ITALSAT Propagation Experiment at 18.7, 39.6, and 49.5 GHz at Spino D'Adda: Three Years of CPA Statistics

Roberto Polonio and Carlo Riva

Abstract— **The ITALSAT propagation experiment, started in early 1991 and still on-going, allows an extensive program of measurements at 18.7, 39.6, and 49.5 GHz. This paper reports the results obtained so far from copolar signal measurements carried out at the Earth station of Spino d'Adda from 1993 to 1995. Statistics of rain and total attenuation and frequency scaling of total attenuation are presented and commented in the light of the ITU-R predictions.**

I. Introduction

THE new applications of satellite based communication systems such as radiomobile personal communications and direct TV broadcasting, will require increasing capacity and, hence, higher and higher transmission frequencies. In 2005 the frequency band around 22 GHz will be used for television broadcast while the new satellite based personal communication systems whose operativity is foreseen before the end of the century will use frequencies up to the EHF band.

Above 20 GHz, the atmospheric effects due to clouds, oxygen, and water vapor can reach values up to several decibels (normally less than 5 dB), while the attenuation due to rain can reach several tens of decibels with considerable variations according to the climate region. These factors, which sometimes act simultaneously, are not easily predictable in statistical terms as required for the design of communication or broadcasting systems: the need to improve our skills in prediction has recently fostered the realization of some important propagation experiments like OLYMPUS, ACTS, COMETS, and ITALSAT.

In particular, the ITALSAT propagation experiment, which is the subject of this paper, has been conceived with the aim at assessing the effect of atmosphere in a radio link at 18.7, 39.6, and 49.5 GHz. The results obtained at Spino d'Adda in a 37.7° elevation slant path during an observation time of three years are reported in this paper and their agreement with the ITU-R predictions commented.

Following this introduction, in Section II, the Earth station in Spino d'Adda is described, in Section III, the results in terms of yearly average and worst month total attenuation cumulative distributions and frequency scaling statistics are presented and, in Section IV, some conclusions are drawn.

Manuscript received April 16, 1997; revised September 2, 1997.

The authors are with the Dipartimento di Elettronica e Informazione, Politecnico di Milano, Milano I-20133, Italy.

Publisher Item Identifier S 0018-926X(98)03369-9.

TABLE I
Characteristics of the ITALSAT Satellite and of the Earth-Station in Spino D'Adda

	ITALSAT satellite	Spino d'Adda station
Beacons' frequencies [GHz] & polarization	18.7 V 39.6 C 49.5 V/H	
EIRP [dBW]	24 to 30	-
Latitude	-	45.4° N
Longitude	13.2° E	9.5° E
Altitude above sea level. [m]	-	84
Elevation	-	37.7°
Antenna diameter [m]	-	3.5
G/T [dB/°K]at 18.7 / 39.6 / 49.5 GHz	-	25.0 30.4 28.6
Sampling rate [Hz]	-	1

II. The ITALSAT Propagation Experiments in Spino D'Adda Station

The ITALSAT satellite carries a propagation payload with three beacons at 18.7 (vertical polarization), 39.6 (circular polarization), and 49.5 GHz (switched between horizontal and vertical). Angle modulation of the 39.6-GHz beacon (sidebands at 500 MHz from the center frequency) allows measurements of amplitude and phase distortion over a band of 1 GHz. The coverage of the satellite is such that the reception is possible from almost the whole Europe with significant margin. The main characteristics of the satellite are shown in Table I.

In Italy, a ground station located in Spino d'Adda received all the three ITALSAT beacons with an antenna of 3.5 m diameter. These signals were coherently detected, sampled at the rate of 1 Hz (even though a sampling rate of 50 samples per second was available for scintillation studies), stored, edited and analyzed off-line by the Centro di Studio sulle Telecomunicazioni Spaziali (CSTS) at Politecnico di Milano. The Spino d'Adda station was also equipped by a set of noise injection radiometers at 13.0, 23.8, and 31.65 GHz, aiming at evaluating the clear-sky attenuation and the liquid water and vapor atmospheric content and by a set of traditional meteo instruments (thermometer, hygrometer, barometer, and rain gauge). The main characteristics of the above mentioned station are also given in Table I [1], [2].

