

RECOMMENDATION ITU-R S.1061-1*

**Utilization of fade countermeasure strategies and techniques
in the fixed-satellite service**

(1994-2007)

Scope

Satellite systems are one of the most effective ways to provide high-speed multimedia services. Use of higher frequency bands due to limited RF spectrum and the demand for high-speed services necessitates efficient countermeasure strategies for rain attenuation in the satellite link. This Recommendation presents an overview of these techniques, briefly describing guidance for planning the utilization of fade countermeasure techniques in the fixed-satellite service (FSS).

The ITU Radiocommunication Assembly,

considering

- a) that pressure on the limited RF spectrum from the increased demand for satellite services is leading to the use of higher frequency bands;
- b) that one of the major drawbacks associated with higher frequency satellite systems is the large signal attenuation caused by rain;
- c) that satellite channel performance as set forth in Recommendations ITU-R S.353, ITU-R S.522, ITU-R S.614, ITU-R S.1062, ITU-R S.1420, ITU-R S.1711, ITU-R S.579 and ITU-R S.1424 may be difficult to be achieved, in an economic way, by resorting only to power margin;
- d) that several systems have been developed to cope with rain attenuation whose performance and complexity are such that their applicability depends on the particular type of network involved,

recommends

- 1 that the material contained in Annex 1 should give guidance for planning the utilization of fade countermeasure techniques in the fixed-satellite service (FSS).

NOTE 1 – It should be noted that the subject techniques may even be used in combination provided that no basic incompatibility exists among them.

* Radiocommunication Study Group 4 made editorial amendments to this Recommendation in 2001 in accordance with Resolution ITU-R 44 (RA-2000).

Annex 1

Fade countermeasures in satellite communication systems

1 Site diversity operation

1.1 General design considerations

The performance required for diversity earth stations is decided not only by the rain climate but also by the diversity configuration. The first kind of configuration is balanced diversity (diversity by two earth stations with equal performance). The other configuration is unbalanced diversity. In this configuration, the performance of one earth station (main station) is made sufficiently high, so that the performance requirements of the other station (sub-station) may be considerably reduced. Such an unbalanced diversity configuration is expected when the main station antenna is equipped with a multiple-frequency band feeds such as 6/4 GHz and 14/11 GHz, and/or when the sub-station has to be simplified for technical and operational reasons.

Table 1 summarizes the results of sample calculations of the antenna diameter and the maximum transmit power required for balanced diversity links with low elevation angles. Estimates are given for two assumed diversity links: (A) Yamaguchi-Hofu (diversity distance = 20 km) and (B) Yamaguchi-Hamada (100 km); both in Japan.

It is seen from this Table that the antenna diameters required for the 14/11 GHz FM link (14 GHz for uplink and 11 GHz for downlink) are about 28 m and 19 m for cases (A) and (B), respectively. When the diameter of the main station can be made larger than those values, the required diameter for the sub-station becomes smaller. Values shown in this Table are derived using many of the link parameters established for Intelsat-V satellites, so they are subject to change when the link parameters are different from those used here.

TABLE 1

Sample calculations of the required performances for balanced diversity links with low elevation angles (14/11 GHz)

Location	(A) Yamaguchi-Hofu	(B) Yamaguchi-Hamada
Elevation angle (degrees)	9.1 9.1	9.1 8.4
Diversity distance (km)	20	100
FM		
Required antenna diameter (m)	28/32	19/22
Required transmit power ⁽¹⁾ (W)		
(maximum value)	730	510
TDMA ⁽²⁾		
Required antenna diameter (m)	17/19	11/12
Required transmit power (W)		
(maximum value)	530	400

⁽¹⁾ Values for 792 channel FDM-FM carrier (25 MHz).

⁽²⁾ Values for 4-phase CPSK at 120 Mbit/s with forward error-correction.

