ACTS Propagation Measurements in Maryland and Virginia

Asoka Dissanayake and Kuan-Ting Lin
COMSAT Laboratories
22300 COMSAT Drive, Clarksburg, MD 20871

1. Introduction

Rapid growth in new satellite services incorporating Very Small Aperture Terminals (VSAT) and Ultra Small Aperture Terminals (USAT) is expected in the coming years. Small size terminals allow for widespread use of satellite services in small business and domestic applications. Due to congestion of lower frequency bands such as C and Ku, most of these services will use Ka-band (20/30 GHz) frequencies. Propagation impairments produced by the troposphere is a limiting factor for the effective use of the 20/30 GHz band and the use of smaller earth terminals makes it difficult to provide sufficient link margins for propagation related outages. In this context, reliable prediction of propagation impairments for low-margin systems becomes important, Due to the complexity of propagation phenomena propagation modeling is mainly attempted on empirical basis. As such, availability of reliable measured data that extend to probability levels well in excess of the traditional limit of 1 % is of great importance in the development, validation, and refinement of propagation models. The beacon payload on the ACTS satellite together with the propagation measurement terminals developed under the NASA ACTS propagation program provide an excellent opportunity to collect such data on a long-term basis. This paper presents results of ACTS propagation measurements conducted in the Washington DC metropolitan area by COMSAT Laboratories. The measurement program involves three sites, two in Maryland and one in Virginia. Measurements started soon after the launch of the ACTS satellite in September 1993. However, not all three sites were brought on line at the same time, Results from only two sites are presented in this paper; results from the third site are given in Reference 1. Use of multiple sites for the measurement enabled the investigation of site diversity to combat rain fading. Two of the sites use radiometers along with beacon measurement systems, thus allowing a careful estimation of gaseous absorption and other phenomena that produce relatively low attenuation levels. This helps to characterize the attenuation distribution for low availability levels, especially those between 10/0 and 10O/O. Several meteorological sensors are also deployed to help evaluate propagation models and to investigate the dependence of propagation impairments on meteorological factors.

A description of the measurement sites and the equipment used is given in Section 2. The three measurement systems are not identical and different data analysis procedures are used for the three systems. However, in each case the under-lying analysis principles can be considered the same. Data analysis procedure used to convert raw data collected to a form suitable for the generation of attenuation statistics and other useful results are discussed in Section 3. Section 4 provides the salient results of the experiment. One of the sites reports results over a period of24 months and the second site reports 21 months of data. Most of the results are presented in the form of monthly statistics. Comparison of standard model predictions with the measurement results is presented under summary and conclusions in Section 5.

2. Experiment Details

Figure 1 shows the measurement configuration. The three sites are located at Clarksburg, MD, Laurel, MD, and Reston, VA. At each site the approximate elevation angle to the ACTS satellite is 39°. The terminal at Clarksburg was developed at COMSAT Laboratories and is capable of receiving both 20 and 27 GHz beacon signals. The Laurel terminal is a Ka-band communication terminal which can receive only the 20 GHz beacon signal. The terminal at Reston is one of the NASA A(TS Propagation Terminals (APT) that can receive both the beacons Table 1 gives all relevant geographical and receiving terminal parameters for the three sites.

Table 1. Measurement Site Parameters and Receiving System Details

Parameter	Clarksburg, MD	Reston,	Laurel, MD
Latitude	39.22° N	38.95”	39.17° N
Longitude	7’7,28° W	77.33° W	76.90° W
Elevation Angle	38.8°	39.1’	38.7°
Azimuth Angle	213.5°	213.6	214.0°
Polarization Angle	64,7°	64.5’	64.3°
Distance from Clarksburg		30.5 k	32.9 km
Antenna Diameter	1.2m	1.2 n	1.2m
Antenna Gain 20 GHz	46,0 dB	46.0 d	46.0 dB
Antenna Gain 27 GHz	48.7	48.7	
Antenna Beamwidth 20 GHz	0,85°	0.85	0.85°
Antenna Beamwidth 27 GHz	0.63°	0.62	
G/T 20 GHz	14.2 dB/K	14.2 dI /K	15 dB/K
G/T 27 GHz	16.8 dB/K	16.8 dI	
Detection Bandwidth	64 Hz	2011	400 Hz
Dynamic Range 20 GHz	28 dB	30 d]	22 dB
Dynamic Range 27 GHz	26 dB	29 dI	
Sampling Rate: Beacons	5 Hz	1 Hz	5 Hz
:Radiometers	3 sec.	1 Hz	
Meteorological Sensors:			
Rain Rate	Yes	Yes	Yes
Temperature	Yes	***Yes***	No
Humidity	Yes	Yes	No
Pressure	No	Yes	No
Wind Speed	Yes	Yes	***No***

The APT uses a fully digital receiver with a detection bandwidth of20 Hz. The receiver at Clark sburg uses the same RF electronics as the APT; the IF receiver is a selective level meter with a detection bandwidth of 64 Hz. The laurel site also uses a selective level meter as the IF receiver with a somewhat larger detection bandwidth of400

Hz. Total power radiometers which share the same RF electronics as the beacon receivers are used in the APT. These require periodic calibration using a noise diode and a reference load, The calibration is carried out at 15 minute intervals and lasts approximately 20 seconds. During the calibration the beacon signal is not available. The radiometers are also calibrated using hot and cold loads every six weeks. Radiometers in the Clarksburg terminal also share the RF electronics with the beacon receivers. However, they are of Dicke type where gain variations in the receiving system are removed by switching between the antenna and a highly stable reference load. The switching operation is such that it does not interfere with the beacon reception in any noticeable manner. Calibration of the Dicke radiometers are carried out using hot and cold loads on a bimonthly basis. All three terminals share a common antenna design. The antenna gain was found to degrade appreciably when the antenna surface is subject to wetting. Although the degradation can be somewhat reduced using a hydrophobic coating, the measurements are made without any treatment to the antenna surface.

Data collection at the Clarksburg site started in October 1993, the Reston site in March 1994, and the Laurel site in September 1993. After the first 12 months of measurements the terminal at Reston was moved to a new site approximately 1 km away from the old site. Due to the closeness of the two sites no significant climatalogical differences are expected and the data from the two sites are treated as belonging to a single site.

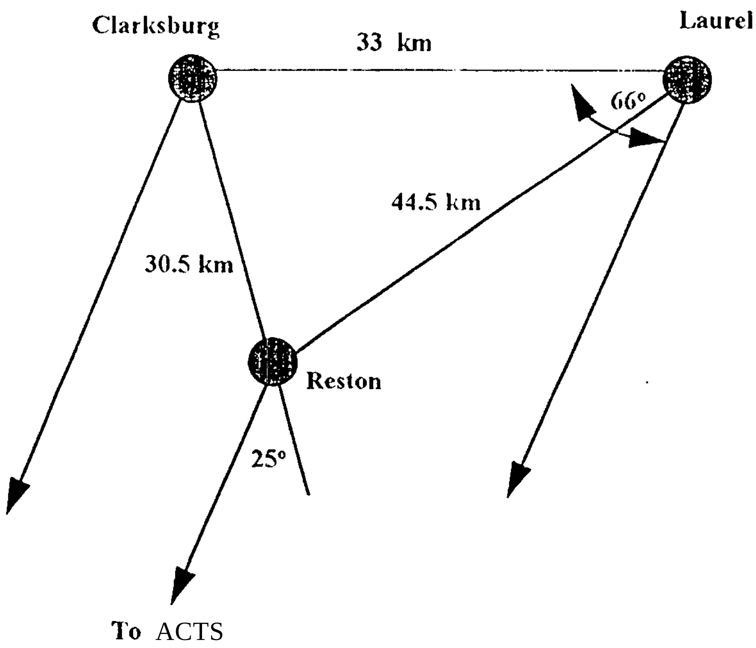


*Figure 1 **Experiment Site** Configuration*

3. Data Analysis Procedures

Data analysis is carried out in two stages: a preprocessing stage to remove all undesired features in the raw data and the analysis stage where relevant statistics and other information are generated. The preprocessing stage. involves the removal of:

- outliers
- modulation pulses
- calibration intervals
- sun outages
- signal loss due to eclipse operation
- satellite generated interference in the 20 GHz radiometer

Outliers are generated by power line surges and other types of short-lived disturbances. Modulation pulses are present only on the 20 GHz beacon channel and these manifest as signal enhancements ranging from 0.4 dB to 0.8 dB. Both automatic and manual calibration intervals are present in the beacon and radiometer channels and these must be removed and new calibration constants derived to process the subsequent data, Sun interference on radiometer channels occurs twice a year and these must be identified and removed, During the eclipse operation of the satellite, transition from solar to battery power and vice versa generate rapid frequency drifts that cannot be tracked by the receivers; these must be identified and removed. Satellite spot beams generate sufficient noise to interfere with the operation of the 20 GHz I audiometers. Frequent use of the east spot beam of the satellite in the Washington DC area by other ACTS experimenters required additional processing to remove these interferences.

In addition, radiometer calibration, bias removal of the beacon signals, and conversion of rain accumulation to rain rate are carried out during the preprocessing stage. The radiometer calibration process involves matching the radiometer estimated attenuation with the attenuation estimations based on meteorological data under clear-sky conditions. The bias removal involves the separation of equipment induced variations in the beacon signal from those due to propagation effects. Bias removal is carried out assuming that the radiometer provides a very good estimate of the signal attenuation under clear-sky and low attenuation conditions, The rain gauge used for the measurement provides sample values of rain accumulation and the preprocessing software converts these into rain rates.

Data analysis for the Reston terminal (APT) was carried out using the standard software supplied by NASA. The analysis software is described in Reference 2. However, the software is not capable of removing all of the undesired contaminants mentioned above. The processed data were visually inspected to identify these contaminants and they were removed manually. As an example., the satellite interferences on the 20 GHz radiometer were removed by declaring such episodes as invalid data. The sun interferences on the radiometer channels were removed by interpolating across the interference event.

Data from the Clarksburg terminal were analyzed using a separate software package. The preprocessing steps are essentially the same as those for the Reston terminal. However, data were subjected to visual inspection before and after the preprocessing stage for the identification and eventual removal of all contaminants. Additionally, the 5 samples per second input data were averaged to obtain one second samples at the output.

The preprocessed data are used to generate different types of statistics. The statistical analysis of the APT data is based on one minute averages; that of the Clarksburg data is based on one second samples,

4. **Results**

The following list gives the different types of' analysis carried out in monthly units and will be presented in an interim report to NASA.

1, Cumulative distribution function of 20.2 GHz beacon attenuation
2. Cumulative distribution function of 27.5 GHz beacon attenuation
3. Cumulative distribution function of 20.2 GHz radiometrically derived attenuation
4. Cumulative distribution function of27.5 GHz radiometrically derived attenuation
5, Cumulative distribution function of20.2 GHz clear sky attenuation
6. Cumulative distribution function of27.5 GHz clear sky attenuation
7 Cumulative distribution function of 20.2 GHz sky noise temperature
8 Cumulative distribution function of 27.5 GHz sky noise temperature
9 Cumulative distribution function of20.2 GHz beacon standard deviation (1 minute average)
10 Cumulative distribution function of 27.5 GHz beacon standard deviation (1 minute average)
11 Cumulative distribution function of20.2 GHz radiometrically derived attenuation standard deviation (1 minute average)
12 Cumulative distribution function of 27.5 GHz radiometrically derived attenuation standard deviation (1 minute average)
13. Cumulative distribution function of 20.2 GHz fade duration
14. Cumulative distribution function of 27.5 GHz fade duration
15. Cumulative distribution function of 20.2 GHz inter-fade intervals
16. Cumulative distribution function of 27.5 GHz inler-fade intervals
17. Cumulative distribution function of rain rate
18. Cumulative distribution function of ambient temperature
19. Cumulative distribution function of humidity
20. Cumulative distribution function of pressure

As mentioned in the previous section the results for the Reston site are generated with one minute averages of the various parameters. Results for the Clarksburg site are generated using onc second samples; however, these are presented only as annual summaries in the next section Joint attenuation statistics between Clarksburg and Reston for the first 12 months ofjoint operation are also presented in the next section; only the 20 and 27 GHz beacon attenuation are given. Results from the Laurel site can be found in Reference 1.

