CHAPTER 6

SITE-DIVERSITY DISTRIBUTIONS

6.1 Introduction

A three-year radiometric study of rain attenuation at 12 GHz on earth-space paths in Southeast Asia was performed since March 1, 1992. One of the conclusions of this research is the severe rain climate which has a serious impact on satellite communications systems in this region, and some forms of compensation technique will be essential to maintain service quality at acceptable levels. Site diversity is a powerful technique to improve performance, but few measurements are available for Southeast Asia climate.

This Chapter describes a part of the study involving two radiometers: one installed at the General Post Office (GTO) in Bangkok and the second installed at the Si-racha earth station, about 80 km from the southeast of Bangkok. Both radiometers were directed toward the position of a geostationary satellite at 174^0 E longitude, resulting in elevation angles of about 8 degrees at the two sites. Statistics of site diversity improvement obtained from this experiment are discussed in terms of the prediction method described by the ITU-R P.837 [1994].

6.2 Data Analysis

Figure 6.1 indicates the measurement configuration at about 80 km site-separation. One reason for selecting this configuration is that the Si-racha earth station is the gateway of Thailand while Bangkok will be the second gateway station. In the future, there may be a possibility to implement the Ku-band earth station at those locations with relatively low elevation angle less than 10 degrees. The diversity distribution of rain attenuation is considered to be the joint probability distribution of the single site distribution of two sites which can be expressed by:

$$P(Ai, Aj > \alpha) = \frac{\Sigma T(Ai, Aj, > \alpha)}{T_{total}}$$

where

$P(Ai, Aj > \alpha)$ is the joint probability distribution of attenuation of both sites,

$\Sigma T(Ai, Aj, > \alpha)$ is the total accumulation time of the joint event of Ai and Aj,

T_{total} is the total observation period (seconds)

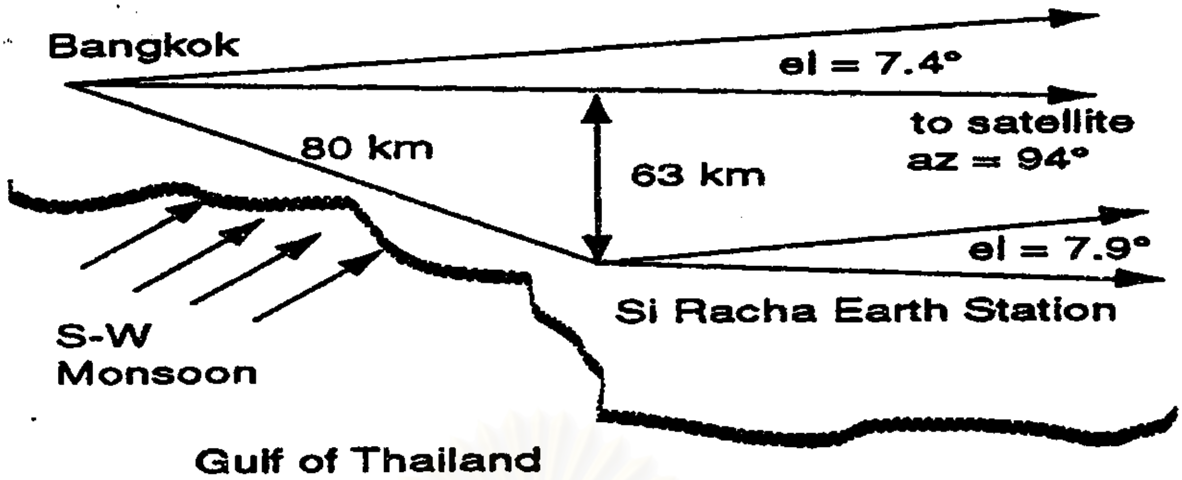

Figure 6.1 Site-diversity configuration between Bangkok and Si-racha

The diversity results are calculated from the time series of sky noise temperature for the two sites. The measurements taken at the two sites at the same time were compared, and the smallest of the two was used to create a distribution of (diversity) sky noise temperatures, while the individual measurement was used to create distributions for each site. In the case that there was no valid data at one of the sites, then that particular period was excluded from consideration. Finally, the sky noise distributions were converted to attenuation as described above. During a three year observation, data availability of a diversity analysis were at about 85%.

