later examples will show the more typical erratic operation of noise sources. The slanting lines across the time-history view are a result of the bursts of broad-band noise occurring at the voltage peaks on a nearby distribution line interacting with the slower scan time of the spectrum analyzer used to obtain the example. The noise bursts are separated by 8.33 ms while the scan time is 200 ms.

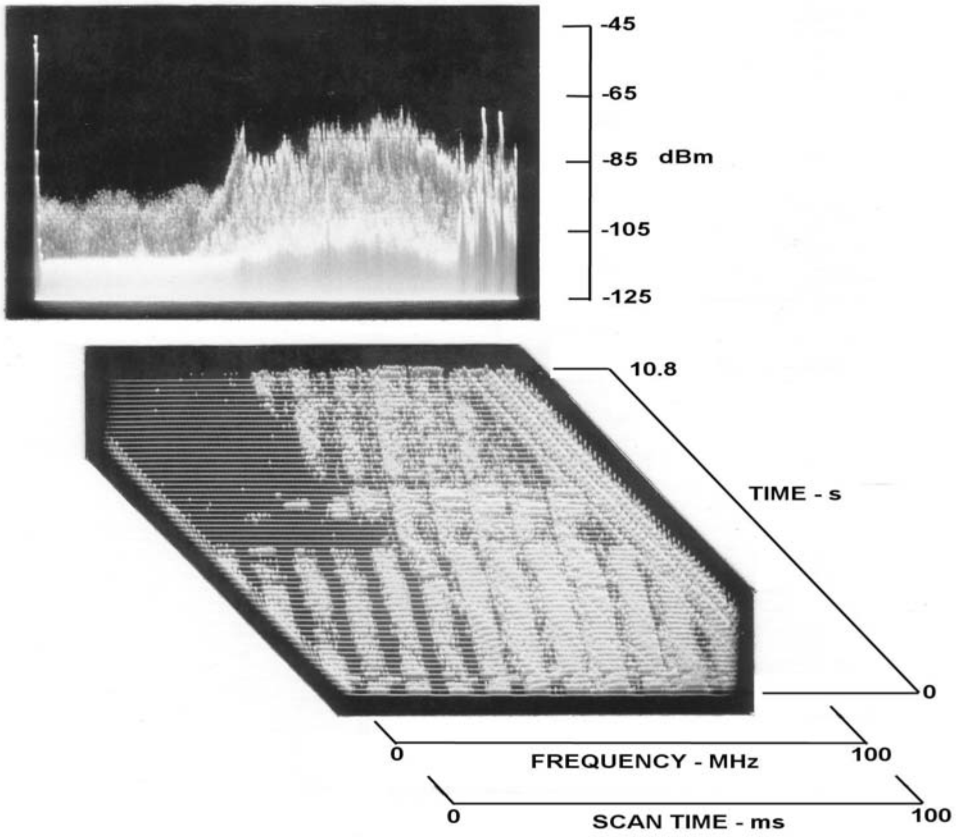
This example shows severe radio noise originating from sources on an electric-power distribution line where the nearest source was more than one km from the antennas at the site. The example illustrates the adverse impact radio noise can have on signal reception. The maximum amplitude of typical signals of interest to the site is about –80 dBm, a further indication of the adverse impact of the noise.

Since the noise shown in Figure 7 is impulsive, its amplitude is limited by the measurement-system bandwidth (30 kHz for this example). The noise amplitude can be scaled to any desired receiver bandwidth using the curve in Figure 3. The amplitude of discrete-frequency signals can be obtained from the amplitude scale.

A small line of information is provided at the bottom of this and all subsequent examples. The parameters in this line provide information about the measurement as well as key instrumentation parameters. Each item listed in the line is separated by a comma, and they are:

Site identification, date in yymmdd format, local time, center frequency in MHz, frequency span in MHz, IF bandwidth in kHz, scan time in ms, antenna identification, filter identification, preamplifier gain in dB, IF reference level, and RF attenuation.

Figure 8 shows a case where the source of power-line noise is erratic in operation as shown in the time-history view. In this case the source was only about 100 meters from the receiver site, allowing noise to be received up into the VHF band.



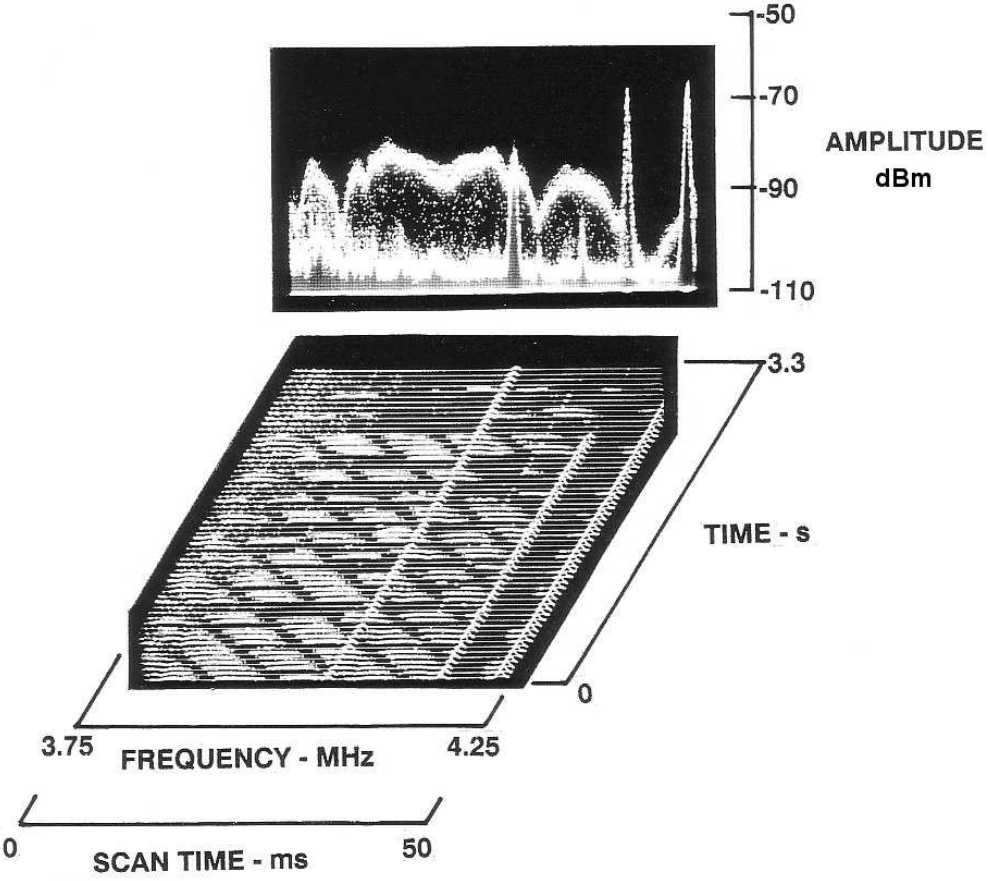
SARGENT, 860713, 1500, 50, 100, 300, 100, 1m, NF, 24, 0, -20

Figure 8 Coarse-Scale Properties of Power-Line Noise, Example 2

One noise source was active for the entire time of the observation of Figure 8. The amplitude of this source was higher at the VHF frequencies of 40 to 100 MHz than for the 2- to 30-MHz HF band. A second source became active about ½ way down the time axis of the time-history view. The second source added additional radio noise to the HF band and added very high noise into the VHF band up to and beyond 100 MHz.

The slanting lines are further apart than those in Figure 7 because of the use of a faster scan time of 100 ms compared with 200 ms for the prior example. Since the bursts of noise from the two sources overlap in the time-history view, the two sources are on the same phase of a three-phase overhead distribution line.

Figure 9 shows another example of the erratic impact of power-line noise on the reception of signals. In this case the source was located more than a km from the receiving site. The time-history view shows the erratic operation of the source. The upper view shows that each burst of noise has the same spectral structure, indicating that each burst of noise is from the same erratically-operating source. The peaks and nulls in amplitude are well defined.

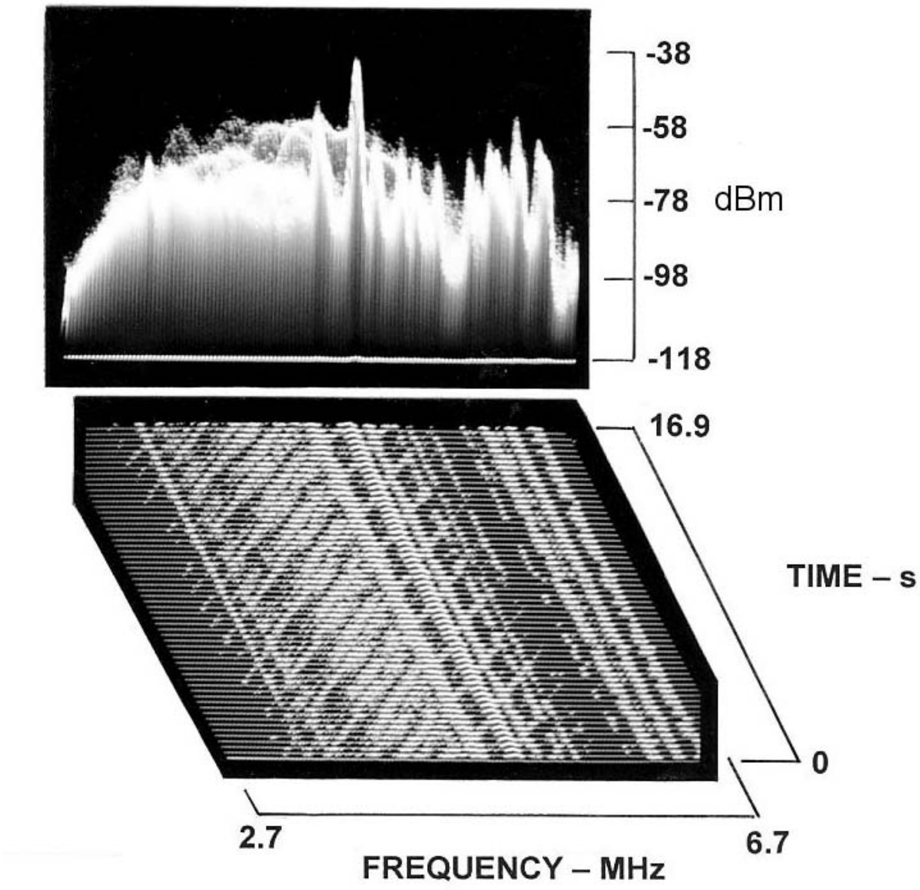


AN, 900808, 1028, 4, 0.5, 30, 50, NF, C MON 232, 20, 0, -20

Figure 9 Coarse-Scale Properties of Power-Line Noise, Example 3

Two strong signals near the upper end of the frequency scale exceeded the noise and could be received. One signal slightly above 4 MHz exceeded the noise by a slight amount, and it could be received along with noise. Another signal can be seen about ¾ of the way up the frequency scale that is below the noise level and could not be received during the noise bursts, but it could be received in the brief intervals between each noise burst.

Figure 10 shows an example of noise from multiple sources on a distribution line. The lower view shows that sources are on two phases of a 3-phase distribution line. Both sources were more than 2 km from the site. The upper view shows the spectral shape of each source as well as several discrete-frequency signals.



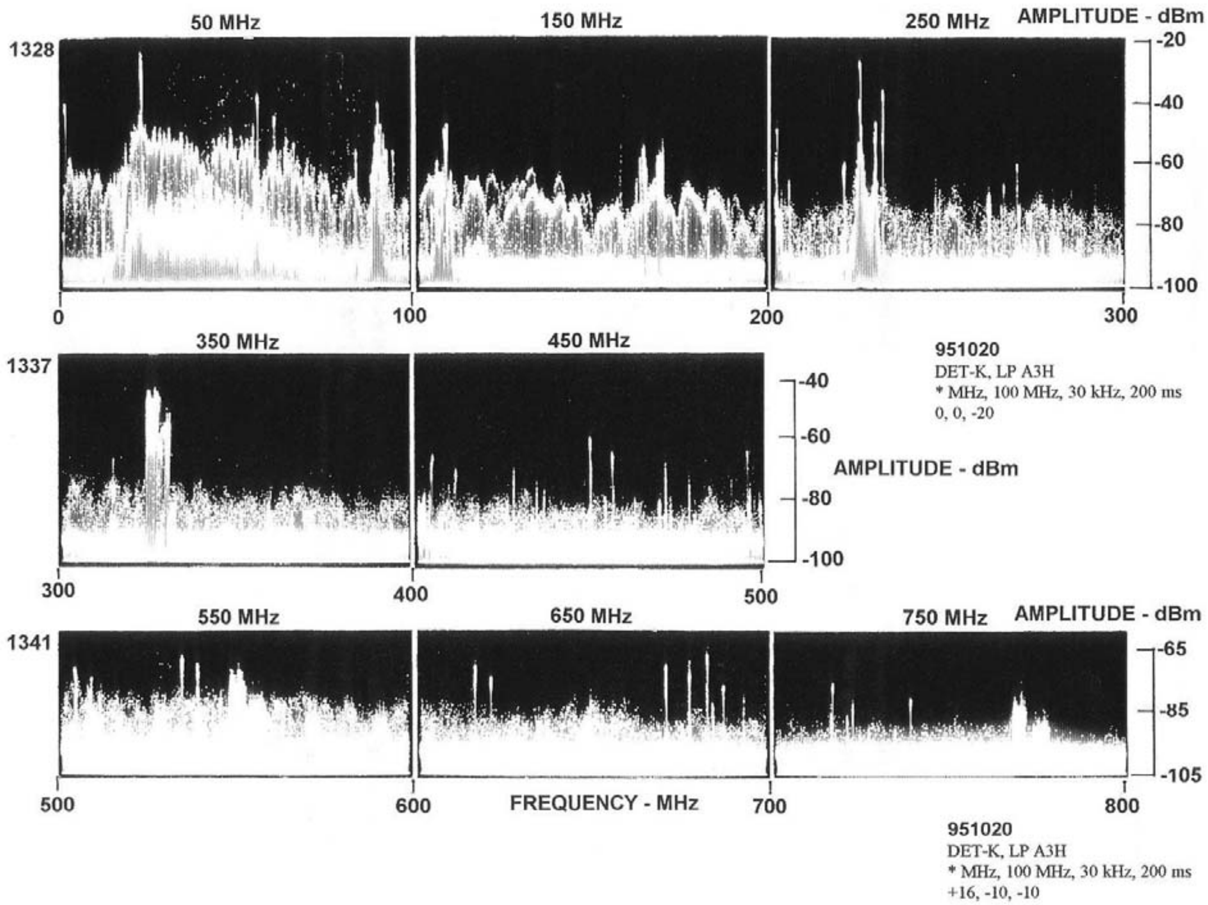
ROT, 000906, 0835, 4.2, 5, 30, 200, LBM 120, PS-3, BPF 2-6, 11, 0, -30

Figure 10 Coarse-Scale Properties of Power-Line Noise, Example 4

The non-flat spectral content of each sources of power-line noise is shown in the amplitude vs.-frequency view. The signal-to-noise ratio of each individual signal can be determined from the data. Signals without sufficient amplitude margin over the noise cannot be received.

One final example of the gross spectral content of noise from a source on a power line is provided in Figure 11. In this case multiple sources of noise were present from three bell insulators on a pole located about 100 meters from the receiving site's antenna. This line provided electric power to this site and to another site several km further away.

Severe noise was noted throughout the entire HF and VHF bands and up into the UHF band. The sources were eliminated by replacing the bells with polymer insulators. After replacement the noise floor dropped significantly across the entire frequency span of the data, and the site was able to resume normal signal-reception tasks in all bands. Only a few cases of low-level noise remained from more distant sources. The nearby sources had to be eliminated before the lower-level and more distant sources could be detected and be dealt with.



951020
DET-K, LP A3H
* MHz, 100 MHz, 30 kHz, 200 ms
0, 0, -20

951020
DET-K, LP A3H
* MHz, 100 MHz, 30 kHz, 200 ms
+16, -10, -10

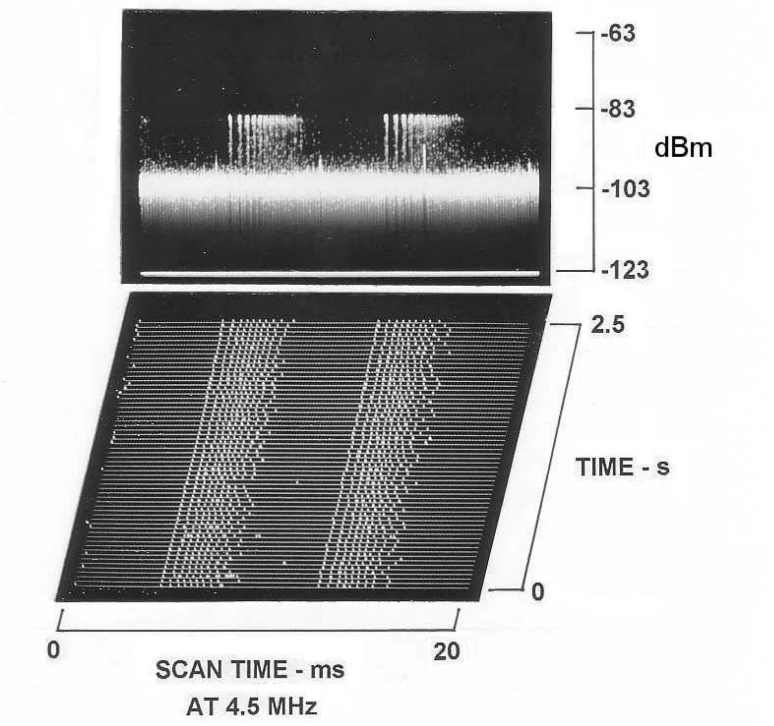
Figure 11 Noise at a HF/VHF/UHF Site

2.4 Fine-Scale Properties of Power-Line Noise

Knowledge of the fine-scale temporal structure of power-line noise provides considerable information about each source of noise. Such information when obtained at the site is essential for the successful completion of external source-location and source-hardware identification efforts.

Two common types of noise will be encountered along with several less common types. These types are closely related to the source mechanisms. The first is sometimes referred to as "gap noise" and its source is the very small breakdown of an insulating oxide layer between two metal components. The second common type is from the breakdown of air between two closely-spaced conducting objects. The first type is called *micro sparking* in this document. The second is called *sparking*.

Figure 11 shows an example of the fine-scale presentation of the micro sparking. This source was traced to the breakdown of the oxide layer between the two metal parts of the clevis and pin joining two parts of a dual bell insulator.

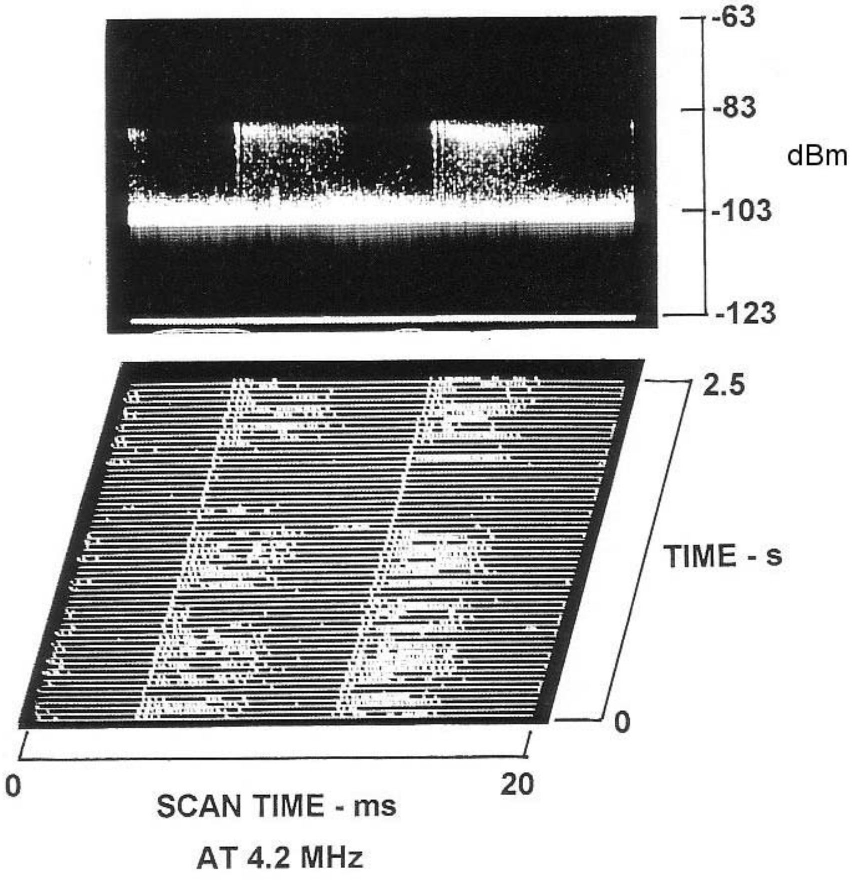


HAN, PASTEUP, 950407, 1439, 4.5, 0, 30, 20(LS), LBM 180, PS(-3), BPF 1, 20, 0, -20

Figure 12 Fine-Scale Temporal Structure, Example 1

The example in Figure 12 was obtained with the scan process of the spectrum analyzer synchronized to the power-line frequency. The scan time of 20 ms resulted in bursts of noise in the view where the bursts are separated by 8.33 ms. The timing of the first impulse of each group is very stable, and it occurs when the power-line voltage reaches the breakdown point of a thin insulating oxide layer. Successive impulses occur in accordance with the model of the breakdown process provided in Section 3. The timing of subsequent breakdowns is less stable, and the creation of the impulses stops when the power-line voltage falls below the breakdown point of the thin oxide layer. This process results in a succession of bursts of noise where the bursts are synchronized to the power-line frequency. The amplitude of each impulse is almost identical. This and the pulse-spacing pattern result in a distinctive temporal structure that is easy to recognize during noise measurements at a receiving site. The noise creation and radiation mechanism is described more fully in Section 3.

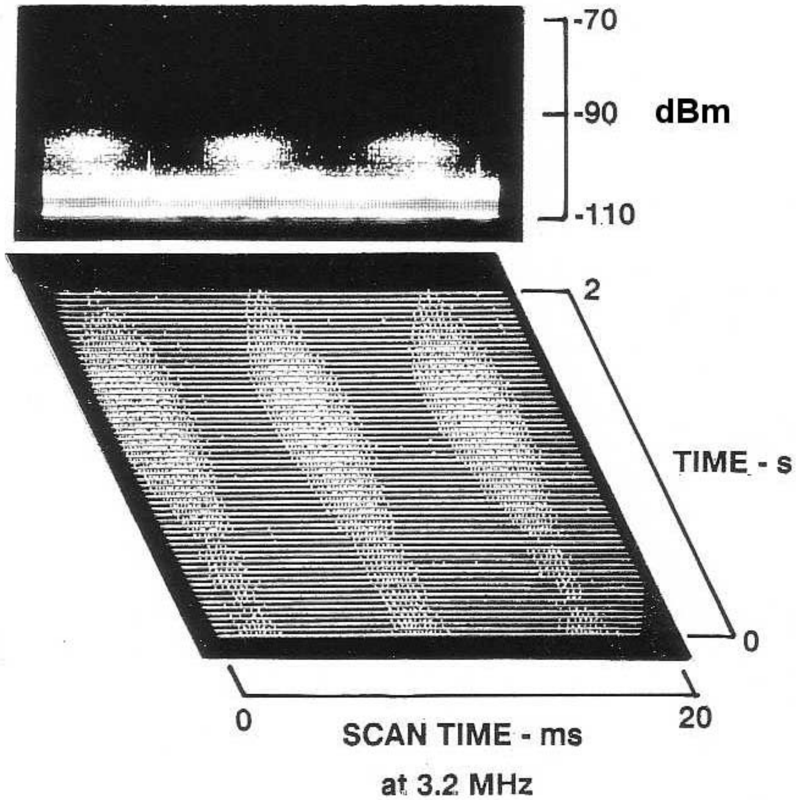
Figure 13 shows a case where the breakdown process is erratic. Such a source can quickly change from continuous operation to intermittent operation and back, or it can remain in a stable state for minutes to tens of minutes.



HAN, PASTEUP, 950407, 1502, 4.2, 0, 30, 20(LS), LBM 180, PS(-3), BPF 1, 20, 0, -20

Figure 13 Fine Scale Temporal Structure, Example 2

Figure 14 shows an example of micro-sparking noise from a bell insulator source where the insulator was moving slightly from wind. The data was obtained with the scan time of the spectrum analyzer synchronized to the power-line frequency. Slight changes in the physical configuration of the oxide-layer breakdown from wind movement can produce large changes in the temporal structure of the noise. A few minutes after this example was obtained, the source became inactive for the remainder of the day.

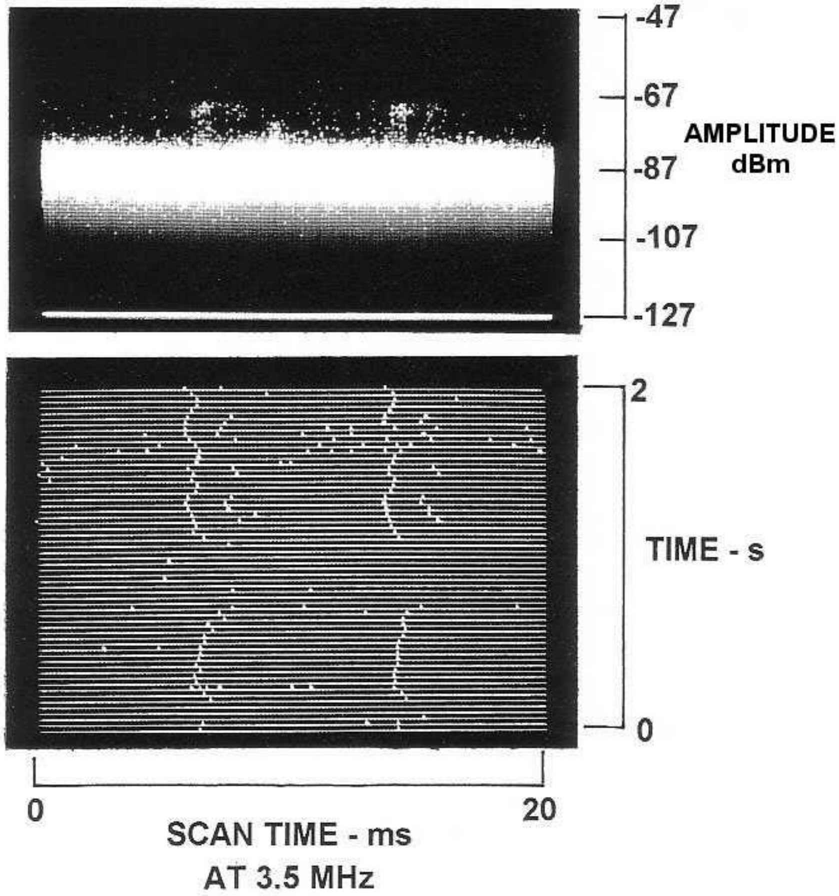


HOM, PASTEUP, 900425, 1515, 3.2, 0, 30, 20(LS), LBM 312, (-3), BPF 1, 20, -10, -

Figure 14 Fine-Scale Temporal Structure, Example 3

The sources of the microsparking noise shown in the previous three figures are frequently hidden behind metal objects, and the spark is so small that it is not visible to the eye. Also it does not produce sufficient energy to result in reliable detection with an infrared sensor. Noise from this kind of source can be reliably detected with a VHF RF probe.