5. Summary Results

Statistical results presented as monthly units in the previous section were used to generate annual statistics of attenuation and fade durations. In addition, statistics of frequency scaling ratio between the two beacon frequencies were generated. In the ensuing pages, most of the statistical results are compared with appropriate propagation models.

5.1 Rain Rate

Rain measurements at the Reston site was not successful due to difficulties with the rain gauge and only the results from Clarksburg are presented, Figure 2 shows the cumulative distribution of rain rate for the two measurement years (November 1993 to October 1994 and November 1994 to October 1995). It is seen that the second year experienced less rainfall than the first year. Also shown in the figure are the rain rates from three models:

- Rice-Holemberg model [3]
- ITU rain zone classification [4]
- Crane global rain model [5]

The Rice-H olmberg model requires average annual accumulation of rainfall, M (mm), and the fraction of rainfall due to thunderstorm activity, β. Based on long-term meteorological data, these two parameters for the Clarksburg site are: M = 936 mm and $\beta = 0.29$. According to ITU rain zone classification the Clarksburg site belongs to rain zone K; global rain zone for the site is D2. It is seen that the Rice-Holmberg and Global models provide closer fits to the measured data averaged over the two year period than the ITU model. However, it should be noted that all three models attempt to provide average rain statistics over a relatively longer measurement period (> 5 years).

5.2 Single Site Attenuation

Attenuation statistics for the two year period from November 1993 to October 1995 for the Clarksburg site are shown in Figure 3 and 4 for the beacon frequencies 20 and 27 GHz, respectively. In Figure 5 same statistics for the Reston site are shown; statistics shown are for the 12 months period from March 1994 to February 1994. Since the two sites belong to the same general rain climate the behavior of attenuation statistics in each case is quite similar. As noted earlier, at Clarksburg attenuation is less severe in the second year.

Model predictions of attenuation statistics for the two sites are also shown in Fig. 3 and 4. Two models are shown: ITU-R rain attenuation model [6], and SPM [7]. The ITU-R models include gaseous absorption based on the ITU-R gaseous absorption model; gaseous absorption corresponding to average temperature and relative humidity conditions is added to the rain attenuation. In the case of SPM, gaseous absorption, cloud attenuation, and melting layer attenuation are included in the prediction. It is seen that SPM provides a better agreement with measured data than the other model.

5.3 Joint Attenuation

Figures 6 through 17 show various joint attenuation statistics for the Clarksburg and Reston sites; measurement period: March, 1994 to February, 1995. These are:

- monthly single site and joint attenuation
- annual single site and joint attenuation with model predictions
- annual statistics of unbalance diversity

From Fig 14 and 15 it is seen that the ITU-R site diversity model generally under predicts the diversity gain for attenuation levels above about 5 dB. Diversity gain is less susceptible to year-to-year variations and therefore, no plausible explanation can be given for the discrepancy.

5.4 Fade Durations

Figures 18 - 21 present statistics of fade durations and inter-fade intervals over a period of 12 months at Clarksburg.