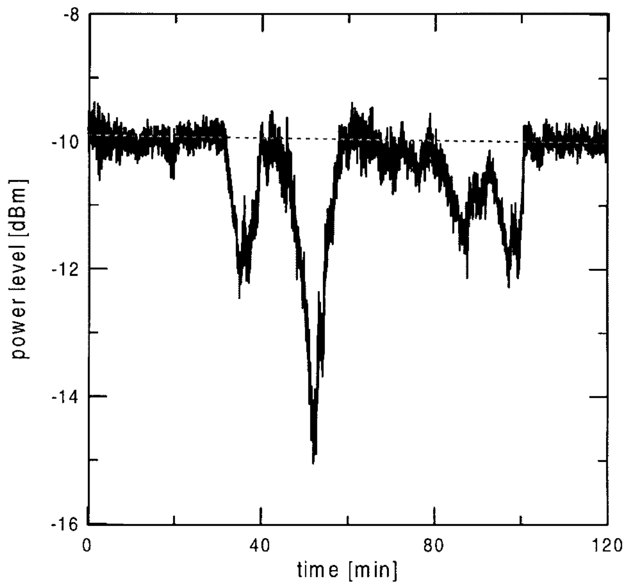

Fig. 1. Time series showing a typical rainy event at 50 GHz. The dotted line indicates the calculated zero clear-sky level [April 15, 1993, 21:00 universal time coordinated (UTC)].

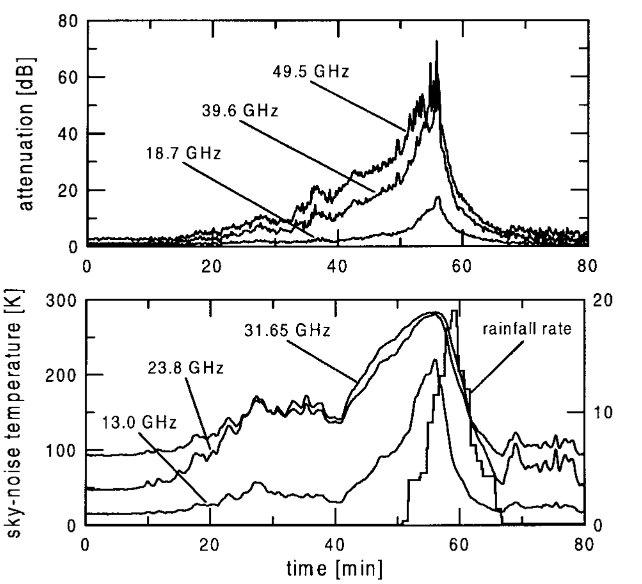

Fig. 2. ITALSAT data sample of total attenuation, radiometric, and rainfall rate measurements (August 24, 1994, 19:10 UTC).

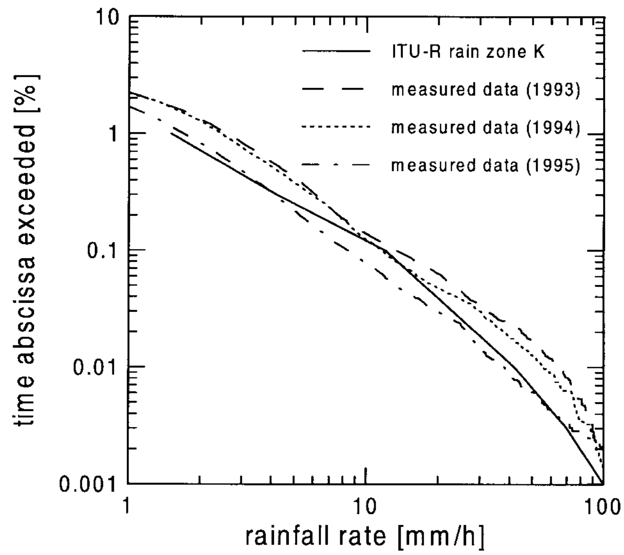

Fig. 3. Cumulative distribution of rainfall rate measured at Spino d'Adda in 1993 (dash line), 1994 (dot line), and 1995 (dot-dash line) and predicted by ITU-R for rain zone K (solid line).

