peak near 18 kHz along with a smaller increase at lower frequencies. The deep null at 12 kHz remained untouched by the noise change, and a new peak at 20 kHz appeared. Similar abrupt changes in noise level were frequently noted during either the harmonic and noise surveys using electric- and magnetic-field sensors or during the directly coupled measurements using voltage and current probes. These changes have been observed on distribution lines of all utilities at which data were taken. Whenever the source of the abrupt changes was identified, the source was always a switching device operated by a utility customer.

5.2.3 Nonharmonic Signals And Noise

During the measurement of harmonics and synchronous impulses at DLC frequencies, other nonharmonic signals and noise were frequently observed. Because these signals and noise can interfer with the operation of DLC systems, typical cases are briefly summarized. Figure 5-17 shows sideband signals around 60 Hz and the third harmonic of 60 Hz. These sidebands were caused by the operation of a standard fractional horsepower capacitor-start induction motor. The data in Figure 5-17 were taken under controlled conditions after the source had been traced to the operation of a table saw in the garage of a residence. The frequency-versus-amplitude view shows that the sideband current was about 2 A during unloaded operation of the motor. The 3-axis view shows that the sidebands decreased in amplitude and moved closer to the fundamental and closer to the harmonic when load was applied. A weak second harmonic appeared when load was applied. The sidebands appeared on higher order odd harmonics at progressively lower amplitude as harmonic number increased.

Signals like those shown in Figure 5-17 were often observed during the initial surveys of distribution lines. Their source was not immediately determined because of their intermittent nature and the lack of access to all customers of the utilities.

Figure 5-18 shows another type of signal commonly observed during surveys of distribution lines. The signal shown was traced to a vacuum cleaner used for general shop cleaning tasks. The commutator-type motor produced a distinctive signature as the motor increased speed after it was turned on. The frequency of the signal generated by the commutator type motor varied with the particular device measured, but all such devices examined produced signals in the range employed by DLC systems.

Figure 5-19 shows a transient observed on a distribution line. The transient was measured during a line survey, hence only relative voltage is shown on the amplitude scale. The transient amplitude was about 30 dB above the background harmonic amplitude, and the spectral extent covered frequencies commonly used by DLC systems. This example is given to illustrate that single impulses do appear on distribution lines with considerable amplitude at frequencies used by DLC systems. The spectral shape, amplitude, and frequencies affected vary considerably from one impulse to another.

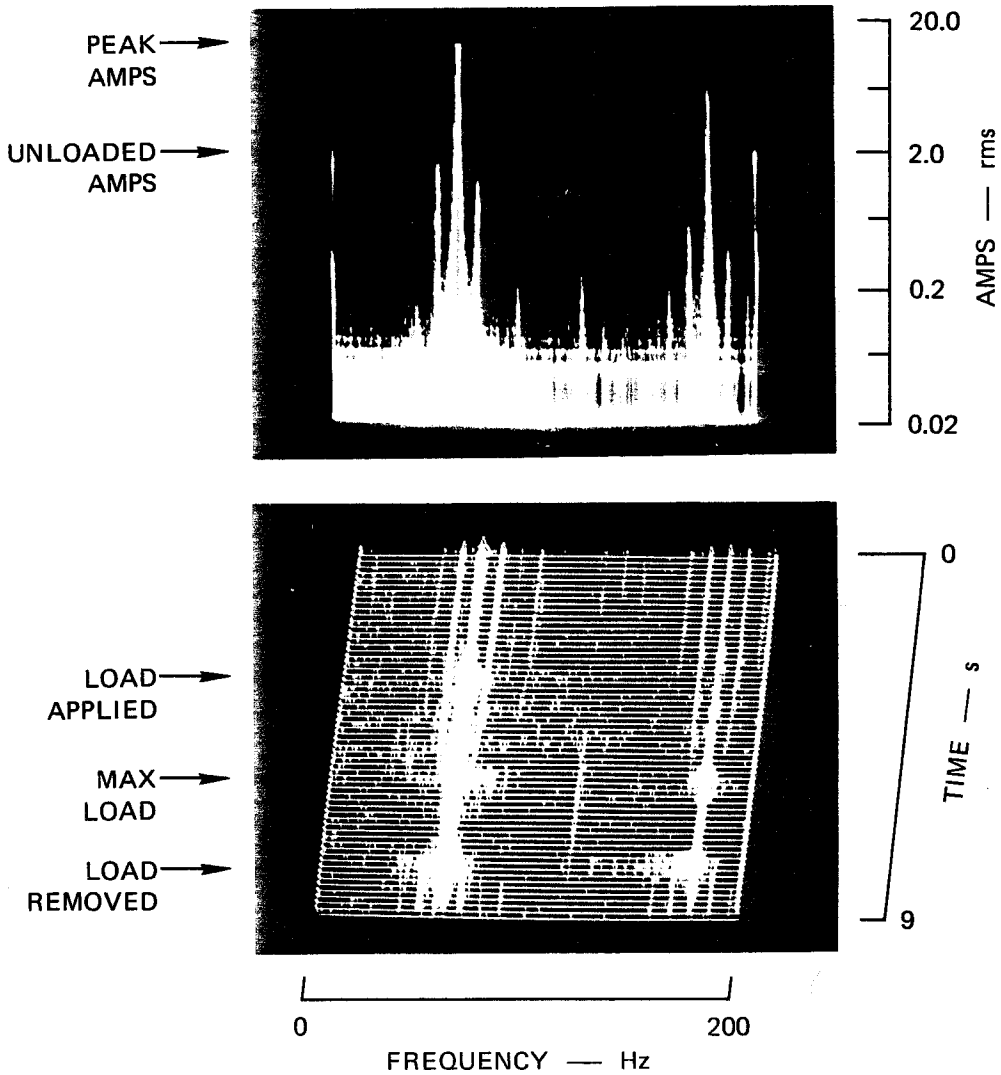

Figure 5-17. Sideband Signals at 60 Hz and Odd Harmonics

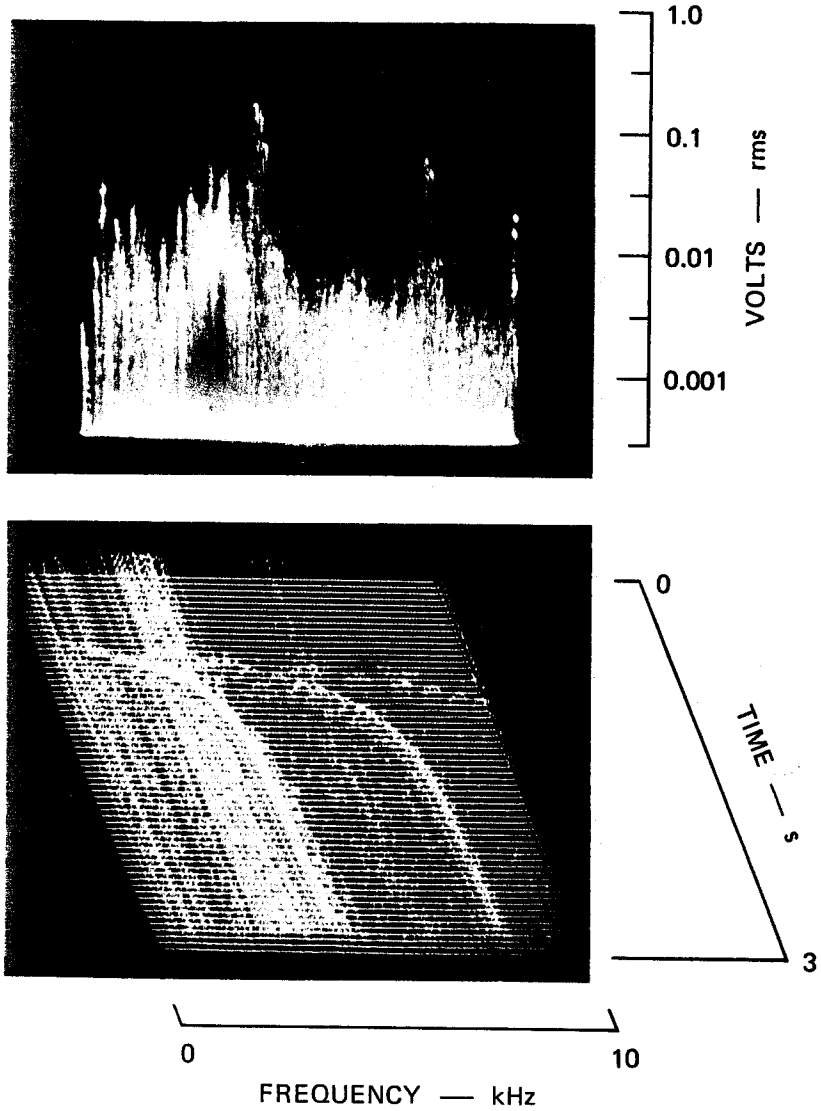

Figure 5-18. Frequency Varying Signals, 0 to 10 kHz

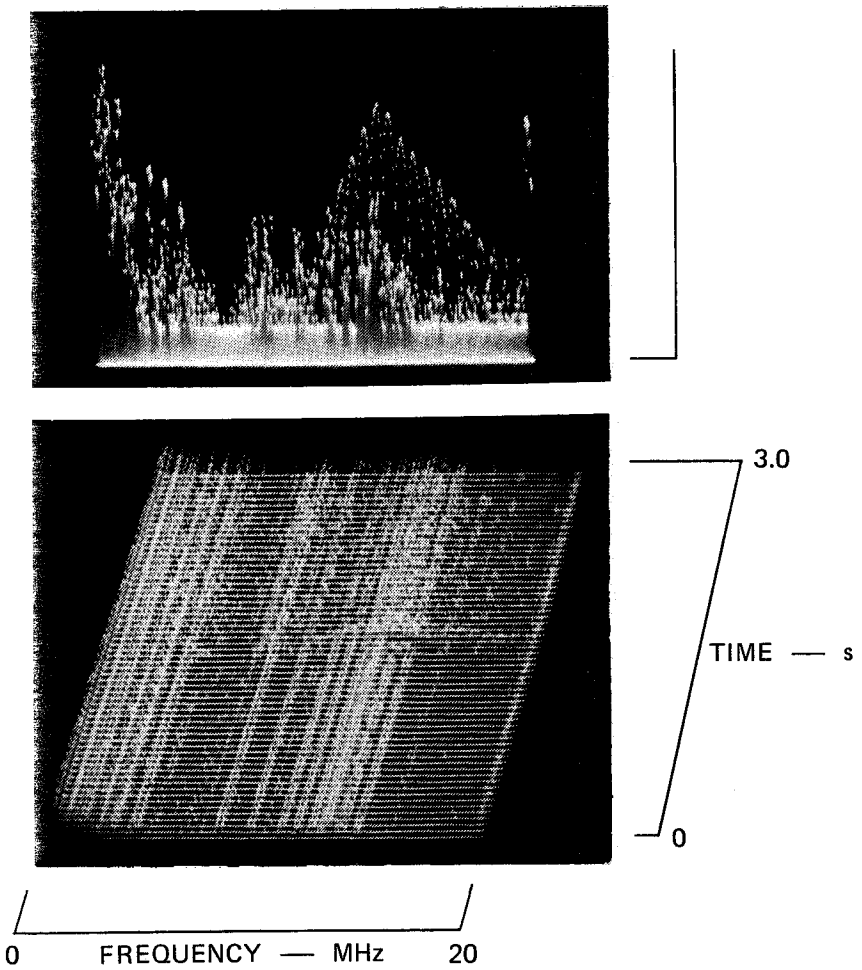

Figure 5-19. Spectral View of Transient, 0 to 20 kHz

5.2.4 Gap Noise

The term "gap noise" describes a common type of radio noise associated with distribution lines. The noise originates from minute discharges between two charged metallic objects located on distribution line support poles. These metal objects (braces, bolts, lag screws, insulator supports, and the like) are exposed to relatively high perodic electric fields from the distribution line conductors. If the metallic objects are not firmly connected or if a metal joint is corroded, minute discharges can take place between two metallic objects that have been charged to different instantaenous potentials. These discharges are very small, typically a few thousands of an inch in length.

Gap noise has distinctive temporal properties caused by source characteristics. The formation of a gap discharge results in a sharp decrease in the potential difference between the two metallic objects involved in the process. This decrease extinguishes the discharge. The potential difference then increases and reforms the discharge. This processes repeats itself until the waveshape of the line voltage causes a temporary decrease in the exciting electric field. Typically, 5 to 8 impulses will be formed at each peak in the line-voltage waveform. These small arcs cause current to flow in the metallic objects involved. The impulses cause broad-band impulsive noise to be radiated directly from the hardware and inductively couple the impulsive noise to the distribution-line conductors.

The gap-noise source mechanism has been extensively studied by Arai et al in a series of laboratory investigations [3]. While the laboratory results presented by Arai and his associates are consistent with results from field measurements, important differences in the temporal and spectral structure of gap noise measured in the laboratory and in the field have been noted. For example, the spectral structure of gap noise measured in the field is modified by the electric resonance of the metallic objects involved, and the peak radiated amplitude occurs at the resonant frequencies of metal hardware attached to the source or near the source. Maximum radiated field strengths in the general vicinity of a gap noise source usually can be found at VHF frequencies. At lower frequencies (500 kHz to about 15 MHz), gap noise is inductively coupled into the distribution-line conductors, and it is then conducted along the line for several pole spans. If other nearby support poles have gap noise sources, then these lower-frequency signals can cause gap noise to appear along significant sections of a distribution line.

Gap-formation processes depend on weather. Gaps become conductors when wet and will not support the discharge process. Gap noise increases during dry periods and decreases during peroids of high humidity and rain. The dependence of the gap process on humidity causes the effects of gap noise to vary as a complex function of diurnal and weather conditions. Also, minor physical changes in the gap configuration can affect the discharge process. The physical movement of poles, conductors, and hardware by wind or by striking a support pole with a hammer, boot, or other object can alter the discharge process.

Gap noise was investigated on distribution lines operating at 12, 24, and 35 kV. In all cases, the general spectral and temporal characteristics of the noise were similar. The number of support poles/ mile containing gap noise sources, however, was considerably higher for distribution lines operating at 35 kV than for lines operating at the lower voltages.

Figure 5-20 shows the temporal structure of gap noise from a single source on a support pole for a single-phase 13.8-kV distribution line at a measurement frequency of 55 MHz. The figure shows groups of impulses spaced at 8.33-ms intervals. The amplitude-versus-time view in the upper part of the figure shows that all impulses were constant in amplitude. In the 3-axis view of the same data, the temporal structure of the noise for 60 successive scans of data is shown. Small variations in timing from one impulse to the next impulse and from one scan to the next scan are shown in the 3-axis view. Small variations in impulse timing from instabilities in the discharge process are shown in the view.

Figure 5-21 shows gap noise from multiple sources on the support pole of a three-phase 13.8 kV distribution line. Four distinct gap-source mechanisms can be identified in the data. The constant amplitude characteristic of each individual group of impulses and the timing of the groups of impulses associated with voltage peaks of the three-phase line aid in analyzing the complex temporal structure of noise from multiple sources.