6. References

1. J. Goldhirsh; Diversity Experiments at Ka-Band
   NAPEX-96, Fairbanks, AL, 1996

2. R. Crane; Data Processing Procedures
   NAPEX-96, Fairbanks, Al, 1996

3. P. L. Rice, N. R. Holmberg; Cumulative Time Statistics of Surface Point Rainfall Rates
   IEEE Trans COM-21, 1973

4. CCIR Study Group V; Report 563, 1990

5. R. Crane; A Two-component Rain Model for the Prediction of Attenuation Statistics
   Radio Science, Vol. 17, 19S2

6, l-l-U Recommendation 618

7. A. Dissanayake; Propagation Models for Ka-band Applications
ACTS Propagation Workshop, APSW VIII, Norman, OK, 1 99s

Figure 2 Rain Rate Cumulative Distribution

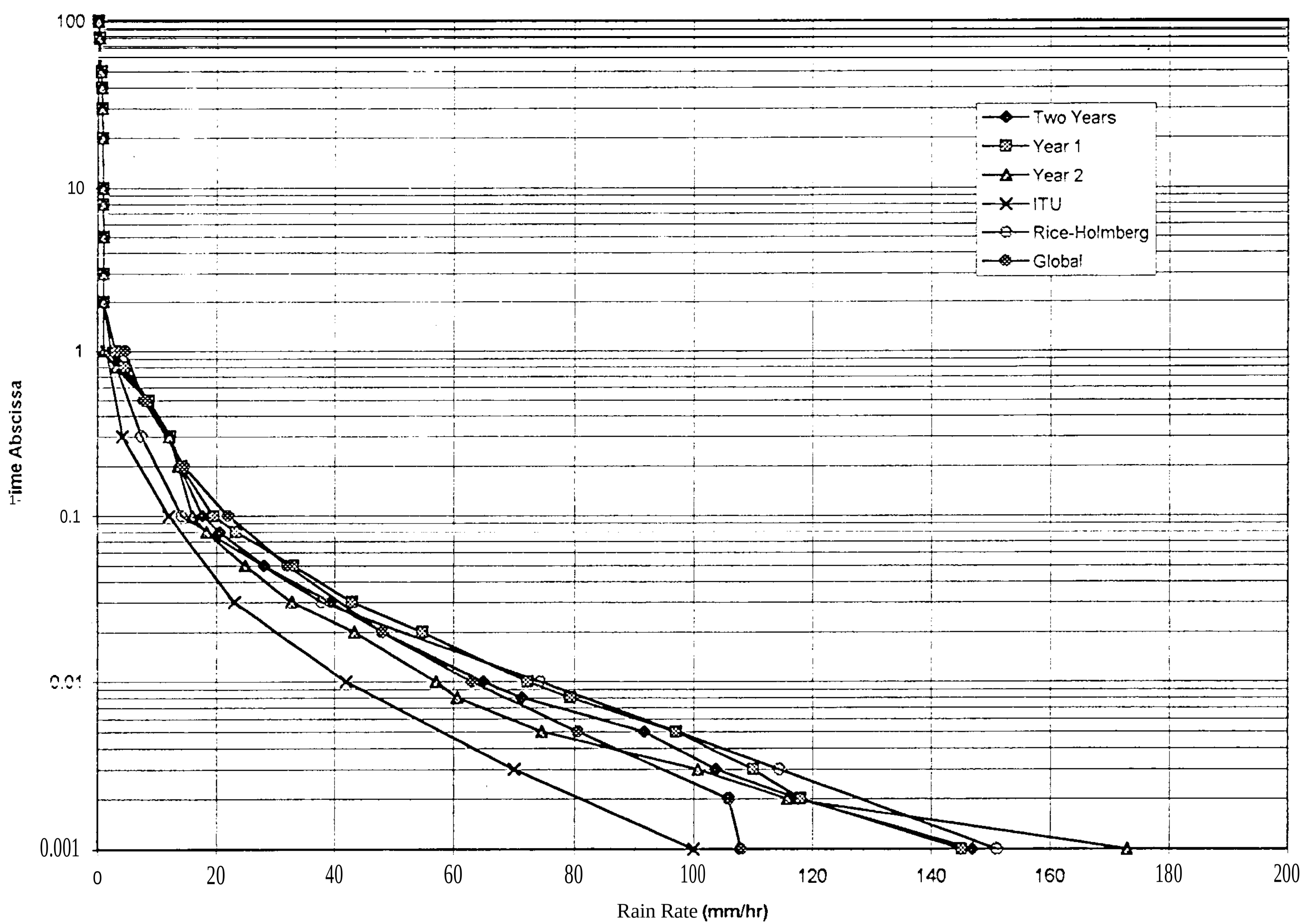


Figure 320.2 GHz Attenuation Cumulative Distribution: Clarksburg

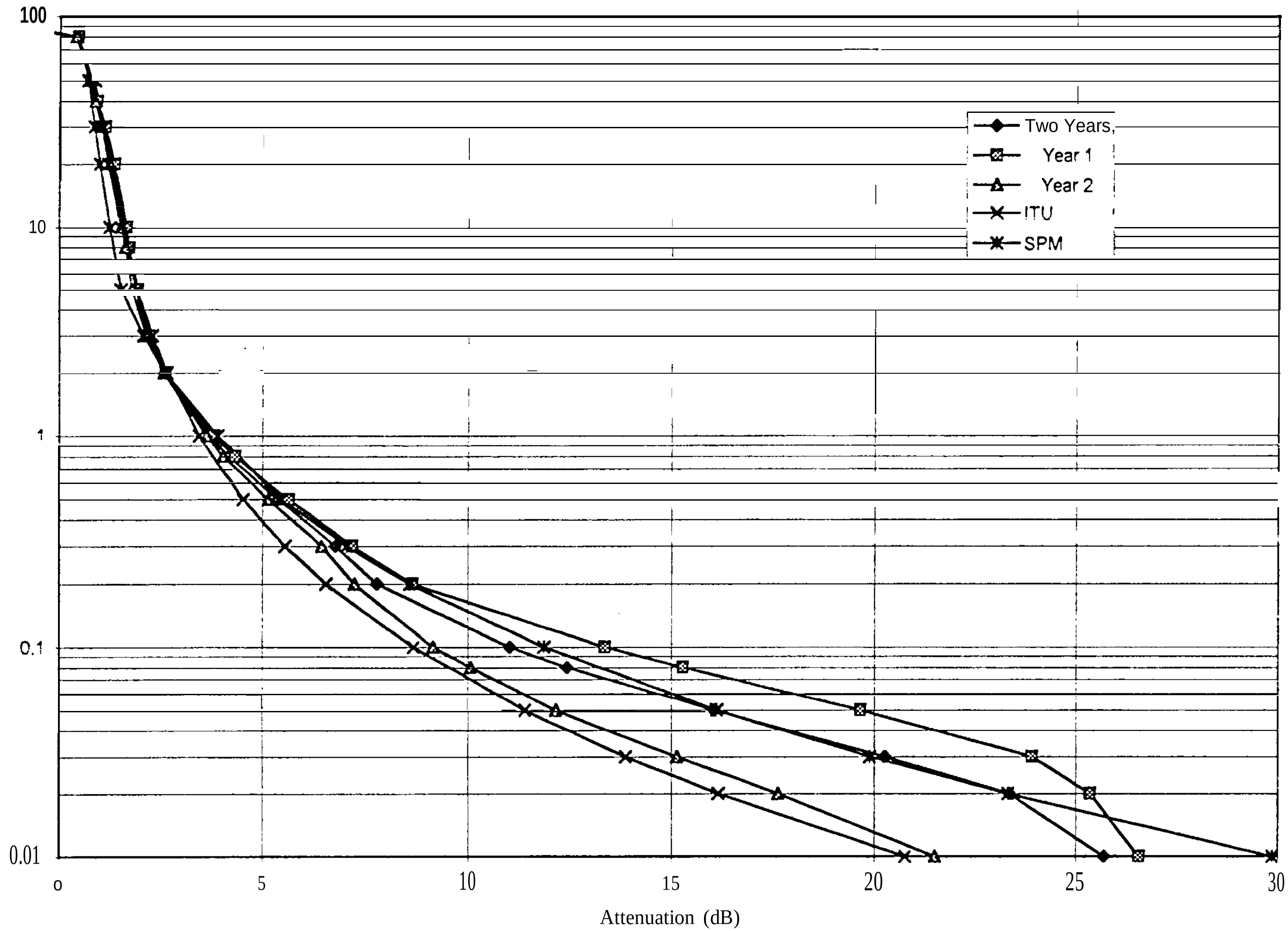


Figure 427.5 GHz Attenuation Cumulative Distribution: Clarksburg

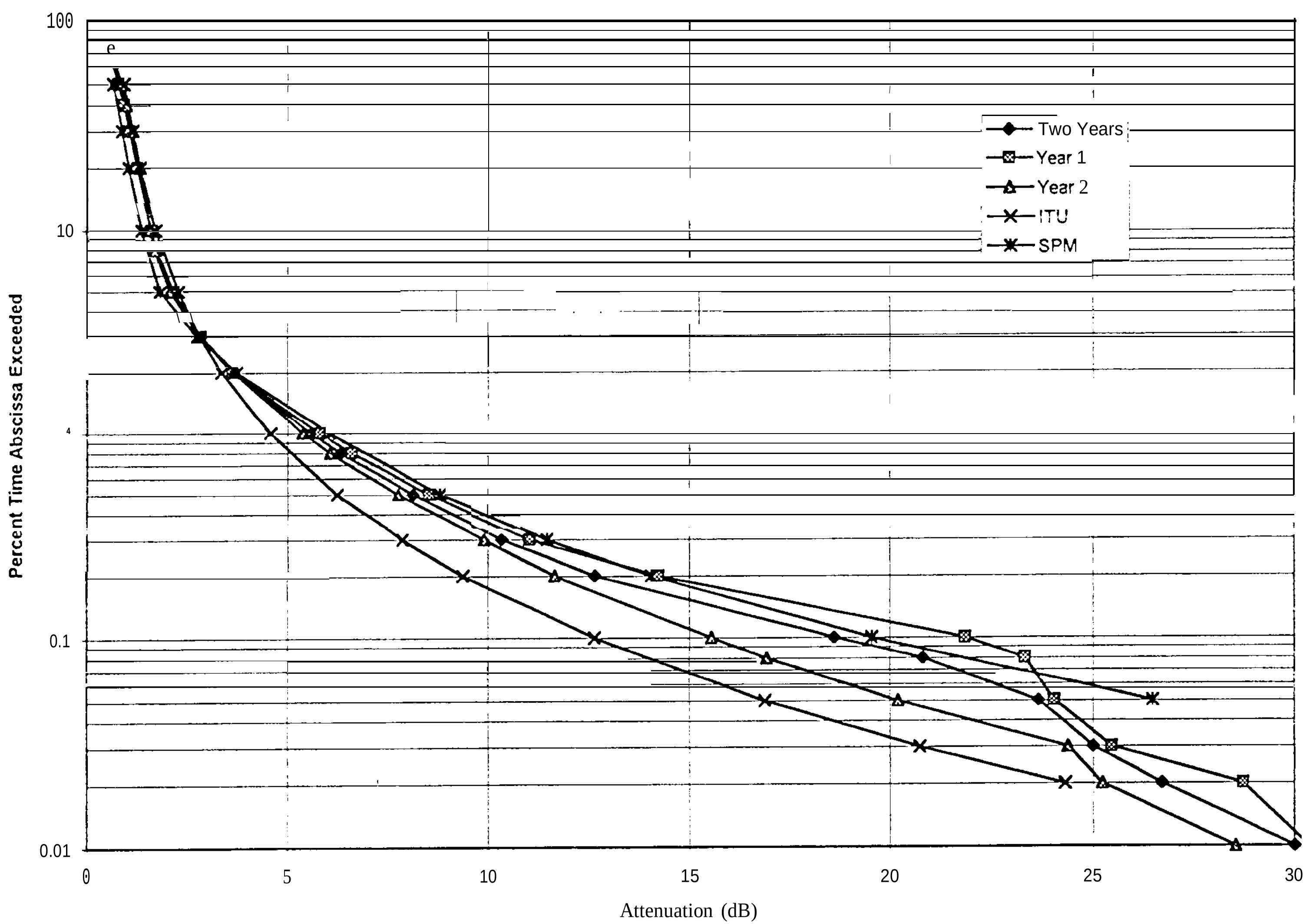
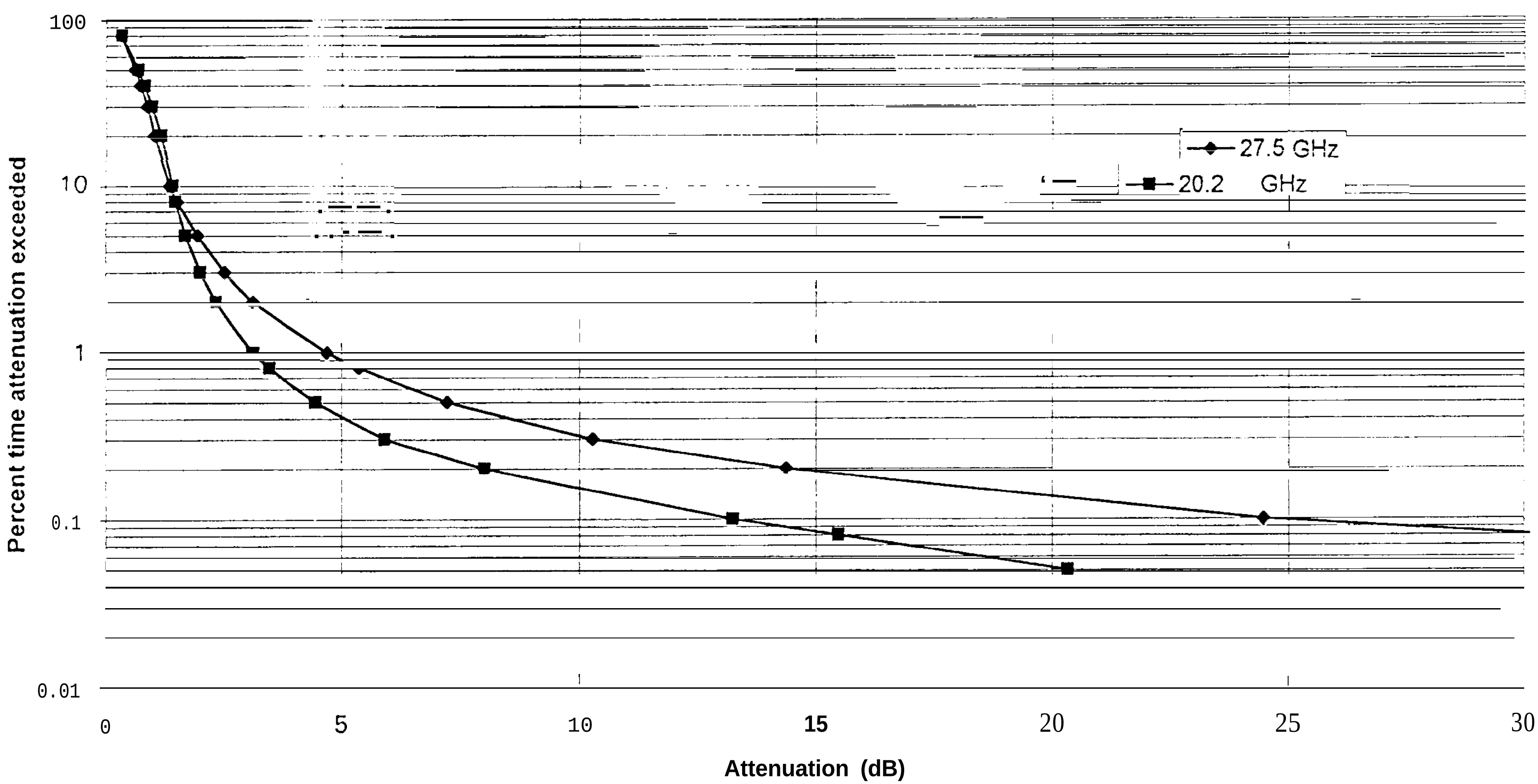


Figure 5. 27.5 and 20.2 GHz Attenuation Distribution: Reston



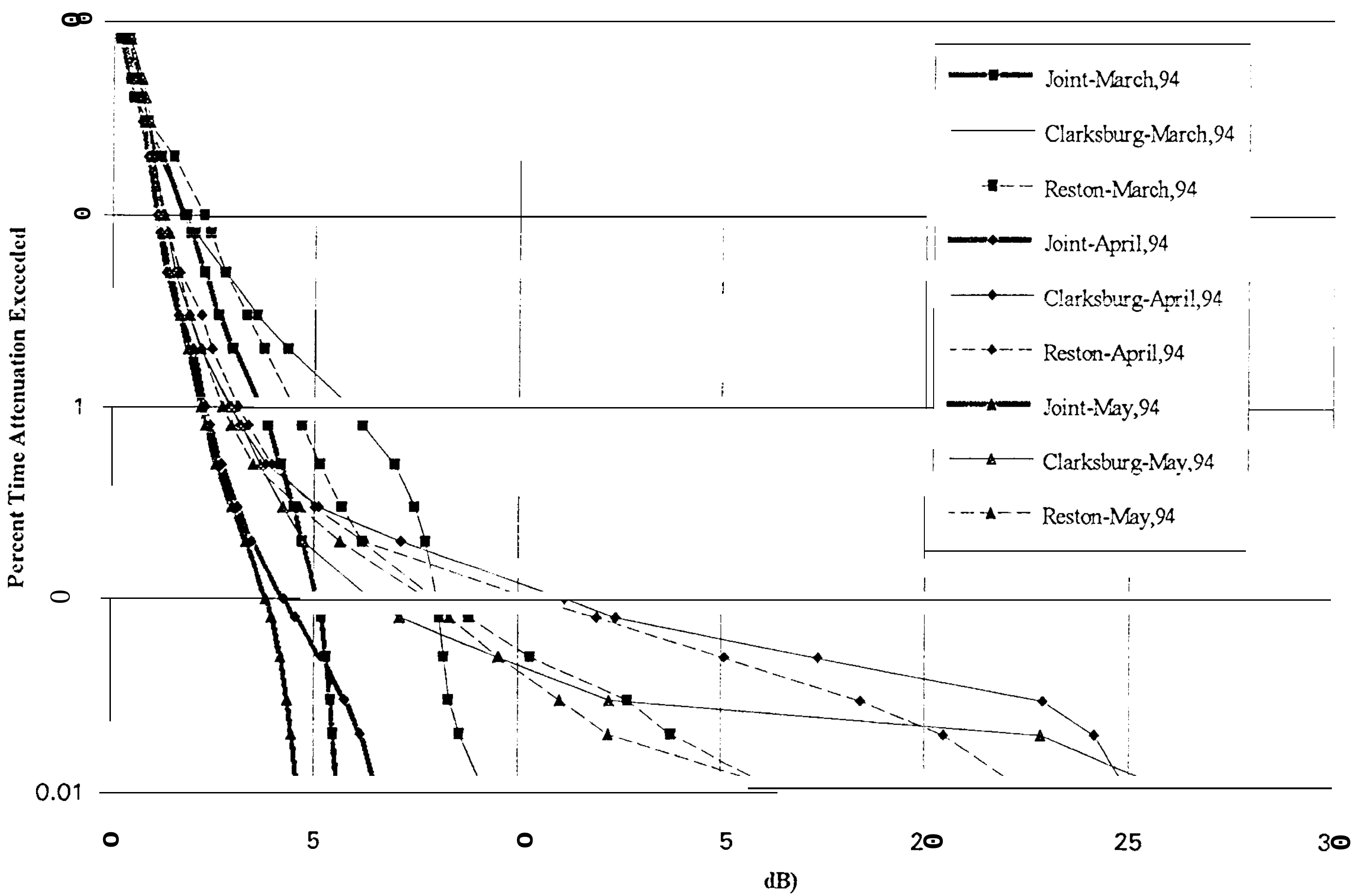


Figure 6 Single Site and Joint Cumulative Distribution of Attenuation at 20 GHz; March, April, and May 1994