Figure 15 shows an entirely different fine-scale temporal structure. This example of sparking noise was caused by the erratic breakdown of air at the end of an insulated tie wire used to fasten an insulated conductor to a post insulator. The source was several km from the receiving site. The erratic initiation time of the initial arc is shown in the time-history view along with a more erratic second arc. The spacing between the two pairs of breakdowns is 8.33 ms, indicating the arc occurred at both the positive and negative peaks of the line-voltage waveform.

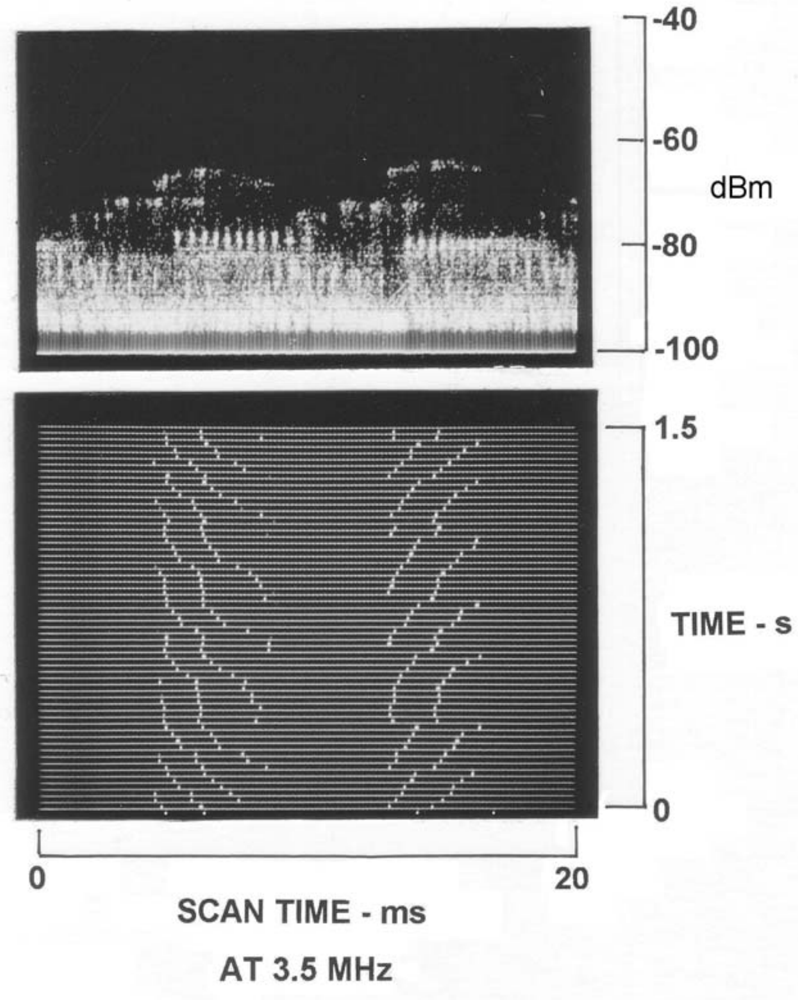


HAN, 959816, 1524, 3.5, 0, 30, 20(LS), LB 168, PD -3, BPF 1, 20, 0, -30
Source 9508-04, Phase C

Figure 15 Fine-Scale Temporal Structure, Example 4

Because the breakdown process of a small arc is usually quite erratic, the temporal structure will vary considerably with time and from one source to another source. Most examples will show the erratic timing of the initial pulse followed by one or two additional pulses, also with erratic timing.

In some cases the sparking process will produce well-defined temporal patterns in the time-history view. Figure 16 shows one such case where the timing of the pulses produced a distinctive pattern. The upper view shows that at least four sources of noise were present, but the threshold control for the time-history view was adjusted to permit viewing only the distinctive structure of the highest level noise. This allowed the site operator to concentrate on the highest-level noise before proceeding to the lower-level cases.

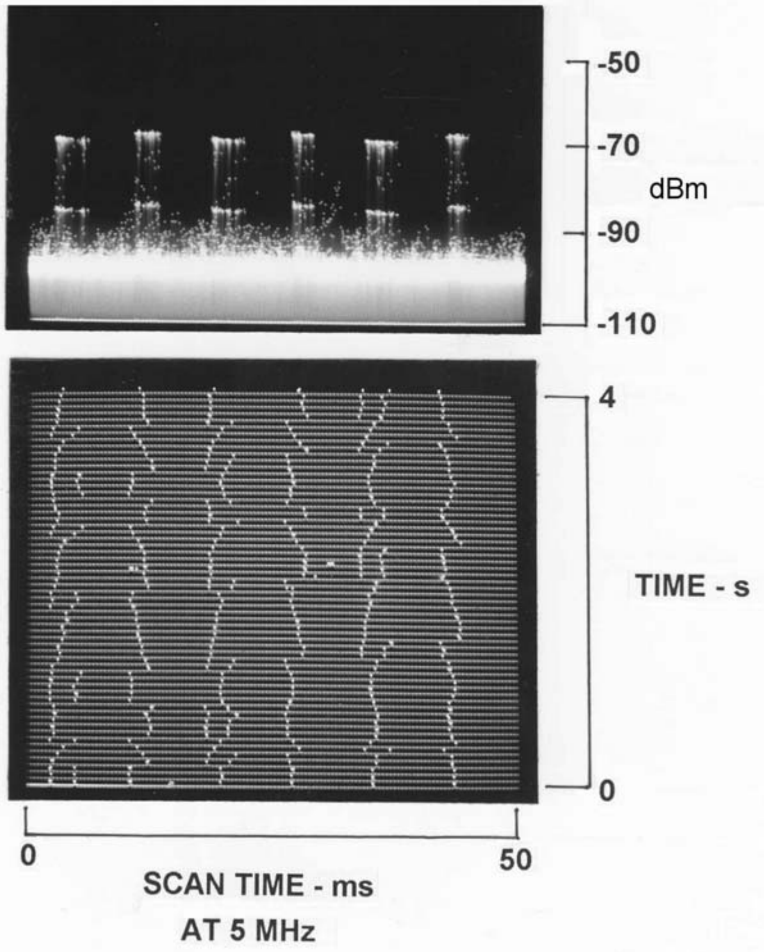


HUM, 930523, 1245, 3.5, 0, 30, 20(LS), P-225, BPF 1, 0, 0, -20

Figure 16 Fine-Scale Temporal Structure, Example 5

Figure 17 shows another example of the distinctive temporal pattern of sparking noise from the small arcing between the bottom threaded part of a pin insulator and its support bolt. The pin insulator had not been sufficiently tightened to form a solid metallic contact between the insulator threads and its mounting bolt. This allowed a thin insulating oxide layer to build up between the insulator threads and the mounting bolt resulting in a potential difference between the insulator threads and the mounting bolt.

Similar patterns can occur from other arcing sources.

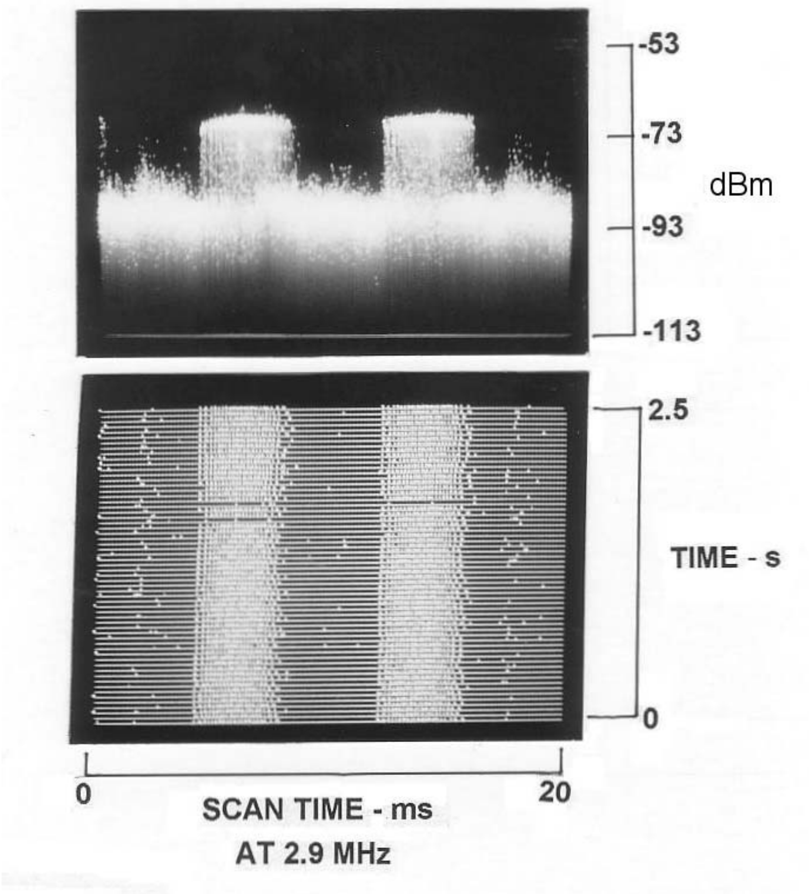


SAB, PASTE UP, 950911, 1100, 5, 0, 30, 50(LS), LBM 276, BPF 2-8, 0, 0, -30
SOURCE 9509-1

Figure 17 Fine-Scale Temporal Structure from a Small Arc

High voltage transients can be impressed on a distribution line during nearby or direct lightning strikes. Lightning arresters provide a path to ground to dissipate the charge buildup from a lightning strike, but their internal components can be damaged from a potent strike. The internal components of a damaged lightning arrester can then breakdown at the normal line voltage and at multiple locations within the arrester. The resulting overlapping arcing and microsparking can result in very potent radio noise at a receiver site located within line of sight of an overhead line associated with the source.

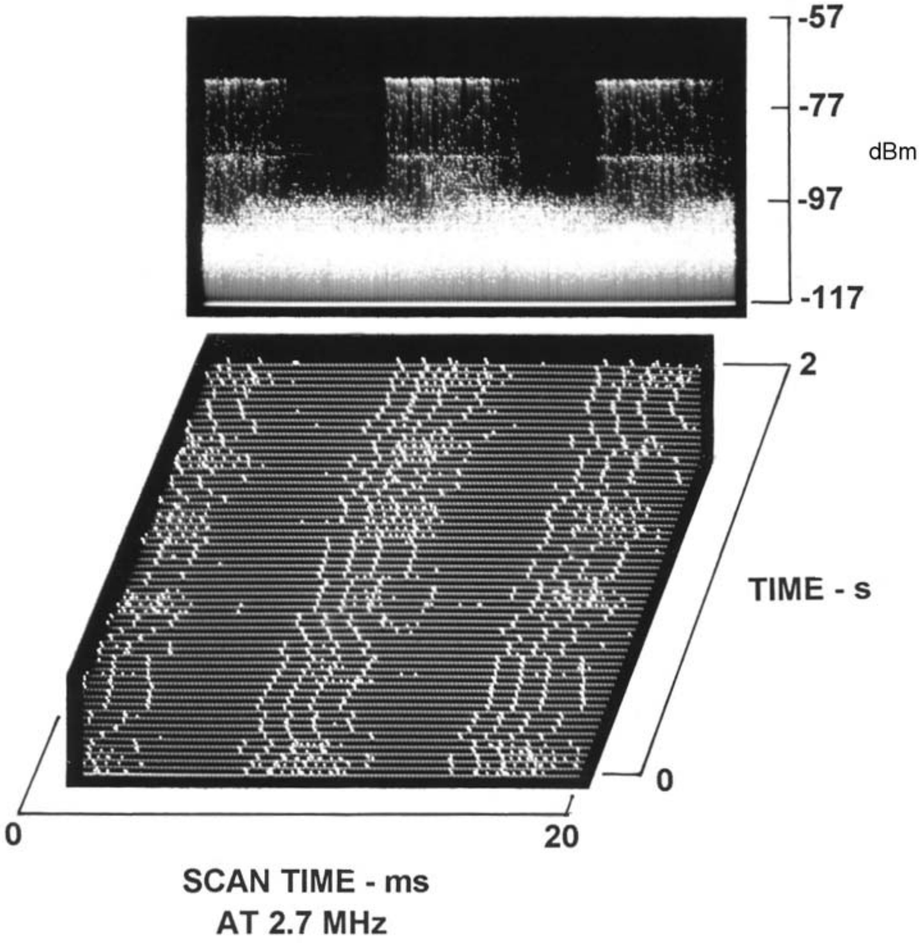
Figure 18 shows the temporal structure of radio noise from a damaged lighting arrester located several km from a receiving site. The temporal structure can be similar to that of a gap source, but the amplitude will not be quite as flat and the pulses will be usually be overlapping in time from multiple breakdowns. Lightning arrester sources are often more active at times of high humidity and often become inactive during times of low humidity.



HAN, PASTEUP, 950405, 0835, 2.9, 0, 30, 20(LS) LBM 60/72, PS(-3), BPF 9, 20, -10, -10

Figure 18 Fine-Scale Temporal Structure, Example 6

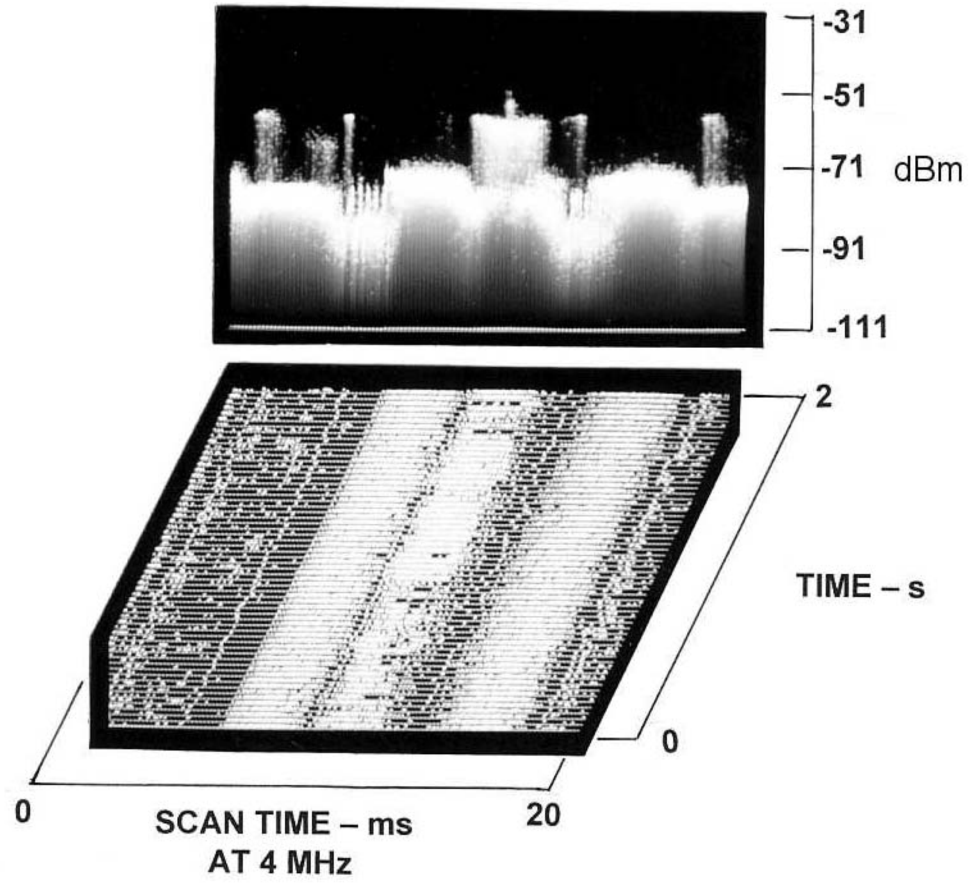
The distinctive temporal structure of Figure 19 suggests the source is probably different from the prior examples. A guy wire attached to a distribution line pole rubbed against other metal hardware and produced erratic microsparking that generated this complex temporal structure. The pole was about 2 km from the receiving site.



SAB, PASTEUP, 950919, 1030, 2.7, 0, 30, 20 (LS), LBM 288, PS (-3), BPF 9, 20, 0, -20
Source 9509-11

Figure 19 Guy Wire Rubbing Against Metal Hardware

The previous fine-scale views of radio noise from sources on distribution lines were obtained at times when only a single dominant source or a few sources were in operation. At times radio noise from multiple sources will be found, and the site operator must be able to distinguish between each source. Figure 20 shows an example of multiple sources. At least six and possibly seven sources are present. In this case, the site operator would place emphasis on the strongest sources, eliminate them, and then deal with the lower level sources.



ROT, 000913, 0940, 4, 0, 30, 20(LS 60), LBM 120, BPF 1, 11, 0, -20

Figure 20 Fine-Scale Temporal Structure, Example 7

2.5 Power-Conversion Devices

2.5.1 General Comments

Modern solid-state switching devices are used to alter electric power, control electric power, and change electric power from one form to another form. These devices are used in a wide variety of equipment and devices ranging from uninterruptible power supplies, switching power supplies, variable-speed controllers for electric induction motors, heating controls, light dimmers, solar power systems, and many other applications. Devices employing solid-state switching can place high levels of impulse current and voltage onto the electric wiring, ground conductors, and other metal components associated with a source. These impulses pass through the transformer providing power to a facility with little loss and onto the conductors of an overhead distribution line providing electric power to the facility. Noise radiating from the building conductors and the overhead power-line conductors of a distribution line associated with such a facility can result in severe radio interference at a radio receiving facility located within line-of-sight of the overhead lines providing electricity to a facility containing a power-conversion device. In some cases recent laws mandating the use of these devices in an attempt to conserve energy further exacerbate the noise problem at a receiving site.

The temporal and spectral content of the radiation is determined by the electrical design of the power-conversion device. The spectral content is further modified by the electrical impedances of its facility wiring, the electrical path from the facility to the overhead lines, and radiation from the overhead lines. While the temporal structure of a specific source is usually maintained and can be observed at a distant receiving site, the spectral shape of the broadband noise can contain deep nulls and peaks in amplitude caused by the electrical characteristics of the path between the source and the receiving site. However, the temporal structure can vary from one source to another, thus providing a means to distinguish one source from another.

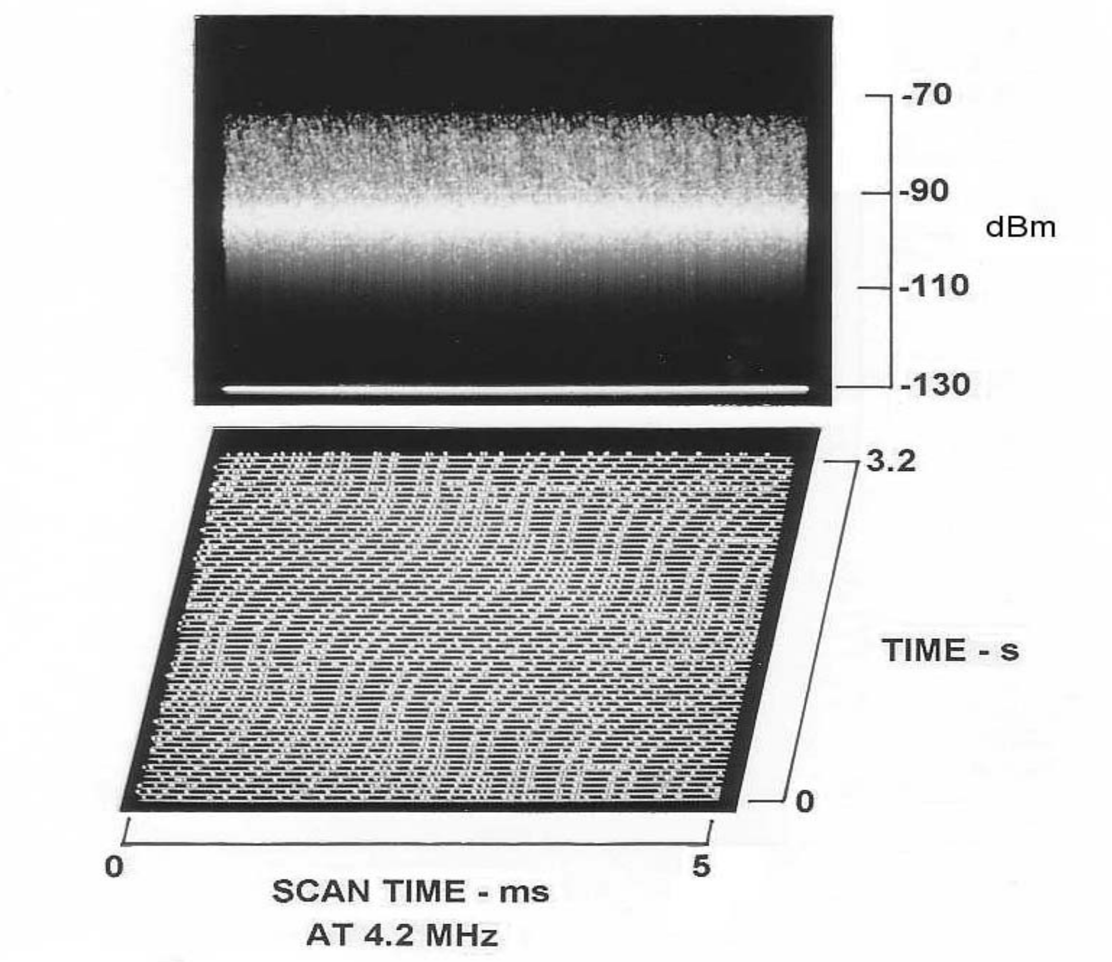
2.5.2 Variable-Speed Electric-Motor Drives

Variable-frequency power can be used to vary the speed of a standard induction electric motor where the motor size can vary from a fractional horse-power up to a multiple horsepower motor. Solid-state power-conversion devices are commonly used to change the fixed-frequency of electric power into a variable frequency power, thus providing a simple and effective means to change and control the speed of the motor. This technique can be used for a large variety of applications such as the control of the flow of air in facility, the speed of a conveyor belt, the flow of air into a ceramic furnace, and many other similar applications.

Harmful levels of radio noise from variable-speed drives were first encountered at a radio-receiving site in 1995. Since that time the population of such devices has dramatically increased due to their effectiveness, low cost, numerous applications, and new laws mandating their use. Since most such devices were intended for industrial uses, little attention was given to the impulsive current and voltage they imposed on the electric wires and other conductors in the facility housing these devices. While they generate sufficient noise to affect the reception of signals from AM/FM broadcast and television stations, the affected receivers were often within the facilities housing the power-conversion devices and under their direct control. However, radiation from the facility conductors and the overhead power lines providing electric power to such facilities extend far beyond the source facility. Any LF through VHF radio-receiving site within line of sight of the overhead power lines associated with such a facility is susceptible to radio interference.

Figure 21 shows an example of the fine-scale temporal structure of noise generated by a controller used to vary the speed of a fractional horse-power electric induction motor. This particular controller was located about 3 km from the receiving site.

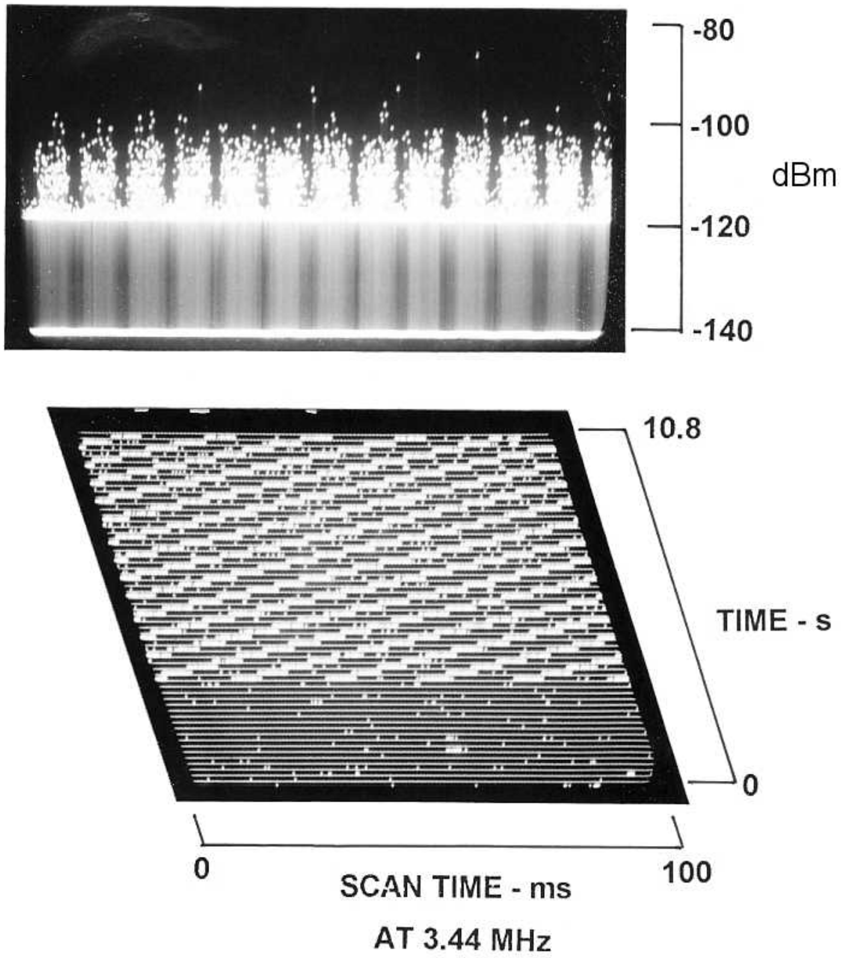
The data was obtained at the receiving site at a fixed frequency of 4.2 MHz to allow the time-varying temporal structure to be portrayed without encountering deep nulls and peaks in the spectral content of the data. The variations in the speed of the motor are clearly shown in the time-history view. The amplitude of the noise is considerably higher than the maximum amplitude of all signals of interest to the site.



HAN, PASTE UP, 950808, 1508, 4.2, 0, 100, 5, LBM 324, BPF 9, 20, 0, -30
Motor Controller Bravo

Figure 21 Fine-Scale Temporal Structure of Noise from a Motor Controller

Figure 22 shows the fine-scale temporal structure of noise from the variable-speed electric-motor drive used to rotate a VHF acquisition antenna a nearby VHF receiving site. The HF receiving antenna was about 1/2 km from the rotating antenna at the VHF site.



