CHARACTERIZATION OF THE HDTV CHANNEL IN THE SAN FRANCISCO AREA

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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

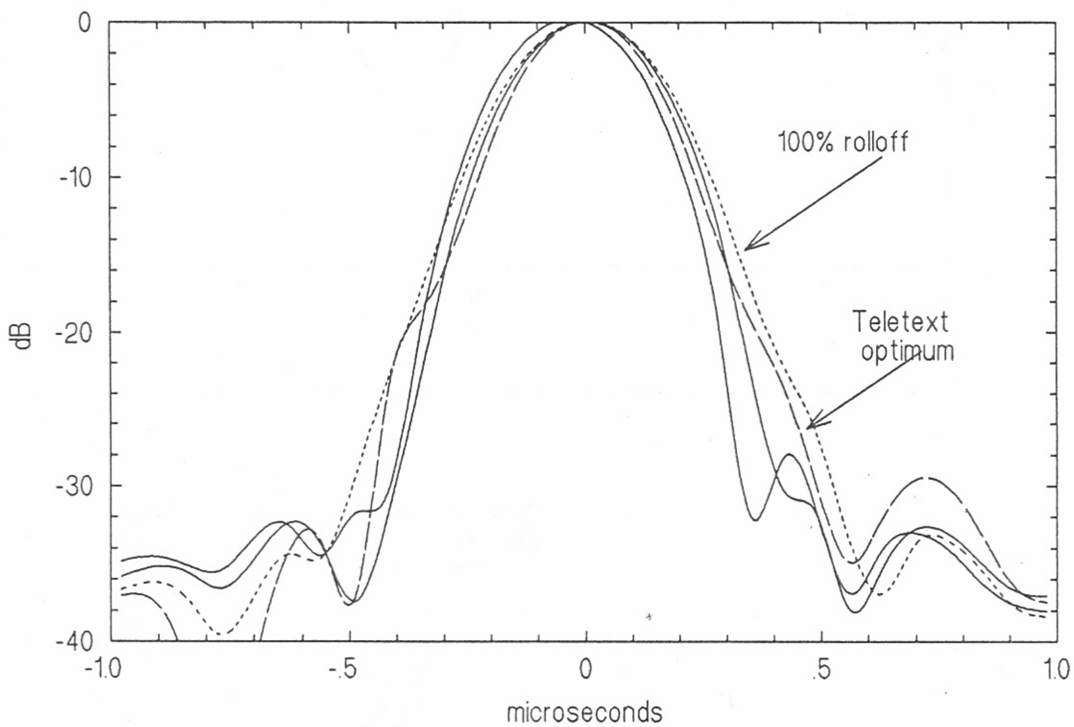

Figure 1. A closeup of the four suggested pulse shapes.