Figures 6.2 - 6.3 show example of attenuation events on September 3, 1993 and March 20, 1993, respectively. Figure 6.2 attenuation occurred in Bangkok site between 0900UT to 15.00UT, and in Si-racha between 1400UT-1800UT. There was a very small joint attenuation occurring in both sites between 14.00UT - 15.00UT and 20.00UT - 22.00UT. The Universal Time (UT) lags the Local time (LT) about 7 hours. Figure 6.3 shows attenuation event occurring in Si-racha a little more than two hours before a similar event occurred at Bangkok.

The dark shaded portion of the diagram is mathematically the intersection of the two attenuation time series and represents the optimum diversity performance. It is readily seen that the diversity system does not experience attenuations greater than 2 dB, whereas both of the single site attenuations exceed 10 dB for more than one and a half hour.

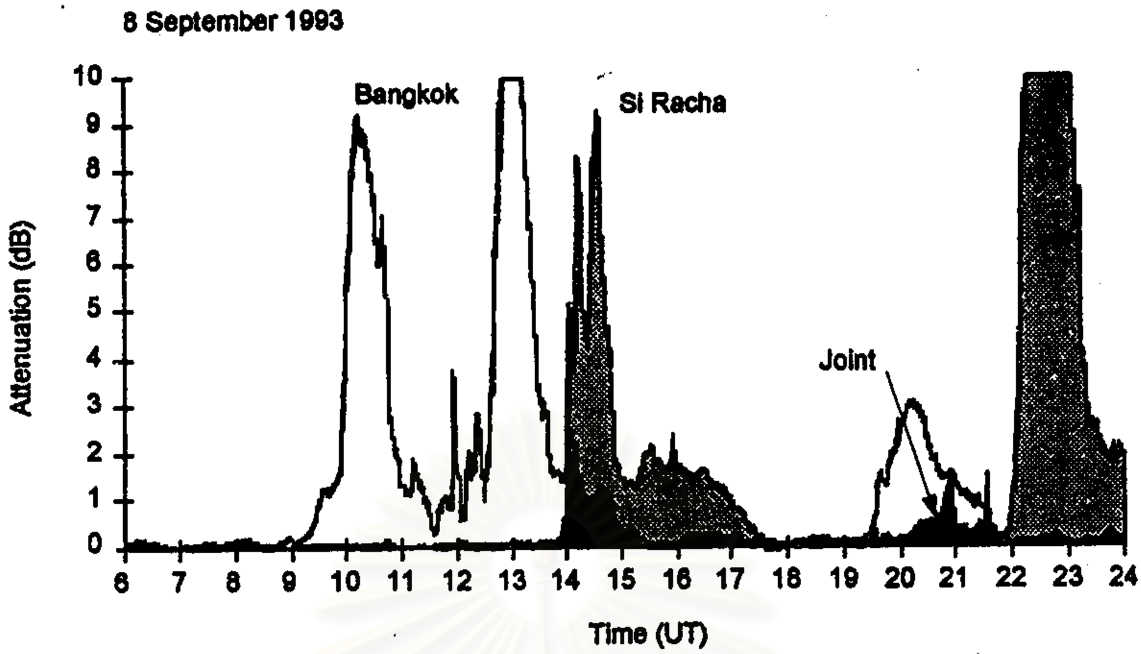

Figure 6.2 Simultaneous attenuation measurements in Bangkok and Si-racha for an 18 hour period on September 8, 1993, showing potential improvement from site diversity (the dark area).

