REPORT 760-2

LINK POWER BUDGETS FOR A MARITIME MOBILE-SATELLITE SERVICE

(Question 87/8)

(1978-1982-1990)

1. Introduction

The purpose of this Report is basically two-fold:

- to list the parameters which must be taken into account when determining link power budgets for a future maritime mobile-satellite system, and the conditions under which these parameters apply;
- to provide examples of link power budgets to illustrate the application of these parameters.

Link power budgets are required in order to determine the likely power requirements and physical characteristics of the space sector (satellite) and the earth sector (coast earth stations and ship earth stations). The overall design for a future system will rely to a great extent on the experience acquired in the development and operation of existing and planned maritime satellite systems, and hence considerable guidance on the choice of suitable power budget parameters can be obtained by reference to the INMARSAT system [INMARSAT, 1978; MARISAT, 1977].

The link budget examples given in this report relate to analogue systems with global coverage by a satellite system utilizing a shaped beam. The example mobile standards used are derived from those of the analogue INMARSAT Standard A system. Examples of link budgets for digital systems are presented in Report 921.

2. Power budget philosophy

The philosophy adopted in this Report is to assume a "reference" system configuration from which corresponding parameters for other configurations may be derived. From the propagation viewpoint, the channel quality obtained with a maritime satellite system will be strongly dependent on the satellite elevation angle, and so it would appear reasonable to adopt the elevation angle as one of the parameters on which to base the reference system. The reference configuration for the power budgets is assumed here to apply at satellite elevation angles of 5° for coast earth stations and 10° for ship earth stations; corresponding parameters and resultant channel qualities for elevation angles other than these may then be derived.

A further criterion adopted here is to assume that parameters for the earth sector are the same as for existing, or planned, systems; in particular, INMARSAT standard-A ship earth stations are assumed.

3. Telephony channel parameters

Telephony is expected to be the dominant service in terms of system power requirements and hence the power budgets are based on a telephony channel.

For the purpose of presenting information on link budget examples in this paper, as a reference it has been assumed that an overall carrier-to-noise density ratio (C/N_0) of 53 dBHz should be achieved for at least 80% of the time in both directions of transmission, with satellite elevation angles of 5° at coast earth stations and 10° at ship earth stations and with no multipath fading on ship/satellite links. This objective has been used as the reference configuration for the power budgets, as shown in the extreme right-hand column of Tables I and II. The current CCIR telephone channel quality objective for telephone channels in the maritime mobile-satellite service corresponds to an overall C/N_0 of about 52 to 53 dBHz (see Recommendation 547 and Report 752 [INMARSAT, 1978].

In addition to the reference configuration, example power budgets are shown in Tables I and II for ship elevation angles of 5° and 10° when multipath fading occurs on ship/satellite links. The fading parameters are assumed to be applicable to conditions obtaining for at least 99% of the time. However, insufficient experimental data is available to reliably establish required fading margins for any confidence level.

Single-channel-per-carrier operation in frequency division multiple access is envisaged for telephony, with narrowband frequency modulation and speech processing (e.g. 2 : 1 syllabic companding). With C/N_0 of 53 dBHz at the demodulator input, a suitable receiver noise bandwidth would be 30 kHz with 50 kHz channel spacing: the corresponding carrier-to-noise ratio (C/N) would be about 8 dB.

Threshold extension demodulators, with a nominal threshold of around 50 dBHz, would be required to ensure a graceful degradation of speech quality with reducing signal level.

4. Space sector parameters

The space sector configuration assumed here is based on global coverage in both shore-to-ship and ship-to-shore directions of transmission. Assumptions regarding the characteristics of the 1.5/1.6 GHz antenna and the intermodulation noise performance of the transponders are summarized below.

4.1 *1.5/1.6 GHz antenna*

The critical transmission path, from the viewpoint of satellite power requirements, is that in the satellite-to-ship direction at 1.5 GHz. Efficient use of the available satellite power for earth coverage may be obtained by assuming a shaped beam antenna [Wood and Boswell, 1974; Lancrenon *et al.*, 1976]. The trade-off between beam-centre and beam-edge gain with this antenna provides an almost constant received flux density at the earth's surface for all elevation angles, and thus optimizes system performance for those ship earth stations at the edge of the coverage area where propagation effects are at their most severe. Similar compensation may also be provided on the up-path at 1.6 GHz.