Figure 5-22 shows the temporal structure of gap noise from a 34.5-kV distribution line. The temporal properties are remarkably similar to that shown for the two previous examples that were taken from a 13.8-kV distribution line. No feature in the data was found that could be related to the operating voltage of a distribution line. Other examples of gap noise obtained from sources on towers supporting a 235-kV transmission lines were also similar and could not be distinguished from distribution line gap noise.

The spectral structure of gap noise shows that the sharp impulses created by the discharge process cover a wide range of frequencies. Figure 5-23 shows the spectral detail of a single source of gap noise on a 34.5-kV distribution line. Peaks and nulls in the noise amplitude versus frequency were caused by the resonance properties of the noise radiation mechanism. The arrangements of the peaks and nulls change from source to source of gap noise, but the general nature of the spectral view is similar for all sources.

The previous examples were taken from sources of gap noise that were relatively stable over periods of several minuites. Sources of gap noise often operate erratically. Figure 5-24 shows gap noise with brief interuptions in the discharge process. These interuptions become more frequent as the source becomes less stable from increased humidity or changes in physical configuration. A source of gap noise can change rapidly from a continuous source to an intermittent source to a nonsource.

The presence of a nearby source of gap noise can be ascertained from the unique and distinctive temporal and spectral characteristics

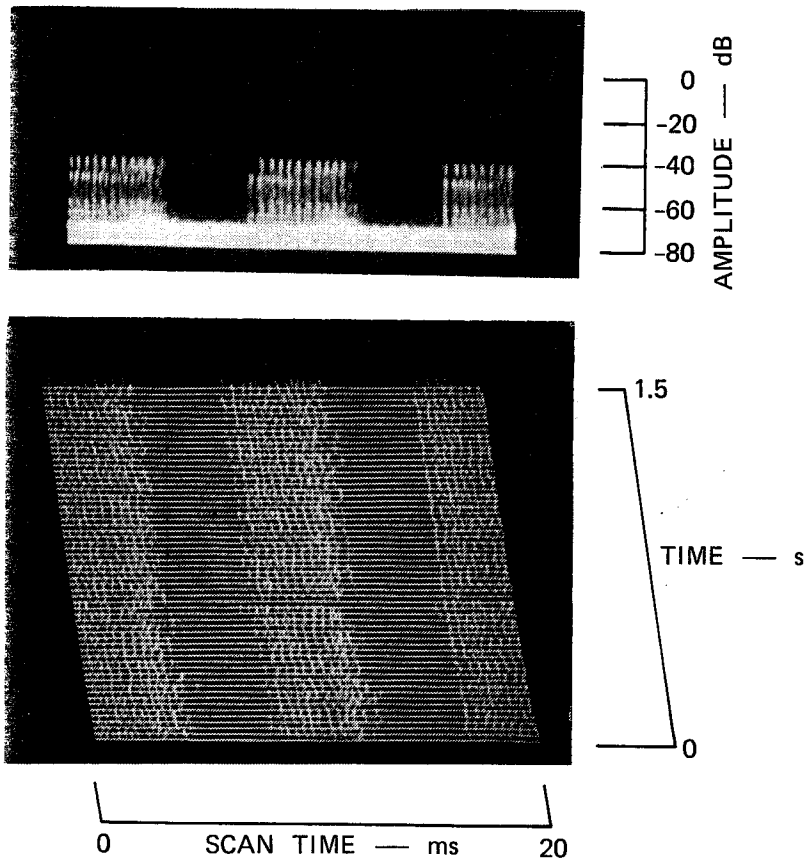

Figure 5-20. Temporal View of Gap Noise at 50 MHz, 13.8-kV Line, Single Dominant Source

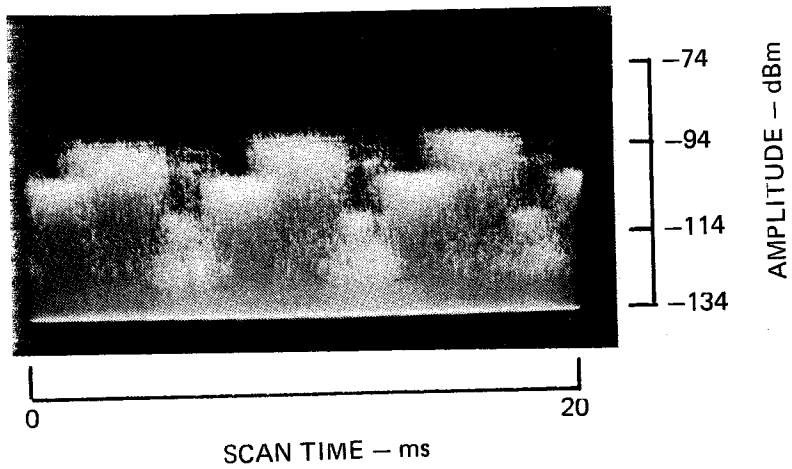

Figure 5-21. Temporal View of Gap Noise at 55 MHz, 13.8-kV Line, Multiple Sources

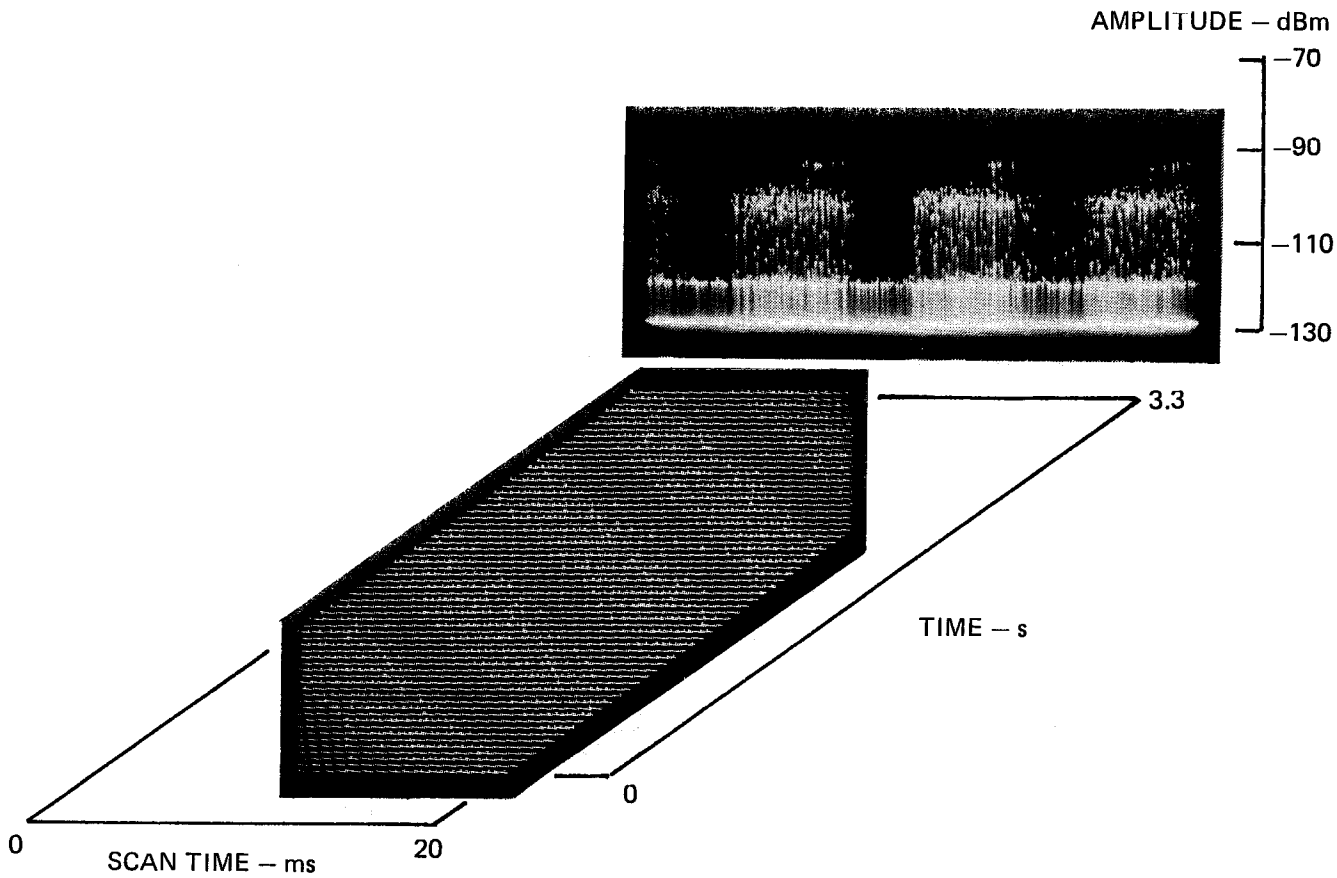

Figure 5-22. Temporal View of Gap Noise, 34.5-kV Line, Single Source

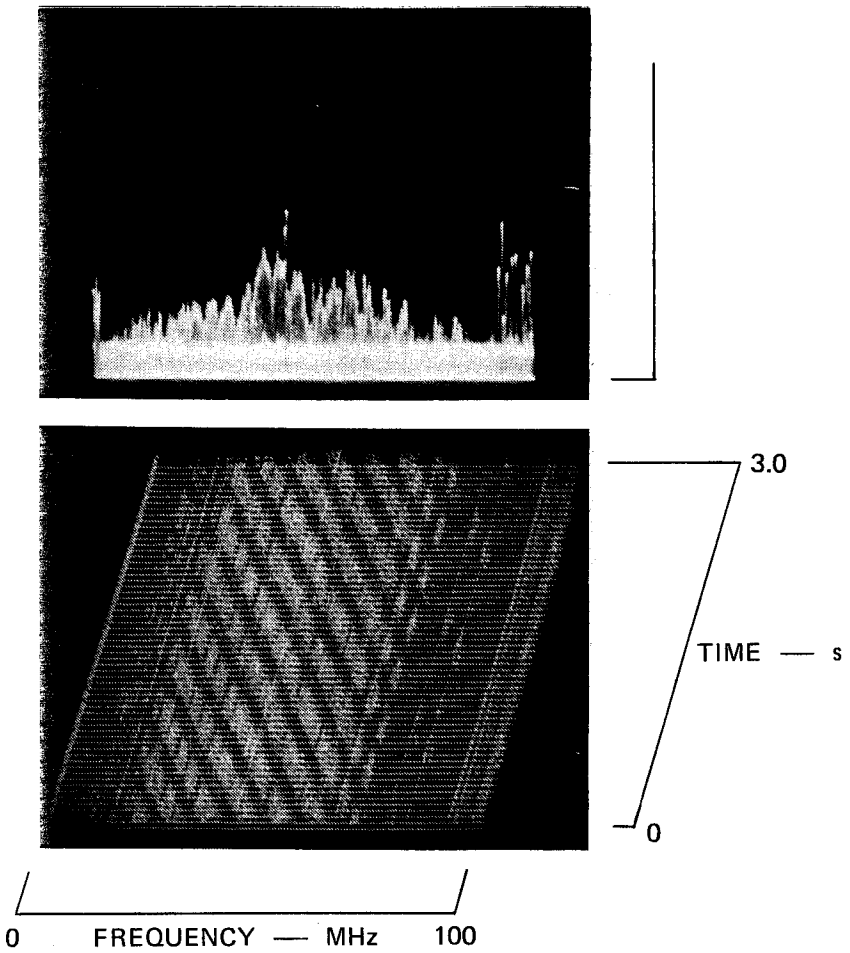

Figure 5-23. Spectral Structure of Gap Noise, 34.5-kV Line, Single Source

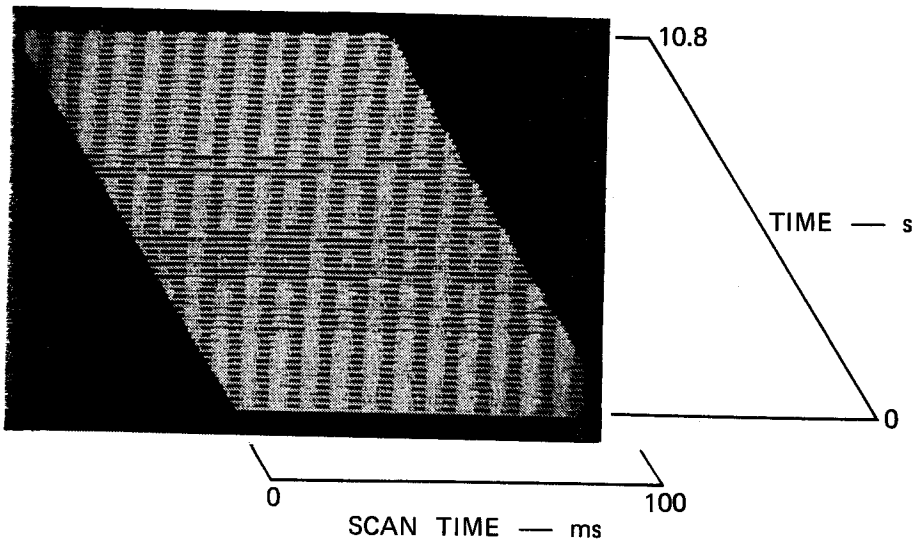

Figure 5-24. Brief Interruptions in Gap Noise

of the radiated noise. Locating the supporting pole containing the source can sometimes be confusing. A procedure for locating sources of gap noise was developed during the field work on EPRI Project 2017-1. It involved moving the instrumentation van along the distribution line at any constant speed up to about 50 kph. The scanning analyzer was adjusted to scan a large block of frequencies at VHF and UHF, and the output of the analyzer was shown on the 3-axis time-history display. A distinct peak in the frequency of received noise would show as the van passed by the affected support pole. Figure 5-25 shows an example of the peak in frequency of the broad-band noise from source of a gap as the van passed a support pole for a 13.8-kV line. Figure 5-26 shows an example of a distribution line with four adjacent support poles, each of which contained a source of gap noise. The pole labeled Hale-Kalana contained the most active source.

The technique of using a moving van with the scanning receiver and 3-axis display has proven to be a reliable means of locating active sources of gap noise. Often several passes had to be made along each distribution line to ensure that all the sources were located because intermittent sources were not always active on the first pass. In addition, the technique could only be used only on days with low humidity. The technique suggests that reasonable success in locating sources of gap noise can be achieved with a fixed-tuned VHF AM receiver (an FM receiver is not suitable) that is tuned to any unoccupied frequency from about 150 MHz up to about 250 MHz. Ocassionally, this procedure will fail to find a gap source because of the presence of deep spectral nulls in the gap noise. This can be avoided by using two or more AM receivers tuned to widely spaced frequencies.