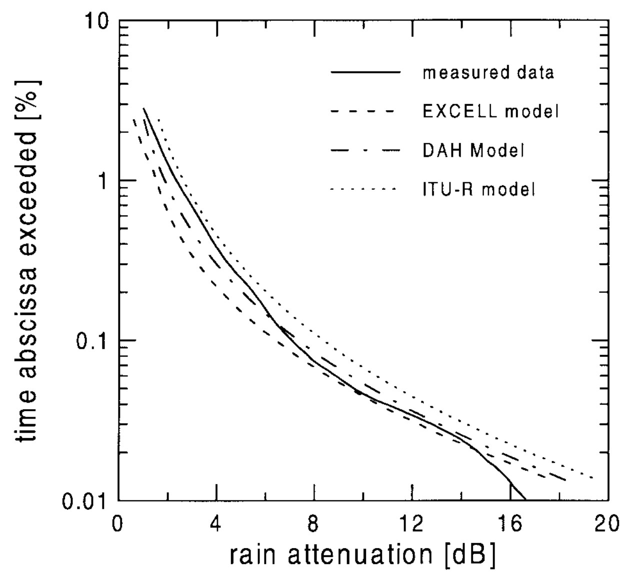

Fig. 4. Cumulative distribution of rain attenuation at 18.7 GHz measured with the ITALSAT station at Spino d'Adda in 1993 (solid line) and predicted by DAH (dotted-dashed line), EXCELL (dashed line), and ITU-R (dotted line) models for rainfall rate distribution measured at Spino d'Adda in 1993 (see Fig. 3).

III. Results

Due to the uncertainty that always exists about the signal level, which would be received in absence of atmosphere (true "free-space" level), the use of the radiometers is mandatory to fix the "0-dB level" template for the reference of the measurements, which, in this case, provide the total attenuation with respect to the absence of atmosphere.

Since the radiometers were not available in 1993, a simple procedure was applied to obtain the *rain attenuation* conventionally intended as that obtained by drawing a straight line connecting the signal level just before and after the event, as shown by the dotted line of Fig. 1.

Fig. 2 shows an example of time series of total attenuation at 18.7, 39.6, and 49.5 GHz, sky-noise temperature at 13.0, 23.8, and 31.65 GHz and local rainfall rate obtained during ITALSAT measurement campaign using these data. Cumulative distributions of rain and total attenuation and rainfall rate have been obtained, modeled, and compared with models predictions.

Cumulative Distributions

Fig. 3 shows the rainfall rate statistics for 1993, 1994, and 1995; the solid line represents the rainfall rate distribution of the ITU-R rain zone K. As seen, the spread of the data is rather limited and a nice agreement exists with the cumulative distribution relative to the ITU-R rain zone.

Figs. 4–6 show the cumulative distribution of measured rain attenuation obtained, respectively, at 18.7, 39.6, and

