Results of the OTS down-link performance measurements

Results of the OTS Down-Link Performance Measurements

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1 Introduction

Geostationary satellites for fixed services are operating in general in the 6 GHz band for up-link and in the 4 GHz band for down-link. At present several satellite systems above 10 GHz are planned as follows:

- In the Intelsat system, the Intelsat IV-A satellite is being replaced by the Intelsat V, which will uses the 4/6 GHz as well as the 11/14 GHz band.
- The European Communications Satellite (ECS) will use 11/14 GHz band from 1983 onwards.
- The direct TV broadcasting satellite will operate at 12 GHz band (down-link) and 18 GHz (up-link).
- The special business services such as Telecom are foreseen at 12 and 14 GHz.

To better use the available frequency spectrum the dual polarization technique is being applied. It allows simultaneous transmission of two signals at the same frequency but at different polarizations.

As compared to the 4/6 GHz bands, the transmission links to satellites at frequencies above 10 GHz are strongly affected or even interrupted by precipitations such as heavy rains or thunderstorms. This disturbance is due to the following reasons:

- The signal is attenuated in two ways. Electromagnetic wave energie is absorbed by the water droplets as well as scattered out.
- The water in the atmosphere and on the earth station antenna causes an increase of noise temperature and thereby, reduces the figure of merit G/T of the earth station.
- The inhomogeneity due to precipitations causes a depolarization effect on the dual orthogonal polarized signals which deteriorate the polarization isolation. This effect introduces a co-channel interference between frequency reuse cross polarized channels.

In order to investigate the influence of tropospheric effects on the satellite-to-earth link above 10 GHz a radiometer was installed on 1 January 1978. It was located on the roof of the PTT's R & D building in Berne and registered the sky noise temperature at 11.4 GHz. In May 1978 the European Orbital-Test-Satellite (OTS-2) was successfully launched. This satellite allowed to measure propagation effects at 11 GHz and 14 GHz bands. As part of an experimental PTT project the linear polarized OTS beacon signal at 11.575 GHz has been received since May 1978.

2 Description of the Experiment

The measurement of the OTS beacon signal as well as the sky noise temperature was carried out with linear horizontal polarization. The elevation and the azimuth of the rooftop reception antennas amounted to 36° and 177°, respectively. Thus, the antennas were directed nearly towards south. For the OTS antenna the tilt angle (deviation from horizontal polarization) was 2.5°.

The reception antenna was not equipped with a de-icing system. As a consequence the accumulation of wet snow caused significant events lasting hours or even days in extrem cases. Two different reception measurement statistics were worked out. One contains the results registered during rain and show which represents the receiving conditions for an antenna without de-icing. The second statistics eliminates all events due to snow deposition on the antenna. This represents a commercial earth station with a well functioning de-icing system.

The OTS experiment within the scope of Europe, the measurement objectives of the PTT, the OTS reception equipment as well as the radiometer were described in an earlier article [1]. Therefore, *Table I* provides a summary of the important data only.

Table I. Important characteristics of the PTT receiving equipment

Characteristics	OTS terminal	Radiometer
Antenna diameter	3 m	1.75 m
Polarization	linear	linear
Frequency	11.575 GHz	11.4 GHz
Polarization discrimination	>40 dB	–
Received level	– 110 dBm	–
Sensitivity	–	~ 0.5 K
Receiver noise temperature	1400 K	630 K

3 Attenuation Measurements with OTS at 11.6 GHz

31 Measurement Accuracy

With a continuous registration of the received power level of the OTS beacon signal the additional attenuation due to precipitations was determined. The free space attenuation during clear weather was taken as reference. The measurement accuracy is dependent on the stability of the beacon transmit level and of the earth station equipment as well as on the depointing of the reception antenna due to positional change of the satellite. The reception equipment is provided with a reference oscillator whose signal can be periodically fed instead of the satellite signal for short periods. Thus, the

