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DÜSSELDORF
21.5-1.6 1990
CCIR

XVIIth PLENARY ASSEMBLY
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INTERNATIONAL TELECOMMUNICATION UNION

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ANNEX TO VOLUME IV – PART 1

FIXED-SATELLITE SERVICE

CCIR INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

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FIXED-SATELLITE SERVICE

(Study Group 4)

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- SUSCEPTIBILITY TO INTERFERENCE

4B1: SYSTEMS ASPECTS

REPORT 552-4

USE OF FREQUENCY BANDS ABOVE 10 GHz IN THE FIXED-SATELLITE SERVICE

(Study Programme 27C/4)

(1974-1978-1982-1986-1990)

1. Introduction

This Report makes a preliminary examination of some of the technical factors which should be considered in the design of systems of the fixed-satellite service which are intended for use in frequency bands above about 10 GHz. Since the allocated bandwidth is generally wider at frequencies above about 10 GHz, the use of these frequencies would facilitate the design of high-capacity systems. The use of the 30/20 GHz bands, would facilitate the design of very high capacity systems employing spot beam antennas.

The factors considered in this Report are:

- analogue system performance,
- system configuration strategies,
- frequency sharing with terrestrial systems,
- design considerations for systems in the fixed-satellite service.

2. Analogue system performance

CCITT Recommendation G.222 (see sections 1.2.1, 1.2.2 and 1.2.3) states the required design objective for an analogue telephony HRC of 2,500 km as:

- 10,000 pWOp for 20% of any month
- 50,000 pWOp for 0.1% of any month
- 1 x 10^6 pWO for 0.01% of any month.

Reference to satellite systems is made by citation of Recommendation 353 of the CCIR which is:

"that the noise power, at a point of zero relative level in any telephone channel in the hypothetical reference circuit as defined in Recommendation 352 should not exceed the provisional values given below:

1.1 10 000 pW0p psophometrically-weighted one-minute mean power for more than 20% of any month;

1.2 50 000 pW0p psophometrically-weighted one-minute mean power for more than 0.3% of any month;

1.3 1 000 000 pW0 unweighted (with an integrating time of 5 ms), for more than 0.01% of any year; "

CCIR Recommendation 353 has been developed to be in compliance with the requirements of the CCITT, although there are some small differences. However, the concept of availability is not contained in the current version of the Recommendation and the following analysis shows the impact of its inclusion. The analysis is limited to 14/11 GHz systems since the performance of 6/4 GHz systems is not generally affected by propagation fades.

Performance of 14/11 GHz systems compliant with Recommendation G.222

The 10,000 pW0p requirement for 20% of any month is interpreted as applying to the worst month*, i.e., for the poorest propagation month. The same interpretation is applied to the 50,000 pW0p clause.

A standard link concept is used for the analysis to correspond to the current practice of other terrestrial systems of allowing 1 pW0p/km for design, or a link of 10,000 km. The operational locations for such links are typically at 40 degrees latitude and 25 degrees elevation angle. The climates for these latitudes exhibit rain rates, for 0.01% of the time, between 30 and 60 mm/hour. A value of 50 mm is chosen for the analysis. Calculations of the rain attenuation are then made in accordance with the methods of Study Group 5.

Propagation availability factor (as defined in Report 997) is taken as 10% of the duration of fade which results in reaching the system threshold. Two cases are shown in Figure 1, one at 50,000 pW0p and one at 100,000 pW0p. The margin in the first case is 7 dB and is 10 dB for the second.

The performance for the path expressed in terms of the available time will meet all of the G.222 performance objectives for the climate and latitudes assumed in this study. For low antenna elevation angles and higher rain rates, it may be more difficult to meet G.222. Further studies are required for such cases.

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* The definition of the worst month is provided in Recommendation 581.