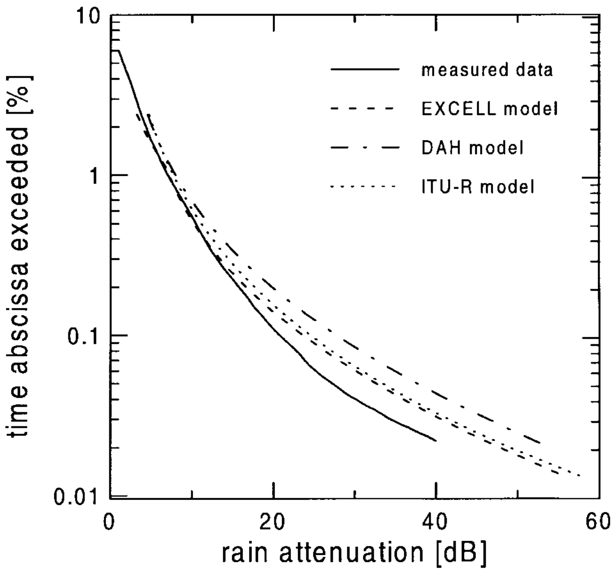

Fig. 5. Cumulative distribution of rain attenuation at 39.6 GHz measured with the ITALSAT station at Spino d'Adda in 1993 (solid line) and predicted by DAH (dotted-dashed line), EXCELL (dashed line) and ITU-R (dotted line) models for rainfall rate distribution measured at Spino d'Adda in 1993 (see Fig. 3).

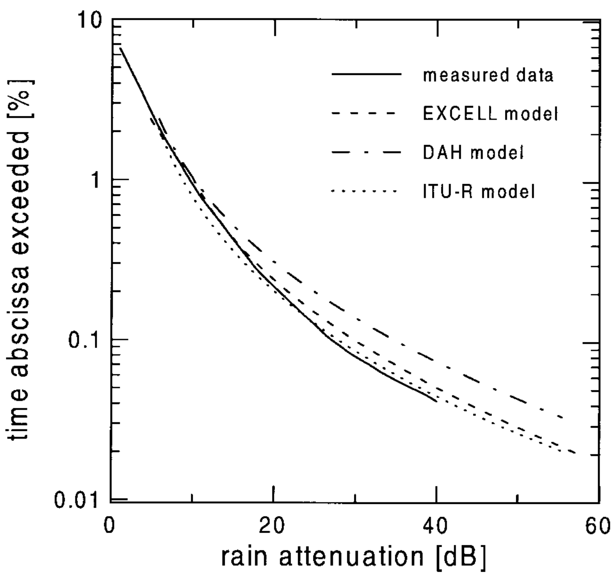

Fig. 6. Cumulative distribution of rain attenuation at 49.5 GHz measured with the ITALSAT station at Spino d'Adda in 1993 (solid line) and predicted by DAH (dotted-dashed line), EXCELL (dashed line), and ITU-R (dotted line) models for rainfall rate distribution measured at Spino d'Adda in 1993 (see Fig. 3).

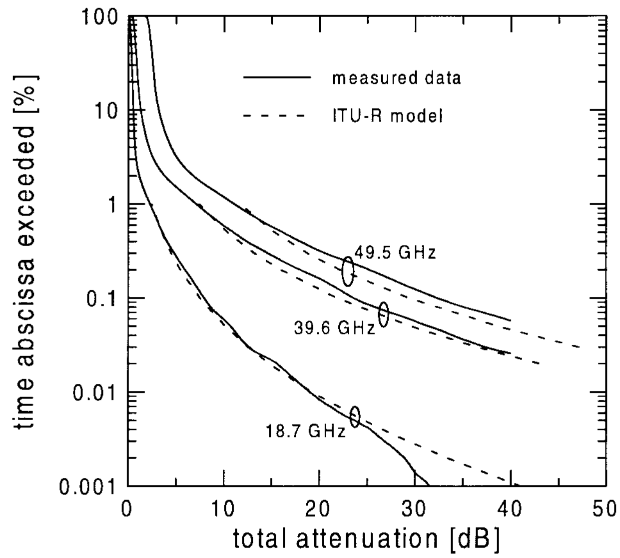

Fig. 7. Cumulative distribution of total attenuation at 18.7, 39.6, and 49.5 GHz measured with the ITALSAT station at Spino d'Adda in 1994 (solid line) and predicted by ITU-R (dashed line) for rainfall rate distribution measured at Spino d'Adda in 1994 (see Fig. 3).