Assumptions :

Frequency: 14.5 (uplink)/11.7 (downlink) GHz

Orbital position of satellite: 63° E, 0° N

Satellite e.i.r.p.: 41.1 dBW

Antenna diameters are estimated for two cases, namely:

$T_s = 50$ K and $T_s = 150$ K

T_s : system noise temperature of the earth-station antenna

Efficiency of the earth-station antenna: 65%

Estimates are based on the rain-rate statistics obtained for those locations.

The calculation methods of the required performances (antenna diameter and e.i.r.p.) for the diversity earth stations are different depending on the diversity configurations. In the design of a balanced diversity link, calculations have to be based upon the joint probability distribution of the rain attenuation at both locations, while in the case of an unbalanced diversity configuration, the cumulative time distribution of the rain attenuation and the conditional probability of the attenuation are required.

The conditional probability $P(L''/L')$ is the probability with which the rain attenuation at the site of the sub-station exceeds L'' under the condition that the rain attenuation at the main site exceeds L' .

In order to perform reliable estimates of the earth station requirements, reliable statistics on the basis of the long-term propagation measurements are needed.

1.2 Site diversity switch-over operation

To implement diversity earth stations, care should be exercised on the switch-over operation, because, in the event of switch-over, short duration signal loss or overlap may occur due to the difference in path length of diversity routes or carrier phase discontinuity.

In analogue transmissions such as FM-FDMA, switch-over in transmitting will necessarily cause discontinuity of carrier phase which will result in a signal transient at the demodulator output in the receiving earth stations. Signal transients due to switch-over at the receive earth station may be

avoided by carefully adjusting the electrical path length of each diversity link measured from the switch-over equipment to the satellite.

In digital transmissions it is possible to avoid signal transients even in the event of switch-over at the transmit earth station by providing dummy intervals in the transmitting signal sequence and making the switch-over during the dummy interval. In the receiving earth stations the dummy intervals should be discarded whether or not switch-over took place.

Transient switch-over both in the transmitting and receiving of the diversity system may most conveniently be achieved in TDMA transmission. The dummy intervals are built-in because TDMA transmission occupies only a part of the TDMA frame. Furthermore, TDMA demodulators are capable of receiving burst mode carriers of incoherent phase. Therefore, phase incoherency of TDMA carriers does not cause any difficulty. The only possible problem of site diversity operation of TDMA transmission would be the necessity of very precise transmit timing control even for the initial transmission from the stand-by station. This may be solved either by continuously transmitting a dummy burst from the stand-by station or by obtaining sufficiently accurate ranging data of the satellite which is possible when the TDMA system employs open loop synchronization. In TDMA transmission, the path lengths of diversity routes can be equalized using the reception timing of frame synchronization signals. The reception timing of signals from both diversity routes can be automatically equalized by controlling the variable delay line inserted in one of the diversity routes. An experimental system using the dummy burst technique has been tested.

For route selection in diversity operation, it is necessary to measure the transmission quality of diversity routes. Because the diversity effect may degrade depending on the choice of the measuring method of link quality, care should be taken on selecting the measuring time duration and achievable accuracy.

1.3 Diversity interconnect link

A factor which must be considered is that the ITU-R hypothetical reference circuit contained in Recommendation ITU-R S.352 and the ITU-R hypothetical reference digital path contained in Recommendation ITU-R S.521 include the diversity interconnection links (DIL) to the diversity switching point and any additional modulation/demodulation equipment required. This would mean that system noise budgets must include all the effects of the DIL.

