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Characterization of the HDTV Channel in the San Francisco Area

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U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary

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PREFACE

Certain commercial equipment, instruments, or materials are identified in this report to adequately describe the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

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CHARACTERIZATION OF THE HDTV CHANNEL IN THE SAN FRANCISCO AREA

George Hufford, John Godwin, and Vincent Lawrence*

If over-the-air High Definition Television (HDTV) is to become a reality it would be useful to know the multipath characteristics of the radio channel over which it will be carried. The Institute for Telecommunication Sciences (ITS) has begun a program to measure these characteristics in locations that might represent consumer habits. This is the second report of the program. It discusses a few details concerning the measurement techniques and describes measurements made in the vicinity of San Francisco, California.

Keywords: channel characterization; delay spread; high definition television; impulse responses; multipath; pseudonoise codes; radio propagation; spectra

1. INTRODUCTION

A high definition television (HDTV) system is an example of a wideband communication system and as such will suffer if there is multipath in the propagation channel. For the design and testing of these systems, it is helpful to know how much multipath there is and what its characteristics are. This is particularly true of an over-the-air service in and around an urban area.

The Institute for Telecommunication Sciences (ITS) has begun a program to measure these characteristics under just such circumstances. In a previous report (Hufford *et al.*, 1990) we have described the measurement system, told how it was deployed in the Denver, Colorado, area, and displayed the data that were observed. In the present report, we describe a further stage in the program in which the measurement system was deployed in and near San Francisco, California, where the building styles and the notorious hills seemed to offer a distinct contrast to Denver.

The measurement system was designed to be both imitative of television practice and inexpensive. The transmitters are those of operating television stations with a test signal inserted on an otherwise unused one of the vertical blanking interval video lines. The receiving system includes off-the-shelf studio equipment to isolate the indicated line, a digitizer card which digitizes the test signal as received, and a PC-compatible computer

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which stores the results on disc. Signal processing to obtain impulse responses and analysis of the resulting portrayals of multipath are done off-line.

With such a measurement system, we believe we have eliminated several sources of error that might otherwise appear. The only real drawbacks seem to be a fairly low resolution and an inability at times for the receiver to synchronize with the proper line. The latter happens mainly when the signal is too weak or when the multipath is extreme. One might almost say that the statistics we obtain are conditioned by the requirement that HDTV reception is even possible.

2. PULSE SHAPES

An important design choice for the measurement system is the type of test signal to use. It will be a black and white video signal on a single horizontal line, but otherwise may be freely determined. Because it uses the line efficiently and because the subsequent processing is fairly simple, we have chosen to use a "pseudonoise code" that is transmitted as a sequence of high-level and low-level bits much in the manner of a teletext signal.

Attempting to be conservative in what we ask television stations to carry for us, we have indeed tried to design the signal to look just like a teletext line. For example, the bit rate is the teletext bit rate of approximately 5.73 MHz and the bit levels are at a nominal 0 and 70 IRE units. In addition to such parameters we must also "shape" the bits to restrict their spectrum—in particular, to keep them out of the audio channel.

Exactly what shape to use has been of some concern, and in developing the system we considered several possibilities. In the end we programmed into the digital test generator four different pseudonoise test signals. Three of them used the well-known raised cosine filters with different roll-off values equal to 47% (the minimum value for acceptable performance here), 55%, and 100%. The fourth signal we called the "teletext optimum." It was shaped according to a kind of compromise filter suggested by Sablatash *et al.,* (1989), and designed to approximate a number of appropriate criteria.

The resulting pulse shapes (after the vestigial sideband filters and after correlation with a square wave signal) are shown superimposed on each other in Figure 1. Looking only at the peaks, the teletext optimum shape does give the narrowest pulse and the 100% roll-off the widest, but the differences are very small.

In the Denver measurements we used the 100% roll-off shape. In San Francisco, however, we changed to the teletext optimum shape. Figure 2 shows this pulse in further detail.

Figures 1 and 2 emphasize the detailed shapes of the principle parts of the pulses. In Figure 3 we show how the four shapes appear over the full 20 μs length of the code. These are derived from simulated signals that have been devised and processed on a small desktop computer. They should exhibit neither noise nor multipath. We did, however, use the same file for the digitization of the pseudonoise code that we used for the test generator, and we attribute what appears to be noise.in Figure 3 to a "quantization noise" introduced by the limited precision of the digitization and the sampling processes.

In San Francisco both transmitting stations were kind enough to put on-line all four of the test signals. Thus we were able to test all four shapes as they appear in the field. Figure 4 shows the four shapes together as they were measured on a fairly clean path and

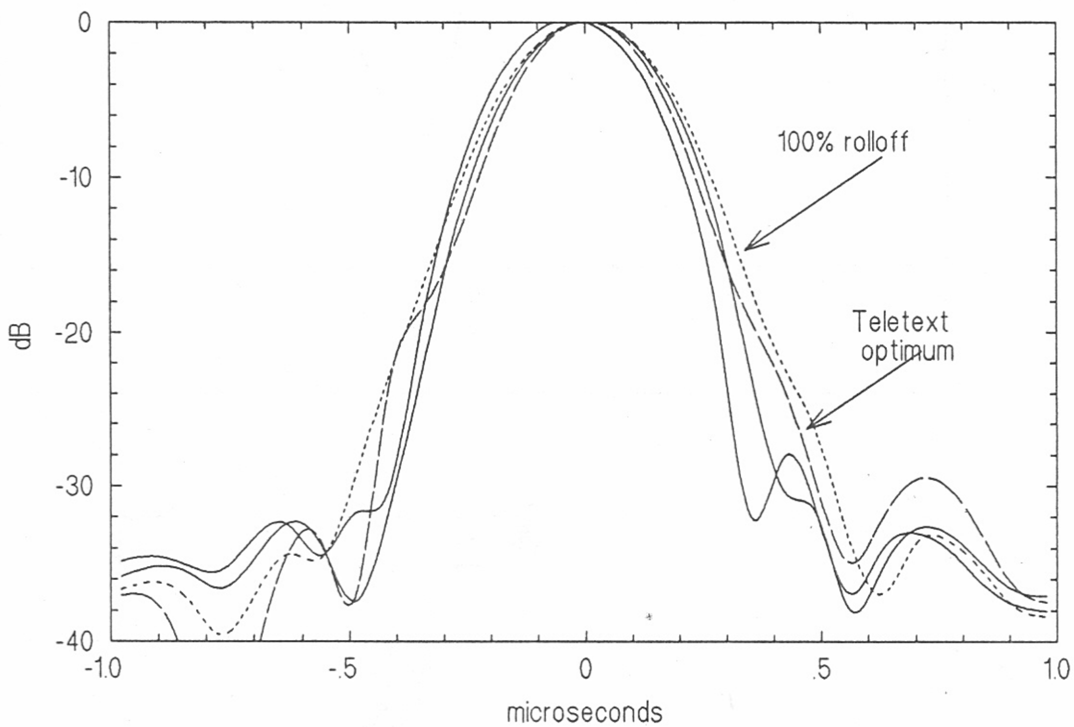

Figure 1. A closeup of the four suggested pulse shapes.

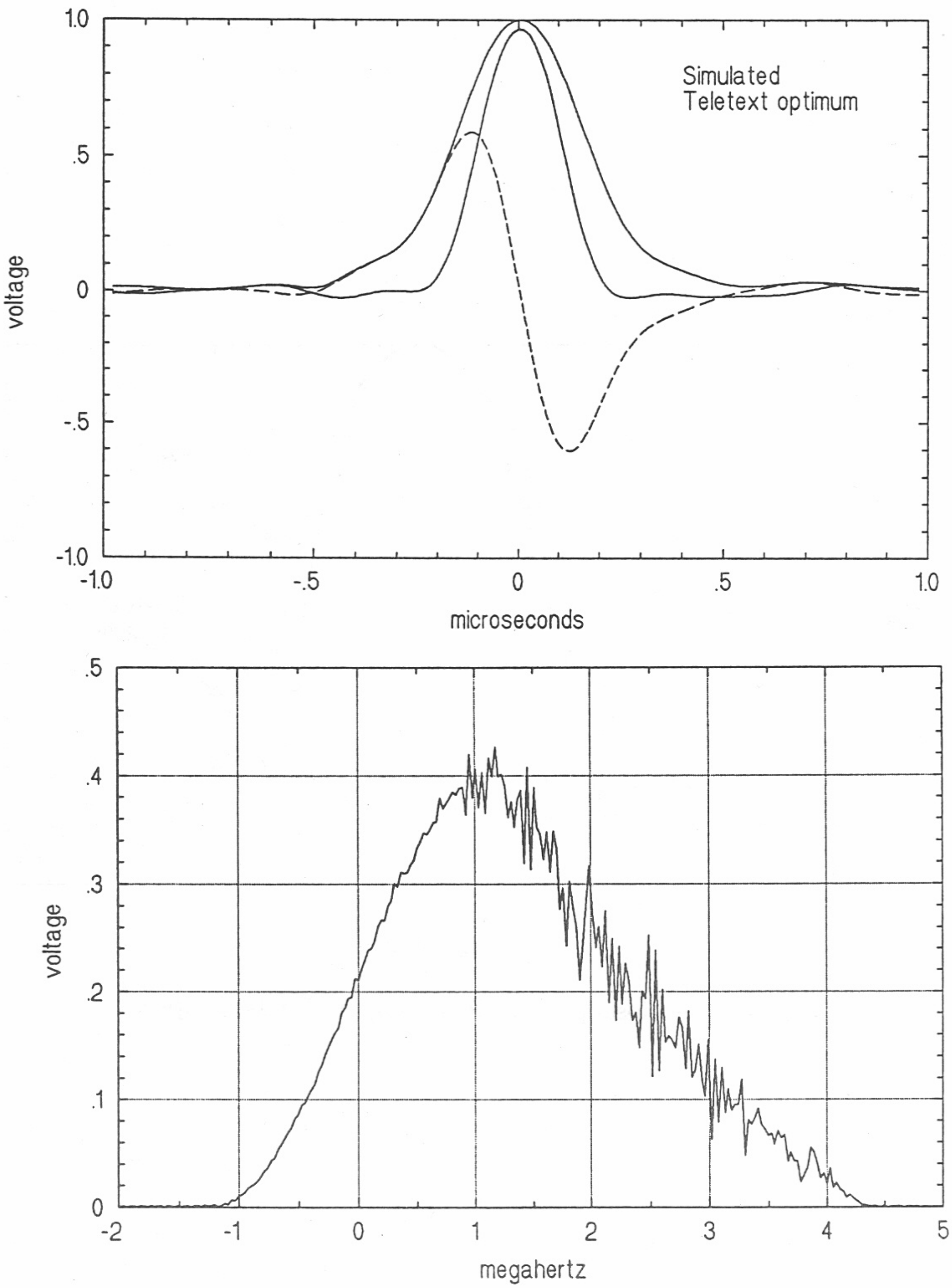

Figure 2. The teletext optimum pulse shape. The top graph shows the in-phase and quadrature-phase components and also the amplitude; the lower graph shows the amplitude of the spectrum.

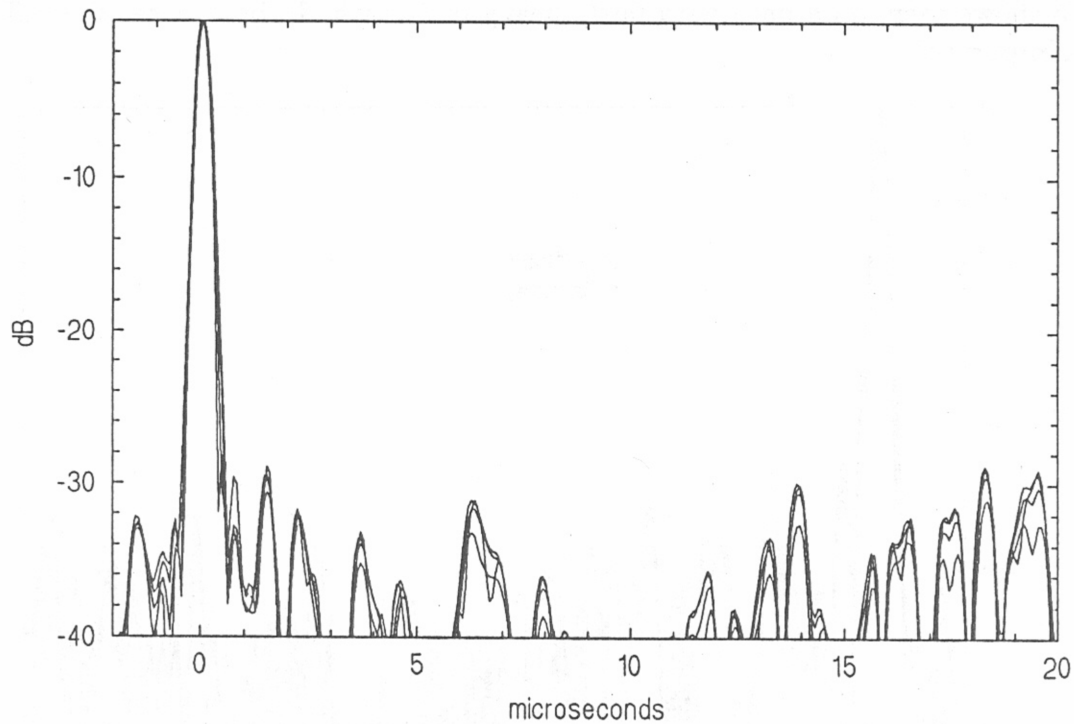

Figure 3. A wider view of the four pulse shapes.