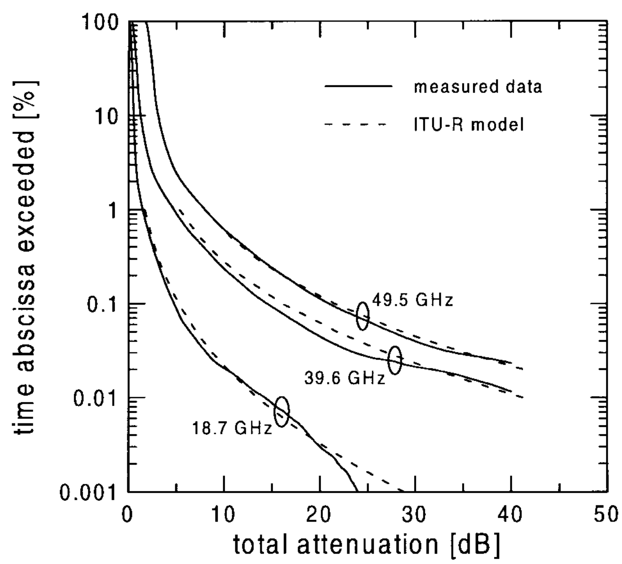

Fig. 8. Cumulative distribution of total attenuation at 18.7, 39.6, and 49.5 GHz measured with the ITALSAT station at Spino d'Adda in 1995 (solid line) and predicted by ITU-R (dashed line) for rainfall rate distribution measured at Spino d'Adda in 1995 (see Fig. 3).

49.5 (vertical polarization) GHz (solid lines). The predictions obtained from the rainfall rate distribution measured at Spino d'Adda in 1993 using DAH (only rain effect) [3] (dotted-dashed line), EXCELL [4] (dashed line), and ITU-R [5] (dotted line) models (the most accurate models according to ITU-R tests [6]) are also shown. The agreement appears reasonable, even if DAH model tends to overestimate a little at 40 and 50 GHz.

The total attenuation obtained from the data recorded in the single years 1994 and 1995 are shown in Figs. 7 and 8, respectively, for the beacons at 18.7, 39.6, and 49.5 (vertical polarization) GHz (solid lines). To compare the measured curves with ITU-R prediction, the oxygen attenuation values of 0.077 dB at 18.7 GHz, 0.368 dB at 39.6 GHz, and 1.818 dB at 49.5 GHz (average values for Europe according to [7]), have been added to the rain attenuation predicted with ITU-R model [5] using the measured rainfall rate distributions. The predicted curves are also shown in Figs. 7 and 8 (dashed lines) for 1994 and 1995. As seen, the agreement between measured and predicted values is excellent.

As already obtained in literature for lower frequencies [8], the measured cumulative distributions shown in Figs. 7 and 8 can be well approximated between 0.01 and 1% of the time

TABLE II
LOG-SLOPE VALUES γ OF THE POWER-LAW MODEL USED TO FIT THE CUMULATIVE DISTRIBUTIONS OF TOTAL ATTENUATION MEASURED IN 1994 AND 1995

