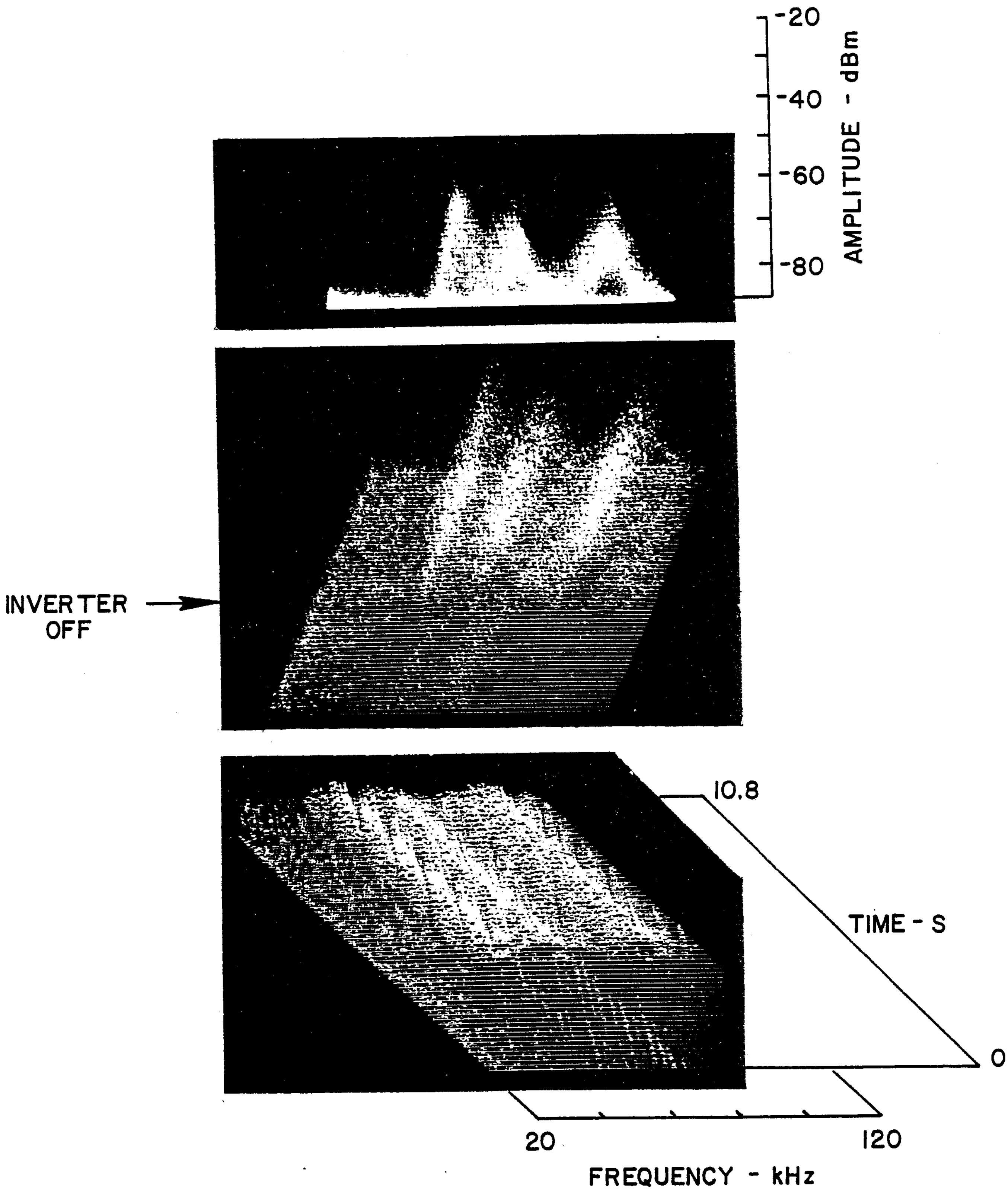

Figure 8 UTC Riser Pole Site, 6/27/78, 1423

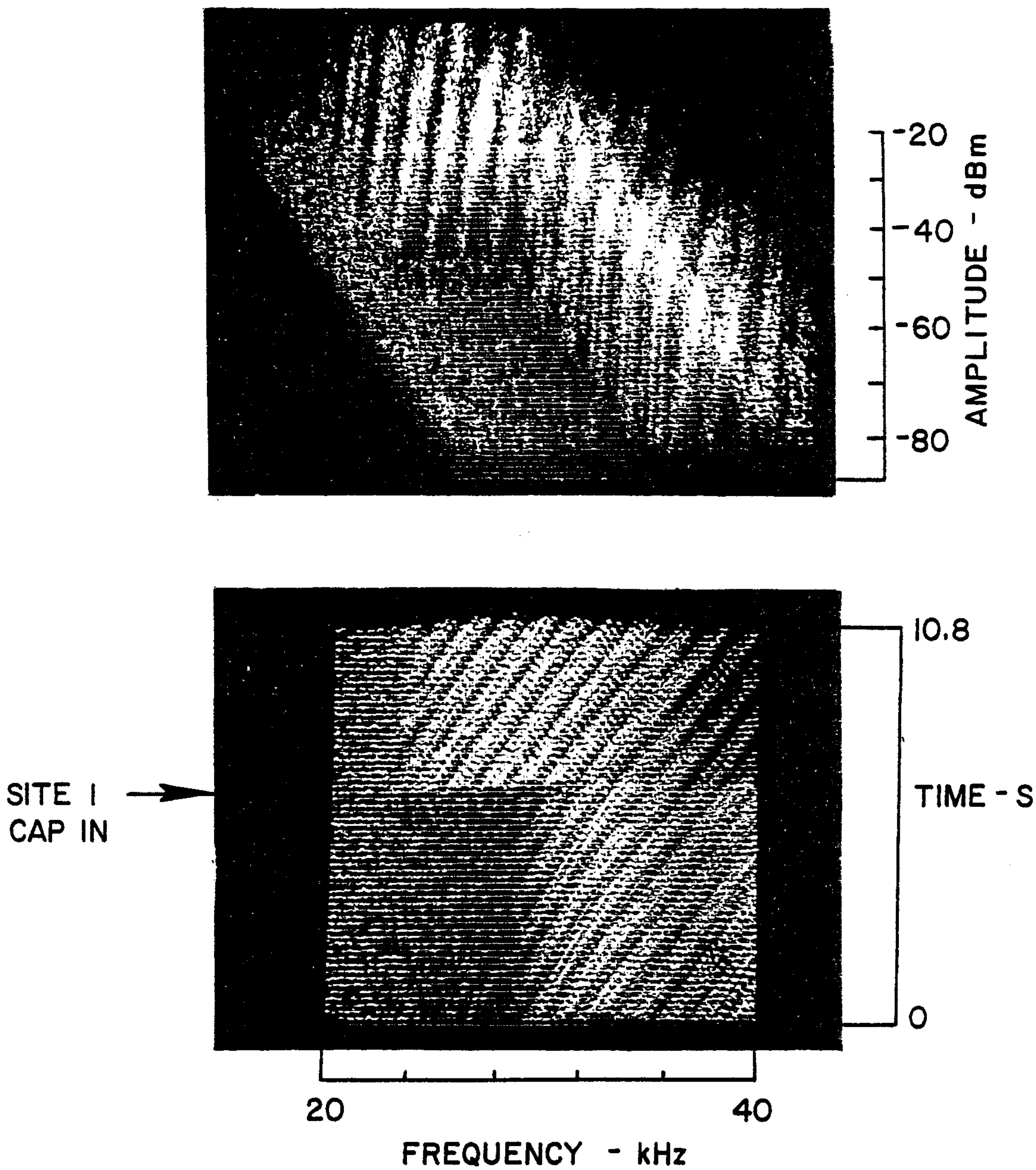

Figure 9 UTC Riser Pole Site, 6/27/78, 1400

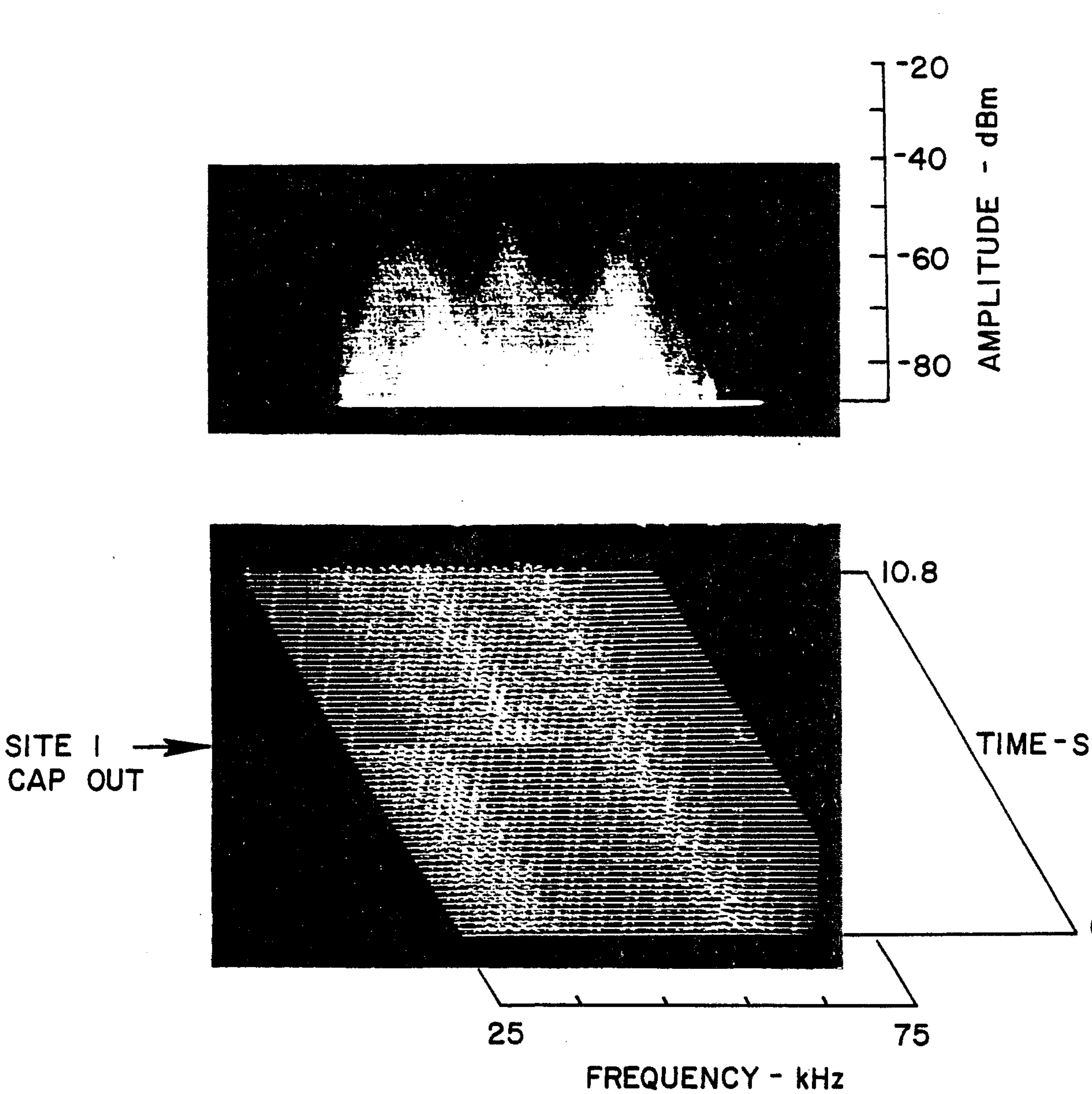

Figure 10 UTC Riser Pole Site, 6/27/78, 1443

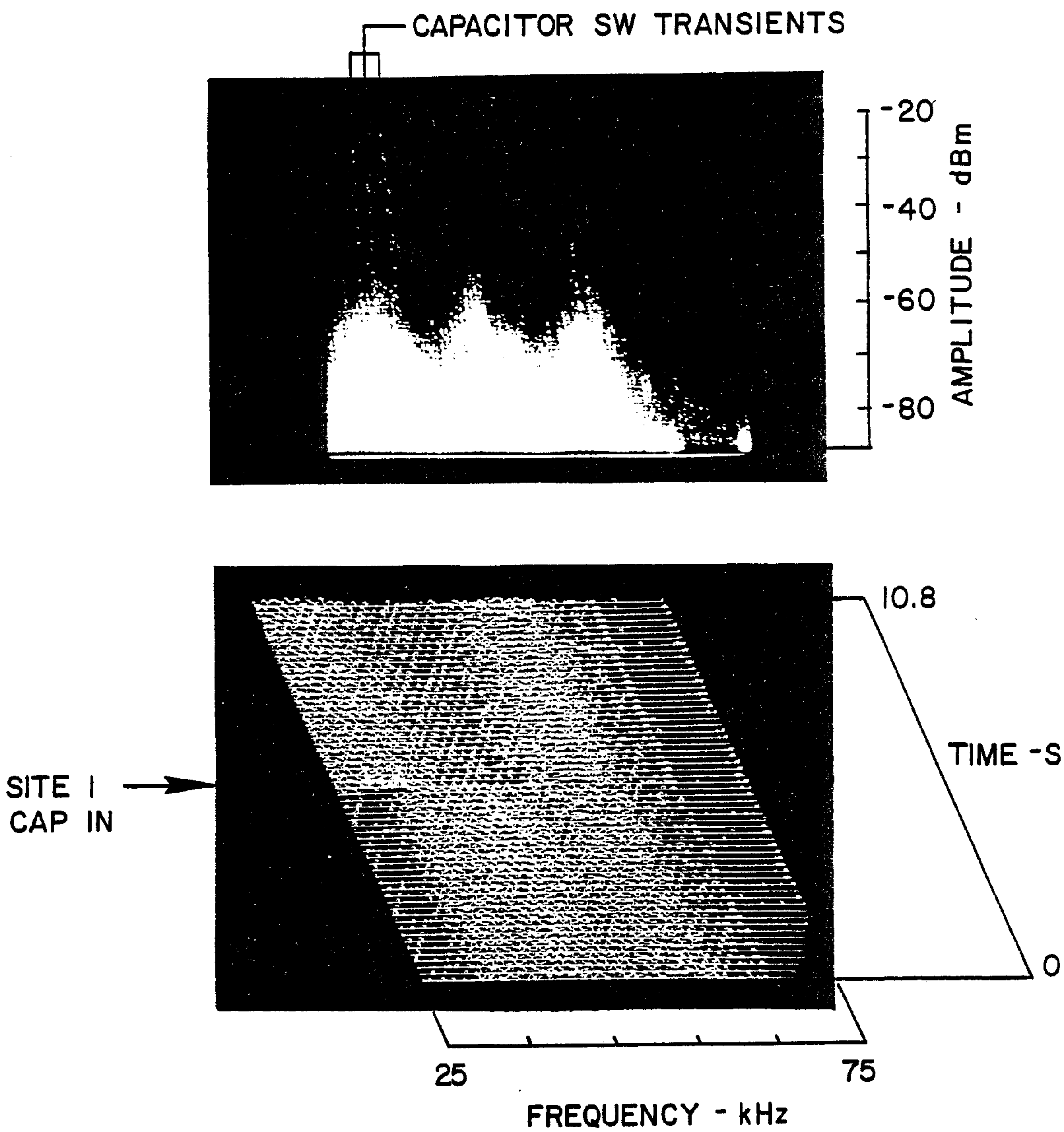

Figure 11 UTC Riser Pole Site, 6/27/78, 1449

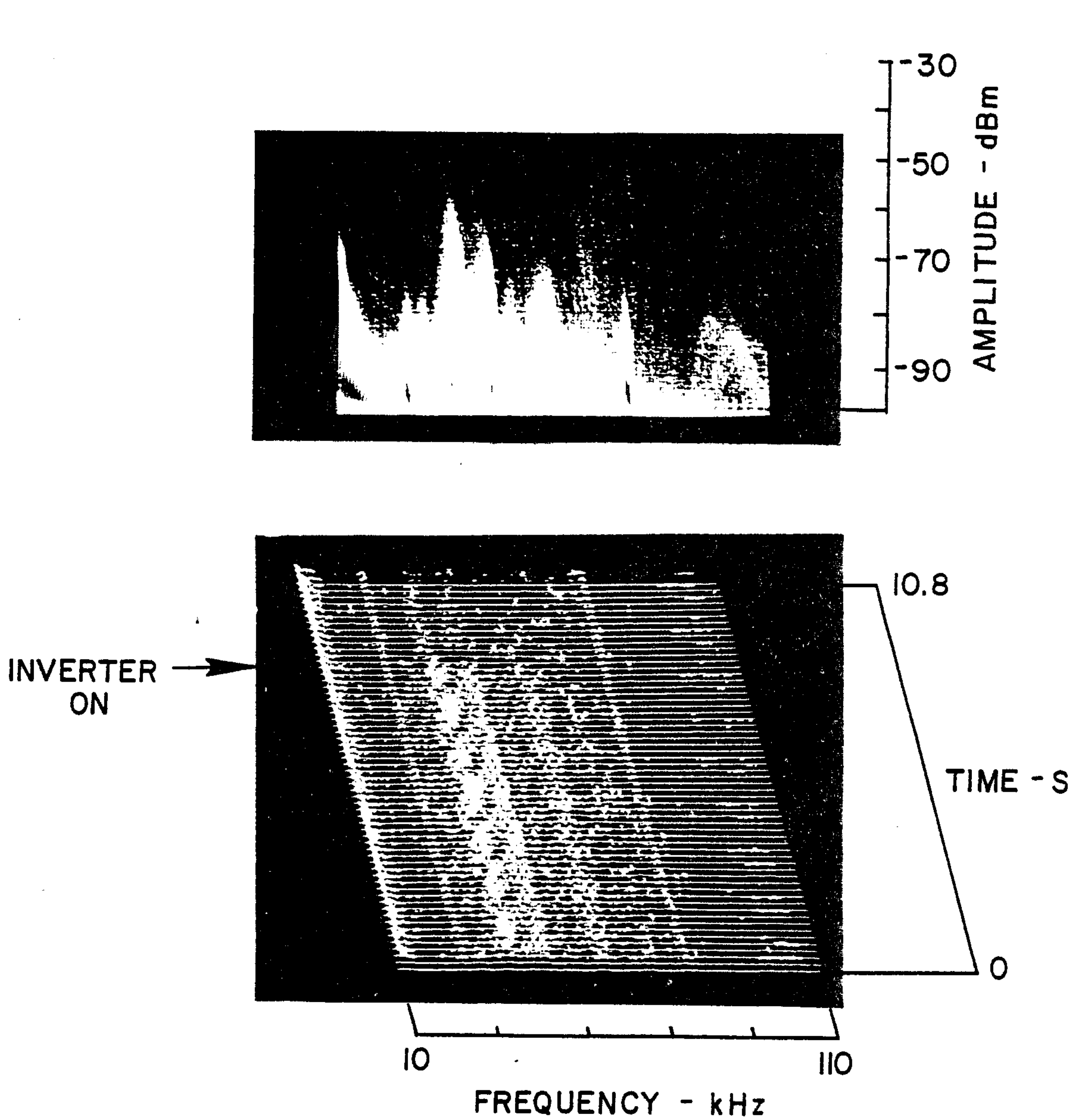

Figure 12 UTC Riser Pole Site, 6/27/78, 1520

3.3.4 Discussion of UTC Riser Pole Results

The background and converter noise measurements at the UTC Riser Pole site produced data which were unusual and of high interest. The pressure of time schedules prevented the systematic collection of all data of interest. However, the 3-axis views shown in Figures 3 through 12 provide a reasonable record of the most prominent features of background and converter noise.

The background noise measurements at the UTC Riser Pole site, supplemented by the other more general data from the UTC Gatehouse 3 site described later in the report, strongly suggested that the UTC facility contained a number of high power switching devices associated with industrial process controls, furnace controls, motor controls, and similar equipment. These devices generated significant levels of impulse power which were propagated back through the plant electrical power system and onto the CL&P distribution line. At the completion of the background measurements of impulsive noise synchronous with the power line frequency emanating from the CL&P distribution line, serious questions arose concerning possible excessive interference from this unexpected noise when trying to observe inverter-generated noise. Subsequent measurements of the very high levels of impulsive noise generated by the UTC experimental bridge eliminated this problem at the UTC Riser Pole site.

The peaks and nulls in the amplitude vs. frequency views of both background and converter noise clearly suggested that source-to-measurement mechanisms involved frequency-sensitive components. Intuitively, these frequency-sensitive mechanisms were expected since they existed at the lower frequencies of the harmonic measurements. However, very little data on the VLF/LF properties of power system components were available to aid in even crude modeling of elements associated with the system being observed. Internal plant wiring, transformers, capacitors, underground cables, overhead cables, meters, switches, and other power handling components were involved in the source-to-measurement system whose technical properties were not known at the frequencies of interest.

The observed spectral changes of converter noise as the UTC Riser Pole capacitor bank was switched in and out (see Figures 8 through 11) indicated that the frequency response characteristics of the source/capacitor/CL&P distribution line combination changed very significantly. These changes complicated the task of data interpretation, and they raised significant questions concerning the resonant properties of the circuit elements and combinations of circuit elements involved.

All examples of inverter-generated impulsive noise showed primary noise components spaced at about 2.8 msec intervals, the value expected for three-phase switching devices. There is evidence of additional structure in all of the views which was not adequately defined by the 100 ms/scan setting of the scanning receiver. This additional structure suggested that the inverter operated with a more complex switching arrangement than that required to generate simple square wave shapes on each phase. It would have been of interest to obtain data at lower scan times and relate the more detailed and expanded noise structure to inverter operation. However, time was not available for this type of exploratory effort.