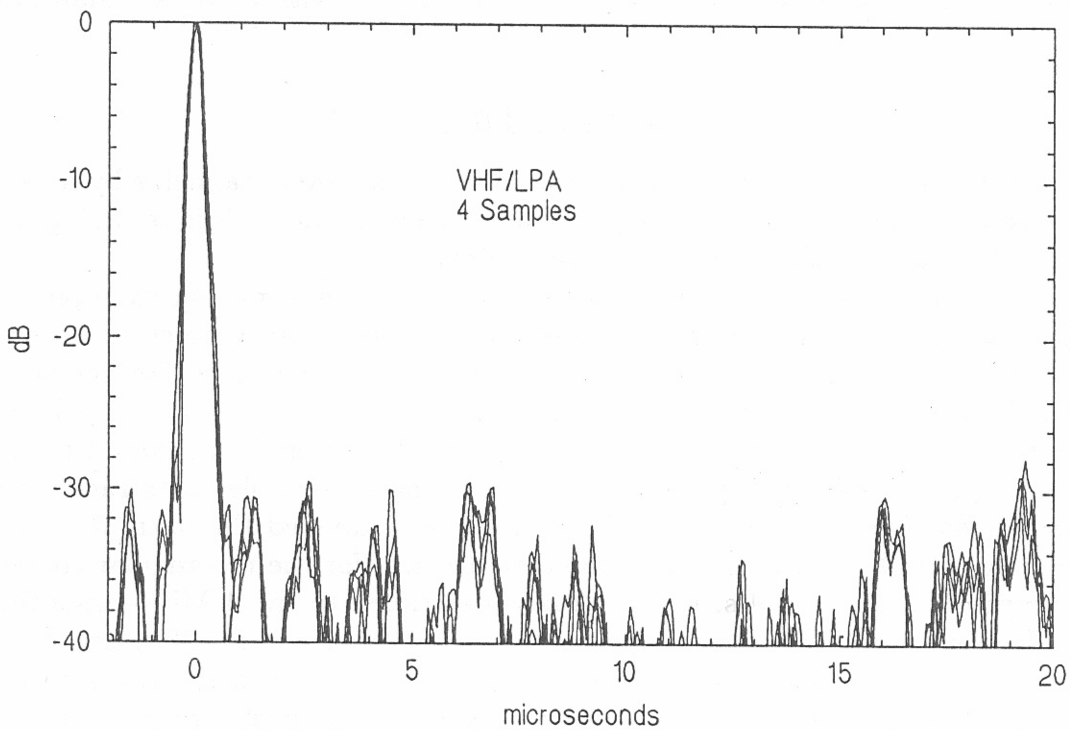

Figure 4. The four pulse shapes as observed on a relatively clean path.

Figure 5 shows them on a path with fairly heavy multipath. In both cases the differences seem unimportant.

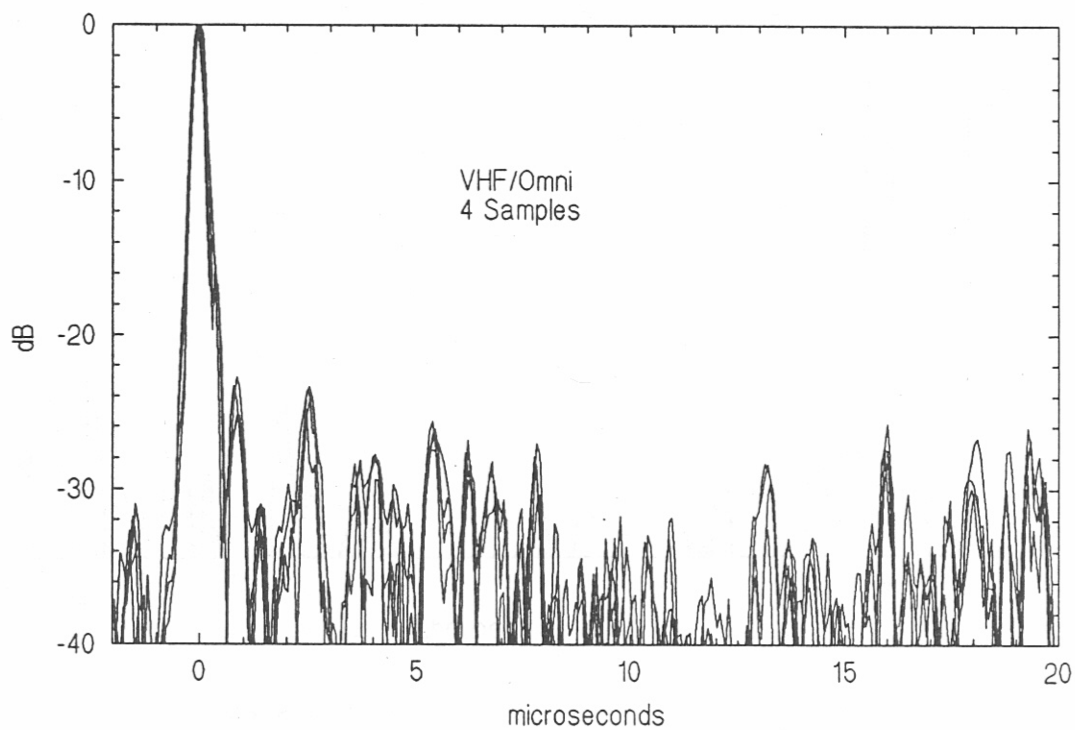

Figure 5. The four pulse shapes as observed on a path with moderate multipath.

3. SPECTRA

The most direct way to look at multipath in a transmission channel is by means of its impulse response. But since multipath translates into frequency selective fading, it might be of interest to have available the spectrum as well.

It is not entirely clear how one should represent the spectrum. For example, we have found the (complex-valued) impulse response measured on a fairly quiet path, windowed it slightly to allow a smooth fit into a longer time base, taken the Fourier transform, and plotted the results in Figure 6. As the figure shows, most variability here arises from the filters imposed on the transmitted signal: the vestigial sideband filter and the shaping filter. Since these are known functions, we should be able to extract them from the measured data. For the graph in Figure 7 we have divided the data in Figure 6 by these functions—and also by another amount to account for the rectangular shape of the correlation process. The results, which we have restricted to the 4 MHz range from -0.5 to 3.5 MHz (relative to the carrier frequency), seem rather good. Of course there may be further filtering action caused perhaps by the video circuits in the transmitter or by frequency-dependent responses in the antennas or in the receiver circuits. To eliminate these we would require a careful calibration that is beyond our reach.

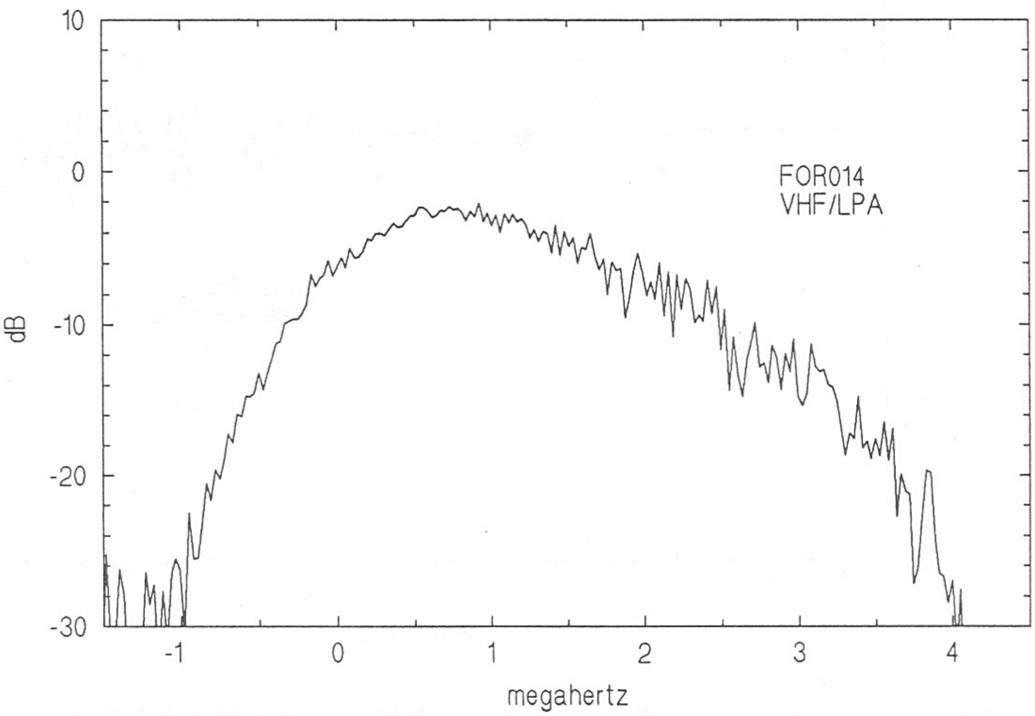

Figure 6. The uncorrected spectrum of the impulse response observed on the relatively clean path of Figure 4.

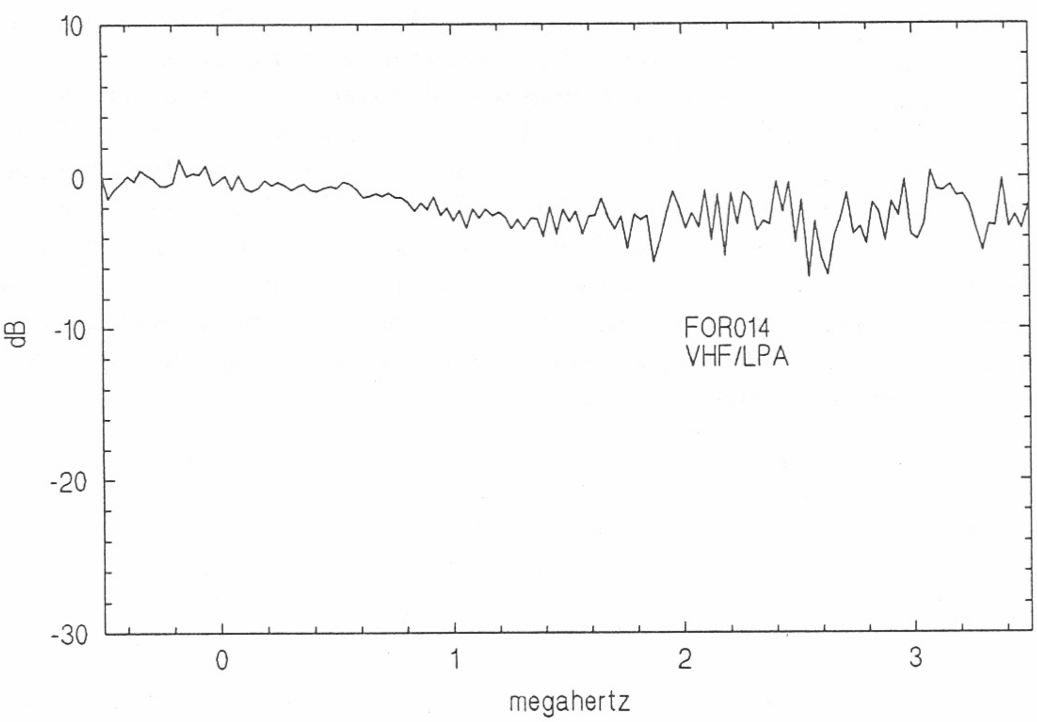

Figure 7. The spectrum of Figure 6 after division by spectra of the known, computable filters.

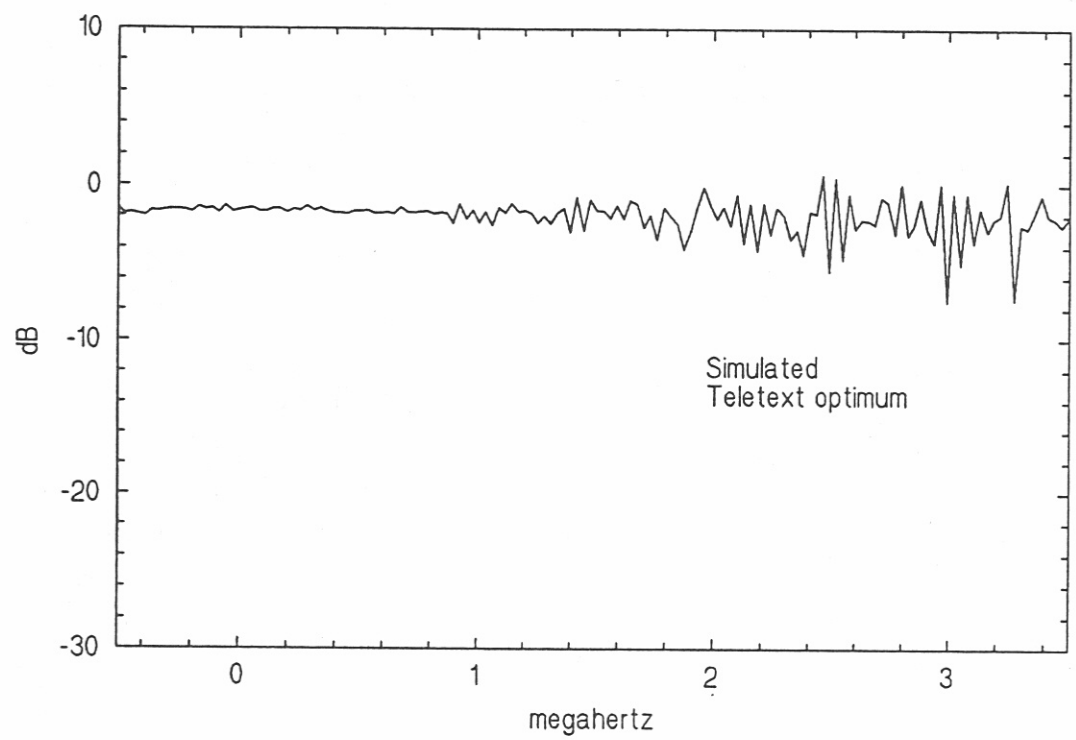

Figure 8. The corrected spectrum of the simulated teletext optimum pulse in Figures 2 and 3.

In Figure 8 we have plotted the corrected spectrum of the simulated pulse in Figure 2. It should, of course, be a horizontal straight line. Again we attribute deviations from the ideal to the quantization noise described in connection with Figure 3.

Figures 9, 10, and 11 show more examples of corrected spectra. At the top of each we have plotted the impulse responses so that the two representations may be compared. Note that Figures 7 and 9 can serve as a calibration of sorts for the two channels.

If, as suggested in our first report, the channel is a GWSSUS (a Gaussian Wide Sense Stationary Uncorrelated Scatterers channel, first described and named by Bello, 1963) then the spectrum will be a stationary, complex-valued, Gaussian process in which the independent variable is the frequency. It will be colored and, because of the contribution from the direct wave, it will have a nonzero mean. The sample spectra we have shown do not, we think, contradict such behavior.