Frequency [GHz]	γ(1994)	γ(1995)
18.7	2.3	2.1
39.6	2.2	2.1
49.5	2.1	2.4

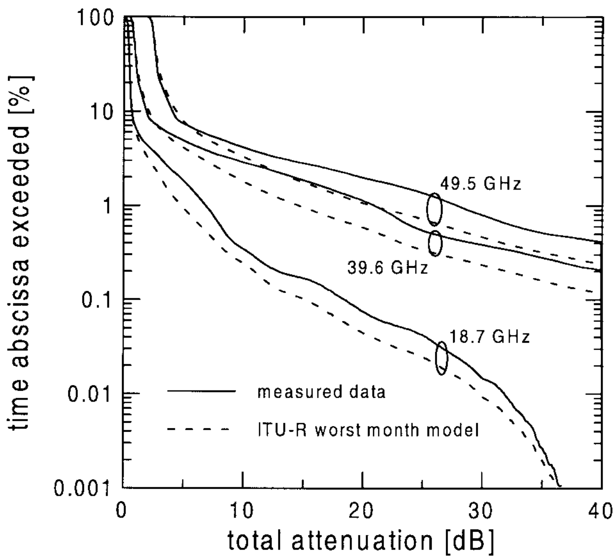

Fig. 9. Worst month statistics of total attenuation at 18.7, 39.6, and 49.5 GHz measured with the ITALSAT station at Spino d'Adda in 1994 (solid line) and predicted by ITU-R (dashed line).

by a power-law model of the type

$$P(A) = CA^{-\gamma} \tag{1}$$

where A [dB] is the total attenuation and P is the percentage time A is exceeded. Table II gives the γ values obtained by a least-square fitting of the measured data.

Worst Month Statistics

The concept of worst-month statistics has been introduced to describe the cyclostationarity of many propagation processes and to take into account rare and severe anomalous propagation conditions: such statistics are of particular interest for telecommunication systems which have to meet the "any month" performance criteria [9].

In Figs. 9 and 10 the worst month total attenuation statistics are shown for 1994 and 1995 (solid lines) together with the curves predicted by ITU-R model [10] (dashed lines) where the "worst month conversion factor" has been applied to the yearly cumulative distribution. As seen these predictions seem to underestimate the measured data.

Frequency Scaling of Total Attenuation

In the future, satellite communication systems the short-term frequency scaling technique will be helpful in accomplishing the "up-link power control" systems. The same technique, which consists in evaluating the ratio between concurrent time series of attenuation at different frequencies, can be also helpful to calculate the joint outage probability between the down and up link.

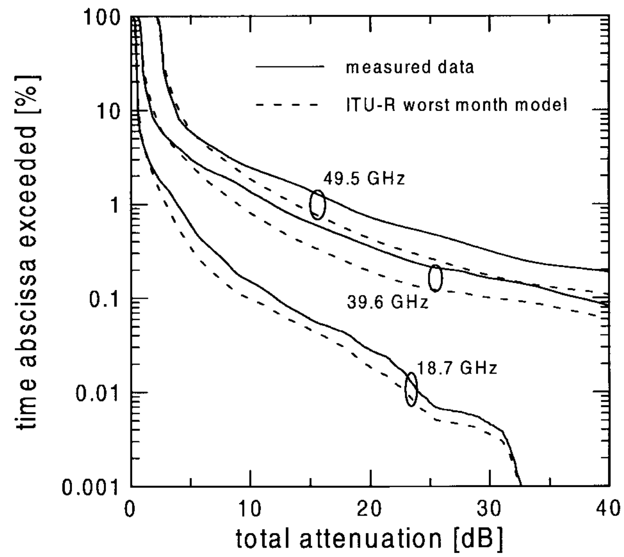

Fig. 10. Worst month statistics of total attenuation at 18.7, 39.6, and 49.5 GHz measured with the ITALSAT station at Spino d'Adda in 1995 (solid line) and predicted by ITU-R (dashed line).