Most utility personnel are aware of the sensitivity of the operation of gap noise sources to physical changes in the source. Wind and other movement of hardware related to gap sources often change the noise characteristics. Noise crews often strike a pole with a sledge or shake a pole by pulling on a guy wire while listening to a radio to detect changes in noise level. Figure 5-27 shows variations in gap noise caused by such actions. Near the top of the 3-axis view (14 s on time axis) a pole with an inactive gap noise source was given a good swift kick by a utility worker's boot. A brief burst of gap noise occured. The pole was again kicked at 9 s on the time axis and another brief burst of gap noise occured. At about 4 s on the time axis, a metal conduit on the side of the pole was given a good stiff kick which resulted in a strong 3-s duration burst of gap noise. The amplitude-versus-frequency variations of the gap noise are shown in the top photograph of the figure. During operation of the gap noise source, the noise floor increased from 20 to 40 dB above the ambient noise of the location.

Figure 5-28 show another example of the pole with an inactive gap noise source when the pole was given a sharp blow 5 min after the previous example was obtained. The source of the gap noise was activated by the blow at about 10 s on the time axis and remained active for several minutes. The spectral and temporal properties of the gap noise were nearly identical to those shown in the previous example.

GAP NOISE

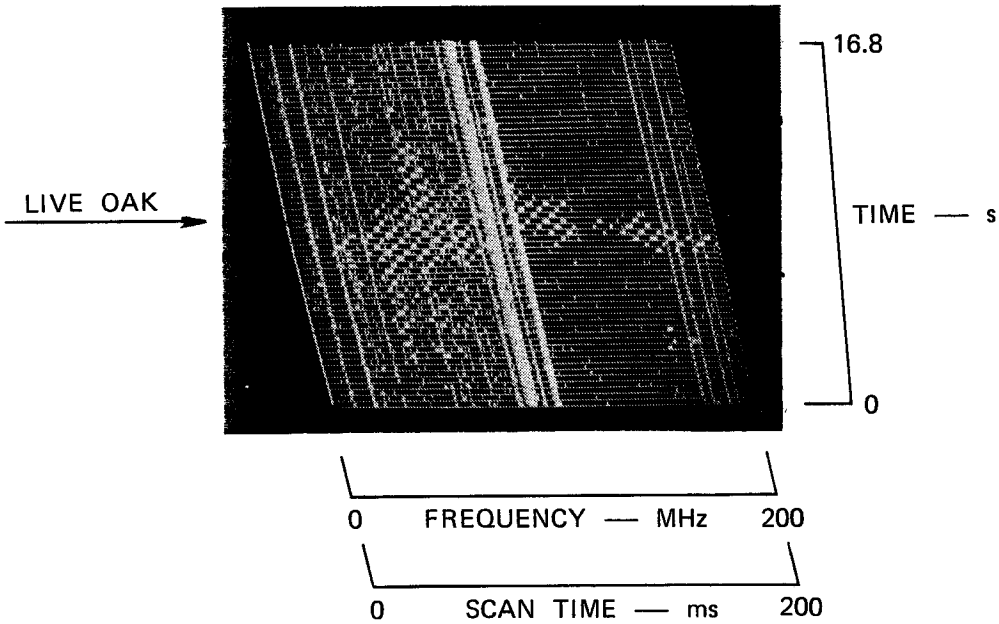

Figure 5-25. Frequency Peak from Moving Measurement of Gap Noise, Single Source

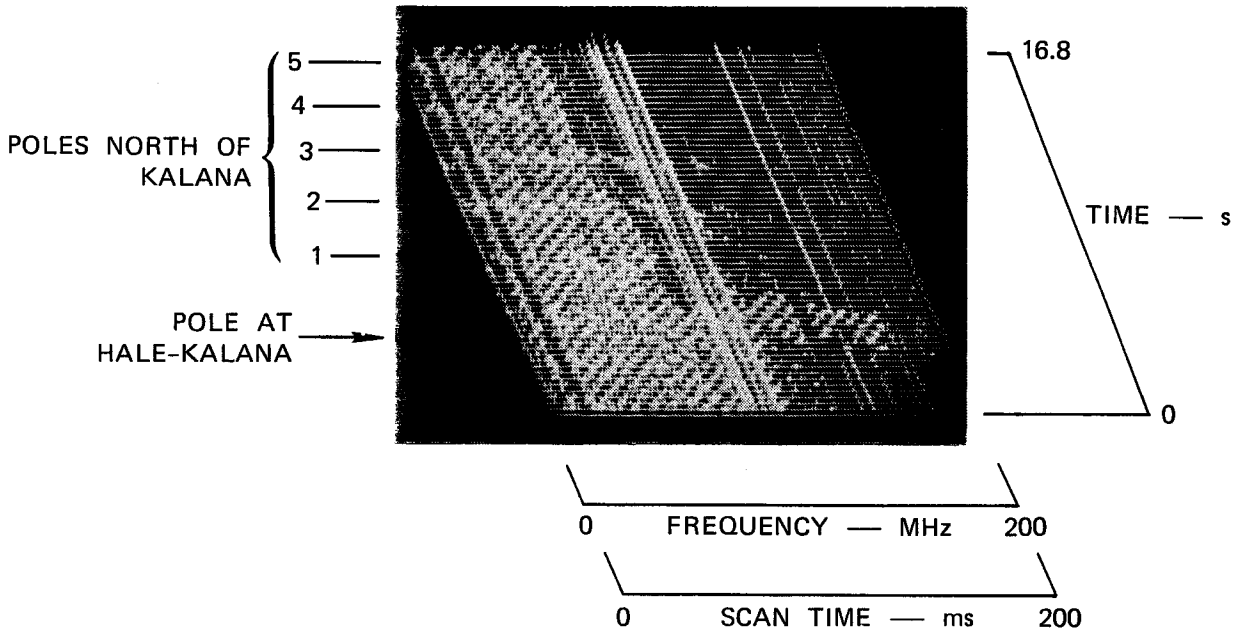

Figure 5-26. Frequency Peak from Gap Noise on Four Adjacent Line-Support Poles

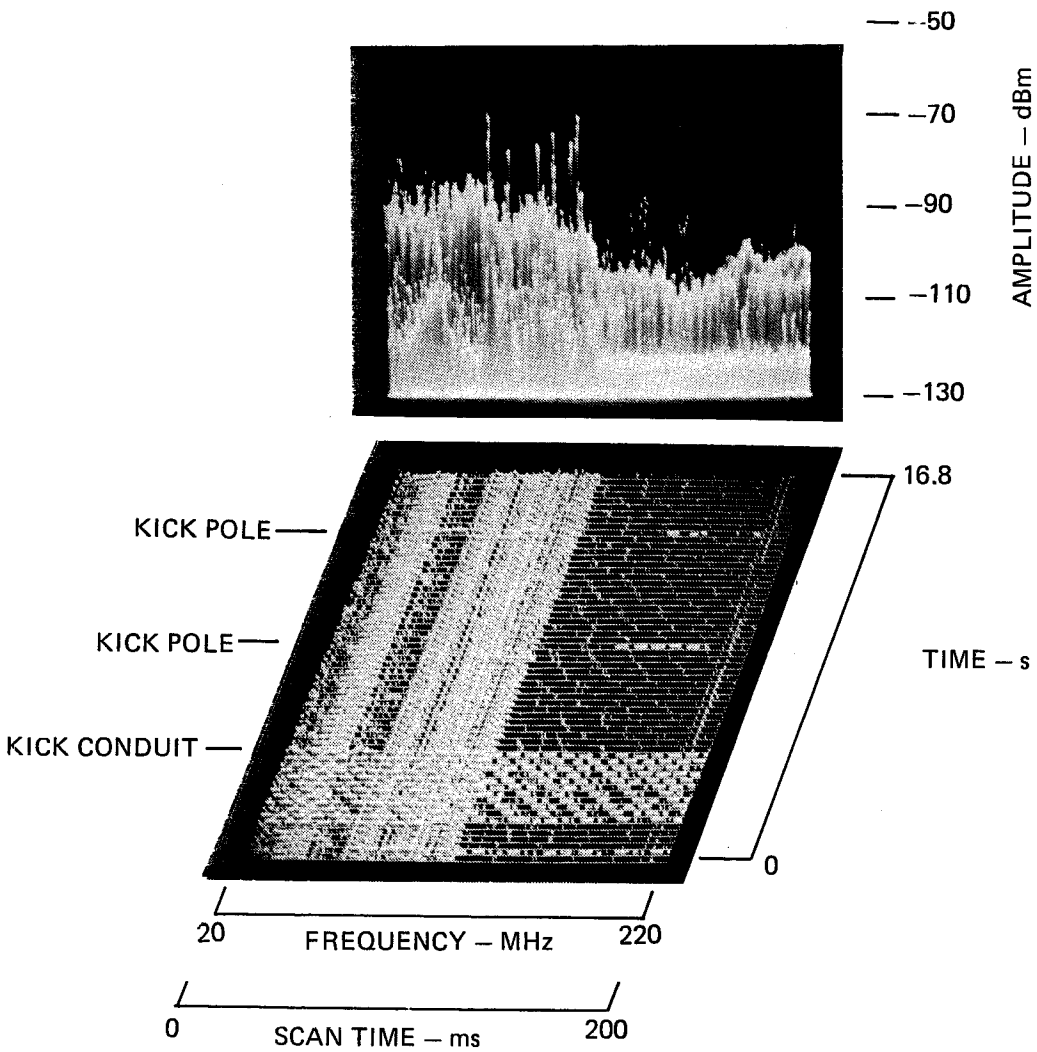

Figure 5-27. Temporal and Spectral Variations in Gap Noise caused by Striking Pole

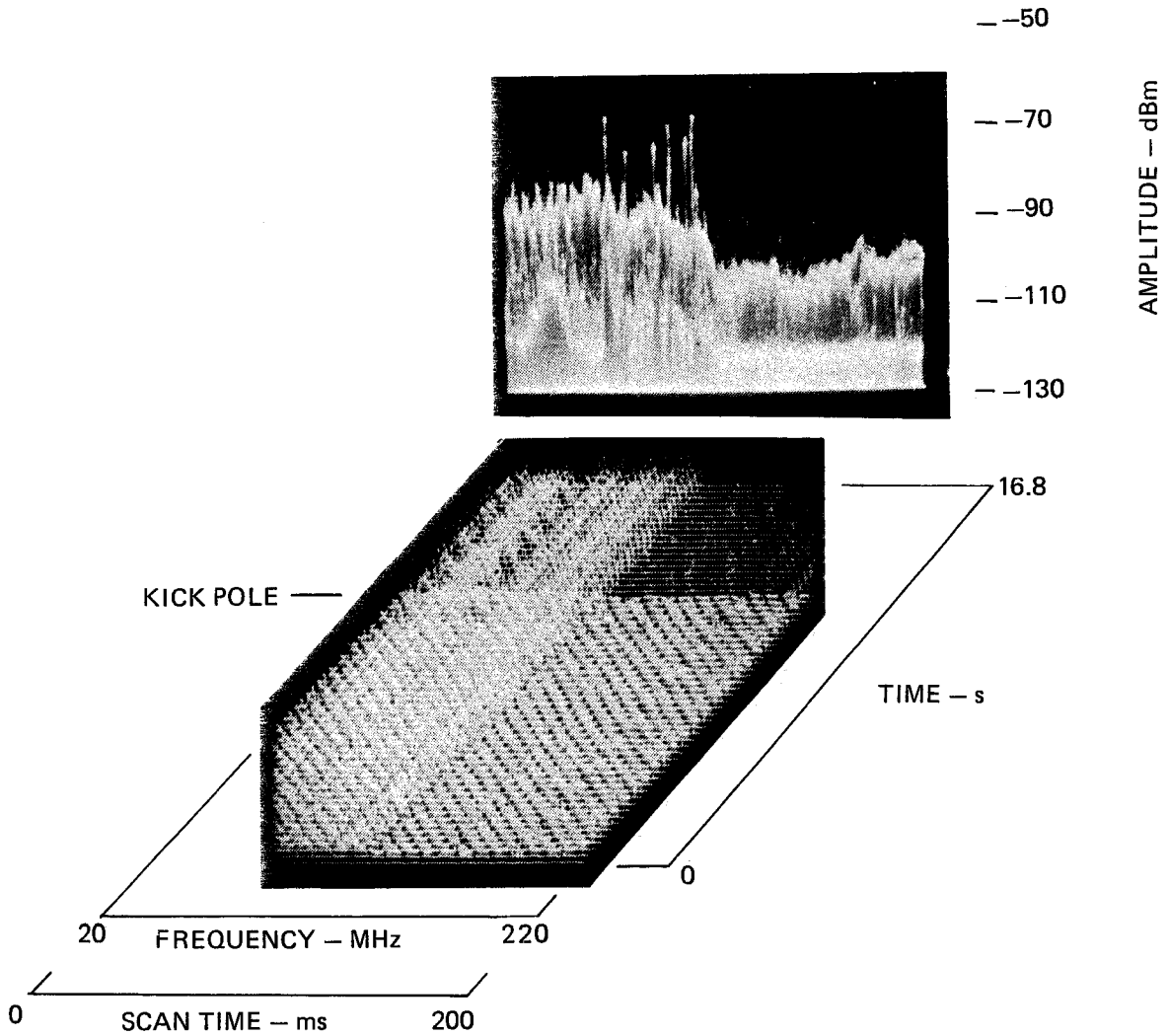

Figure 5-28. Temporal and Spectral Variations in Gap Noise caused by a Hard Blow to the Pole

Figure 5-29 show another aspect of gap noise. While we were examining the distribution-line pole containing the asource of gap noise, the wind speed increased to about 10 mph. This increased wind speed was sufficient to cause a slight movement in the distribution-line conductors and the support pole containing the gap source. Changes in gap noise are shown along the time axis of the 3-axis view.

Figures 5-27 through 5-29 show the high varibility of gap noise from a single source. These variations, along with additional variations from weather, make gap noise an extremely erratic and difficult type of noise to describe simply. In some cases a single pole will contain two or three sources of gap noise. Each source is usually independently erratic and variable: the resulting temporal and spectral structure of the radio noise produced by multiple sources can be quite complex.

5.2.5 Noise From Insulator Leakage

Radio noise was not found during the field measurements that could be traced to distribution-line insulator leakage. Several cases of reported insulator noise on distribution lines were investigated, and all cases were identified as gap noise. Examples of insulator failure from arcing, pitting, and developing carbon paths across the insulator surface were noted during the work, but the actual process of such failures on distribution line insulators that produced radio noise was not detected during the course of the work. This observation does not imply that all insulators used to support distribution line conductors were free from sources of noise. Some types of insulators contained metallic support structures sources of gap noise. Strings of bell-type insulators connected together to provide horziontal support for conductors, and hence were lightly loaded, were always excellent candidates for sources of gap noise.

The findings suggest, rather, that insulator leakage is not a widespread source of radio noise on distribution lines. The practice of hosing down dirty insulators on distribution lines probably temporarily stops the operation of sources of gap-noise more than it eliminates insulator leakage noise.

5.2.6 Other Noise

The dominant types of noise found on distribution lines are described in subsections 5.2.2 through 5.2.5. During the measurements, we found many additional forms of noise that were less prominent but still serious if encountered at a particular location and time. Examples of these less dominant types of noise illustrate their characteristics and potential for interfering with communication systems.