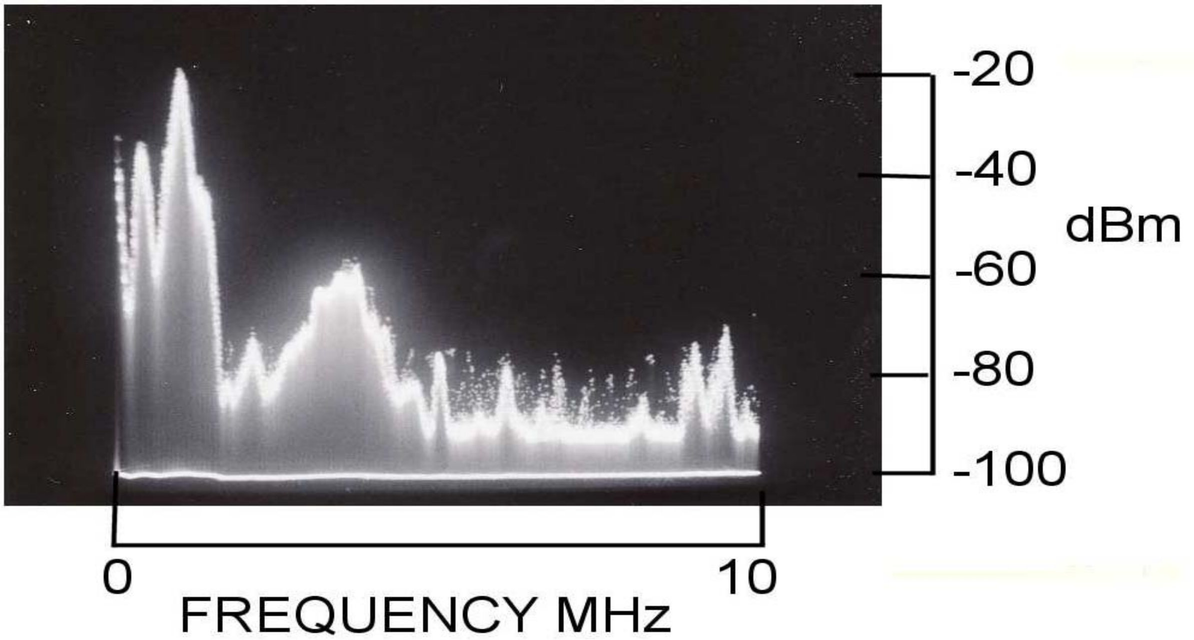
EDZ, 920514, 1043, 3.44, 0, 10, 100(LS), F-1, 20, 0, -40
Noise from controller of ACQ Antenna

Figure 22 Acquisition Antenna Controller Noise

The time-history view shows the antenna controller was operating during the upper part of the view, and it turned off about ¾ of the way down the view. Strong bursts of noise occurred at about 20-ms intervals. Since the scan process of the spectrum analyzer was synchronized to the frequency of the local power source, the slanting lines show that the controller operated at close to, but not quite, half the frequency of the local 50-Hz power.

2.5.3 Power-Conversion Device for a Residential Solar Power Installation

Solar- and wind power-generation systems use solid-state-switching devices to convert their power into a format compatible with other electric power systems. Figure 23 shows an example of the coarse-scale spectral content of noise from a direct-current to alternating-current converter used with a residential solar power system. The noise was recorded at a radio amateur's site located 1 km from the residence containing the converter. Very large spectral peaks and nulls of noise across the 10-MHz-wide band existed at the input to the radio amateur's receiver. These peaks and nulls prevent the use of a single amplitude value to characterize the noise, however noise amplitude can be provided at any specific frequency.

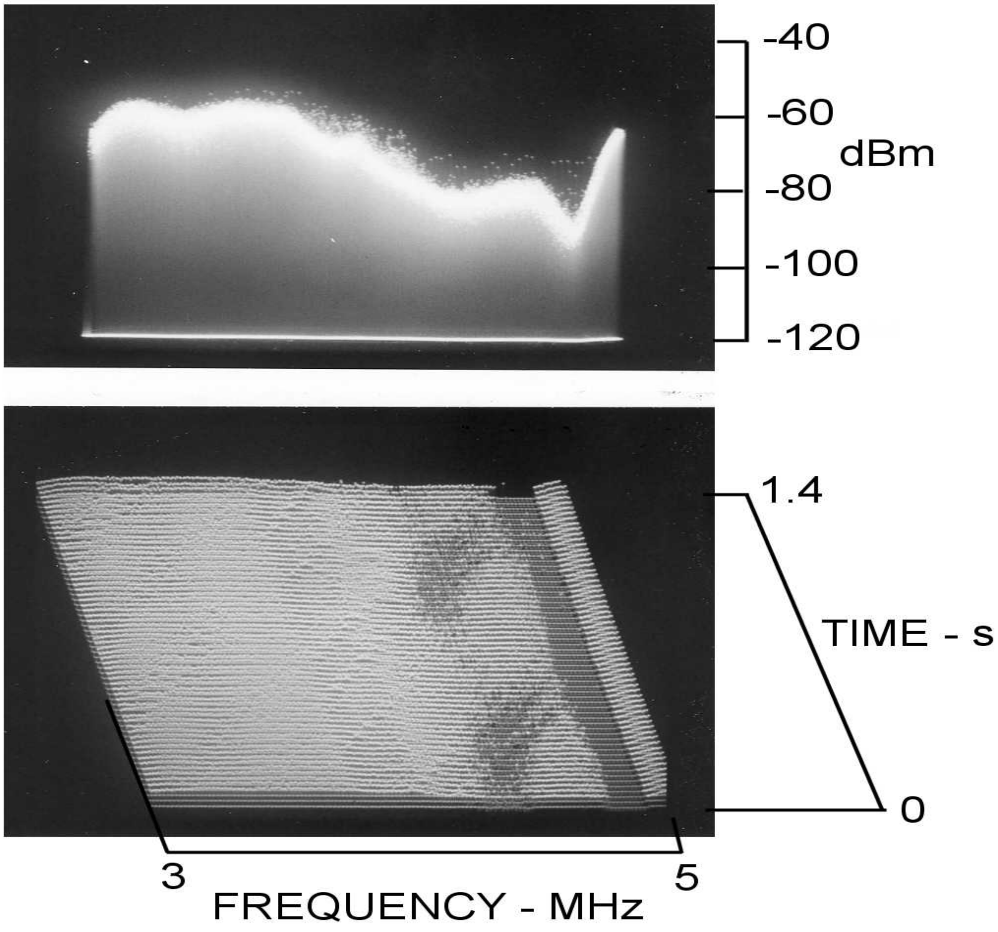


K6GDI, 030621, 1037, 5, 10, 100, 100(LS), 80 m DIPOLE, NF, 0, 0, -2

Figure 23 Solar Converter Noise at K6GDI

The residence with the solar converter was visited and measurements were made to determine the radiation mechanism. Current probes on the conductors between the converter and the house wiring indicated the broadband noise current was very low and radiation from the house wiring and the overhead power line feeding the residence could not explain the high levels of noise at the receiver location. A current probe on the DC conductors running from the converter to the roof-mounted solar cells indicated very high levels of conducted broadband noise. These conductors were about 50 meters in length, and they (along with the solar cell conductors) were the primary radiators of the broadband noise.

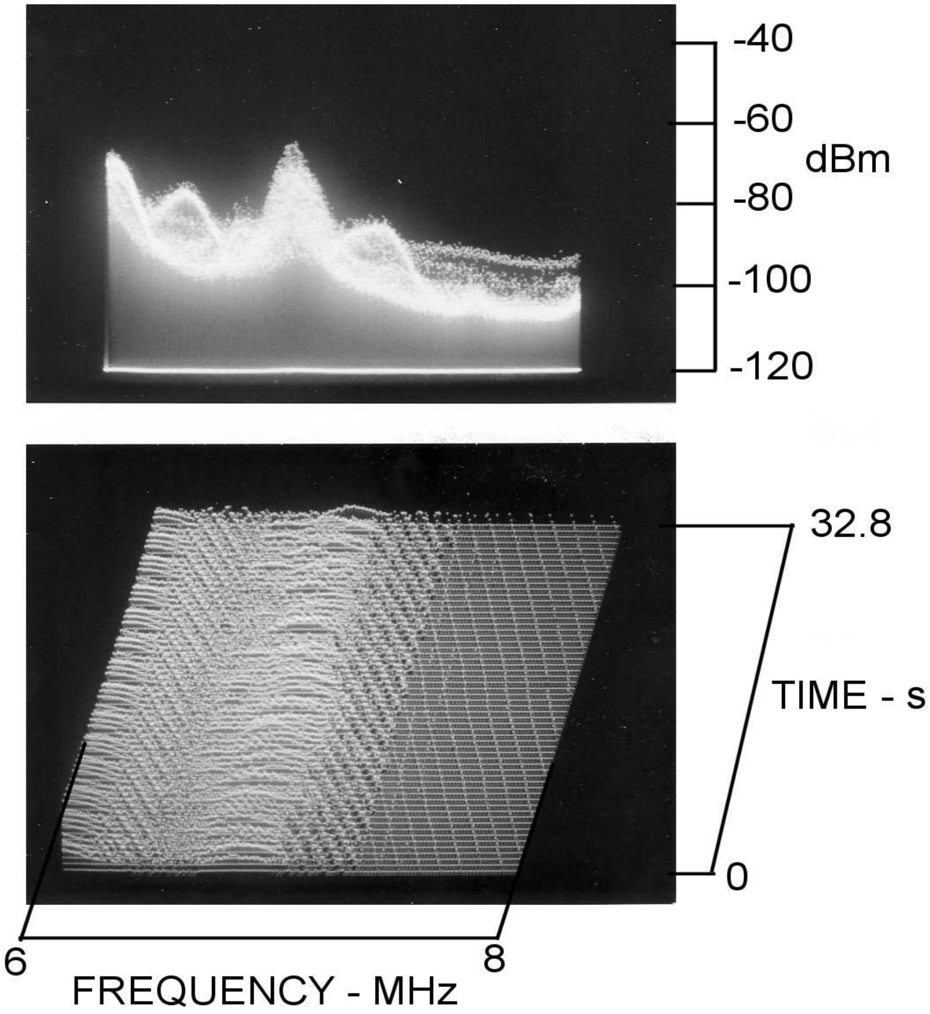
Since the radio amateur operator at K6GDI was the control station for a large-scale net operating on the 80-meter amateur band, the noise level in that band at his receiver input terminals was examined. The 80-meter band extends from 3.5 to 4 MHz, the center portion of the frequency range shown in Figure 24. The upper view shows the amplitude of the noise as delivered from his antenna to his receiver while the time-history view shows the noise was essentially continuous in time. While some temporal structure from impulses associated with converter switching is visible in the time-history view, its amplitude is nearly equal to the more continuous noise. The amplitude of signal levels during normal network operation range from about -130 dBm up to a high of about -80 dBm for single-sideband signals detected in a 3-kHz receiver bandwidth. The end result is that all signals from other stations in the network will be covered by the solar-system noise.



K6GDI, 030621, 1052, 4, 2, 100, 20, 80 m DIPOLE, F 2-8, 20, 0, -20

Figure 24 Solar Converter Noise at the 80-Meter Amateur Band

The amateur radio station also operated on 40 meters. A check of solar-converter noise at that band was also made. The 40-meter amateur band extends from 7.000 to 7.300 MHz, at the middle of the frequency range shown in Figure 25. The upper view shows significant peaks and nulls in noise amplitude across the frequency range shown. The two sets of slanting lines in the lower view show that repetitive impulses are present at two different rates. Apparently, the dc voltage from the solar cells was sampled at a different rate from the line frequency. Amateur radio operation at the low end of the band is not feasible, and only a few exceptionally strong signals will barely exceed the noise level at the upper edge of the band.



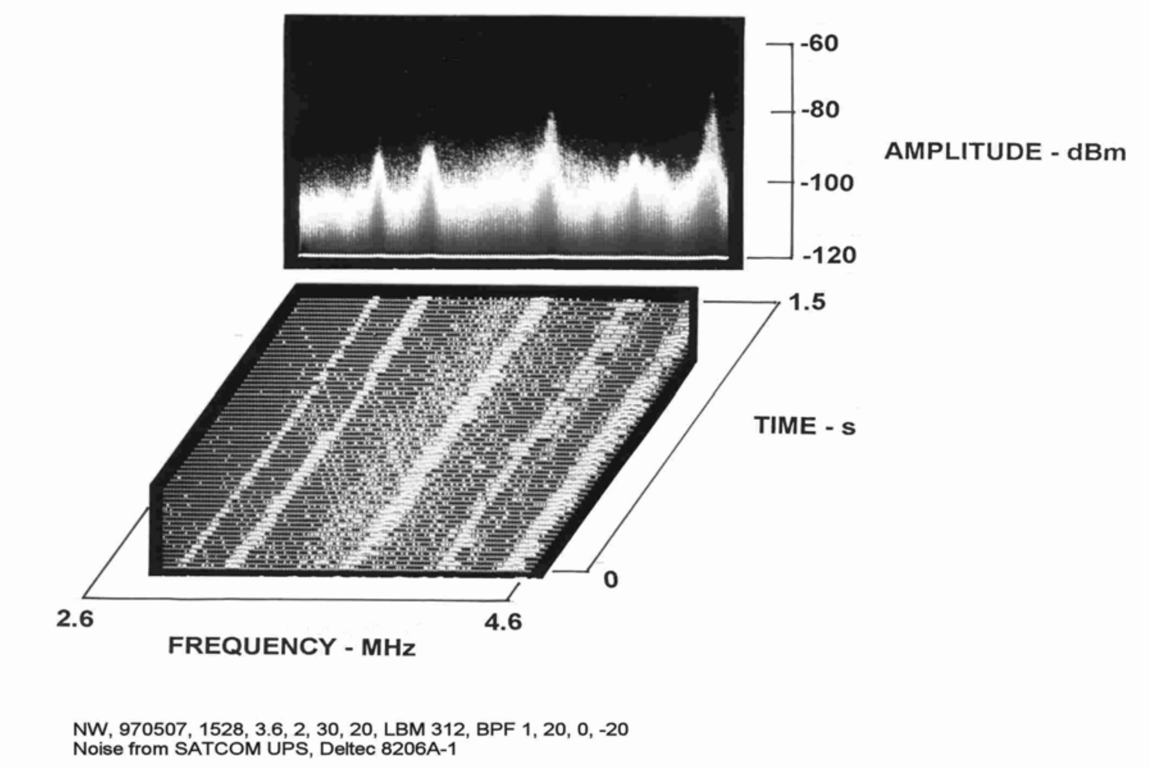
K6GDI, 030621, 1043, 7, 2, 100, 500, 80 m DIPOLE, F 2-8, , 20, 0, -20

Figure 25 Solar Converter Noise at the 40-Meter Amateur Band

2.5.4 Uninterruptible Power Supply

Some radio-receiving sites are located close to other facilities. In one case a satellite communications terminal was located about 1 km from an HF and VHF receiving site. The satellite terminal was equipped with an Uninterruptible Power Supply (UPS) to allow it to continue operation during short-duration power outages. The site was also equipped with diesel-powered generators for longer periods of power failures.

When the satellite terminal was placed into operation, a new radio noise source appeared at the HF site. Figure 26 shows the temporal and spectral properties of the new interference that was traced to the UPS in the satellite terminal. The slanting lines represent impulses from the switching process of the power-conversion devices in the UPS. The UPS noise made it impossible to receive the low-level ambient signals that are also shown in the example.



NW, 970507, 1528, 3.6, 2, 30, 20, LBM 312, BPF 1, 20, 0, -20
Noise from SATCOM UPS, Deltec 8206A-1

Figure 26 Interference from a UPS Located 1-km from a Receiving Site

An additional and even more potent noise source affecting other parts of the HF spectrum was also traced to the new satellite communications facility. In this case the noise was traced to a second power-conversion device that was used to control the field current in the diesel-powered generators. Neither the UPS nor the power-conversion device caused harmful interference at the microwave frequencies used by the satellite terminal, but they did cause harmful levels of interference to the nearby, but separate, HF site.

2.6 Other External Sources

2.6.1 General Comments

A noise investigator will encounter a number of additional sources of noise external to a receiving site in addition to those associated with hardware on power lines or from power-control devices. Knowledge of other sources and the temporal and spectral properties of their noise are essential to avoid the high cost and excessive time of false location, identification, and mitigation efforts.

2.6.2 Ignition Noise

In past years ignition noise from automobiles and trucks with gasoline engines was a prominent problem. In some cases the use of automobiles was restricted near antennas and other special precautions were taken to avoid ignition-noise problems. These precautions often included special equipment to monitor ignition-noise levels of automobiles as they approached a site. Quiet vehicles were allowed access to a site, but noisy vehicles were denied access.

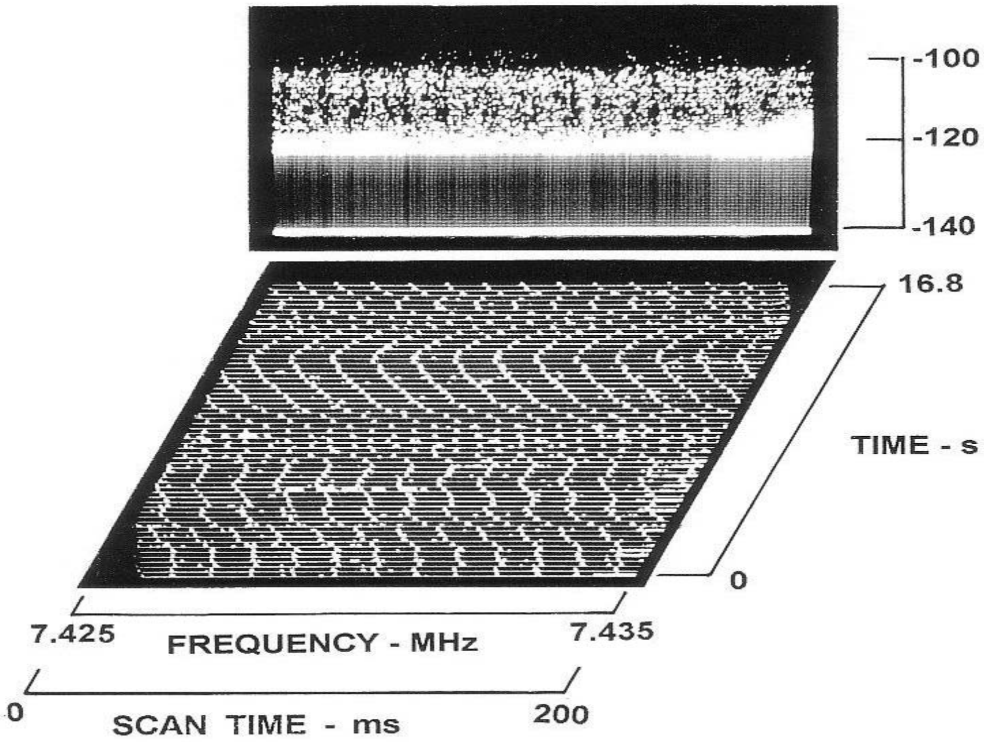
With recent improvements in the design of ignition systems for gasoline motors and the compliance of automobile manufacturers with modern radio-noise standards, vehicular radio noise has almost, but not quite, been eliminated. Modern automobiles can usually be operated close to the antennas of a receiving site with very little or no problem. Only older automobiles and trucks, those with modified ignition systems, those with faulty ignition systems, motorcycles, and other small vehicles are now of concern. Fortunately, the population of such vehicles is low, and only minimal effort is required to identify noisy vehicles and restrict their use near a receiving site.

In addition, special gasoline-powered vehicles and other devices exist that radiate excessive ignition noise, and they are sometimes used in the vicinity of receiving sites. Devices such as weed whackers, lawn mowers, small utility vehicles, gasoline-powered electric generators, diesel-powered electric generators using electronic power control and power conversion, and other similar equipment are often major sources of radio noise. Such vehicles and devices are not required to meet the noise limits imposed on automobile and truck manufacturers. Their use at and near receiving sites must be strictly controlled.

Older diesel-powered vehicles were exceptionally noise quiet, but modern diesel engines have electronic powered injection and fuel-control systems. The current impulses on conductors in these systems result in excessive noise levels similar to ignition noise, and most of today’s diesel-powered vehicles are unsuited for use in and around radio receiving sites.

Yet one more source of radio noise can be traced to modern devices. Most late model portable electric generators (either gasoline or diesel powered) provide direct-current electrical power. Power-conversion devices are used to convert the electric power into 50-Hz or 60-Hz alternating power at 120/240-V or other desired voltages. Impulsive noise from such generators renders them unsuitable for use on and around radio receiving sites unless they are especially modified to reduce impulsive noise to harmless levels.

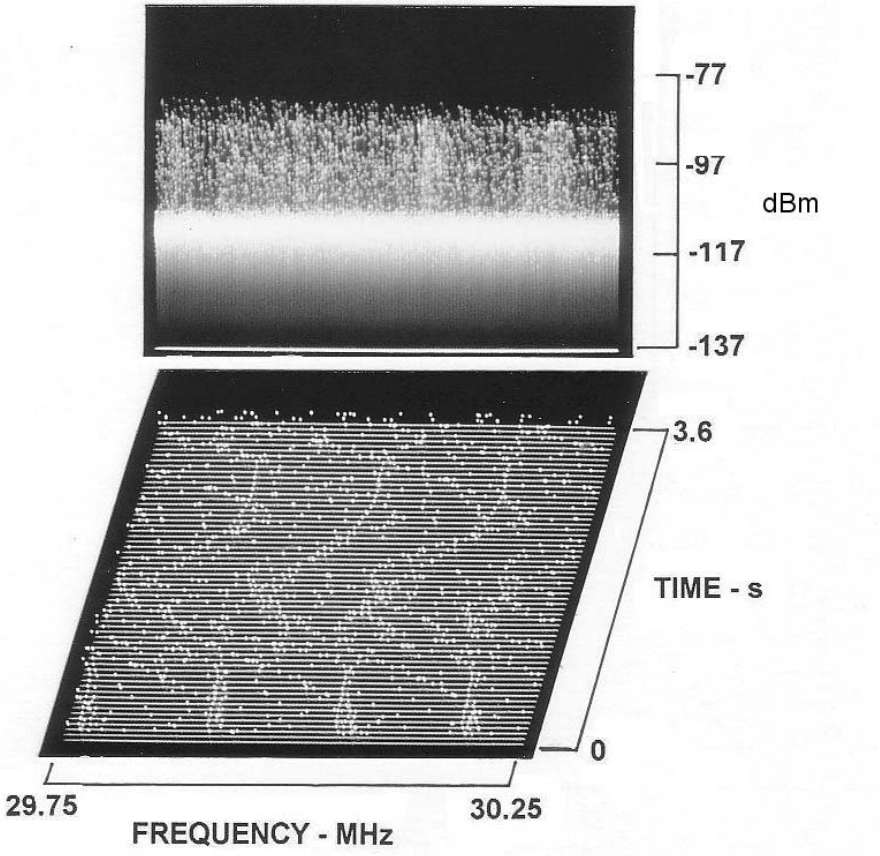
Figure 27 shows an example of ignition noise observed at a receiving site. The curved pattern of the noise impulses is caused by the changing rotation rate of the engine. The time between impulses from the ignition system changed with the engine rotation rate. The variable timing of the impulses interacted with the slower (but constant) scan time of the spectrum analyzer used to receive the noise. The source of this example was a single-cylinder motorcycle.



EDZ, PASTE UP, 920513, 1522, 7.45, 0.01, 1, 200(LS), CM, F 2, 20, 0, -40

Figure 27 Temporal Structure of Ignition Noise

Figure 28 shows the fine-scale temporal structure of radio noise from the small gasoline engines of multiple weed whackers. The weed whackers were trimming grass and weeds around the antennas of a receiving site, and they induced impulsive noise into the ground plane of the receiving antenna. The smoothly changing pattern of the impulses from the more prominent sources can be seen in the time-history view. Normal receiving tasks could not be accomplished at this site while gardening work was underway.



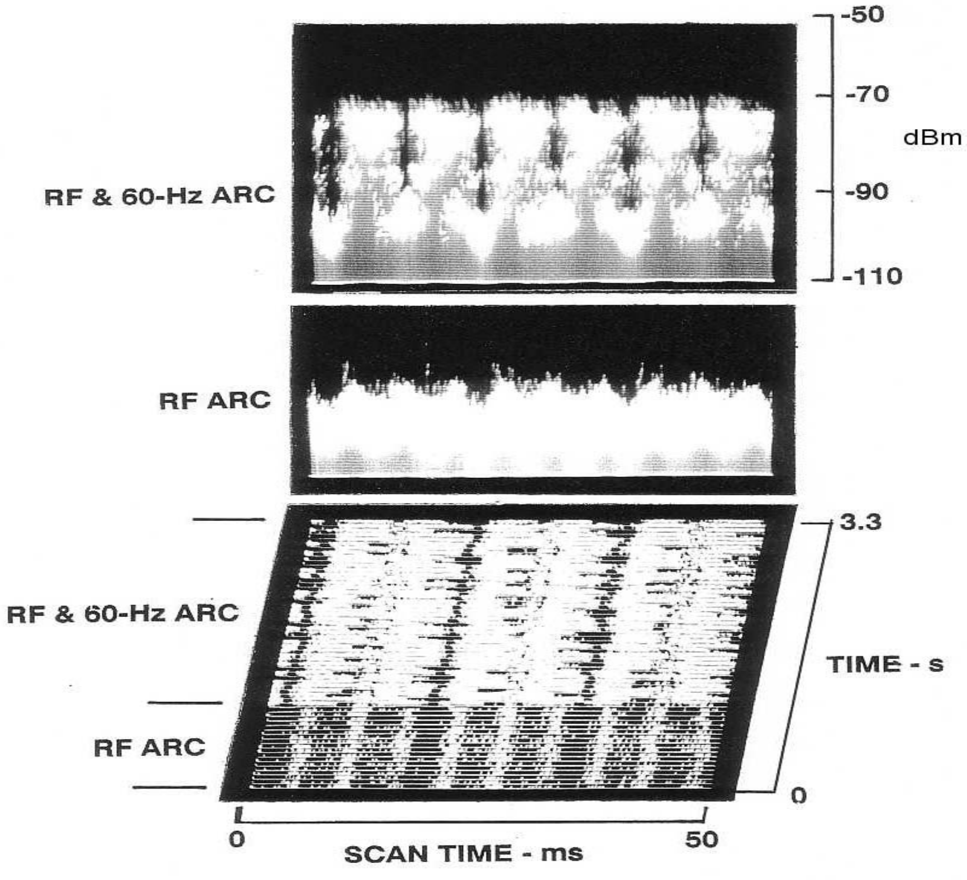
HAN, PASTE UP, 950808, 0940, 30, 5, 30, 50, HBM 96, PS(-3), HPF 25, 20, 0, -40

Figure 28 Temporal Structure of Noise from Multiple Weed Whackers

2.6.3 RF Stabilized Arc Welders

RF stabilized arc welders use radio-frequency power in the medium-frequency band to establish an arc, but the RF arc produced by the medium-frequency does not penetrate metal sufficiently for welding. RF-Stabilizers start an arc with a radio-frequency and then apply alternating current to the arc at the power-line frequency in parallel with the radio frequency. The combined arc from both radio-frequency and 60-Hz power is very stable and penetrates metal sufficiently for welding. Such arcs are widely used to weld Aluminum and other metals. Unfortunately, these devices feed harmonics of radio-frequency and the power-line frequency along with intermodulation products of both frequencies onto the electric-power wiring of a facility and onto overhead power lines supplying electric power to the facility.