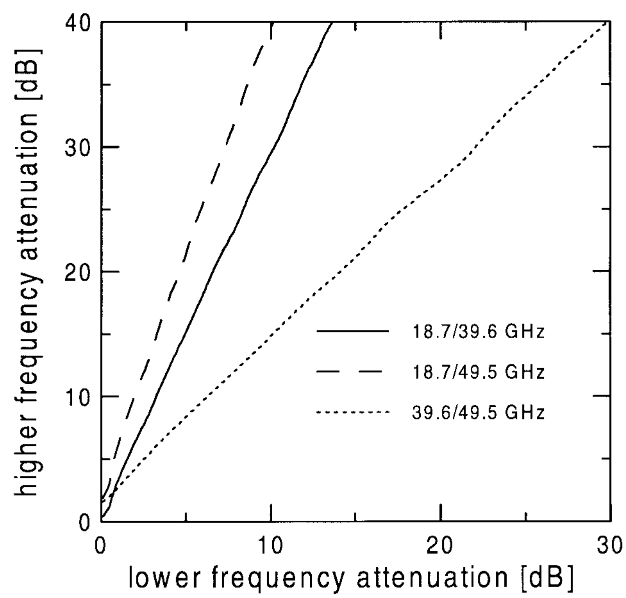

Fig. 11. Long-term frequency scaling statistics of total attenuation measured with the ITALSAT station at Spino d'Adda in 1994.

On the other hand, the long-term frequency scaling statistics, obtained by evaluating the ratio between attenuation at different frequencies and at the same probability, can be used to scale the results of old long-lasting campaigns of measurements to new frequencies.

Figs. 11 and 12 show, respectively, for 1994 and 1995, the total attenuation at the higher frequency as a function of the equiprobable total attenuation at the lower frequency for the three beacon couples 18.7/39.6 (solid line), 18.7/49.5 (dashed line), and 39.6/49.5 (dotted line).

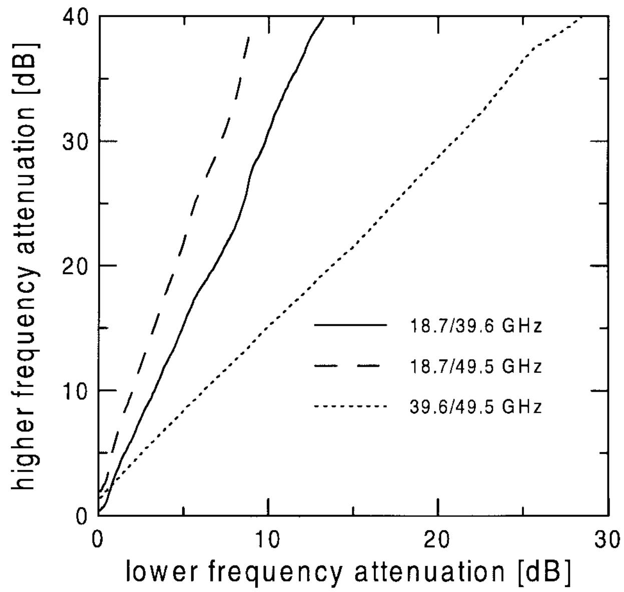

Fig. 12. Long-term frequency scaling statistics of total attenuation measured with the ITALSAT station at Spino d'Adda in 1995.

TABLE III
LONG-TERM FREQUENCY SCALING RATIO MEASURED IN 1994 AND 1995 AND PREDICTED BY ITU-R MODEL

Long term frequency scaling ratios	18.7/39.6 GHz	18.7/49.5 GHz	39.6/49.5 GHz
Measured (1994)	2.92	3.79	1.28
Measured (1995)	3.05	4.01	1.38
ITU-R model	3.35	4.46	1.34

Table III shows the long-term frequency scaling ratios measured in 1994 and 1995 and predicted by ITU-R model [11]. Indeed, the frequency scaling ratios provided by ITU-R model seem slightly higher than the experimental values even thought their agreement is well within the 8–10%, as already observed at the lower frequencies [12].

IV. CONCLUSIONS

Copolar signal measurements obtained from the ITALSAT propagation experiment, carried out at Spino d'Adda (latitude 45.4°N) at 18.7, 39.6, and 49.5 GHz between 1993 and 1995, were presented. The ITU-R model prediction [5] for the rainfall rate distributions measured at Spino d'Adda shows a good agreement with measured data especially in 1995. If approximated by a power-law model in the probability range between 0.01–1%, $P \propto A^{-\gamma}$, the exponent γ assumes a value very close to two.