4.2 *Intermodulation noise performance*

The satellite amplifier carrier-to-intermodulation-noise density ratio (C/I_0) in Table I for the shore-to-ship link is shown to be a limiting factor in determining the resultant C/N_0 and therefore must be optimized against amplifier output power. For typical amplifiers and suitable frequency plans that minimize intermodulation noise in occupied channels, a C/I value of about 19 dB in a 30 kHz bandwidth may be reasonably achieved with significant satellite amplifier loading. This results in the assumed C/I_0 of 63.8 dBHz for the shore-to-ship direction.

In the ship-to-shore direction, as given in Table II, a C/I_0 of 70 dBHz has been assumed as the satellite amplifier is not expected to be as power limited as in the shore-to-ship direction.

5. Earth sector parameters

The following ship earth station and coast earth station radio frequency characteristics have been adopted as the basis for the power budgets:

Ship earth station G/T : -4 dB(K^{-1}) (Standard-A);

Ship earth station e.i.r.p. : 37 dBW;

Coast earth station G/T : 32 dB(K^{-1});

Coast earth station e.i.r.p. : 60 dBW.

5.1 *Ship earth station*

The assumed G/T of -4 dB(K^{-1}) is a net value which includes allowances for power losses due to pointing accuracy, misaligned polarization ellipses, diplexer and dry radome; an additional allowance is shown in the link budgets for loss due to a wet radome. This sensitivity may be achieved with an antenna of 23 dBi gain and a transistorized receive amplifier of 500 K total system noise temperature. An appropriate antenna would be a paraboloid of 1.2 m diameter, with 60% illumination efficiency, and a beamwidth of approximately 10° to the -3 dB points; an axial ratio of about 2 dB has been assumed. For the purposes of the link budget calculations, the pointing and polarization losses have been considered separately.

No allowance has been made in the power budgets for blockage effects from the ship's superstructure; these would depend on the individual ship and could, in theory, be eliminated by choosing an unobstructed site.

5.2 *Coast earth station*

For a clear-sky G/T of 32 dB(K^{-1}) at 5° elevation, a total system clear-sky noise temperature of 100 K has been assumed for the calculation of noise temperature degradation under fading conditions. Fading parameters for 4/6 GHz links are assumed to be applicable to propagation conditions obtaining for 99.99% of the time; the channel quality of the overall links between coast earth stations and ship earth stations is thus mainly determined by the loss parameters on ship/satellite links at 1.5/1.6 GHz.

An appropriate coast earth station's antenna diameter would be 13 m, assuming an illumination efficiency of 60%. The antenna axial ratio has been assumed to be 0.5 dB; for the purposes of the link budget calculations, polarization and pointing losses have been considered separately.

The up-link intermodulation noise from all coast earth station transmit amplifiers has been assumed to result in a total up link C/I greater than 30 dB in a 30 kHz bandwidth. This assumption is consistent with the current INMARSAT Coast Earth Station Technical Requirements Document and the expected performance of typical frequency plans that could be employed. This results in the C/I_0 value of 75 dBHz used in Table I.

6. Derivation of link margins

The margins necessary to achieve the desired objectives for the satellite links are dependent upon many factors including the satellite characteristics, ship earth station and coast earth station characteristics, weather, sea states and satellite elevation angles. The overall system design should include link margins consistent with the following factors:

- minimum elevation angle considered for service;
- tolerable performance degradation for elevation angles lower than the minimum design point.

The choice of link margins in relation to elevation angle (α) and the system design will affect the performance of the entire system (as seen from the terrestrial network). A system designed to achieve a specified quality for a stated percentage of time, with margins to allow for degradations occurring at low elevation angles, will achieve this quality for much higher percentages of time when calls to and from all ships within the coverage area are considered.

The margins required to compensate for losses other than the basic free space path loss can be grouped into categories of long-term (fixed and random losses) and short-term.

6.1 *Long-term losses*

Long-term losses may be defined as those which would tend to last for a period of at least a minute per occurrence.