3.4 SUBSTATION ENTRANCE SITE

3.4.1 Measurement Conditions

A site was selected near the entrance to the CL&P substation, the system source supplying electrical power to the distribution lines studied. The site was located about 500' from the substation near the junction of Feeders 1A and 1B where access to the overhead 13.8 kV distribution line was available. The measurement van was located directly under the 13.8 kV overhead line approximately mid-span between support poles. Measurements were made at the Substation Entrance site on 6/28/78 from 0730 to 1200 hours local time.

Measurement system parameters for the various 3-axis views taken at the Substation Entrance site are summarized in Table 2. These parameters will be useful to those individuals who wish to scale the 3-axis views for some specific detail.

Table 2

MEASUREMENT PARAMETERS, SUBSTATION ENTRANCE SITE

FIG. NO.	DATE	LOCAL TIME	ANTENNA	FREQ. CENTER kHz	FREQ. WIDTH kHz	IF BAND-WIDTH kHz	SCAN TIME ms	IF REF. dB	RF REF. dB	CAP. UTC	CAP. S.P.P.	UTC CONV.
13	6/28/78	0845	Loop	90	20	1	100	-30	0	on	on	off
14	6/28/78	0837	Loop	170	20	1	50	-30	0	on	on	off
15	6/28/78	0851	Loop	1000	50	1	100	-30	0	on	on	off
16	6/28/78	0928	Loop	1000	50	1	100	-30	0	on	on	off
17	6/28/78	0952	Loop	500	50	1	100	-30	0	on	on	off
18	6/28/78	0956	Loop	500	50	1	100	-40	0	off/on	on	off
19	6/28/78	1029	Loop	50	50	1	100	-40	0	off/on	on	on
20	6/28/78	1105	Loop	50	50	1	100	-40	0	off	off/on	on
21	6/28/78	1114	Loop	50	50	1	100	-40	0	off	on/off	on
22	6/28/78	1125	Loop	50	50	1	100	-40	0	off	on	on/off
23	6/28/78	1140	Loop	50	50	1	100	-40	0	off	on	on/off

3.4.2 Background Measurements

Background noise measurements were made prior to the converter tests to define the levels and structure of noise from sources other than the converter. Background noise is shown in Figures 13 through 17. Low levels of impulsive noise associated with 3Ø synchronous switching devices were found in the 90 to 100 kHz range (Figure 13), the 160 to 180 kHz range (Figure 14), and the 975 to 1025 kHz range (Figure 15). A second view of noise emanating from the distribution line in the 975 to 1025 kHz range is shown in Figure 16. This view was taken 37 minutes after the data shown in Figure 15, and the predominant noise changed from a low level 3Ø synchronous switching type of source to a single phase positive and negative source with considerable time width of each noise impulse. The spacing between impulses was 8.3 ms and the width of each pulse varied from about 2 to 4 ms.

Somewhat later in the measurement period the onset of the more diffuse but synchronous noise was observed as shown in Figure 17. An impulsive noise source can be seen from 10.8 downward to about 6 seconds on the time axis. The impulses were spaced 16.6 msec apart, suggesting a single phase switching device operating on either the positive or the negative portion of the 60 Hz power line frequency. At 6 seconds a second noise source was noted with a broad and diffuse time duration of about 2 to 3 ms and at a spacing of 8.3 ms. The 8.3 ms spacing between pulses implied a single phase source operating on both the positive and negative portions of the 60 Hz line frequency. Both the 16.6 ms impulsive noise and the more diffuse 8.3 ms noise can be seen from 6 to 0 seconds on the time scale.

The background measurements at the Substation Entrance site suggest that impulsive noise and diffuse impulsive noise were present on the transmission line most of the daytime hours. Also, the measurements suggest that the detailed properties changed with time as various sources were energized and de-energized. Time stable noise levels and states were not found.