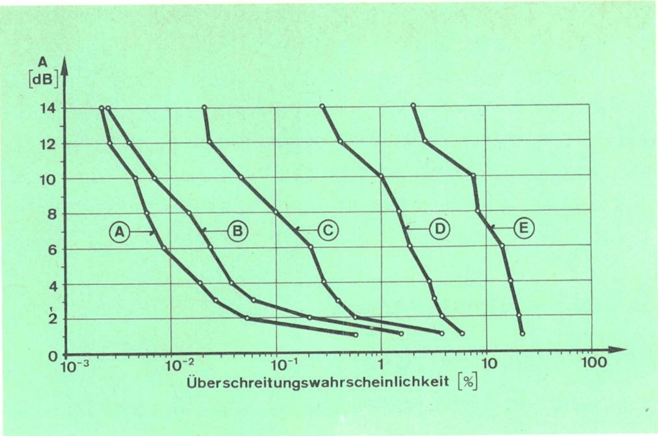

Fig. 1
Cumulative distribution of attenuation at 11.6 GHz satellite to earth link

Ⓐ 1978 without snow
Ⓑ 1979 without snow
Ⓒ Worst month 1978/79 without snow coverage
Ⓓ 1978 with snow
Ⓔ Worst month 1978/79 with snow coverage
Überschreitungswahrscheinlichkeit — Probability of exceeding

measurement errors of the reception equipment can be largely eliminated during evaluation of the recorded data.

The statistical data on the additional attenuation due to precipitations are subjected to a measurement error of ≤ ±0.5 dB.

32 Cumulative Distribution of Attenuation

Figure 1 shows the cumulative distribution for the years 1978 and 1979 as well as for the worst months of 1978 and 1979 with and without snow. The curves for the worst month are the envelopes of all the monthly curves [2] of the reception measurements with OTS for the years 1978 and 1979. The worst month with snow essentially corresponds to the month of December 1979 and that without snow to the month of June 1979.

In satellite systems such as Intelsat or ECS an attenuation of 8 dB will deteriorate the quality of the link to the point as making it unusable. The probability that this attenuation level is exceeded is about hundred times higher for antennas without de-icing system as compared to antennas with de-icing. With unheated antenna, satellite link interruptions for 8 pc of the worst month should be expected which corresponds to 59 hours. On the other hand, for an antenna with de-icing, interruptions will occur for only 40 min (0.095 pc).

The attenuation events with extremely long durations in winter are not really due to the snow in the atmosphere. It is rather the gain of the antenna which is reduced by the deposition of snow or ice on the antenna surface.

33 Statistics of the Events

The number of exceedings of a given attenuation (including snow conditions) for the worst as well as for the average month are shown in *Figure 2*. The values for the worst month correspond mostly to those of the month of June 1979. An attenuation of 8 dB, for example, will be exceeded 16 times in the worst month, whereas only 3 times in an average month.

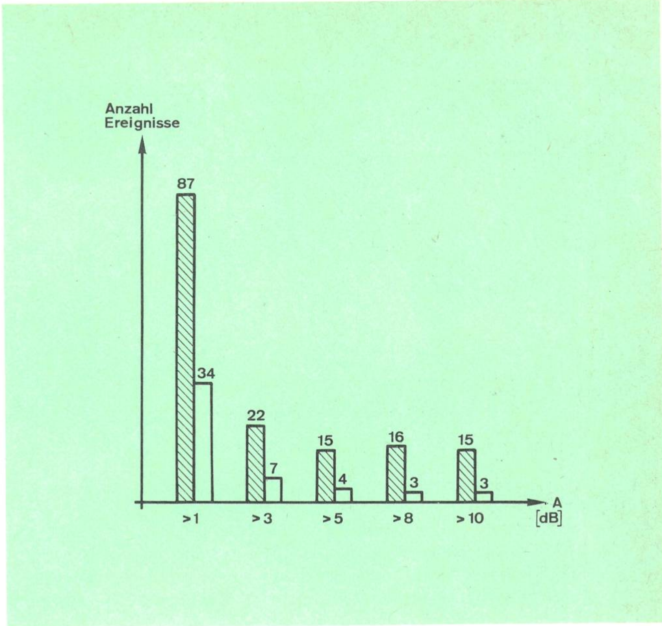

Fig. 2
Number of times exceeding the attenuation per month (including snow condition)

▨ Worst month: Envelope of the monthly events from June 1978 to December 1979
□ Average month: Average of the monthly events from June 1978 to December 1979
Anzahl Ereignisse — Number of events

Figure 3 shows the average duration of the events from June 1978 to December 1979. The average duration due to rain is in the order of minutes. It is in the order of hours if one considers the snow coverage of the antenna. For an attenuation of 8 dB the average duration for an antenna with heating is 2.7 min and for an antenna without heating 124 min.