Figure 5-30 shows the temporal properties of a type of noise that was observed on the distribution lines of several utilities

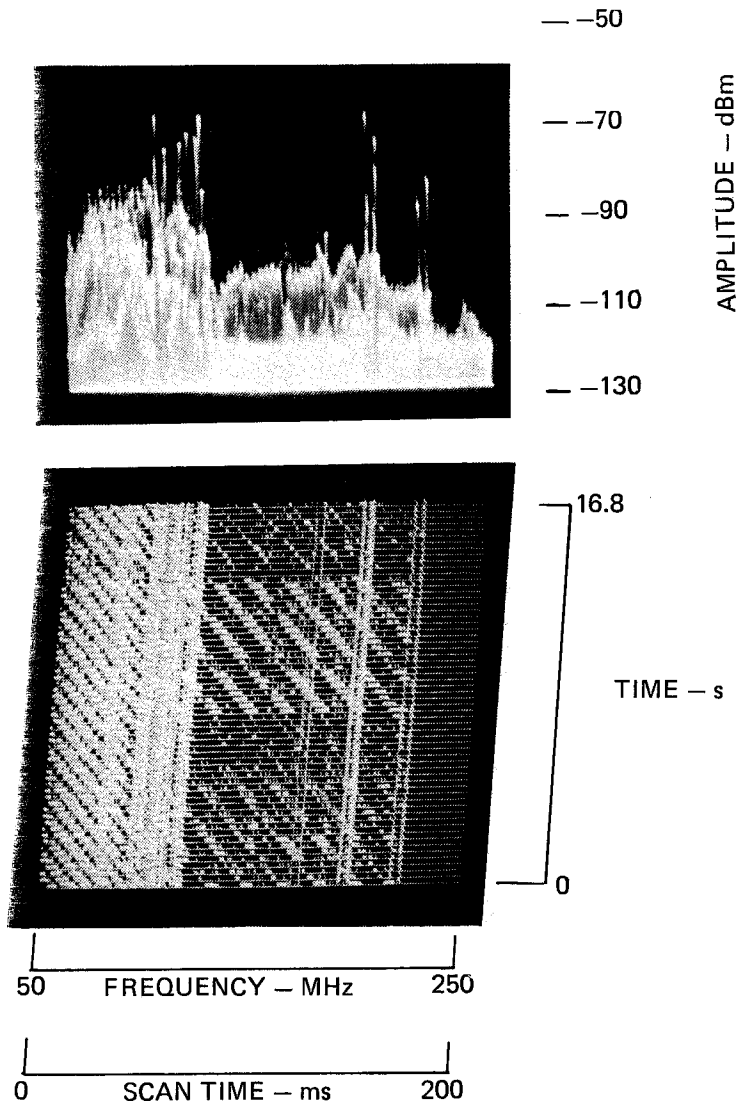

Figure 5-29. Temporal and Spectral Variations in Gap Noise caused by Wind Moving the Pole

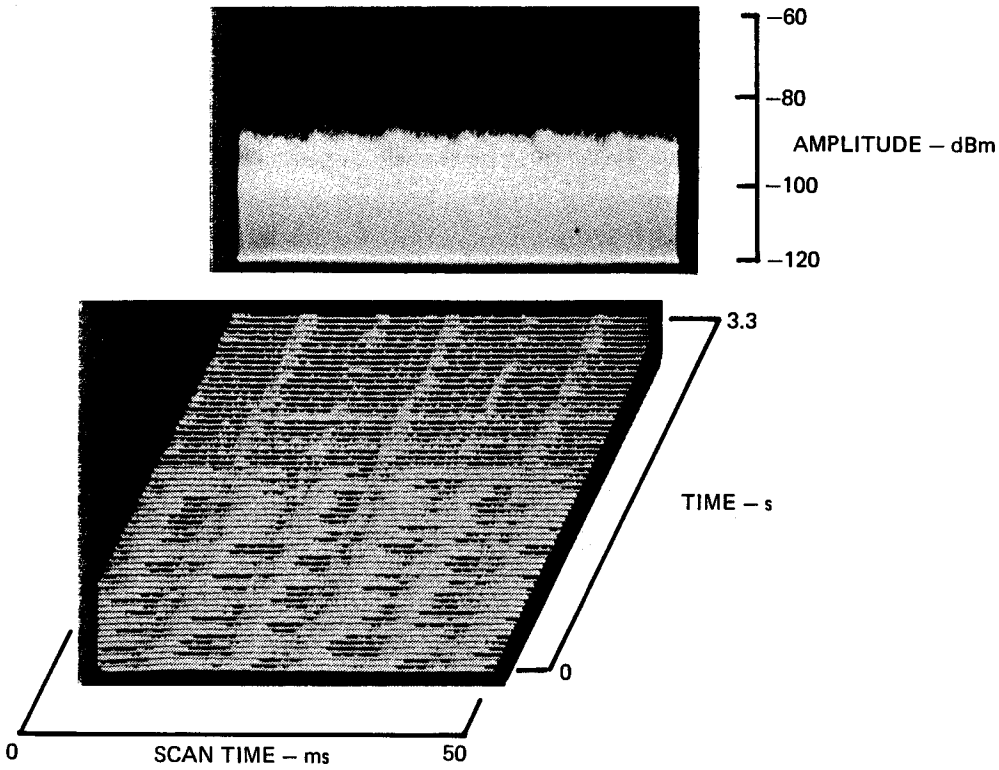

Figure 5-30. Temporal Characteristics of Noise from RF-Stabilized Welder

throughout the nation. The noise was highly intermittent, often very strong in amplitude, and, in some instances, was a major source of interference to communications facilities operating in the vicinity of the noise source. The noise was traced to an RF-stabilized welder operated by a manufacturer of small aluminum boats. Voltage and current impulses from the welder were conducted from the manufacturing plant to a nearby distribution-line transformer, the noise passed through the transformer and was imposed on the distribution line feeding the plant. A spectral view of noise from the RF-stabilized welder taken under the 13.8-kV distribution line feeding the plant about 30 m from the distribution-line transformer is shown in Figure 5-31. The distribution line conducted and radiated the noise into numerous homes, businesses, and a major communications facility. The noise shown in Figures 5-30 and 5-31 affected the reception of AM radio, FM radio, television, and other radio signals at residences along the distribution line to about three miles from the source. A major communication facility located six miles from the source was severely affected while the welder was in operation.

The severe interference caused by RF-stablized welders suggested that noise from standard arc welders be investigated. Only minor interference was encountered from standard arc welders at very short distances from welders.

Other kinds of signals and noise were occasionally observed during the field measurements. However, no additional signal or noise occured to the extent of those described above. Because all of the significant signals and noise on distribution system of primary interest to this study originated from devices operated by customers (except gap noise), the introduction of new electrical devices and products in future years may also introduce new types of noise into distribution systems. Past examples of new product introduction strongly support this suggestion. For example, the widespread use of SCR devices to controll loads introducted line-synshronous transients and their harmonics into the distribution system. This further suggests that the utilities must maintain a continuous vigilance for new types on signals and noise, and the utilities must continue to persue means to control and minimize customer generated signals and noise that are introduced into the distribution system.

The real-time presentation of the spectral and temporal details of noise by the instrumentation permitted the equipment operators to immediately identify new and intermittent noise. Each kind or type of noise observed during the measurements produced a distinctive visual signature. The ability to immediately distinguish one type of noise from another was of considerable value in the difficult task of identifying and locating noise sources.

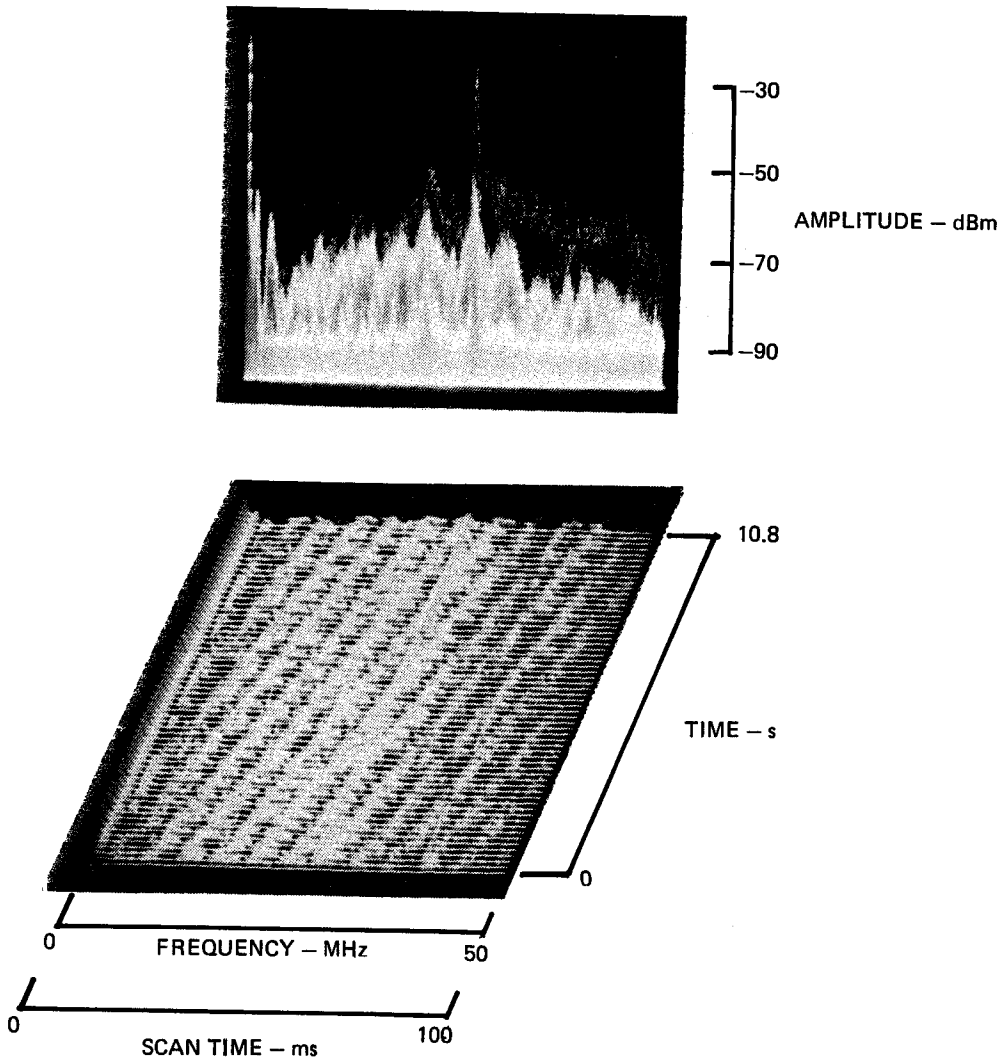

Figure 5-31. Spectral Characteristics of Noise from RF-Stabilized Welder

5.3 DISTRIBUTION LINE CARRIER SIGNALS

5.3.1 Measured Signals

Experimental DLC signals were installed at several of the utilities that were visited during project work. As stated earlier, defining harmonics and noise on distribution lines used for the transmission of DLC signals was emphasized. Whenever possible, DLC signals were measured, and the signal amplitudes were compared to noise levels. An attempt was made to gather as much data as possible at DLC terminals with a history of poor performance to gain insight into the causes of poor performance of some DLC terminals.

Figure 5-32 shows a DLC signal that was injected into a 12.0-kV distribution line at a substation. Transformer coupling was used from the DLC terminal to the distribution line. The carrier at 5800 Hz is shown along with modulation sidebands from the DLC signal. The signal injection current was about 12 A at the time of the measurement. No distortion or interference was found on the signal injected into the distribution line. The frequency scale of the spectrum analyzer was then expanded to examine the primary sideband near the carrier and the carrier. Figure 5-33 shows the expanded view. The sidebands and the carrier are also free of distortion in the expanded view.

Figure 5-34 shows the DLC signal at a location several miles from the substation at a remote terminal used to control a residential load. The voltage injected into a DLC receiver at the remote location is shown along with other discrete frequency signals. The discrete-frequency signals shown in the view are mixture of modulation sidebands and harmonics of the power-line frequency. The harmonic number is identified at the top of the view along with the sidebands. The sidebands are about 10 dB higher than nearby harmonics, which is a sufficient signal-to-noise margin so that the DLC system can be operated satisfactorily. Harmonics were present at all remote terminal locations that were examined during the project, and the signal-to-harmonic ratio was similar, or larger, than that shown for most remote terminals.

A remote terminal location with a history of poor and intermittent performance was selected for measuring signal and noise amplitude. Figure 5-35 shows the voltage and current at the terminals of the remote DLC receiver during the transmission of a test signal from the substation associated with the terminal. The voltage signal was used by the receiver for signal detection. The DLC carrier and sidebands were below the level of nearby harmonics, and the level of the signal voltage compared to the harmonics was clearly insufficient for satisfactory performance of the remote terminal receiver. A comparison of harmonic amplitudes with those of Figure 5-34 show that the harmonic levels are similar for both cases, but, that the signal level is lower in Figure 5-35.