Figure 29 shows an example of severe radio noise from an RF-stabilized welder recorded at a receiving site. The RF stabilized welder facility (making aluminum fishing boats) was more than 11 km from the receiving site.



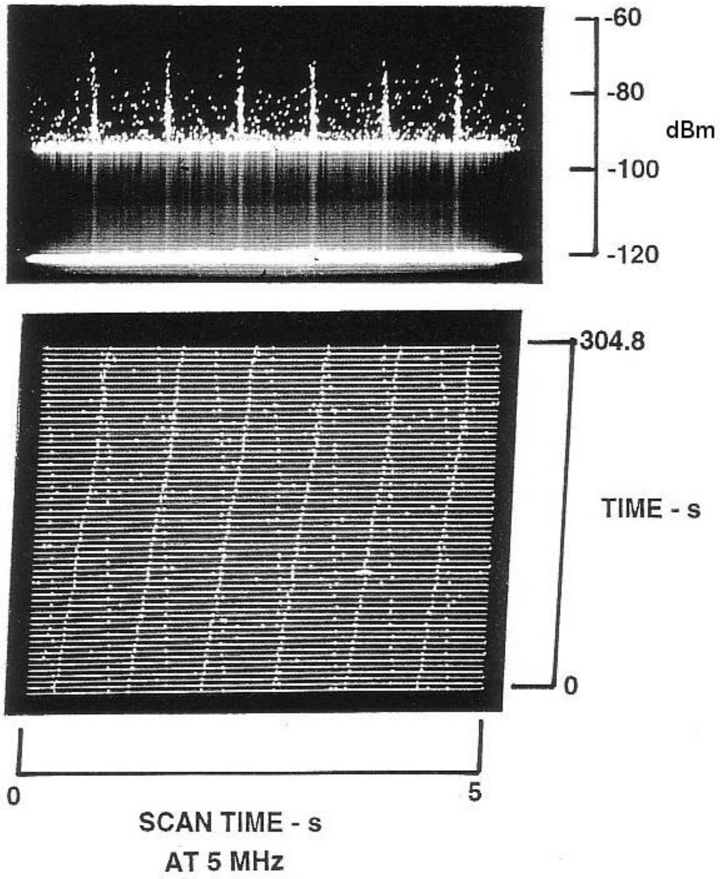
SI, PASTE UP, 830609, 1430, 2.5, 0, 30, 50(LS), LBM 312, NF, 0, 0, -30

Figure 29 Noise from an Industrial RF Stabilized Welder

2.6.4 Electric Fences

Electric fences are often used in the rural areas surrounding receiving sites. Some electric-fence controllers inject significant levels of pulse voltage and current into the fence conductors, and the electrically long fence wires are efficient radiators of broadband impulsive noise.

Figure 30 shows an example of pulses from two fences as received at a receiving site. In this case the noise was received on a 20-ft length of television mast material that was used for a test antenna at a receiving site. The noise peaks, spaced roughly 1-second apart, produced very strong impulses in the receiver. The fences were more than 1 km from the receiving site.



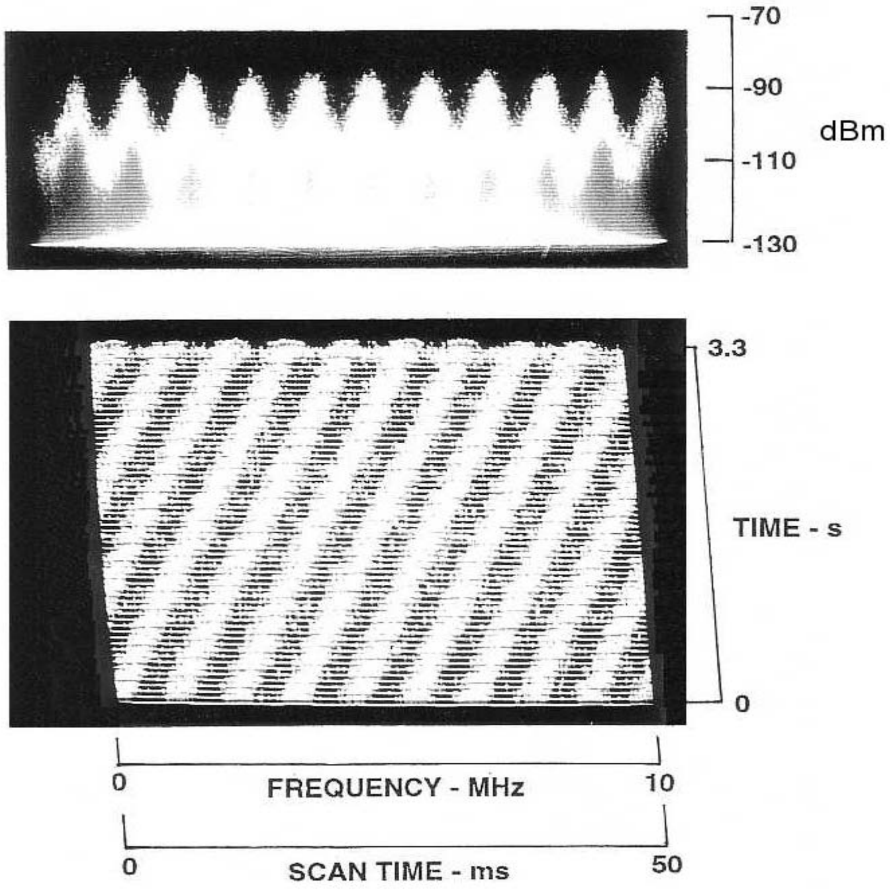
EDZ, 910911, 1530, 5, 0, 10, 5000, 20-FT PIPE, BPF 2-8, 20, -20, -20

Figure 30 Noise from Two Electric Fences

2.6.5 Corona Noise

Corona noise is sometimes observed at a receiving site. It is not included in the earlier descriptions of noise from primary sources because corona noise sources exist only on transmission lines operating at high voltages (typically from 69 to as high as 750 kV and in some special cases up to 1 MV). The lower voltage levels used on distribution lines (from 1.2 to about 35 kV) will not support the air breakdown process of corona-noise sources.

Figure 31 shows the temporal structure of corona noise. Each burst contains a vast number of overlapping impulses where the amplitude of each individual impulse is a function of the line voltage. The rounded shape of each noise burst is typical for corona noise. In this example, the scan process of the analyzer was not synchronized to the power-line frequency, thus slanting lines were formed in the time-history view.



SI, 910814, 1535, 5, 10, 10, 50, 3m, NF, 20, 0, -40

Figure 31 Corona Noise

The source of the corona noise in Figure 31 was identified as the breakdown of air at very small and sharp metal protrusions that formed on the upper side of the arm of a high voltage switch in a substation operating at 135,000 volts. The substation was located about 2 km from the receiving site. When these small protrusions were removed the corona noise disappeared.

2.6.6 Broadband over Power Lines

Recently radio amateurs and other organizations have experienced severe radio-noise problems from Broadband over Power Lines (BPL). The authors of this document have not encountered noise from BPL at the many radio receiving sites where extensive noise measurements were made (more than 45 sites worldwide). This is because BPL was not used on overhead-power lines within line of sight of any of the sites at the time of the visits.

Since the receiving sites of concern are designed to detect and receive very weak signals operating with a variety of modulation formats, available evidence clearly indicates BPL will be a major source of radio noise and radio interference if implemented on power lines within line of sight of a radio receiving site. Serious degradation in signal detection and signal reception is expected if BPL is used on power lines within line of sight of a receiving site.

Of special concern is that BPL operates in an environment which contains nonlinear equipment, devices, and contacts. This enhances the possibility of the production of harmonics, intermodulation products, and intermodulation noise at higher and lower frequencies than used by BPL. While such spectral components may be low in amplitude compared to the normal interference experienced by BPL and some receiving sites, such interference can be of significant concern to more specialized receiving sites.

<u>This major new source of radio noise and interference needs to be carefully examined by site planners, site managers, and site operators as well as by organizations managing the radio spectrum</u>. Means to prohibit the use of BPL at or near present or possible future radio-receiving sites must be implemented, and a means to deal with any existing BPL system already installed at or near a radio-receiving site needs to be implemented.

3. Step 2—EXAMPLES OF SOURCE DEVICES

3.1 Power-Line Sources

3.1.1 General Information

A detailed knowledge of power-line hardware and noise-production mechanisms on distribution and transmission lines is essential to locate, identify, and mitigate sources of radio noise on power lines. This is a difficult and time-consuming process for a number of reasons. Power-line hardware is considerably different from that normally encountered in receiving sites, thus personnel at such sites will not be familiar with the hardware or noise sources. Also, the hardware varies from country to country, electric utility to electric utility, and even within the territory served by an electric utility. Electric-utility linemen and radio-noise specialists go through several years of apprenticeship training to become acquainted with the vast variety of hardware, line-construction standards, line-construction procedures, noise-generation mechanisms, and safety procedures before they are considered proficient in power-line maintenance and radio-noise mitigation. This kind of experience cannot be obtained from this handbook. This handbook is only an aid in the process of gaining the required experience.

The prior section has indicated that two basic sources exist on electric-utility distribution lines. These are microsparking from the breakdown of very thin layers of insulation oxide found on the surface of metal hardware, and sparking from the breakdown of air between two pieces of metal or from one charged object to another charged object. In microsparking, the spark is very small (as small as 0.002 cm) and generally invisible. Sparking sources can be as short as a fraction of a cm or up to about 2-cm long. The common characteristic of these two mechanisms is a step-function in current flow which generates almost infinite spectral components. These two mechanisms can be associated with a variety of hardware on distribution lines. A third source, corona noise, occurs from the breakdown of air around a conductor, and it is found only on transmission lines.

Table 1 lists the most common items of hardware on electric-utility distribution lines that have caused harmful noise at radio receiving sites. Only six sources appear on this short list.

Table 1 Most Common Sources

Source Hardware	Rating
Bell Insulators	1
Loose Hardware	2
Lightning Arrester	3
Insulated tie wires on either bare or insulated conductors and bare tie wires on insulated conductors	3
Arcing between inadequately spaced and unbonded metal components	3
Improperly assembled transitions between overhead conductors and underground cables	3

A number of less-common sources have been encountered during noise-mitigation work at receiving sites and during other source-identification tasks. Table 2 lists these sources.

Table 2 Other Sources

Sources
Loose crossarm brace
Loose crossarm bolts
Loose transformer bolts
Loose insulator on a pin bolt
Loose insulator bolt on a cross arm
Loose staples on a bond or ground wire
Bond or ground wire too close to hardware
Loose tie wire
Bad connection on a primary or secondary conductor
Less than 1½ inch spacing between hardware not bonded together
Loose saddle clamp on insulator
Carbonized rubber saddle pad with a pin or post insulator
Broken or flashed insulator
Failure of transformer insulator
Twisted wire connections
Loose split bolts
Loose aluminum conductor connections
Insulated tie wire on insulated conductor
Broken bond or ground wire
Tree branches touching primary guy wire above Johnny Ball
Tree branches touching primary conductor
Slack or broken guy wire
Guy wire touching another guy wire
Guy wire touching a metal object
Guy wire touching telephone, CATV, or TV cable
Guy wire touching telephone, CATV, or TV cable messenger wire
Loose switch contacts
Loose switch mounting bolts
Loose fuse contact between fuse and fuse holder

* The authors of this handbook are grateful for the help of several utility radio noise specialists in compiling this list of sources. We are especially thankful for the help of Mr. Wally Hanifin (now retired) of the Pacific Gas and Electric Company.

Of interest is that some hardware items often thought to be common sources are not on the two lists. Examples are aging of hardware, corrosion, and dirty insulators. None have been identified as sources on distribution lines during the field work associated with this handbook.

3.1.2 Bell Insulator

Many sources of radio noise have been traced to the bell insulator. Figure 32 shows a two-section bell insulator used on distribution lines. Single, dual, and triple bells are commonly used on distribution lines operating at 10- to 40-kV phase-to-phase or phase-to-ground potentials. Single bells are commonly used on lines operating at voltages of 13 kV or less.

Figure 32 Bell Insulator

The bell insulator is rugged, has a long life (typically 40 years or longer), does not significantly deteriorate with exposure and age, retains its insulation properties with age, normally tolerates flashovers from lightning, and is inexpensive. These desirable properties have made the bell insulator a popular item with many utilities and public works departments. Yet, the bell insulator has gradually been recognized as a major source of radio noise. Because of this, some utilities are now using other types of insulators to replace bells.

About 1 out of 100 bell insulators is a source of radio noise at a radio-receiving site. The reasons why one particular bell insulator becomes a source of noise are obscure and not well understood. Visual inspection seldom reveals a flaw or any other reason why one bell generates noise and many others do not.

The particular bell insulator shown in Figure 32 was removed from service because of lightning damage. A long burn mark is visible on the metal portion of the left section along with a short streak on the left rib of the left porcelain insulator. Another short streak is visible on the first rib of the porcelain at the right end of the bell. In addition, the clevis on the right end of the insulator shows burn damage around its hole. These visible marks on the insulator were caused by a flashover from a direct lightning strike. Apparently the flashover jumped over the center of the insulator.

The burn marks did not result in radio noise, and thus were of no concern to noise-mitigation personnel or to the operation of a nearby radio-receiving site. The decision to replace such a bell, if it is not a source of noise, should be left to personnel of the electric-utility or public-works organization operating the line.

The primary source of bell-insulator noise has been traced to the electrical breakdown of a thin layer of oxide that forms on the surface of the metal parts of the insulator. The breakdown process is complex and has been extensively investigated by Beaseley[2]. The oxide-layer breakdown can occur at any of several locations on the bell. The locations are the clevis-pin joining connecting the sections of a bell, the end connection to the supporting pole, and the connection to the line conductor.

To better understand the noise-generation mechanism, an equivalent electrical circuit of a two-section bell has been developed. Figure 33 shows a sketch of a bell and the equivalent circuit. Each component of the equivalent circuit is located immediately below the corresponding part of the insulator.

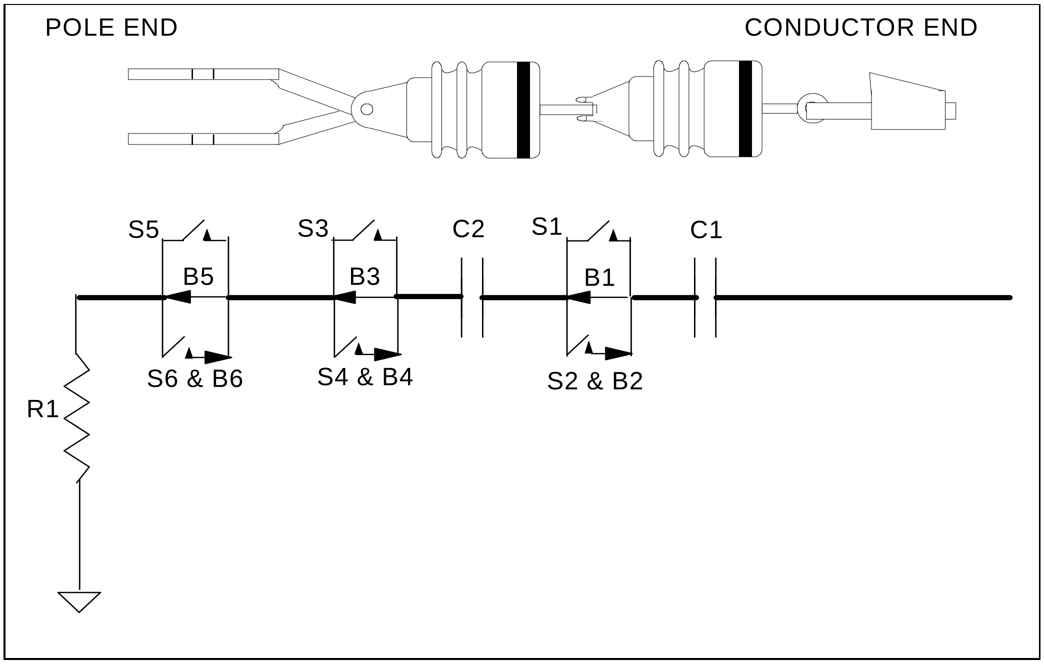


Figure 33 Circuit Diagram of a Bell Insulator

The equivalent circuit can be modified to fit a one-, two-, or three-section bell insulator. A two-section bell was chosen for the example since it is the most common configuration found on distribution lines. C1 is the capacitance across the ceramic, or glass, insulation of the section near the hot line. This capacitance is considerably larger for a bell type than other types of insulators because of its internal construction. The metal line-attachment component extends inside the ceramic or glass insulation material and inside the metal component of the opposite side. The two metal components and the high dielectric constant of the insulation material

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[2] William L. Beaseley, An investigation of the Radiated Signals Produced by Small Sparks on Power Lines, Ph.D. dissertation, Texas A&M University, January 1970

produce the relatively high capacitance across each section of a bell insulator, and this capacitance is one of the factors involved in noise generation. Typical values of capacitance across a section of a bell insulator range from about 35 to 45 pf. This capacitance is sufficient to provide significant capacitive transfer of electric charge from the hot line to right side of the insulator that is opposite in phase to the potential of the line.

S1 is closed if the clevis pin between the two sections provides a conducting connection. When S1 is closed, that portion of the bell will not generate radio noise. It is open when the two sections of the insulator are separated by a thin layer of insulating oxide.

If S1 is open, then B1, S2, and B2 must be considered. B1 is shown as an arrow pointing left. This represents the insulating oxide layer between the two metal portions of a bell insulator. A charge transfer occurs in one direction across the thin layer of oxide when the oxide breaks down. The arrow indicates the transfer of charge during the positive portion of the line-voltage waveform. A potential of about 800 to 900 volts across the insulating oxide layer will cause it to break down.

If S1 is open, S2 may be open or closed. If S2 is open, a potential cannot be induced across B2 on the negative portion of the line-voltage waveform. If S2 is closed, then the insulating layer, B2, can break down on the negative half of the line-voltage waveform. This produces a second set of breakdowns, separated in time from the positive set by one half the period of the line-voltage waveform.

The charge transfer across B1 and B2 produces a brief pulse of current with a magnitude of about 7 to 9 amperes. This burst of current equalizes the potential on each side of S1 which terminates the oxide breakdown and the flow of current. The charge may then build up and repeat itself for one to twelve more times during each positive portion of the voltage waveform and also for the negative portion of the voltage waveform when S2 is closed.

If S1 is closed by a good electrical connection at the interconnecting clevis pin, the potential appears at the left side of the second bell section. This results in a transfer of charge through C2. If S3 is open, the potential difference appears across oxide layer B3. It can break down in manner similar to the process described for B1. If S4 is closed, another breakdown can occur at the opposite portion of the line-voltage waveform and produce a second set of impulses.

If both S1 and S3 are closed, a potential appears across the oxide layer on the clevis-pin joint on the insulator-to-post support hardware. A similar breakdown process can then take place at B5 and B6. The transfer of charge across C1 and C2 will result in a micro spark at B5 and B6 only if the pole-to-ground resistance is very high.

All of the oxide layer breakdown conditions and locations described have been identified during power-line noise-mitigation efforts. Since the insulating oxide layer is only about 0.001 to 0.01 inch thick, the breakdown process cannot be considered an arc or even a spark. It is called a *micro spark* in this document. The charge transfer process across the B elements is similar to the reverse breakdown process in a diode, commonly called a charge avalanche process.

Still another factor must be considered in the bell-insulator noise-mechanism process. An overhead distribution line is an excellent receiving antenna. Electric potentials (and current) are induced onto overhead lines from a number of sources, and these potentials ride on top of the normal line voltage. Such sources are:

- Radio signals from nearby transmitters
- Transients from lightning
- Transients and noise from customer sources
- Transients from customer and utility switching operations

All such sources add voltage to the normal line potential. Their sum can start, alter, change, and aggravate the operation of a microspark source in a bell insulator.

Furthermore, weather conditions can alter the operation of a microspark type of source. High humidity can cause one of all of the switches to close and terminate the operation of a source. Wind can alter the physical shape of any or all of the switches and alter the operation of a source.

At one time, it was believed that bells at the ends of short slack spans of conductors were more susceptible to microsparking than those at the ends of long tight spans. Field measurements have shown that this is not a reliable indicator of a source of noise.

Figure 34 illustrated the relationship between the line voltage waveform and the temporal structure of a typical microspark breakdown process.

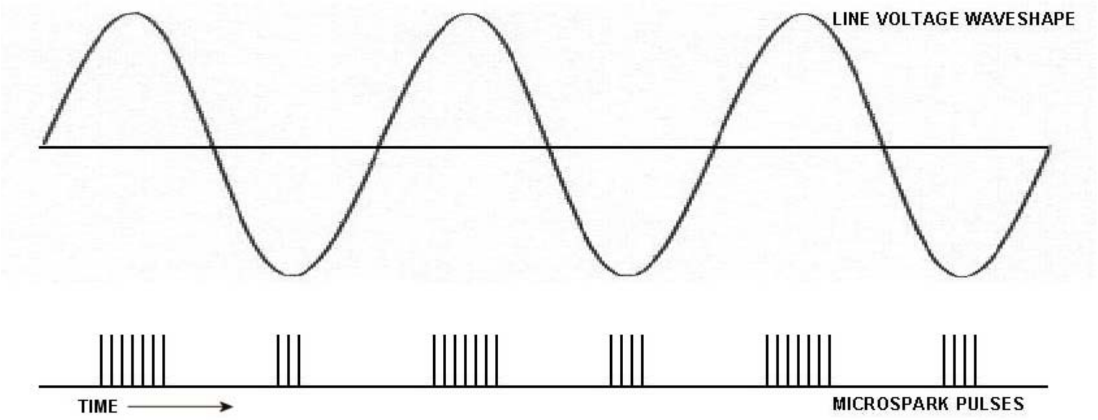

Figure 34 Sketch of Microspark Breakdown Process

The following steps summarize the multiple breakdown process of a microsparking source.

1. As the line voltage increases, the breakdown threshold of the thin layer of oxide is reached.
2. A large avalanche of current flows across the thin layer of oxide (7 to 9 A).
3. The potential across the oxide layer is equalized and the current flow stops. The breakdown is extinguished after a few microseconds of time.

4. The potential across the layer of oxide again increases to the breakdown point and another surge of current is generated. Each surge is equal in amplitude.
5. This process continues until the line voltage decreases to the point where it can no longer support the breakdown process.
6. This process is often, but not always, repeated on the opposite polarity of the line-voltage waveform. Sometimes it is repeated with different pulse patterns.

This process usually generates multiple microsparks during each voltage maximum. Each group contains about 1 to about 12 impulses. If only half of the voltage waveform produces a breakdown, the time interval between groups of impulses will be 16.6 ms for a 60-Hz power line and 20 ms for a 50-Hz power line. If the positive and negative portions of the line-voltage waveform both produce breakdowns of the layer of oxide, the time interval between groups of impulses will be 8.3 ms for a 60-Hz line and 10 ms for a 50-Hz power line. Each impulse causes a nearly equal impulse current to flow since the breakdown process is the same for all impulses. If the mechanism is very stable, the variation in pulse-to-pulse spacing with respect to voltage will be visible in the time-history view of the temporal structure of a succession of groups.

Still another factor must be considered to explain the full impact of radio noise from a microsparking source on a bell insulator. The impulse generated by each breakdown of the oxide layer is capacitively coupled onto the overhead power-line conductor by the relatively low RF impedance of capacitors C1 and C2. Impulse currents of 7 to 9 amperes in magnitude are injected onto the overhead line. These impulses create a strong electromagnetic field which efficiently radiates outward from the overhead line.

The radiation pattern of an electrically-long distribution-line conductor contains many nulls and lobes in accordance with the normal long-wire antenna-radiation principles. Since impulse current flowing in the antenna is similar to the levels of antenna current generated by a low- to medium-power transmitter, the amplitude of noise collected by a distant receiving site will be similar to that from such a transmitter.

3.1.3 Tie Wires

Tie wires are widely used to attach conductors to post, pin, spool, and saddle insulators. Bare conductors and bare tie wires are commonly used on US distribution lines. Insulated conductors are often found on the distribution lines of other countries, and sometimes they are found on short sections of US distribution lines. Unfortunately, from a noise standpoint, insulated conductors are becoming more popular in congested areas where a configuration called “compact line construction” is used. This construction is a problem because of the high electric fields resulting from the close spacing of the conductors.

Both bare and insulated tie wires can be found on both bare and insulated conductors. Bare preformed tie wires on bare conductors rarely produce radio noise since the tie wires are firmly bonded to the line conductors. This prevents the tie wire from assuming a potential different from the line conductor. The use of bare preformed tie wires is the preferred method of attaching bare line conductors to post or pin insulators.

Insulated tie wires on either an insulated conductor or a bare conductor can become a significant source of radio noise, and such construction, while standard for many electric utilities, should be discouraged. A number of examples of this kind of construction and the noise-source mechanism are provided, and Figure 35 shows an example of an insulated tie-wire holding an insulated conductor to a pin insulator.

Figure 35 Insulated Tie Wire on an Insulated Conductor

Figure 36 shows example of a small gage insulated tie wire holding a bare conductor to a pin insulator.

Figure 36 Insulated Tie Wire on a Bare Conductor

The capacitance between the conductor and the tie wire shown in Figures 35 and 36 is about 30 to 50 pf. This is sufficient to charge the tie wire to a potential nearly equal to the line-to-ground potential but of the opposite polarity. While the insulation between the conductor and the tie wire will usually tolerate the normal potential difference, other factors must be considered. The insulation on both the tie wire and the conductor deteriorates with exposure and age. In addition, overhead conductors carry significant levels of radio signals, transients from utility switching actions, transients from customer operations, radio noise from customers, and transients from lightning and atmospheric electricity. These sources all have high-frequency components, up to tens of megahertz that add directly to the normal line potential. The normal potential difference between the conductor and the tie wire, along with the added potential provided by transients and other sources, is often sufficient to cause failure of the insulation on the conductor and tie wire. The insulation of even a new or replacement tie wire can quickly fail from the added potential difference caused by such sources; especially that from a nearby lightning strike. Once the insulation is penetrated with a spark and weakened, the normal potential difference between the line conductor and the tie wire is often sufficient to cause the breakdown process to continue.