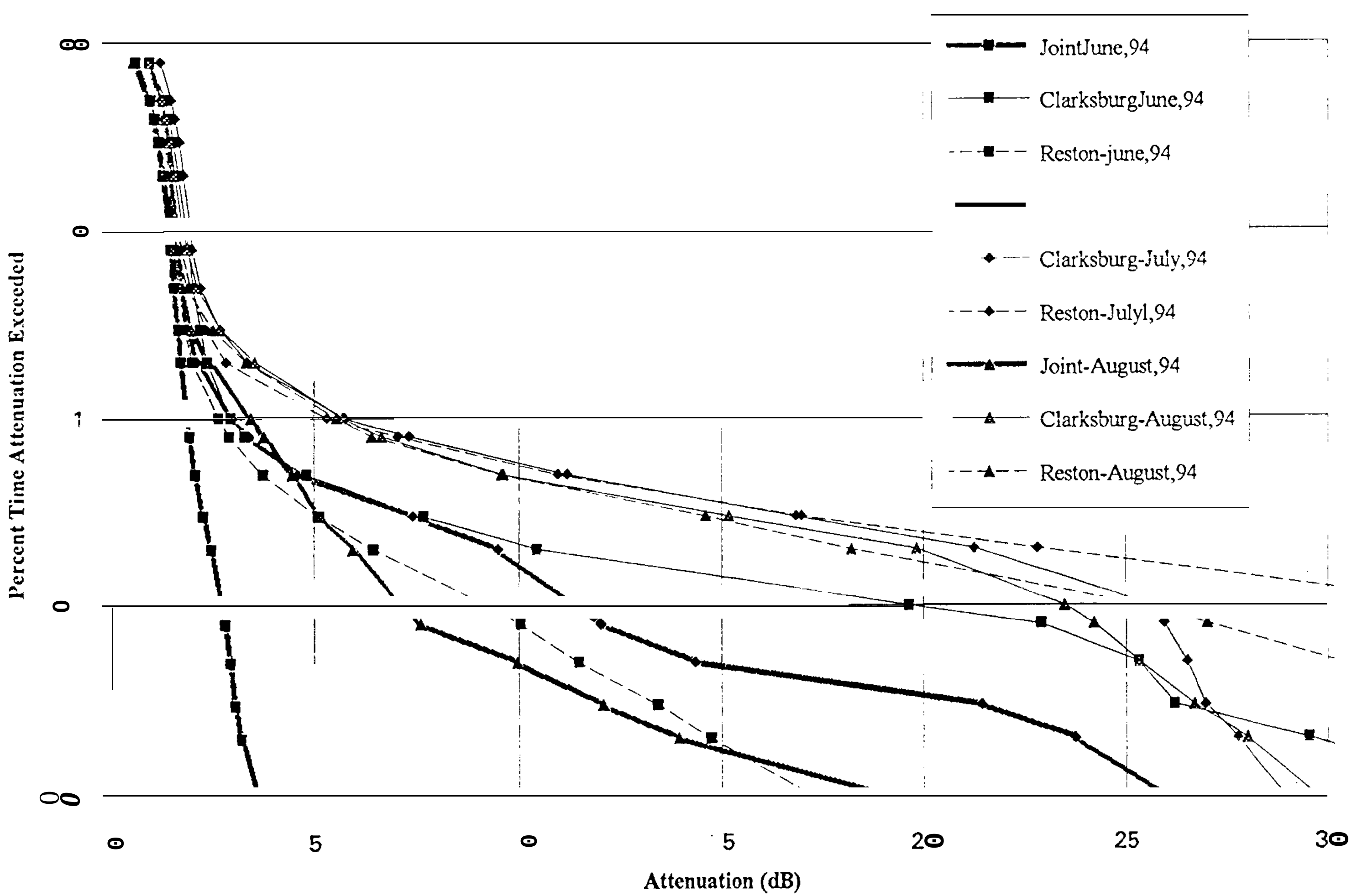


Figure 7 Single Site and Joint Cumulative Distribution of Attenuation at 20 GHz; June, and August 1994

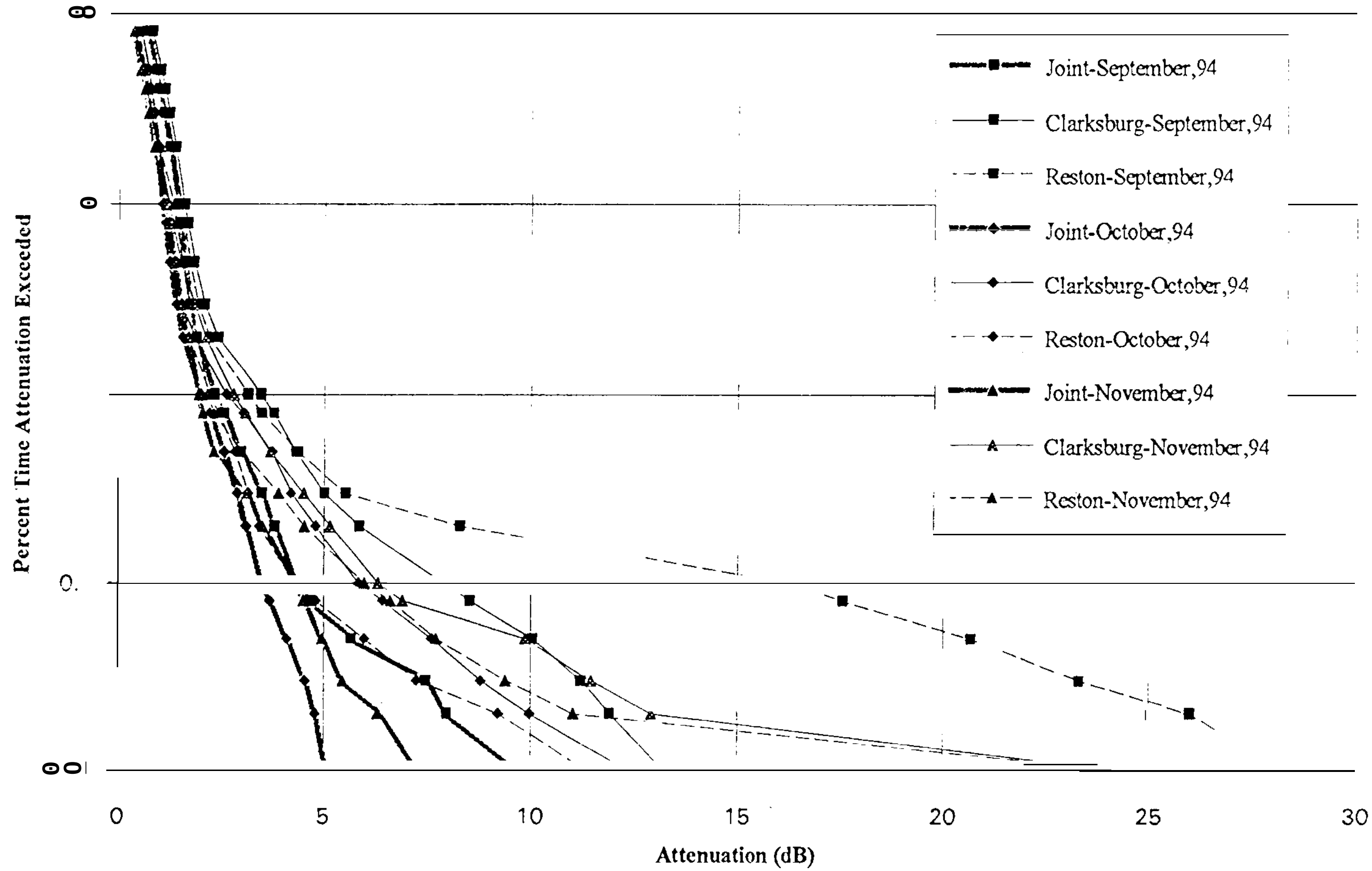


Figure 8 Single Site and Joint Cumulative Distribution of Attenuation at 20 GHz; September, October, and November 1994

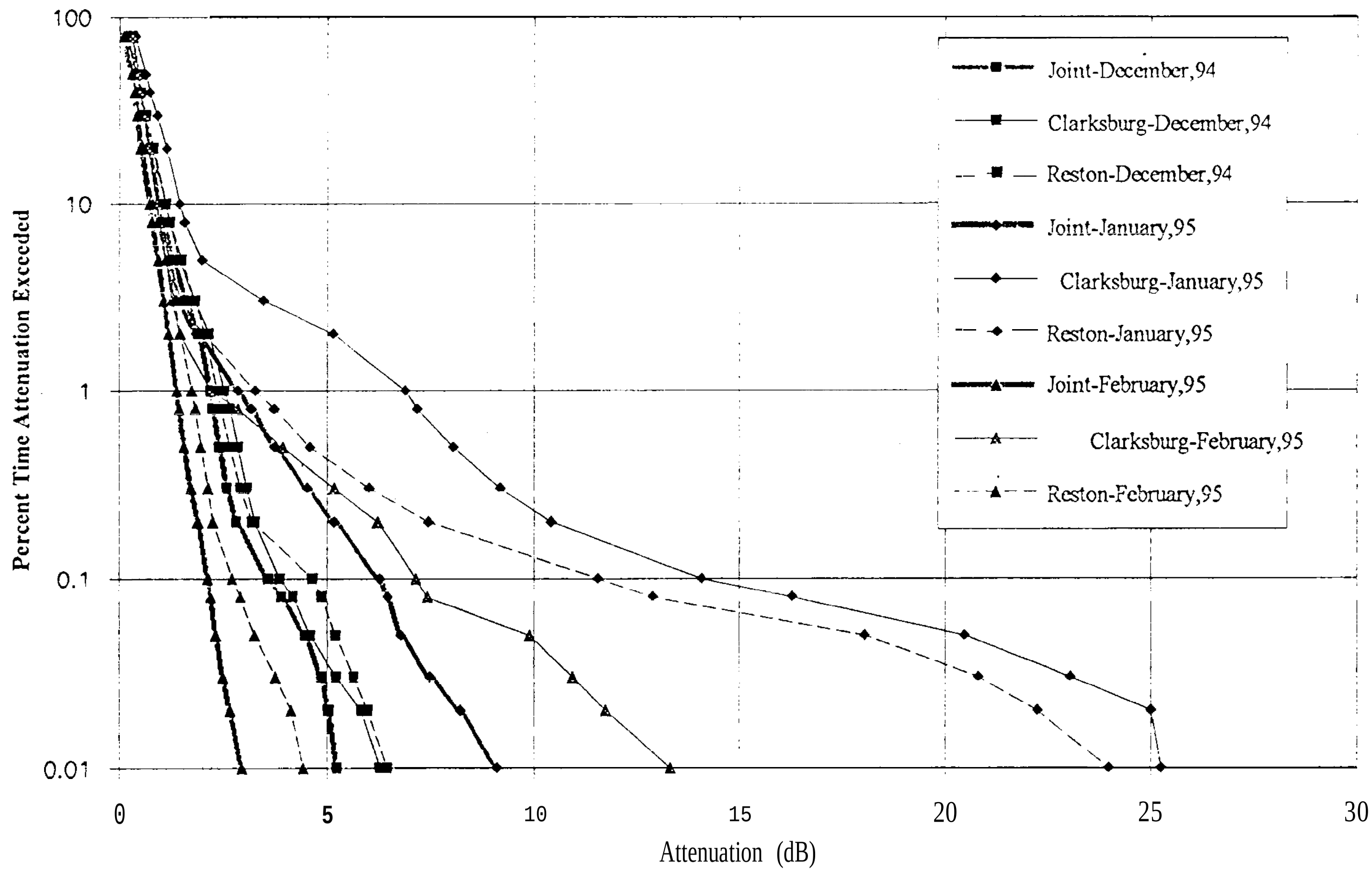


Figure 9 Single Site and Joint Cumulative Distribution of Attenuation at 20 GHz; December 1994, January and February 1995