4 Sky Noise Temperature Measurement

41 In General

An essential factor of the earth station is its figure of merit G/T. G is the reception gain of the antenna and T is the system noise temperature which is the result of re-

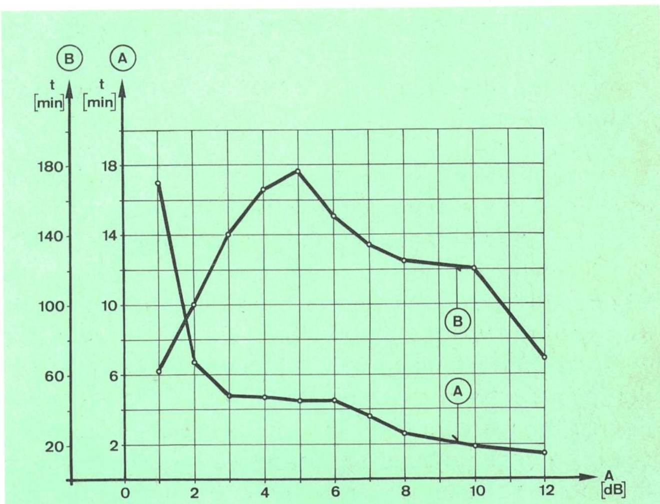

Fig. 3
Average duration of attenuation, average value of the events from June 1978 to December 1979

Ⓐ Without snow
Ⓑ With snow

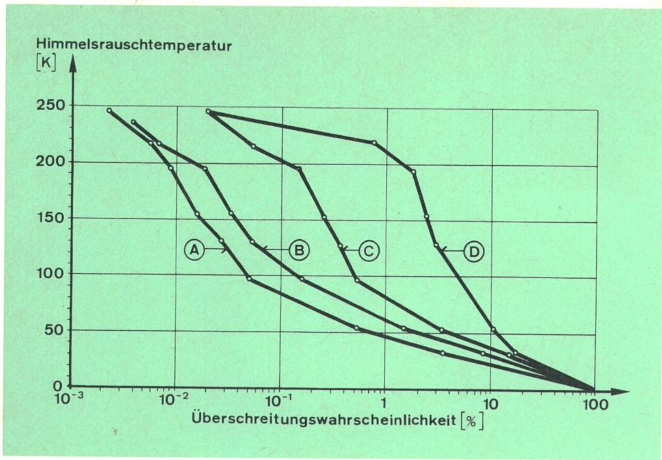

Fig. 4
Cumulative distribution of the sky noise temperature
Ⓐ 1978 without snow coverage of the antenna
Ⓑ 1979 without snow coverage of the antenna
Ⓒ 1978/79 worst month, without snow coverage of the antenna
Ⓓ 1978/79 worst month, including snow coverage of the antenna
Himmelrauschtemperatur — Sky noise temperature
Überschreitungswahrscheinlichkeit — Probability of exceeding

ceiver, antenna and sky noise temperature. The G/T factor of the earth station is dependent on the weather conditions as the sky noise temperature increases during bad weather. The specifications in the international satellite systems ask for a G/T value during a specified time of the month or year, which shall not be decreased below this prescribed minimum. Therefore, the information on the variation of sky noise temperature is required for the planning of the earth station. This can be measured with an accuracy of ± 7 K (average absolute error) with the radiometer employed in this programme. This measurement accuracy is valid for clear sky conditions. The error will be smaller with increasing sky noise temperature.

42 Cumulative Distribution of the Sky Noise Temperature

Figure 4 shows the following cumulative distribution:

- yearly curve for 1978 without snow coverage
- yearly curve for 1979 without snow coverage
- worst months of the years 1978 and 1979 without snow coverage
- worst months of the years 1978 and 1979 including snow coverage

The worst month without snow coverage corresponds essentially to the month of June 1979 and that with snow coverage to the month of January 1979. The probability of exceeding the sky noise temperature for the worst month with snow is about ten times higher at maximum to that of the worst month without snow. A comparison with the corresponding monthly curve for the attenuation (Fig. 1) shows that there the ratio of the probabilities for the worst months with and without snow coverage is up to about hundred. Therefore snow coverage of the antenna affects ten times more the attenuation statistic than it does the corresponding statistic of the sky noise temperature. This is due to the reduction of reception antenna gain because of the snow coverage, as already mentioned in connection with the attenuation statistics. Thus the electromagnetic waves are attenuated with a corresponding increase of the noise temperature on the one hand and on the other hand the antenna radiation diagram is altered due to snow coverage. Thereby, the antenna beam is not optimally directed towards the satellite, which will cause attenuation of the received satellite signal. This part of the reduction in gain does not create an increase of noise temperature and therfore it can not be measured with a radiometer.