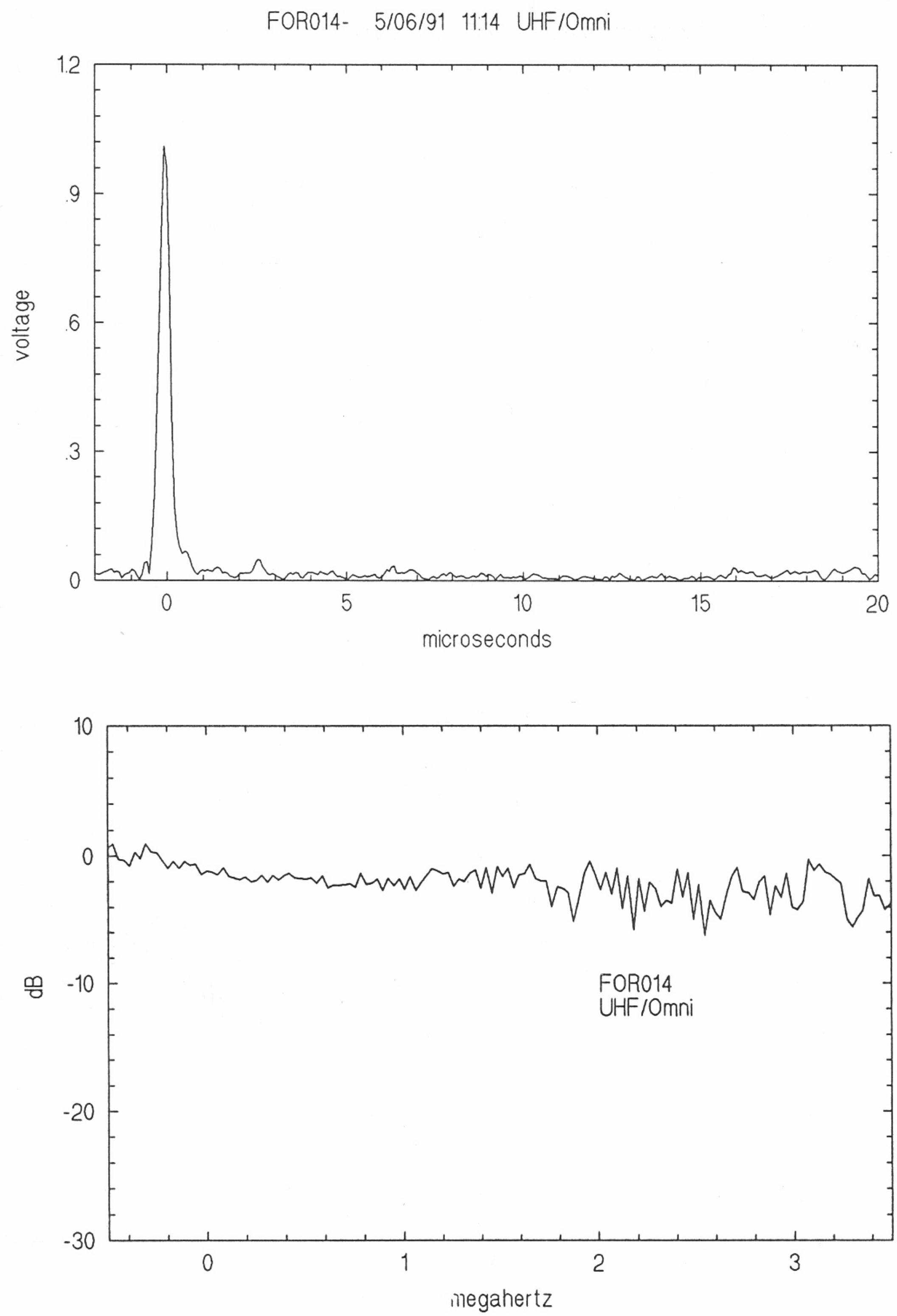

Figure 9. The impulse response and spectrum observed on the UHF channel for the same path as used in Figure 7.

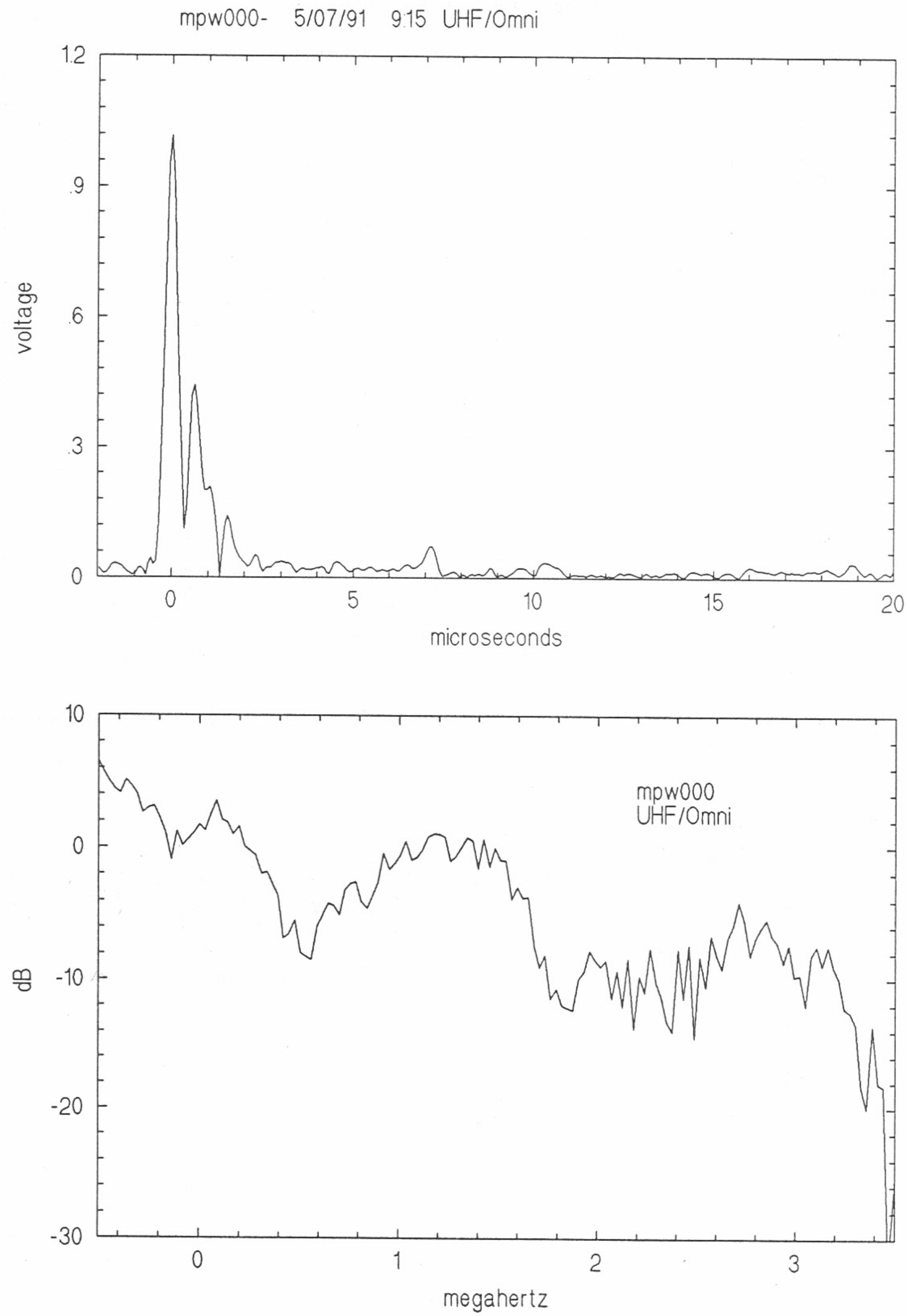

Figure 10. The impulse response and spectrum on a path showing moderate multipath.

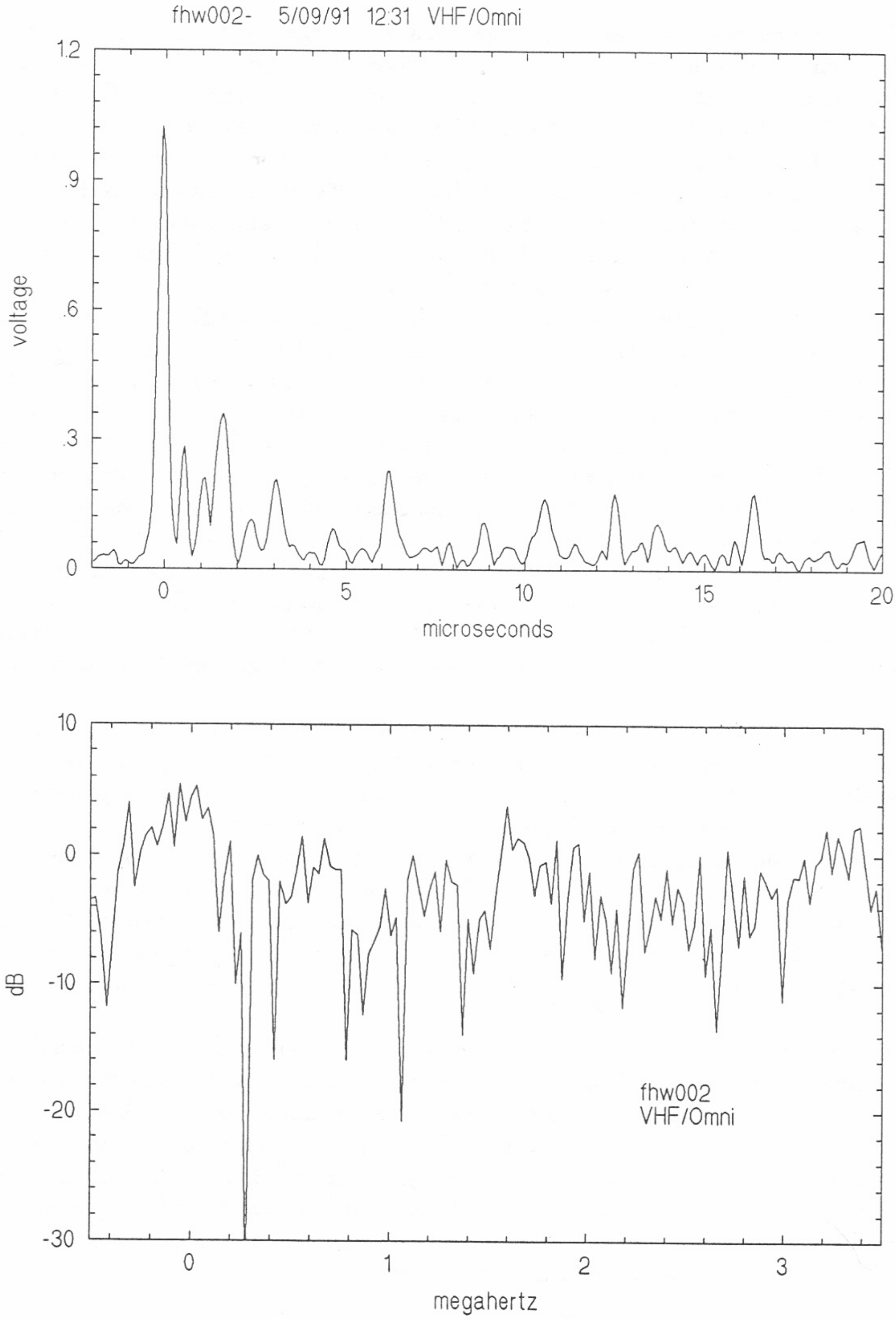

Figure 11. The impulse response and spectrum on a path with severe multipath.

4. SAN FRANCISCO DATA

The San Francisco-Oakland-San Jose area is a large metropolis of almost 6 million people. Located on the shores of the Pacific Ocean and the San Francisco Bay, it has a dry but equable climate. San Francisco itself is at the northern tip of the San Francisco Peninsula along with the famous 200 m high hills. Except for the expansive parks, the city is densely covered with structures—mostly 3- or 4-story residences. The "financial district" contains the tall buildings including the 260 m Transamerica Pyramid. The district is towards the northeast corner of the peninsula and overlooks the harbor and the bay. Because of the backdrop of hills, however, the tall buildings do not provide a dominant skyline like, say, New York or even Denver.

South of the city lies what is called the lower peninsula. To its west are the Santa Cruz Mountains rising to 800 m or more, often with a dense cover of redwood trees. On the eastern side of the lower peninsula is the low, flat basin that contains the San Francisco Bay along with the many suburban communities that surround the bay. Oakland is across the bay, about 15 km from San Francisco, and San Jose is to the south about 70 km away.

Many of the area's television stations have antennas on the Mt. Sutro Tower, a large open-girder structure with three large antenna stacks at its corners. The tower is located on Mt. Sutro near the geographic center of San Francisco. The ground is 250 m above sea level and the tower rises another 300 m. From its top there is an excellent view of the bay and the surrounding communities, even out to, and beyond, San Jose. There are, of course, shadowed areas behind the hills of the city, but Oakland and the bay communities are line-of-sight and the corresponding heights above average terrain must be nearly the full 550 m.

For our measurements we had the cooperation of two television stations transmitting from Mt. Sutro. One, a VHF station, was KGO-TV on channel 7, and the other was a UHF station, KBHK-TV on channel 44. Both are full power stations; channel 7 has an effective radiated power of 316 kW, and channel 44 has 5 MW.

The receiving system involved the same equipment used in the Denver measurements. In particular, we received each of the two frequencies on two antennas: an omnidirectional turnstile antenna and a directional (650 beamwidth) log-periodic antenna. During a measurement the log-periodic antenna was always pointed in the direction of the transmitting tower, and all antennas were mounted about 9 m above the street on a single pneumatic mast.

As in the previous measurements, our choice of receiver sites emphasized *archetypal* areas—areas where the buildings and vegetation are somewhat homogeneous so that multipath characteristics ought to be consistent. Thus we choose an area that we characterize as "wooded residential" or "near the urban high rise" and then select several sites, about one block apart, where sets of measurements are made. Figure 12 is a map showing the general San Francisco region and the archetypal locations we chose for our measurements. The numbers accompanying each location are the figure numbers in this report where the corresponding measurement statistics are displayed.

