show comparisons of the GSM1800 scenario in Fig. 3 on the first 100m with different cross-sectional shapes used for the simulations. In addition to the arched cross section (Fig. 7), a pure circular cross section with radius r_{cs} = 2.675m (Fig. 8), and a rectangular cross section of width w = 5.25m and height h = 4.28m (Fig. 9) are applied, all covering the same area. The mean errors and standard deviations are calculated on the first 100m. Again, it turns out that the correct modelling of the tunnel's cross section affects the accuracy of the modelling results significantly.

D. Fast fading characteristics

An interesting question is, whether the fast fading in a tunnel can be characterized by a standard probability density function (PDF). The fast fading envelope is obtained by normalizing the received signal to its local root mean square (RMS) value. Generally, a window length of at least 40 wavelengths is chosen for the RMS determination [5], [6]. The resulting fading envelope is compared to the following classical distribution functions: Gaussian (normal), lognormal, Nakagami, Rayleigh, Rician and Weibull [7], [8]. In order to determine the parameters of the respective distributions, a least-mean-square (LMS) based parameter fitting can be used [9]. The LMS optimization is based on a simplex method [10]. As an example, Figs. 10 and 11 show the results of the LMS optimization for the DCS1800 measurement[2] of Fig. 5.

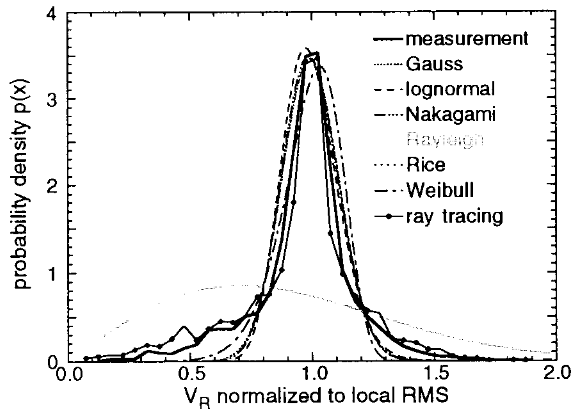

Fig. 10. Least-mean-square (LMS) best fit probability density functions (PDF) for the measurement of Fig. 5, RMS window length: $60\lambda_0$

The best fits for all measurements are achieved using Rician distributions at both frequencies, which is congruent with the literature [11]. Nevertheless, except for the Rayleigh distribution, all other densities lead to similar results, as indicated by Figs. 10 and 11. The interesting area of the curves, however, is in the lower V_R-range corresponding to very low received signal levels, the so-called deep-fades. In this region, none of the curves obtained by the LMS optimization leads to satisfactory results. Another way to determine the parameters of the various densities is given by a recursive application of the chi-square and Kolmogorov-Smirnov goodness-of-fit tests [12], [6]. The chi-square test is particularly suited for a fitting in the area of low received values due to its sensitivity in regions of low probability. Figure 12 shows the results for the PDF's obtained by a simplex optimization with the chi-square criterion. The fitted curves now approximate the measurement for low received values more closely for the chi-square fitting compared to the LMS fitting (Fig. 12 compared to Fig. 10). However, an overall match could not be achieved by neither of the analytical densities. Furthermore, no significant improvement could be achieved using the Kolmogorov-Smirnov criterion instead of the LMS fitting. Consequently, a complete characterization of the fast fading characteristics in a tunnel by standard analytical density functions appears to be impossible. In contrast, the PDF and CDF extracted from the prediction in Fig. 5 approach the measurement more closely over the entire range of V_R. The corresponding predicted curves are drawn in all figures, marked by black diamonds (and "ray tracing").

[2]Generally, a sampling of at least $\lambda_0/2$ is required for a non-ambiguous fast fading characterization. This requirement is clearly violated by the performed measurements. Nevertheless, for all GSM900 and GSM1800 measurements the obtained fading characteristics led to similar results.

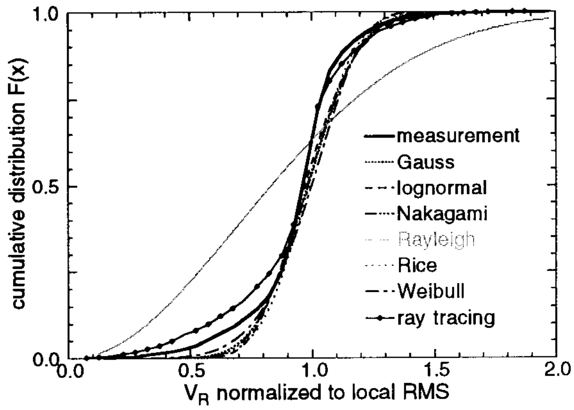

Fig. 11. Least-mean-square (LMS) best fit cumulative distribution functions (CDF) for the measurement of Fig. 5, RMS window length: $60\lambda_0$

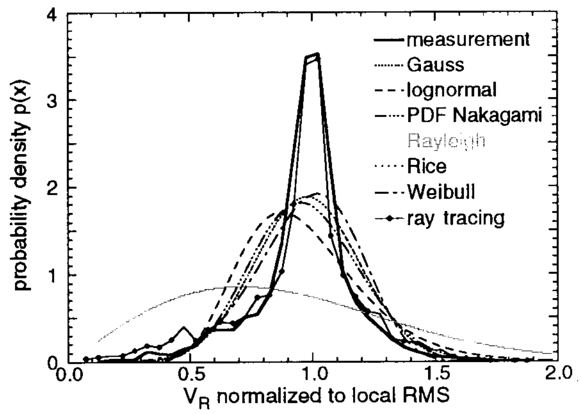

Fig. 12. Chi-square best fit probability density functions (PDF) for the measurement of Fig. 5, RMS window length: $60\lambda_0$