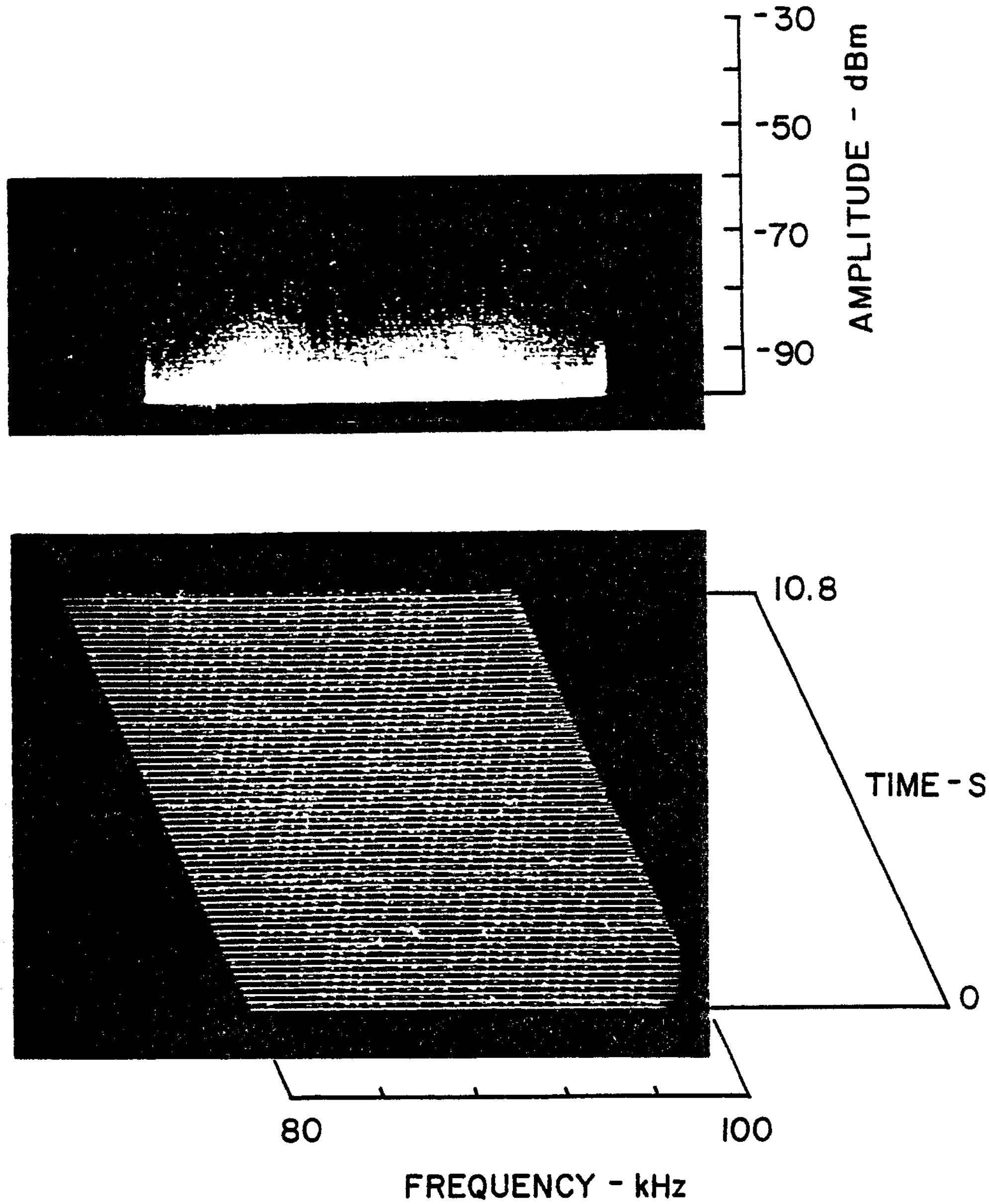

Figure 13 Substation Entrance Site, 6/28/78, 0845

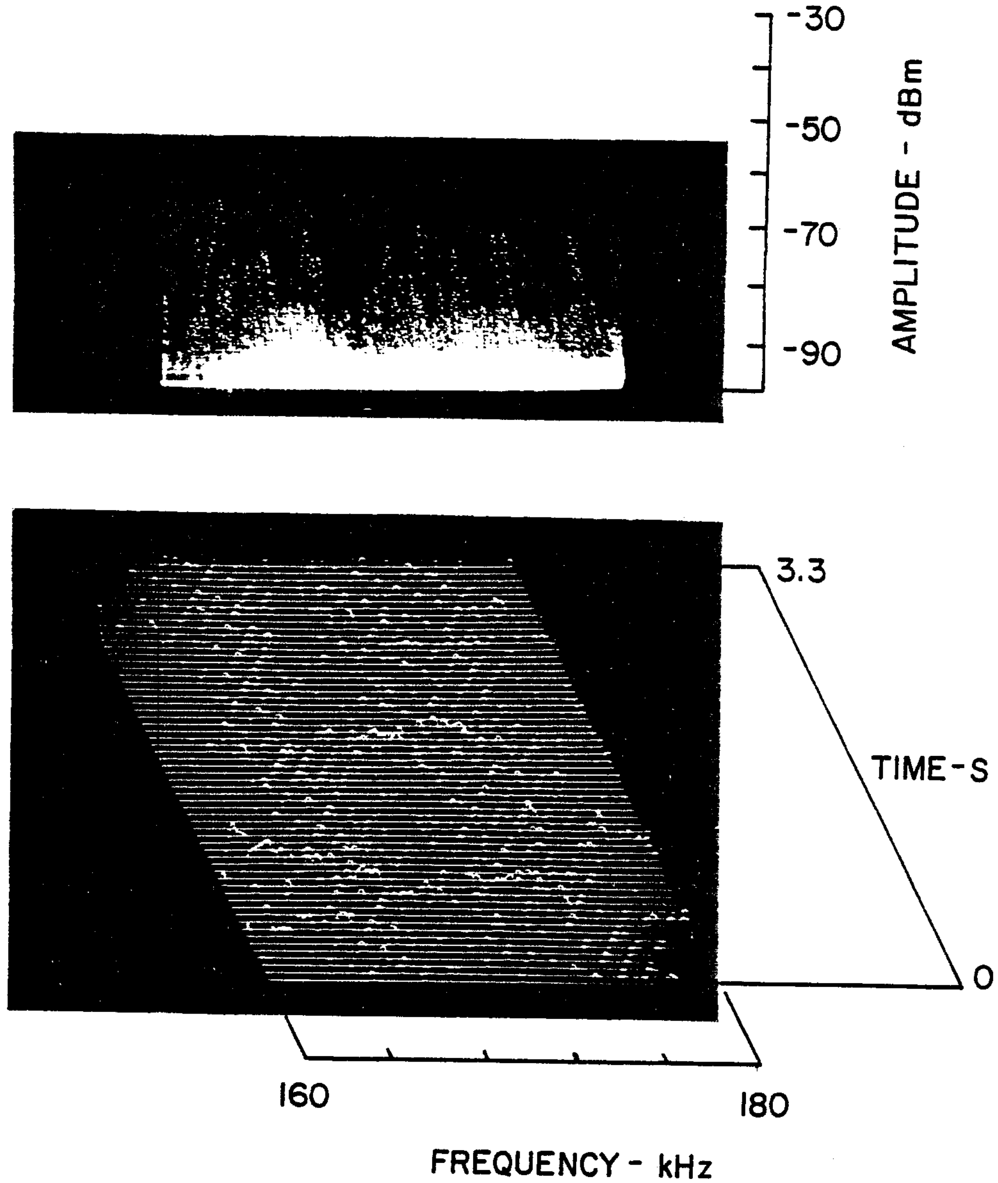

Figure 14 Substation Entrance Site, 6/28/78, 0837

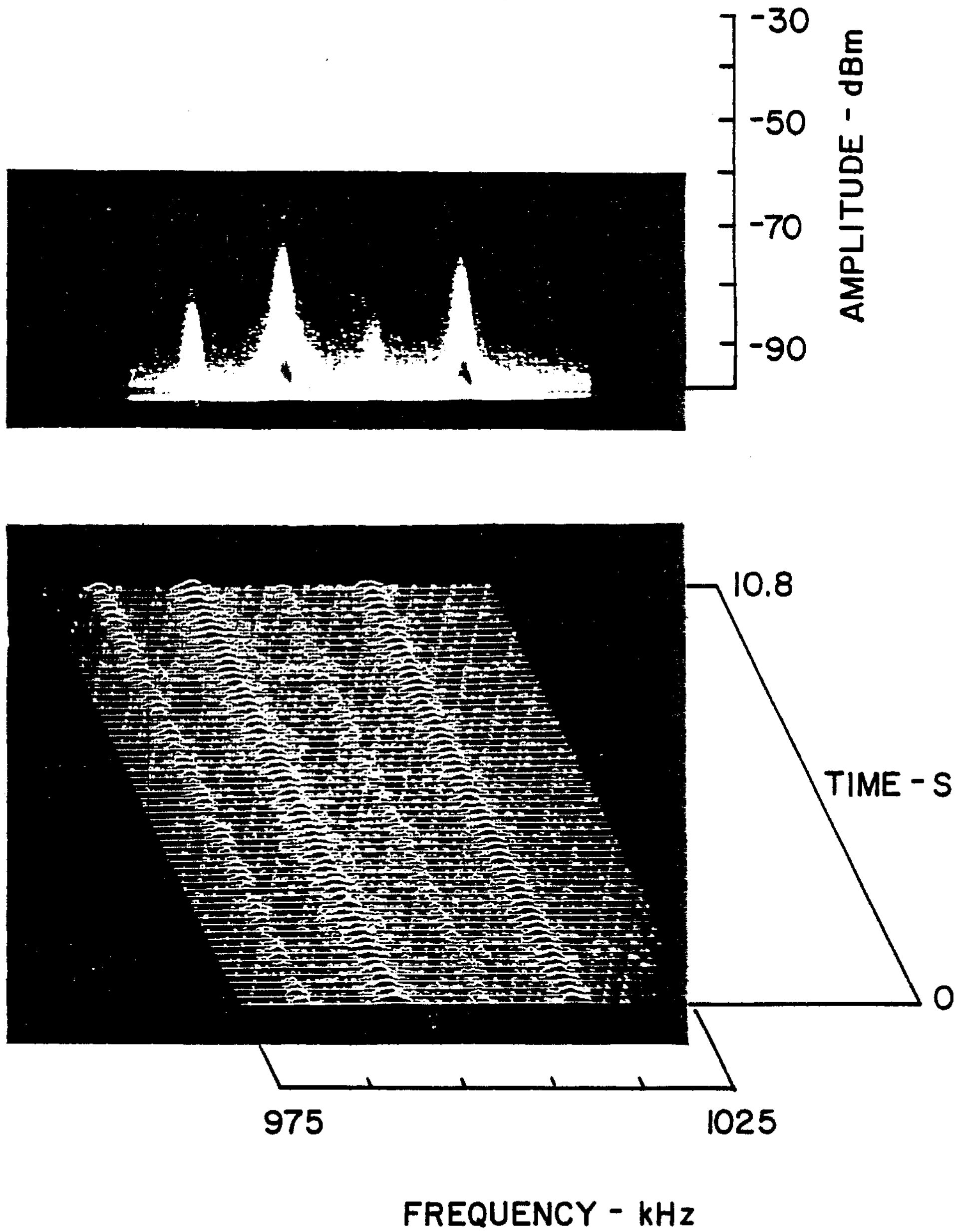

Figure 15 Substation Entrance Site, 6/28/78, 0851

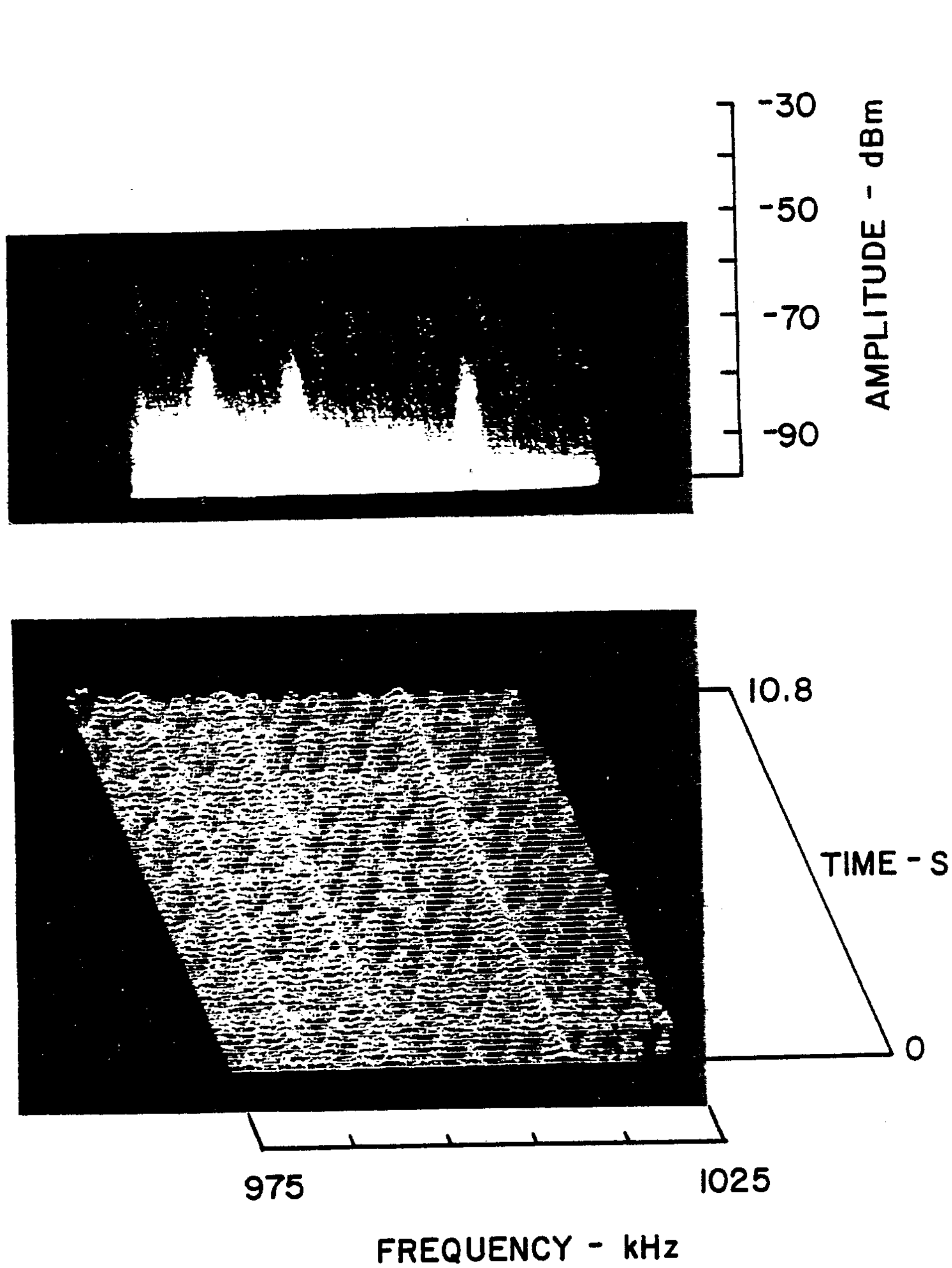

Figure 16   Substation Entrance Site, 6/28/78, 0928

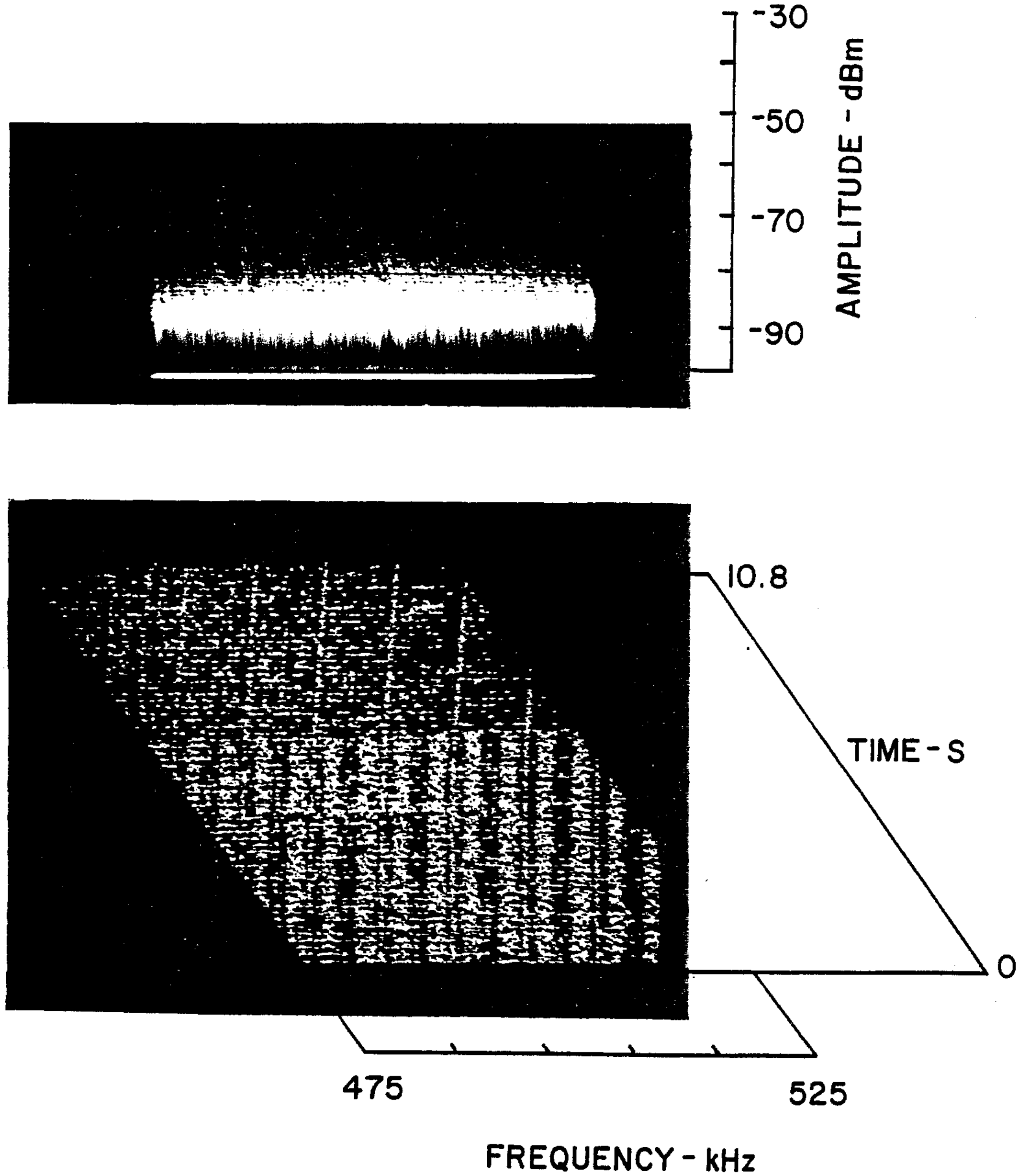

Figure 17 Substation Entrance Site, 6/28/78, 0952

3.4.3 Converter Measurements

A series of measurements directly related to UTC inverter operation was undertaken immediately after completion of background measurements. Figure 18 shows background noise with the converter off, the Spring Pond capacitor bank in, and as the UTC Riser Pole capacitor bank was switched from in to out. No measureable change in noise level was observed.

In Figure 19, the converter was on, the Spring Pond Park capacitor bank in, and the UTC Riser Pole capacitor bank was switched from out to in. Converter noise can be seen in the lower view in the bands centered at 30, 40, and 70 kHz from 10.8 seconds down to 6 seconds on the time axis. The converter noise was severely attenuated at all observed frequencies when the UTC Riser Pole capacitor bank was switched in. Background impulsive noise was not affected by the capacitor switching.

In Figure 20, the converter was on, the UTC capacitor bank was out, and the Spring Pond capacitor bank was switched from out to in. Converter-generated noise can be seen at about 40 and 50 kHz. Neither the converter noise nor the background impulsive noise changed as the Spring Pond capacitor bank was switched from in to out.

Converter noise amplitudes as well as background noise amplitudes can be determined from the upper views of Figures 20 and 21. Background noise levels exceeded the converter noise levels in both measurements by about 10 dB.

In Figure 22, the UTC Riser Pole capacitor bank was out, the Spring Pond capacitor bank was in, and the converter was switched off at 5 seconds on the time axis. The 40 kHz converter noise turned off and part of the noise at 50 kHz turned off. Apparently a second noise source contributed some background noise at 50 kHz. The impulsive noise background was not affected by the converter off action.

Another test similar to that shown in Figure 22 was conducted later in time when the background noise level had diminished somewhat. This is shown in Figure 23 where the 40 kHz converter noise was present but the 50 kHz noise component was not observed. This suggested that something had changed propagation characteristics of the distribution line between the 50 kHz source and the substation or the 50 kHz source had been turned off.