6.1.1 *Fixed long-term losses*

Long-term losses which occur with certainty should be included in the path loss for all calculations. The composite margin for these losses in dB is their sum:

$$L_f = \sum_j L_{f,j} \tag{1}$$

6.1.2 *Random long-term losses*

Several of the long-term losses tend to occur randomly and are generally independent of each other. The cumulative mean loss ($\bar{L}_l$) and variance (σ_l^2) may be obtained by summing the individual means and variances:

$$\bar{L}_l = \sum_j \bar{L}_{l,j}\,; \quad \sigma_l^2 = \sum_j \sigma_{l,j}^2 \tag{2,3}$$

6.2 *Short-term losses*

Short-term losses may be defined as those which would tend to last for a period of less than a minute per occurrence. Since the occurrence of a significant short-term fading period may be infrequent, uncertain, or may only occur at certain times of the day, consideration should be given to the fading statistics when establishing fade margins.

Short-term losses tend to be independent of each other and to have different statistical distributions. The cumulative margins needed for these losses may be strongly dependent on elevation angle (α), since the elevation angle independent losses are relatively small or infrequent.

The cumulative mean loss ($\bar{L}_s$) and variance (σ_s^2) for the cumulative short-term losses may be obtained by summing the individual mean losses and variances:

$$\bar{L}_s = \sum_i \bar{L}_{s,i} \; ; \; \sigma_s^2 = \sum_i \sigma_{s,i}^2 \qquad (4, 5)$$

6.3 *Cumulative margins for all losses*

Since the long-term and short-term losses are reasonably numerous and independent, the total margin requirements can be approximated by a normal loss distribution having a mean given by:

$$L \simeq L_f + \bar{L}_l + \bar{L}_s \qquad \text{dB} \qquad (6)$$

and standard deviation given by:

$$\sigma \simeq (\sigma_l^2 + \sigma_s^2)^{1/2} \qquad \text{dB} \qquad (7)$$

The appropriate cumulative margin in dB, corresponding to time-percentages of 80%, 99% and 99.99%, would then be given by:

$$\begin{aligned} M\,(80\%) &= L + 0.85\,\sigma \\ M\,(99\%) &= L + 2.33\,\sigma \\ M\,(99.99\%) &= L + 3.72\,\sigma \end{aligned} \qquad (8)$$

7. **Margins at 1.5/1.6 GHz for ship/satellite links**

7.1 *Long-term losses*

Long-term losses for which margins may be needed are as follows:

$L_a(\alpha)$: atmospheric absorption in dB: a function of the ship-to-satellite elevation angle (α); derived here from Report 714;

$L_e(\alpha)$: excess attenuation in dB, exceeded for not more than 20% or 1% of the time; this is considered to be negligible at 1.5/1.6 GHz;

L_r : radome (if used) loss in dB; the losses due to a dry radome (0.2 dB) may already be accounted for in the definition of ship earth station antenna gain and receive sensitivity (G/T), as is assumed here;

L_p : polarization coupling loss in dB: a function of ship earth station antenna and satellite antenna axial ratio (2 dB and 3 dB respectively); the worst case is misaligned polarization ellipses;

L_b : ship structure blockage loss in dB: a function of antenna placement, size and shape of the obstruction, direction and ship earth station antenna beamwidth.

Additional degradations due to an increase in system noise temperature caused by various losses are as follows:

DT_r : ratio in dB of the system noise temperature, when a radome is fitted to the system noise temperature without the radome; this may already be accounted for in the G/T value, as has been assumed here, but an allowance is required for the degradation in noise temperature due to a wet radome;

ΔT_a : temperature increase due to atmospheric absorption; this is considered negligible for a system noise temperature of 500 K.

7.1.1 *Fixed long-term losses*

The composite margin for fixed long-term losses is given by:

$$L_f(\alpha) = L_a(\alpha) + L_r(\text{dry}) \tag{9}$$

7.1.2 *Random long-term losses*

Cumulative statistics for random long-term losses would include, for example, L_p and L_r (wet); typical means and standard deviations for these loss factors might be as follows:

Loss factor	*Mean Loss (dB)*	*Standard deviation (dB)*
L_p	0.2	0.09
L_r (wet)	0.2	0.13
DT_r (wet)	0.1	0.09 (reference noise temperature = 500 K)

The inclusion of blockage loss (L_b) in the margin calculations may not be consistent with ship earth station installation practice and operational objectives. Normal practice may be to install the ship earth station antenna with a completely unobstructed view for elevation angles above the system design point and not to provide a system-wide margin for blockage, as has been assumed here.