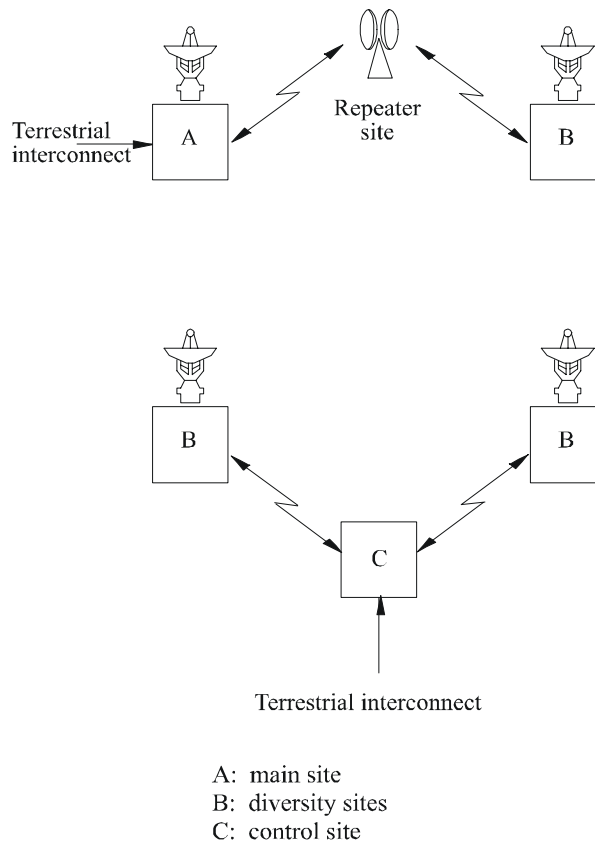
1.3.1 Basic configuration

1.3.1.1 Physical aspects

There are a number of different specific configurations which can be considered and there could be reasons for preferring one of these. Two of these are identified and described in this Annex as (see Fig. 1):

- a main site which contains the diversity switch and the terrestrial interface. The diversity site is connected by a two-hop microwave DIL using either an active, or passive, repeater. (A repeater site is assumed, since the likelihood of mutual visibility of the diversity sites is small);
- dual diversity sites and a separate control site with the interface and diversity switch; single microwave hops for each site to the control site.

FIGURE 1
Diversity configurations



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It may also be possible to employ cable or waveguide links for the DIL. When both FDM-FM and TDM (FDMA or TDMA) are used at an earth station, two parallel links would usually be required.

1.3.1.2 Modulation requirements

When FDM-FM is used, remodulation will be required because the satellite link modulation and baseband configurations are usually different from those conventionally used for terrestrial systems. The main difference is associated with the channel packaging. The terrestrial system will usually combine the channels in one or more basebands in each direction and will use a relatively low modulation index. The earth station will break these basebands down into multiple, multi-destination, transmit basebands; different from those on the terrestrial system and using a different modulation index. The receive basebands are even more numerous and may consist of only a few channels and these must be re-combined into the terrestrial basebands. This process requires modulation/demodulation equipment at the main earth station site and at the diversity site where conventional design of the DIL is used. All configurations can be implemented using the remodulation technique at the expense of providing duplicate equipment at the diversity site.

An alternative technique is to use the same modulation arrangements on the terrestrial system as used on the satellite system. Such a technique would appear to be technically feasible although not conventional. The incentive is to save the cost of remodulation equipment at perhaps some added cost to the terrestrial system, although savings may also result for this element as well. The use of such a technique is only applicable to the second configuration of Fig. 1. When TDM is used (FDMA or TDMA), either technique could be employed. In the case of TDMA, diversity switching is performed between bursts (see § 1.2). The same modulation could be used on the DIL as used on

the satellite system although the data rates would not normally be those of a conventional terrestrial digital radio system.

1.3.2 Technical factors

1.3.2.1 Frequency selection

Frequency selection for a microwave DIL requires careful study to ensure that the required overall performance is obtained. Information on terrestrial microwave propagation is shown in the relevant texts of Radiocommunication Study Group 3.

1.3.2.2 Bandwidth requirements

The bandwidth required to implement the DIL can be related to the earth station bandwidth by a factor which may be unity or less, depending upon whether re-modulation is used or not. If only frequency translation is used then bandwidth requirements must be MHz for MHz. By re-modulating, a greater channel density can be achieved by using smaller FM modulation indices at the expense of a substantial multiplex interface.