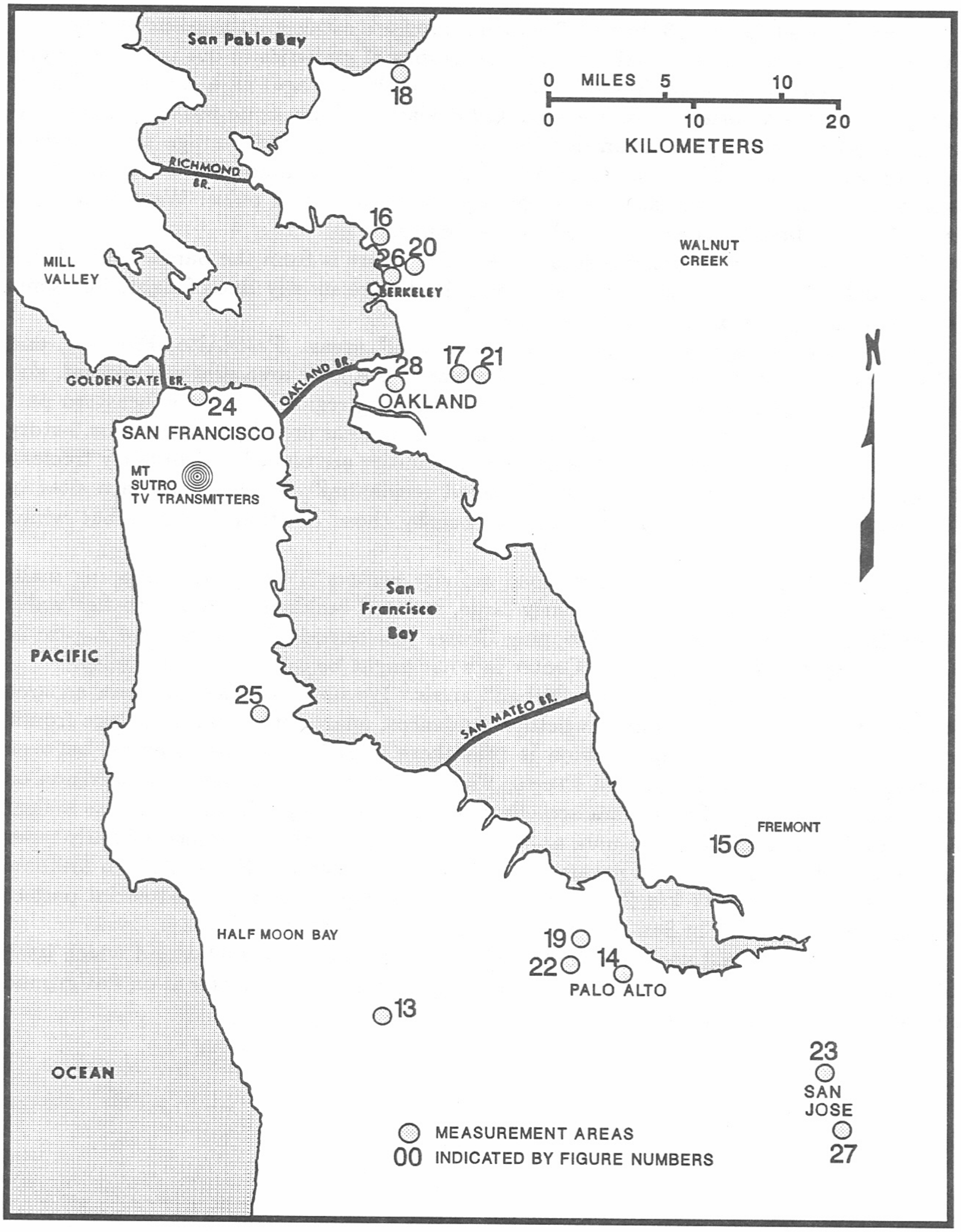

Figure 12. Map of the San Francisco region showing the archetypal measurement areas.

These figures (Figures 13 through 28) then comprise a catalog of the statistics observed within the archetypal areas. In them, as in the graphs of statistics in our previous paper, we have plotted the average "power" (the square of the voltage) as a function of delay time, and then, as a dotted curve, the standard deviation of this same power. (Recall that if the complex voltage is Gaussian distributed then the computed average and standard deviation will be, to within sampling error, equal.) To help the interpretation, results have been expressed in decibels relative to the peak power in the direct pulse. We conclude our discussion with brief comments for each of the figures.

Figure 13: A "mountainous rural" area. The figure is from the Santa Cruz Mountains, about 50 km south of the transmitters. Paths are mostly line-of-sight, but some sites are inside groves of large redwood trees.

Figures 14 through 18: Five "open residential" areas. Palo Alto, Fremont, and Berkeley are all in flat areas near the bay. Piedmont is a hilly area east of Oakland, and Pinole has moderate hills and is in the newly developing region in the northeastern part of the bay area. The homes in the Fremont and Pinole areas are of the large 2- or 3-story types that are currently popular. The other communities are older but still fairly treeless.

Figures 19, 20, and 21: Three "wooded residential" areas. These are sites in Palo Alto, Berkeley, and Piedmont that are nearby those mentioned above, but which are older and now have well-developed trees.

Figures 22 and 23: Two "suburban activity centers." These are shopping malls or industrial parks where there are fairly large, isolated buildings, often with flat walls. Figure 22 here is in the Stanford Shopping Center just outside Palo Alto, and Figure 23 is near the Santa Clara Convention Center in what might be called "Silicon Valley."

Figures 24 through 27: Four "urban" areas. We use this term to mean an area dominated by fairly low buildings, whether residences, apartment buildings, store fronts, or warehouses. The deciding criterion is that there is little open space either between buildings or between buildings and streets. Figure 24 is in Cow Hollow, a subdivision on the north-central edge of San Francisco. Part of it is shaded by hills and part has a clear path. Although to the eye the area appears homogeneous, the difference in path types may be a much more important parameter in fixing the archetype. Figure 25 is in Millbrae just south of the city (17 km from the transmitters), Figure 26 in an industrial part of Berkeley, and Figure 27 in San Jose near that city's civic center.

Figure 28: In and near the "high rise" area. This figure is in Oakland which itself has a cluster of tall buildings. The highest is only 120 m, but the cluster is on flat ground and exposed from all sides.

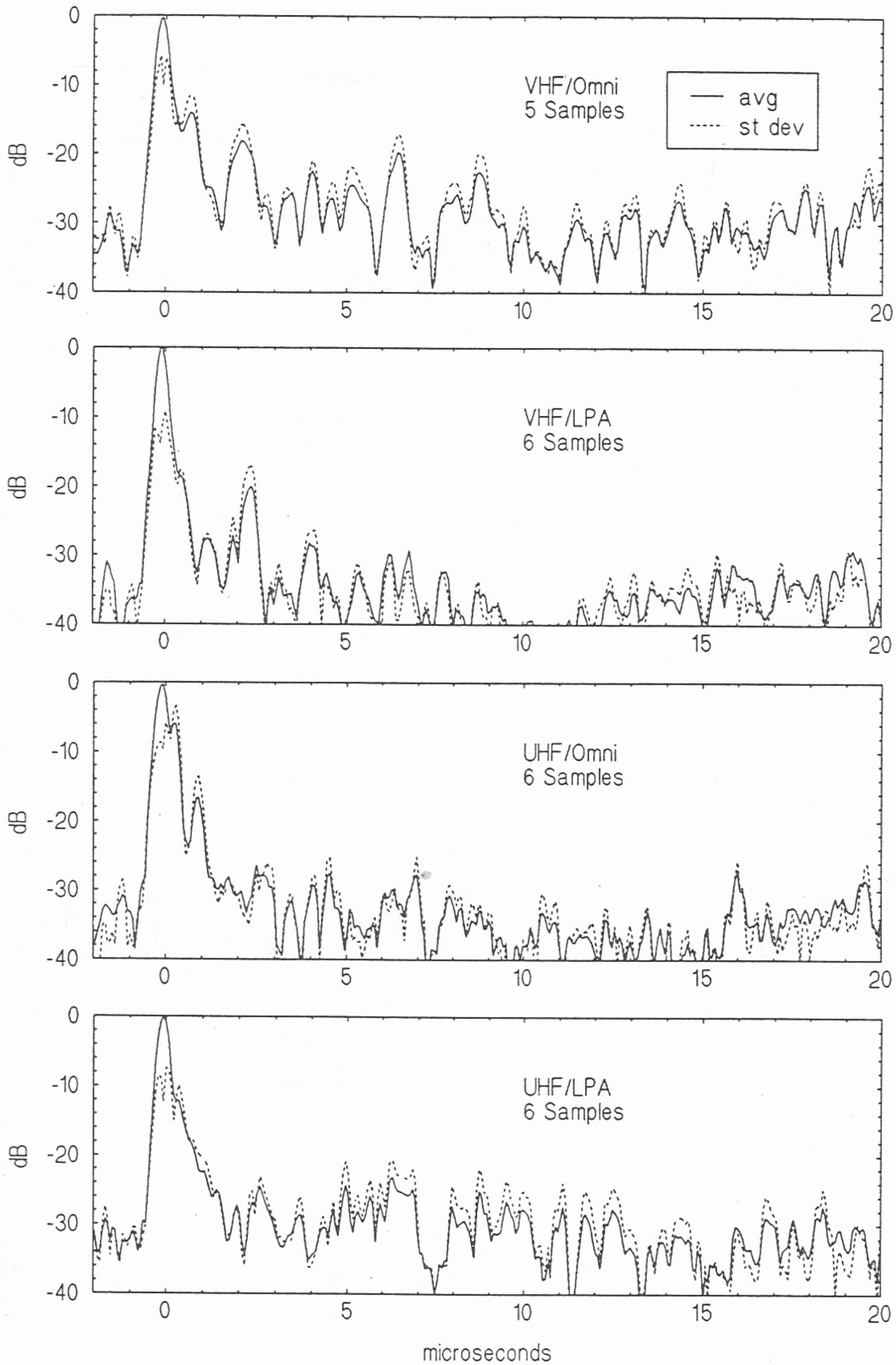

Figure 13. A mountainous rural area in the Santa Cruz Mountains.

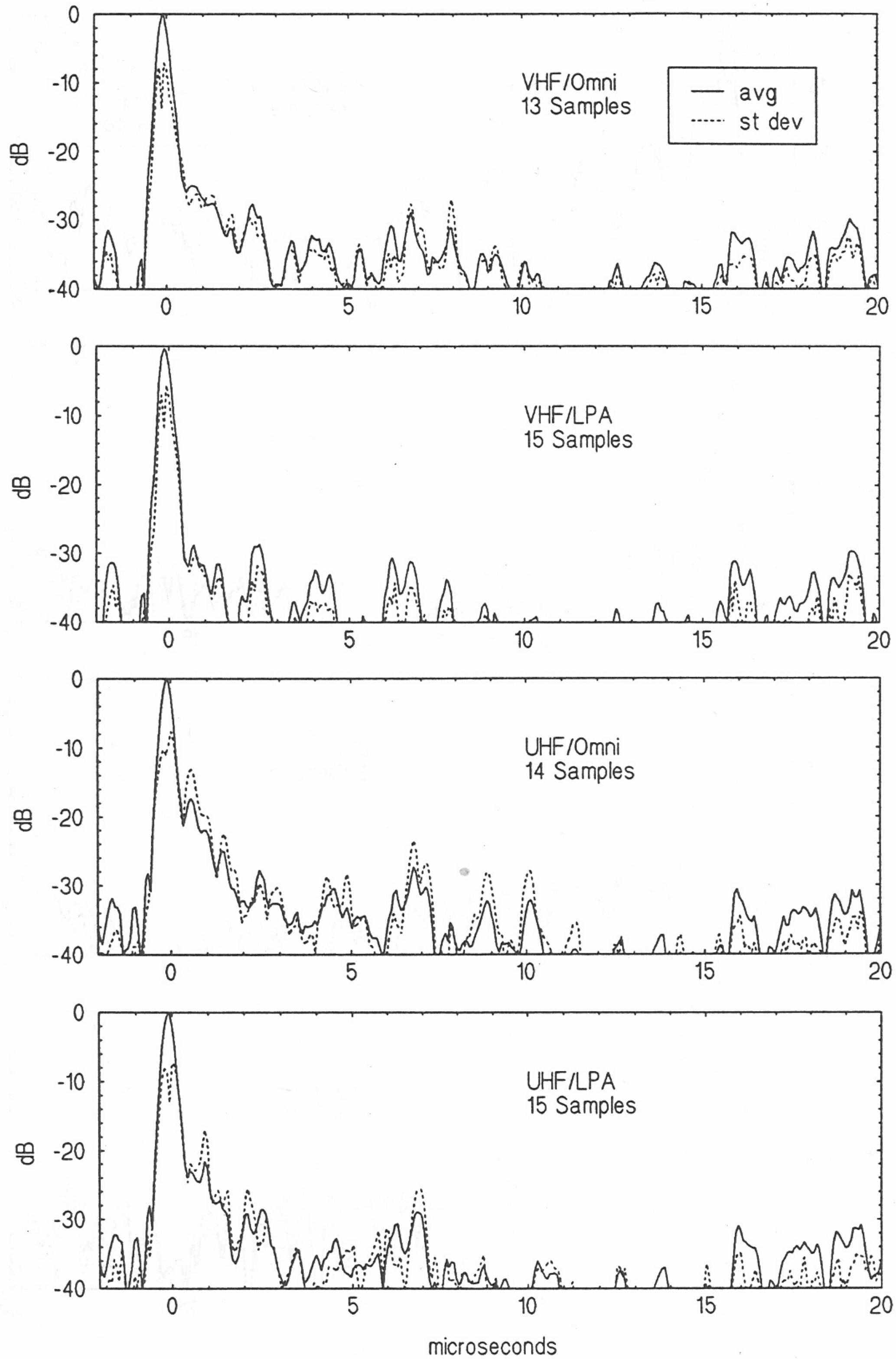

Figure 14. An open residential area in Palo Alto.