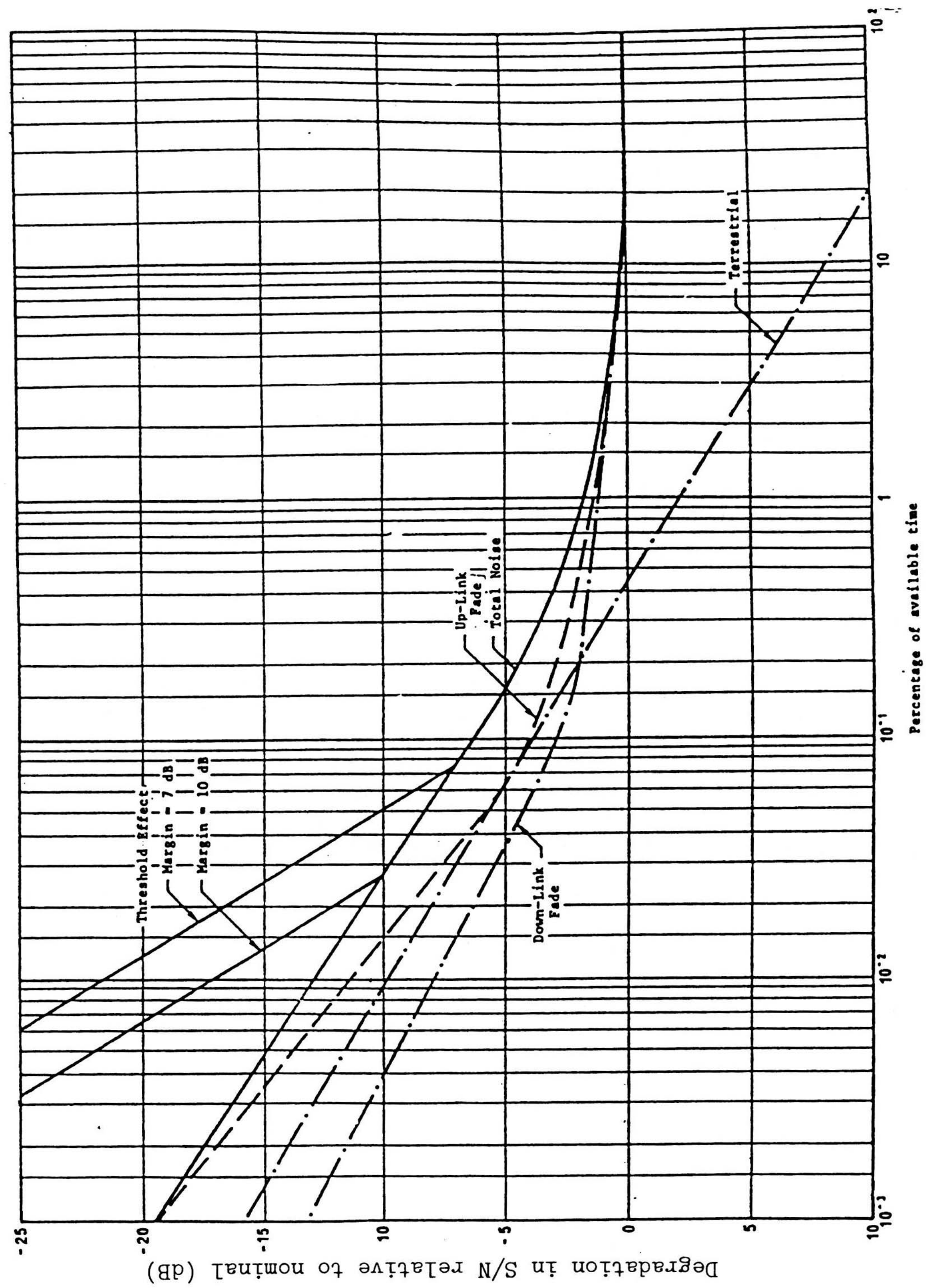

FIGURE 1

14/11 GHz noise performance as a function of available time

3. System configuration strategies

Scatter and absorption by cloud and precipitation increase rapidly at frequencies above about 10 GHz, and this adds considerably to the problems of designing such systems. Without the use of special techniques it may be quite impracticable to provide the large rain margins necessary to meet the required standards of performance.

Four possible ways in which the severe effects of precipitation at the higher frequencies can be overcome are:

(a) the use of site diversity;

(b) the use of a lower alternative frequency band to that normally used, and which is much less affected by precipitation;

(c) the use of adaptive systems which alter the transmission parameters during changing propagation conditions;

(d) the use of multiple narrow beam on-board antennas with possible extension to the single station per beam (SSPB) concept.

In the first approach referred to in (a) above advantage can be taken from the fact that for earth stations spaced a suitable distance apart (i.e. 10 to 30 km) the correlation of precipitation between them is almost negligible and the probability that both stations will be affected simultaneously by heavy rain is likely to be very small. The technique is to connect the two earth stations providing the diversity, by a transmission line free from the effects of precipitation, and select for operational use the earth station which is least affected. Diversity operation is discussed in detail in Annex I.

In the second approach referred to in (b) above, the assumption is that a number of earth stations within a system normally operate at frequencies which can be severely affected by precipitation, i.e. above about 10 GHz. However, since the probability of more than one station at a time being affected is likely to be small, the technique of switching into use a lower frequency band at the earth station badly affected by precipitation, can be employed [Mori *et al.*, 1978]. To make a better utilization of the normally unused lower alternative frequency band, it may be possible to normally carry the traffic in the lower frequency band and interchange the operating frequency bands between stations operating in the lower frequency and those operating in the higher frequencies under adverse weather conditions [Kosaka, 1978]. Based on this concept, an experimental system using 30/20 GHz and 6/4 GHz bands was constructed [Kosaka *et al.*, 1982].

In the third approach, referred to in (c) above, system performance of digital systems may be improved by reducing the information rate transmitted or increasing the transmitted power (up-link power control) during poor propagation conditions. Examples of this approach are given in Annexes II, III and IV.