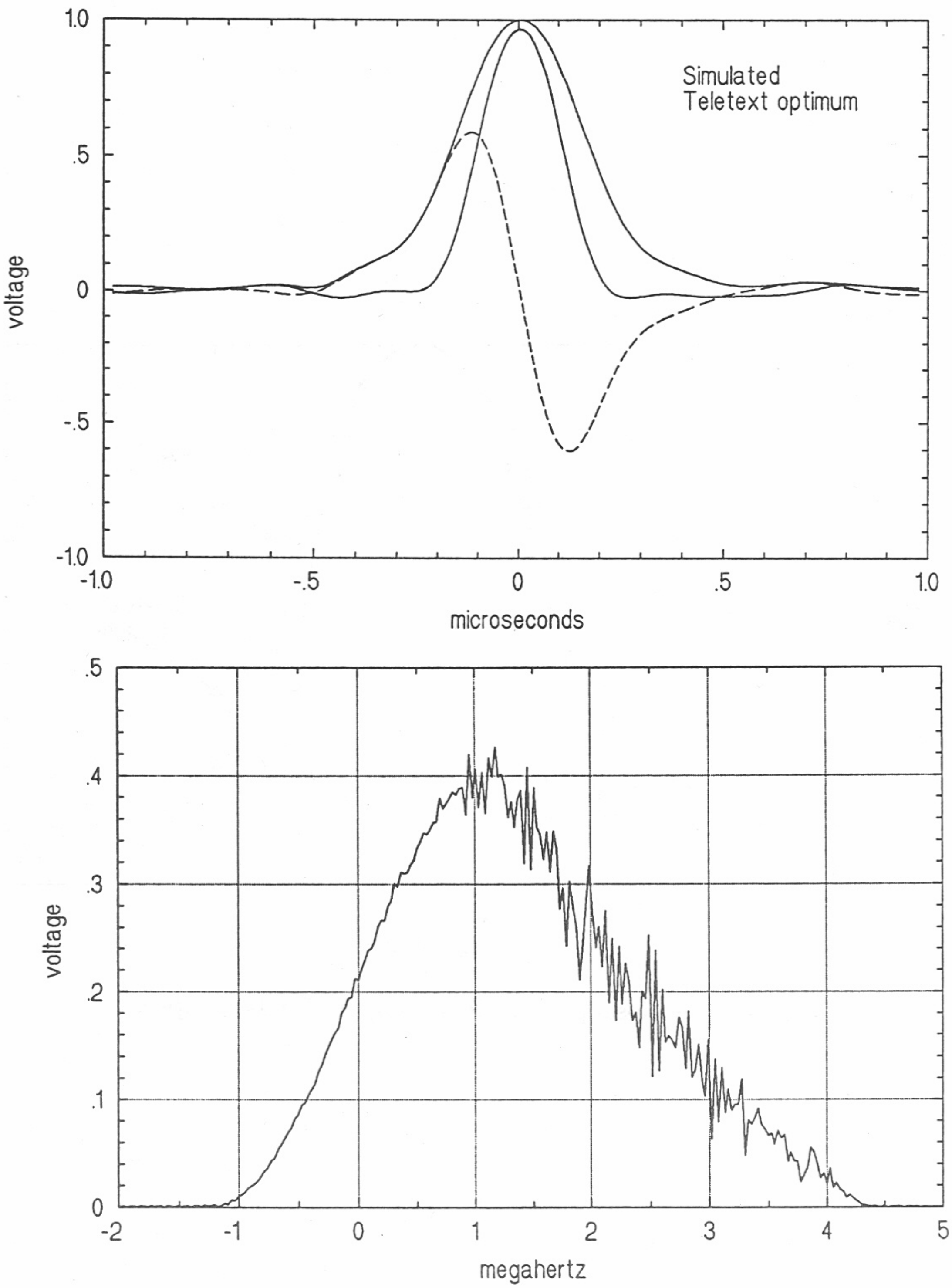

Figure 2. The teletext optimum pulse shape. The top graph shows the in-phase and quadrature-phase components and also the amplitude; the lower graph shows the amplitude of the spectrum.