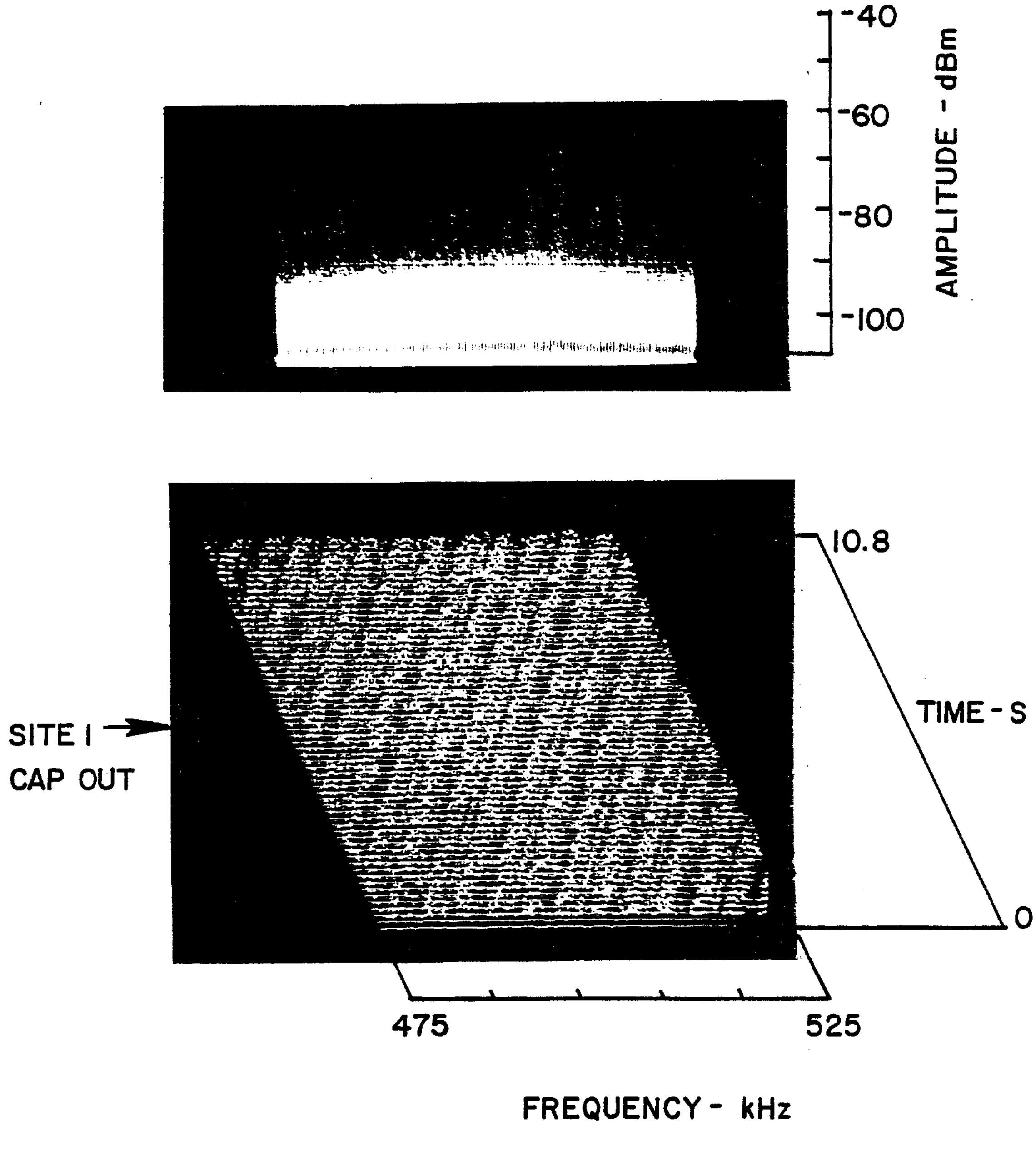

Figure 18 Substation Entrance Site, 6/28/78, 0956

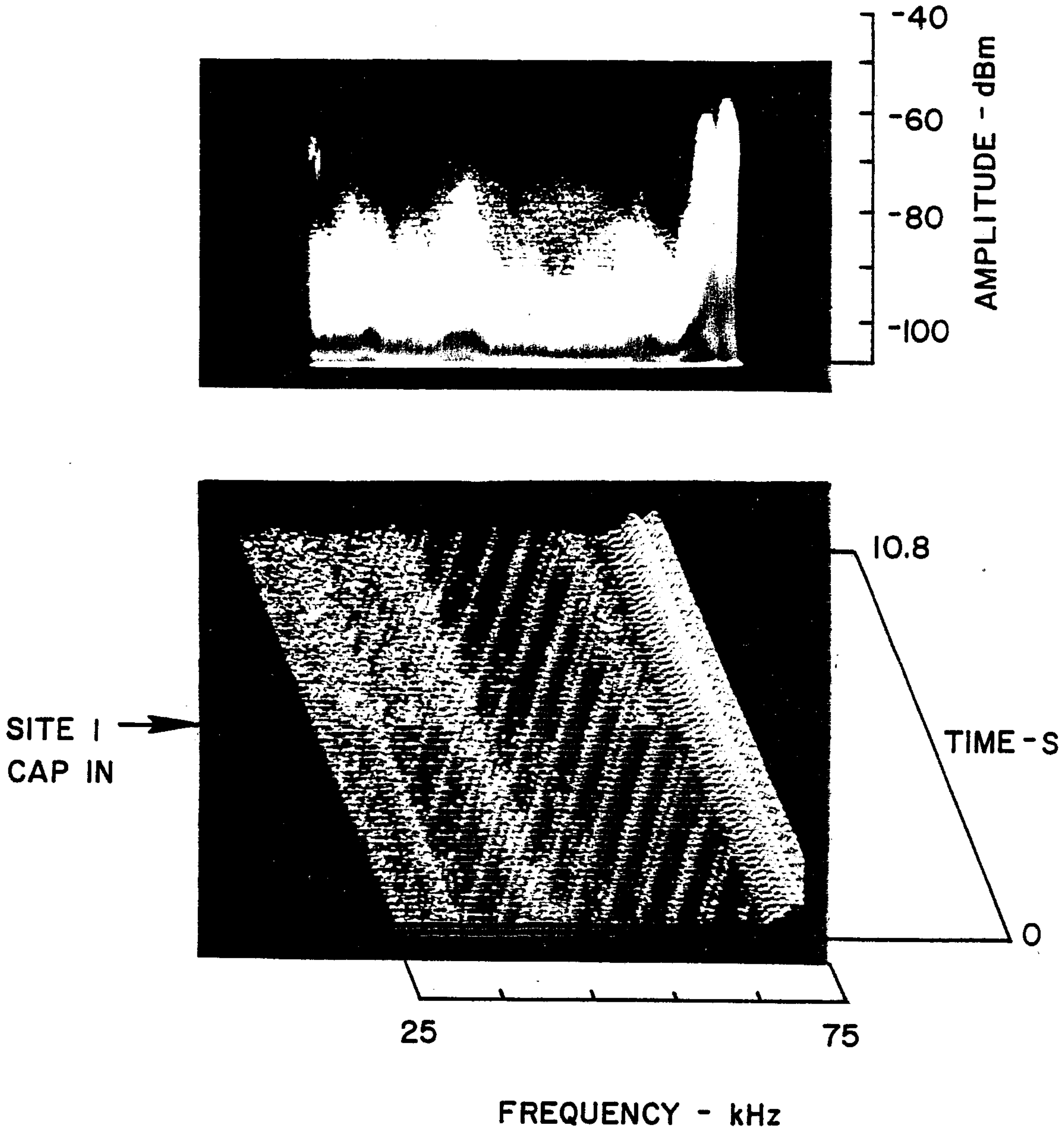

Figure 19 Substation Entrance Site, 6/28/78, 1029

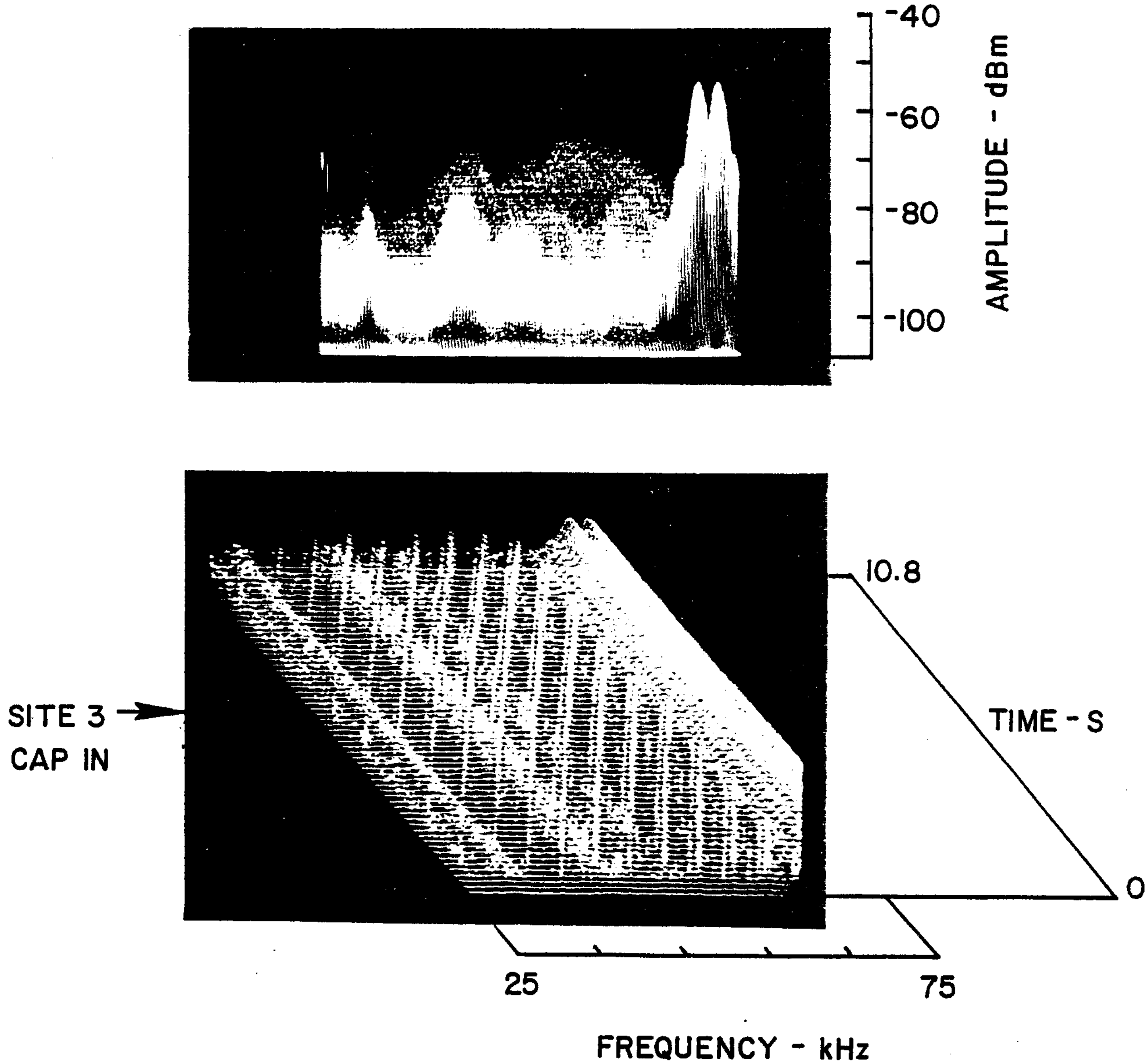

Figure 20 Substation Entrance Site, 6/28/78, 1105

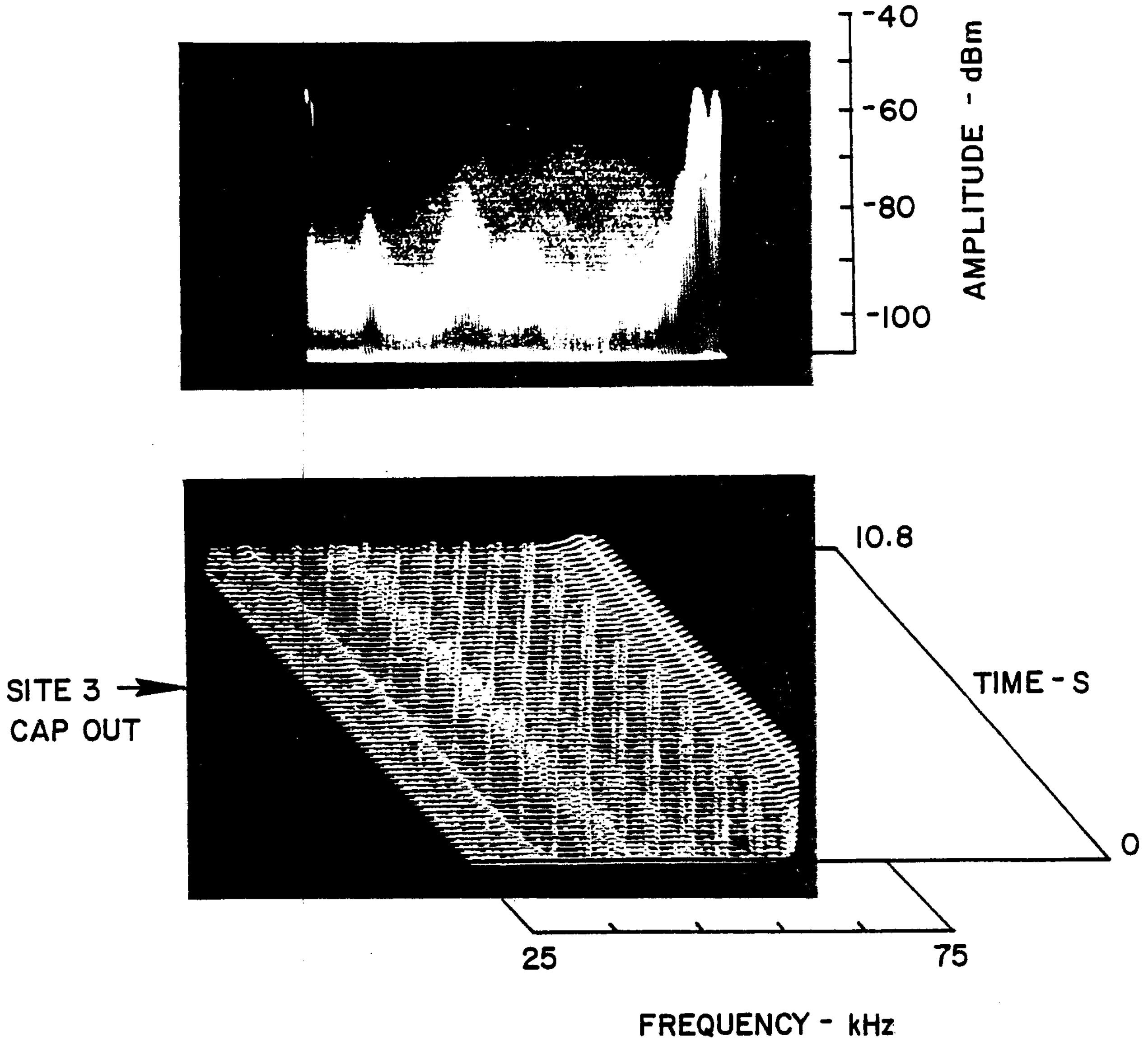

Figure 21 Substation Entrance Site, 6/28/78, 1114

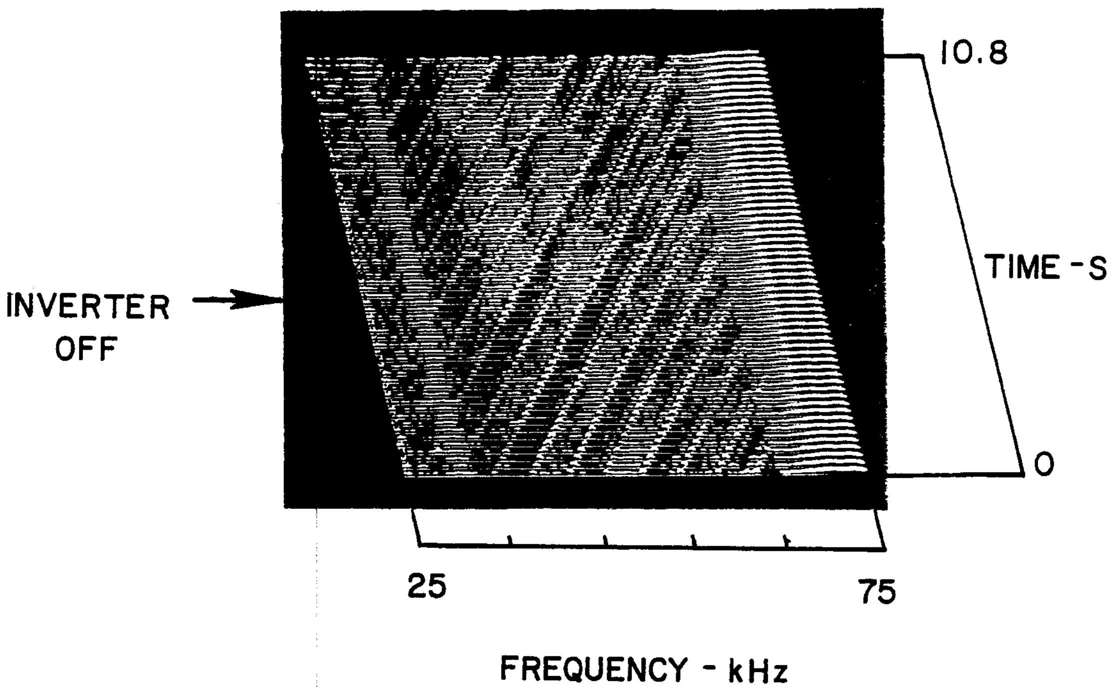

Figure 22 Substation Entrance Site, 6/28/78, 1125

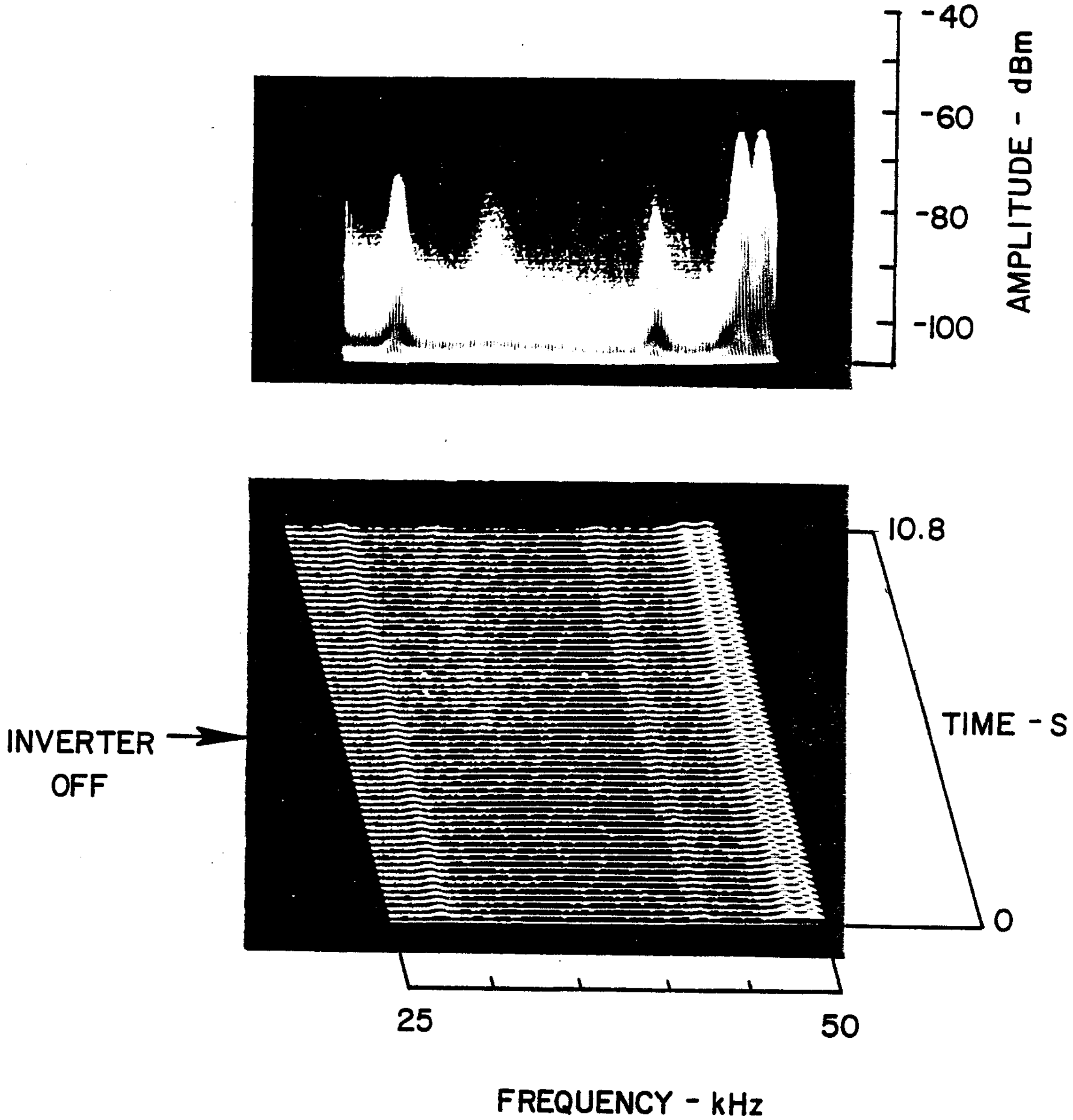

Figure 23 Substation Entrance Site, 6/28/78, 1140

3.5 SPRING POND PARK SITE

3.5.1 Measurement Conditions

A site located directly across the street from the entrance to the Spring Pond Park was used for the third set of measurements. A 600 kVAR capacitor bank, identified as the Spring Pond Park capacitor bank, was located about one pole span away in the direction of the source. The measurement van was located directly under the 13.8 kV overhead distribution line in a small clearing at the edge of the road. Measurements were made at the Spring Pond Park Site on 6/28/78 from 1230 to 1530 hours local time.

Measurement system parameters for the 3-axis views taken at the Spring Park Pond site are summarized in Table 3. These parameters will be useful to those readers who wish to scale the 3-axis views for some specific detail.

Table 3

MEASUREMENT PARAMETERS, SPRING POND PARK SITE

FIG. NO.	DATE	LOCAL TIME	ANTENNA	FREQ. CENTER kHz	FREQ. WIDTH kHz	IF BAND-WIDTH kHz	SCAN TIME ms	IF REF. dB	RF REF. dB	CAP. UTC	CAP. S.P.P.	UTC CONV.
24	6/28/78	1250	Loop	50	50	1	100	-40	0	on	on	off
25	6/28/78	1304	Loop	200	100	1	100	-40	0	on	on	off
26	6/28/78	1319	Loop	50	50	1	100	-40	0	on	on/off	off
27	6/28/78	1344	Loop	50	100	1	100	-40	0	on/off	on	off
28	6/28/78	1410	Loop	50	100	1	100	-40	0	on/off	on	on
29	6/28/78	1410A	Loop	50	100	1	100	-40	0	on/off	on	on

3.5.2 Background Measurements

Background noise measurements were made prior to converter noise tests to define the levels and structure of noise which might obscure and make difficult the measurement of converter-generated noise. Examples of background noise found at the Spring Pond Park site are given in Figures 24 and 25. Figure 24 shows a modest strength impulsive noise with maximum amplitude at 60 kHz. Noise components extended across the entire 25 to 75 kHz band under observation at amplitudes shown in the upper view. Occasional very strong transient bursts of noise from unknown sources can also be seen in the upper view. The predominant impulsive noise in Figure 24 occurred at intervals of 8.3 msec which implied a single phase positive and negative switching source. Additional lower amplitude impulses can also be seen in the lower view which may be from another single phase source on a different line phase.