The insulation breakdown typically occurs at sharp bends in the tie wires and at the end of the tie wires. The electric field between the line conductor and a tie wire is maximum at such locations. Once a breakdown occurs, the insulation properties are decreased, and a continuous sparking can take place between the two conductors. Each spark induces an impulse of current into the overhead conductors. These current impulses have high-frequency spectral components that radiate from the overhead lines.

The minimum length of the sparking path between the line conductor and the tie wire is the thickness of the insulation. Once started, the sparking path can expand in length and follow the path of damaged insulation. Tie wire sparking paths up to ½ inch in length, and sometimes longer, are common. Multiple failures on a single tie wire can occur. Figure 37 shows an example of the breakdown of an insulated tie wire. Severe deterioration of the insulation occurred from sparking.

Figure 37 Insulation Failure at a Bend in a Tie Wire

Figure 38 shows the deterioration of insulation from sparking at and near the end of a tie wire where the potential between the tie wire and the line conductor is high at the high-frequency spectral components of the sparking process. This is similar to the high potential that exists at the ends of a dipole antenna. Note that the insulation has been trimmed from the end of the tie wire by sparking as well as causing damage to the insulation at several places a few inches from the end of the tie wire.

Figure 38 Insulation Failure at the End of a Tie Wire

In addition to the above sparking problem, deteriorated tie-wire insulation can sometimes allow the tie-wire conductor to come into contact, or near contact, with the line conductor. If a layer of oxide forms between the tie-wire conductor and the line conductor, or a very small spacing exists between them, micro sparking can also occur. Both sparking and micro-sparking sources can exist on a damaged tie wire, sometimes simultaneously.

3.1.4 Lightning Arresters

A new lightning arrester seldom generates radio noise, however all lightning arresters, old and new, can be damaged by lightning or other severe line transients. When damaged, lightning arresters can be sources of severe radio noise.

Figure 39 shows a lightning-damaged arrester installed on one phase of a three-phase distribution line. The top of the arrester is connected to the line conductor and the bottom end at one time was connected to a ground wire. Note that the bottom connection to ground has been blown free from the arrester by lightning, a key indication that the internal components of the arrester probably have been damaged. The bottom connection of many arresters has been designed to separate from the body of the arrester as shown in the photograph. In addition the bottom connection of some arresters will purposely turn brown when damaged as shown in the photograph.

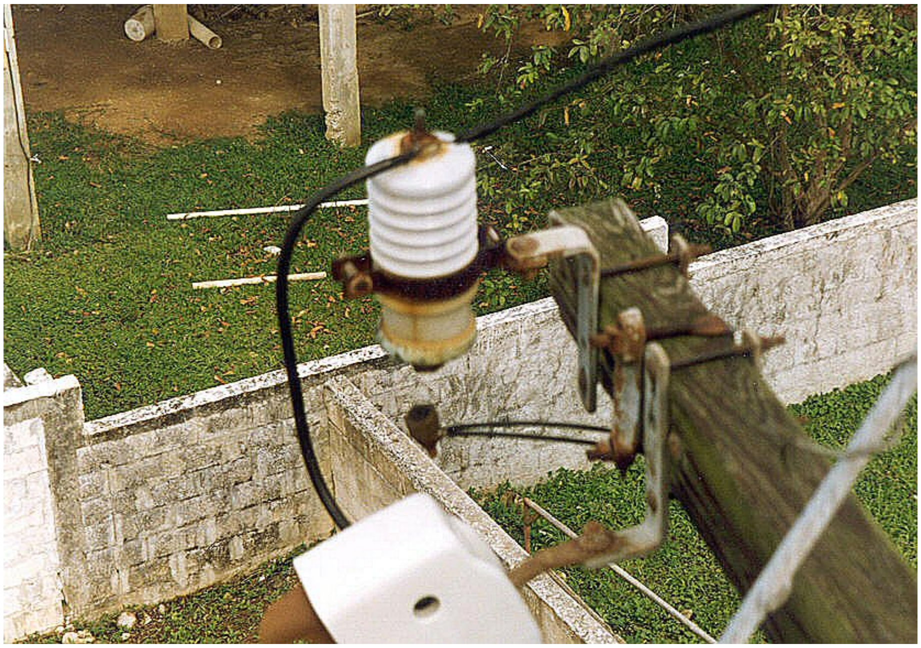

Figure 39 Example of a Damaged Lightning Arrester

The radio noise is caused by the failure of the insulating gap or semiconductor material inside the arrester. This results in micro sparking and sometimes sparking inside the arrester. A single spark source can occur inside an arrester or several microsparking sources can occur. Multiple sources of microsparks often produce groups of overlapping impulses during the maximum part of the line-voltage waveform.

Any lightning arrester with either indicator of damage should be immediately replaced or as a minimum be disconnected from the overhead-line conductor. It is a good practice to locate all lightning arresters within line of sight of the uppermost part of the antennas of a receiving site on a map and visually inspect each arrester after each severe lightning storm as well as check damaged arresters for radio noise.

3.1.5 Loose and Unbonded Hardware

Loose and unbonded hardware is often a source of radio noise. This includes a large number of potential sources including loose bolts, loose insulator-support pins, loose crossarm braces, inadequately separated conducting objects, loose staples on ground conductors, debris on the line, and leakage paths caused by insulation degradation or failure.

Sparking can occur between any two conducting objects located within the near-zone electric field of a line conductor or which can be excited by an electrical leakage path. Sparking between two adjacent pieces of metal can be avoided by maintaining a spacing of at least 1½ inches or more or by solidly bonding closer-spaced items.

Figure 40 shows an example of a hardware source. In this case an insulator support bolt protruded through the crossarm and touched the crossarm brace. During wet weather the bolt-to-crossarm spacing opened and caused a small gap to exist. Sparking across this gap caused severe radio noise to a receiving site located 2 km from the source.

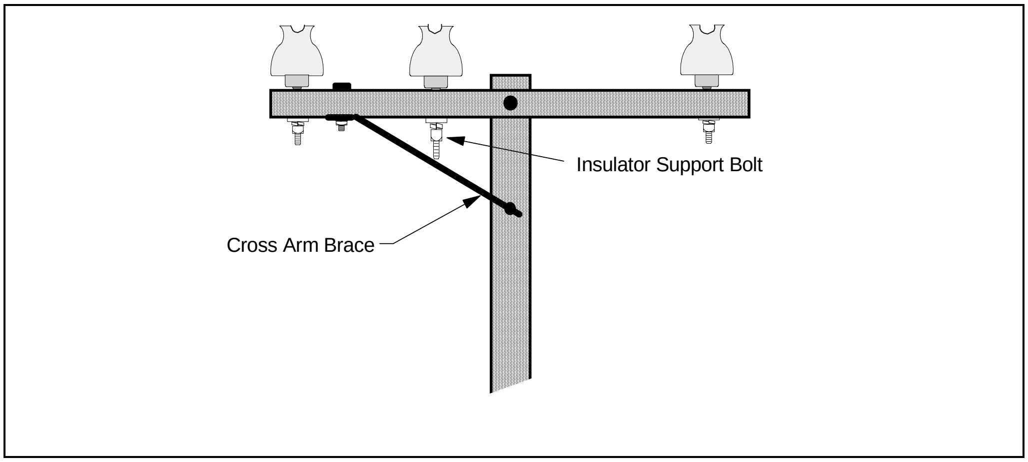

Figure 40 Hardware Source, Example 1

Figure 41 shows a source where a ground wire used to bond metal components together passed over the metal brace supporting a plastic crossarm. A small spark occurred between the ground wire and the brace. This induced noise current into the ground wire and other nearby objects. The length of the ground wire was sufficient to make it an efficient radiator of the noise.

Figure 41 Hardware Source, Example 2

Figure 42 shows still another example of a hardware source. A close inspection of the wood behind the insulator shows extensive cracking and dry rot. This loosened the support bolts and associated hardware, and allowed sparking and micro-sparking sources to form on the insulator support components. Occasional puffs of smoke were seen emanating from the cracks due to the conduction of carbonized wood.

Figure 42 Hardware Source, Example 3

Figure 43 shows still another example of a hardware source. In this case the line construction crew carelessly left a loose bolt in a hole on the end of a metal crossarm. Movement of the bolt from wind or pole movement caused an intermittent and erratic micro-sparking source to exist.

Figure 43 Hardware Source, Example 4

Debris can sometimes be found hanging on the conductors of a distribution line or from other nearby conductors. Such metal objects form intermittent contacts with a conductor whose electrical properties change with wind and moisture. A small layer of rust can develop between such an object and the line conductor which will break down from the difference in potential between the line and the debris. Such mechanisms generate highly erratic impulses of noise with noise bursts synchronous with the line frequency.

Figure 44 shows an example of debris found hanging on the conductor of a distribution line while trying to locate a highly intermittent and erratic source of noise at a receiving site. In this case, a child's swing seat was tossed onto the line by mischievous teen-age youngsters who were playing in the street.

Figure 44 Debris on a Distribution Line Conductor

Other kinds of debris can be very difficult to spot since the object can be a small piece of wire or other very small metal object. For example a small piece of wire or metal object can be blown onto an overhead conductor by wind, a piece of tie-wire can work its way along a conductor from line movement, or small pieces of debris can be flung up onto a line by a power mower. While most noise sources are associated with line-support hardware on a pole, debris can be found anywhere on or between line-support hardware, and is often found in mid-span, at the lowest point on a line conductor. In many cases the debris is very difficult to visually locate.

3.1.6 Spool Insulators

Spool insulators are occasionally found on distribution lines although they were designed for (are more often found on) lower-voltage secondary lines. Figure 45 shows an example of a spool insulator that was removed during the upgrading of a distribution line. The line conductor is supported by passing it through the spool at the right end of the insulator assembly. The left clevis is attached to pole hardware. Often an insulated conductor is used to increase the insulation protection of the line.

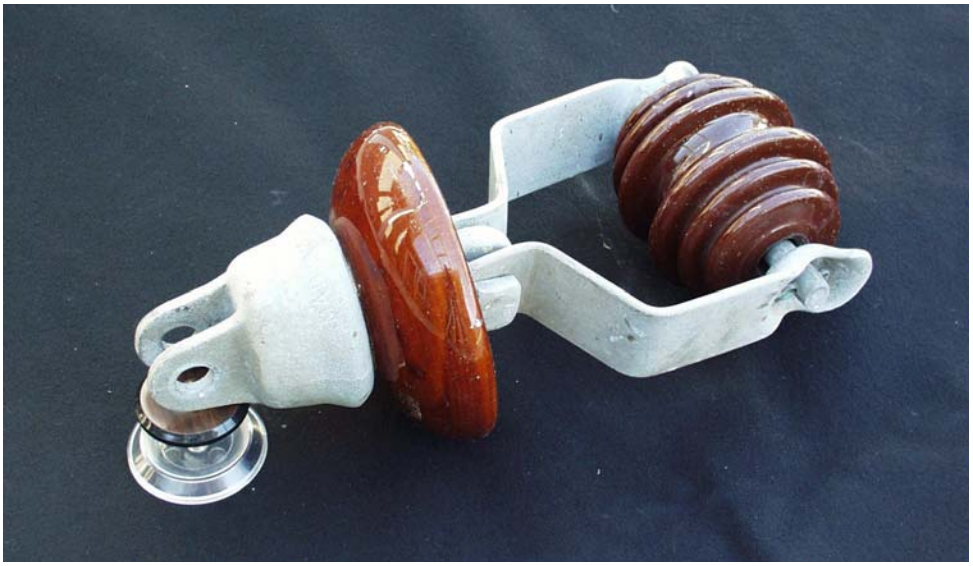

Figure 45 Spool Insulator

The spool insulator is often a source of radio noise for two reasons. First, the spacing between of the line conductor from the metal support parts of the insulator is minimal, and under some conditions this can result in sparking. Next, the capacitance between the line conductor and the metal support parts of the spool is sufficient to pass a charge through the spool and onto the insulated metal spool-support hardware. The capacitance across the single section of the bell on the spool is similar to that of a bell insulator. These two factors can result in microsparking at the metal-to-metal junctions of the insulator similar to that described earlier for the bell insulator. Furthermore if insulated conductors are used with a spool, the insulation can break down, resulting in sparking and microsparking sources similar to that generated by an insulated tie wire.

Lastly, insulated tie wires are sometimes used to attach bare or insulated line conductors onto the spool, and this can result in the tie-wire to conductor breakdown along with the resulting combinations of sparking and microsparking source mechanisms described earlier for tie wires.

Figure 46 shows a spool insulator used at the end of a short span of overhead conductor. The tie wire fastening the conductor to the spool is insulated. In addition, the conductor is wrapped with plastic insulation. This combination is especially prone to breakdown and the generation of sparking sources.

Figure 46 Spool with Insulated Tie Wire and Insulated Conductor

Several cases of the conductor slipping off a spool due to a loose tie wire have been noted. In such cases the conductor often comes in direct contact with the spool support metal, causing a metal-to-metal contact with the resulting erratic radio noise.

Because of the propensity of spool insulators to support one or more noise sources, their use on distribution lines is strongly discouraged. This is especially true of distribution lines located within line of sight of a receiving site.

3.1.7 Underground Distribution Lines

Underground electrical distribution is generally considered to be noise quiet, but there are notable exceptions. Some of these exceptions are described in this section.

Customer sources of noise can be conducted over a section of an underground distribution line and onto overhead lines, and radiation of the noise from the overhead portion of the distribution system can be encountered at a receiving site. The source will appear to be at the transition from the underground to the overhead line. Most cases of such noise will have a distinctive temporal structure that will provide considerable information about the type of source. Facilities obtaining their electric power from the underground portion of the distribution system must then be examined to locate and identify the source device. Often there will be sufficient radiation from a facility containing a source that it can be located by measurement from nearby roads and parking lots with the instrumentation used to locate poles with sources. In most cases, the facility containing the source will be located a short distance from the underground-to-overhead transition.

The insulation used on underground lines experiences high levels of dielectric stress, and failures in the insulation can occur. A sparking type of source from initial stages in the breakdown process can result in small local areas of noise emanating directly from the underground line. Fortunately, such noise rapidly attenuates along the underground line and only radiates harmful levels of noise from an overhead line if the source is close to an underground-to-overhead transition. The temporal structure of such a source usually starts with a single small spark and progresses to multiple overlapping sparks. Such sources should be reported to the electric utility operating the underground line since insulation breakdown eventually progresses to total failure.

The most prevalent sources of noise related to underground construction are the transitions from an underground cable to an overhead line, the transition of an underground line to the terminals of a surface-mounted transformer, and the transition from an underground cable to switch gear. It is sometimes difficult to distinguish such sources from those caused by a nearby cable insulation failure.

The metal enclosure housing a surface-mounted customer transformer or switch gear is normally grounded for safety considerations. In rare cases the ground connection can be broken. When this is the case, a sparking source inside the enclosure can induce surface currents on the outside of the enclosure. Radiation from the surface current can be a source of noise at a nearby receiving site.

Problems arising from underground construction peculiarities and transitions from underground to surface hardware are difficult to identify and resolve, and they will present the radio-noise investigator with great challenges in properly identifying the actual source mechanism and prescribing practical and effective mitigation actions. Only experienced utility or public works personnel should obtain access to, and work on, underground cables and the transition to surface hardware because of the specialized construction and the safety considerations involved.

3.2 Power-Conversion Sources

3.2.1 Background Information

Devices to convert electrical power from one form to another form have been used since the early days of the distribution of electricity, but the relatively recent development of solid-state switching devices capable of handling large currents and withstanding large potentials has greatly expanded applications for these devices. They are presently used to change alternating current to direct current, direct current to alternating current, 50- or 60-Hz current into variable-frequency current, and many other tasks. The switching process breaks the power into a series of short pulses of current and voltage. These short pulses (with steep rise and fall times) have spectral components that extend up into the HF and VHF frequencies and sometimes even higher into the UHF band.

The first through fourth editions of this handbook did not mention radio noise from power-control devices, because they simply were not a major source of radio noise affecting the operation of receiving sites. By the time the fifth edition was published, it was apparent that such devices were becoming a significant source of radio noise, and their numbers would increase over the next few years. Unfortunately, not enough information about the radio-interference aspects of power-control devices had been collected to fully document the extent of their radio-noise problem as the 5th edition was being prepared.

Every desktop and laptop computer uses a switching-power supply to convert the available electric supply into the various voltage levels required to operate the computer, but this is only one of a vast number of applications for solid-state switching devices. Fortunately, most of these devices are designed such that the transients produced by them are largely contained within the device. Unfortunately, some are not so designed and induce undesired electrical impulses into the power conductors of the building housing them and onto overhead power lines. Generally, it is impulsive current on the overhead power lines that is the radiation mechanism.

In the United States, the Federal Communications Commission sets limits on the amount of radio noise which switching devices and other electronic equipment can inject into the power conductors of a residence or an industrial facility. Part 15 of the FCC Rules[3] provides for two classes of protection from radio noise generated by such devices. Devices in the Class A category have limits intended to satisfy the needs of industrial facilities where significant amounts of radio noise can be tolerated. Devices in the Class B category have a stricter limit to meet the needs of residential areas where the density of radio and television receivers is high. All electronic devices marketed in the United States must be tested for compliance with the noise limits contained in the FCC Rules, and each item must have a label indicating it meets the requirements of its category.

Figure 47 shows an example of such a label for a Class A product intended for use by industry. The text on this notice clearly indicates the device might, and probably does, generate unacceptable amounts of radio noise for use in a residential area. The notice does not mention the possibility of radio noise at radio-receiving sites.

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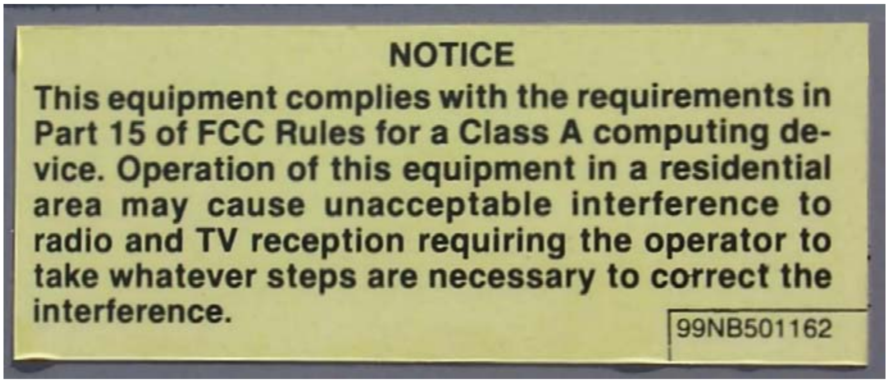
[3] Code of Federal Regulations, 47CFR Part 15, Radio Frequency Devices; Subpart B, Unintentional Radiators



NOTICE

This equipment complies with the requirements in Part 15 of FCC Rules for a Class A computing device. Operation of this equipment in a residential area may cause unacceptable interference to radio and TV reception requiring the operator to take whatever steps are necessary to correct the interference.

99NB501162

Figure 47 Radio-Interference Label from a Class A Electronic Device

Unfortunately, radio noise from a Class A device located in an industrial facility can be conducted along the facility wiring, through the meter, through a pole transformer, and onto overhead power lines providing electrical power to the facility. Overhead power lines carrying noise current efficiently radiate the noise which appears as radio interference to a nearby radio receiver. While the source of the noise is the power-conversion device, it is the conductors of an overhead power line that radiate the noise or sometimes other conductors in a building. Both the source and the conductors carrying noise current are part of the noise-source mechanism.

Radio noise originating from a number of power-conversion devices has been encountered during noise surveys at receiving sites. Among these are:

- Variable-speed controller providing power to a fractional horse power electric motor driving a pump at a hydroponics farm.
- Variable-speed controller providing power to a fractional horsepower electric motor driving a belt for sorting flowers.
- Variable-speed controller providing power to a fractional horsepower electric motor driving an exhaust fan at a ceramics furnace.
- Variable-speed controller providing power to an electric motor providing power to the air-circulating fan of a building.
- Variable-speed controller providing power to an electric motor used to drive a moving platform of a research water tank.
- Variable-current controller used to provide power to the field winding of a large electric generator located at a satellite communications facility.
- Uninterruptible power supply for a satellite receiving facility.
- Variable-frequency controller providing power to an electric motor at a water-pumping station.
- Controllers and power converters for residential solar power systems.

3.2.2 Examples of Power-Conversion Sources

Several examples of power-conversion devices are provided in this section. Each example produced harmful levels of radio noise at a receiving site. The examples show the diversity and variety of power-conversion devices and their applications.

Figure 48 shows the outside housing for the controller and motor of an air-conditioning system of a large radio-receiving facility. A radio-noise specialist is pointing at the Class A warning notice on the housing that clearly indicated this device was a likely source of radio noise. The controller injected high levels of noise current onto the outside surface of the housing, onto pipes leading to and from the housing, and onto the conduits providing power to the controller. Radio noise emanating from these conductors was intercepted by the site's antennas and fed to its receivers, resulting in severe interference to the reception of radio signals.

The variable-speed controller for the air-conditioning motor for this installation was intended for use in an industrial facility, and it was properly labeled for that type of use. The controller was improperly installed at an HF radio-receiving site where it caused severe radio interference as indicated by its warning label. This is a clear example of poor site engineering. Only devices approved for Class B residential use should be considered for installed at locations at or within line of sight of radio receiving sites. Noise measurements should be performed on selected examples, and low-noise devices selected for critical tasks.

Figure 48 Housing for Variable-Speed Motor Controller and Motor

Figure 49 shows another example of a source of radio interference at a receiving site from a power-conversion device. The photograph shows the controllers for two variable-speed electric-motors used to control the flow of water from a nearby storage tank into the local-area water-distribution system. Electric power enters the controller enclosure at the bottom. The motors are located directly below and behind the controller. Variable-frequency electric-power is provided to the motors by short conductors that also exit from the bottom of the enclosure.

Figure 49 Variable-Frequency Controllers for Two Electric Motors

Figure 50 shows the motors and the water-control valves associated with the controller in the previous figure. The motors are standard fractional horsepower induction motors that are widely used in many kinds of low- to modest-size variable-speed applications.

Figure 50 View of Variable-Speed Motors and their Loads

In this case the controller injected switching impulses onto the building wiring, the impulses were conducted to an outside pole transformer, passed through the transformer and onto the overhead distribution line conductors. Radiation from the overhead-line conductors caused radio noise at a receiving site located several km away.

Figure 51 shows the controller used to convert direct-current voltage from solar cells into alternating current at the frequency of the power provided by an electric utility. In this case the controller was used in a residence where solar-generated electricity was used to supplement power from the electric utility serving the area. High levels of switching impulses were injected onto the conductors running from the controller to the roof-mounted solar cells, and radiation from these conductors resulted in severe noise to a receiving site located more than a km from the source.

Figure 51 Solar Power Converter

The controller shown in Figure 51 did not contain a FCC Class A or B label. Because of this it was a unit improperly marketed in the United States. This particular model is no longer available, but it raises questions about similar units that are built with no consideration of man-made radio noise or of units built to FCC Class A specifications that find their way into residences. Several complaints of radio noise from such devices have been reported, and in most cases the resident had insufficient knowledge and background to understand the implications of the noise ratings.

Figure 52 shows a controller and three induction motors used to control the flow of enriched water to plants in a hydroponics farm located about 11 km from a receiving site. The controller is shown in the top view and the three motors it controls are shown in the bottom view.

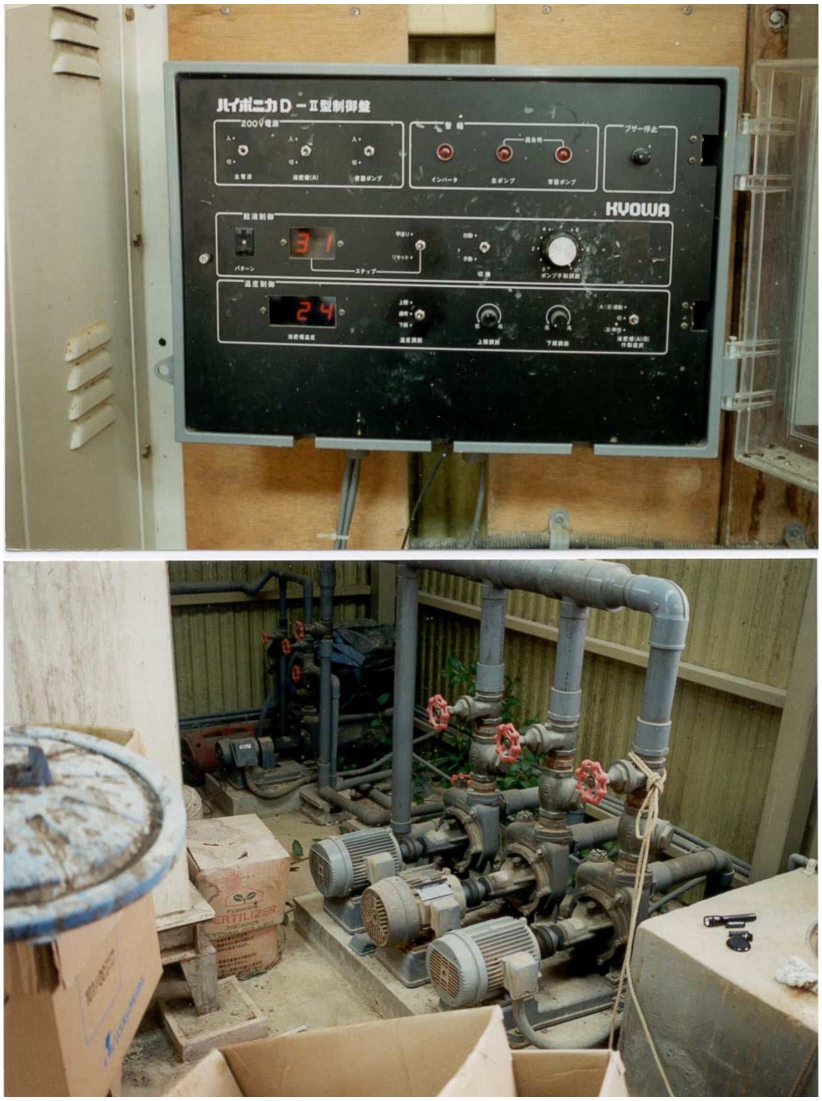


Figure 52 Motor Controller at a Hydroponics Farm

Figure 53 shows the external electric power feed into the building containing the hydroponics farm. The controller was located inside the building on the inside of the wall shown in photograph. The power drop was connected to an overhead pole transformer located about 30 meters from the building, and the overhead line feeding electric power to the transformer ran along the road in front of the building. Controller-generated radio noise radiated from the overhead distribution line.