A second location with a history of poor performance was investigated. Figure 5-36 shows the amplitude of the signal, modulation sidebands, and harmonics. The signal, sidebands, and

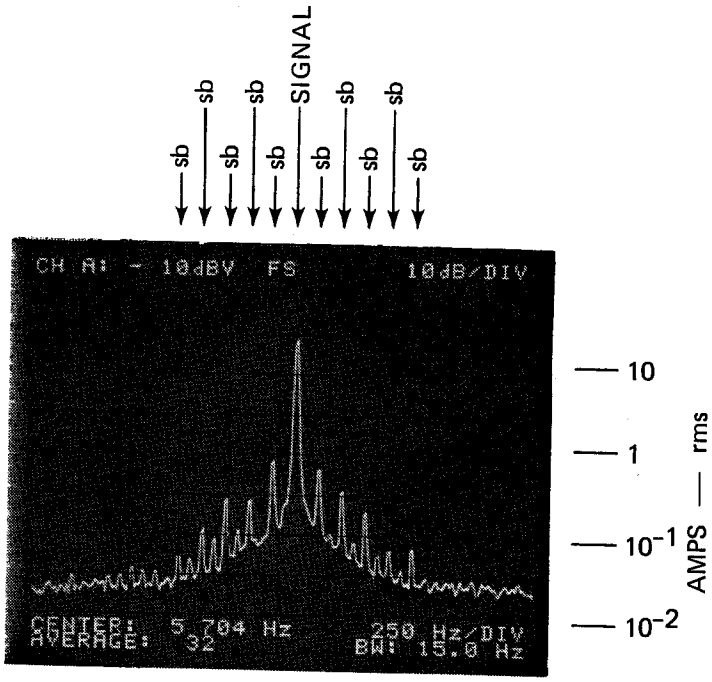

Figure 5-32. DLC-Transmitter Signal, Substation Location, Transformer Coupling

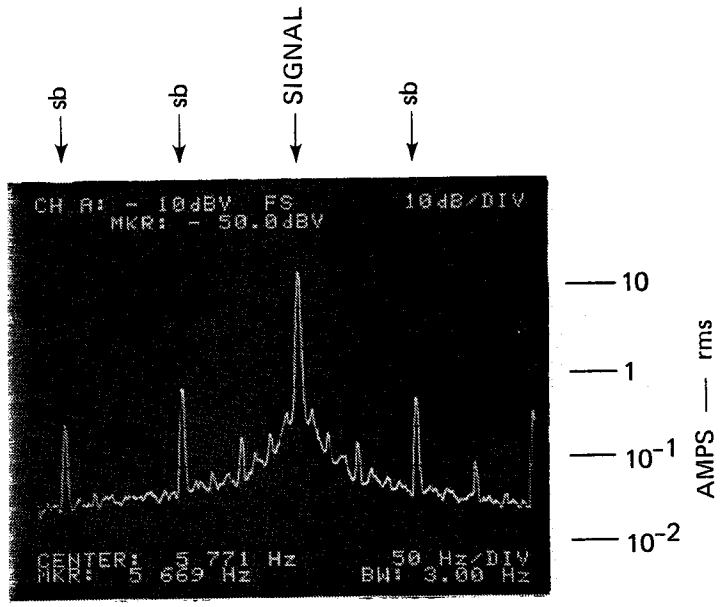

Figure 5-33. Expanded View of DLC Signal

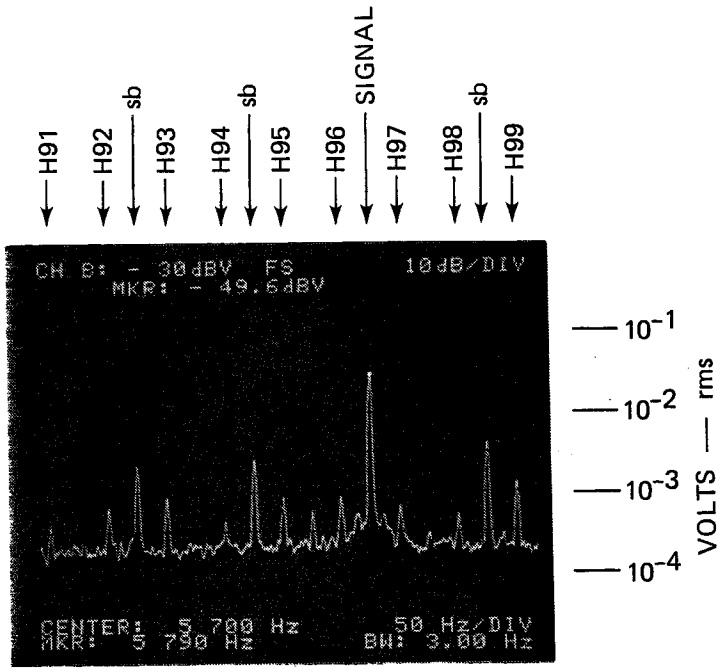

Figure 5-34. DLC Signal, Remote Location A, Transformer Coupling

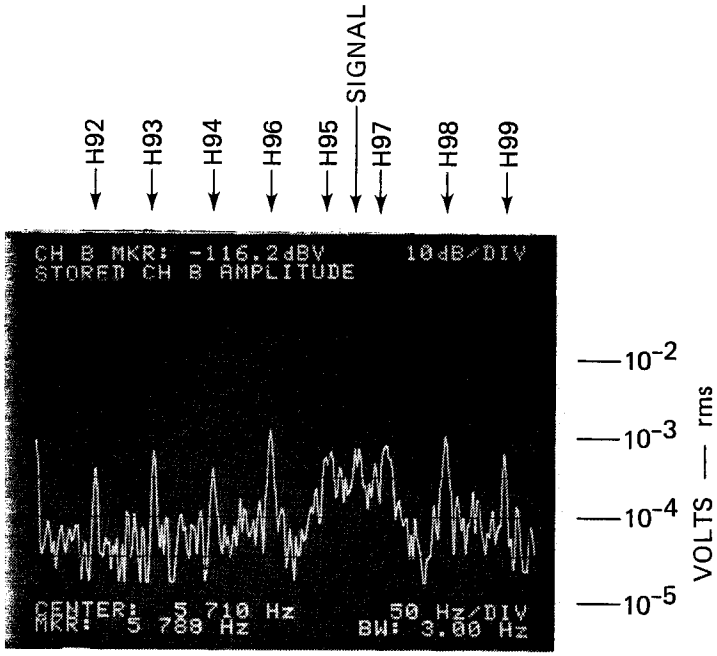

Figure 5-35. DLC Signal, Remote Location B, Transformer Coupling

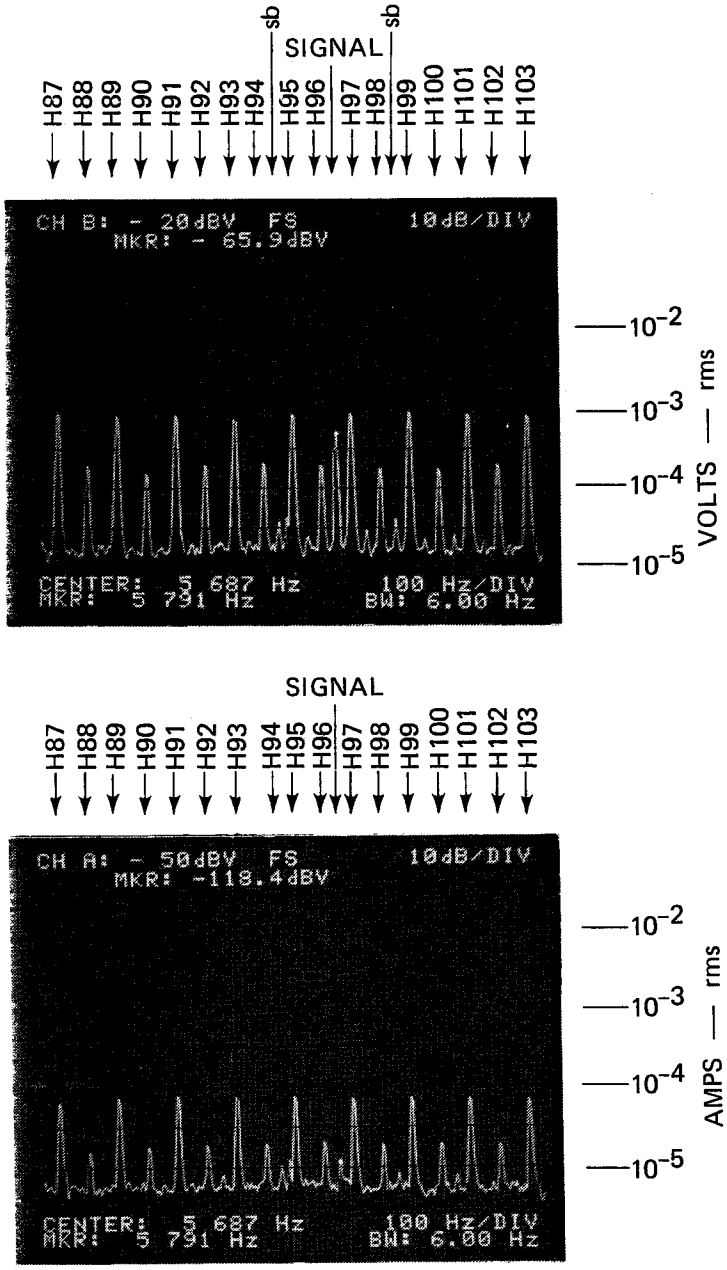

Figure 5-36. DLC Signal, Remote Location C, Transformer Coupling

harmonics are identified along the top of the view. Again, the signal and sideband amplitudes are below that of nearby harmonics. The signal-to-harmonic ratio was insufficient for satisfartory operation of the remote terminal.

A third location with a history of marginal operation was investigated. Figure 5-37 shows the amplitude of the signal, the modulation sidebands, and the harmonics. The signal carrier was about 10 dB higher than the nearby harmonics, and the modulation sidebands were about equal in amplitude to the nearby harmonics. The spectral structure of the noise between the harmonics was more complex that in the previous examples. The resulting signal-to-harmonic ratio plus background noise was insufficient for reliable operation of the DLC system.

A fourth location with generally good performance was investigated. Figure 5-38 show tha amplitude of signal, modulation sidebands, and harmonics. The signal carrier was about 15 dB above the nearby harmonics and the modulation sidebands were 5 to 10 dB above the nearby harmonics. A comparison of harmonic levels in this figure with those in examples Figures 5-34, 5-35, and 5-36 show that the harmonic amplitudes were 10 to 15 dB higher for the fourth location. Even with the higher harmonic levels, operational performance was reasonable because of the increased signal level at the terminal location.

A DLC terminal with a history of poor performance at a fifth location was investigated. This location was relatively close to the substation, and good performance was expected at the remote DLC terminal because of a high signal-to-harmonic ratio. Figure 5-39 shows the signal measured at the receiver terminals of the remote terminal. Strong intermodulation sidebands spaced 60 Hz apart which prevented receiving the DLC signal modulation sidebands were found on the signal at the remote terminal. The transmitter signal was reexamined and found free of intermodulation. Figures 5-29 and 5-30 show the transmitter signal. A line survey indicated that the source of the intermodulation was near the remote terminal, but roads and terrain prevented completing a full line survey in the time allocated for the measurements. When the remote terminal was disconnected from the line, the intermodulation remained. When a nearby battery charger providing power for a remotely operated switch was disconnected, the intermodulation remained. No other obvious device that would produce intermodulation was located, but it remained clear that a nonlinear device that produced intermodulation products was near the remote terminal. The investigation was ended because of a lack of time for extensive troubleshooting.

The example of nonlinear mixing of DLC signals with the 60-Hz line voltage shown in Figure 5-39 was the only such example that was found during the project. Although apparently rare, some mechanism existed near the remote terminal that cause the intermodulation. Other remote terminals on the same distribution line were not affected by the intermodulation.

The examples provided in Figures 5-32 through 5-39 were selected from a large number of measurements to illustrate the reason for the poor performance of a few DLC terminals. These examples do not

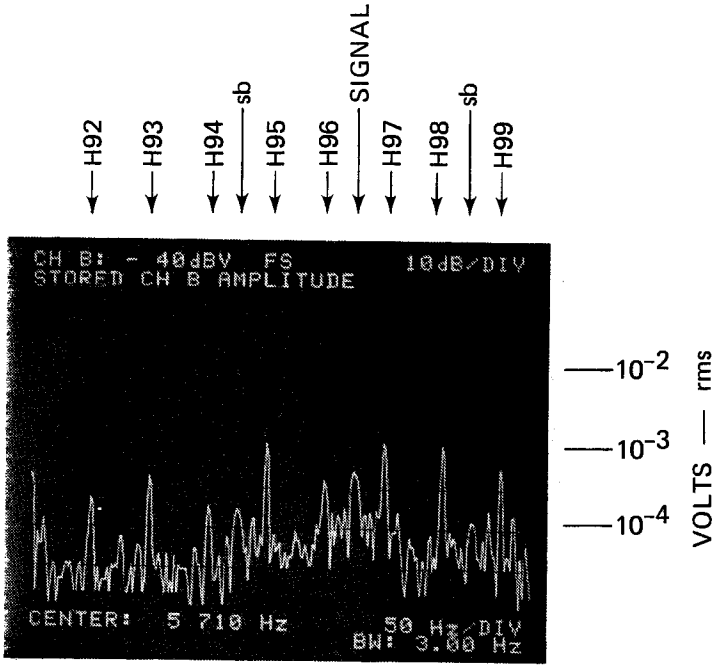

Figure 5-37. DLC Signal, Remote Location D, Transformer Coupling

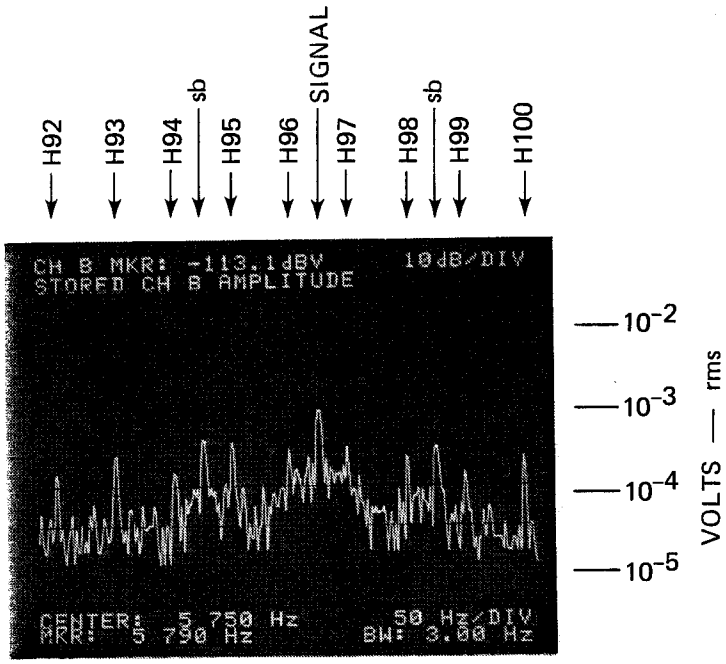

Figure 5-38. DLC Signal, Remote Location E, Transformer Coupling

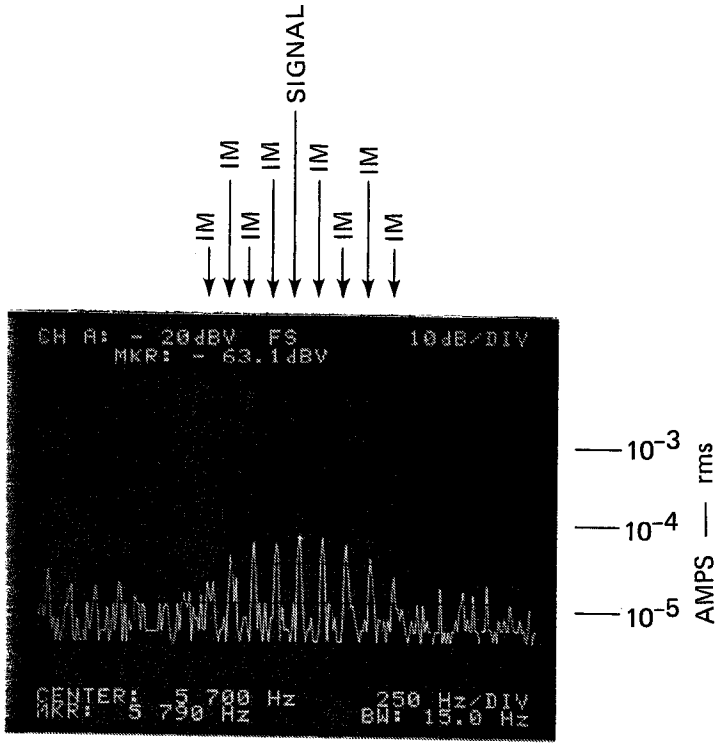

Figure 5-39. Unusual Intermodulation Products on DLC Signal

represent the much higher signal-to-harmonic ratios found at the majority of the DLC terminals that provide reliable service. They show that the dominant noise that limited the performance of DLC terminals was in the form of discrete frequency harmonics of the line frequency. In most cases, these harmonics originated from switching devices operated by customers.

