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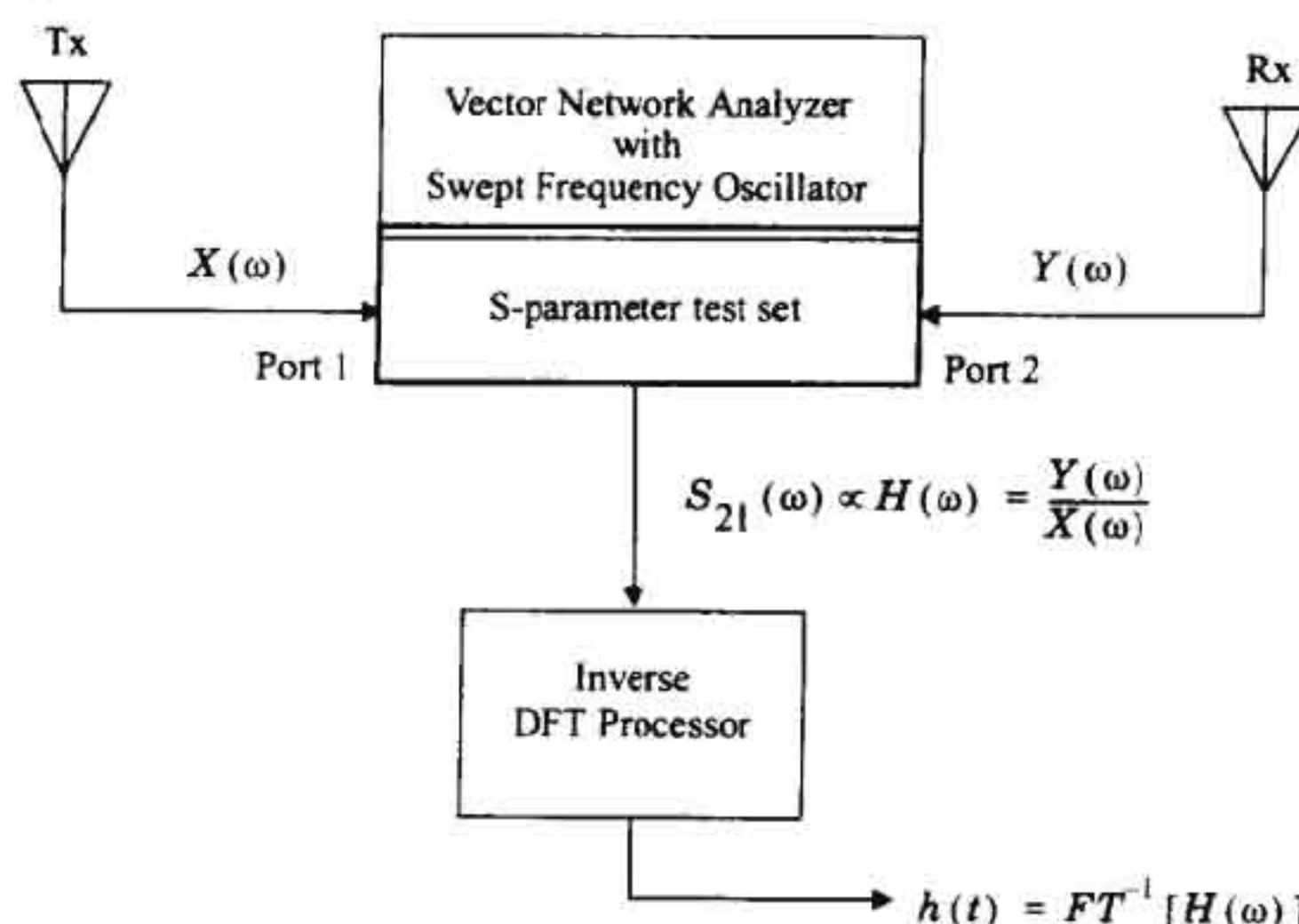
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4.3.3 Frequency Domain Channel Sounding

Because of the dual relationship between time domain and frequency domain techniques, it is possible to measure the channel impulse response in the frequency domain. Figure 4.8 shows a frequency domain channel sounder used for measuring channel impulse responses. A vector network analyzer controls a synthesized frequency sweeper, and an S-parameter test set is used to monitor the frequency response of the channel. The sweeper scans a particular frequency band (centered on the carrier) by stepping through discrete frequencies. The number and spacings of these frequency steps impact the time resolution of the impulse response measurement. For each frequency step, the S-parameter test set transmits a known signal level at port 1 and monitors the received signal level at port 2. These signal levels allow the analyzer to determine the complex response (i.e., transmissivity $S_{21}(\omega)$) of the channel over the measured frequency range. The transmissivity response is a frequency domain representation of the channel impulse response. This response is then converted to the time domain using inverse discrete Fourier transform (IDFT) processing, giving a band-limited version of the impulse response. In theory, this technique works well and indirectly provides amplitude and phase information in the time domain. However, the system requires careful calibration and hardwired synchronization between the transmitter and receiver, making it useful only for very close mea-

surements (e.g., indoor channel sounding). Another limitation with this system is the non-real-time nature of the measurement. For time varying channels, the channel frequency response can change rapidly, giving an erroneous impulse response measurement. To mitigate this effect, fast sweep times are necessary to keep the total swept frequency response measurement interval as short as possible. A faster sweep time can be accomplished by reducing the number of frequency steps, but this sacrifices time resolution and excess delay range in the time domain. The swept frequency system has been used successfully for indoor propagation studies by Pahlavan [Pah95] and Zaghloul, et.al. [Zag91a], [Zag91b].





