RECOMMENDATION ITU-R M.1087

METHODS FOR EVALUATING SHARING BETWEEN SYSTEMS IN THE LAND MOBILE SERVICE AND SPREAD-SPECTRUM LOW-EARTH ORBIT (LEO) SYSTEMS IN THE MOBILE-SATELLITE SERVICES (MSS) BELOW 1 GHz

(Questions ITU-R 83/8 and ITU-R 84/8)

(1994)

The ITU Radiocommunication Assembly,

considering

a) that the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92) has provided frequency allocations for low-Earth orbit mobile-satellite services (LEO MSS) below 1 GHz;

b) that in these bands sharing with other services is anticipated;

c) that LEO MSS can provide beneficial radiocommunication services such as emergency alerting (however, these services are not intended to be identified as safety services as specified in the Radio Regulations (RR) and geographical position determination to a large population;

d) that satellites in low-Earth orbit provide a practical platform for communication equipment in space;

e) that low power MSS systems employing direct-sequence spread-spectrum modulation contribute minimally to the overall noise level within these bands. However, in the vicinity of mobile earth stations, substantial RF emission could be present;

f) that spread-spectrum techniques are technically feasible and may provide a means of sharing between existing mobile services and low-power, low duty-cycle mobile-satellite services,

recommends

1. that the methods described in Annex 1 be used for analysing sharing between land mobile service and a spread-spectrum LEO MSS below 1 GHz.

ANNEX 1

Methods for examining the impact of RF emissions between land mobile systems and spread-spectrum LEO MSS systems below 1 GHz

1. Introduction

The search for the means by which spread-spectrum LEO MSS systems can share the radio spectrum with land mobile users of the bands below 1 GHz allocated by WARC-92 to MSS is the objective of this Annex. These bands include allocations to meteorological satellite, mobile and some other radiocommunication services.

The methods developed in this Annex are applied to two typical examples of spread-spectrum LEO MSS systems in the Appendices. Appendix 1 contains typical system parameters of two spread-spectrum LEO MSS systems. Appendix 2 shows how these methods can be applied.

2. Method for sharing between existing land mobile services and LEO MSS spread-spectrum Earth-to-space links (148-149.9 MHz)

Mutual sharing between land mobile services and spread-spectrum LEO MSS systems is facilitated by:

– the use of the spread-spectrum modulation which is inherently able to accept additional interference from other sources;

– the directivity of the MSS fixed earth station antennas (an 18 dB gain Yagi covers only 9.8% of the sky);

– the constantly moving footprint of the LEO MSS satellite reception area across the surface of the Earth which minimizes its exposure to the heaviest interference from ground based transmitters;

– the near continuous reappearing presence of other satellites in the constellation which can perform the required communication links from positions of lesser interference on the satellite;

– limitations on the duration of time over which MSS terminal transmissions may occur (up to 500 ms has been suggested);

– duty-cycle limitations (1% in 1 to 15 min has been suggested).

Signals from land mobile users currently assigned to the proposed uplink band are typically narrow-band signals (16 kHz or less). The land mobile transmitters, especially the base stations, are high power compared to the user terminals of the proposed MSS systems. Thus the MSS must be reasonably immune to the land mobile signals.

The incidence of land mobile terminal interference will be observed principally on the uplink used by small user terminals transmitting to the satellite. Appendix 2 gives an example of the uplink power/noise budget from a typical MSS mobile terminal in the 148.0-149.9 MHz band to demonstrate how these methods are to be applied.

2.1 Analysis of interference induced by a VHF spread-spectrum MSS system on a land mobile system

In the Earth-to-space link, MSS control and data acquisition (CDA) stations and MSS mobile user terminals could cause interference to land mobile stations. The interference analysis is done separately for the land mobile terminal and for the land mobile base station, using two criteria:

– the separation distance required for the protection of the land mobile receiver;

– statistical considerations assuming a uniformly distributed MSS mobile user population.