5 Depolarization Measurement

51 Measurement Conditions

In addition to the wanted horizontal polarized co-polar signal the vertical cross-polarized component can also be measured. Due to the following reasons cross-talk of polarization occurs:

- the polarization characteristics of the satellite transmit and of the earth station reception antenna are not ideal
- the inhomogeneity in the atmosphere (e.g. rain drops)

The power level difference between the co-polar and the depolarized signal is known as cross-polar discrimination. During the measurements with OTS in Berne the XPD with clear weather conditions was better than 40 dB. It varied between 40 and 48 dB in a period of 24 hours. This variation is mainly due to diurnal change of the satellite position as a non-tracking receive rooftop antenna is used.

52 Cumulative Distribution of the Cross-polar Discrimination XPD

Figure 5 shows the cumulative distribution of XPD for 1978 and 1979. With a well heated antenna the XPD falls in both years bellow 28 dB during 0.009 pc of the year (47 min). This XPD of 28 dB hardly does deteriorate the bit error ratio of a digital transmission system such as 4 PSK [3]. When the deposition of snow on the antenna is considered, the XPD becomes worse than 28 dB during 1740 min (0.33 pc of the year).

A comparison of the cumulative distribution of the XPD with those of the attenuation (Fig. 1) shows that with linear polarization the influence of XPD on the quality of the digital link can be neglected. The attenuation

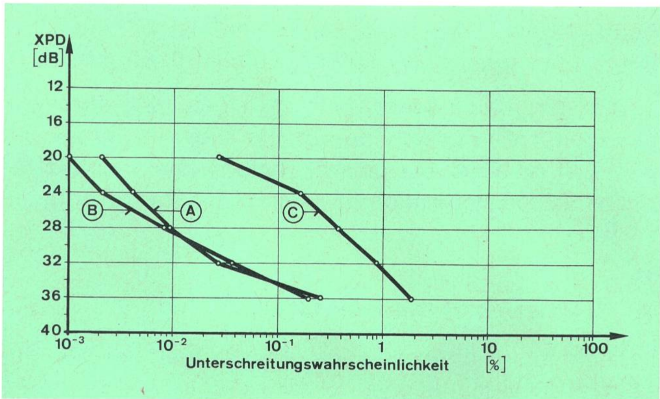

Fig. 5
Cumulative distribution of the polarization discrimination XPD
Ⓐ 1978 without snow coverage of the antenna
Ⓑ 1979 without snow coverage of the antenna
Ⓒ 1979 including snow coverage of the antenna
Unterschreitungswahrscheinlichkeit — Probability of falling below