Figure 25 shows impulsive noise from a single phase positive and negative switching source at 150 to 190 kHz. A second impulsive noise was noted at 200 and 230 kHz where the impulses were not synchronized with power line frequency. A few random noise transients also appeared in the upper view of Figure 25.

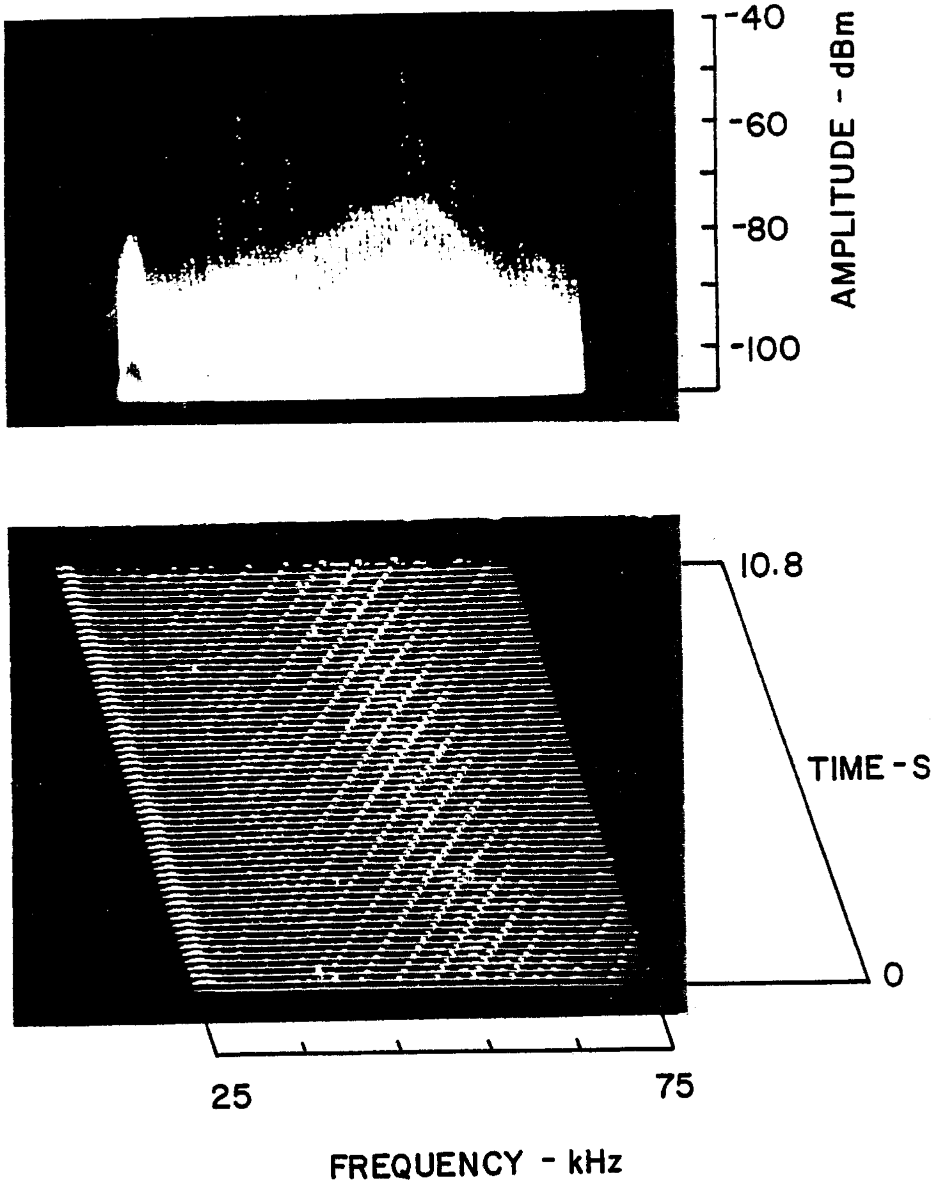

Figure 24   Spring Pond Park Site, 6/28/78, 1250

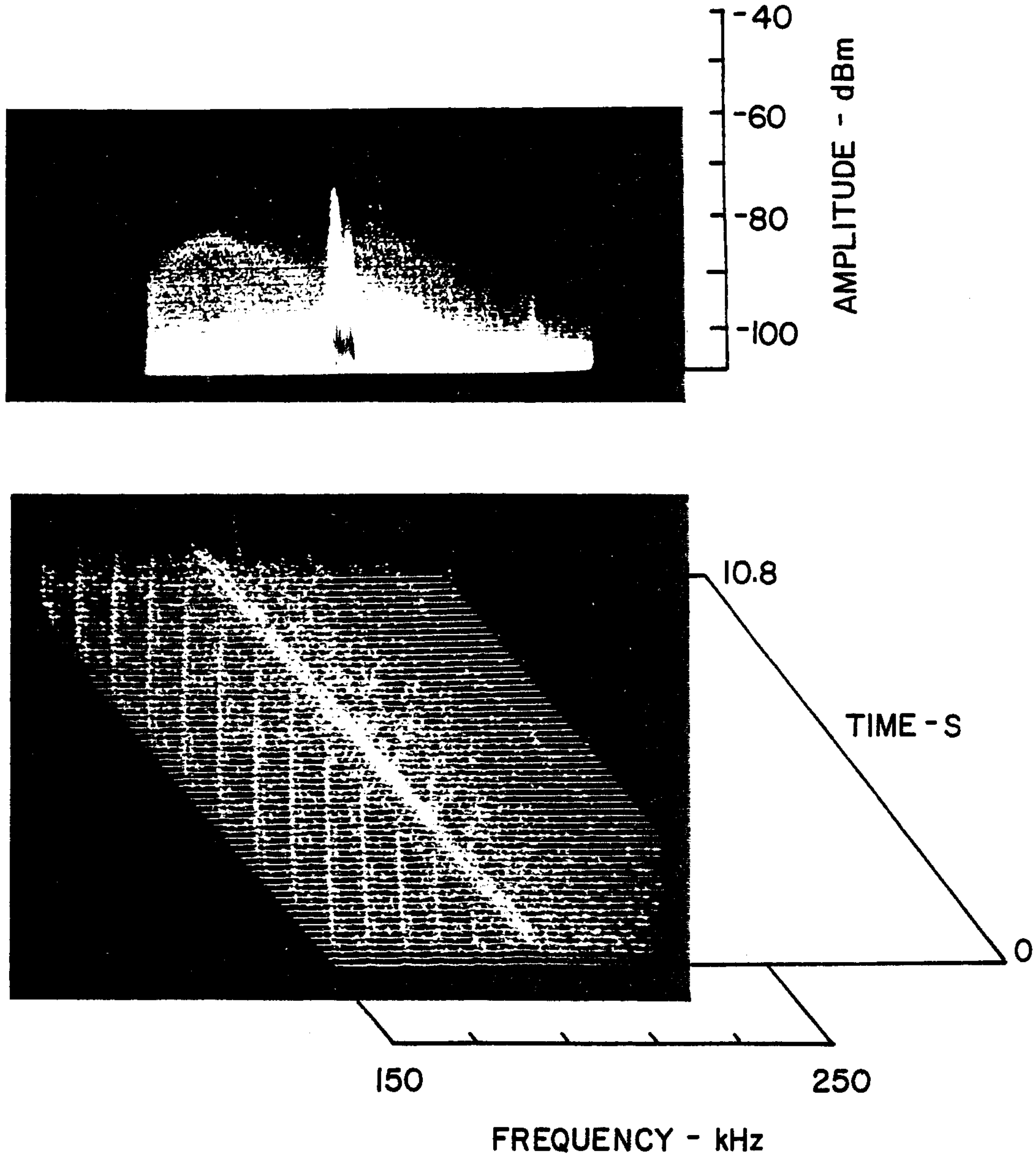

Figure 25 Spring Pond Park Site, 6/28/78, 1304

3.5.3 Converter Measurements

In Figure 26 data are shown with the converter off, the UTC Riser Pole capacitor bank on, and as the Spring Pond Park capacitor bank was switched from in to out. No significant change in background noise was noted. Switching transients were observed as the capacitor bank was switched. Other transients were also noted in the upper view from unknown sources.

In Figure 27 data are shown with the converter off, the Spring Pond Park capacitor bank in, and as the UTC Riser Pole capacitor bank switched from in to out. The two 3-axis views are identical except for small differences in the amplitude threshold, amplitude compression, and azimuth controls on the display. No significant change in background noise was noted as the UTC Riser Pole capacitor bank was switched.

In Figure 28 data are shown with the converter on, the Spring Pond capacitor bank in, and as the UTC Riser Pole capacitor bank was switched from off to on. An increase in noise level at 30 kHz of more than 15 dB was noted. No significant change in background noise was noted over the 10 to 100 kHz frequency range shown in the view. A few noise transients can be seen in the upper view.

The data shown in Figure 28 were segmented into two groups with the time axis expansion capability of the EMTEL display. The upper view of Figure 29 shows noise amplitude vs. frequency when the UTC Riser Pole capacitor was off, which corresponded to the data in Figure 28 from 10.8 down to 5 seconds on the time axis. The lower view of Figure 29 shows noise amplitude vs. frequency when the UTC Riser Pole capacitor bank was in, which corresponded to the data in Figure 28 from 5 to 0 seconds on the time axis. The 30 kHz band of noise from the converter can be easily found in the lower view and it was attenuated by at least 15 dB in the upper view.