Figure 53 Power Feed for Hydroponics Farm

Figure 54 shows the conveyor belt associated with a machine used to sort, process, and prepare flowers for shipment to sales outlets. The speed of the conveyor belt is controlled by a solid-state variable-speed motor controller. The enclosure housing the power-conversion electronics is the grey box under the belt and to the left of the seat of the motorcycle that was parked in the facility. The motor is located under the belt and is not visible in this photograph.

Figure 54 Photograph of Flower Processing Machine with Variable-Speed Drive

4. Step 3—Locate Sources

4.1 Power Line Sources

The location of sources on power lines must be done only by individuals trained in the hardware and safety aspects of working around overhead distribution lines. Carefully read the following warning and comply with all aspects of the warning.

WARNING

Individuals following the field procedures in this section are cautioned that electrical shock hazards, including possible electrocution, exist when working near and around power lines. All personnel working near power lines must use due caution and work under the supervision of trained personnel and be provided with the appropriate safety equipment. Inexperienced personnel should not attempt to work on or near power lines.

The procedures described herein do not require the attachment of instruments or probes directly on power lines. Furthermore the procedures in this document do not require that poles, guy wires, or other conducting objects be touched or moved. This includes striking poles with sledges, mallets and other objects. These and similar actions are specifically excluded as they are dangerous, and they do not produce useful results.

All field personnel and support personnel are cautioned that guy wires, switch handles, damaged ground wires, and other conducting objects may be at high potentials due to leakage, insulation failure, or reactive coupling effects. Stay clear of pole hardware and stand clear of line conductors during noise mitigation work. Be alert to possible mechanical failure, particularly on older lines.

WARNING

Most sources of power-line noise are associated with electrically small metal objects. Thus, direct radiation from the actual source hardware is usually insufficient to account for the reception of such sources at a receiving site; however such sources inject significant levels of noise current into overhead-line conductors, ground conductors, guy wires, and other nearby electrically-long conductors. Radiation of noise from these conductors, rather than direct radiation from the noise source, is a primary aspect of the power-line-noise problem.

Figure 55 shows a block diagram of the factors involved in the reception of power-line noise at a receiving site. Each block in the diagram has electrical characteristics that vary with frequency. A microspark or spark produces spectral components over a very wide portion of the radio spectrum; often up to 1-GHz. Usually the microspark or the spark is not directly connected to the overhead power-line conductors. The electrical properties and dimensions of conductors associated with the source and the capacitive and inductive coupling of the spark to nearby conductors along with the electrical dimensions of these conductors distort the spectral shape of the noise and result in peaks and nulls in its spectral shape. The electrically-long power-line conductors carrying and radiating noise also have significant impedance variations with frequency, and the lobes and nulls of their radiation patterns vary in direction and magnitude with frequency. The propagation path from the radiating power-line conductors to the receiving-site antenna often contain conducting objects such as buildings, trees, other overhead lines, and other conducting objects that introduce frequency-sensitive distortion to the noise. Finally, the lobes and nulls of the receiving-sites' antenna in the direction of a source also change with frequency. All of these factors have a significant impact on the fine-scale and the coarse scale spectral shape of broadband impulsive noise observed at the input terminals of a site's receiver as well as producing smaller changes in the temporal structure with frequency. While these factors complicate the job of precisely defining the spectral and temporal properties of noise observed at a receiving site and relating it to a source, an understanding of the general impact of the various factors on the temporal and spectral properties of noise is essential for the conduct of successful source-location work. The spectral shape of noise observed at a receiving site is much different than the spectral shape of noise observed at or near a source.

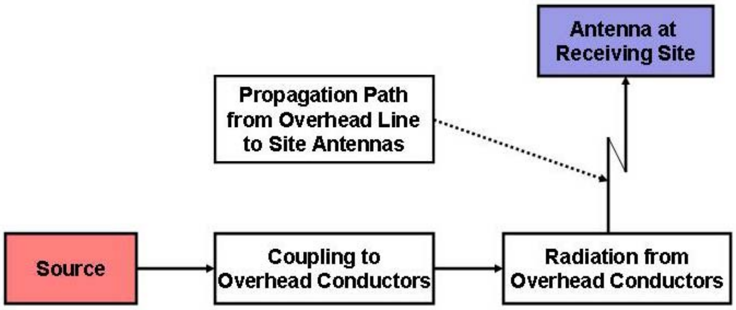
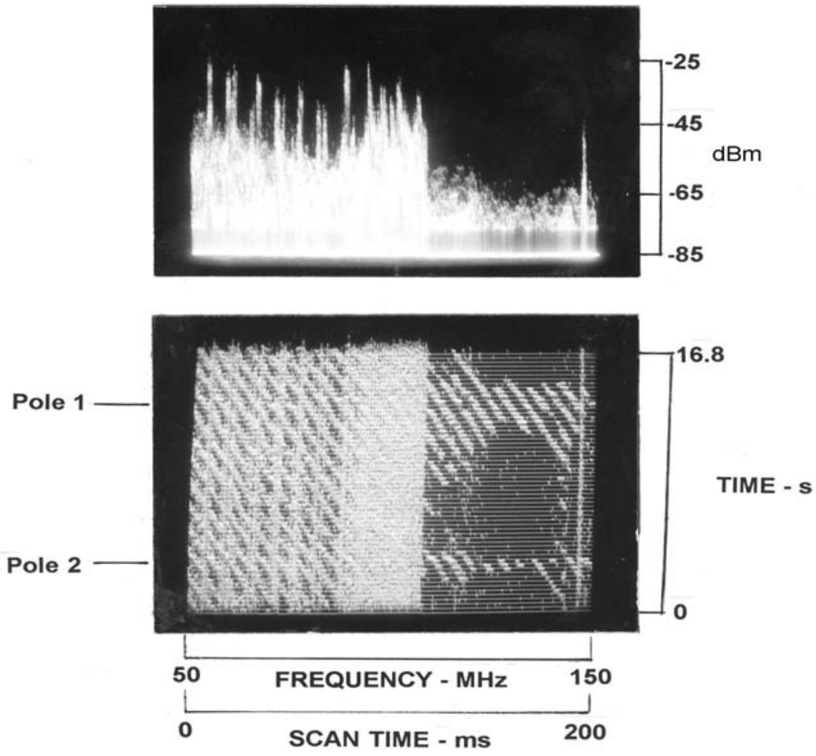


Figure 55 Block Diagram of Source-to-Victim Path

The source-location techniques described in this handbook are based on the distance noise current is conducted along a power line as frequency is varied, and the radiation of noise from these conductors. At low HF frequencies, noise current flows for relatively long distances along the overhead conductors of a power line. At high VHF and low UHF frequencies the amplitude of noise current on a power line decreases rapidly with distance from a source.

Figure 56 illustrates this effect. The time-history view shows noise exceeding a threshold level as a spectrum analyzer and its time-history display are moved along a power line at constant speed. The location of two poles, both containing sources, is shown on the left edge of the time-history view. The poles are about 30-meters apart. At low VHF frequencies (and also at HF frequencies not shown on this example) high levels of noise exist over the entire distance traveled, but at high VHF frequencies, noise is detectable only when near the pole. As a general rule, the higher the frequency the nearer one must be to a source for the noise to exceed a threshold. Thus a portable receiver with an AM detector, a relatively wide IF bandwidth, and a tunable frequency range from HF up to about 1000 MHz is a primary tool for source location.

The data shown in Figure 56 suggests that noise sources on distribution lines built along roads can be located simply by installing a HF/VHF/UHF receiver in an automobile and driving along the road. This indeed is a practical way of locating the general region of a source, but the excessive impulsive noise from the ignition systems of many gasoline-powered automobiles makes it difficult to locate similar impulsive noise from power-line sources. Modern diesel-powered vehicles often radiate excessive impulsive noise from their fuel injection and other digital systems. It is essential that source-location teams use radio-noise-quiet vehicles.



SI, 890119 1535, 100, 100, 100, 200, NF, 1 m, 15, 0, -10
Sears Point Road, Circle Bar Ranch

Figure 56 Variation in Spectral Content with Distance from Sources

Two battery-operated and portable receivers specifically designed for the investigation of radio noise from power lines have been developed for use by electric-utility personnel. They are the Models 240 and 242 MF/HF/VHF/UHF RFI Locators provided by Radar Engineers of Portland Oregon (radarengineers.com). The receivers can be used with a noise-quiet vehicle to search for sources on distribution lines that are located along roads. A 1-meter magnetic mount antenna on the roof of the vehicle can be used to receive noise. When the general region of a source is located, multiple passes with the receiver tuned to higher and higher frequencies may be necessary to pinpoint a source. Subsequent refinements in the final location on foot are often required to ensure that the correct pole or tower is located.

Figure 57 shows two photographs of the Model 240 RFI Locator during a source-location task. In the left view a small rod antenna is used while the receiver is carried along a power line. In the right view the receiver is used with a hand-held log-periodic antenna to determine the direction to a noise source. In both cases one must start at a frequency in the low VHF range and successively use higher frequencies to pinpoint the location of the source.

Figure 57 Source-Location Using the Model 240 or 242 Locator

The display incorporated into the Radar Engineers Models 240 and 242 receivers is highly useful during source-location work. Its presentation of the temporal structure of noise from a nearby source enables the external team to compare the structure and activity to that observed at a receiving site. Figure 58 shows an example of the temporal structure of a source under investigation at a receiving site. The signal-strength meter is shown below the display along with other controls.

Figure 58 Temporal Display on Model 240 Receiver

Other hand-held receivers with similar frequency coverage are available from suppliers of communications equipment. Examples are the models IC-R5, IC-R3, IC-R10, and IC-R20 from ICOM (see icomamerica.com), the model TH-G71A from Kenwood (see kenwood.net), and the model AR-8200 series from AOR U.S.A., Inc (see aorusa.com). While these are excellent communications and general-purpose receivers, their narrow IF bandwidths and lack of a display of the temporal structure of noise make them less desirable for source-location work.

Still one more technique can sometimes be used to locate poles containing noise sources. Figure 59 shows a Model 240 RFI Locator on a hilltop overlooking a distribution line. The log-periodic antenna is pointed at the distant distribution line and slowly scanned along the line for noise. Poles on the distant line must be visible from the hilltop. Repeated scans at higher and higher frequency will allow sources on individual poles to be located by this technique with the RFI Locator at distances up to about 1 km from a distribution line.

Figure 59 Hilltop Source Location with RFI Locator

A standard battery operated HF receiver is often useful during source-location work. It can be used to monitor the activity pattern of erratic sources for correlation with the activity pattern observed in the receiving site while the RFI Locator is moved from one location to another. A Sony Model IC 2010 or any equivalent portable HF receiver can be used for this purpose. Some portable receivers have an RF gain control which is useful to avoid overloading. Alternatively, the length of the antenna can be shortened to reduce overloading problems.

As source poles are located, a portable GPS is used to determine the location of the source, the direction of the source from the receiving site, and the distance from the source to the site. This information is entered into a source-location log along with other comments. Table 3 shows a suggested source-location log.

Table 3 Source-Location Information

Site ___________________

Source Identification No. ________________

Date ______________

Time _____________

Pole ID __________________

Location ____

Latitude _______________

Longitude _____________

Site-to-Source Bearing _______________

Site-to-Source Distance ________________

Noise Description ____

____

Comments ____

____

Source Hardware ____

Mitigation Actions ____

____

____

____

____

Note: The last two items in Table 3, ***Source Hardware and Mitigation Actions****, cannot be completed until the source hardware is identified. These items are included in the table to permit all information about each source can be recorded in one place.*

Table 4 lists the power-line source-location equipment used to obtain the information needed to produce this handbook.

Table 4 Source-Location Equipment

Item	Model No.	Source
RFI Locator	Model 240 or 242	Radar Engineers
HF Receiver	IC 2010 or eq.	Sony
Log Periodic Antenna	CLP 5130-1 (50 to 1300 MHz	Create
Log Periodic Antenna	CLP 5130-2 (108 to 1300 MHz)	Create
Loopstick Antenna	1700 to 6000 kHz Frequency Range	Palomar Engineers
Whip Antenna	1-meter magnetic Mount	Larson
Short Antenna	14 to 20 inch with BNC	Centurion
GPS	Several Types are Available	
Communications Equipment	As needed for each task	
Noise-Quiet Automobile		Local Rental

A sources-location team must always receive timely information about the activity patterns and the temporal structures of the most harmful sources as determined by real-time measurements within a receiving site. This requires real-time coordination between the internal noise-measurement team and the external source-location team. This coordination can preferably be provided by a dedicated radio link. Alternatively, cellular telephones can be used at locations where such service is available, although with considerably less success because of the need to maintain continuous voice communications over long time periods. It is also useful to pass audio sounds of received noise between the internal and external teams over a radio link, and the narrow audio-frequency range of cellular telephones severely limits their usefulness. In addition, the use of communications devices at or near a source-location effort must ensure that radio interference does not adversely affect the source-location team's efforts. It is essential that all communications equipment employs frequencies well above the upper-frequency limit of the equipment used by the external source-location team.

A detailed knowledge of the various fine- and coarse-scale temporal structures described in Section 2 and of typical real-time activity patterns of many kinds of sources is required by personal of both the internal and the external teams. Any attempt to conduct source-location work without fully trained and qualified personnel will only result in lack of success, frustration, and disappointment in the paucity of results.

4.2 Power-Conversion Sources

Procedures for the location of power-conversion sources are similar to those used for the location of sources on power lines with one major exception. Most power-conversion sources do not radiate sufficient energy above the HF band to use the VHF and UHF frequencies to obtain direction from a site to sources or to locate sources. Because of this, two sequential techniques are used to locate such sources.

4.4.1 Step A

The first step is to use an elevated HF loop-stick antenna at the site along with a Model 240 or 242 RFI Locator. The loop stick and RFI Locator are both tuned to a frequency that maximizes the noise amplitude, and the loop stick is rotated until a null is reached off the end of the antenna. Alternatively, a maximum off the side of the antenna can be used. Either will provide bi-directional information from the site to the source. A review of facilities and potential sources in the two opposite directions will often place emphasis on only one of the directions.

Figure 60 shows a commercially available loop stick antenna mounted on a tripod to obtain direction to a power-conversion source located in a residential area. In this case a tunable loop stick built for use at the low end of the HF band was used. A Model 240 RFI Locator is shown below the antenna, and it shows the temporal structure of noise from a power-conversion device on its display. If multiple sources exist, they can easily be sorted because of differences in their temporal structures, and the direction to each source can be determined. While some practice is needed to find the null off the end of the loop stick or the maximum off the side of the loop stick, the technique can be highly effective in determining the direction to sources.

Figure 60 Loopstick Antenna for Location of Power-Conversion Sources

4.4.2 Step B

The second technique is the use of a broadband HF loop stick antenna mounted on the roof of a noise-quiet vehicle and connected to a Model 242 RFI Locator. Modest increases in noise level will occur as a power-conversion source is approached since high levels of higher-order harmonics of the power-line frequency (along with other spectral components developed by most power-conversion devices) can be detected for hundreds of meters along an overhead power line. With proper design, the loop stick can be made insensitive to low-order harmonics produced by many other sources of little interest. This technique will locate the general vicinity of a power-conversion device. The temporal structure of the noise can be observed on the display of the Model 242 RFI Locator and compared with that observed inside the site.

Figure 61 shows a photograph of a medium-frequency loop stick on the roof of a search automobile along with a Model 242 Noise Locator and held in place with a magnet. The loop-stick is normal to the power line as the vehicle moves along a road to maximize its sensitivity to radiation from the power line. A Model 242 RFI Locator is in the vehicle where its display and audio output can be monitored.

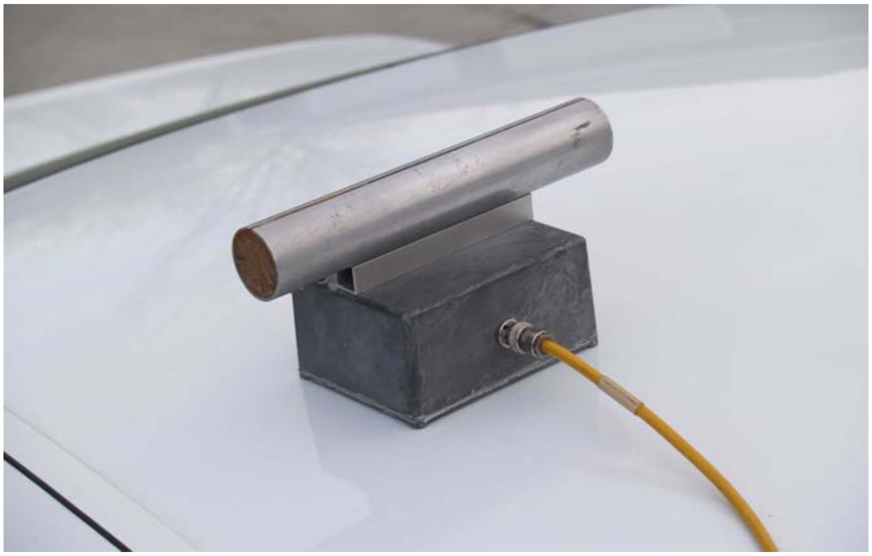


Figure 61 Loopstick Antenna on Roof of Source-Location Automobile

Once the general location of a power-conversion source is determined, the noise from the higher-order harmonics and other spectral components can be examined on the secondary side of each pole-line transformer in the vicinity. The highest noise level will be found on the secondary which provides provide power to the facility containing the power-conversion device.

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5. Step 4—IDENTIFY SOURCES

5.1 Distribution Line Hardware

The identification of specific items of hardware on power poles requires working close to high voltage components. The following warning must be strictly followed during the conduct of source-identification work.

WARNING

Individuals following the procedures described in this handbook are cautioned that electrical shock hazards, including possible electrocution, exist when working near and around power lines. Inexperienced personnel should not attempt to do source-identification work. This part of the radio-noise-mitigation effort must be accomplished by personnel trained to work on hot lines or by utility-trained lineman. All instrumentation must be suitable for use on and near hot lines. Do not assign untrained personnel to this task.

WARNING

The Radar Engineers Model 247 Noise Sniffer is used by the authors and their associates as well as by many electric utilities. It is mounted on the end of a distribution-line rated hot stick. Figure 62 is a view of the instrumentation and equipment used for the identification of pole-line hardware containing noise sources.

Figure 62 Source Identification with a Noise Sniffer

The noise sniffer is fastened to the end of the hot stick and is simply moved around the hardware on the pole until the strongest signal is obtained. This can best be accomplished by elevating the noise sniffer operator to the vicinity of the hardware with a utility-rated bucket truck. In the example shown in Figure 62, the source is located on the clevis pin between two sections of a bell. Never use an ordinary bucket truck designed for general construction work or for telephone line work since these are not insulated for operation near high voltages.

Source activity should always be monitored in the site and also on the ground near the source during sniffer work. The RFI locator receiver described previously or an HF portable receiver can be used for such monitoring. Use a short rod antenna (14” to 18” in length) on the RFI locator when close to an active source.

The Model 247 Noise Sniffer contains both RF and acoustic sensors. The RF sensor is usually the most effective sensor for work on distribution lines because many sources produce little or no useful acoustic noise. In addition, many sources are acoustically isolated from the external regions of hardware. In some cases where the source is very strong, or when a sparking source exists on the outside surface of hardware, the acoustic sensor is useful.

Sometimes the temporal structure of the noise (observed inside the site and confirmed by outside observations) is sufficient to suggest the type of hardware generating the noise. A highly experienced person can sometimes identify hardware by this process. This process requires considerable field experience and a detailed knowledge of a very large number of possible source mechanisms, and this method of hardware identification must be used with great caution.

In principle, the source-identification process is straightforward. In practice, several pitfalls complicate the process. Sometimes a source cannot be located on a specific pole. When this happens, check adjacent and nearby poles to ascertain if the adjacent pole impedance effect (see Section 4.1) has confused the source-location process. In addition, check all hardware such as switch handles, ground conductors, guy wires, braces, and other possible sources that may be nearby (see list of sources in Tables 1 and 2). Another pitfall is the presence of multiple sources on a pole. In such cases, all sources on a pole should be eliminated by effective mitigation actions.

There can also be cases where noise is conducted onto an overhead line from an underground line. In such cases, underground-to-overhead cable heads should be on the pole. A source on the underground line can be differentiated from sparking at a faulty cable head with the RF and acoustic sensors. If the acoustic sensor indicates a source, it probably will be from a sparking cable head. If the RF sensor indicates a source of noise at the cable head and the acoustic sensor does not, the source probably is on the underground line.

Still another problem is that the operator of the sniffer must have knowledge of a wide variety of pole-line hardware. In addition, the operator must know what hardware can generate radio noise, the noise-source mechanisms, and what replacement hardware can be used to eliminate each individual noise source.

Still one more technique is available for identifying source hardware. An ultrasonic dish is available from Radar Engineers that is effective at identifying the hardware associated with some sparking sources. Figure 63 is a photograph of the Model 250 Ultrasonic Parabolic Pinpointer pointed at a sparking source on a pole. It can detect radio noise from sparking sources from the ground as long as the source is in line of sight of the dish. Thus, it is useful to walk around a pole suspected of containing a sparking source to maximize noise detection and source identification.

While the Ultrasonic Pinpointer is primarily useful in identifying sparking and corona sources on transmission lines, its small size and light weight of the device make it very useful to carry along overhead distribution lines for preliminary searches for sparking sources.

Figure 63 Ultrasonic Parabolic Pinpointer

While the ultrasonic sensor provides an excellent means to detect and identify hardware with sparking sources that are in line of sight, it cannot detect many micro-sparking sources that emit little or no acoustic energy. It is excellent auxiliary tool, but it must be used with care and with other sensors capable of detecting and finding micro-sparking sources such as those associated with bell insulators, insulated tie wires, and lightning arresters. Also, the sensor cannot provide information about the temporal structure of a noise for comparison with the properties of noise affecting the reception of radio signals from a receiving site.

The combination of the Model 250 Parabolic Pinpointer, the Model 240 or 242 RFI Locator, and the Model 247 Sniffer provides a comprehensive means to identify noise-generating hardware on power lines.

Table 4 lists the source-identification instrumentation used by the teams participating in the field work that supported the information provided in this handbook.

5.2 Identification of Power-Conversion Sources

Once the facility containing a power-conversion device is located, identification of the actual hardware generating the noise is often a matter of visual inspection of the facility. This is especially the case for individuals familiar with such power-conversion. Nevertheless, verification of the actual source is recommended. Several options are available to the source-location team. They are:

5.2.1 Technique A

Scan all circuit breakers at the electric-power panel of a facility with a circuit sniffer. The Radar Engineers Model 245 Circuit Sniffer is an effective instrument for this task. It will locate circuit breakers feeding power to devices that generate wide-band radio noise.

Figure 64 is a photograph of the Model 245 Circuit Sniffer in use at a small facility where a switching power supply on a fiber-to-wire converter caused radio interference to a nearby receiving facility. The circuit breaker carrying radio noise was quickly identified and its conductors were traced to the offending source of noise. Turning the power-supply off at the converter verified it was the source of the noise.

Figure 64 Using the Model 245 Circuit Sniffer

5.2.2 Technique B

The Radar Engineers Model 242 RFI Locator is an excellent instrument to sniff a facility for sources of radio noise when it is equipped with a small antenna or an RFI-locator probe. This instrument allows the RFI investigator to observe the temporal structure of noise and compare it with the temporal structure observed at a receiver site. This capability is highly useful in source-verification tasks.

Figure 65 shows the Model 242 RFI Locator in use with a loop stick antenna to identify conductors associated with a power-conversion device that carry excessive levels of EMI current. The conduit near the loop stick carried significant levels of broadband conducted noise current from a variable-speed motor drive located to the rear of the operator. This instrument and the similar Model 240 RFI Locator have also been used with other antennas and probes with excellent results.

Figure 65 Using the Model 242 RFI Locator and Probe

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6. Step 5—SOURCE MITIGATION

6.1 Power-Line Sources

Distribution power lines constructed in accordance with the information provided in Appendix A rarely contain a source of radio noise. Such lines have been constructed on a trial basis, and all were completely free of noise sources for many years. However, most distribution lines are constructed in accordance with the practices and hardware of each electric utility, and radio noise problems are rarely a consideration in such construction. It is then necessary to locate each source of noise and identify each item of hardware generating radio noise that adversely affects signal reception at a receiving site. Practical and successful mitigation procedures are described in this section.

6.1.1 Bell Insulators

Clips and brushes have been designed to be inserted into the clevis of a Bell Insulator. Either one provides a conducting path between the metal parts of the insulator thus preventing the build up of charge across oxide layers that form on the surface of the metal parts. These devices provide a temporary means to prevent the operation of the noise source, but with time they become loose from the almost continuous movement of the line conductors, the bell, and other components of a distribution line. The clips and brushes eventually loosen and fall out. The noise then reappears. Since clips and brushes do not provide a long-term solution their use to correct noise problems at a radio-receiving site is not recommended.

Figure 66 shows a clip and a brush. They are manually inserted into the clevis connecting the metal parts of a bell. Both are made of stainless steel to deter corrosion from weather exposure.

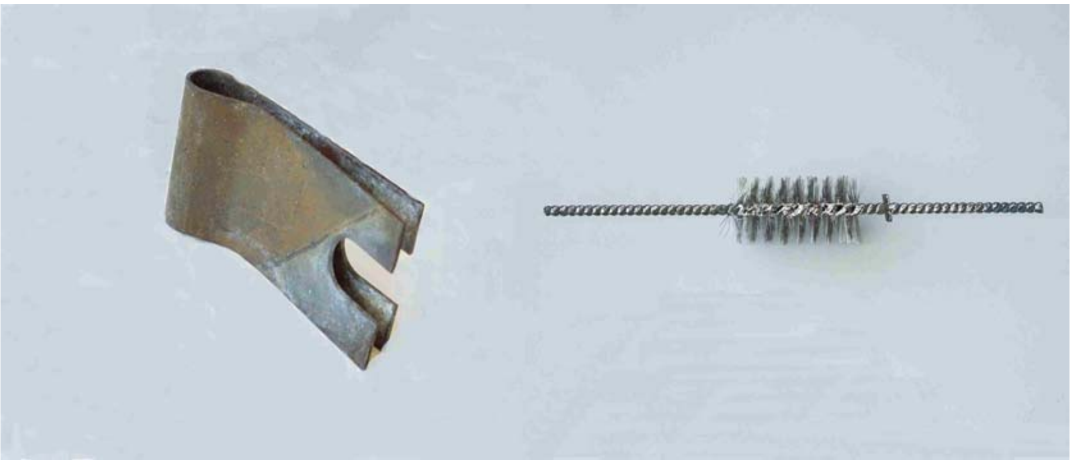

Figure 66 Clips and Brushes

Usually utility personnel will replace a noisy bell with a new bell insulator, but a replacement bell insulator will often become a source of noise after a short period of use. Thus, never replace a bell insulator found to be a source of noise with another bell insulator.

The only effective mitigation action is to replace a bell insulator identified as a source of radio noise with a polymer insulator. Furthermore replace all bell insulators on a pole containing a noisy bell with polymer insulators. This is the only effective way to eliminate bell-related sources.