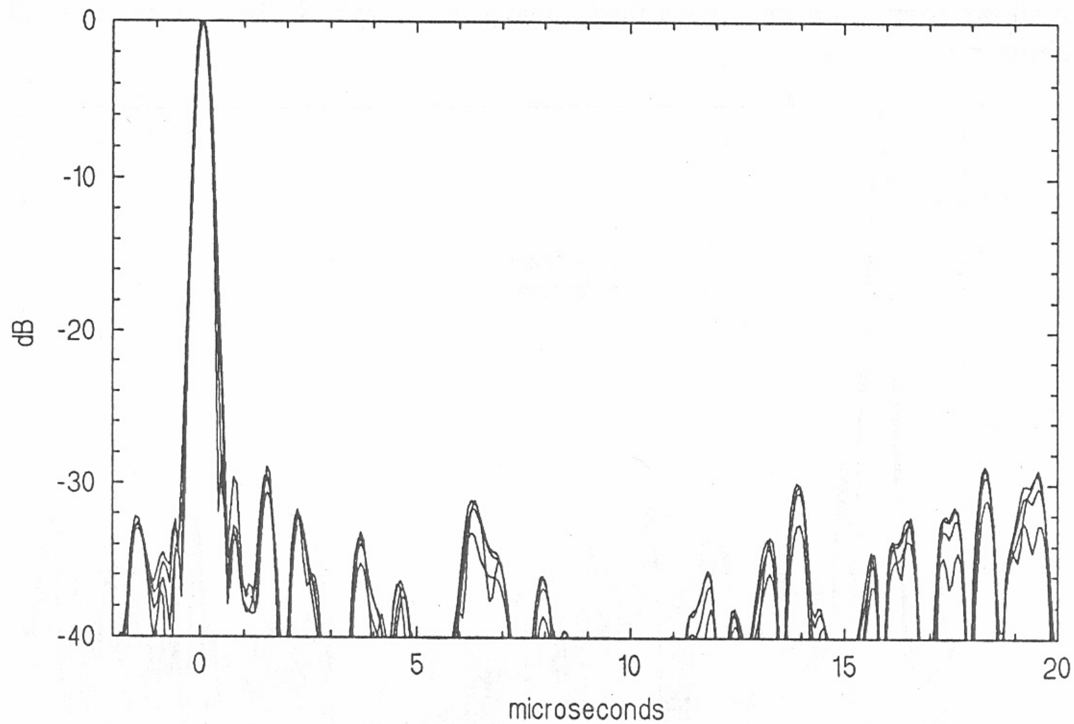

Figure 3. A wider view of the four pulse shapes.

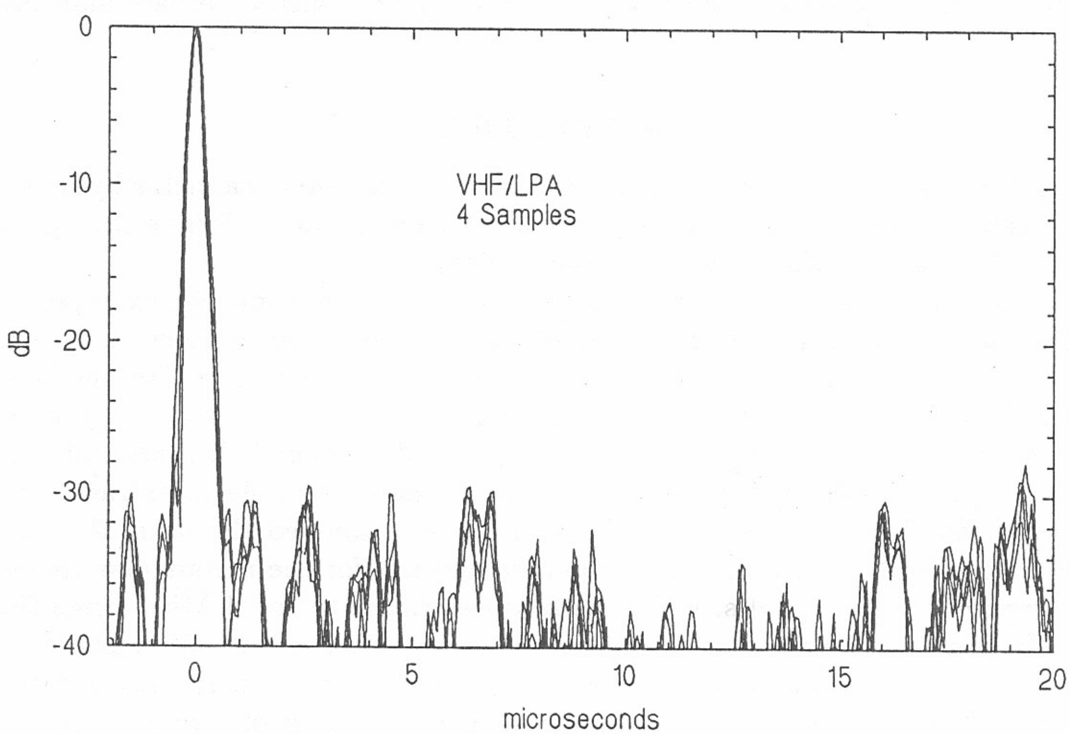

Figure 4. The four pulse shapes as observed on a relatively clean path.