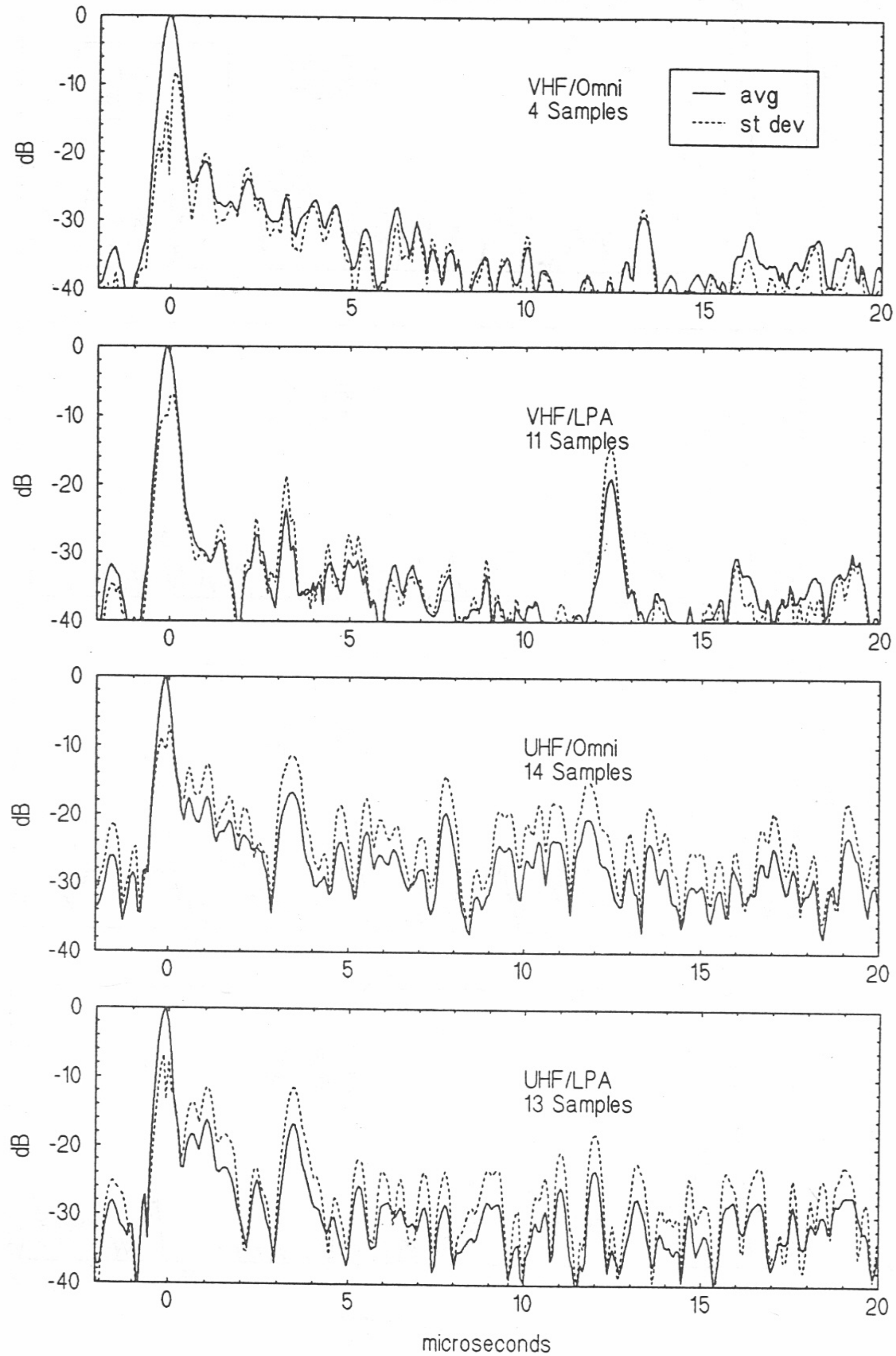

Figure 15. An open residential area in Fremont.

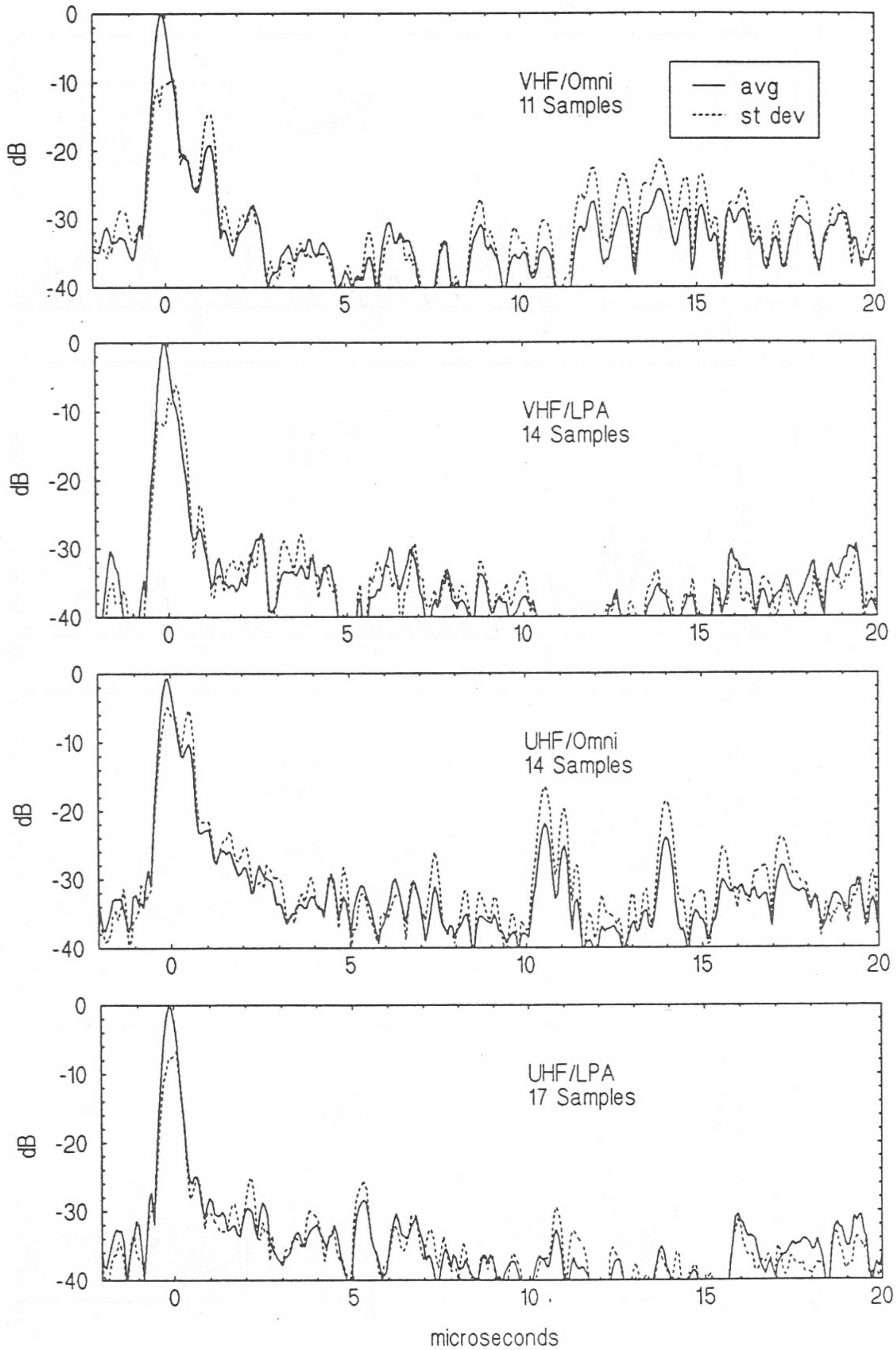

Figure 16. An open residential area in Berkeley.

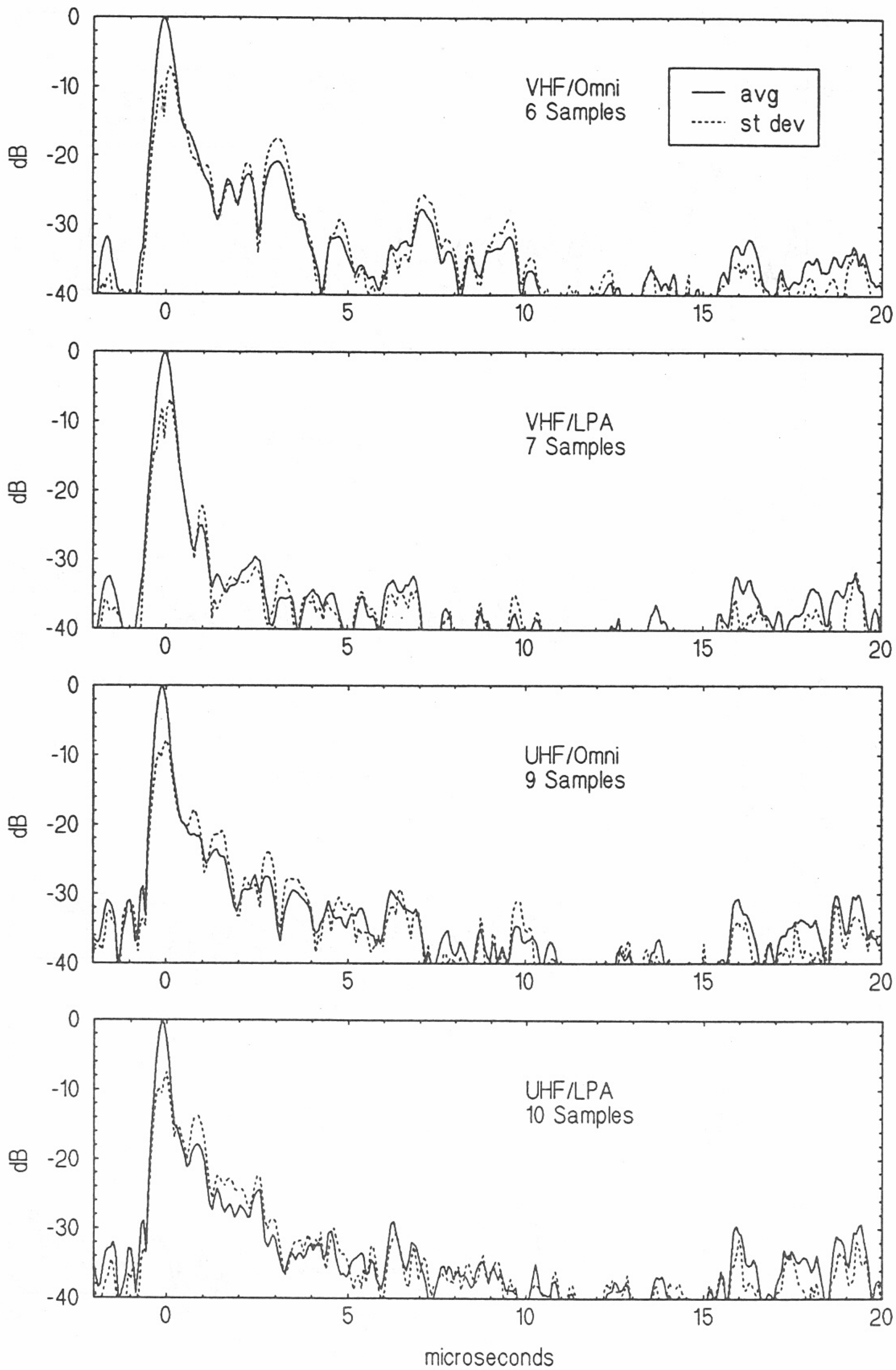

Figure 17. An open residential area in Piedmont.

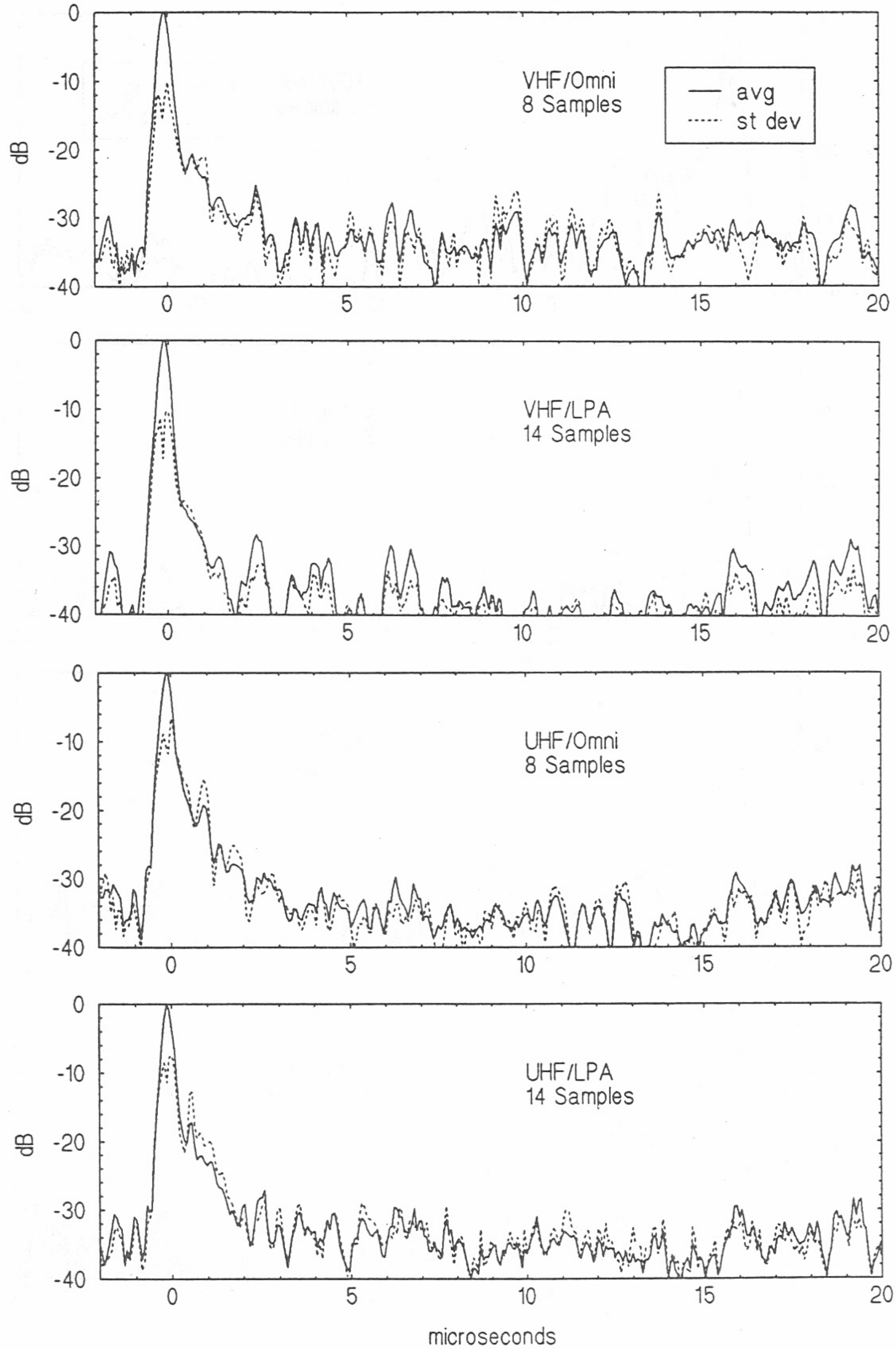

Figure 18. An open residential area in Pinole.