Figure 67 shows an example of a polymer insulator. Variations will exist in the configuration of a polymer from one model to another, but all contain a fiberglass rod covered by a weatherproof polymer material. Metal components on each end of the insulator are attached by compression onto the fiberglass rod. Since the end-to-end capacitance of a polymer insulator is extremely low, sufficient charge cannot accumulate on the metal components at the ends of the insulator to support a microspark type of noise source.

Figure 67 Example of a Polymer Insulator

6.1.2 Sparking Sources

Sparking sources are caused by the breakdown of air between two closely-spaced metal objects or between a metal object and a plastic component that has accumulated a surface charge. Metal components can be bonded together and grounded to earth. This prevents a voltage difference between components. Alternatively, all metal components on a distribution line can be separated by at least 1½ inches. These two actions will eliminate sparking sources associated with hardware.

6.1.3 Tie Wires

A variety of ways to use tie wires exist. In the United States most distribution-line conductors are not insulated. Usually bare tie wires are used on bare line conductors. This results in the tie wire and the conductors being at the same potential. Thus, microsparking or sparking cannot occur. However, if the tie wire is poorly and loosely wrapped around the conductor and the insulator, the rubbing between the tie wire and the conductor can result in a noise source. This kind of source is relatively rare and can be corrected by replacing the loose tie wire with a tightly wrapped tie wire.

In may countries and in some isolated locations in the United States, the conductors of a distribution line are insulated. Thus, a potential difference can exist between the line conductor and either a bare or an insulated tie wire. A nearby lightning strike or a nearby radio transmitter can induce a voltage on the line conductor and further increase the potential difference between the tie wire and the line conductor. Eventually, the insulation on the line and/or on the tie wire will start to break down. The breakdown usually starts at the end of the tie wire or at a sharp bend in the tie wire where impedance effects result in high potentials similar to the high potential that exists at the ends of an antenna. Once the insulation breakdown process starts, carbon deposits caused by the small intermittent arcing can result in a noise source.

Utility personnel usually replace a damaged tie wire with a new tie wire. This is only a temporary solution since the process that initiated the original arcing is often repeated. The only effective way to permanently eliminate such a source is to eliminate the potential difference between the tie wire and the line conductor. Figure 68 shows a method of eliminating the potential difference where the tie wire is electrically connected to the line conductor with a bronze cable clamp. In this example an insulated tie wire is used on an insulated line conductor. A short portion of the insulation on both the tie wire and the line conductor was stripped to allow the bronze cable clamp to be attached to both conductors.

Figure 68 Tie Wire Source Mitigation, Example 1

Figure 69 shows another example where the tie wire is electrically connected to the line conductor. In this example, a bare tie wire is used on an insulated line conductor. The line conductor was stripped of its insulation where it was attached to the insulator.

Figure 69 Tie Wire Source Mitigation, Example 2

6.2 Power-Conversion Sources

It is impractical to provide specific mitigation instructions for each of the many sources of radio noise associated with power-conversion devices. Small devices can often be mitigated with minimal changes and at low cost. Large devices often require considerable modification at high cost. The general approach is identical to all such sources, and this section describes the procedures needed to eliminate radio noise from power-conversion sources.

The best approach is to ensure that the procurement of any equipment or system containing a power-conversion device meets the Class B radio-noise requirements of the Federal Communications Commission of the United States or similar requirements in other countries. Devices that meet the Class A radio noise requirements of the Federal Communications Commission or similar requirements of other countries should never be used within line-of-sight of an HF, VHF, or UHF receiving site. In addition, power-conversion devices that are not rated must be avoided.

Since a receiving site often cannot control the installation and use of electronic devices in other facilities located within line of sight, the source-location and source-identification procedures described in Section 4 must be followed. The basic mitigation process and techniques are described in this section.

After a power-conversion source is located and identified, it must be inspected to determine the best approach to control the coupling of radio noise from the source onto power, conduits, ground conductors, and other conductors associated with the operation of the source. The actual source of impulsive current and voltage must be placed inside an electromagnetically shielded enclosure and all impulsive current and voltage on conductors entering or exiting this enclosure must reduced to harmless levels. This can be a small enclosure for a physically small source or it can be a large shielded room for a physically large device.

Figure 70 shows the start of this process where the source is completely enclosed within an electromagnetic barrier.

Figure 70 Source Enclosed within an Electromagnetic Barrier

Figure 70 describes a somewhat impractical case since power must be provided to the source, a ground must be provided, the source probably will be connected to other devices, and conductors are often required to control the operation of the source. Figure 71 shows how power can be applied to a source. A filter can be installed directly onto the metallic surface of the enclosure and power can be provided through the filter. The filter allows electric power to be provided to the source at low loss while the higher-frequency noise is attenuated and cannot be conducted onto the outside power conductors. Small and inexpensive filters can be used on low-power sources, but large filters will be required for high-power sources.

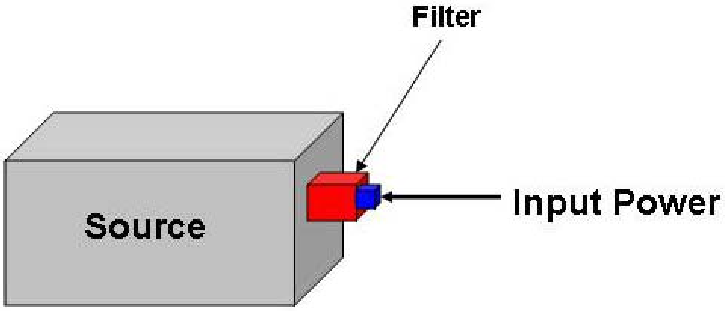

Figure 71 Provision of Power to a Source

Most sources operate an external device. For example, many sources operate variable-speed induction electric motors by varying the frequency of the power provided to the motor. A second filter can be installed on the surface of the electromagnetic barrier to prevent the conduction of noise current and noise voltage to external conductors. Alternatively, the electronic barrier can be extended to include the conductors from the barrier to the motor. Most electric motors are sufficiently enclosed in metal to provide a suitable electromagnetic barrier. Figure 72 shows such a configuration where conduit is used between the source and the motor or other load to shield the conductors. The conduit must be electrically bonded to the source barrier and to the metal barrier enclosing the motor or other load.

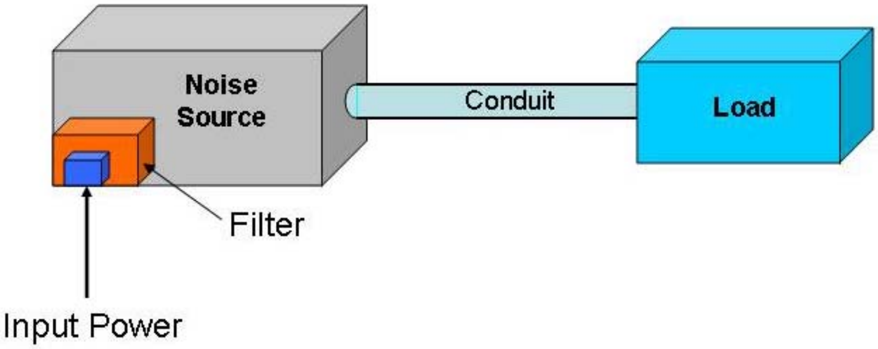

Figure 72 Source-to-Load Connection

Most electrical and electronic installations require a safety or green-wire ground. Ground conductors can carry significant amounts of noise current and voltage (often higher levels than the power conductors), and they must also be controlled. Figure 73 shows an effective means to prevent the conduction of noise current and voltage from a source to an outside conductor over a ground wire. Ground conductors inside the barrier are bonded to the inside surface of the barrier. Ground conductors outside the barrier are bonded to the outside surface of the barrier. This provides a path for noise current flowing on the internal ground conductor to return its source inside the barrier while the barrier provides a shield that prevents the conduction of noise current and voltage to the outside ground conductor. Since the barrier will conduct low-frequency power-related current, all safety aspects of the green-wire ground are maintained.

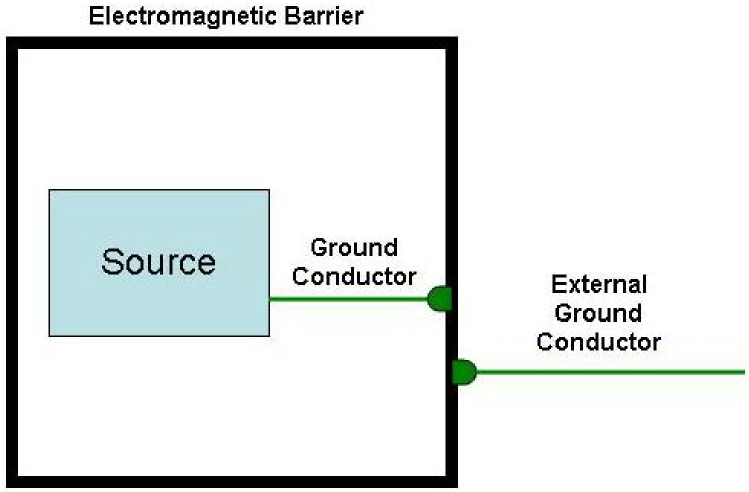

Figure 73 Barrier Treatment of Ground Conductor

Additional filters can be provided on the surface of the barrier to permit control wires and other conductors carrying low-frequency signals to pass through the barrier. If high-frequency signals must pass through the barrier a coaxial cable bulkhead connector can be added to the barrier, however, both the source of, and the load for, the high-frequency signals must be contained within a barrier, the cable and the load similar to the way the motor is contained within the barrier as shown in Figure 72.

It is essential that the process described in Figures 70 through 73 be strictly followed to eliminate noise problems from power-conversion devices. Any uncontrolled conductor that is allowed to penetrate the barrier, regardless of its importance, will carry noise current outside the barrier where it can be transferred to other nearby conducting material by inductive and/or capacitive coupling mechanisms or by direct conduction. There is no shortcut to the mitigation process.

Figure 74 shows an example of a successful installation of filters on the metal box containing the electronics for a variable-speed motor drive. In this case two filters were required since the system used both 120-V single-phase and 240-V three-phase electric power. The filters were bolted directly onto the side of the metal box, and care was given to ensuring that the filter case was in direct contact with the housing. An additional small box was added to each filter to provide physical support for the input power conductors. This filter prevented noise current and voltage from escaping the metal box on the power and green-wire ground conductors.

Figure 74 Filter Installation to Suppress Motor-Controller Noise

Conductors from the controller to two electric motors exited the case on its lower side. These conductors were inside conduits that ran from the controller's case to each motor, and the conduits were bonded to the controller's case and to the motor's housing. Additional conductors associated with an external control box used to adjust motor speed also exited the controller's case. These conductors were in a flexible shielded cable, and the shield was terminated at the controller's case and at the control-box case. No unshielded conductor that might carry noise current was allowed to penetrate the controller's case.

The modifications shown in Figure 74 proved to be highly effective in containing harmful levels of noise current within the controller's case, conduits and loads, and the procedure corrected a severe noise problem.

An example of an ineffective filter installation is provided to illustrate some common deficiencies that occur in improperly engineered attempts to solve electromagnetic-noise problems. Figure 75 shows a filter installed to prevent EMI current and voltage from causing problems at a receiving site. The filter was installed in a standard metal case that provided an excellent and acceptable shield around the filter.

Figure 75 Improper Filter Configuration

Several improper aspects of the filter installation resulted in the total lack of suppression of a severe electromagnetic noise problem. These aspects are:

- Both input and output conductors penetrated a shield. The input conductors carried high levels of noise current. Some of this current was inductively and capacitively coupled to the interior surface of the shield case and in turn was inductively and capacitively coupled to the output conductors.
- The green-wire ground conductor also carried high levels of noise current and voltage. The input and output green wires were connected together, and this provided a direct conduction path for noise current and voltage to bypass the filter and be conducted to the output conductors.

- An examination of the source device showed that the conduit from the source to the filter housing was not terminated at the source device. This induced noise current and voltage onto the outside surface of the conduit. This noise current and voltage was then conducted to the filter box, onto the outside surface of the filter box, and onto the outside surface of the conduit running from the filter container to the motor. Since this conduit was bonded to other metal objects, noise current and voltage was conducted onto a number of other conducting objects. These conducting objects constituted a complex, but effective, radiator of the noise.

There is no simple corrective action that can be taken to alter or correct the deficiencies of the filter installation shown in Figure 75. In this case the source device was very small and its enclosure could be a small and inexpensive metal box along with the appropriate filters on its surface. The mitigation actions require:

1. The small source device itself must be enclosed in a small metal box.
2. All conductors entering and exiting this box must pass through filters with the exception of the green-wire ground.
3. The green-wire ground must be connected as shown in Figure 74.
4. Then remove the existing filter installation and reconnect all conductors in a normal configuration.

7. SUMMARY COMMENTS

This handbook is based on experience accumulated by the US Navy’s Signal-To-Noise Enhancement Program (SNEP) teams over almost three decades of investigating Man-Made Radio-Noise problems at HF, VHF, and UHF receiving sites. Much has been learned from the detailed efforts needed to understand, document, and correct radio-noise problems. Many myths about radio noise were exposed and considerable progress was made in understanding sources, the impact of noise on signal reception, and effective noise mitigation procedures and well as ineffective procedures. During this time the team found that few electric utilities still maintain radio-noise specialists to aid in troubleshooting noise problems. In past years these individuals obtained decades of experience working on overhead and underground power lines problems and accrued much practical experience on solving radio-noise problems through trial and error. The SNEP teams learned to respect the detailed knowledge of these individuals about noise sources and noise mitigation. Unfortunately, the electric utilities are rapidly eliminating such positions for cost reasons, and trained replacements are simply no longer available.

Instrumentation to understand noise problems in a receiving site remains a major technical and management problem. New models of spectrum analyzers are simply not suitable to replace the old instruments used to investigate noise problems in sites. Current models cannot cope with the time-varying signal and noise problems encountered in receiving sites.

Nor are site planners, site managers and site staff trained to cope with the highly intermittent and erratic signal and noise conditions encountered. Of special concern is that the simple things like noise amplitude could not be described in normal terms of average, root-mean-square, or peak amplitude. Also, the more advanced terms of amplitude probability distributions, percent-of-time above a certain level, and other stationary statistical descriptors do not apply to the erratic noise conditions found at receiving sites. The noise encountered can only be described by complex non-stationary statistical procedures, suggesting that a valid description of noise is a highly complex mathematical process. This complex matter was avoided in this document by providing time-history examples of the noise. These examples illustrate the time and frequency changing properties of noise as well as its temporal variations with time.

To further complicate the matter, noise was mostly impulsive where the bandwidth of the noise was always wider than the receiver bandwidth. This results in the amplitude of impulsive noise being a function of receiver bandwidth. To partly cope with this major problem, the measurement bandwidth associated with each example of data is provided.

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Appendix A

NOISE-FREE DISTRIBUTION LINES

NOISE-FREE OVERHEAD DISTRIBUTION LINES

A.1 INTRODUCTION

The perverse nature and erratic occurrence of power-line noise complicate efforts to understand and eliminate its impact on receiving sites. To further confuse matters, some sections of distribution lines are completely free of sources of radio noise while other sections contain numerous sources. The differences are often poorly understood by electric-utility or public works personnel.

During the mitigation of power-line noise at receiving sites, sections of a number of distribution lines have been changed from noise-producing to noise-free lines. Distribution lines modified in accordance with the procedures described in this appendix have remained noise free for more than ten years. No section of a distribution line modified in accordance with these procedures has yet reverted into a noise-producing line. This success has shown that overhead distribution lines can be made noise free even though some are very close to receiving sites and some provide power to them. These cases have shown that overhead power lines can be built in the near vicinity of radio receiving sites which have no adverse impact on their reception of weak radio signals in the HF, VHF, and UHF bands. It is a matter of using line-hardware and line-construction techniques which inhibit the operation of noise sources.

While noise-free distribution lines can be built, there can be several roadblocks to achieving this goal. First, there is a considerable amount of misinformation available about the mechanisms of noise sources. Some of the misunderstood aspects of power-line noise have even achieved legendary and mythical status. Second, radio noise is often not a key consideration in the formulation of line-construction and line-maintenance practices and techniques by the electric utilities or public works departments. Each has its own set of guidelines for the construction and maintenance of overhead lines. These guidelines have evolved over many years into effective procedures for the efficient and low-cost delivery of electric power to customers. Sources of radio-noise on overhead distribution lines are an additional and separate aspect of this process often ignored because of the lack of information about sources or simple economics. Since radio-noise sources rarely affect the efficient and low-cost delivery of electric power, they are easily neglected or given secondary status by utility or public works personnel.

A.2 NOISE-FREE CONSTRUCTION AND MAINTENANCE TECHNIQUES

A.2.1 Background Information

This portion of Appendix A describes construction and maintenance techniques and practices which produce noise-free overhead distribution lines. The techniques and practices are specifically intended for use on distribution lines in the vicinity of HF, VHF, and UHF receiving sites. While some public works departments and some electric utilities now partly, or completely, follow these practices and techniques, others do not. Partial compliance with the techniques and practices will not provide noise-free overhead lines as turning out the lights in a room seldom makes the room completely dark.

SPECIAL NOTE

In the past it was recommended that overhead power lines not be allowed within two or three miles of a receiving site. This recommendation has not been strictly followed, and many violations of this recommendation exist near receiving sites. The list of violations includes many overhead power feeds to receiving sites. Unfortunately, the concept of the two and three mile distance limits is not supported by technical data or by technical analyses. These limits are ineffective, and they must be disregarded.

In actual practice, all overhead distribution lines within line of sight of the uppermost part of the antennas at a receiving site must be free of harmful noise sources. A practical maximum distance limit is not feasible until a distance of about 30 km from a receiving site is reached.

A.2.2 New Overhead Line Construction

Whenever possible, encourage the use of underground power lines with customer service transformers installed in metal enclosures on concrete pads for all new construction within line of sight of an HF, VHF, or UHF receiving site. When this is not feasible due to cost, lack of right of way, or other problems, new overhead lines and new extensions to existing lines can be made noise free by strictly complying with the following line-construction practices. These practices are directed at the prevention of sources of radio noise on new distribution lines, new extensions to existing lines, and new customer-service connections. The practices and techniques apply to all single-phase and multiple-phase distribution lines operating at line-to-line and line-to-ground voltages from 2 kV up to 35 kV.

Lower voltage secondary lines seldom contain source of noise although they sometimes carry customer-generated noise onto overhead power lines. Customer-generated noise will pass through distribution-line transformers with little or no significant attenuation; the suggestion that such transformers will isolate noise sources from overhead distribution lines is inaccurate.

A.3 NOISE-FREE TECHNIQUES FOR NEW LINE CONSTRUCTION

A.3.1 Insulators:

- Do not use ceramic or glass bell insulators on new lines. Use only polymer type insulators for suspension or tension insulators. Use a polymer insulator with a voltage rating one level above the line-to-line and the line-to-ground voltage. This ensures that sufficient line-to-pole spacing is provided to prevent the activation of noise sources associated with the insulator attachment hardware.
- Do not use spool insulators on new distribution lines. Replace spool insulators with polymer-type insulators which have a voltage rating one level above the line-to-line and the line-to-ground voltage. This ensures that sufficient line-to-pole spacing is provided to prevent the occurrence of noise sources associated with the insulator support hardware.
- Do not use pin insulators and pin bolts. Use post insulators to avoid loose internal screw joints.
- Use post insulators with bare conductors and bare preformed tie wires whenever possible.
- When post insulators with saddle clamps are used, ensure that the saddle clamp is tightened sufficiently to eliminate any possibility of line-conductor movement in the saddle clamp.
- Do not install elastomer pads on the top of pin or post insulators to provide a soft cushion for the conductor. If unusual wear is anticipated, use a preformed line-reinforcement sleeve.

A.3.2 Tie Wires

- Use bare preformed tie wires on bare conductors whenever possible.
- Do not use insulated tie wires on either insulated or bare conductors unless the tie-wire conductor is firmly bonded to the line conductor.
- If insulated line conductors are used, firmly bond each tie-wire conductor to the line conductor.
- If bare tie wires are used on bare conductors, use preformed tie wires or ensure that wrapped tie wires are firmly bonded to the line conductor.
- Do not use plastic, semi-conductor or other non-conducting tie wires.

A.3.3 Hardware

- Do not use lag screws on wooden poles or crossarms. Use through-bolts, and install a combination of a large flat washer and two-turn lock washers or spring washers on all bolts to spread the pressure over a larger surface and reduce the incidence of loosening from wood shrinkage.
- Ensure that a minimum of 1½ inch spacing is maintained between all unbonded metal objects. This includes the spacing between ground and guy wires and all other conductive objects.
- Bond all unenergized objects to earth ground. Leave nothing floating. If metal towers are used to support a distribution line, bond all unenergized objects to the metal tower and ground the tower. Insure that all tower joints are tight.
- On wooden poles, use only insulated staples to support ground wires. Do not use bare staples.
- Use only pressure treated components for wooden construction. Never use untreated wooden poles, crossarms, or other components which are subject to shrinkage and premature failure.

A.4 NOISE-FREE TECHNIQUES AND PRACTICES FOR EXISTING LINES

Noise sources on existing distribution lines can be eliminated as long as the line-support hardware already meets good, normal construction standards. Do not try to eliminate sources on lines containing dry-rotted wooden components or other abnormal construction until the public works department or electric utility operating the line corrects such deficiencies and brings the lines up to good condition.

The following procedures and practices will eliminate sources of noise on distribution lines operating at line-to-line or line-to-ground voltages from 2 kV up to 35 kV.

A4.1 Insulators

- Where a bell insulator is identified as a noise source, replace all bells on the same pole with polymer-type insulators. Use polymer insulators with a voltage rating one step higher than the line-to-line or line-to-ground voltage.
- Never replace a bell insulator with another bell insulator.
- Replace pin insulators found to be noisy with post insulators.
- Eliminate all spool insulators, except those on secondary lines (600 V or less).

A4.2 Lightning Arresters

- Immediately remove every lightning arrester identified as a source of noise. Replace each with a new arrester of the appropriate rating.
- Remove all lightning arresters with discoloration on the bottom ceramic ring of the arrester or if the bottom ground conductor has separated from the arrester. Replace them with new arresters of the appropriate rating.
- Check all lightning arresters within line of sight after each major lightning storm. Immediately remove and replace all damaged or noisy arresters.

A4.3 Hardware

- Tighten all hardware on each pole identified with a source of noise.
- Remove all lag bolts on wooden poles containing a source of noise and replace them with through bolts. Add large flat washers and two-turn lock washers or spring washers to each bolt.
- Replace all wooden components, such as crossarms and poles, suffering dry-rot damage since hardware cannot be tightened sufficiently to keep poles free of sparking sources. Use only pressure-treated wooden components.
- Maintain 1½ inch or greater spacing between unbonded metal objects.
- Bond all metal objects together. On wooden pole construction run a ground wire to an earth ground. On steel towers, use the tower as a ground conductor.
- Use insulated staples to support ground wires on wooden poles. Replace damaged staples. Never use uninsulated staples.

A.5 INEFFECTIVE ACTIONS

Field experience has shown that many corrective or repair actions taken do not lead to noise-free overhead distribution power lines. Knowledge of these items avoids wasting time, resources, and money on useless mitigation actions. Most of the ineffective actions are based on popular myths about power lines and their noise sources. Some of these things are listed below.

- Do not wash insulators on a distribution line. It is not an effective noise-mitigation technique, and the process may be very misleading. Dirty insulators on a distribution line rarely are a source of radio noise. The moisture from washing an insulator will temporarily render most sources inactive. They will become active again as soon as the source mechanisms dry. Dirty insulators can sometimes cause a power delivery problem in heavy industrial areas and in high-humidity areas which support the growth of fungus on insulators. Utility personnel in the affected areas are well aware of this problem, and they can take the necessary corrective actions to keep power flowing.
- Do not waste time on noise sources which do not affect the performance of a receiving site. If a source does not affect the ability of a receiving site to receive radio signals, ignore it. Attention to such sources is a needless waste of time and resources. Concentrate on those sources that do affect the performance of a receiving site.
- Do not expect public works or utility personnel to find the sources that affect the operation of your site based only on general radio-interference complaints. This rarely works. Public works and utility personnel do not normally have access to your site; hence, they do not know what kind of noise is adversely affecting your site. Successful and effective mitigation actions start within a receiving site. The determination of the general activity of each source and the fine-scale temporal and spectral structure of each source of power-line noise which adversely affects radio-signal reception are key items needed to start the identification and location process. Also, your noise may not originate from a power line. Noise from many other electrical sources can be very similar to that from power lines. Be completely sure that your problem is related to power lines and document each case of radio interference before you involve public works or utility personnel.
- Never hammer or shake distribution-line poles or guy wires. This action induces movement along several spans of line, and it rarely provides the information needed to identify the pole containing a specific source affecting a receiving site. In addition, serious safety issues arise since even the slight movement of a pole can result in the failure of line-support hardware. Locate poles containing noise sources with the radio techniques described in the main body of this handbook.
- Untrained personnel must not touch guy wires, switch handles, fuse blocks, or other hardware on a pole. This is not necessary to locate sources, and such hardware should always be treated as energized, as it is often energized through leakage current and/or by induction. Leave all pole work up to public works or utility personnel who have had many years of training on safety issues and are qualified to work on overhead lines.
- Never rebuild a section of overhead lines in a blind attempt to use this gross approach to eliminate sources of radio interference. This is a costly and ineffective approach that often winds up with more sources that previously existed. This approach will work only when the noise-free techniques described in this appendix are employed. If a section of line has deteriorated to the extent that it is unusable or unsafe, then utility or public works personnel must correct such problems in accordance with noise-free techniques and practices.

A.6 ADDITIONAL COMMENTS

The authors have encountered a number of practical problems in implementing noise-free practices and procedures on distribution lines. Each public works department or utility constructs and maintains their lines in accordance with established practices and procedures. Line hardware is purchased and stocked to meet these practices and procedures. Linemen are trained to strictly follow established practices and procedures and to use only approved hardware. It is often useful to obtain a copy of the line-construction and line-maintenance procedures used by the public works department or the utility operating overhead distribution lines with noise sources.

Changing the procurement, stocking, and installation process to use noise-free components and procedures (e.g., the use of polymer insulators in place of the old reliable bell insulators) is often a complex process. Changing the line-construction techniques (e.g., the elimination of insulated tie wires) also can be a time-consuming process that often requires fundamental changes in old established procedures and changes in the training of lineman. Yet these obstacles can be overcome provided the technical aspects of the need for change are justified to the line operators.

Another major problem is that the managers and operators of receiving sites usually lack detailed knowledge about power lines, the terminology used by line operators, noise-source mechanisms, effective source-location techniques, and effective mitigation actions. Since radio interference from sources associated with overhead power-lines is the major factor adversely affecting the reception of signals at most HF/VHF/UHF receiving sites, serious attention to this plaguing problem is needed. This handbook was devised to aid in this problem.