5.3.2 Other Signals

During the measurements, a number of miscellaneous communication signals were found on distribution lines within the normal frequency range used by DLC systems. Several examples of these signals are provided to demonstrate their presence on distribution lines. Figure 5-40 shows a DLC signal at 5280 Hz and two other signals at 4280 and 6080 Hz. The data were taken at 1330 LT during a line survey at a location in the center of an isolated long section of a distribution line. The measurement location was free of customers for about a mile in each direction. The DLC signal shown in the figure was from a system under test by the utility. The non-DLC signals were from customers using the same distribution line for communication from one facility to another facility.

Five minutes after the data for Figure 5-40 were taken, another non-DLC signal was found at the same location on 7500 Hz (1335 LT). Figure 5-41 shows the 7500 Hz signal. Twenty-nine minutes later (1359 LT), the DLC signal was received along with two additional signals (Figure 5-42) at 3900 Hz and 7100 Hz.

At 1421 LT, the 4280-Hz signal reappeared along with another signal at 5630 Hz. Figure 5-43 shows these signals along with the DLC signal at 5280 Hz. At 1500 LT, the 7100-Hz and 7500-Hz signals reappeared with a new signal at 3700 Hz (Figure 5.44).

All non-DLC signals shown in Figures 5-40 through 5-44 were found on one distribution line. Seven communications signals (signals at 3700, 3900, 4280, 5630, 6080, 7100, and 7500 Hz) were found on the same line that the utility used for DLC a communication system operating at 5280 Hz. Additional signals may well be using the same line since the monitoring period lasted only a few hours. Fortunately, none of the observed signals interferred with the utility's DLC system. Of interest was that the utility was unaware of any of the presence of any of the signals on their line.

The use of utility distribution lines by customers was observed at many locations throughout the conutry. Apparently, this is a common informal practice that has grown from isolated cases into a general and growing situtation. The uncontrolled presence of such signals on distribution lines will sooner or later interfer with a utility-operated DLC system. The continued expansion of this situtation will eventually result in conflicts for frequencies and in the costs of resolving the conflicts.

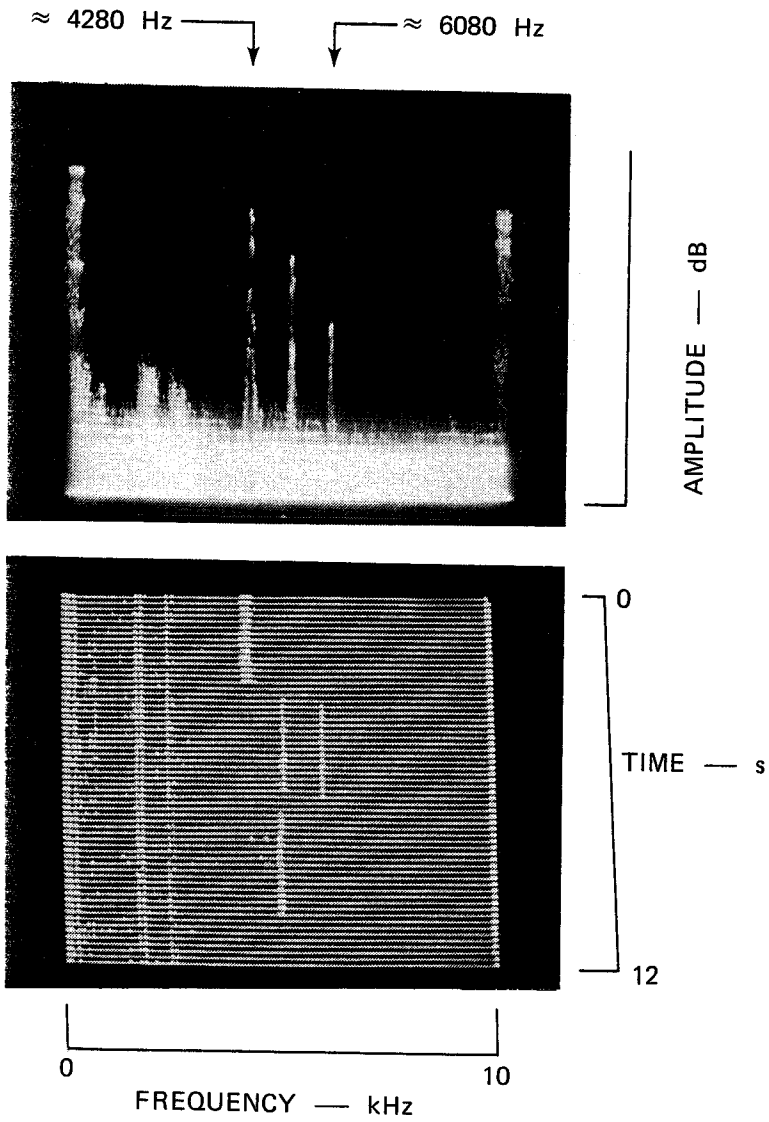

Figure 5-40 Other Signals, Example A

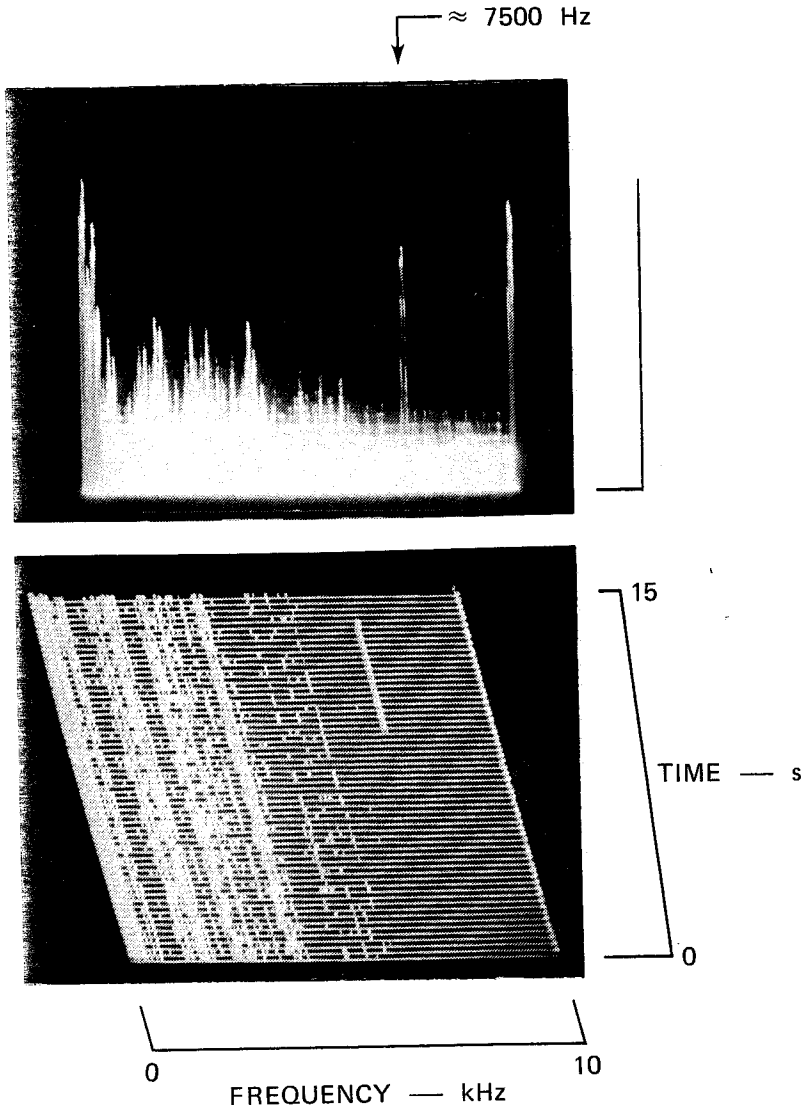

Figure 5-41. Other Signals, Example B

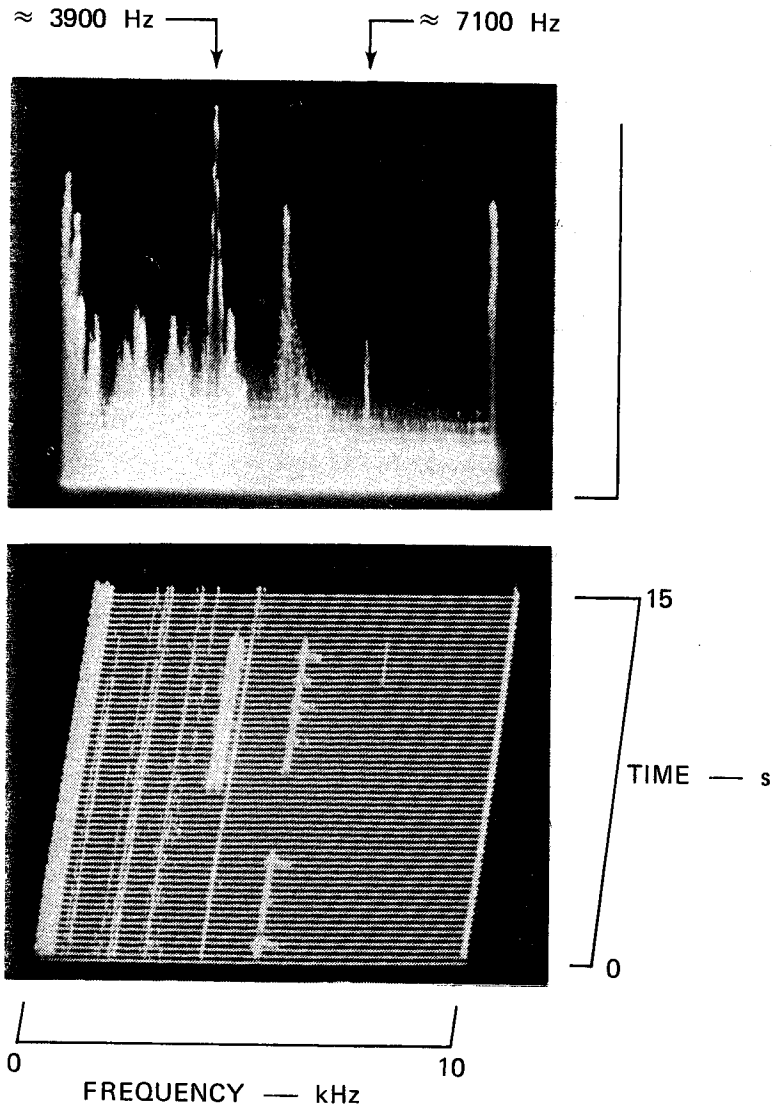

Figure 5-42. Other Signals, Example C

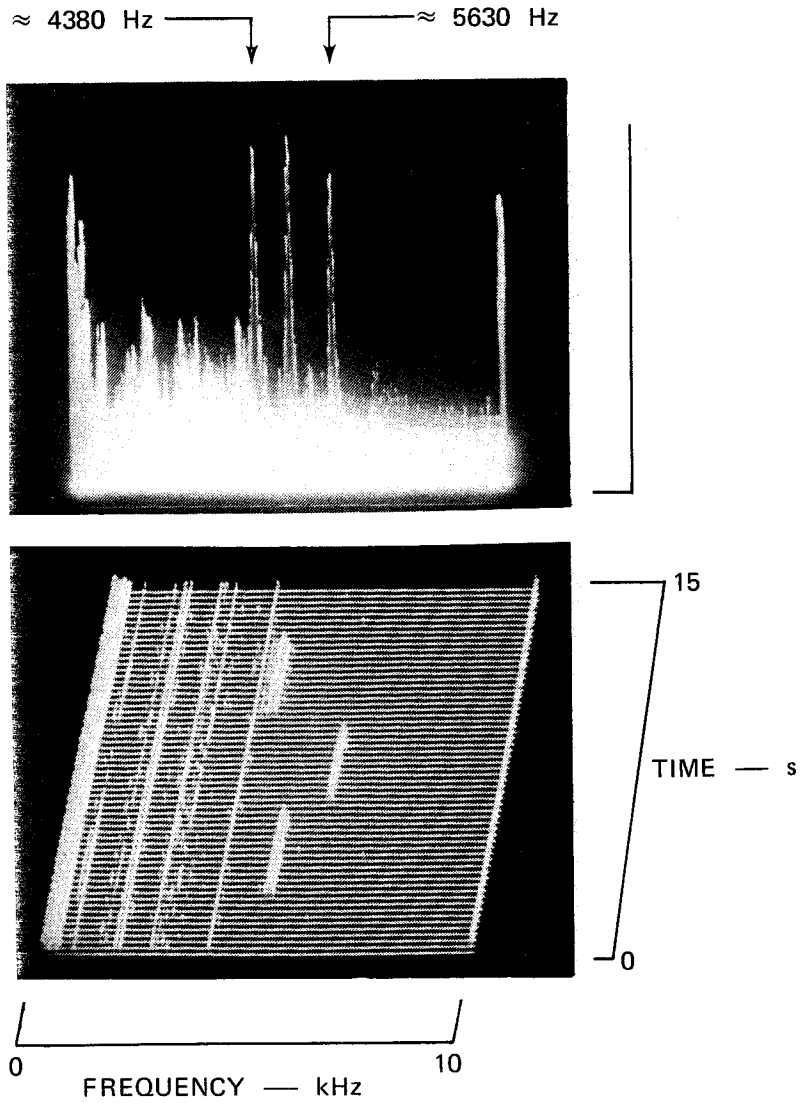

Figure 5-43. Other Signals, Example D

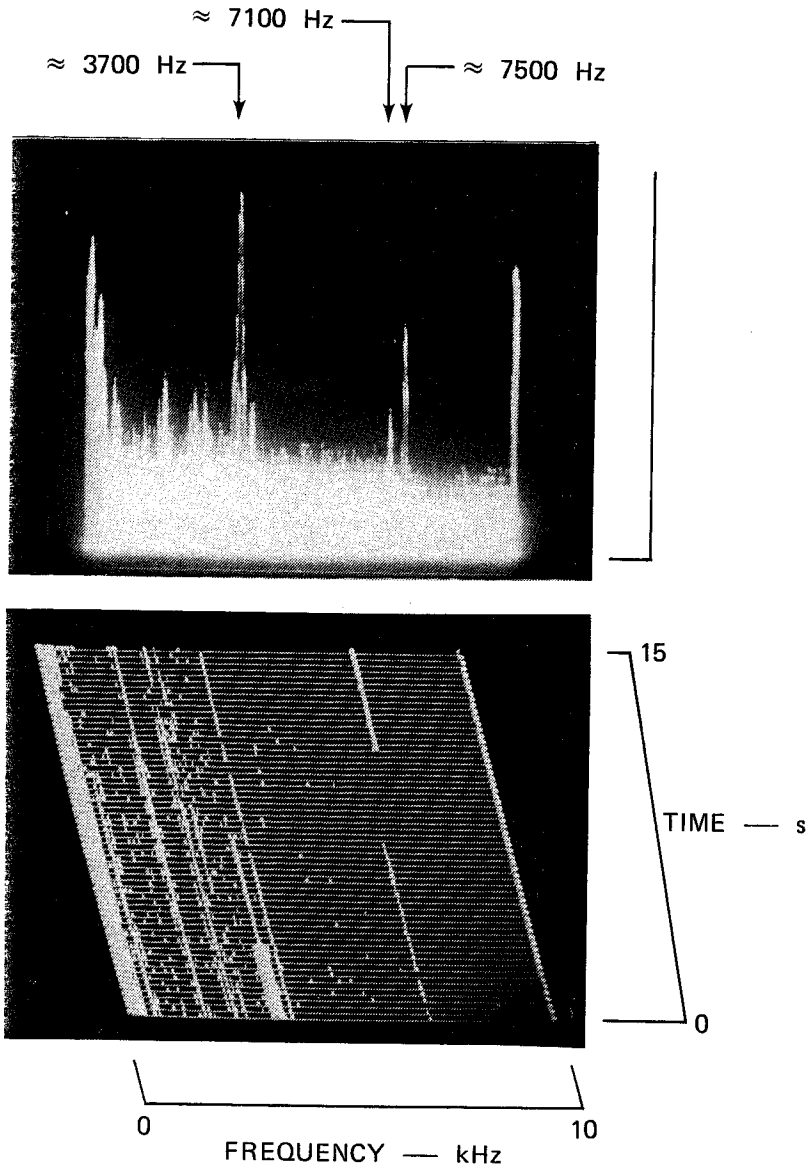

Figure 5-44. Other Signals, Example E

5.4 SUBAUDIO BROADCAST SIGNALS

Broadcast stations cover major metropolitan and suburban areas with strong signals. Major broadcast stations often cover significant portions of the operating area of utilities, and the introduction of subaudio modulation of the carrier of a broadcast station provides a reliable channel for communication from a utility to customers. The return channel from customers to the utility must be provided by other means.