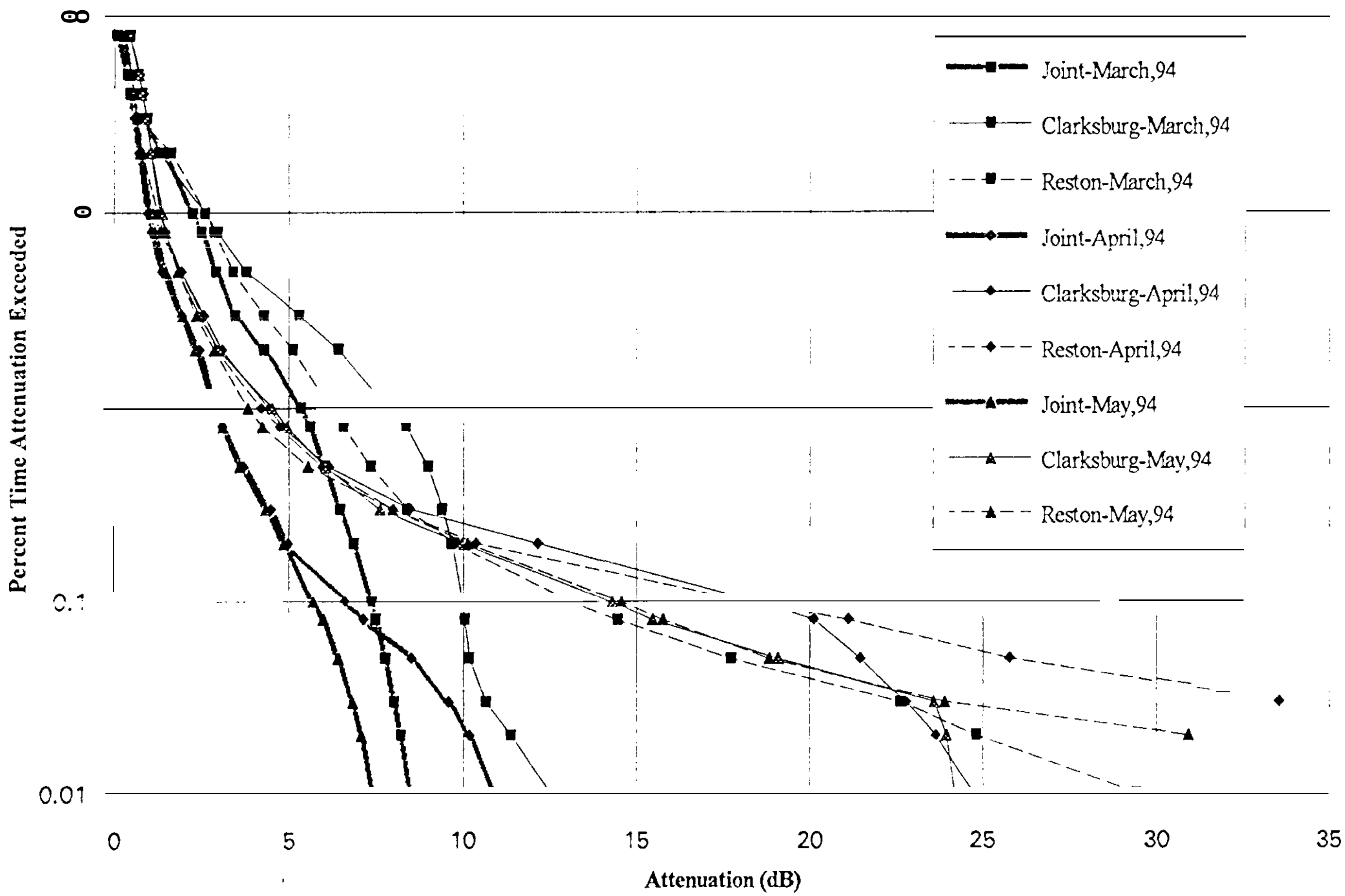


Figure 10 Single Site and Joint Cumulative Distribution of Attenuation at 27.5 GHz; March, April, and May 1994

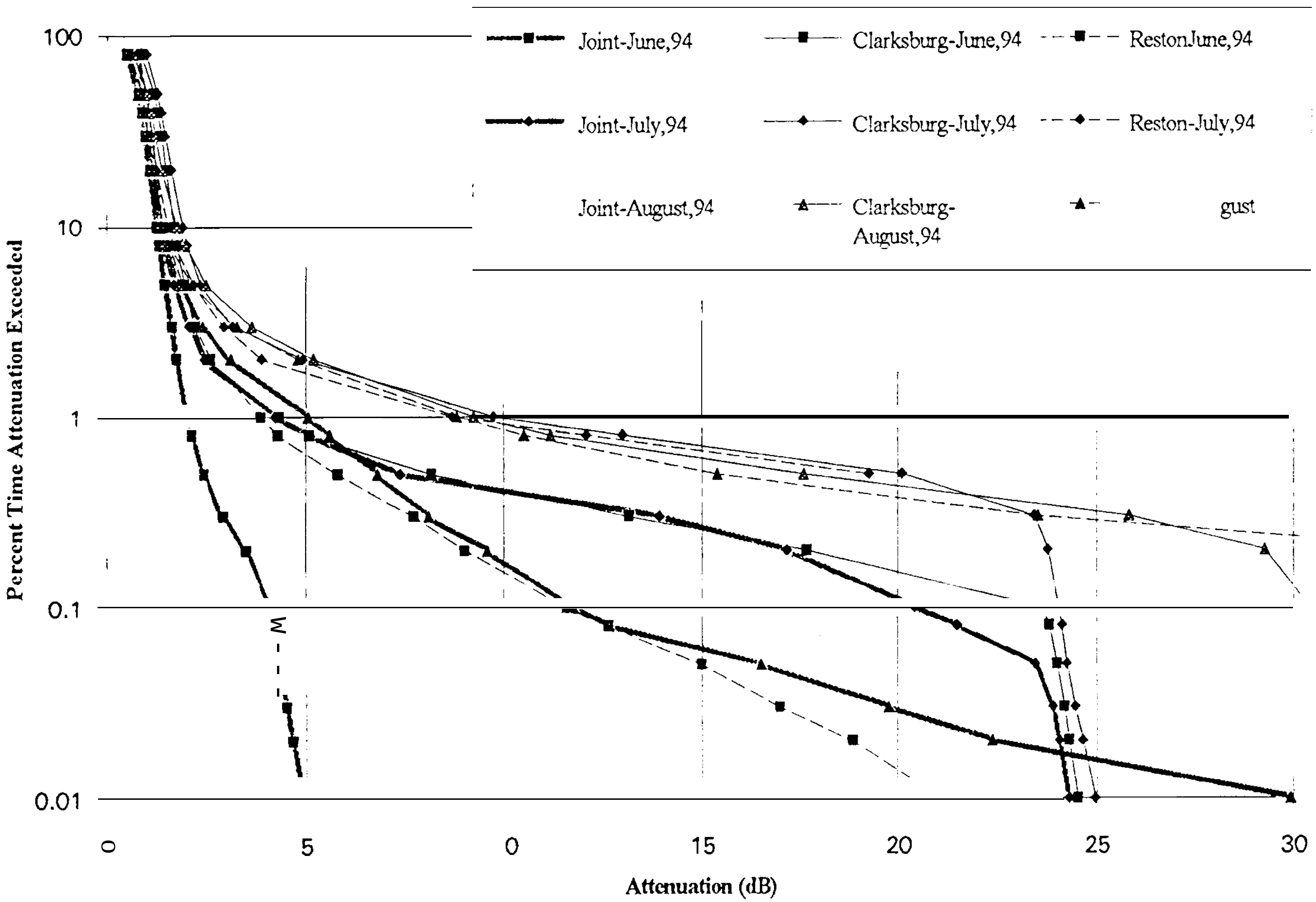


Figure 11 Single Site and Joint Cumulative Distribution of Attenuation at 27.5 GHz; June, July, and August 1994

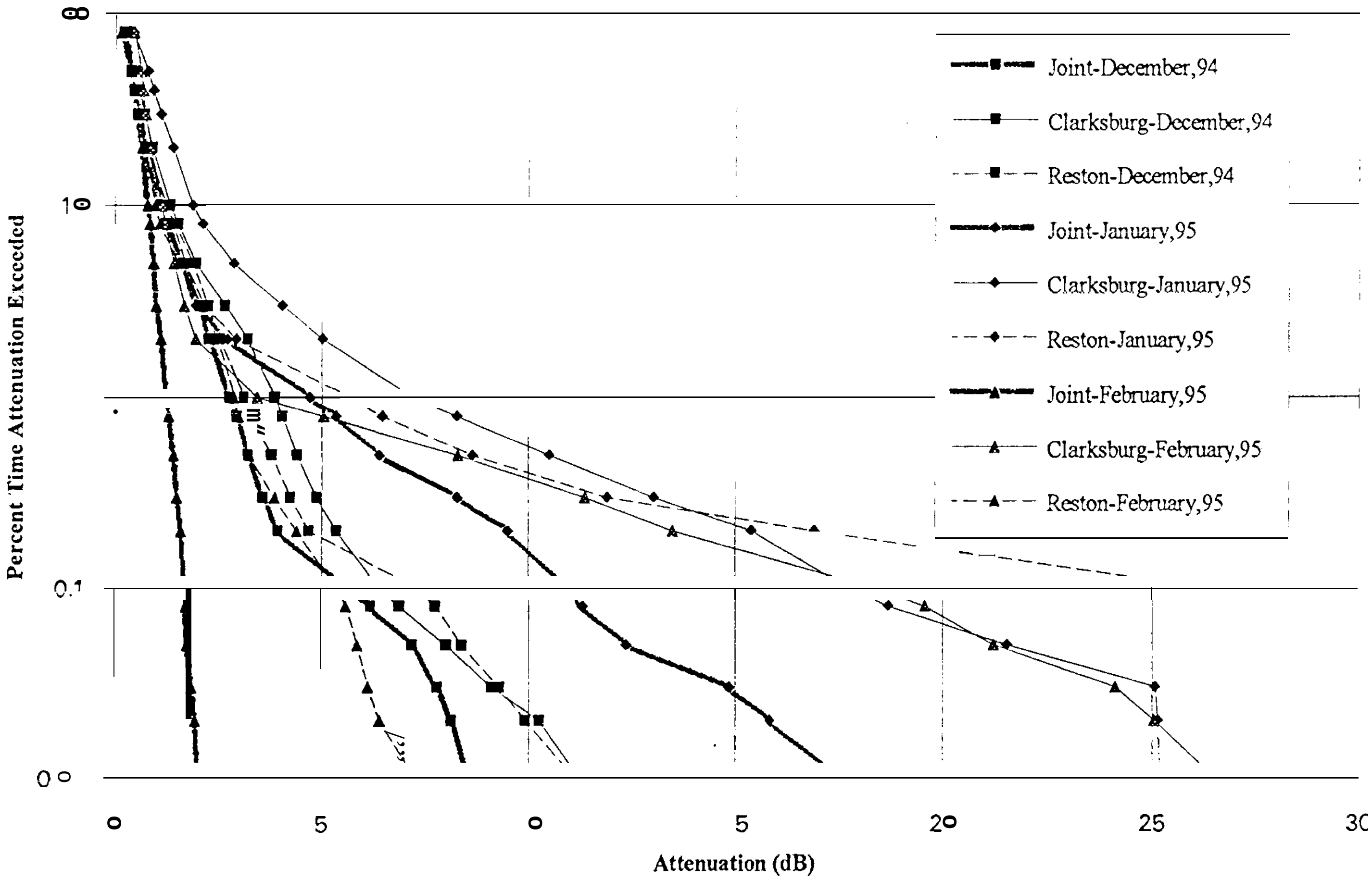


Figure 12 Single Site and Joint Cumulative Distribution of Attenuation at 27.5 GHz; September, October, and November 1994