Still another problem is that the physical aspects of power lines seldom remain static. Line updates, new higher-capacity lines, lines to serve new customers, and line-maintenance actions are continuously underway. This is especially the case in growing and developing areas. Thus, noise mitigation will be a moving target unless there is effective and ongoing coordination and cooperation between the site and the public works department or the electrical utility operating the lines. The use of noise-free techniques and practices during distribution-line modifications, line maintenance, and the installation of new lines will prevent ongoing noise problems.

There are no restrictions on the reproduction and distribution of this handbook. Provide copies of it to all utility and public works organizations operating distribution lines within line of sight of a receiving site, and encourage them to follow the noise-free practices described.

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Appendix B

SIGNALS LOST FROM SITE PARAMETERS AND MAN-MADE RADIO NOISE

B.1 THE PERFORMANCE EVALUATION TECHNIQUE (PET-2A)

A program named the Performance Evaluation Technique (PET) was developed by the staff and students of the Naval Postgraduate School to evaluate the ability of an HF site to receive radio signals. This program was improved during more than two decades of staff and student participation in radio-noise and signal-reception surveys at receiving sites, eventually developing into version PET-2A[4]. This is a relatively simple program using the HF propagation prediction program (PROPHET) and spreadsheets (Lotus 123). Any similar propagation prediction program or spreadsheet program 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.

The PET-2A program calculates the effects of the following items on the reception of signals from a distant source:

- source transmitter power,
- type of source transmitting antenna,
- type of the modulation,
- ionospheric radio-propagation conditions,
- type of receiving antenna,
- RF path loss from the receiving antenna to the receiver,
- radio noise introduced by components in a site's RF path,
- site's receiver bandwidth,
- site's receiver sensitivity, and
- man-made radio-noise levels at a site.

Signal sources are chosen within the primary and secondary coverage areas of a site. The primary coverage area of a receiving site is defined as that area within one ionospheric hop of the site location. The secondary coverage area is defined as the area between the one-hop limit and the two-hop limit. A source in the secondary coverage area will typically provide signal levels 10- to 20-dB lower than the same source when located in the one-hop area. The reception of signals from sources beyond the two-hop limit is considered to be too unreliable for consistent reception.

As part of the analysis, a great-circle map is typically generated to show the one-hop and the two-hop coverage areas for each site examined. This map provides an overview of the areas of the globe that can be effectively covered by a radio-receiving site.

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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, Electrical and Computer Engineering Department, Naval Postgraduate School, Monterey, CA, August 1996

Figure 76 shows a block diagram of the PET-2A process. Six types of input data are required. They are:

1. Signal level at the output port of a receiving antenna from a propagation prediction program.
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, is 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.

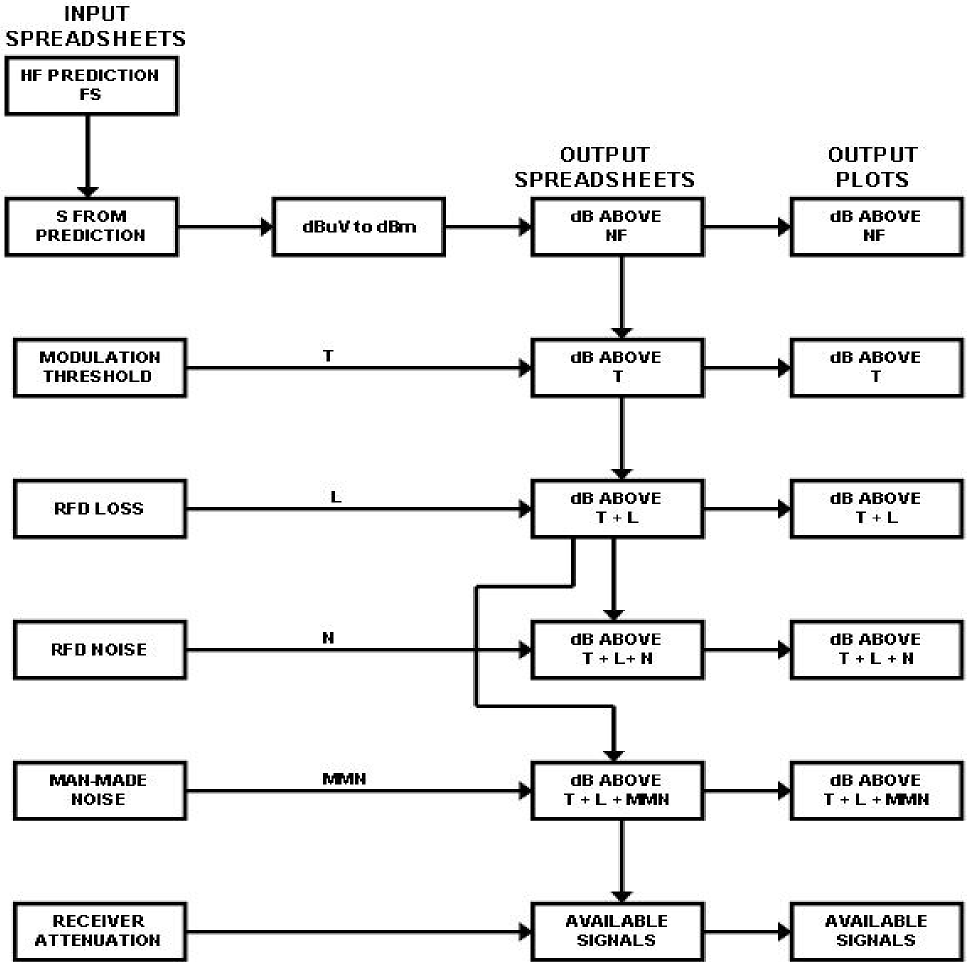

Figure 76 Block Diagram of PET-2A

Figure 76 uses a number of abbreviations to minimize the amount of text in each block. These abbreviations are:

FS	Signal Strength module of PROPHET or other similar program.
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 signal-source and the receiver sites. Enter these parameters into the FS module of PROPHET Version 5.1 or other propagation program 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 Frequency (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. Enter the actual data. A 3-axis plot will appear as Plot 5. This plot shows detectable signals that exceed the modulation-detection threshold, RFD loss, RFD noise, and man-made noise.

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 desired output plots. 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 Plots 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 of 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. The same kind of information is available from the Internet[5].

While a number of propagation prediction programs are available to provide information about the signal path between a source and a receiving site, the program "Advanced PROPHET" developed by the Naval Ocean Systems Center, San Diego, CA was used for the examples in this document. PROPHET provides a plot of average hourly diurnal values of the Maximum Usable Frequency (MUF), the Lowest Useful Frequency (LUF), and the Frequency of Optimum Transmission (FOT). In addition PROPHET provides tables of the hourly average signal level

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

expected to be delivered by the receiving antenna to the site’s Radio Frequency Distribution (RFD) system.

Most PET-2A tasks subsequent to the production of the examples shown in this document have used the Proplab-2 prediction program. This program provides a means to use near real time ionospheric parameters as well as non-great circles modes of propagation. Since the distribution of the PROPHET program is limited and the program is not being updated and maintained, new users might find the Proplab-2 program to be more suitable.

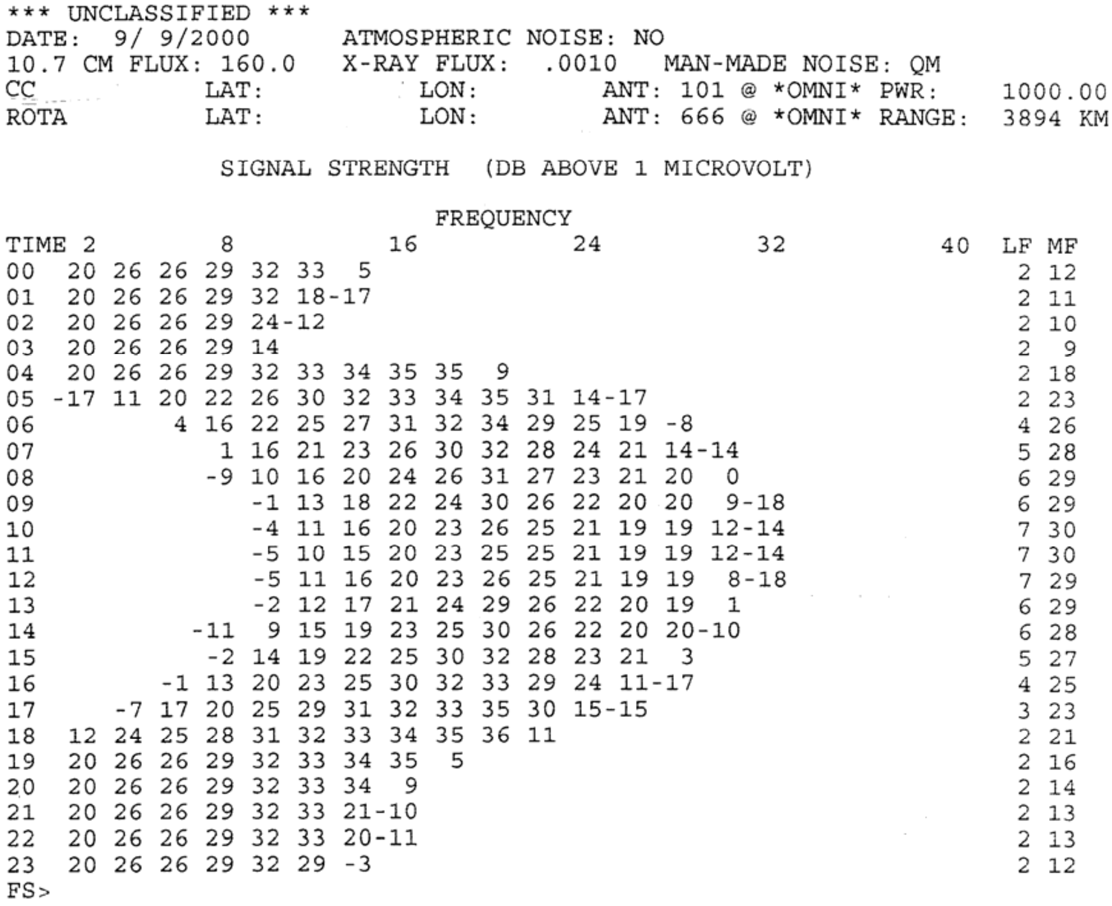
B.2 AN EXAMPLE OF PET-2A

The first step in the use of PET-2A is to select candidate locations for a few signal sources and to determine the primary properties of each source. Table 1 shows the properties of a source labeled as Source 1. This source was being received at the receiving site being evaluated. The source characteristics are as follows:

Identification Symbol	TEST 1
Latitude	
Longitude	
Antenna	λ/2 Dipole
Power	1000 Watts
Modulation	3-kHz digital modulation
Distance	3900 km
Coverage Area	Primary

Next, a propagation prediction program is used to determine the average values of the Maximum Useable Frequency (MUF) and the Lowest Useful Frequency (LUF) for each hour of the day on the path from the source to the receiving site along with the average values of hourly received signal strengths. Ionospheric conditions for the date of the investigation were used for the production of the examples. This date was the nearest mid-month date to the accumulation of site data. Actual values of man-made radio noise obtained during a 24-hour measurement period at the receiving site were used in the analysis.

Figure 77 provides a listing of the hourly signal strengths in 2-MHz increments of frequency across the entire HF band. This data is used as the first input into the PET-2A program.



```
*** UNCLASSIFIED ***
DATE:  9/ 9/2000      ATMOSPHERIC NOISE: NO
10.7 CM FLUX: 160.0   X-RAY FLUX:  .0010   MAN-MADE NOISE: QM
CC           LAT:          LON:        ANT: 101 @ *OMNI* PWR:    1000.00
ROTA         LAT:          LON:        ANT: 666 @ *OMNI* RANGE:  3894 KM

              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 12-14              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 77 Average Values of Received Signals for the Test Case

The above values are converted into dBm for a 50-Ohm load and entered into Spreadsheet 1. These values represent the average signal strength obtained at the output terminals of an omi-directional antenna located at the receiver site.

Next the modulation detection threshold of the receiving system is entered into Spreadsheet 2. This is the signal margin above noise needed to detect the received signal and provide a low error copy of the modulation of that signal.

In this case, the receiving site contained cable loss between the antenna and the receiver. This loss was measured and entered into Spreadsheet 3.

In some cases, additional radio noise is generated by components between the antenna and the receiver. Thus, the noise at the input terminals of a receiver is measured with the antenna removed from the site's signal-distribution system and replaced with a suitable termination. This noise level is entered into Spreadsheet 4

The man-made radio-noise values at the antenna terminals are measured in two-hour increments over a 24-hour period, and these values are entered into Spreadsheet 5. In this case the external noise was entirely from sources on distribution power lines that were within line of sight of the uppermost part of the antenna used for reception. The sources varied in distance from the site's antenna from 1 km to more than 10 km. During this measurement some erratic variations in noise level were noted because of changes in the activity of sources. The level at the time of the measurement was used rather than the peak or minimum noted between measurement times

Finally, some receivers contain an attenuator at their input to limit the maximum signal level. This is done to prevent overloading the receiver with the resultant loss of linearity and the introduction of intermodulation products and intermodulation noise. The receiver used for this analysis did not contain such an attenuator.

Figure 78 provides an example of the measured man-made noise levels for the site. In this case the levels are expressed in dB above -130 dBm where -130 dBm is the minimum signal-detection level for the specific receiver used in the analysis when it used a 3-kHz signal-detection bandwidth.

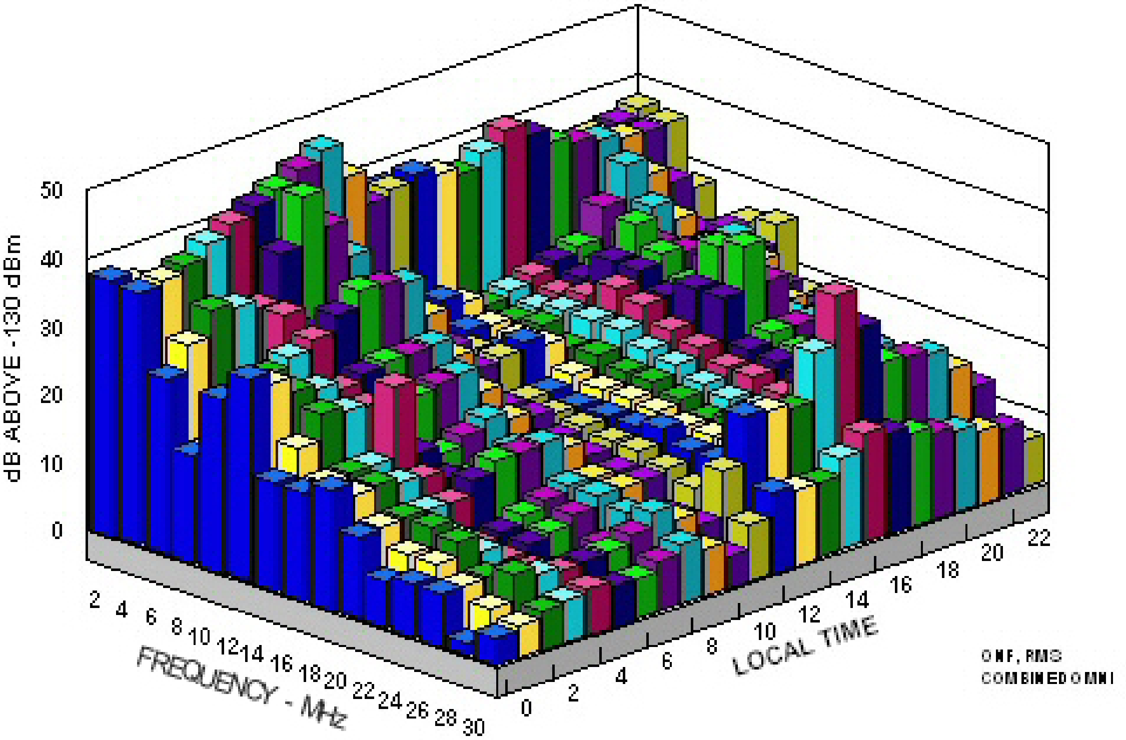


Figure 78 Radio Noise Levels at the Antenna Output Terminals

Output 1 of the PET-2A program provides an overview of the signal strengths available at the antenna terminals where the amplitude scale is in dB above -130 dBm. This output illustrates the ability of the site to detect signals under perfect site conditions with no signal-distribution loss, no signal-distribution noise, a 0-dB modulation-detection margin, and no man-made radio noise. Figure 79 shows a plot of predicted received signal levels for the source selected and at the year and season of the measurement.

The impact of the ionosphere on signal propagation is evident in this example. The diurnal changes in the MUF and LUF are prominent aspects of the example along with the impact of path absorption on signal strength. In this case a few signals would be received at frequencies above the upper limit of the HF band during the mid afternoon hours. Signals would also be received from the source at frequencies below the lower limit of the HF band after midnight and during the early morning hours.

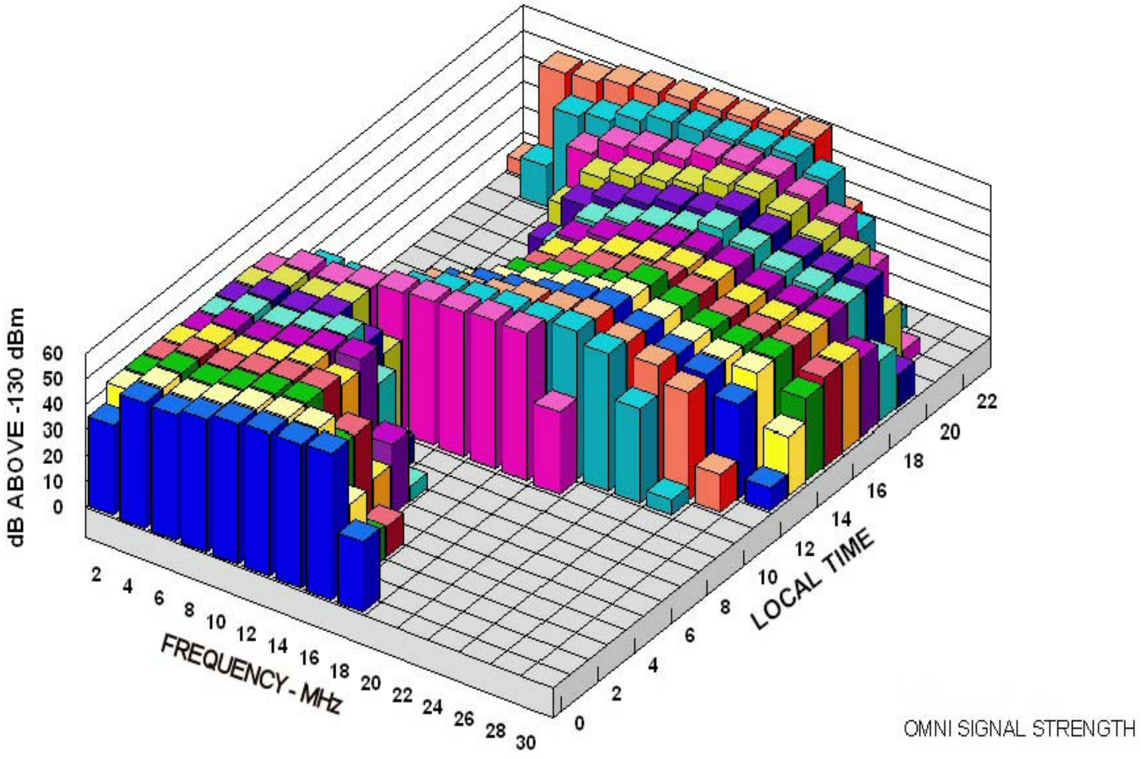


Figure 79 Signal Levels at the Antenna Output Terminals

The prior figure does not take into account the need for a margin in signal strength to detect and receive a signal at a low error rate. A signal-detection threshold of 12 dB was used for this example. In this example the detection margin was combined with the values of RFD loss and RFD noise to generate Output Plot 4 of the PET-2A program. These two items prevent the reception of some of the low-level signals. Figure 80 shows the remaining signals that can be detected by a receiver.

About 11% of the signals were lost due to the consideration of the detection threshold, RFD loss and RFD noise. This is a reasonable loss for these parameters at a practical site since there will be some signal loss between the antenna and a small amount of noise will be added by components in the signal distribution system.

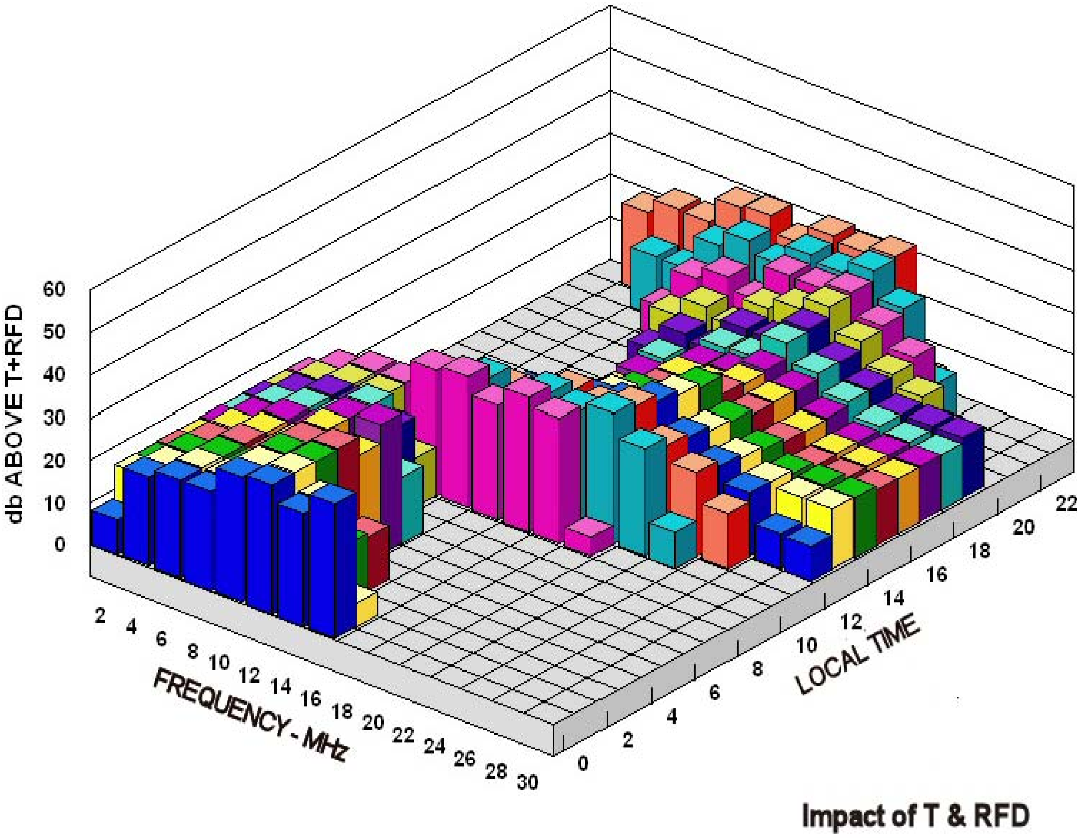


Figure 80 Signals Remaining after T+RFD

The high noise levels shown in the operating noise floor in Figure 79 suggest that additional signals will be lost when the man-made noise levels are considered. Figure 81 shows signals left when all site factors including the detection threshold, RFD loss, RFD noise, and man-made noise are considered. Man-made noise accounted for an additional loss of 46% of the signals impinging on the sites antennas from the selected source. This high loss indicates that considerable attention needs to be given to the mitigation of the sources of man-made radio noise if the site is to become an effective receiving site.

The PET-2A program can be repeated for additional signal sources and sources with different parameters as long as the sources are within the primary and secondary coverage areas of the receiving site. Such results provide a means to evaluate the present state of a site and to assess the effectiveness of noise-mitigation actions undertaken to improve signal reception.

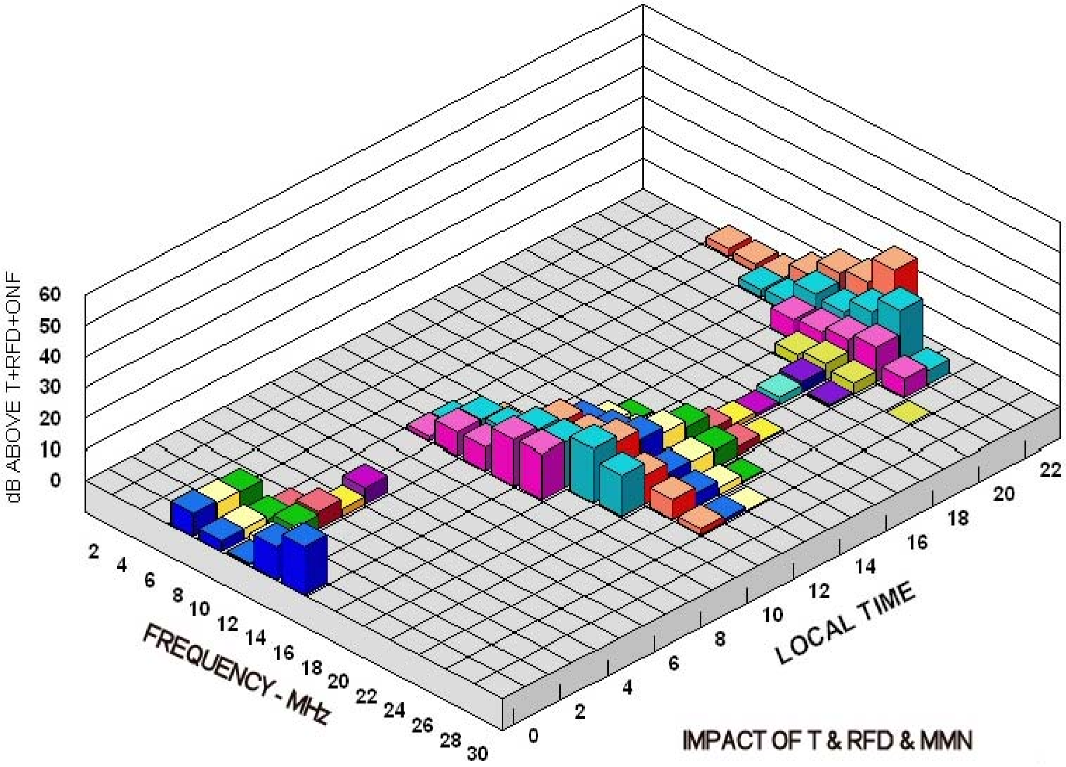


Figure 81 Signals Remaining after T + RFD + MMN

The above examples of the PET-2A program illustrate how a site manager can determine the ability of his site to receive radio signals. Additional outputs can be provided to further examine signal loss due to any component of a site.

A similar program is used to assess signal-reception loss at VHF and UHF sites.

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