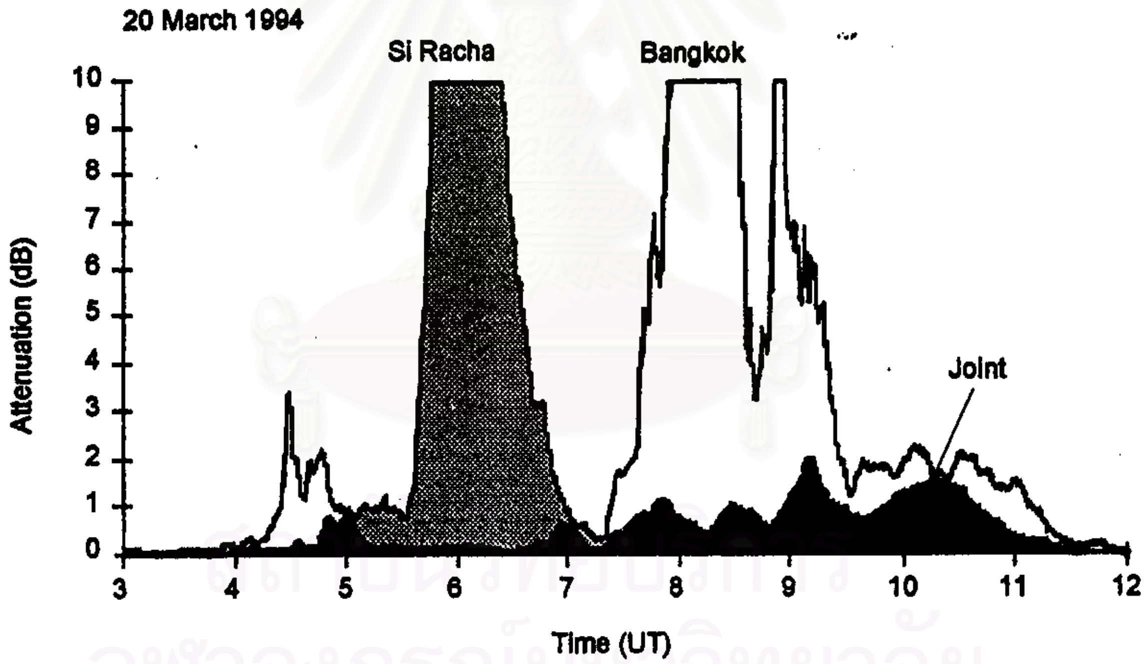

Figure 6.3 Simultaneous attenuation measurements in Bangkok and Si-racha for a nine hour period on March20, 1993, showing potential improvement from site diversity (the dark area).

Figures 6.4 and 6.5 show other events of rain attenuation on June 28, 1994 and November 30, 1994. In Figure 6.4, indicates a joint attenuation between 1500UT to 1600UT having attenuation reaching 6 dB. Figure 6.5 shows the outstanding of the diversity operation, severe attenuation occurring at Si-racha between 0900UT- 1100UT and attenuation in Bangkok from 1000UT to 1200UT. There is a joint event between 1000UT - 1200UT with small attenuation.