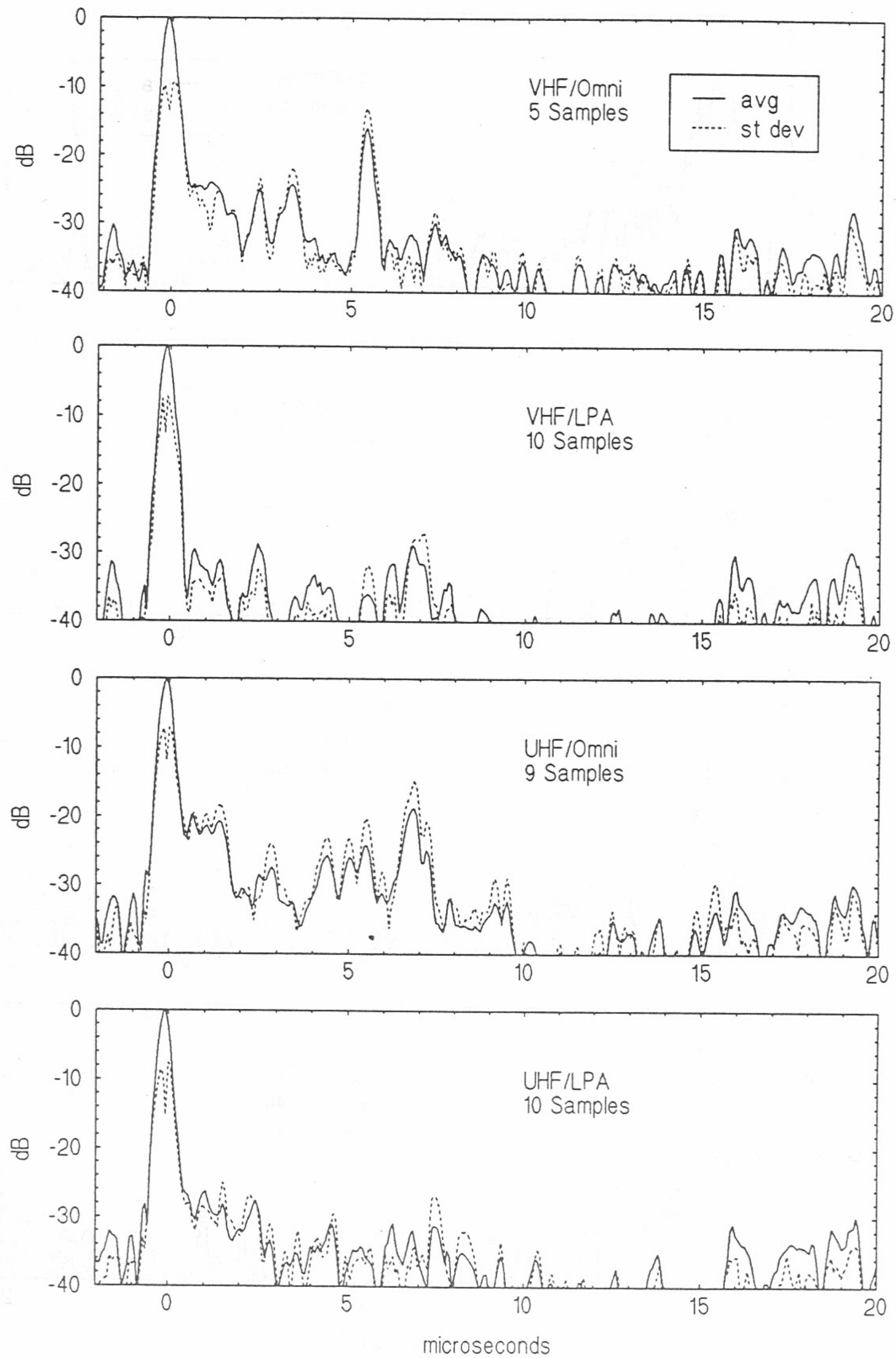

Figure 19. A wooded residential area in Palo Alto.

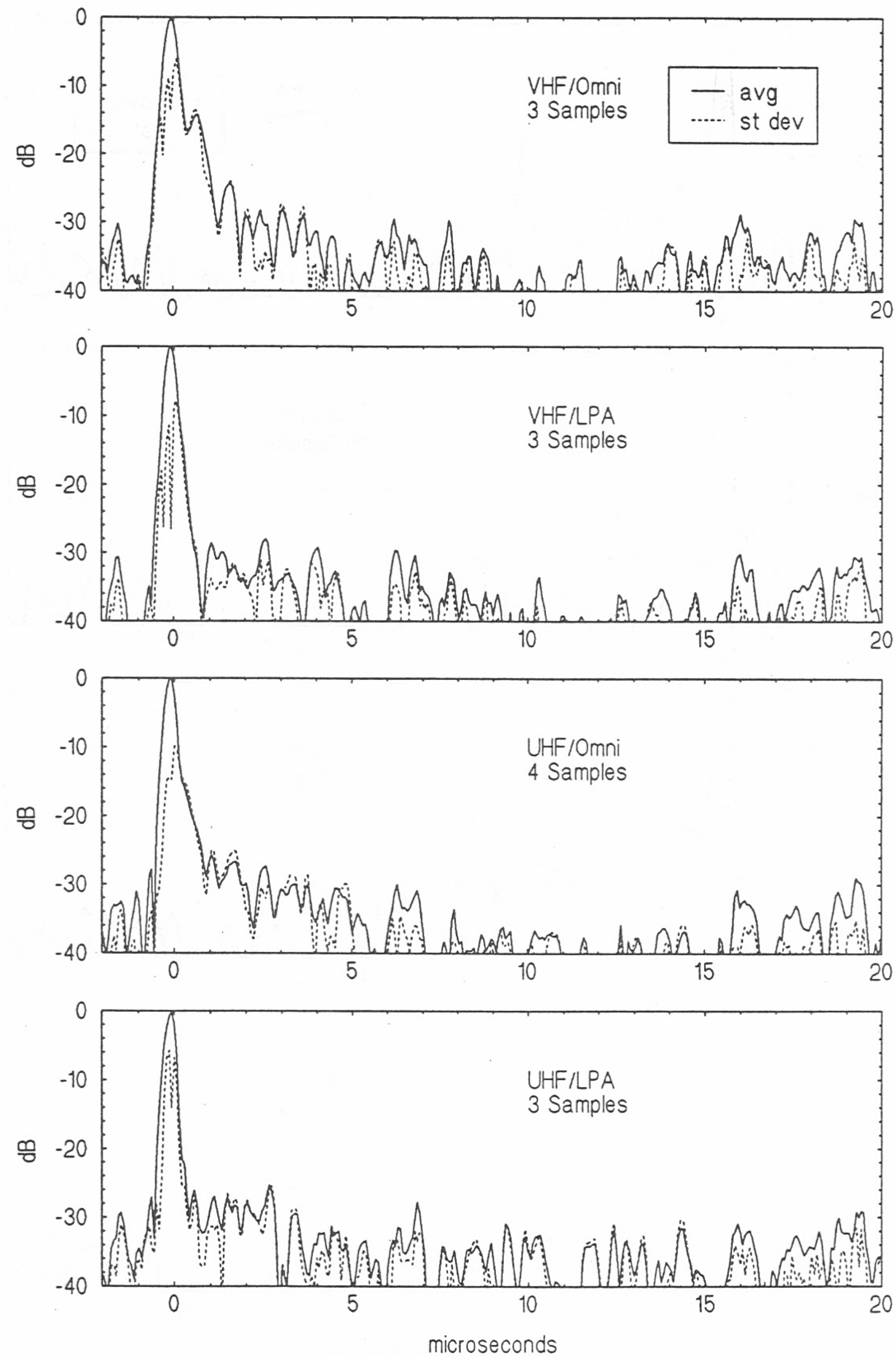

Figure 20. A wooded residential area in Berkeley.

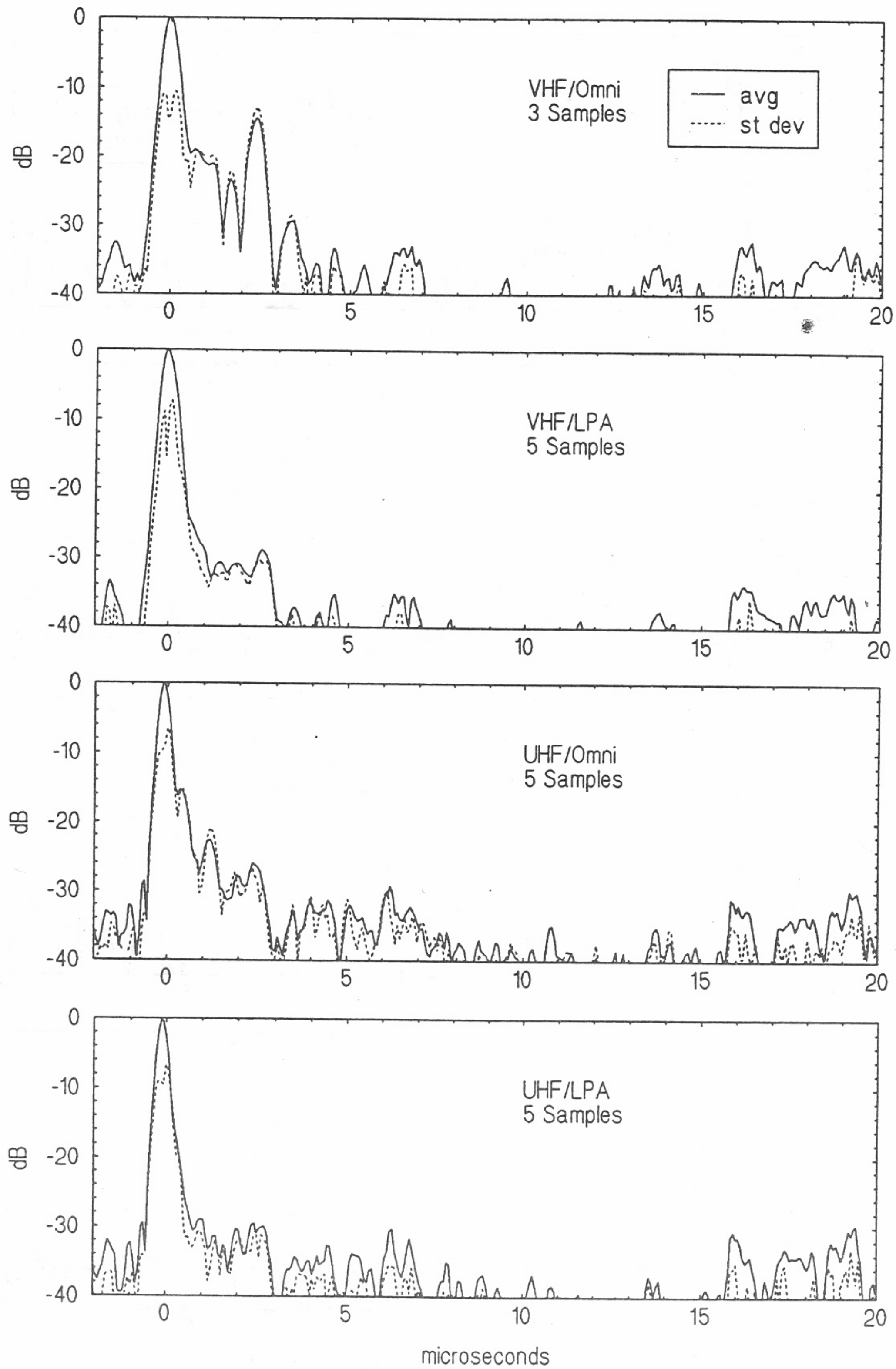

Figure 21. A wooded residential area in Piedmont.