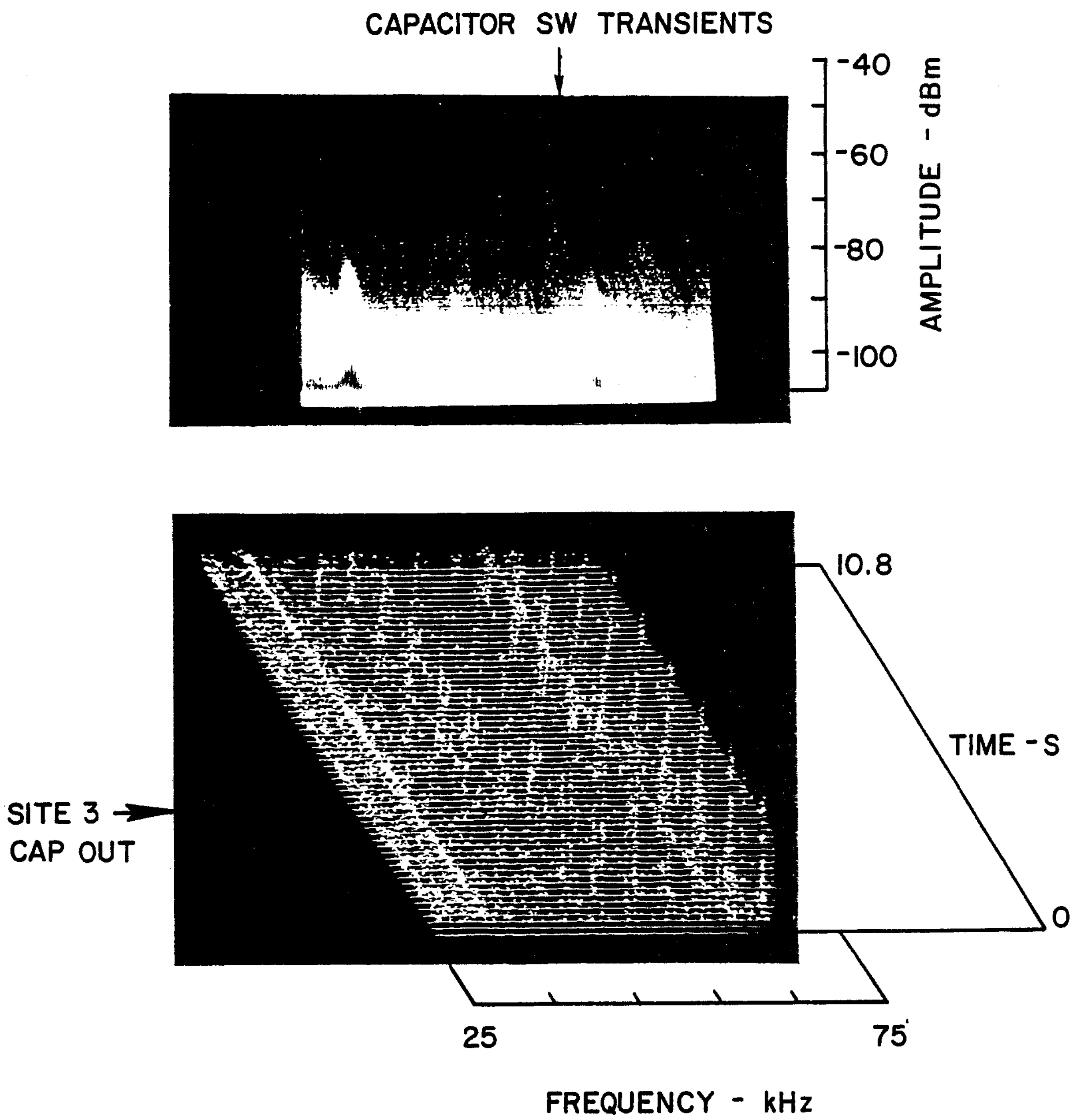

Figure 26 Spring Pond Park Site, 6/28/78, 1319

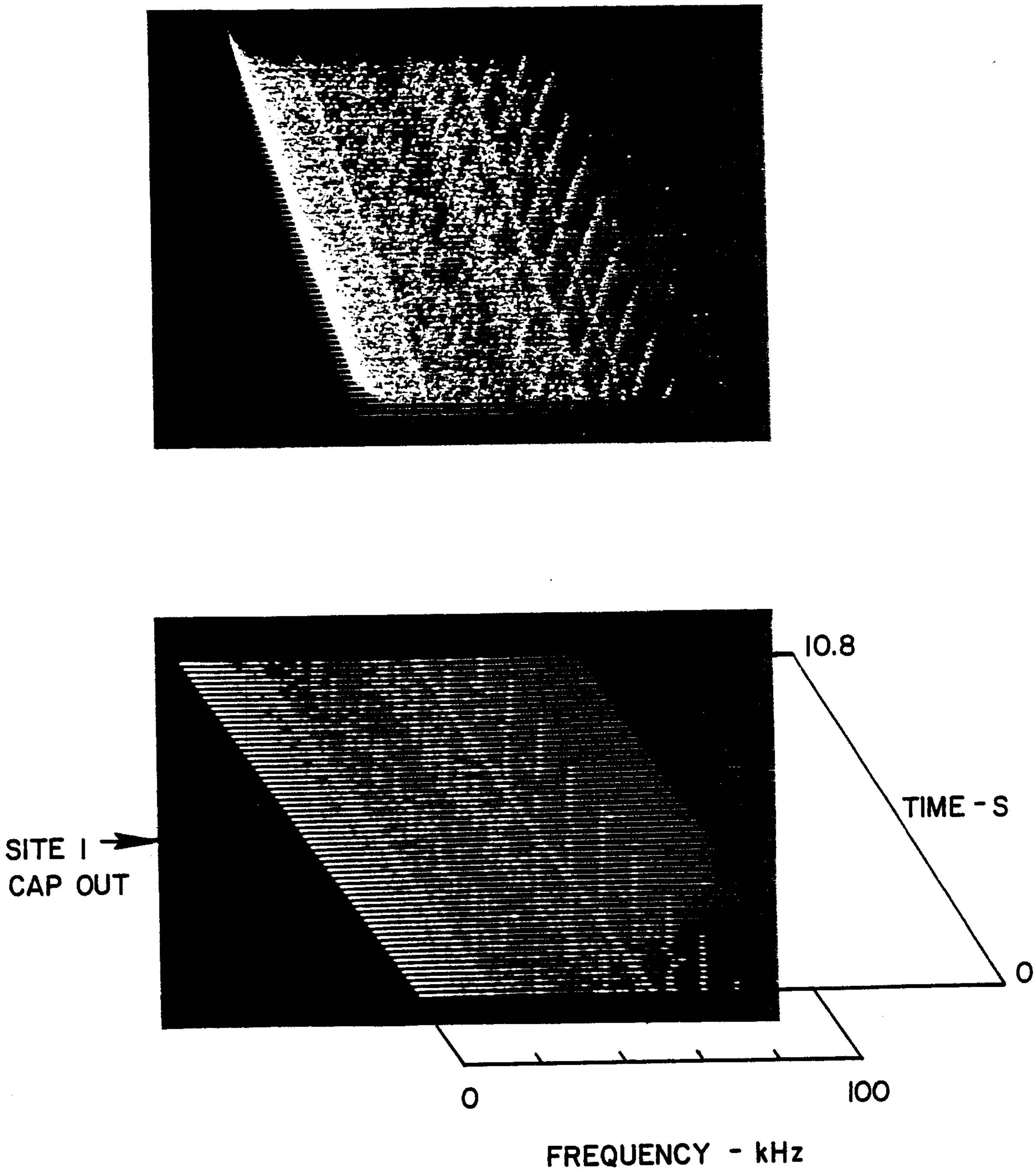

Figure 27 Spring Pond Park Site, 6/28/78, 1344

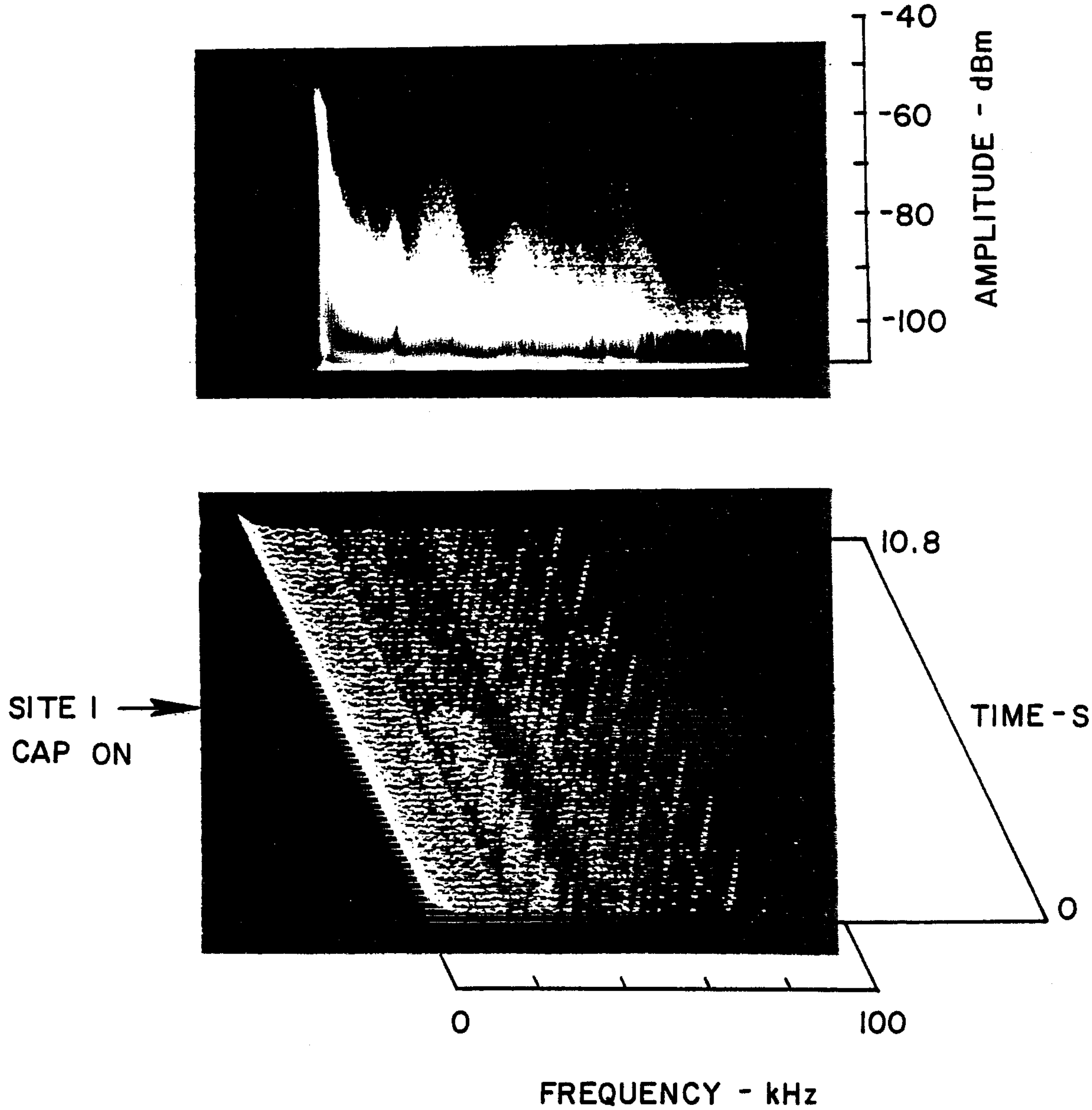

Figure 28 Spring Pond Park Site, 6/28/78, 1410

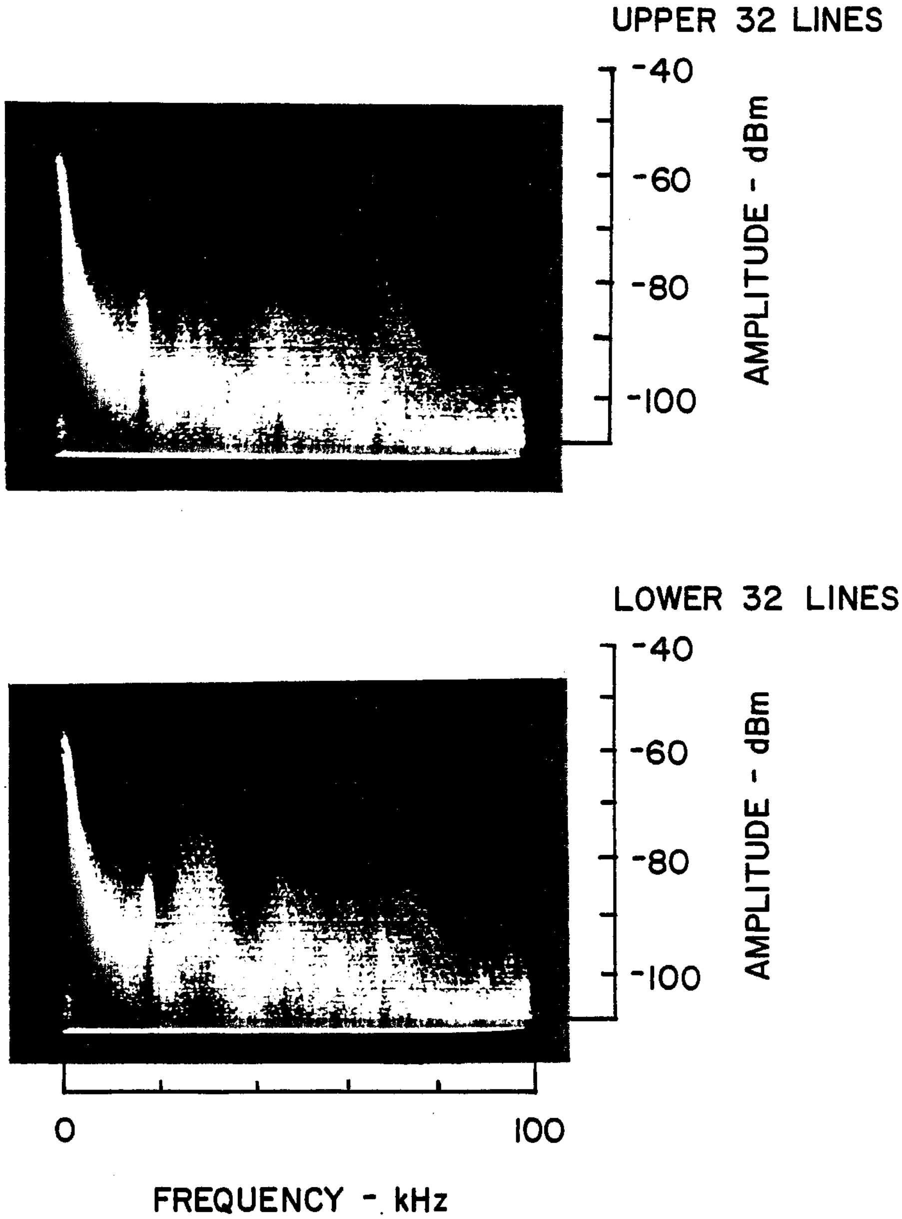

Figure 29 Spring Pond Park Site, 6/28/78, 1410A

3.6 VULCAN RADIATOR SITE

3.6.1 Measurement Conditions

A site located in front of the Vulcan Radiator plant was used for the fourth set of measurements. The measurement van was located directly under the 13.8 kV overhead distribution line between the Vulcan Radiator parking lot and the street. Measurements were made at the Vulcan Radiator site on 6/29/78 from 0800 to 1200 hours local time.

Measurement system parameters for the 3-axis views taken at the Vulcan Radiator site are summarized in Table 4. These parameters will be useful to those readers who wish to scale the 3-axis views for some specific detail.

Table 4

MEASUREMENT PARAMETERS, VULCAN RADIATOR SITE

FIG. NO.	DATE	LOCAL TIME	ANTENNA	FREQ. CENTER	FREQ. WIDTH	IF BAND-WIDTH kHz	SCAN TIME ms	IF REF. dB	RF REF. dB	CAP. UTC	CAP. S.P.P.	UTC CONV.
30	6/29/78	0843	Loop	50 kHz	100 kHz	1	100	-40	0	on	on	off
31	6/29/78	0930	Whip	4 MHz	5 MHz	10	100	-40	0	on	on	off
32	6/29/78	0933	Whip	20 MHz	5 MHz	10	100	-40	0	on	on	off
33	6/29/78	0945	Whip	30 MHz	5 MHz	10	100	-40	0	on	on	off
34	6/29/78	0940	Whip	40 MHz	5 MHz	10	100	-40	0	on	on	off

3.6.2 Background Measurements

Background noise at the Vulcan Radiator site over the 10 to 100 kHz range is shown in Figure 30. Impulsive noise was found in the 25 to 80 kHz range of frequencies with maximum noise at 60 kHz. Peaks and nulls in the amplitude vs. frequency presentation were prominent features. The impulses occurred at 8.3 ms intervals suggesting a single phase source which triggered on both the positive and negative portions of the line frequency. Further measurements made at frequencies up to 1000 kHz indicated that impulsive or other forms of power line-associated noise were very low.

At even higher frequencies a different form of power line-associated noise was found. The 3-axis views in Figure 31 show weak bands of diffuse impulsive noise over the 1.5 to 6.5 MHz frequencies. Further measurements at 17.5 to 22.5 MHz (see Figure 32) showed a combination of impulsive noise and diffuse impulsive noise emanating from the line. Higher frequencies at 27.5 to 32.5 MHz shown in Figure 33 gave an unusual time spread diffuse type of impulsive noise emanating from the distribution line. Similar noise properties were noted at the 37.5 to 42.5 MHz frequencies as shown in Figure 34. All background noise examples had distinct peaks and nulls in the amplitude vs. frequency views which suggested that resonant elements were involved in the noise source to radiation mechanisms.