The equation to be applied is shown below. Its purpose is to calculate the electric field intensity at a specified distance between antennas of known heights. By substituting values for maximum desired electric field intensity, the formula can be solved for separation distance.

$$d = \sqrt{\frac{88 h_1 h_2 \sqrt{P}}{\lambda\, E}}$$

where:

E: sensitivity of receiver to be protected (V/m)

P: e.i.r.p. of interferer in a 4 kHz band (W/4 kHz)

d: distance between antennas (m)

h_1, h_2: height of antennas (m) (10 m^2 is generally used for the product of antenna heights)

λ: wavelength (m).

The electric field to be protected is given by:

$$E = \sqrt{120\pi \, 10^{(pfd/10)}}$$

where:

pfd : –150 dB(W/m^2/4 kHz) (in accordance with RR No. 608A and RR No. 608B)

2.2 Analysis of interference induced by the land mobile service on a spread-spectrum LEO MSS system

To determine the effect of interference caused by transmission from land mobile users in the 148.0-149.9 MHz band, both computational and experimental methods may be used.

A satellite with a payload consisting of a suitable repeater could be flown in LEO. Analysis of the repeated signals would allow one to characterize the traffic of mobile services in the subject band. Limited experimentation with spread-spectrum signals may also confirm the link budget analysis.

To compute the effect of interference caused by transmissions in the 148.0-149.9 MHz band from land mobile users, it is first assumed that these users are uniformly distributed over the footprint of the satellite antenna. Users closer to the sub-satellite point will have less space loss, but the satellite antenna pattern may be shaped to partially compensate for the effect of range. An expression taking these considerations into account is developed to estimate the total noise induced by other services on a LEO MSS.

Having such a model for interference level, we can proceed by creating a detailed link budget which includes the effect of MSS user location (in terms of elevation angle to the satellite) and the noise contribution from all sources including the MSS self-interference as well as interference from existing users. By experimenting with different values of user-to-satellite elevation angle, values of elevation angle which produce a positive operating margin can be found for different levels of interference. This method is demonstrated in Appendix 2 for typical system parameters.

It must be understood by LEO MSS system designers that there is a potential for future increase in mobile-service traffic.

2.2.1 Total noise induced by the land mobile service on a spread-spectrum LEO MSS

It is desired to compute the total power observed at satellite S (refer to Fig. 1) from a large number of emitters, N_e, uniformly distributed over the spherical cap included in the satellite footprint. That footprint, however, is much larger than most continents and there is no land mobile service at sea. Thus we will spread the N_e emitters over an area the approximate size of the continental United States – an area having a 40° central angle (β = 20°).

The area of a spherical cap of central angle β is

$$\text{Area} = 2\pi R^2 (1 - \cos\beta) = a$$

Thus the density of emitters is:

$$\text{density} = \frac{N_e}{\text{Area}} = \frac{N_e}{2\pi R^2 (1 - \cos\beta)}$$

and the number of emitters in an incremental area, *da*:

$$da = 2\pi R^2 \sin\beta \, \mathrm{d}\beta$$

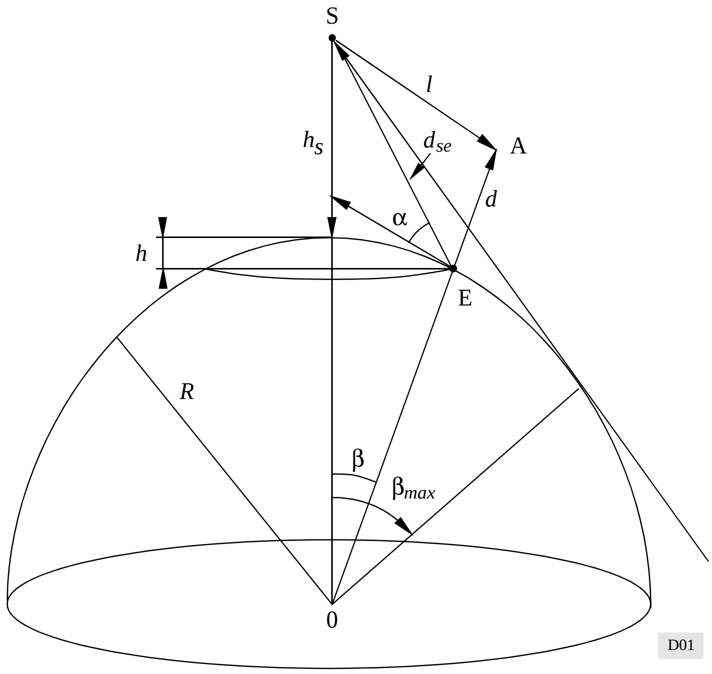
is:

$$dN = \text{density} \times da = \frac{N_e \sin\beta \, \mathrm{d}\beta}{1 - \cos 20°}$$

where β is the angle subtended at the centre of the Earth between the satellite (S) and emitter (E).