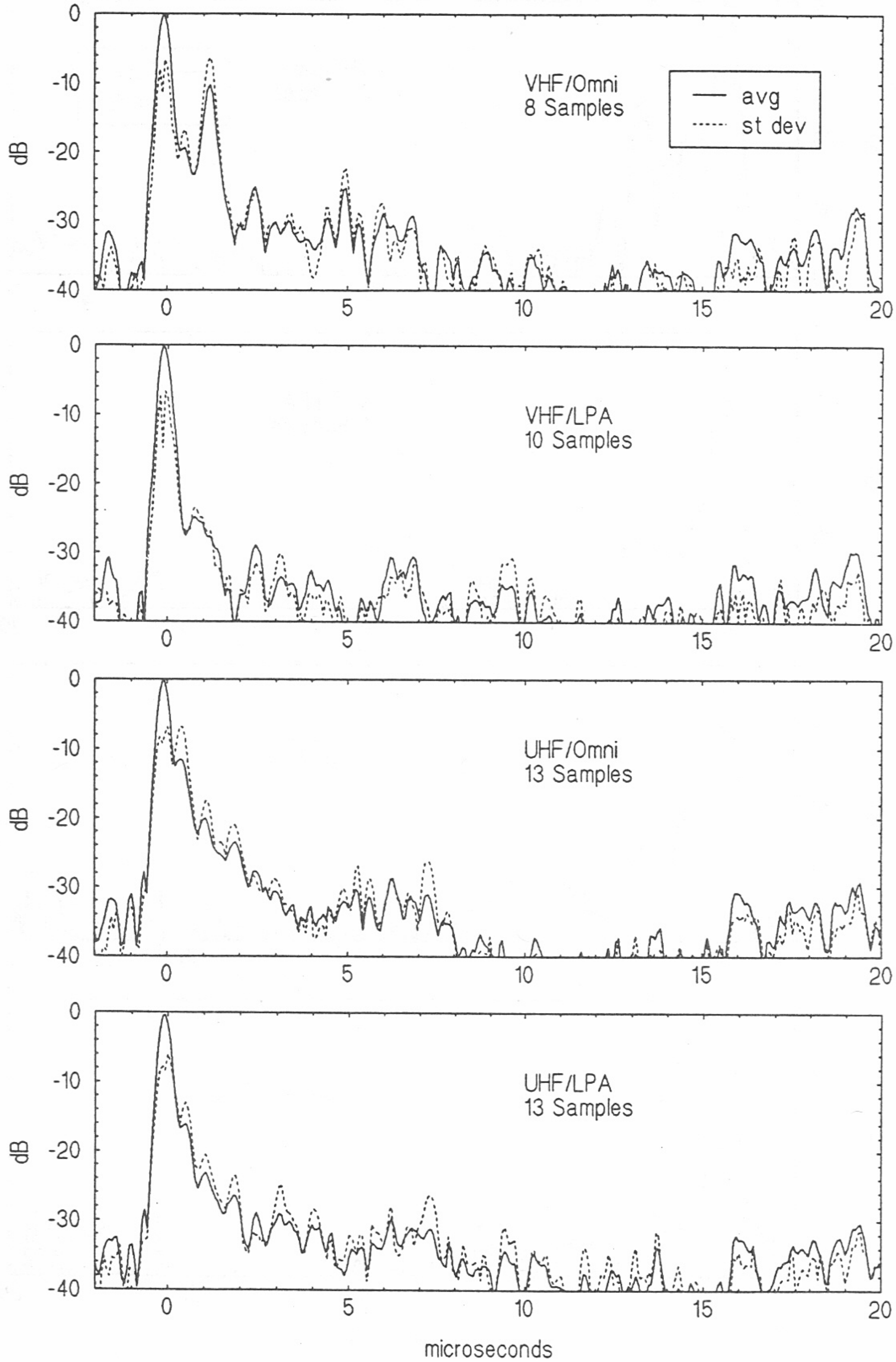

Figure 22. A suburban activity center in Palo Alto.

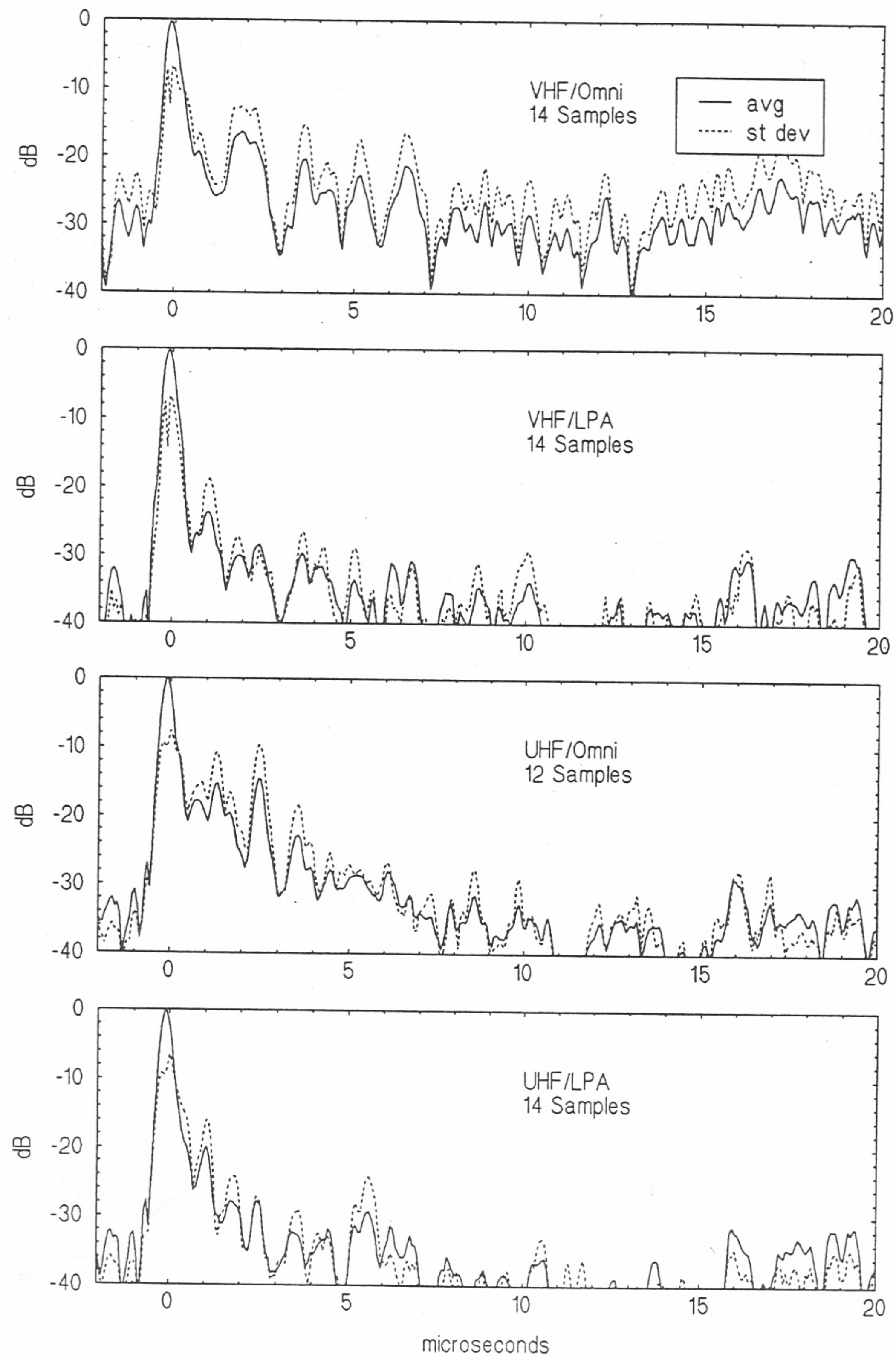

Figure 23. A suburban activity center in Santa Clara.

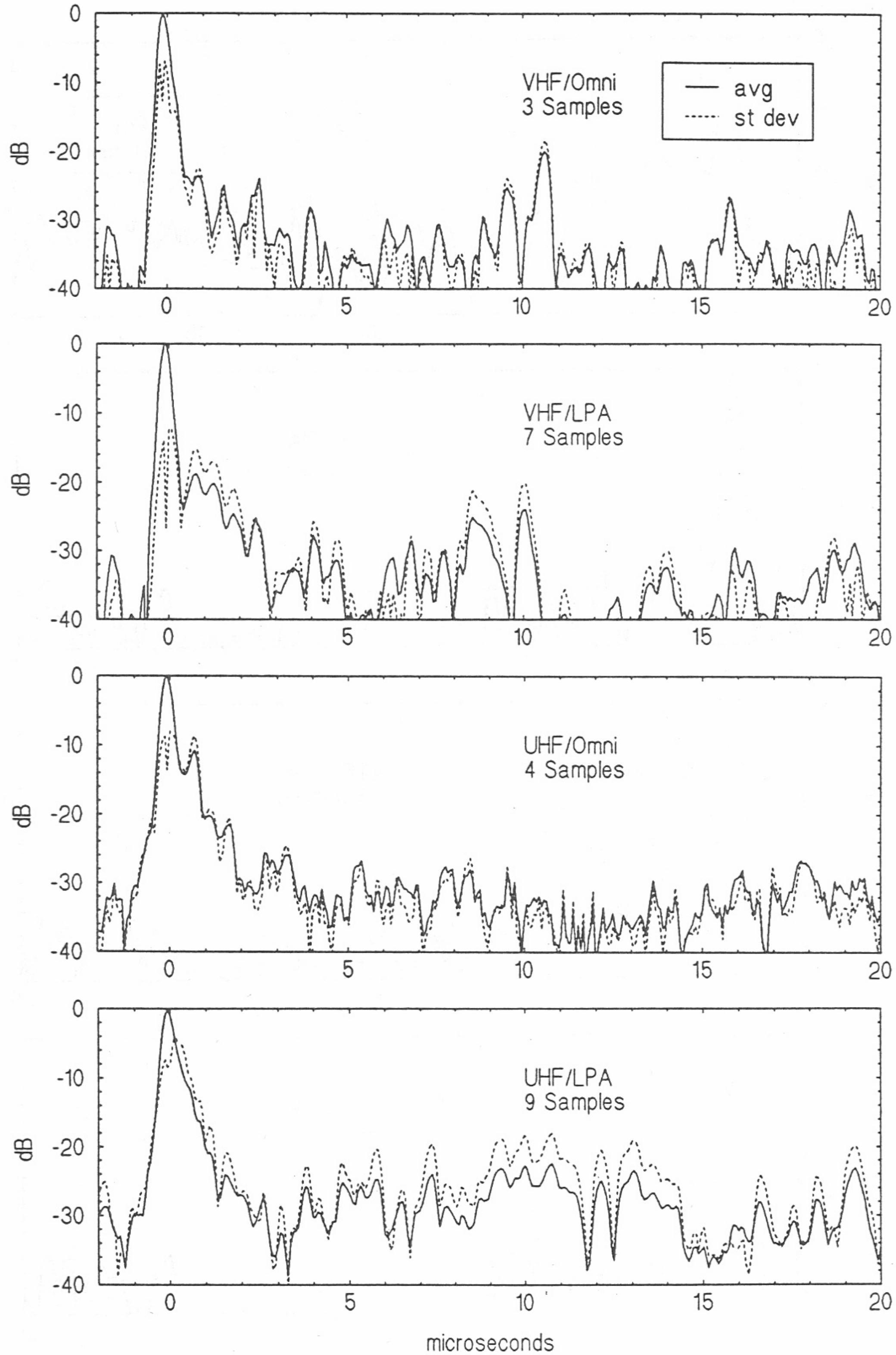

Figure 24. An urban area in the Cow Hollow region.

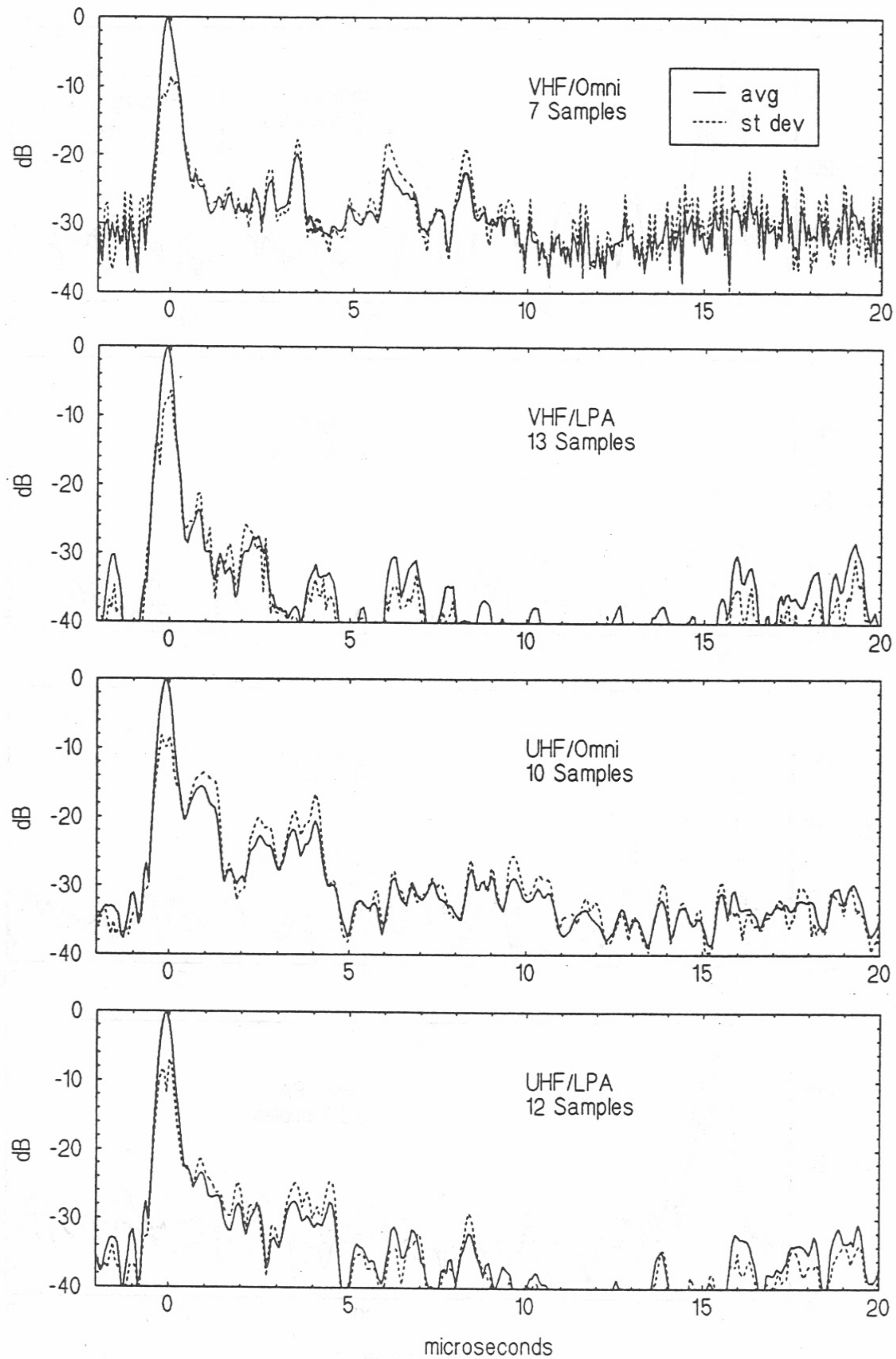

Figure 25. An urban area in Millbrae.