Adaptive fade countermeasure (FCM) techniques give selective enhancement to carriers undergoing fading. Some FCM methods require that the user is prepared to accept a lower data rate during fading, as in Annex II, but other methods allocate part of a shared resource overhead (eg. power, frequency, time) to any fading carriers within the network, and thus maintain the user rate (see Annex III and IV). Adaptive methods use the shared resource efficiently by apportioning resource to carriers according to the depth of fading.

In the 30/20 GHz frequency range, even in temperate zones, fade depths for significant portions of time are too great for simple fixed fade margins to be a practical solution, so some FCM is essential if the bands are to be exploited. For applications requiring high availability in the wetter climatic zones, stations will suffer even more frequent and severe fading, and there is a practical limit to the fade depth which can be countered by an adaptive system, the deeper fades requiring unacceptable high levels of shared resource. Although further propagation studies are required, indications are that it is practical to operate a shared resource adaptive scheme for an availability corresponding to Recommendation 522 in climatic zone E, but for greater availability in the wetter regions, the diversity methods, which are not adaptive and may be expensive in the earth sector, seem the only suitable option for trunk satellite services.

In the fourth approach referred to in (d) above, the objective is to avoid complications of design and operation of earth stations, even at the expense of making the satellite more complicated due to the use of complex multiple beam on-board antennas with several narrow beams which however provide for both high satellite e.i.r.p. and high satellite G/T to compensate for the propagation effects.

Examples of various existing and planned system implementations in the 30/20 GHz frequency bands are given in Annex V.

4. Frequency sharing with terrestrial systems

At frequencies above about 10 GHz variations in the level of the wanted and unwanted signals due to precipitation, and the effects of scatter, have a greater influence on the minimum separation distance obtainable between earth stations of the fixed-satellite service, and terrestrial stations of the fixed service.

The effect of scatter can be overcome by careful site selection to avoid beam intersection of the two systems, and by using cross-polarization in the case of linearly polarized waves and, since the basic transmission loss over a given path increases with frequency, the separation distance between stations of the two systems can be less at the higher frequencies. By arranging that the separation angle between an earth station and terrestrial stations is more than about 20 to 30 degrees, the minimum separation distance can be reduced to a few kilometres and the effect of the fluctuation of the wanted and unwanted signals caused by differential rain attenuation of the two systems can be avoided to some extent.

5. Design aspects of systems in the fixed-satellite service at frequencies above 10 GHz

For systems in the fixed-satellite service which use frequency bands above 10 GHz, the effects of hydrometeors, especially rainfall, are particularly important and must be taken into account when the systems are designed. The most reliable calculation of the effects of hydrometeors may be made on the basis of experimental distributions of attenuation due to hydrometeors against time. This distribution varies with the frequency and the time of the year and depends on climatic conditions at the site of the earth station and the angle at which the satellite is visible.

It should also be borne in mind that the correlation between attenuations on the paths of the satellite link declines with the distance between earth stations and increased intensiveness of precipitations. A further de-correlating factor is the frequency difference between the up-link and the down-link.

The relevant data on propagation can be found in Reports 564 and 565. In addition to that, since 1969, continuous rain attenuation experiments on earth-satellite paths have been carried out at various locations in the United States of America. The measurement frequencies include 11.7, 13.6, 15.5, 17.8, 19 and 28.5 GHz. Interim results of the 10 year (1969-1978) experiments have been published in various technical journals and conference proceedings. [Lin, *et al.*, 1980] summarizes new results and the previously published results and discusses radio communication systems. The summary includes the geographic dependence, the frequency dependence, the diurnal, monthly, and yearly variations of rain attenuation statistics, the diversity improvement factors, the fade duration distributions, the dynamic rain attenuation behaviour, the long-term (20 years) rain rate distribution for United State of America locations and a simple empirical model for rain attenuation.

The data indicate that the 28.5 GHz earth-satellite radio link, assuming 20 dB fade margin, will require site-diversity protection for most United States of America locations to meet the conventional long-haul reliability objective. Operation in this or higher frequency bands would, therefore, probably require new network operation procedures.

On the other hand, the site-diversity protection may be avoidable for frequencies at or below 14 GHz where the antenna elevation angle is relatively high.

The earth-station satellite link at 19 GHz may or may not require site-diversity protection, depending on earth-station location and satellite orbital position. Other major findings are:

– Rain-induced outages on earth-satellite radio links have higher service impact than multipath-fading-induced outages on terrestrial (6/4 GHz) radio relays even if the two systems are engineered for equal total outage time. This is because multipath fading occurs mostly during the early morning hours of low telephone activity. Furthermore, multipath fading is frequency selective and interrupts only a fraction of the frequency band at a time. By contrast, about 35% of rain outages will occur during telephone busy hours, and the outage will interrupt all traffic on an earth-satellite radio link at the same time.

– Site-diversity protection can reduce the rain outage time by at least one order of magnitude if site separation exceeds 20 km. Orbital diversity protection, although effective against sun-transit outages, reduces rain outage time by less than 20%.