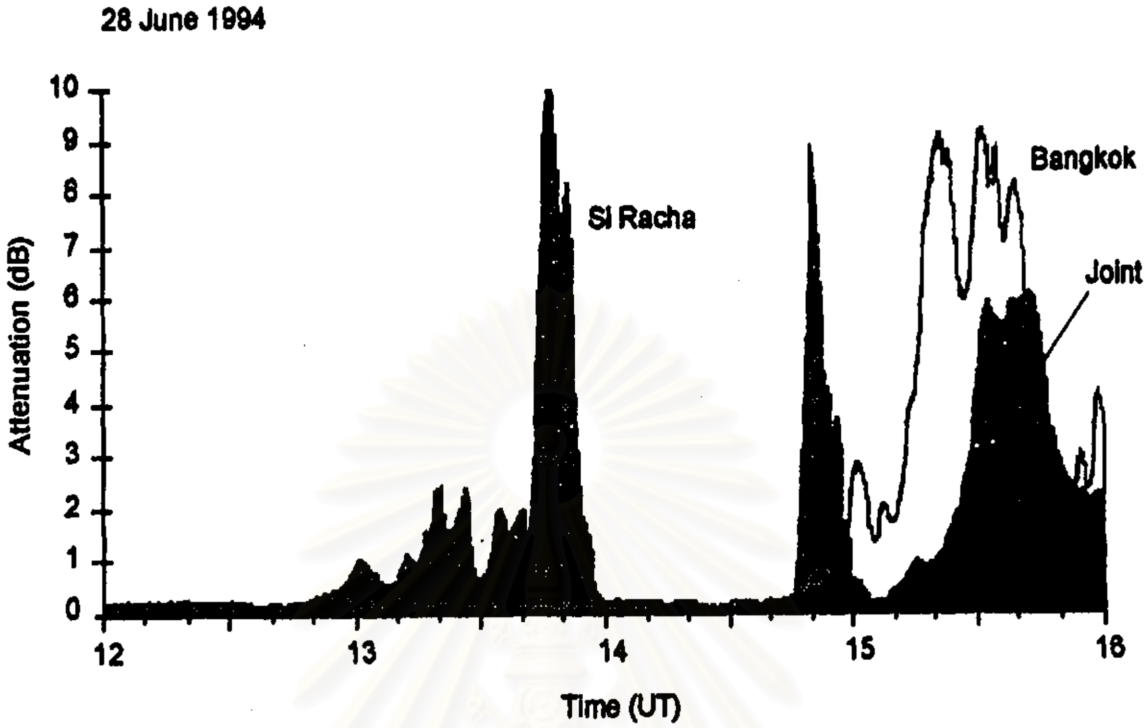

Figure 6.4 Simultaneous attenuation measurements in Bangkok and Si-racha for a five hour period on June 28, 1994, showing potential improvement from site diversity.

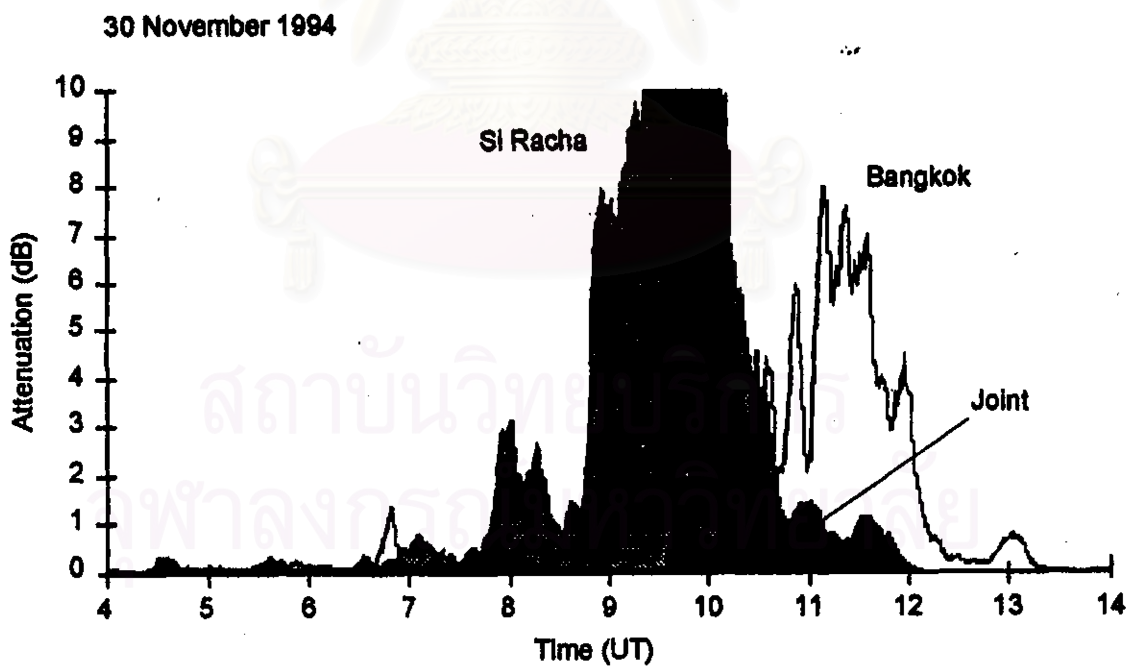

Figure 6.5 Simultaneous attenuation measurements in Bangkok and Si-racha for a ten hour period on November 30, 1994, showing potential improvement from site diversity.