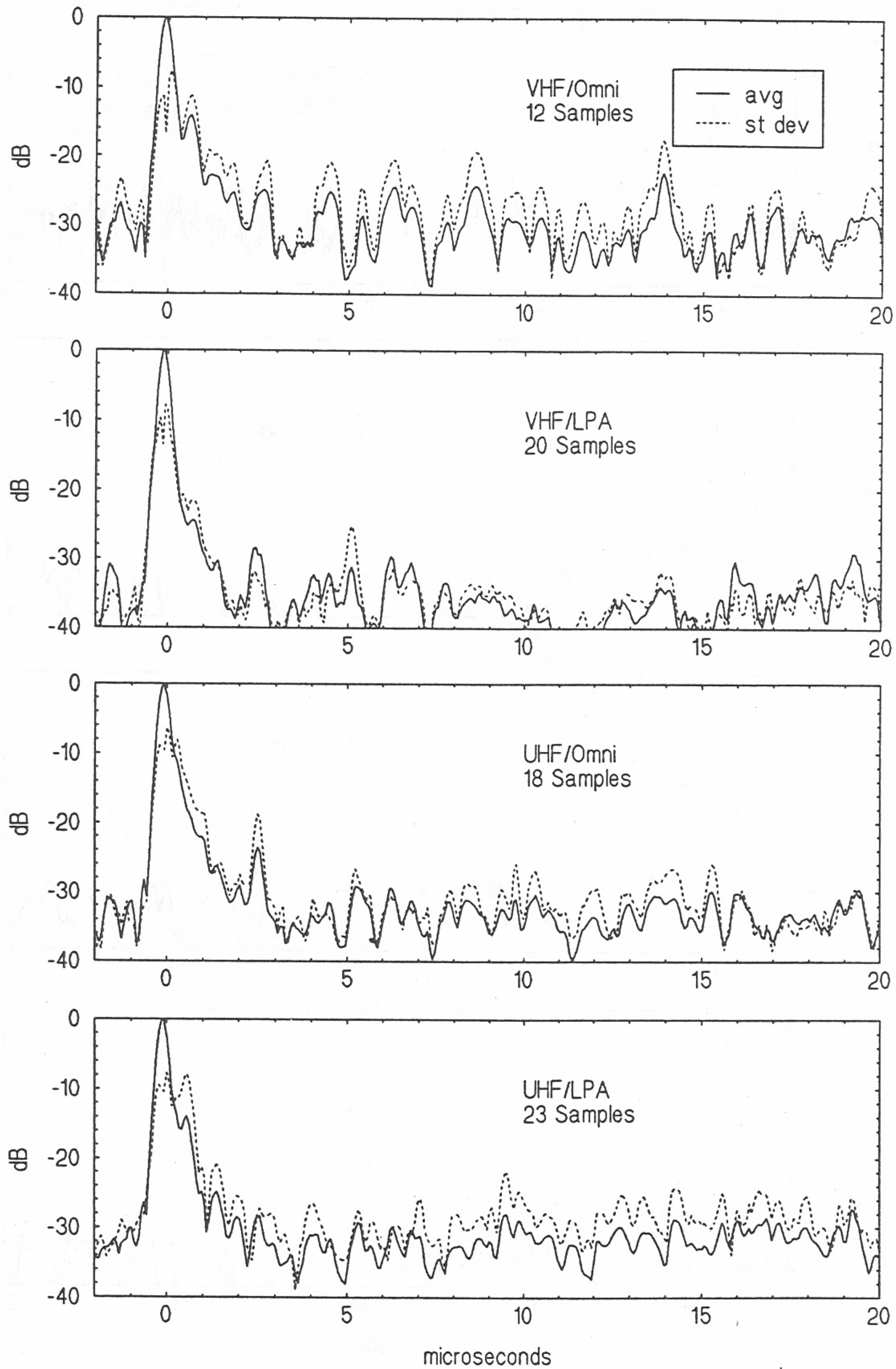

Figure 26. An urban area in Berkeley.

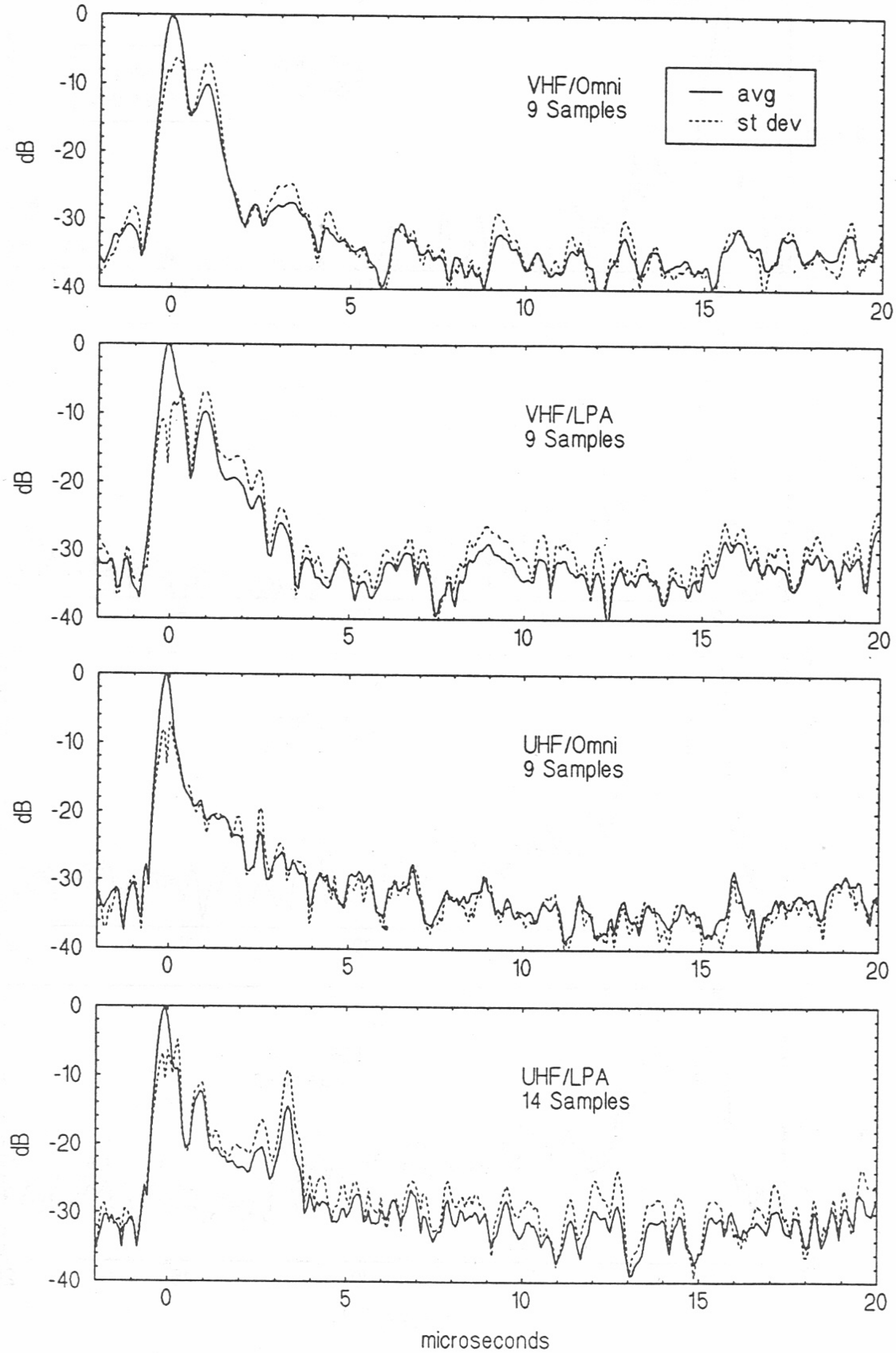

Figure 27. An urban area in San Jose.

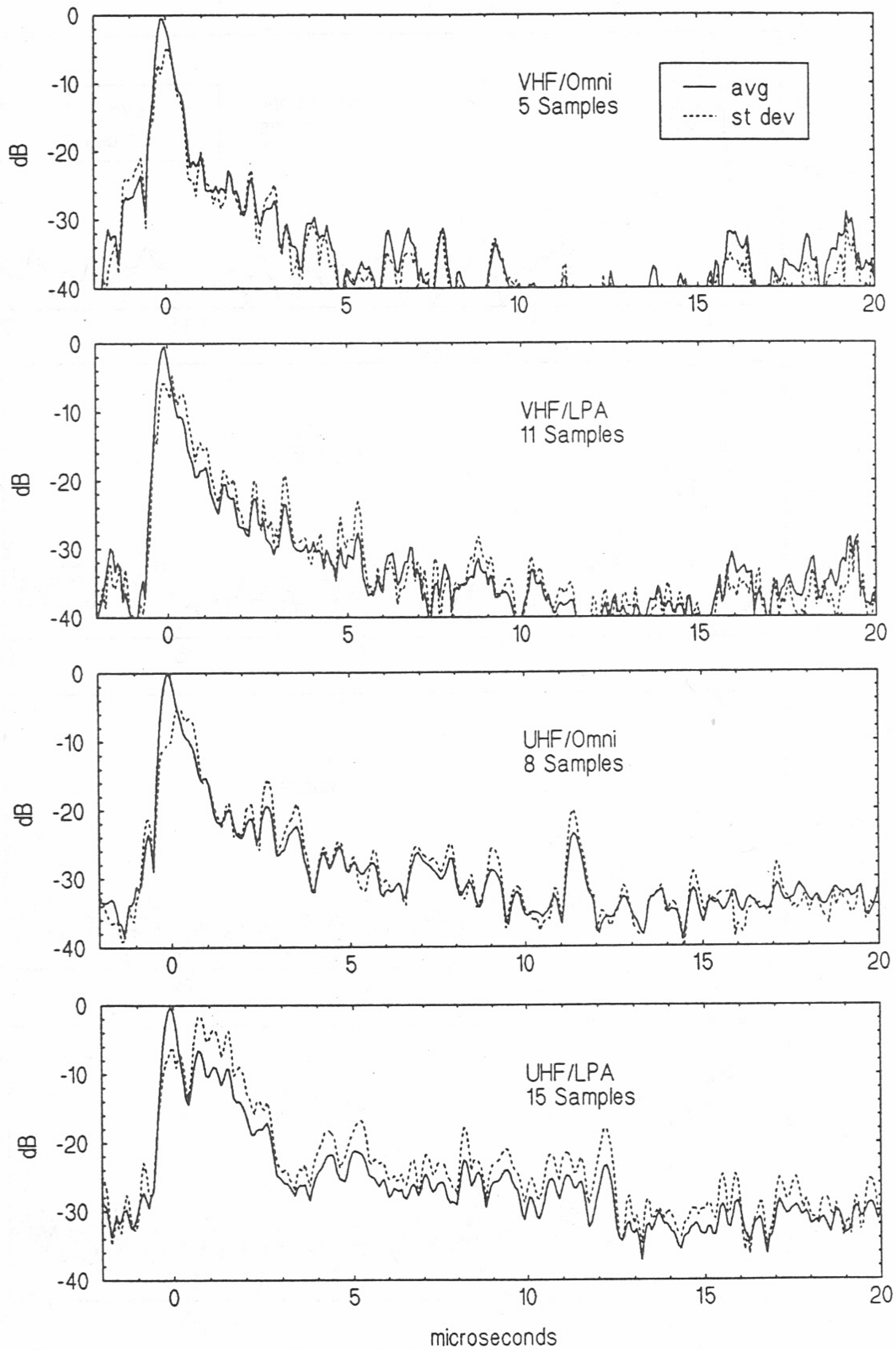

Figure 28. In and near downtown Oakland.

5. CONCLUSIONS

Figures 13 through 28 provide a fairly complete statistical summary of our measurements. Each solid curve describes the average power function $p(t)$ for one set of sample measurements. The parameters of a set include the frequency band, the antenna type, and the local area of receiver sites; if a set is a fair representation of the associated population then $p(t)$ will be a valid estimate of the most important population parameter. Indeed, if the hypothesis is correct that the complex impulse response is distributed according to the Gaussian law with uniform distributed phase, then $p(t)$ alone is sufficient to describe the complete distribution. If that hypothesis proves wrong, the second most important parameter is the standard deviation as given in our figures by the dotted curves. The next important parameter is probably the correlation coefficient between values of the impulse response at two time delays. At present that computation seems beyond our reach.

When we compare these results with the previous results in Denver, we find much in common. Multipath is almost always present, particularly when buildings are nearby. On average, there still seems to be a little more multipath at UHF than at VHF and distinctly more on the omnidirectional antennas than on the directional antennas. There also seems to be more multipath in San Francisco than in Denver, although the difference is not great.

A possible next step in the analysis of these data might be to construct smooth curves through the functions $p(t)$. Doing this is complicated by the fact that so little of the function is available to us. For small t the function is dominated by the direct pulse; for large t it is buried in the noise. Our present suggestion is to try a straight line plotted by hand through the peaks in our figures. Since these figures are in decibels, this means that we are trying to claim $p(t) = \alpha e^{-\beta t}$ and that there are only the two parameters α and β to estimate. If this approach seems promising then a further step would be to find a way to compute these estimations from the data.

6. ACKNOWLEDGEMENTS

We recognize the generous support of the management and the technical staff at KGO-TV and KBHK-TV who worked with us to install the test signal generators in their facilities, and who allowed us to broadcast the signal during a line in the vertical blanking interval. These measurements would not have been possible without this support, and the authors gratefully extend their thanks to the staffs at KGO and KBHK.

7. REFERENCES

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Hufford, G. A., J. R. Godwin, R. J. Matheson, V. S. Lawrence, and L. E. Pratt (1990), Characterization of the HDTV channel in the Denver area, NTIA Report 90-271 (NTIS Order No. PB 91-176388).

Sablatash, M., J. L. Lodge, and K. W. Moreland (1989), Theory and methods for design of pulse shapes for broadcast teletext, *IEEE Tran8. Broadcasting,* **BC-35**, pp. 40-55.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

If over-the-air High Definition Television (HDTV) is to become a reality it would be useful to know the multipath characteristics of the radio channel over which it will be carried. The Institute for Telecommunication Sciences (ITS) has begun a program to measure these characteristics in locations that might represent consumer habits. This is the second report of the program. It discusses a few details concerning the measurement techniques and describes measurements made in the vicinity of San Francisco, California.

16. Key Words *(Alphabetical order, separated by semicolons)*

Channel characterization; delay spread; high definition television; impulse responses; multipath; pseudonoise codes; radio propagation; spectra

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