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

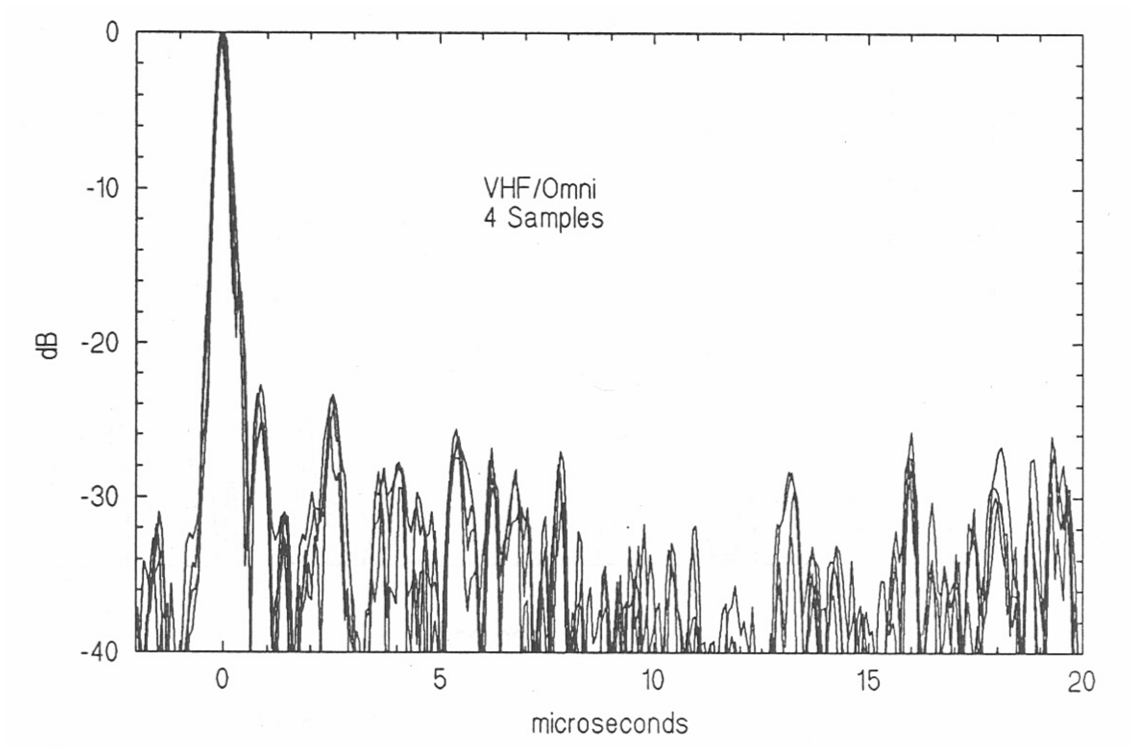

Figure 5. The four pulse shapes as observed on a path with moderate multipath.

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.

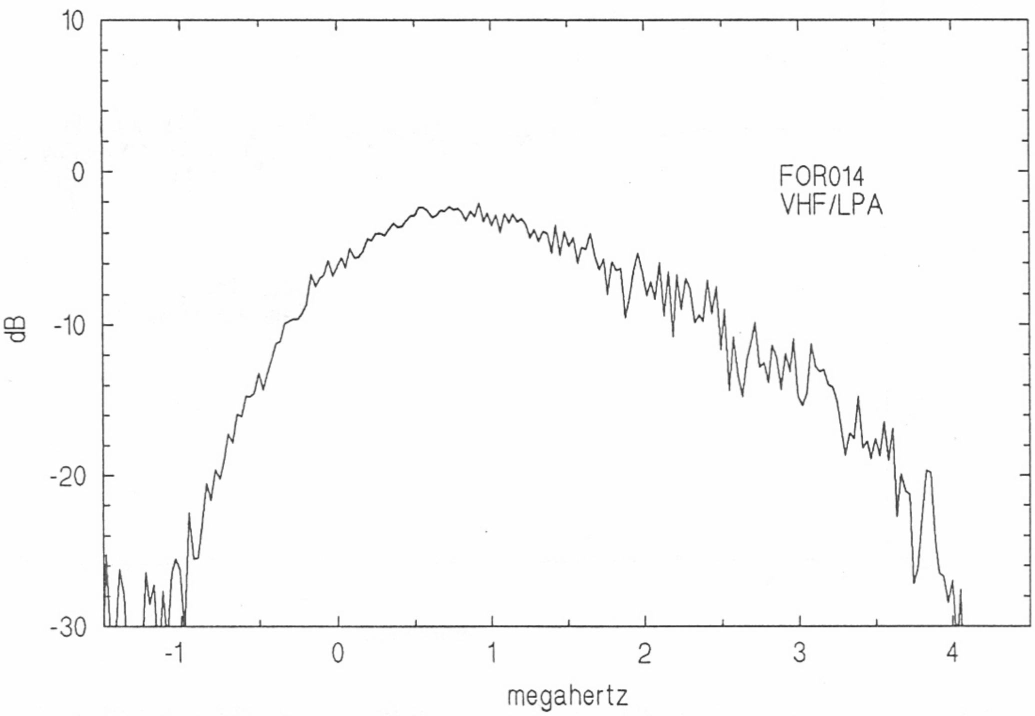

Figure 6. The uncorrected spectrum of the impulse response observed on the relatively clean path of Figure 4.