6.3 Diversity Distributions

Figure 6.6 shows the month of September in 1992, 1993 and 1994 which was chosen because the month of August and September appear to be the months with the greatest rain attenuation. The solid curves at the top of the diagram show the distributions of a single site attenuation for the two sites. These curves show the attenuation to be quite severe, with 10 dB attenuation being exceeded at about one percent of the months at both sites. The improvement afforded by the diversity is shown by the dashed curves. For the month of September in 1992 and 1993, the diversity attenuation was about 4 dB at 0.01 percent level, an improvement of a factor greater than 100 in percentage of time occurrence. There was significantly less improvement in September 1994, with 9.5 dB of attenuation remaining for 0.1% of the month.

Figure 6.7 shows the diversity improvement obtained on an annual basis for each of the three one-year periods starting from March 1992 to February 1993 (year-1), March 1993 to February 1994 (year-2), and March 1994 to February 1995 (year-3) respectively. The single-site attenuation distributions are generally less severe than the September data, as they should be if the September attenuation are larger than average.

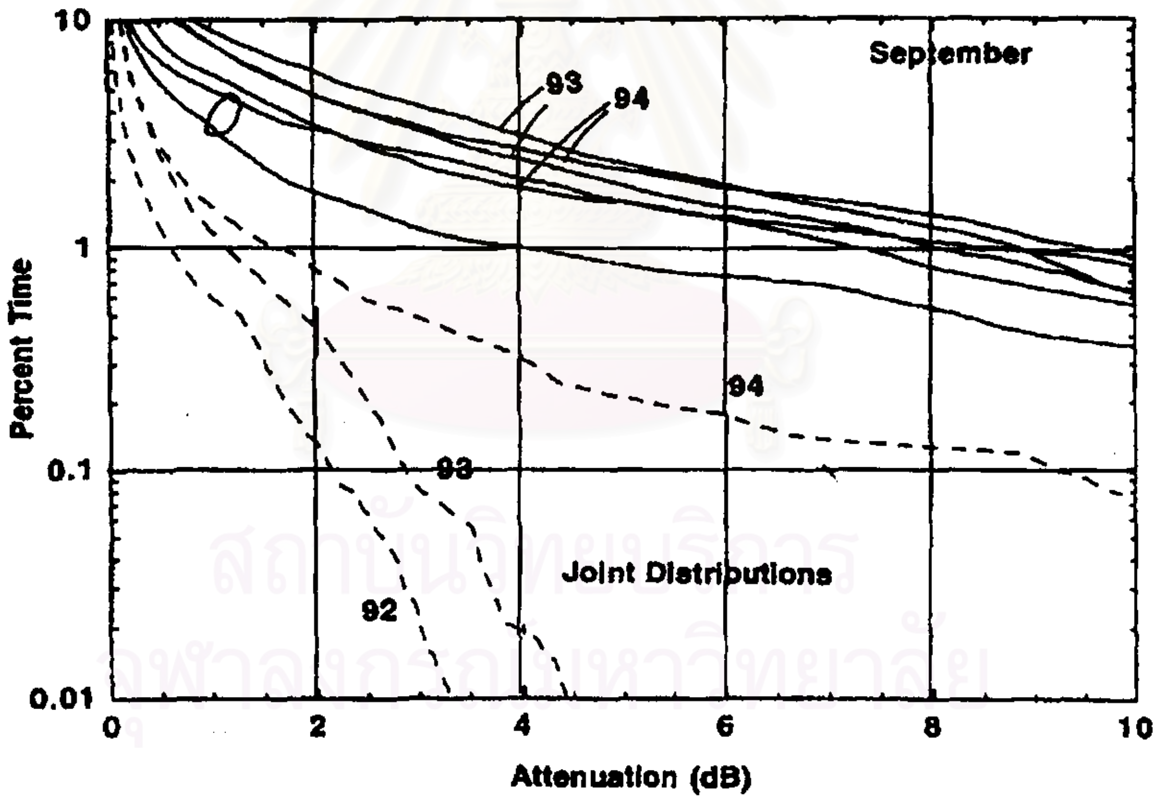

Figure 6.6 Diversity performance for the month of September in 1992, 1993, and 1994. The solid curves are the single sites distributions, and the dashed curves are the joint distribution curves