The subaudio modulation of a broadcast station with an experimental communication system designed for the control of loads at customer locations was examined. Figure 5-45 shows a broadcast signal observed at a customer location with a 1-m rod antenna and a Watkins-Johnson single-sideband receiver. The upper sideband of the receiver was analyzed with the UA500A channelized analyzer and the 7200B display. The carrier signal is shown at its radiated frequency of 1070.000 kHz. The analyzer was adjusted to examine signals in a 500-Hz band of frequencies containing the broadcast carrier. Low-frequency audio modulation products from speech are shown on each side of the carrier frequency. Other low-level discrete frequency modulation products are also shown in the view. These products originated at the broadcast station. The subaudio signal was not present at the time of the view.

Figure 5-46 shows subaudio modulation sidebands from the utility's communication system that extend 30 Hz above and below the carrier frequency. The 5-s duration of the modulation is shown in the 3-axis view. Audio-modulation components from standard broadcast signals are also shown in the view. The subaudio communication signals and the broadcast signals are separated in frequency by the normal low-frequency response cutoff of the broadcast audio channels. Excellent signal-to- noise ratio was achieved over the normal coverage area of the broadcast station.

Figures 5-45 and 5-46 show the communication signals as received on a 1-m rod antenna. In most installations at customer locations, the rod antenna or an alternate loop antenna was installed in the near zone of power wires and close to harmonic and noise sources. At other installations, the power wiring itself can be used as an antenna. For these types of installations, additional noise and harmonics of the power-line frequency may be introduced into the communication system receiver. The necessary measurements to determine the signal-to-noise ratio at practical locations were not made under Project 2017-1.

5.5 SUBSTATION NOISE

Some communication systems suggested for use in distribution automation systems use VHF and UHF receivers that are located in or near distribution substations. Radio noise levels in and near distribution substations was examined at several utilities. Although an exhaustive study of radio noise associated with substation

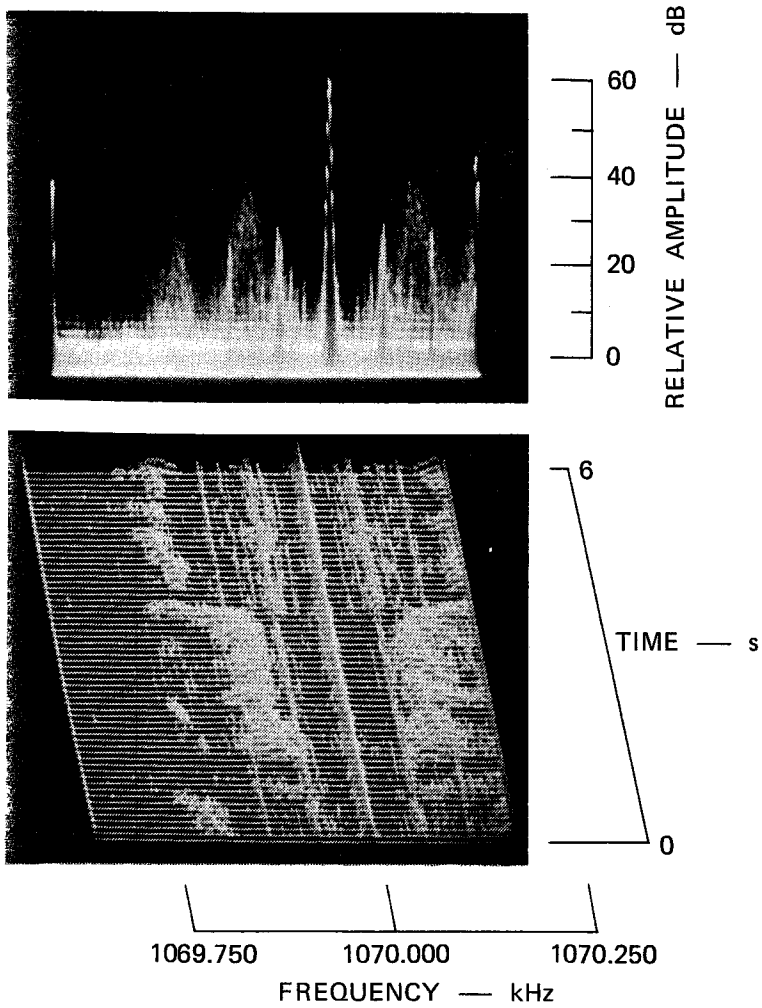

Figure 5-45. Audio and Noise Modulation of Carrier without a Subaudio Signal

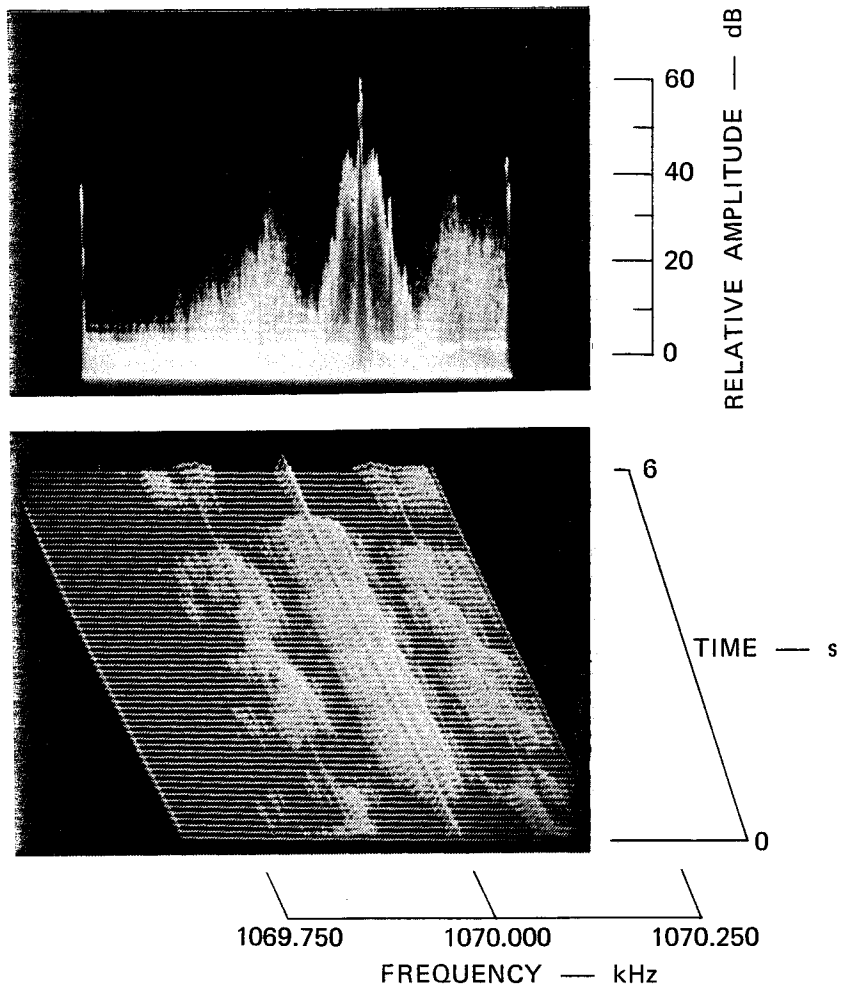

Figure 5-46. Audio and Noise Modulation of Carrier with a Subaudio Signal

locations was not conducted, the measurements did yield data of interest. Typical examples of such data are included in this subsection to provide the reader with a comprehensive summary of all types of radio noise that affect VHF and UHV communication systems.

Figure 5-47 show radio noise observed in a substation at a location near a 230-kV switch. The substation was compact and modest in size. Noise is shown over the frequency range of 50 to 150 MHz. The bottom 3-axis view shows that the noise had considerable temporal structure. The dominant temporal structure consisted of bursts of noise that were synchronized to the power-line frequency. The temporal structure changed somewhat with frequency and time.

The top view in Figure 5-47 shows variations in amplitude versus frequency of the noise. Signals from television and FM stations are shown as sharp vertical lines near the center of the frequency scale. The noise amplitude exhibits complex nulls and peaks.

Figure 5-48 shows the noise over a frequency range of 70 to 90 MHz. Sharper temporal detail is shown along with more consistency in the temporal structure because of the lower frequency span of the view when compared with the data in Figure 4-47. The 3-axis view shows relatively well defined bursts of noise spaced at 16.6 ms intervals along with somewhat erratic bursts of noise between the well defined bursts. The upper view shows variations in amplitude with frequency. The three distinct amplitudes are shown in the top view, which suggests the presence of three noise sources.

Figure 5-49 shows the same noise over a frequency range of 0 to 100 MHz. The data were taken at the same location as that of the previous examples but a few minutes later. The average amplitude of the noise remained generally constant over this period (the amplitude is about -60 dBm at 100 MHz in both views). The average amplitude decreased with decreasing frequency and was very low at frequencies less than about 1 MHz.

The temporal structure of the noise was examined in more detail at a frequency of 75 MHz by tuning the HP 140 spectrum analyzer to that frequency, setting the frequency span to 0 MHz, and synchronizing the analyzer time scan to the power-line frequency. Figure 5-50 shows the resulting temporal structure with the analyzer set on a 50-ms scan time. The dominant noise consisted of three well defined bursts of noise spaced 16.6-ms apart. All impulses in these bursts were constant in amplitude. Additional sets of constant-amplitude bursts appear about 10-dB lower in amplitude that were not as well defined temporally. Additional bursts of noise spaced at 8.33 ms intervals appeared at an amplitude of about -105 dBm. These bursts were not constant in amplitude. A careful examination of the data suggested that additional noise impulses existed at very high amplitudes, however these impulses were not sufficiently well defined in Figure 5-46 to permit analyzing them.

The time scan of the analyzer was changed to 20 ms to provide better temporal resolution of a portion of the substation noise. Figure 5-51 shows the resulting temporal structure of substation noise at 75 MHz. Two amplitude-versus-frequency views are shown along with the 3-axis view. The signal threshold control of the