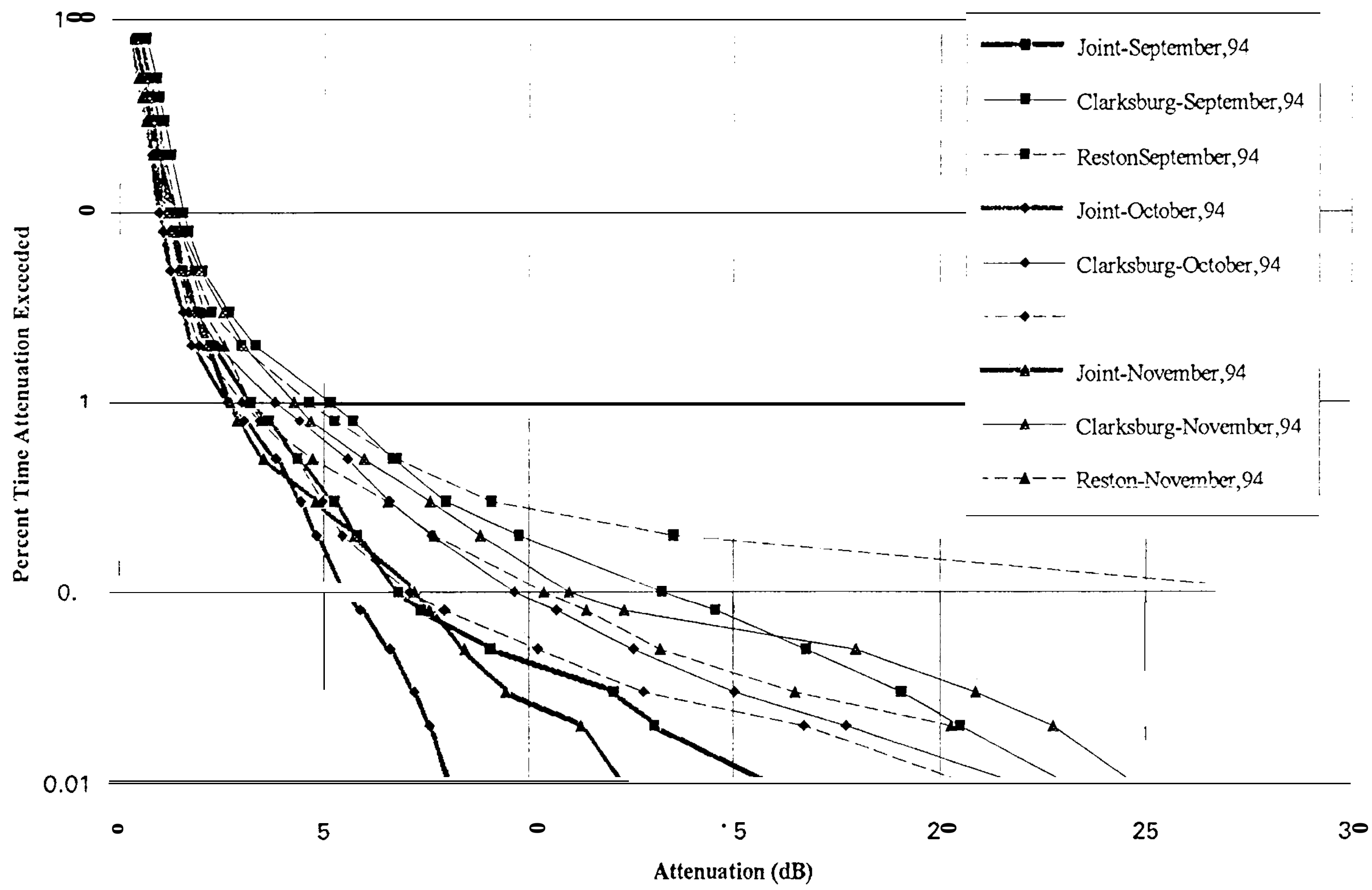


Figure 13 Single Site and Joint Cumulative Distribution of Attenuation at 27.5 GHz; December 1994, January and February 1995

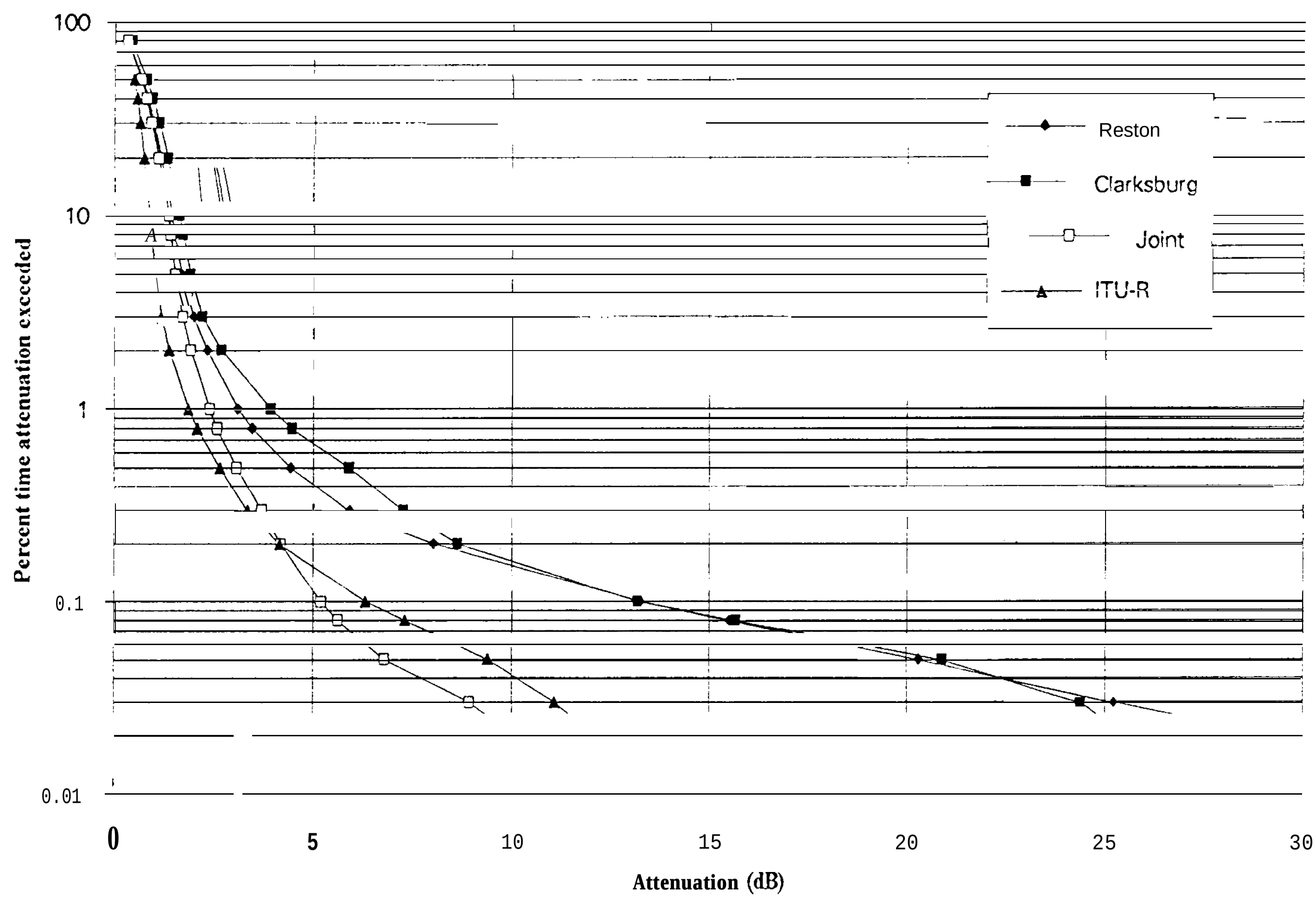


Figure 14 Cumulative Distribution of Single Site and Joint Attenuation at 20 GHz; March 1994- February 1995

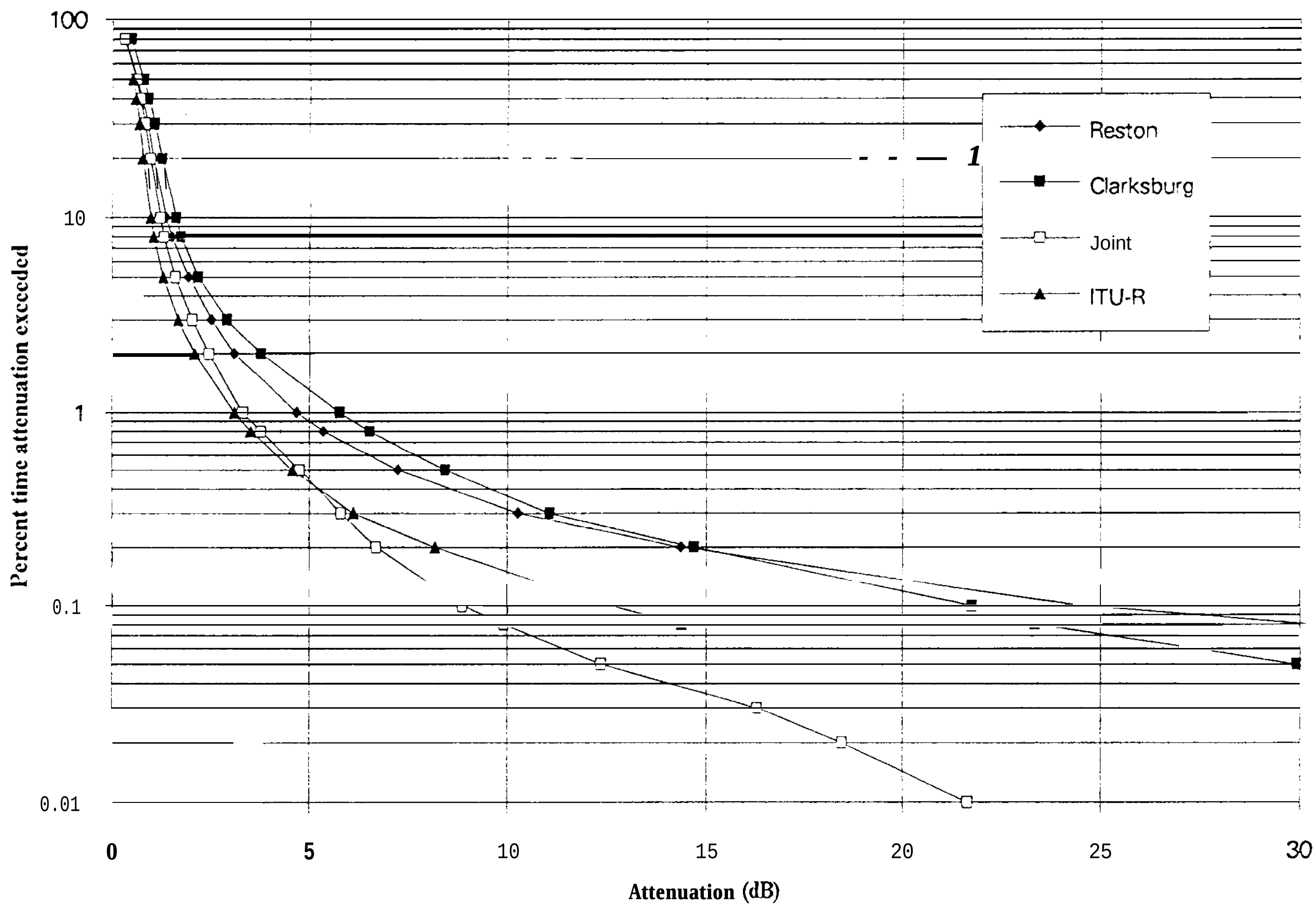


Figure 15 Cumulative Distribution of Single Site and Joint Attenuation at 27.5 GHz; ***March 1994- February 1995***