7.2 *Short-term losses*

Short-term losses for which margins may be needed are as follows:

L_t : ship earth station transmitter power level fluctuations: are assumed here to be ± 0.5 dB for about 95% of the time, corresponding to a mean loss of 0 dB and a standard deviation of 0.25 dB;

ΔG : ship earth station antenna pointing loss in dB: a function of the ship antenna pointing system performance which tends to be worse in high sea states; some designs may exhibit high tracking errors at certain orientations such as in the zenith direction;

L_i : ionospheric fading loss, in dB, due to scintillation; a function of ship location, season and time of day;

$L_m(\alpha)$: multipath fading loss, in dB, due to reflections from the sea and ship structure: the magnitude of the loss for a given percentage of time, and the rate at which the loss varies, will depend upon the sea state, elevation angle (α), link polarization, ship antenna pattern, ship antenna axial ratio in the direction of the reflection region, antenna height above the sea, and antenna system pointing accuracy.

7.2.1 *Antenna pointing loss*

The antenna pointing loss (ΔG) may be small, especially if the ship earth station antennas are equipped for automatic pointing. Typical pointing errors may be normally distributed with a standard deviation of 0.1 beamwidth or less under worst case design conditions, and the corresponding loss distribution would be chi-squared. For simplicity, a 99% loss figure of 0.5 dB has been assumed with a mean loss of 0.3 dB and a standard deviation of 0.09 dB.

7.2.2 *Ionospheric scintillation loss*

Band 9 fading losses due to ionospheric scintillation tend to be noticeable only in the spring and autumn equinox seasons, and primarily near the geomagnetic equator and at high geomagnetic latitudes [Canada, 1973; Golden and Sessions, 1972]. Furthermore, the fading near the geomagnetic equator tends to be more severe than at the high latitudes, and the periods of such fading range from about one to three hours and occur shortly after local sunset. Measurements indicate that maximum fading losses below free space are normally in the range of 3 to 5 dB for the worst fading days and that the deepest fades usually last less than 15 s. During fading periods a loss of about 1.1 dB is expected to be exceeded for not more than 1% of the hours, and 1.8 dB is expected to be exceeded for not more than 0.1% of the hours [Golden and Sessions, 1972]. Cautious estimates of the corresponding standard deviation would be 0.6 dB.

Inclusion of the ionospheric scintillation loss in the cumulative margin would yield the worst case statistics, which would be applicable for a very short time during a few days of the year and to limited geographical locations. For some systems it may be the governing short-term loss and should, therefore, be considered in the selection of "worst hour" margins, but for the purposes of this Report it will not be included.

7.2.3 *Multipath fading loss*

Multipath fading loss statistics are very dependent on elevation angle and could be the dominant factor in the link margin requirement. A considerable number of studies and experiments have been performed to assess the effects of multipath fading; see also Reports 505 (Kyoto, 1978), 599 and 763 [ESRO, 1974; IMCO, 1973; ESA, 1976].

With normal sea conditions in most ocean areas, multipath reflections from the sea surface will be predominantly diffuse and the composite indirect signal will have narrowband Gaussian statistics. Unlike the ship earth station receiver noise, the received carrier-to-multipath-interference ratio (C/I_{mp}) will not be reduced by increasing the satellite transmitter power. Consequently, margins provided for diffuse multipath interference do not serve to increase C/I_{mp}, but only to provide an adequate carrier-to-receiver-thermal-noise ratio such that the ship earth station receiver performance is still acceptable when the multipath fading occurs.

Once the expected value of C/I_{mp} is established for the minimum design elevation angle, the fade depths not exceeded for more than p% of the time can be determined. For example, extrapolation from measured test data shows that a directive antenna with 24 dBi nominal beam-centre gain (10° beamwidth) in a circularly polarized link at 5° elevation would normally enjoy a $C/I_{mp} \simeq 16$ dB. The fading depth would be expected to be less than 2.5 dB for at least 99% of the time [ESRO, 1974; Norton *et al.*, 1965]. In deriving this result, the following assumptions have been made:

(a) the discrimination angle to the reflecting area is approximately 10°;

(b) the antenna pointing system uses a reference independent of the received signal in compensating for ship roll and pitch etc.;

(c) the polarization efficiency factor of the antenna to the multipath energy is unity (i.e. cross-polar response).