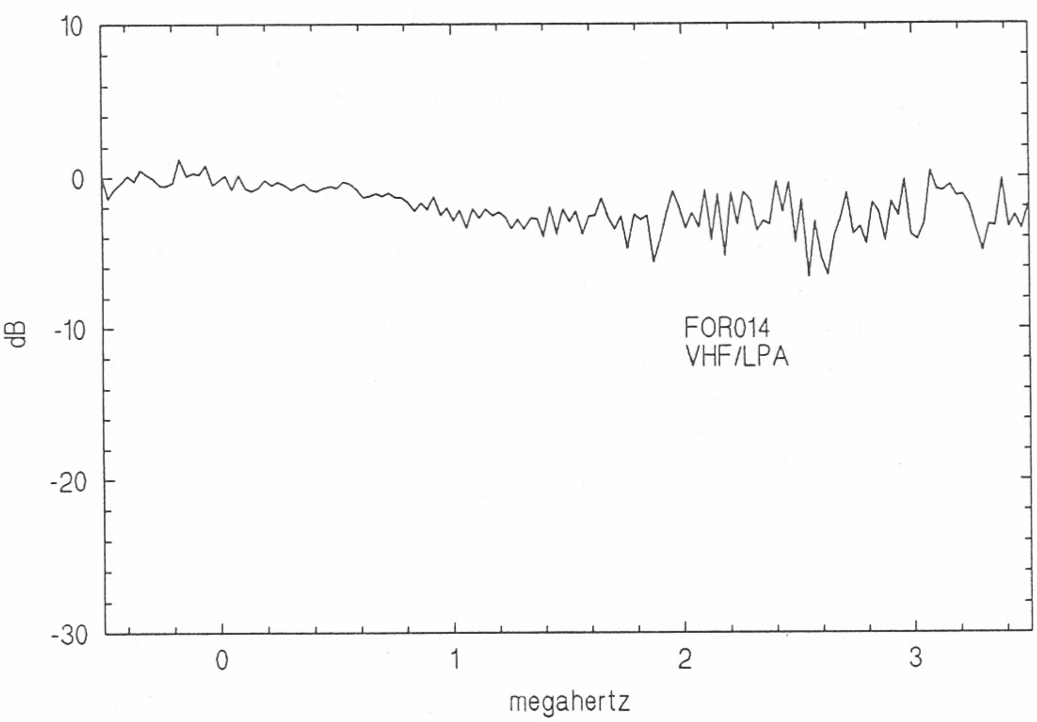

Figure 7. The spectrum of Figure 6 after division by spectra of the known, computable filters.