The exact relationships, if any, between the 25 to 80 kHz impulsive noise (Figure 30) and the noise found at the higher frequencies was not determined. Separate source mechanisms were probably involved with a synchronous single phase switching device being the source of the low frequency noise shown in Figure 30 and a separate unknown source for the other examples. The presence of distinct impulsive properties in the 17.5 to about 20 MHz portion of the data in Figure 32 cannot be explained by the simplistic assumption of two sources.

3.6.3 Converter Measurements

Converter-generated noise was not detected at the Vulcan Radiator site.

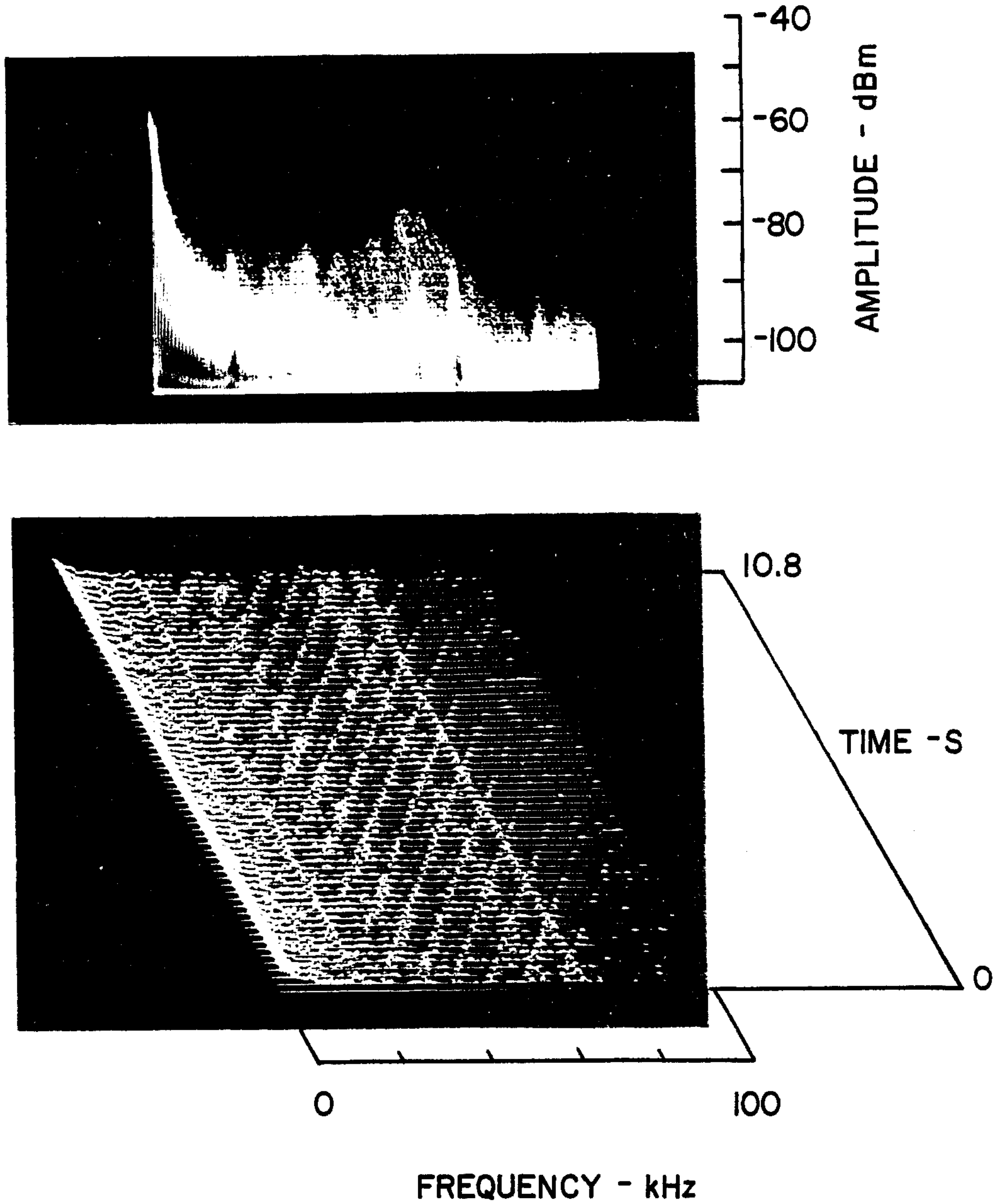

Figure 30 Vulcan Radiator Site, 6/29/78, 0843

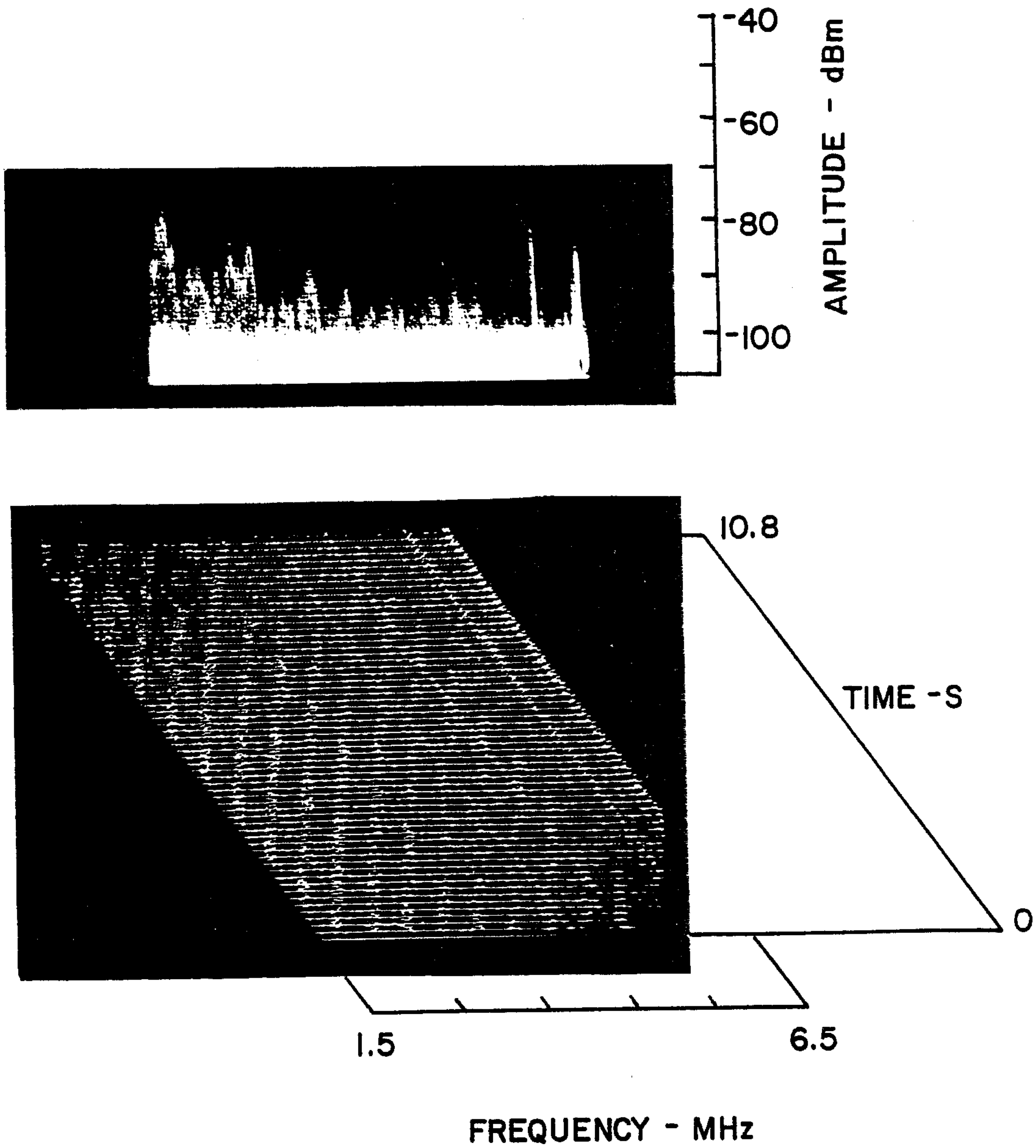

Figure 31 Vulcan Radiator Site, 6/29/78, 0930

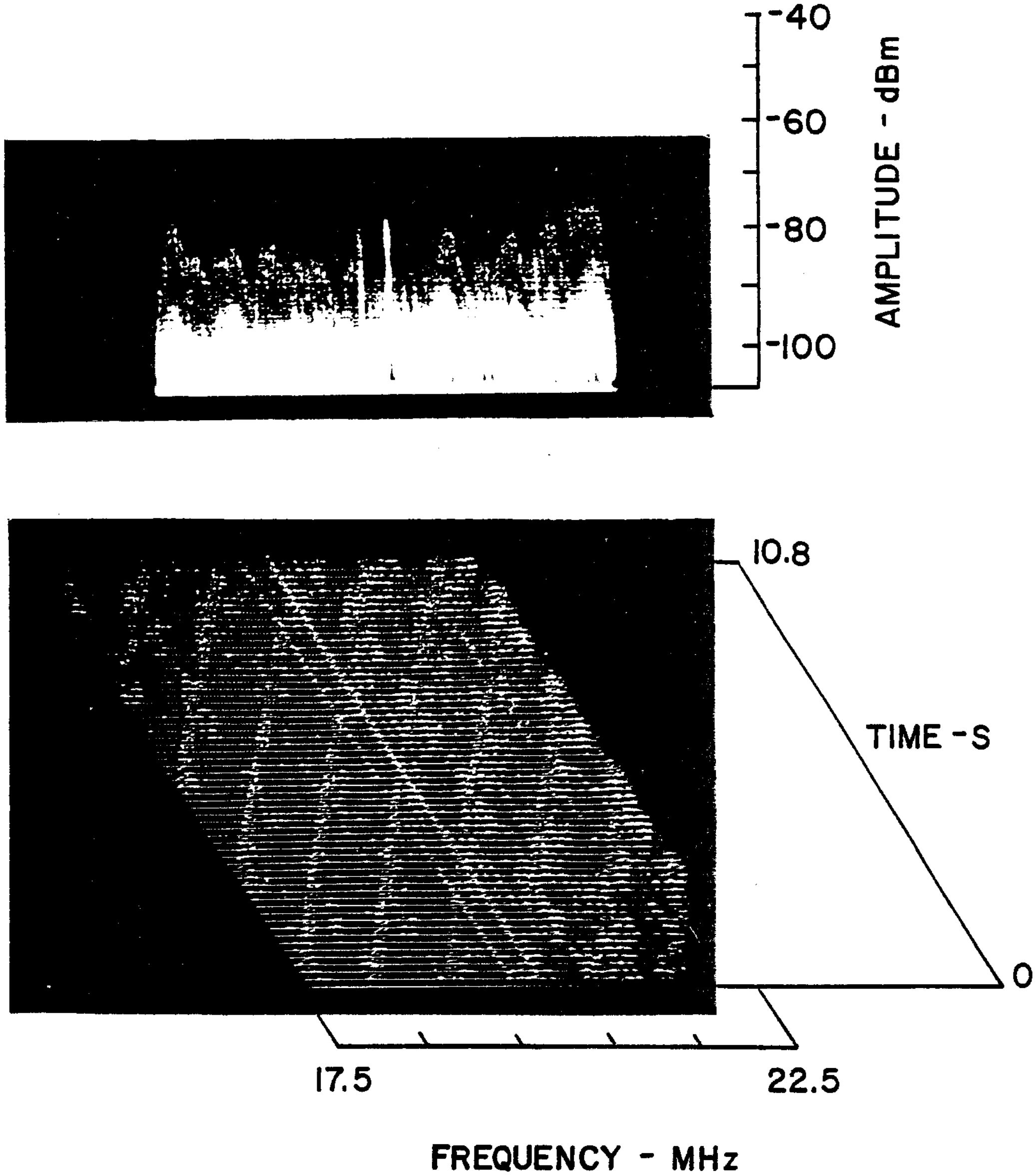

Figure 32 Vulcan Radiator Site, 6/29/78, 0933

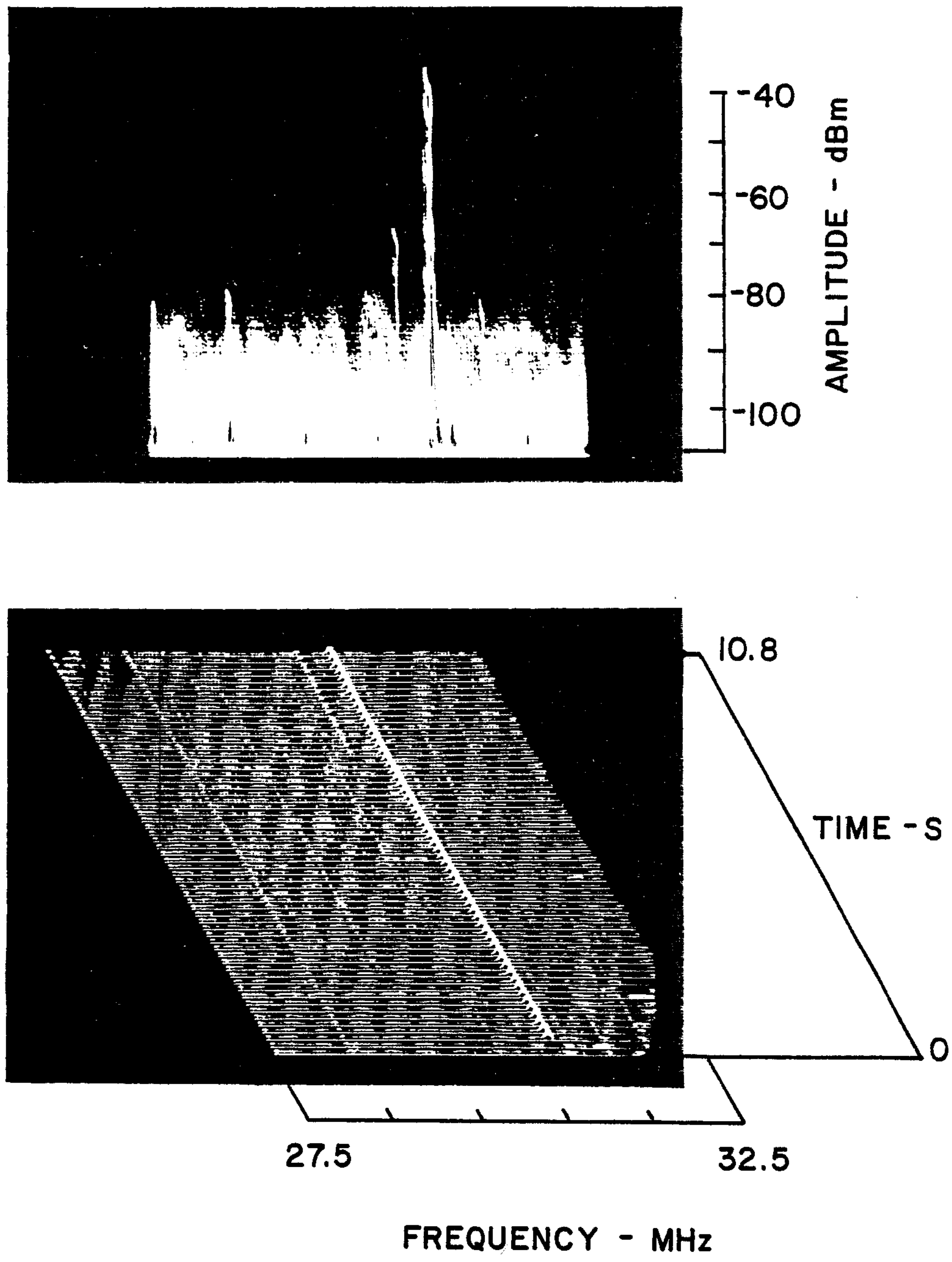

Figure 33 Vulcan Radiator Site, 6/29/78, 0945

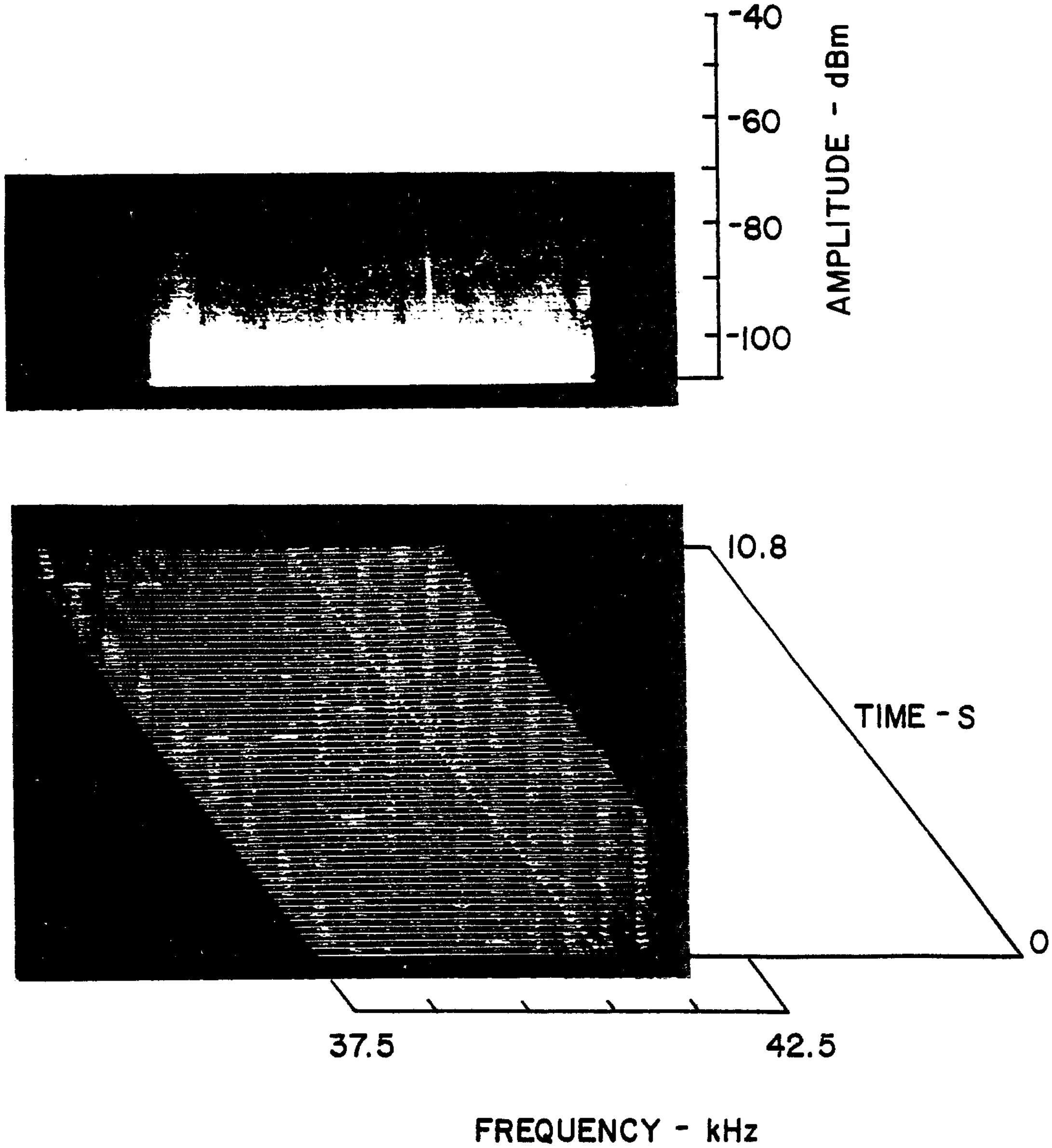

Figure 34 Vulcan Radiator Site, 6/29/78, 0940

3.7 FEEDER 4 SITE

3.7.1 Measurement Conditions

A site on Feeder 4 was selected to explore the propagation of impulsive noise through the substation and onto a separate feeder system. The site was located a short distance from the substation at a location where the vehicles could be parked directly under an unobstructed portion of the distribution line. Measurements were made at the Feeder 4 site on 6/29/79 from 1230 to 1500 hours local time.

Measurement system parameters for the 3-axis views taken at the Feeder 4 site are summarized in Table 5. These parameters will be useful to those readers who wish to scale the 3-axis views for some specific detail.

Table 5

MEASUREMENT PARAMETERS, FEEDER 4 SITE

FIG. NO.	DATE	LOCAL TIME	ANTENNA	FREQ. CENTER kHz	FREQ. WIDTH kHz	IF BAND-WIDTH kHz	SCAN TIME ms	IF REF. dB	RF REF. dB	CAP. UTC	CAP. S.P.P.	UTC CONV.
35	6/29/78	1330	Loop	50	50	1	100	-40	0	on	on	off
36	6/29/78	1341	Loop	50	50	1	100	-40	0	on	on	off

3.7.2 Background Measurements

Background noise levels were explored in Figures 35 and 36. Noise over the 25 to 75 kHz frequencies was examined in Figure 35 where weak bands of diffuse and time spread noise were found over the 40 to 65 kHz portion of the view. The amplitude level of the noise, as shown in the upper view, was low, and a few peaks in noise amplitude level were present.

A second view of noise in the 25 to 75 kHz band was obtained nine minutes after the data of Figure 35 as shown in Figure 36. The noise level had decreased in amplitude, and the noise components synchronous with the line frequency were barely visible in the 55 to 70 kHz portion of the view. The impulsive noise found at other sites was not present in the low frequency background data. Random impulses were present in the data in both Figures 35 and 36.

3.7.3 Converter Measurements

Converter-generated noise was not detected at the Feeder 4 site.

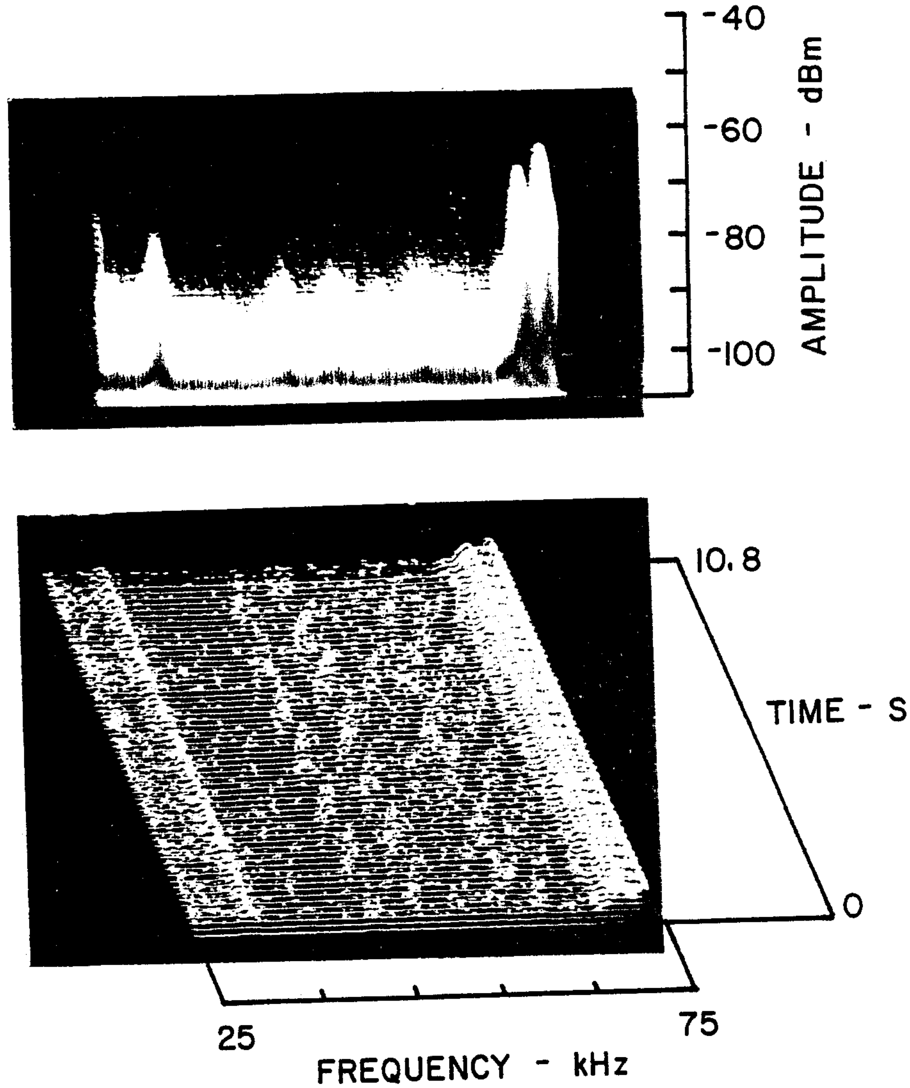

Figure 35 Feeder 4 Site, 6/29/78, 1330

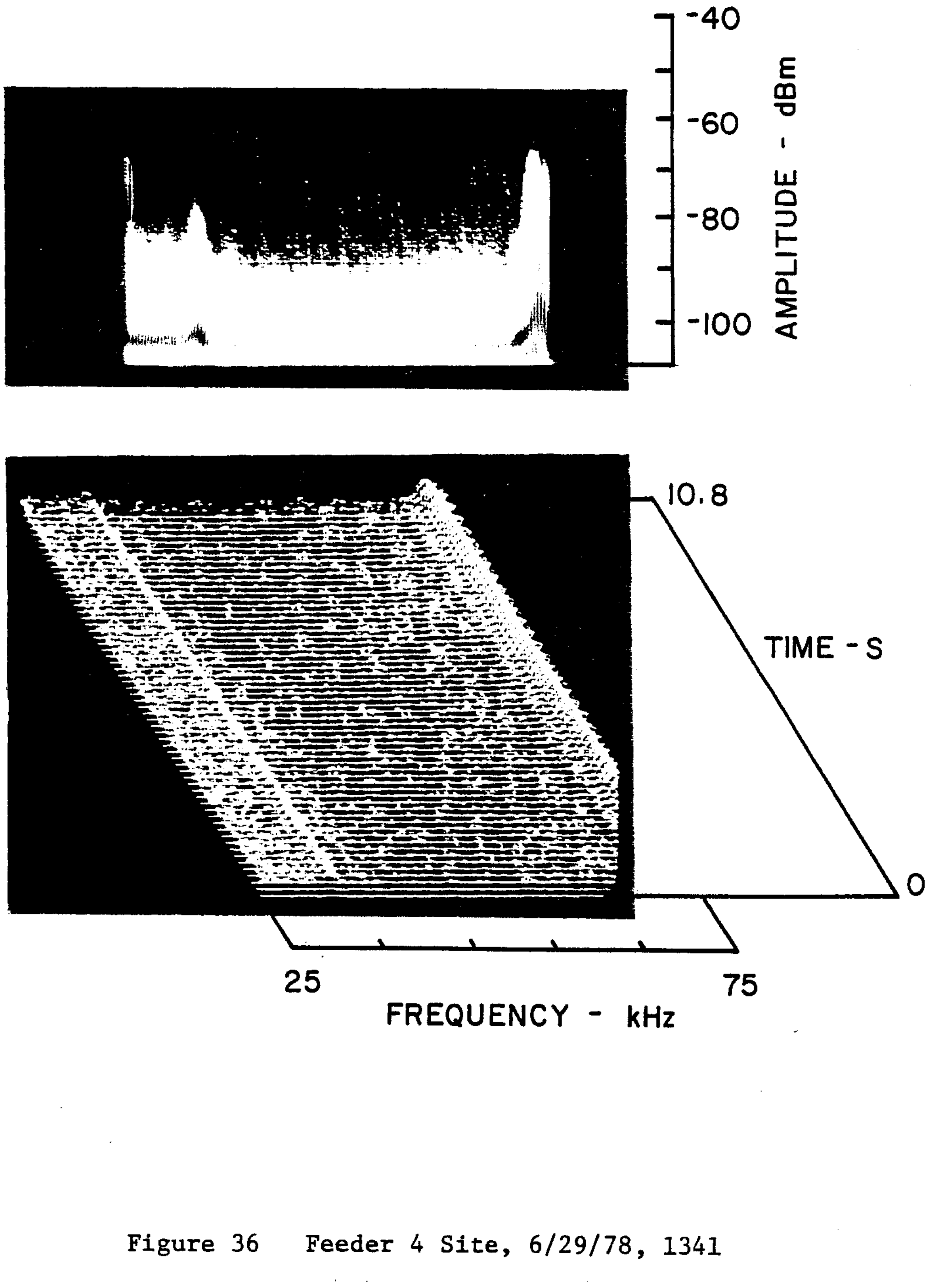

Figure 36 Feeder 4 Site, 6/29/78, 1341

3.8 UTC GATEHOUSE 3 SITE

3.8.1 Measurement Conditions

Instrumentation system operational and calibration tests were made on the day before the start of site measurements.. These tests were made to ensure that all van instrumentation was fully operational after cross-country travel, and to ensure that all measurements would be accurately calibrated in frequency, time, and amplitude. A site at the rear of the UTC Power Systems Division facility near Gatehouse 3 was used for these tests. The Gatehouse 3 measurements were made on 6/26/78, from 0930 to 1500 hours local time.