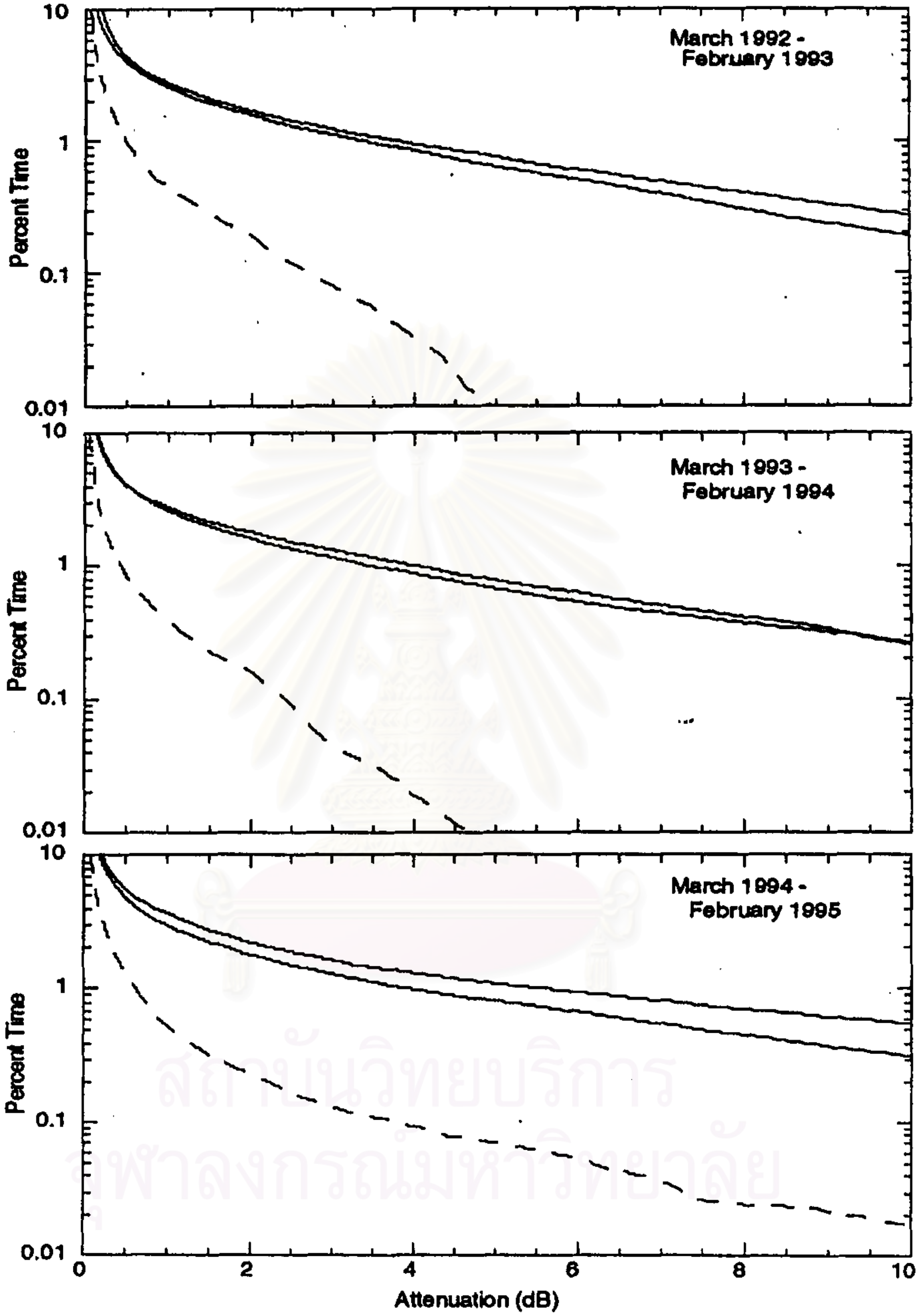

Figure 6.7 Diversity performance of annual cumulative distribution both the single -site distribution (the solid curves) and the joint distribution (the dashed curve).

6.4. Results Compared with the ITU-R Model

The ITU-R P.837 [1994] provides a method for estimating the "diversity improvement factor", defined as the ratio of the single-site attenuation time percentage to the diversity time percentage, at the same attenuation level. The ITU-R recommends the method only for time percentages smaller than 0.1%, since for the rain regimes under which the method was developed, rain rates (and therefore attenuations) are small at larger time percentages. Although this is obviously not the case with the present measurements, it is nonetheless interesting to compare improvement factors estimated from this experiment with those predicted by the ITU-R model.

As can be seen from Figure 6.7, meaningful diversity values can be measured to only about 4 dB for the years 92/93 and 93/94. This is a limit on the range of values that can be compared with the prediction method. The diversity improvement was less in 94/95, so that a wider range of values is available.

Figure 6.8 shows curves calculated according to the method of the ITU-R for a number of values of the separation "d" between stations. Recalling that the separation between Bangkok and Si-racha is 80 kms, it is seen that relatively good diversity improvement was obtained, exceeding that predicted for station separations of 200 kms. Given that the calculations are outside the recommended range of validity of the prediction method, it seems reasonable to say that the agreement with the ITU-R method is acceptable.