Such extrapolations, although useful in deriving an order of magnitude for typical fade depths, should be treated with some caution; in particular, the assumption (c) above would not apply in practice as the cross-polar response of the antenna is expected to be worse off-axis than at beam centre. Furthermore, the corresponding fade depth adopted in existing and planned systems is 4 dB at 5° elevation and 1.8 dB for 10° elevation. These values are in reasonable agreement with the results given in Report 763.

On the basis of analysis and some experiments, the margins required for low percentage fading ($p \leqslant 99\%$) with diffuse multipath fading will be larger than the maximum specular fade for the same conditions.

Loss statistics for diffuse multipath fading are approximately Gaussian for high direct to indirect power ratios ($C/I_{mp} > 10$ dB). The cautious approximation adopted here is to use a zero average ($L_m = 0$ dB) and a standard deviation estimate which is based on the 99% loss values given above.

7.3 *Cumulative margins*

It may be seen that inclusion of margins for blockage and ionospheric scintillation loss may be significant; the approach adopted here is to assume no normal blockage and scintillation losses in establishing the system-wide margins. However, these losses should be included in a "worst case" margin which may be used in conjunction with a "marginally acceptable" quality objective lower than the normal quality criterion for telephony.

8. Margins for feeder links

8.1 *Fixed long-term losses*

The only fixed long-term loss occurring in the power budgets is atmospheric absorption, L_a (α).

8.2 *Random long-term losses*

Random long-term losses include:

L_p : polarization coupling loss: mean loss = 0.05 dB, standard deviation = 0.02 dB for shore/satellite antenna axial ratios of 0.5 dB/3 dB.

L_t : transmitter power fluctuations for 6 GHz operation: mean loss = 0 dB, standard deviation = 0.12 dB.

$L_e(\alpha)$: excess attenuation exceeded for not more than 0.01% of the time: mean loss = 0 dB, standard deviation = 0.27 dB for 6 GHz operation and 0.14 dB for 4 GHz operation.

8.3 *Random short-term losses*

Coast earth station antenna pointing loss is assumed here to be 0.2 dB with a mean loss of 0 dB and a standard deviation of 0.05 dB. No allowance has been made for ionospheric scintillation in the 99.99% loss figures.

$DT_s(\alpha)$: degradation due to excess sky noise in dB : mean loss = 0 dB standard deviation = 0.32 dB.

9. Link power budgets

Cumulative random loss margins in Tables I and II have been calculated from the loss values assumed for each parameter and have been calculated independently for each part of the overall link. The power budgets may be used to determine likely system power requirements and are based on an assumed resultant C/N_0 requirement of 53 dBHz for the telephony reference budget; this assumes 5° elevation at coast earth stations, 10° elevation at ship earth station and no multipath fading on ship/satellite links. The C/N_0 values when multipath fading does occur on ship/satellite links are also indicated, for ship elevation angles of 5° and 10°. It is assumed that the contribution due to all translation local oscillator phase noise is negligible and consequently is not included in the link power budgets.

10. Other factors affecting the link power budget

10.1 *Relative transponder loading*

Since the satellite capacity is designed to meet traffic requirement at a specified grade-of-service, on the average substantially fewer than the full load number of carriers will be busy during the busiest hour. Due to the non-linear amplification characteristic typical of most satellite amplifiers near saturation, the e.i.r.p. per carrier increases in almost direct proportion to the decrease in the number of carriers from full load. Consequently the average per carrier e.i.r.p. during the busiest hour will be greater than the full load e.i.r.p. over a small range of about 1 dB.

For single channel per carrier (SCPC) telephony systems in which blocked calls are cleared (erlang B), the probability, $P(n)$, that exactly n channels or less out of s channels are in use during the busy hour is given by [Cooper, 1972],

$$P(n) = 1 - \sum_{j=n}^{s} p_j$$

where, p_j is the probability that exactly j channels are in use, and is given by

$$p_j = \begin{cases} B(s,a) & for\ j = s \\ \dfrac{B(s,a)}{\prod_{k=j+1}^{s} a/k} & for\ j < s \end{cases}$$

where $B(s, a)$ is the busy hour blocking probability [Dill and Gordon, 1978], and "a" is the busy hour offered traffic (erlangs).