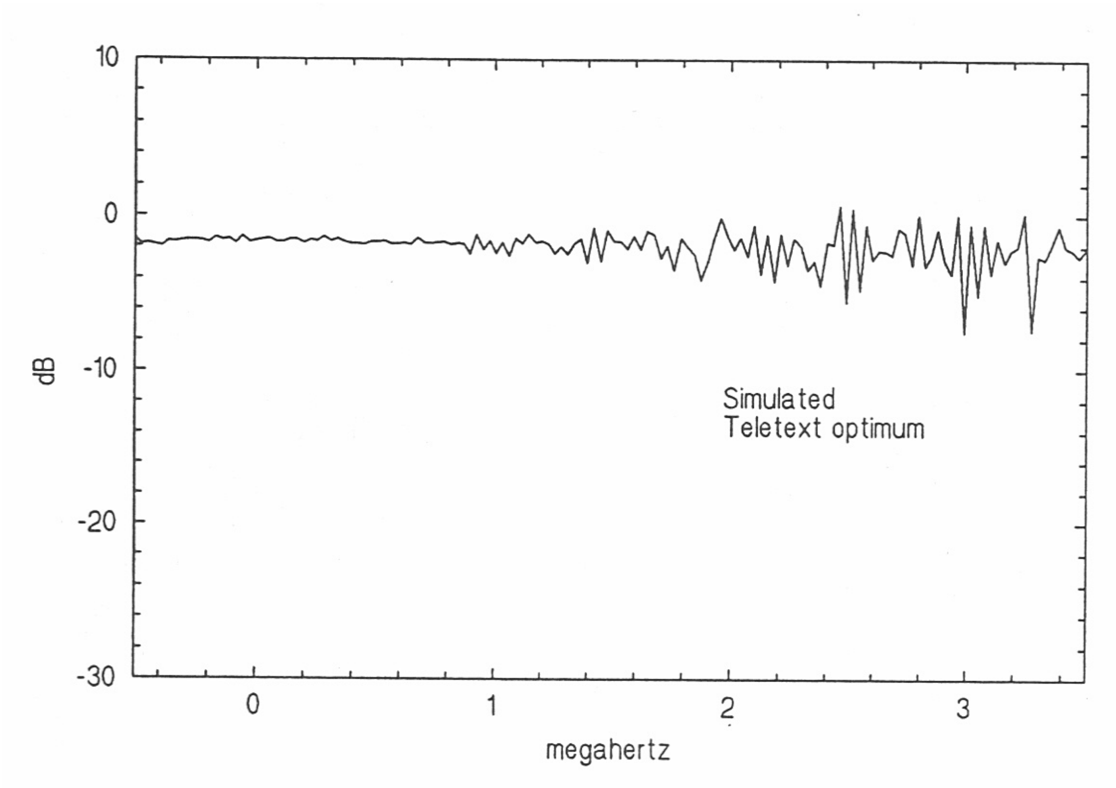

Figure 8. The corrected spectrum of the simulated teletext optimum pulse in Figures 2 and 3.

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.