1.3.2.3 Rain attenuation

Further factors are rain attenuation and site diversity characteristics which are both related to rainfall phenomenon. A dry climate is preferred. Diversity action is a function of the site spacing. It is expected that the nominal spacing required is about 16 km. The best orientation of a line connecting the sites may be assumed to be perpendicular to the direction of predominant weather patterns since the most severe attenuation condition would not be expected to affect both sites simultaneously and maximum diversity action would be obtained. The weather effects on the microwave DIL must be accounted for if the higher frequencies are used for these links, although this should be a secondary consideration.

1.3.2.4 Variations in transmission delay due to diversity switching

Another element of importance is associated with the differential transmission delay between the diversity signals as they arrive at the switching point.

1.3.3 General considerations

Two particular aspects of the diversity interconnection links (DIL) are important:

- the contribution to the overall system noise budgets, and
- the contribution to system outage.

These subjects are studied here to develop the effects of the important parameters and the interrelationship with the satellite link parts of the system.

The diversity link design can be made on two bases. If a re-modulation system is selected, then conventional radio-relay designs can be used. If a translation system is selected, then the design can follow a different pattern and will be very similar to the satellite system transmission design. Fading margins and noise contributions must be accounted for in overall performance. In the special case where the same frequencies are used for the DIL as for the satellite system, then interference noise allowances must also be made.

1.3.3.1 Noise budgets for FDM-FM

The contributions of the DIL to the overall noise of the hypothetical reference circuit have to be made reasonably small in order to maintain the system performance in accordance with Recommendation ITU-R S.353.

It seems reasonable to assume that the DIL noise contribution would be considered as part of the earth station budget (usually 1 500 pW0p), as the DIL actually provides part of the normal earth station function. It only needs to be determined that such a contribution can be kept sufficiently small so that the total of 1 500 pW0p is not exceeded. The fading of the DIL will contribute to the overall short-term noise budget of the link.

The noise contribution from the DIL would have a number of components depending upon the implementation configuration and the frequency bands used. The components are:

a) *Thermal noise*

Conventional ITU-R designs for radio-relay are 1 to 3 pW0p per km or less, and can be held to 10 pW0p or less, for a single hop. Special designs also achieve small contributions. The time varying components due to multipath fading and rain attenuation are relatively large, but for short hops can be controlled to reasonable values. The thermal noise is related dB for dB to the fading from either mechanism.

b) *Basic intrinsic noise*

This is baseband noise and is applicable only to re-modulating configurations. Noise levels of 50 to 100 pW0p are usual for back-to-back basebands. The normal earth station noise budget provides for one such contribution while a re-modulation configuration would add a second contribution.

c) *Interference*

A very small interference contribution would be present from other microwave systems operating in the same frequency bands in some cases. This contribution can be considered to be negligible. For the special case of using the same frequency re-use design, uplink and downlink contributions of interference at the earth station can be expected. Values of the order of 10 to 100 pW0p are estimated for normal operation. In addition, certain fading situations may be accompanied by increases in this noise for very short time periods along with the thermal noise. This configuration does not require re-modulation, so all extra noise associated with item b) is eliminated.

d) *Intermodulation*

A re-modulating design will have an extra modulator-demodulator pair plus IF amplifiers, while the translation design is all conventional earth station equipment and therefore contributes very little intermodulation noise.

Table 2 illustrates a possible noise budget:

TABLE 2

Sample budgets – Free space conditions				
	Re-modulation (2 hops)		Frequency translation (1 hop)	
	Low (pW0p)	High (pW0p)	Low (pW0p)	High (pW0p)
Thermal	2	20	1	10
Baseband intermodulation	50	100	–	–
Interference	–	–	10	100
Intermodulation (RF)	100	200	20	50
Total (pW0p)	152	320	31	160

1.3.3.2 Error budget for TDMA

The contributions of the DIL to the overall error rate of the hypothetical digital reference path have to be made reasonably small in order to maintain the system performance in accordance with this Recommendation.

It should be noted that in the case of the re-modulating DIL the errors will be additive whereas in the case of frequency translation the noise effects will be additive.