Assuming that the transmitter is operated at saturation, the increase in the per carrier e.i.r.p. relative to the full load per carrier e.i.r.p. is with probability $P(n)$,

$$\Delta = 10 \log(s/n)$$

Table III provides several numerical examples in the range of interest. It should be noted, that during the busy hour, all channels or less are in use for $(1 - B(s,a)) \times 100\%$ of the time. For a 2% blocking probability ($B(s,a) = 0.02$), this amounts to 98% of the time.

10.2 *Adaptive control of satellite transmitting power*

In the previous sections, fixed satellite transmitting power is assumed. However, in an SCPC system, in which satellite transmitting power can be changed by controlling coast earth station transmitting power for each SCPC carrier, shore-to-ship satellite link quality (C/N or S/N) could be maintained at the required constant value. This can be achieved by sending back the shore-to-ship satellite link quality measured at the ship earth station through the ship-to-shore link and adaptively controlling the shore earth station transmitting power using the sent back information.

By applying this power control method, random slow variations in satellite link quality caused by satellite antenna gain differences, precipitation or fading can be almost compensated for. Consequently, the number of SCPC channels in the satellite transponder could be increased [Egami *et al.*, 1980].

The study of adaptive power control methods, as a possible means of making more efficient use of satellite power in the long term, should include consideration of the practical, operational and economic effects on current designs of coast earth stations, ship earth stations and the satellite signalling system.

11. Summary

This Report has illustrated how fixed and variable link parameters may be taken into account when developing link power budgets for a maritime mobile-satellite system.

The cumulative loss statistics used to derive the margins have been approximated as normal, with the mean and variance taken to be the sum of the means and the variances of the individual losses.

The independence of the loss factors and the normal distribution assumptions should be checked for any particular link budget design.

Further study will be required on the power budgets for services other than telephony, and for ship earth stations having a G/T other than -4 dB(K^{-1}). Further study is also required into the relationship between traffic, satellite capacity and e.i.r.p. requirements.

TABLE I — *Shore-to-ship link power budget*

	Units	Satellite elevation angle		
		5°		
1. *Shore-to-satellite* (6.42 GHz, 99.99% time)				
Coast earth station e.i.r.p. per channel (nominal value)	dBW	60		
Loss due to transmitter power fluctuations (1)	dB	[0.5]		
Loss due to pointing errors (1)	dB	[0.2]		
Free space path loss	dB	200.9		
Atmospheric absorption loss	dB	0.5		
Excess attenuation due to precipitation (1)	dB	[1.0]		
Polarization coupling loss (1)	dB	[0.1]		
Total margin for random losses	dB	1.2		
Satellite G/T	dB(K^{-1})	−16		
Boltzmann's constant	dB(J/K)	−228.6		
Up-path C/N_0 (thermal noise)	dBHz	70		
Coast earth station C/I_0 (intermodulation noise)	dBHz	75		
Satellite transponder C/I_0 (intermodulation noise)	dBHz	63.8		
Transmitted $C/(N_0 + I_0)$	dBHz	62.6		
		99% time		80% time
		5°	10°	10°
2. *Satellite-to-ship* (1.54 GHz)				
Satellite e.i.r.p. per channel (useful power)	dBW	18.0	18.1	18.1
Free space path loss	dB	188.5	188.4	188.4
Atmospheric absorption loss	dB	0.4	0.2	0.2
Multipath fading loss (1)	dB	[4.0]	[1.8]	[0]
Wet radome additional loss (1)	dB	[0.5]	[0.5]	[0.4]
Noise temperature degradation (1)	dB	[0.3]	[0.3]	[0.2]
Polarization coupling loss (1)	dB	[0.4]	[0.4]	[0.3]
Loss due to tracking errors (1)	dB	[0.5]	[0.5]	[0.4]
Total margin for random losses	dB	4.8	2.7	1.1
Ship earth station G/T	dB(K^{-1})	−3.5	−3.5	−3.5
Boltzmann's constant	dB(J/K)	−228.6	−228.6	−228.6
Down-path C/N_0	dBHz	49.4	51.9	53.5
Transmitted $C/N_0 + I_0)$	dBHz	62.6	62.6	62.6
Resultant $C/(N_0 + I_0)$	dBHz	49.2	51.5	53.0

(1) Random loss; figures indicated [ ] are not included directly in budget, but are combined as described in § 6.3.