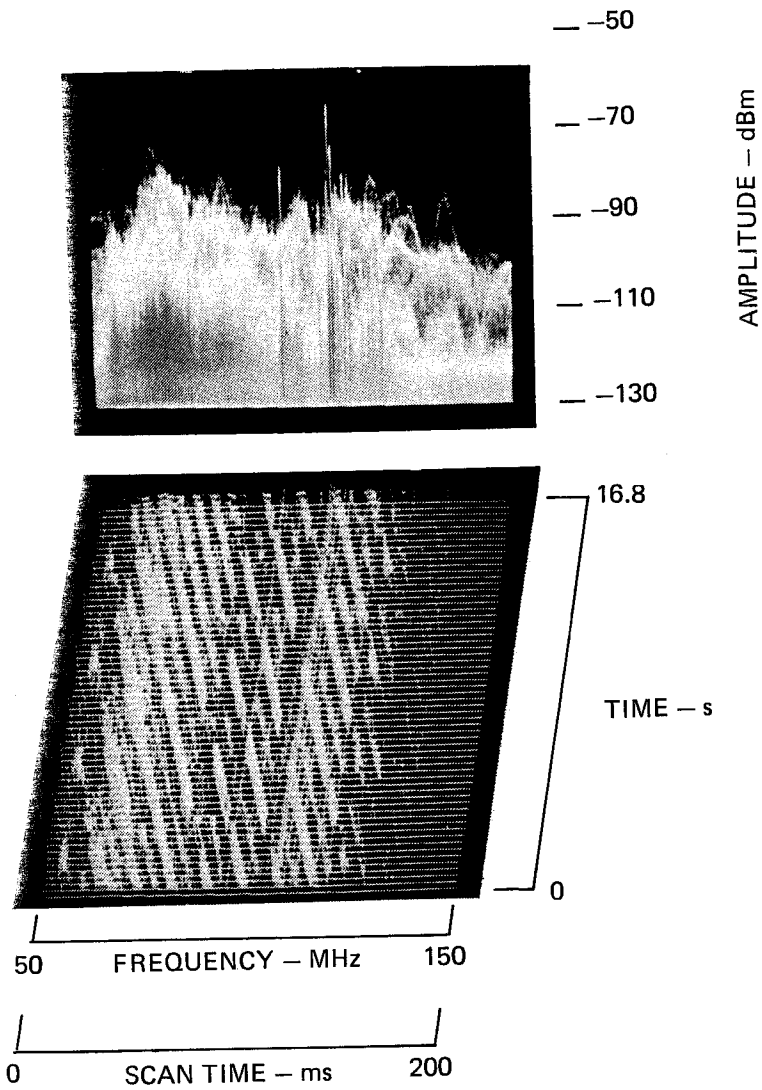

Figure 5-47. Substation Noise, 50 to 150 MHz

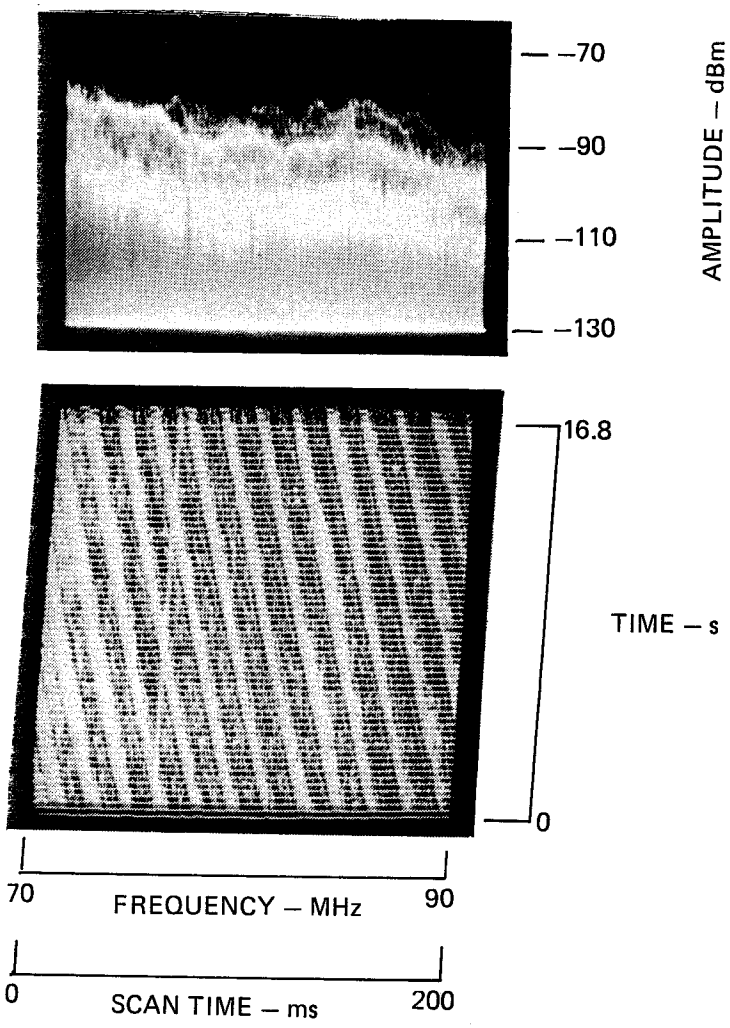

Figure 5-48. Substation Noise, 70 to 90 MHz

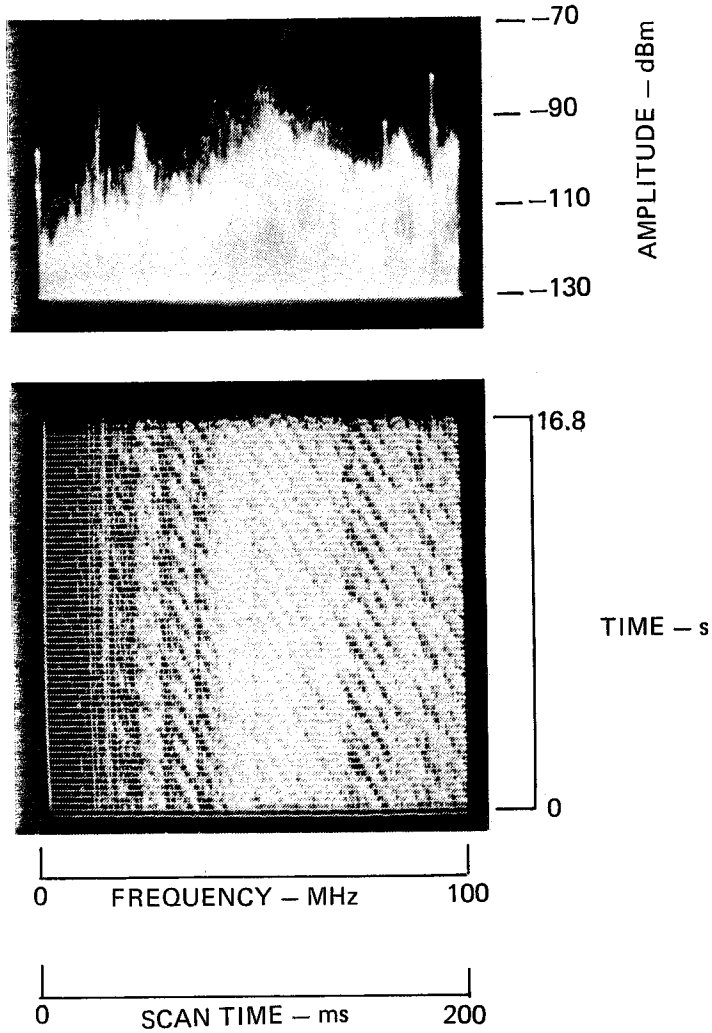

Figure 5-49. Substation Noise, 0 to 100 MHz

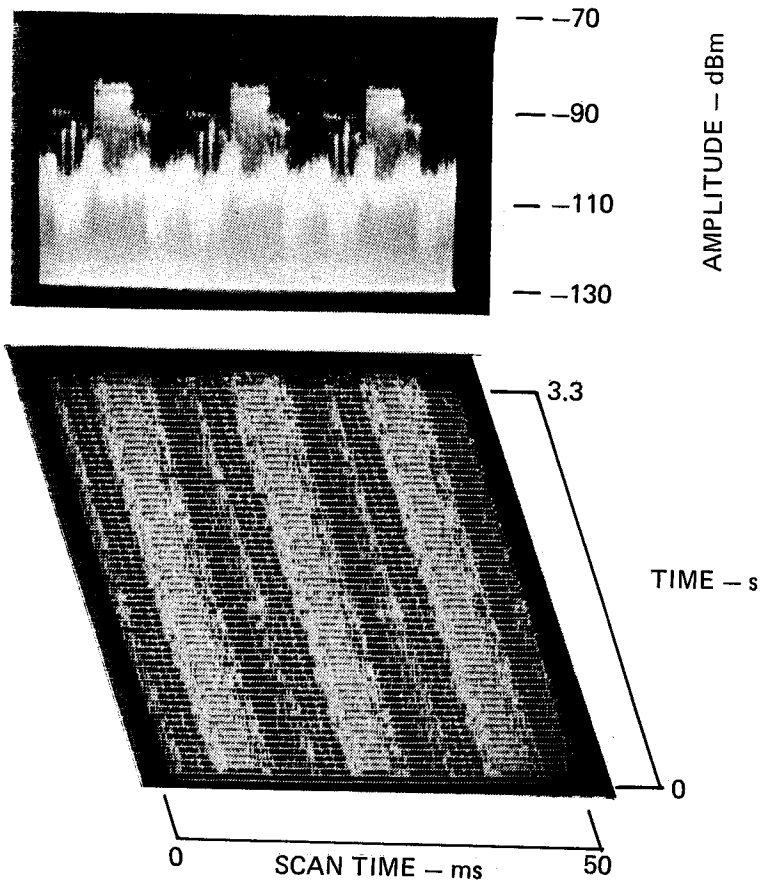

Figure 5-50. Temporal Properties of Substation Noise at 70 MHz, 50-ms Scan Time

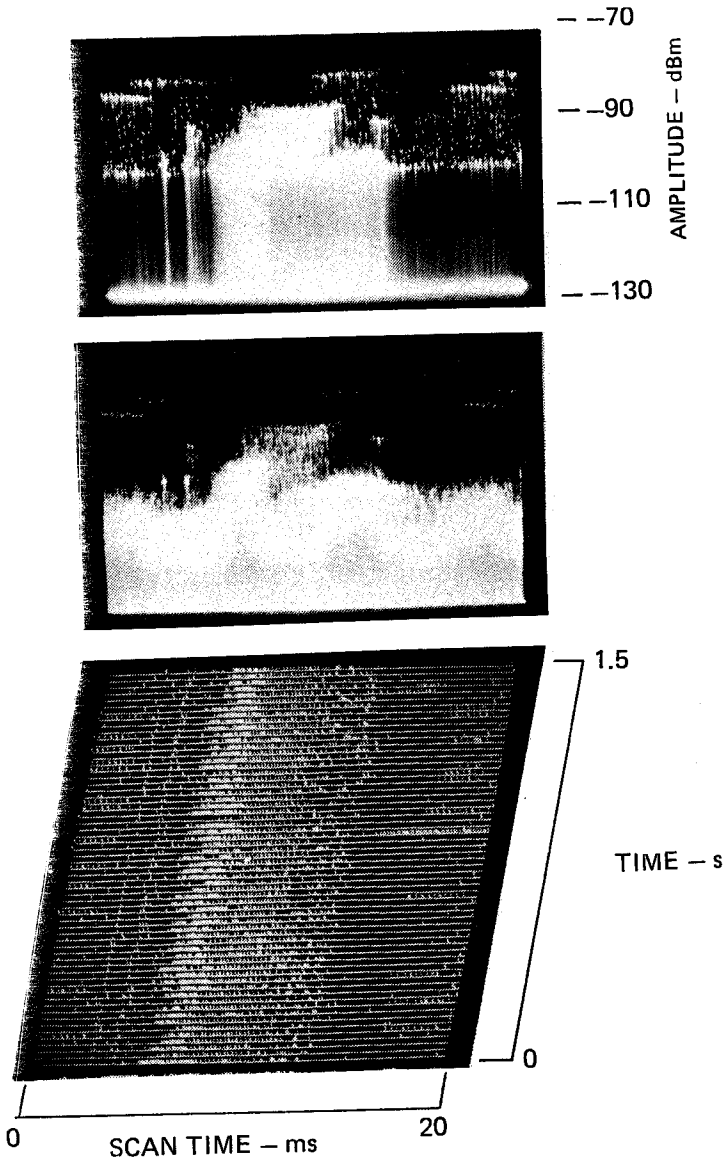

Figure 5-51. Temporal Properties of Substation Noise at 70 MHz, 20-ms Scan Time

display was adjusted to eliminate low amplitude noise in the top amplitude-versus-frequency view. This permitted adjusting the camera exposure so that the high-amplitude impulses could be photographed. A second amplitude-versus-frequency view in the center photograph was provided with the threshold control set to its minimum signal level and shows the variable amplitude impulsive noise at the lower level.

Figures 5-47 through 5-51 provide detailed information about the temporal and spectral structure of noise found in many distribution substations. The flat-amplitude bursts of noise were identified as gap noise (see section 5.2.4 for a discussion of gap noise on distribution lines). Sources of gap noise can be found on most distribution and transmission lines as well as in substations. The source of substation gap noise is identical to the source of distribution-line gap noise; minute discharges between two metallic objects that are exposed to high electric fields. The lower level impulses with nonflat amplitude characteristics were from corona on 235-kV buses and hardware in the substation and associated sections of nearby transmission lines. The ratio of the amplitude of the gap noise and the corona noise will change as the location of the receiving antenna is changed. At most locations useful for purposes of receiving VHF and UHF signals, gap noise levels will usually exceed the amplitude of corona noise.

The operation of sources of substation gap-noise depend on humidity and weather just as do the operation of sources of distribution-line gap noise. Gap noise will decrease and often completely disappear during periods of high humidity or rain. At these times, the amplitude of corona noise usually increases and to some degree compensates for the loss of the gap noise. This mixture of of gap noise and corona noise, modified by humidity and weather, results in complex temporal and spectral characteristics for noise in substations at frequencies above about 1 MHz.

Section 6

DISCUSSION

6.1 GENERAL REMARKS

The data presented in Section 5 are representative of results obtained at all utilities that were visited for measurements. Variations in noise and harmonic levels within a utility were noted from line to line, one time of day to another, weather effects on gap noise, and customer-induced effects. Sudden changes in harmonic and noise levels were related to customer loads. These effects were similar at all utilities visited. No utility deviated significantly from the commonly found erratic and time-changing harmonic and noise conditions. Minor differences were noted from one utility to another (i.e. the greater occurance of gap noise on 34.5-kV lines compared to 13-kV lines), and these differences are discussed in Section 5 and in this section.

The term "harmonic" is used in this report to describe all discrete frequency signals that were found at harmonics of the line frequency regardless of the source of these signals. The occasional reference to very high-harmonic levels does not imply that the utility's distribution-system components were responsible for their presence on utility's lines. In fact, the source of most harmonics on distribution lines, especially those at DLC frequencies, was the utility customer and not the utility.

The frequency range of harmonics was extended upward and somewhat beyond the frequencies commonly used to describe harmonics on power systems. Again, this was because the signals were identifed as discrete frequencies that were precisely related to the fundaental frequency of the power line.

The amplitudes of many harmonics presented in this report were low compared to those that would be of concern to a utility engineer designing a distribution line. The main objective of the work described in this report was not to provide a data base for improving the design of distribution lines, but to measure and define the noise that limits the performance of a DLC system or other communication system that might be used for load managment. The levels measured were germane for that purpose.

The instrumentation used for making the measurements was flexible, comprehensive, and probably more complex than that used by most utilities for similar types of measurements. No simple arrangment of instrumention could be devised that would provide the ability to make all the measurements required for the study. Using four parallel measurement channels proved to be of considerable value when defining the characteristics of harmonics and noise at DLC frequencies. Using deemphasis at low frequencies in the electric-

and magnetic-field sensors was considered somewhat unusual by many utility engineers; however, this was necessary in order to obtain sufficient dynamic range in the signal processing channels so that we could analyze signals and noise at DLC frequencies. The ability to measure the amplitude of harmonics and noise at lower frequencies (below 1 kHz) was preserved, although sensor- calibration factors must be applied to electric- and magnetic-field data below 1 kHz. Using sensors and probes that had a flat response at the frequencies of primary interest simplified the analyzing and presenting the data.

At the beginning of the program, we anticipated that statistical descriptors of amplitude such as rms, average, peak, and amplitude probability distributions (APD) would be used to describe noise that affected the performance of load-managment communication systems. These are common and important parameters that are often used to describe the amplitude of stationary noise. Hagn [4] has provided an excellent summary of the statistical descriptors of man-made radio noise, and Shepard and Lauber [5,6] have used the APD to describe various kinds of radio noise associated with power lines.

As the work progressed, we felt that the presentation of the spectral and temporal features of the data were more important and would be more valuable than attempting to describe the complex aspects of noise by the more conventional parameters. Also, it became apparent that the rms, average, peak, and APDs for most cases of stationary noise associated with distribution lines could be defined from a single 16.6-ms sample of the noise because the statistical properties of the noise were precisely repeated each 16.6 ms. Longer sampling periods were not required to obtain a complete description of the noise. Thus, data from many of the figures in Section 5 can be scaled to obtain the common statistical parameters used by others. If this is done, the reader must realize that these measures will be valid only at the specific frequency of the data scaled. A new set of numbers will be required at each frequency of interest. Thus, using an APD or a single set of standard statistical descriptors to define noise applies only to one frequency and only during periods when the noise remains stationary for a reasonable measurement period.

Situtations where harmonic and noise levels suddenly change in amplitude and in temporal structure were common. These sudden changes were recorded by the instrumentation (Figures 5-16 and 5-24). The noise at such times can best be described as nonstationary. At such times the common statistical descriptors of man-made noise are of limited usefullness. Data at such times are further complicated by irregulalar changes across a band of frequencies. The deterministic form of description provided by the 3-axis views seems to be a reasonable means of presenting examples of nonstationary noise.

6.2 NOISE AT DLC FREQUENCIES

The dominant form of noise affecting the performance of present DLC test systems was the discrete-frequency harmonics of the power-