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4.4 Parameters of Mobile Multipath Channels

Many multipath channel parameters are derived from the power delay profile, given by equation (4.18). Power delay profiles are measured using the techniques discussed in Section 4.4 and are generally represented as plots of relative received power as a function of excess delay with respect to a fixed time delay reference. Power delay profiles are found by averaging instantaneous power delay profile measurements over a local area in order to determine an average small-scale power delay profile. Depending on the time resolution of the probing pulse and the type of multipath channels studied, researchers often choose to sample at spatial separations of a quarter of a wavelength and over receiver movements no greater than 6 m in outdoor channels and no greater than 2 m in indoor channels in the 450 MHz - 6 GHz range. This small-scale sampling avoids

large-scale averaging bias in the resulting small-scale statistics. Figure 4.9 shows typical power delay profile plots from outdoor and indoor channels, determined from a large number of closely sampled instantaneous profiles.

4.4.1 Time Dispersion Parameters

In order to compare different multipath channels and to develop some general design guidelines for wireless systems, parameters which grossly quantify the multipath channel are used. The *mean excess delay*, *rms delay spread*, and *excess delay spread* (X dB) are multipath channel parameters that can be determined from a power delay profile. The time dispersive properties of wide band multipath channels are most commonly quantified by their mean excess delay ($\bar{\tau}$) and rms delay spread (σ_{τ}). The mean excess delay is the first moment of the power delay profile and is defined to be

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k) \tau_k}{\sum_k P(\tau_k)} \tag{4.35}$$

The rms delay spread is the square root of the second central moment of the power delay profile and is defined to be