TABLE II — *Ship-to-shore link power budget*

	Units	Satellite elevation angle		
		99% time		80% time
		5°	10°	10°
1. *Ship-to-satellite* (1.64 GHz)				
Ship earth station e.i.r.p. (nominal value)	dBW	37	37	37
Loss due to transmitter power fluctuations(1)	dB	[0.5]	[0.5]	[0.5]
Loss due to pointing errors(1)	dB	[0.5]	[0.5]	[0.4]
Wet radome additional loss(1)	dB	[0.5]	[0.5]	[0.4]
Free space path loss	dB	189.0	188.9	188.9
Atmospheric absorption loss	dB	0.4	0.2	0.2
Multipath fading loss(1)	dB	[4.0]	[1.8]	[0]
Polarization coupling loss(1)	dB	[0.4]	[0.4]	[0.3]
Total margin for random losses	dB	4.8	2.6	1.0
Satellite G/T	dB(K^{-1})	−12.2	−12.1	−12.1
Boltzmann's constant	dB(J/K)	−228.6	−228.6	−228.6
Up-path C/N_0 (thermal noise)	dBHz	59.2	61.8	63.4
Satellite transponder C/I_0 (intermodulation noise)	dBHz	65.8	68.4	70
Transmitted $C/(N_0 + I_0)$	dBHz	58.3	60.9	62.5
		5°		5°
2. *Satellite-to-shore* (4.20 GHz, 99.99% time)				
Satellite e.i.r.p. per channel (useful power)	dBW	−12.3	−9.7	−8.1
Free space path loss	dB	197.1	197.1	197.1
Atmospheric absorption loss	dB	0.5	0.5	0.5
Excess attenuation due to precipitation(1)	dB	[0.5]	[0.5]	[0.5]
Degradation due to excess sky noise(1)	dB	[1.2]	[1.2]	[1.2]
Polarization coupling loss(1)	dB	[0.1]	[0.1]	[0.1]
Loss due to tracking errors(1)	dB	[0.2]	[0.2]	[0.2]
Total margin for random losses	dB	1.4	1.4	1.4
Coast earth station G/T (clear-sky)	dB(K^{-1})	32	32	32
Boltzmann's constant	dB(J/K)	−228.6	−228.6	−228.6
Down-path C/N_0	dBHz	49.3	51.9	53.5
Transmitted $C/(N_0 + I_0)$	dBHz	58.3	60.9	62.5
Resultant $C/(N_0 + I_0)$	dBHz	48.8	51.4	53.0

(1) Random loss; figures indicated [ ] are not included directly in budget but are combined as described in § 6.3.

TABLE III — *Relative e.i.r.p. per carrier for 2% blocking probability*

Busy hour offered traffic (Erlang) (a)	Number of channels (s)	Number of channels (n)	$P(n)$ (%)	Δ (dB)
17.5	25	21	79.6	0.76
21.93	30	26	81.3	0.62
31.00	40	36	83.4	0.46
40.26	50	45	79.9	0.46
87.97	100	94	80.8	0.27

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REPORT 922-1

REFERENCE RADIATION PATTERN FOR SHIP EARTH-STATION ANTENNAS

(Study Programme 17A/8)

(1982-1986)

1. Introduction

Consideration is given in this Report to the reference antenna pattern for ship earth stations to be used in assessing interference between ship earth stations and either terrestrial stations or space stations of different satellite systems sharing the same frequency bands.

The objective of this Report is to present actual measurement of antenna patterns taken on a test range and show that these measured patterns are well below the reference pattern proposed by other Study Groups and defined by the WARC-79.

2. Existing reference radiation patterns

Reference radiation patterns have been developed in various Study Groups of the CCIR: Report 390 and Report 391 in Study Group 4, Report 771 in Study Group 8 and Report 614 in Study Group 9. These Reports give a reference radiation pattern for antennas with diameter less than 100 λ, as stated below.

$$G = 52 - 10 \log \frac{D}{\lambda} - 25 \log \varphi \quad \text{dB} \quad \text{for } 100 \frac{\lambda}{D} \leq \varphi < \varphi_1$$

$$G = G_1 \quad \text{dB} \quad \text{for } \varphi_1 \leq \varphi$$

where:

D : antenna diameter }
λ : wavelength } expressed in the same unit

φ : angle from beam centre, in degrees