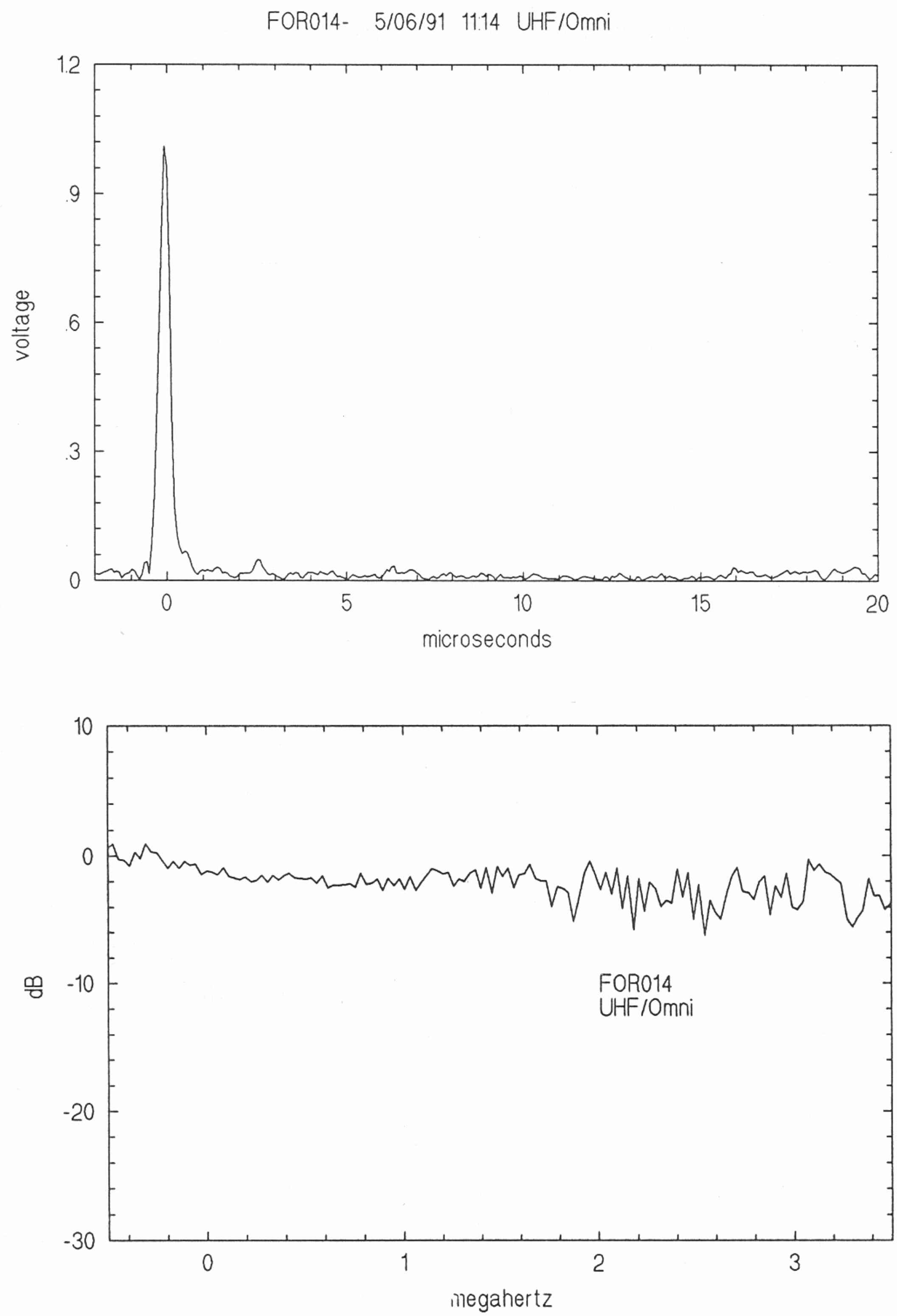

Figure 9. The impulse response and spectrum observed on the UHF channel for the same path as used in Figure 7.

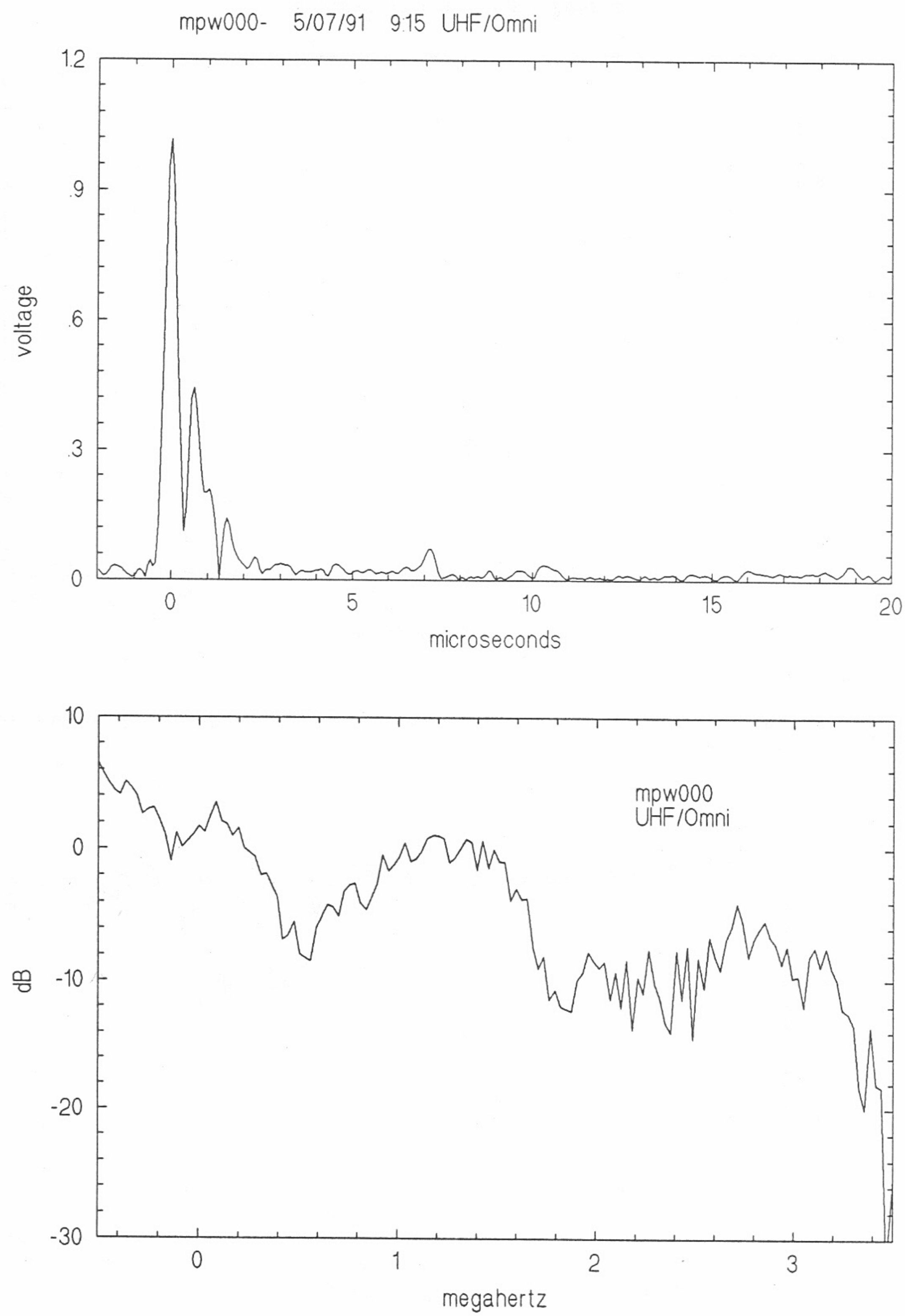

Figure 10. The impulse response and spectrum on a path showing moderate multipath.