The rain attenuation predictions obtained with DAH [3], EXCELL [4], and ITU-R [5] models have been compared with rain attenuation measured at Spino d'Adda in 1993 at 18.7, 39.6, and 49.5 GHz; the agreement seems fairly good especially for EXCELL and ITU-R models.

The worst month statistics were derived and compared with ITU-R model prediction [10], which tends to underestimate the measured data.

Finally, the frequency-scaling statistics were investigated. The frequency-scaling ratio seems in very good agreement with ITU-R prediction [11].

REFERENCES

[1] A. Adamou, F. Barbaliscia, A. Florio, F. Martinino, L. Ordano, and A. Paraboni, "The propagation experiment of the OLYMPUS satellite program," *Rivista Tecnica Selenia*, vol. 11, pp. 157–183, 1989.
[2] A. Sbardellati and O. Alberti, "The 20, 40, 50 GHz propagation beacon," *Rivista Tecnica Selenia*, vol. III, no. 4, pp. 181–188, 1990.
[3] A. Dissanayake, J. Allnutt, and F. Haidara, "A prediction model that combines rain attenuation and other propagation impairments along earth-satellite paths," *IEEE Trans. Antennas Propagat.*, vol. 45, pp. 1546–1558, Oct. 1997.
[4] C. Capsoni, F. Fedi, and A. Paraboni, "A comprehensive meteorologically oriented methodology for the prediction of wave propagation parameters in telecommunication applications beyond 10 GHz," *Radio Sci.*, vol. 22, no. 3, pp. 387–393, 1987.
[5] International Telecommunication Union, Rec. 618-2, CCIR recommendations, Geneva, Switzerland, 1992.
[6] A. Paraboni, "Testing of rain attenuation prediction methods against the measured data contained in the ITU-R data bank," ITU-R Study Group 3 Document, SR2-95/6, Geneva, Switzerland, 1995.
[7] *OPEX Reference Book on Radiometry and Meteorological Measurements*, ESA WPP-083, Noordwijk, The Netherlands, Nov. 1994.
[8] F. Carassa, M. Mauri, and A. Paraboni, "Long term attenuation statistics at 11.6 GHz in the three Italian main stations," *Alta Frequenza*, vol. LVI, no. 1–2, pp. 23–32, 1987.
[9] International Telecommunication Union, Rec. 581-2, recommendations CCIR, XVIIth Plenary Assembly, Düsseldorf, Germany, 1990.
[10] International Telecommunication Union, Rep. 723-3, Rep. CCIR, XVIIth Plenary Assembly, Dusseldorf, Germany, 1990.
[11] International Telecommunication Union, Rep. 721-3, Rep. CCIR, XVIIth Plenary Assembly, Düsseldorf, Germany, 1990.
[12] *OPEX Reference Book on Attenuation Measurement and Prediction*, ESA WPP-083, Noordwijk, The Netherlands, Nov. 1994.

Roberto Polonio was born in Novara, Italy, in 1963. He received the Laurea degree in electronic engineering from the Politecnico di Milano, Italy, in 1991.

From 1993 to 1997, he was with the Politecnico di Milano and CSELT as a Postgraduate Researcher on the Olympus and ITALSAT propagation experiments, microwave radiometry, and radar meteorology. Currently, he is still with Politecnico di Milano involved in a research task in wave propagation in the indoor environment.

Carlo Riva was born in Monza, Milano, Italy, in 1965. He received the Laurea degree in electronic engineering from the Politecnico di Milano, Italy, in 1990.

From 1991 to 1994, he attended the Doctorate course in electronic and communication engineering at the Politecnico di Milano in the propagation field with a special focus on scintillation. For three months in 1992 he was at the European Space Research and Technology Centre, Noordwijk, The Netherlands, working on scintillation. In 1993 he was with the Université Catholique de Louvain, Louvain-la-Neuve, Belgium, for two months, doing research on the separation of turbulence and rain effects on satellite communication links. He is currently with the Politecnico di Milano as Postdoctorate Researcher with a research task in millimeter-wave propagation.