$$\sigma_{\tau} = \sqrt{\tau^2 - (\bar{\tau})^2} \tag{4.36}$$

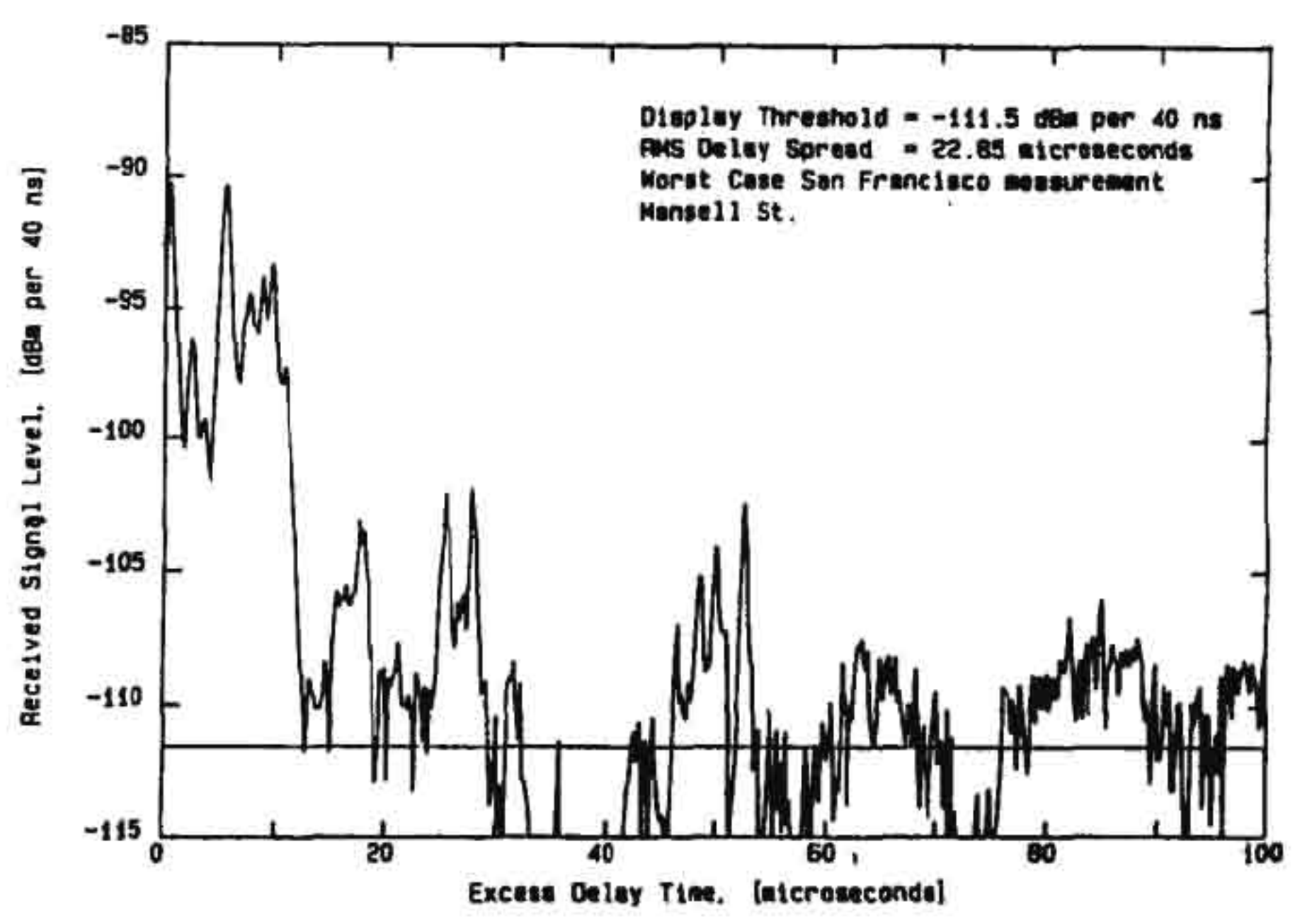
where

$$\tau^2 = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k) \tau_k^2}{\sum_k P(\tau_k)} \tag{4.37}$$

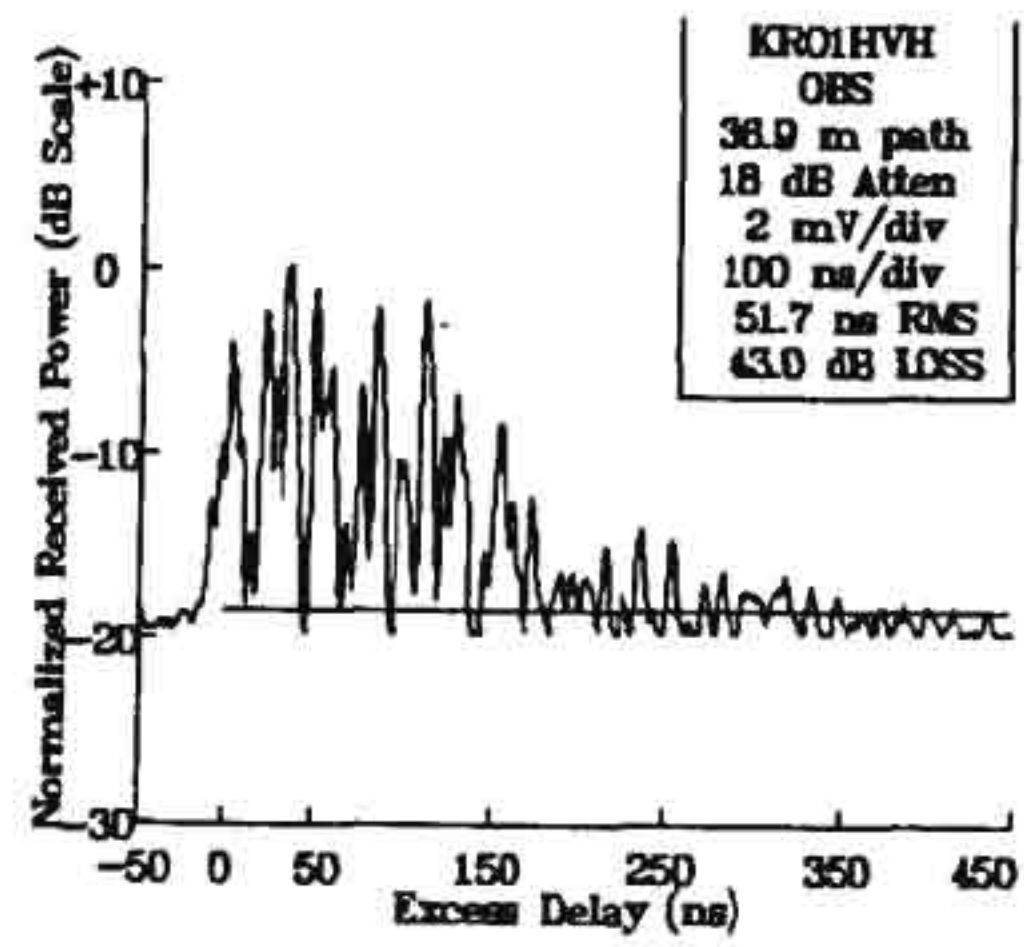
These delays are measured relative to the first detectable signal arriving at the receiver at $\tau_0 = 0$. Equations (4.35) - (4.37) do not rely on the absolute power level of $P(\tau)$, but only the relative amplitudes of the multipath components within $P(\tau)$. Typical values of rms delay spread are on the order of microseconds in outdoor mobile radio channels and on the order of nanoseconds in indoor



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(a)



(b)

Figure 4.9
 Measured multipath power delay profiles
 a) From a 900 MHz cellular system in San Francisco [From [Rap90] © IEEE].
 b) Inside a grocery store at 4 GHz [From [Haw91] © IEEE].