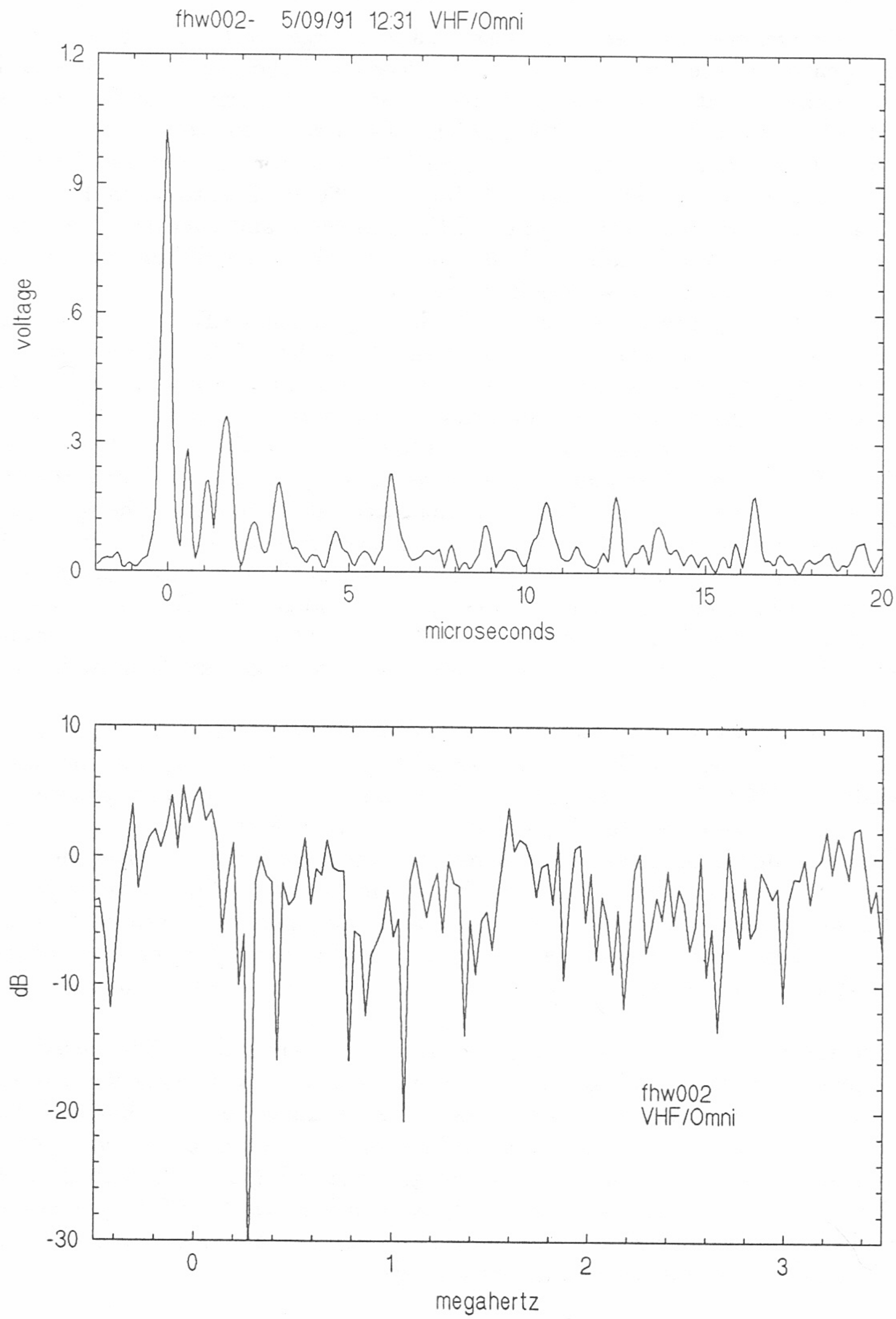

Figure 11. The impulse response and spectrum on a path with severe multipath.