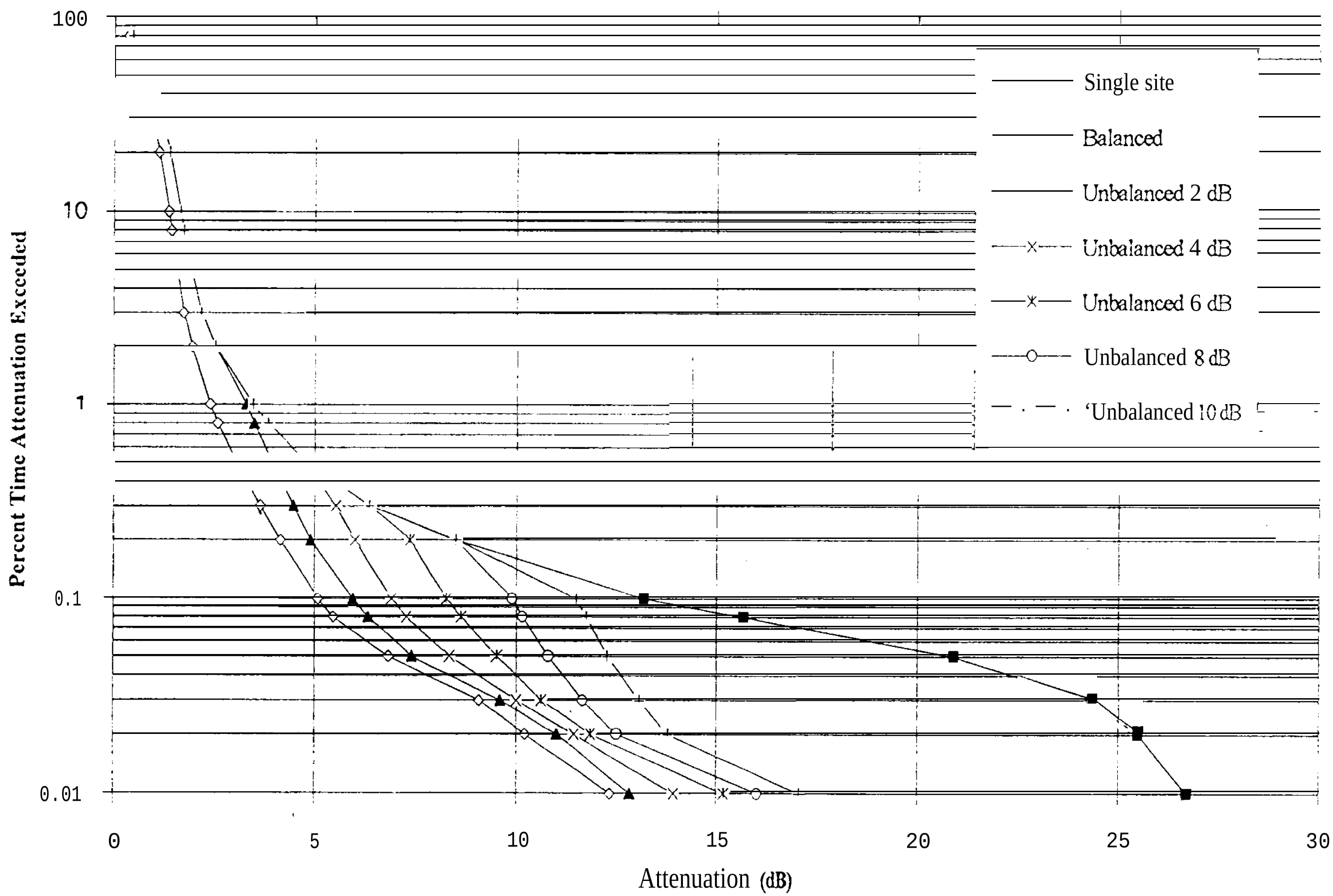


Figure 16 Cumulative Distribution of Joint Attenuation for Unbalanced Diversity at 20 GHz

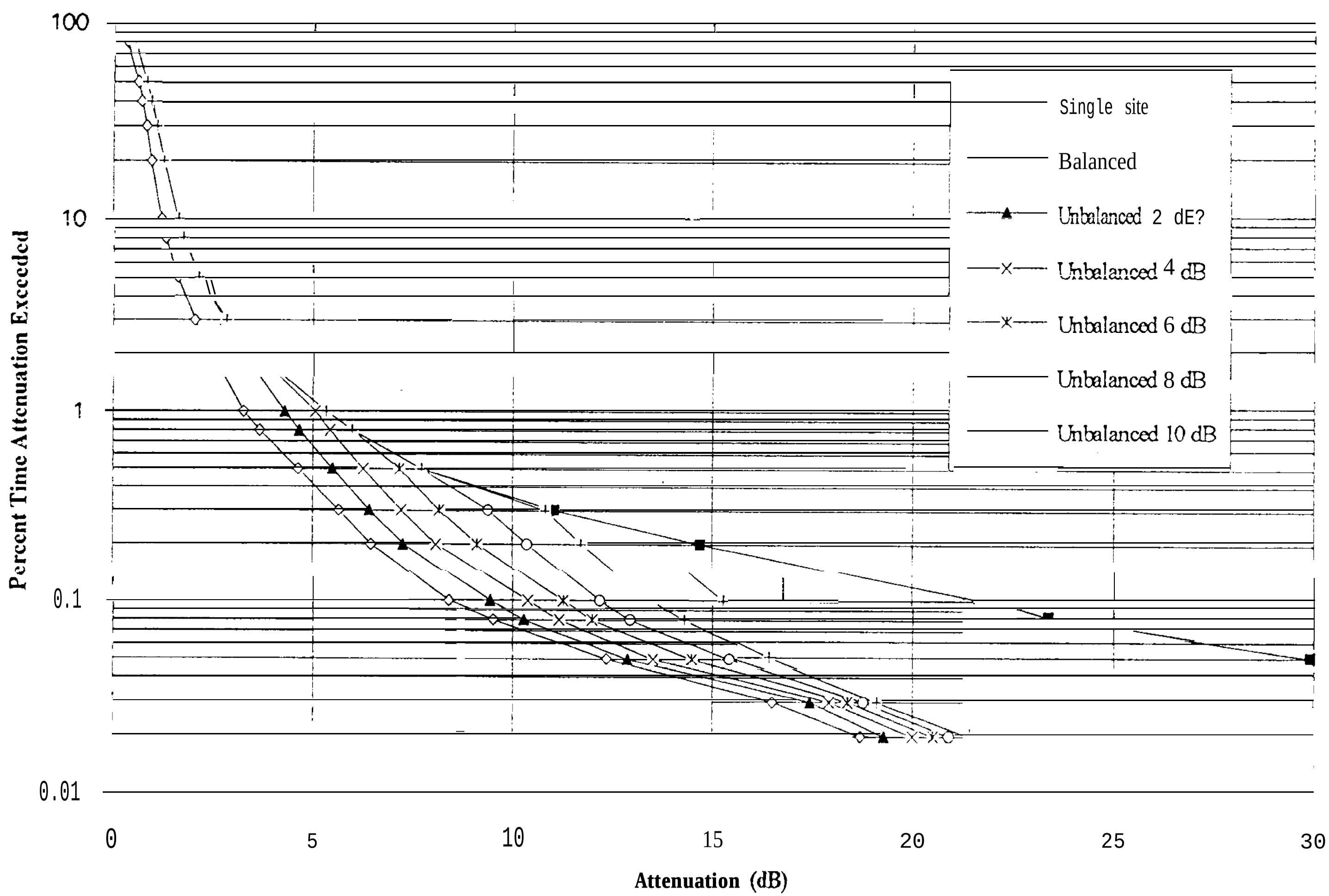


Figure 17 Cumulative Distribution of Joint Attenuation for Unbalanced Diversity at 27.5 GHz

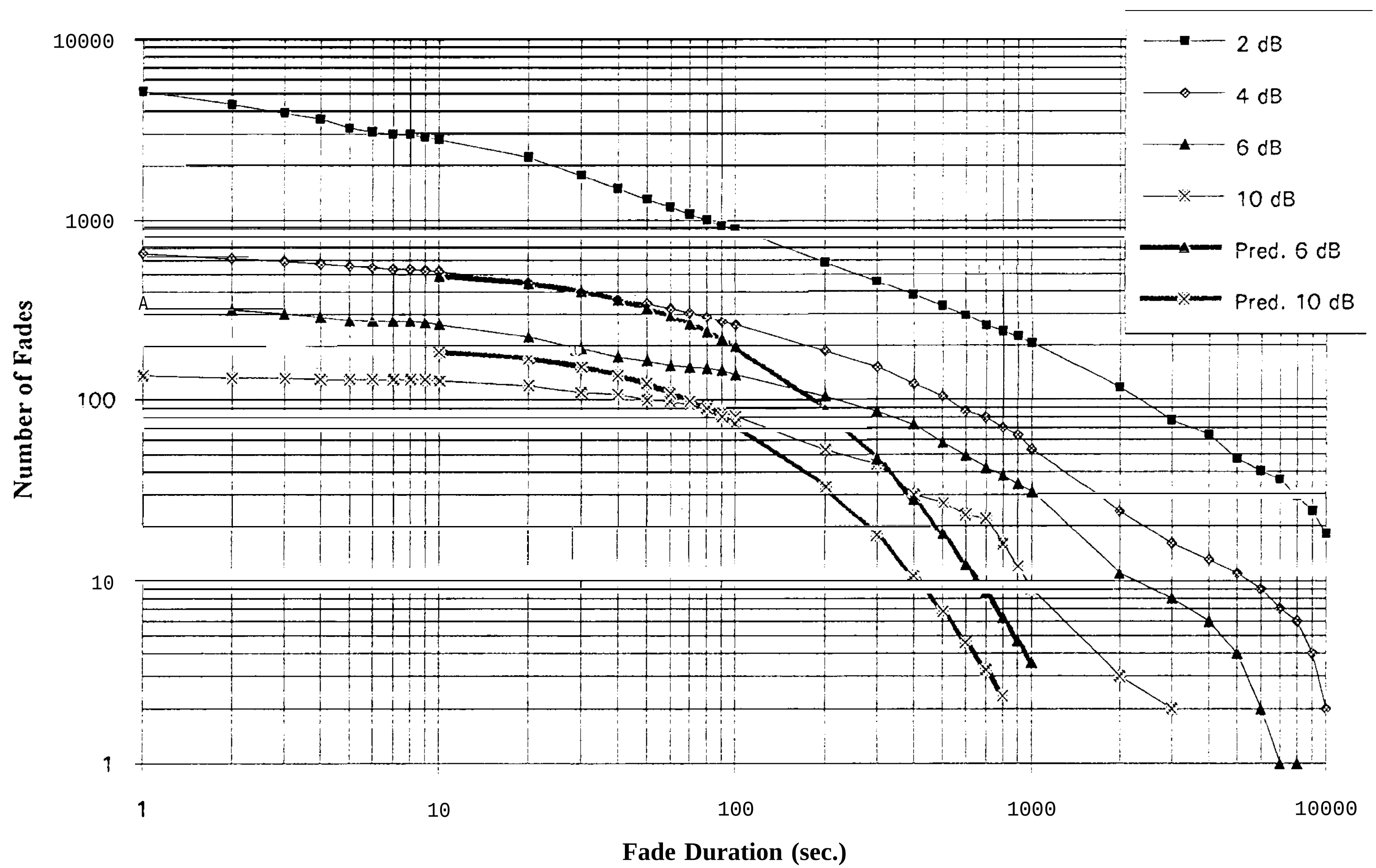


Figure 18 ***Fade Duration Distribution at 20 GHz; measurement period: March 1994 to February 1995***