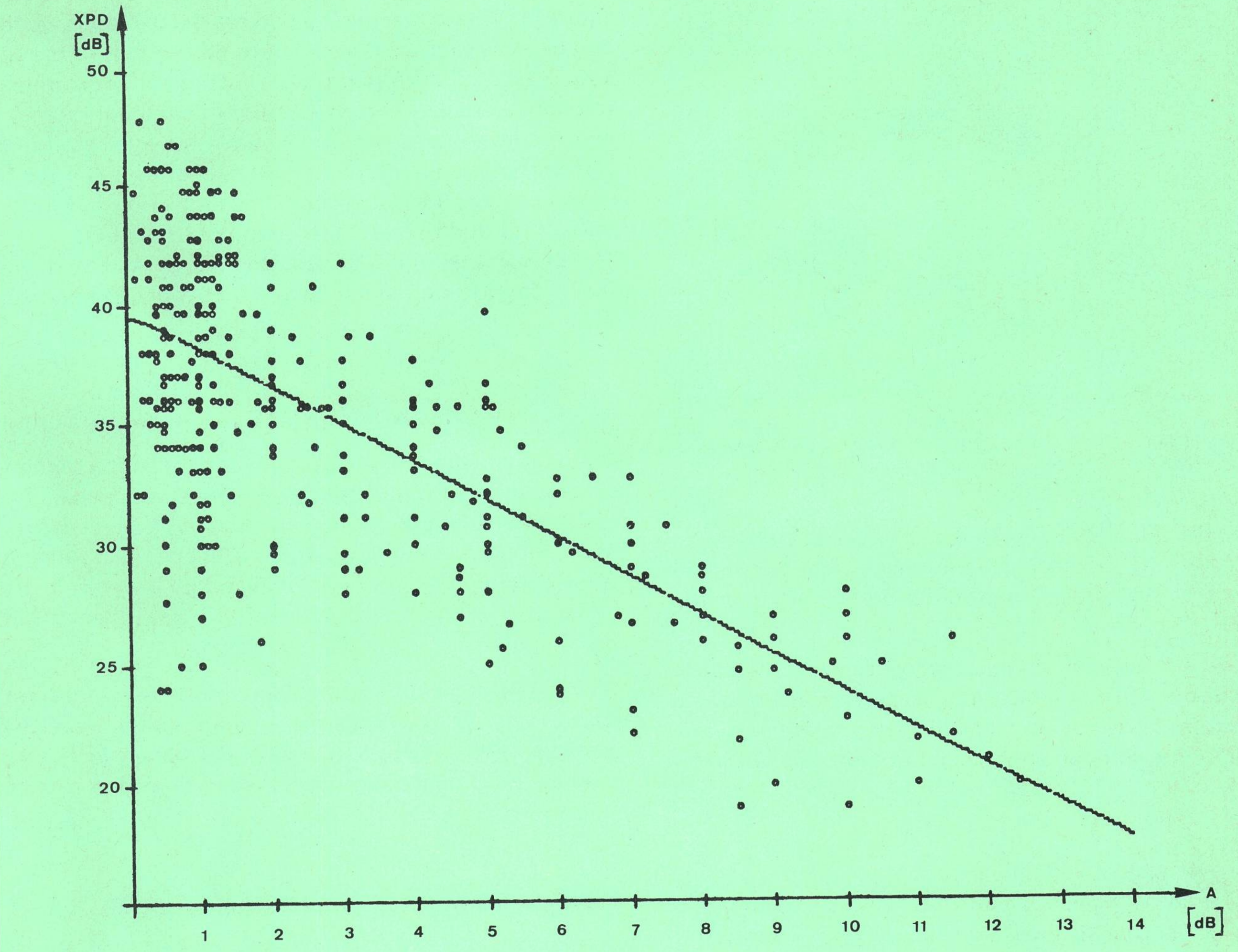

Fig. 6
Scattering diagram A/XPD at f = 11.6 GHz, 5 thunderstorms, 369 points

XPD = 39.7 − 1.59 A		Elevation	36°
Correlation coefficient	0.68	Polarization	Linear
Standard error of estimation	4.6 dB	Tilt angle	2.5°

surpassed 0.01 pc of the year 1979 a value of 9 dB which corresponds to an interruption in most systems. The polarization isolation is 29 dB for the same amount of occurences. This does not really disturb the digital link. The situation is less favourable in circular polarization because there the XPD is more deteriorated by precipitations [6].

6 Conversion of the Attenuation Statistics to other Frequencies

For the up-link, Intelsat V and ECS will use the 14 to 14.5 GHz frequency band and the TV broadcast satellite the 18 GHz band. For the planning of earth stations, propagation statistics are also required for these frequency bands. They can be extrapolated from the measurement results with the help of the following formula:

$$A_2 = A_1 \cdot \left(\frac{f_2}{f_1}\right)^n$$

A_i = Attenuation at f_i frequency

Measurements of the attenuation due to precipitation on terrestrial radio links showed that the attenuation increased approximately with the square of the frequency [4]. Measurements with OTS [5] at 11.6 GHz and 14.5 GHz indicate the value of the exponent between 1.65 and 2.3. An exponent n = 2 may then be taken for an approximative extrapolation of the attenuation statistic above 11 GHz. Therefore, if a heavy rainfall attenuates the signal 3 dB at 11.6 GHz, it can be assumed that the attenuation will be 4.7 dB at 14.5 GHz and more than 7 dB at 18 GHz.