1.3.3.3 Frequency considerations

The fading characteristics as a function of frequency, climate and path length for rainfall can be derived from conventional microwave designs. Rain attenuation and multipath fading are independent events – in fact they are almost mutually exclusive.

Since the expected spacing of a diversity pair of earth stations is of the order of 16 to 24 km and since it is also expected that either a repeater or a common site will be needed, the individual path lengths of the DIL will probably not exceed 16 km. The margins for such a path length can normally be made sufficiently high to accommodate short-term outages as low as 0.001% of the time.

2 Uplink transmitting power control

2.1 Introduction

Uplink power control (UPC) can be used as a means of reducing the effect of uplink attenuation in the higher frequency bands (for example 14/11 and 30/20 GHz bands). This technique could be used to achieve efficient operation of a satellite communication system and to decrease interference to other satellite and terrestrial links by reducing clear-sky e.i.r.p.

2.2 Implementation of UPC

There are various methods of achieving UPC. The most commonly used methods are as follows.

2.2.1 Open-loop UPC method

Open-loop UPC is a method whereby a beacon signal from the satellite is used to measure the downlink rain attenuation. Owing to the correlation between the uplink and downlink rain attenuation, this measurement is used to estimate the uplink rain attenuation level and hence the UPC control values. Most predicted attenuation values coincide with actual values; however, some values differ because of such environmental conditions as wind velocity or raindrop-size distribution. Table 3 shows an example of potential errors in estimating uplink (14 GHz) attenuation from a downlink (11 GHz) measurement.

Some potential error sources have been excluded as being too small to estimate (e.g. antenna tracking error, satellite antenna pointing error, pre-emphasis error, antenna gain degradation, refractive effect at low elevation angles, rapid rainfall rate fluctuation). Also excluded are error sources of a very rare type (e.g. large accumulations of wet snow on the antenna, failure in the control or measurement circuits). Various combinations of these additional error sources could, potentially, make the cumulative uplink power level error larger.

TABLE 3

Example of potential errors in estimating uplink (14 GHz) attenuation from a downlink (11 GHz) measurement is tabulated below

a) Uplink attenuation of less than 1.0 dB			
	Elevation angle		
	5°	15°	25°
Equipment error ⁽¹⁾	0.725	0.725	0.725
Ice attenuation	0.05	0.05	0.05
Water vapour/diffusive	0.20	0.10	0.05
Clear-sky level	0.10	0.10	0.10
Maximum uplink error (dB)	±1.075	±0.975	±0.925
b) Uplink attenuation of between 1 and 6 dB			
	Elevation angle		
	5°	15°	25°
Equipment error ⁽¹⁾	0.725	0.725	0.725
Ice attenuation	0.05	0.05	0.05
Raindrop-size distribution	0.10	0.075	0.05
Water vapour/diffusive	0.20	0.10	0.05
Clear-sky level	0.10	0.10	0.10
Polarization error	0.10	0.075	0.05
Path length error	0.20	0.10	0.05
Melting layer	0.05	0.05	0.05
Maximum uplink error (dB)	±1.525	±1.275	±1.125
c) Uplink attenuation in excess of 6 dB			
	Elevation angle		
	5°	15°	25°
Equipment error ⁽¹⁾	0.725	0.725	0.725
Ice attenuation	0.05	0.05	0.05
Raindrop-size distribution	0.20	0.15	0.10
Water vapour/diffusive	0.10	0.075	0.05
Clear-sky level	0.10	0.10	0.10
Polarization error	0.20	0.15	0.10
Path length error	0.40	0.25	0.15
Melting layer	0.05	0.05	0.05
Maximum uplink error (dB)	±1.825	±1.550	±1.325

- ⁽¹⁾ The equipment error of ±0.725 dB assumed above is estimated on the basis of a ±0.5 dB error being encountered at 11.7 GHz (on the downlink) and assuming a 1.45 scaling factor between 11.7 GHz and 14 GHz. The ±0.5 dB error was obtained using available data and needs further verification by additional measurements.