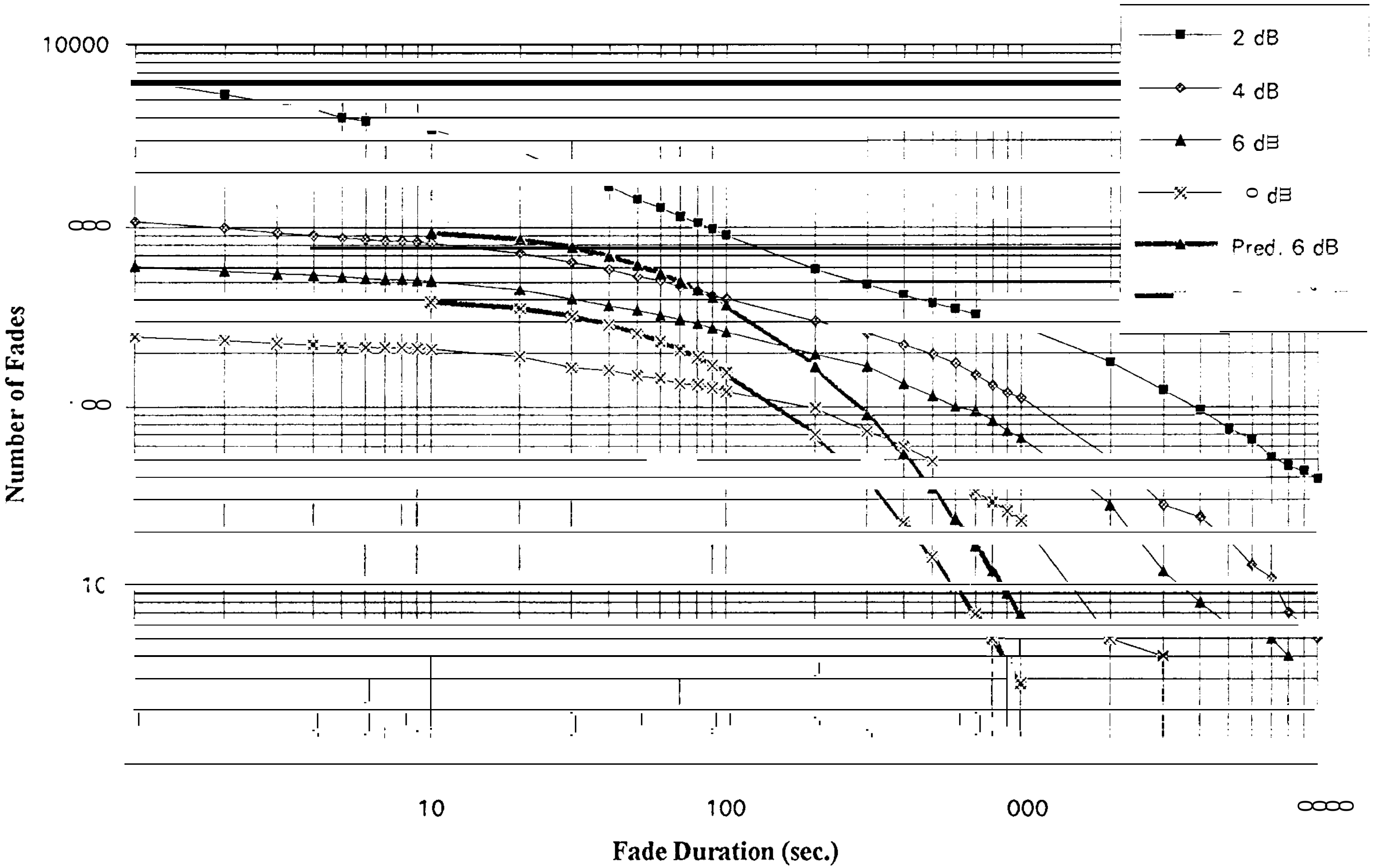


Figure 19 Fade Duration Distribution at 27.5 GHz; measurement period: March 1994 to February 1995

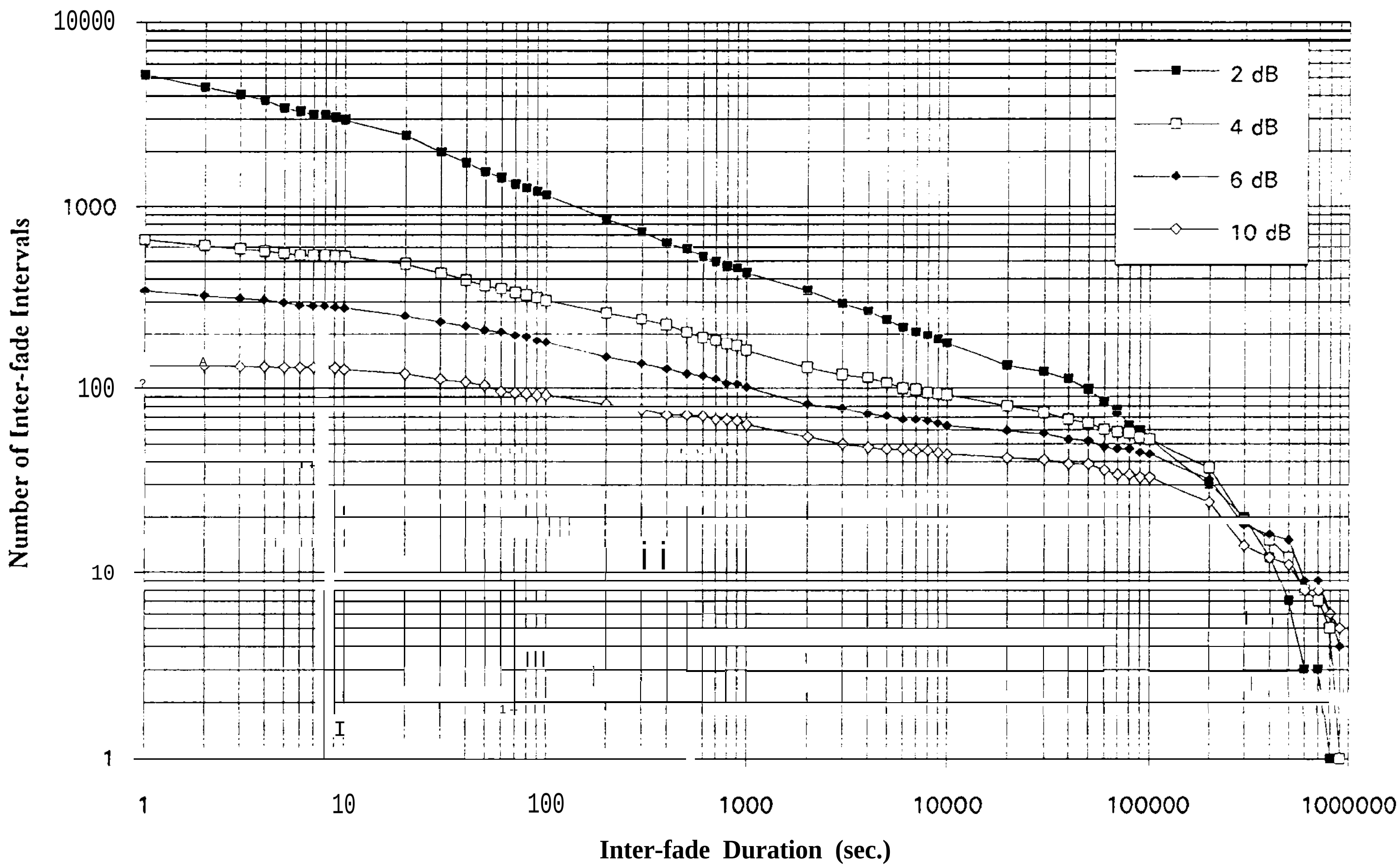


Figure 20 Distribution of Inter-fade Intervals at 20 GHz; measurement period: March 1994 to February 1995

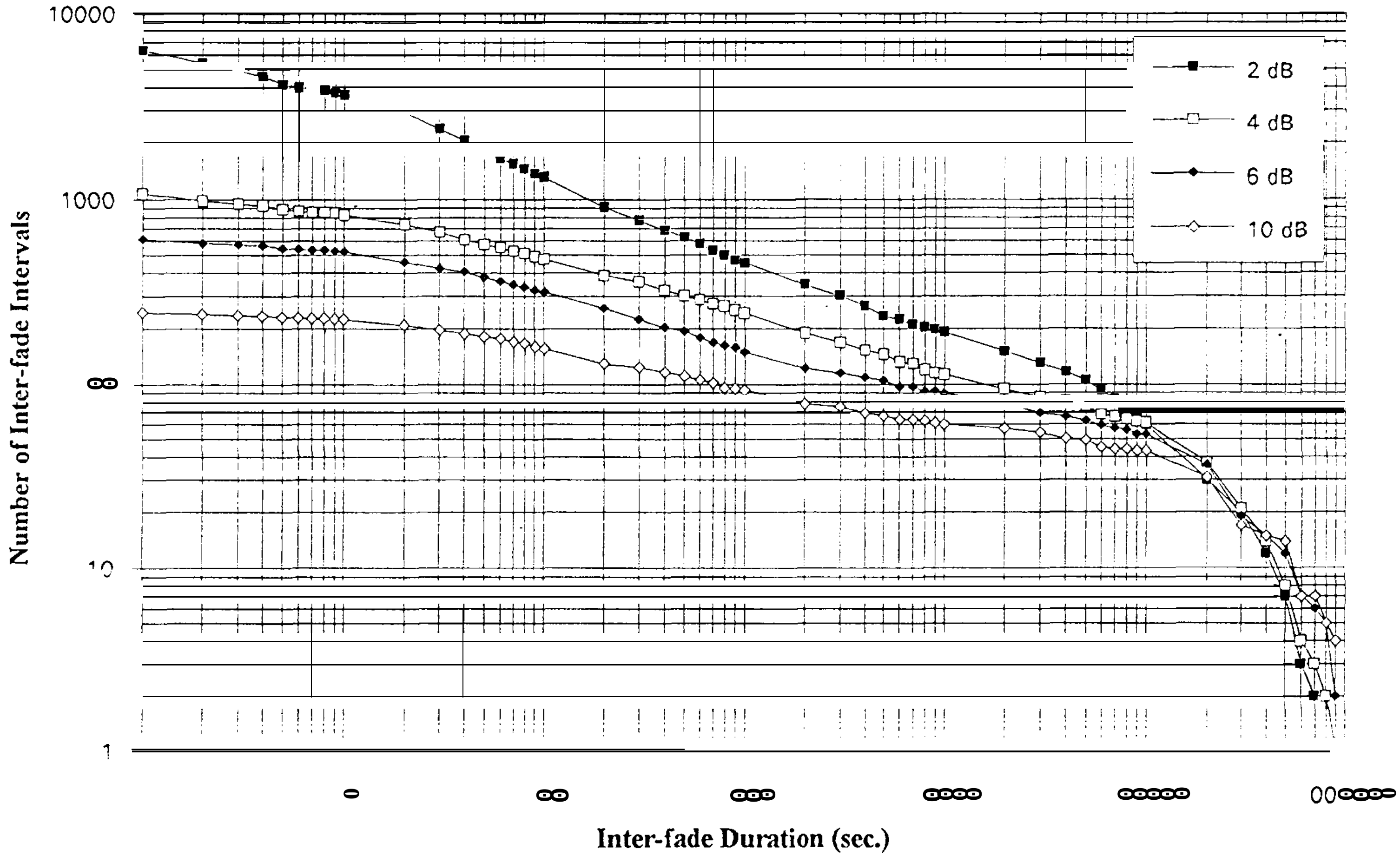


Figure 21 Distribution of Inter-fade Intervals at 20 GHz; measurement period: March 1994 to February 1995