7 Relationship between the Co-polar Attenuation and the XPD

The relationship between the co-polar attenuation and the polarization discrimination XPD is given in the literature such as in the CCIR Report 564-1 or in the reference [6]. The values provided in the CCIR Report 564-1 are applicable to linear polarization for tilt angle between 10° and 80°. The CCIR values cannot be taken for compar-

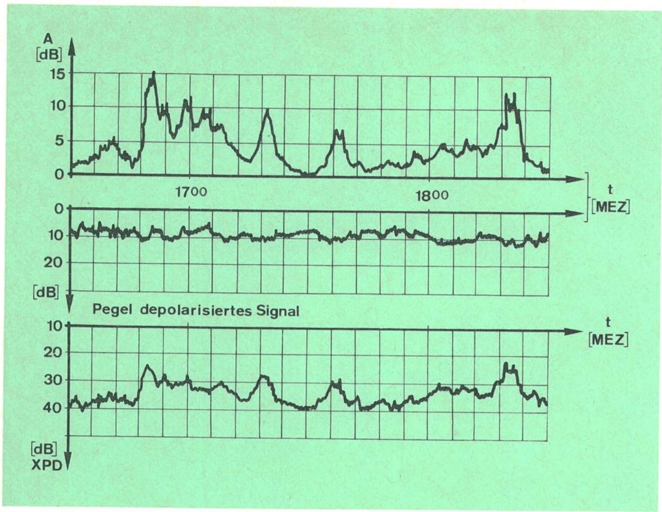

Fig. 7
Recording of the received level during thunderstorm of 11 June 1979
Pegel depolarisiertes Signal — Level of the depolarized signal

ison as the tilt angle in these measurements amounts to only about 2.5°. OTS-measurements in Great Britain and Sweden do not show a very good agreement with the CCIR Report 564-1.

Figure 6 shows the corresponding values of attenuation and the XPD in a scattering diagram. These values were encountered simultaneously in five thunderstorms. A regression line can be calculated with the following equation:

$$XPD = 39.7 - 1.59 \cdot A \text{ (dB)}$$

However, the correlation is poor among these values. The XPD lies between 22 and 33 dB with an attenuation of e.g. 7 dB. Due to the so-called ice crystal effect [7] the XPD may deteriorate without noteworthy co-polar attenuation. Thus, for an attenuation of only 0.5 dB, XPD values between 24 and 48 dB were registered.

The statistical relationship between the attenuation and the XPD should only be taken as a general guideline as wide differences can occur in specific cases.

8 Some Interesting Events

81 Thunderstorm of 11 June 1979

Figure 7 shows the measurements of the received power level during the thunderstorm of 11 June 1979. Several rain cells crossed the link between the satellite and the earth station and caused strong receiving disturbances. The highest signal attenuation amounted to about 16 dB and the worst value for the XPD was 24 dB. The deterioration of the XPD was mainly due to the attenuation of the co-polar signal. These thunderstorms would have meant five interruptions with a duration of 6 min, 3 min, 3 min, 2 min and 4 min in the Intelsat or ECS systems where an attenuation of 8 dB causes the link to be unuseable. The polarization discrimination was better than 24 dB during the entire period of the thunderstorm. The power level of the depolarized signal remained relatively stable during this time and it changed only around 7 dB.

82 Melting Snow on the OTS Receiving Antenna

As already mentioned, snow coverage on the antenna causes strong attenuation of the received signal. *Figure 8* shows the lightly snow covered OTS receiving antenna on the morning of 3 April 1979. The main reflector is covered with 3 cm of wet snow on its lower part. The upper part of the hard-foam covered sub-reflector carries also melting snow *(Fig. 9).*

When the picture was taken, the attenuation surpassed the 20 dB measuring range of the receiving terminal. The PLL receiver could no more synchronize the receiving signal and thus, the link from the satellite was interrupted.

83 Snow Condition on 22/23 January 1980

The following explanations relate to *Figure 10.* Around 12.30 wet snow started to fall. The snow remained on the OTS antenna and it caused great attenuation. Therefore, the receiver could no more synchronize shortly after 13.00 and the link from the satellite was interrupted. At about 15.20 the snow was somewhat melted and the attenuation amounted to about 12 dB «only»; then the receiver was again able to synchronize. Within the next twelve hours the snow melted further and the attenuation decreased correspondingly. At five o'clock in the morning the reception conditions were again back to normal. During this period the power level of the depolarized signal, which is not shown in Figure 10, remained