All instrumentation was found to be in good working order, and the operational and calibration tests were rapidly completed. Since time was available the general radio environment at the UTC plant was explored. Examples of radio environment measurements have been included in the report because the results supplement and complement the site results, and they aid in understanding the complex background signals found on the CL&P distribution lines.

Measurement system parameters for the 3-axis radio environment views taken at the UTC Gatehouse 3 site are summarized in Table 6. These parameters will be useful to those readers who wish to scale the 3-axis views for specific details not covered in the text.

All measurements were made with the 108" whip antenna, and comparable results with the loopstick antenna were not made. Loopstick results would have been somewhat complicated by orientation problems. Given sufficient time, the direction of arrival of each major noise from loop orientation measurements might have provided some data useful in source location within the UTC facility.

Table 6

MEASUREMENT PARAMETERS, UTC GATEHOUSE 3 SITE

FIG. NO.	DATE	LOCAL TIME	ANTENNA	FREQ. CENTER	FREQ. WIDTH	IF BAND-WIDTH kHz	SCAN TIME ms	IF REF. dB	RF REF. dB	CAP. UTC	CAP. S.P.P.	UTC CONV.
37	6/26/78	1005	Whip	300 kHz	500 kHz	1	50	-40	0	—	—	—
38	6/26/78	1014	Whip	400 kHz	500 kHz	1	100	-40	0	—	—	—
39	6/26/78	1135	Whip	44 MHz	10 MHz	10	100	-40	0	—	—	—
40	6/26/78	1231	Whip	70 MHz	100 MHz	100	100	-30	0	—	—	—
41	6/26/78	1249	Whip	62.5 MHz	10 MHz	100	100	-30	0	—	—	—
42	6/26/78	1258	Whip	62.5 MHz	10 MHz	100	100	-30	0	—	—	—

3.8.2 Noise Environment Measurements

Radio noise in the 50 to 550 kHz band was examined at the UTC Gatehouse 3 site as shown in the 3-axis views of Figure 37. A well-defined set of slanting lines spaced at 8.3 msec intervals can be found in the lower view which suggested a source of impulses synchronous with single phase positive and negative triggering of one phase of the overhead distribution line. A second less prominent set of slanting lines can also be seen which precede the main set by 2.8 ms. The second set of lines or impulses (also spaced 8.3 msec apart) appear to be associated with another single phase impulse source associated with a second phase pair of the overhead line. Apparently the third phase pair did not have an impulse source capable of producing noise at the Gatehouse 3 site at this frequency and at this time of day.

The upper view of Figure 37 shows a complex set of peaks and nulls of the impulsive noise signal as well as the amplitude of a few radio signals.

In Figure 38 noise in the 150 to 650 kHz band was examined. A large portion of the frequency range overlapped with that of the previous set of views (Figure 37). and the results were generally consistent with the two sets of data in the 150 to about 400 kHz overlap range where two separate single phase impulsive sources on two different phase pairs of the transmission line are shown in both views. At the 400 to 500 kHz frequencies impulses were spaced 5.5 ms apart. This spacing suggested a source related to a three-phase device operating on either the positive or the negative portions of the power line frequency. Impulsive noise in the 550 to 650 kHz portion of the view contained impulses which were spaced 16 ms apart. The 16 ms spacing suggested a single phase source which triggered on either the positive or the negative portions of the power line frequency.