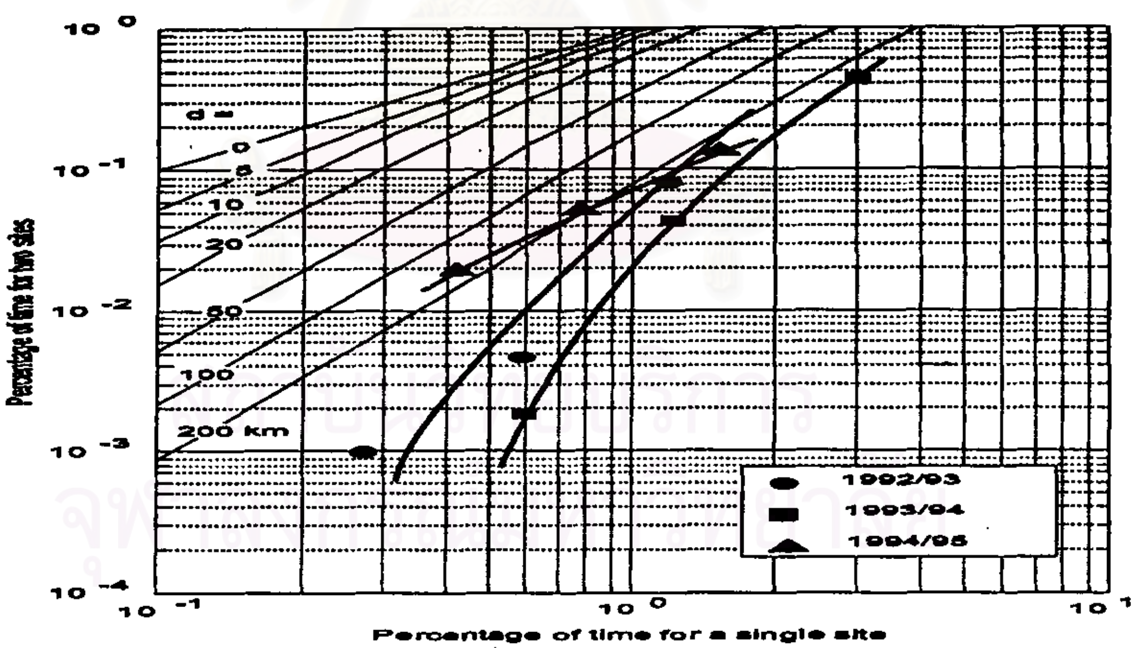

Figure 6.8, Comparison between the diversity improvement factor predicted from ITU-R and that measured over three one-year periods. "p1" is the single-site time percentage of attenuation at a certain level, and "p2" is the diversity time percentage at the same level. "d" is the diversity separation (km).

Figure 6.9 shows the performance of the site diversity called " Diversity Gain (dB)". It is defined as the difference between an average single path attenuation and average joint-path attenuation distribution which can be derived by the curves in Figure 6.7. The measured diversity gain is plotted versus the average single site attenuation (Ideal Gain) and versus the predicted diversity gain by the ITU-R 618-2 [1994]. It shows that the ITU-R model underestimated the measured data. The measured diversity shows the excellent diversity performance.

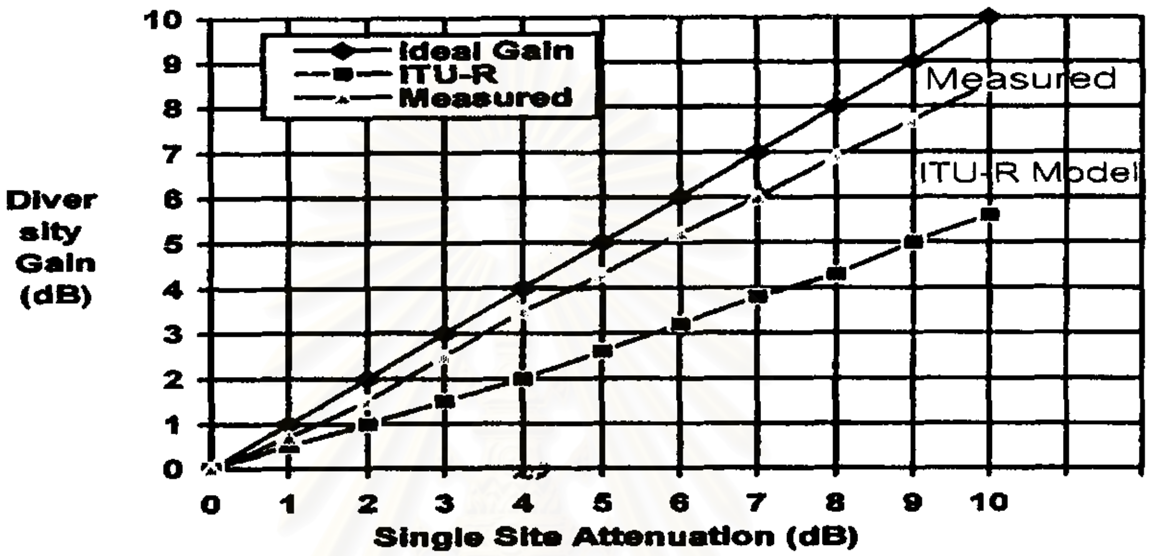

Figure 6.9 Comparison of measured diversity gain with the ITU-R 618-2 [1992] prediction model

6.5.Concluding Remarks

This chapter presents results showing the improvement in rain attenuation statistics on earth-space paths resulting from a site diversity operation in central Thailand. At relatively low elevation angles, on the order of 8 degrees, the measured data indicate that for system link availabilities for 99.9% of the time and less, system margins of less than 3 dB would be necessary for the diversity configuration. A comparison of measured diversity improvement factors with those predicted by the ITU-R indicates that the measured diversity performance exceeds the predicated values. But given the restrictions on the prediction model, quite reasonable agreement was obtained. In addition, it is found that the measured diversity gain shows the excellent performance compared with the current ITU-R 618-4 [1995] model.