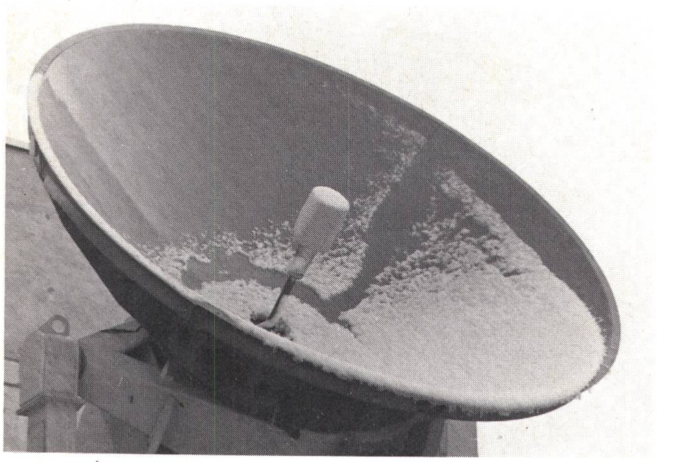

Fig. 8
Melting snow on the receiving antenna on 3 April 1979 at 07.40 hours

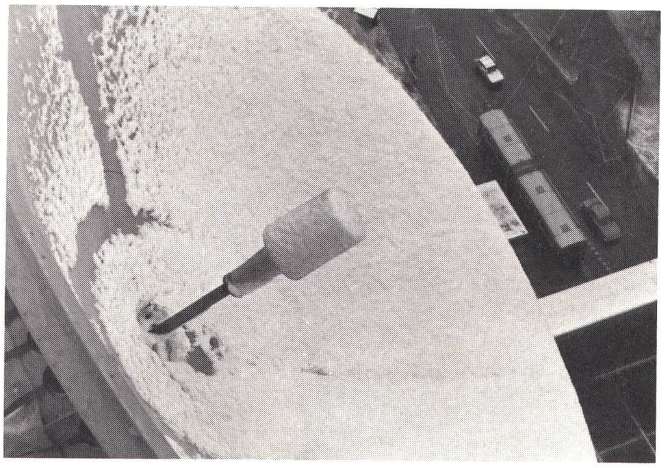

Fig. 9
Snow covered receiving antenna, view from above

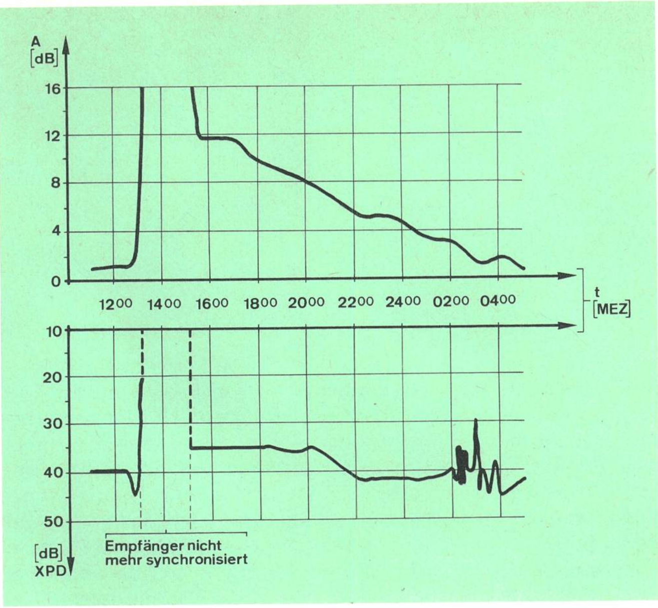

Fig. 10
Snow condition on 22/23 January 1980
Empfänger nicht mehr synchronisiert — Receiver lost synchronization

practically constant. The behaviour of the XPD was mainly due to the co-polar attenuation. Between 2 and 4 o'clock only the power level of the depolarized signal fluctuated by about 20 dB (ice crystal effect). During this time the XPD dropped to 28 dB for one minute.

9 Conclusions

The evaluation of the down-link performance measurements with OTS shows that intense precipitations badly deteriorate the quality of satellite links at frequencies above 10 GHz. During thunderstorms the link may even be interrupted for several minutes. Earth station antennas without heating may suffer interruptions for hours, in extreme cases for days, due to deposition of wet snow. It is not possible to give details on all results of this experiment within the scope of this paper.

Detailed propagation statistics are given in reference [8] for a heated earth station antenna. This report also illuminates the influence of attenuation due to precipitation with a view to planning of the earth stations for the Intelsat or ECS systems.

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