FIGURE 1

Geometry for derivation of total noise equation



The satellite receiving antenna has a pattern that partially compensates for the 9 dB greater space-loss experienced by stations at 5° elevation compared to stations directly below the satellite. As an example, the model for antenna gain as a function of elevation angle might be

$$G_{\mathrm{dB}}(\alpha) = 6.5 - \frac{39}{\pi}\alpha$$

where:

α: elevation angle (rad)

G_{dB}: gain (dB).

The gain at the satellite can be expressed in terms of the angle β subtended at the centre of the Earth between the satellite *S* and the emitter *E*. Thus

$$G_{\mathrm{dB}}(\beta) = 6.5 - \frac{39}{\pi}\,\mathrm{arc\,tan}\left(\frac{1}{\tan\beta} - \frac{1}{r\sin\beta}\right)$$

with:

r: $1 + h_s/R$

where:

h_s: satellite height

R: radius of the Earth.

The power received at the satellite from an individual emitter is the power of the emitter less the path loss between that emitter and the satellite. The path loss between *E* and *S* is given by:

$$\text{path loss}_{\mathrm{dB}} = 20\log\left(\frac{\lambda}{4\pi\, d_{se}}\right)$$

or, expressed as a ratio,

$$PL = \left(\frac{\lambda}{4\pi\, d_{se}}\right)^2$$

We will write the path loss in terms of the attenuation A corresponding to the satellite height, that is, at a 90° elevation angle:

$$A = \left(\frac{\lambda}{4\pi\, h_s} \right)^2$$

so we can write:

$$PL = A \frac{h_s^2}{d_{se}^2}$$

consideration of the geometry as shown in the figure yields this expression for path loss:

$$PL = \frac{A(r - 1)^2}{r^2 + 1 - 2r\cos\beta}$$

where:

$A = PL$ at h_s.

The product of average emitter power (P_1), path loss, antenna gain, and incremental number of emitters integrated over the spherical cap of central angle β yields the total interfering power at the satellite.

Thus:

$$P_{TOT} = \frac{P_1\, N_e\, A(r - 1)^2}{1 - \cos 20°} \int_0^{\beta_{max}} \frac{10^{-\left[\frac{39}{\pi} \text{arc tan} \left(\frac{1}{\tan\beta} - \frac{1}{r \sin\beta} \right) - 6.5 \right] / 10}}{r^2 + 1 - 2r\cos\beta} \sin\beta \, d\beta$$

We now need to determine a value representing the number of interferers N_i.

If we assume a traffic of μ erlang per station, the probability for i stations to emit simultaneously is given by a binomial law:

$$p(i) = \binom{N_e}{i} \mu^i (1 - \mu)^{N_e - i}$$

with N_e: total number of emitting stations. With N_e large and μ small, $p(i)$ tends to be a Poisson's law expression (telephone traffic).

In our case, $p(i)$ is a normal law with a mean value m ($m = N_e\, \mu$) and a variance of $\sigma^2 = N_e\, \mu\, (1 - \mu)$.

To obtain the number of simultaneous emitters N_i which will be exceeded with a probability of 1%, we compute as follows:

$$N_i = m + 2.3\sigma$$

$$N_i = N_e\, \mu + 2.3\sqrt{N_e \mu (1 - \mu)}$$

A table of values of carrier-to-noise density can now be computed for various values of N_i and different traffic assumptions. The carrier-to-noise density (CND) is computed by subtracting the interfering noise power from the power of the desired signal. Thus

$$CND = \text{e.i.r.p}_{desired} - PL - \text{other losses} + \text{receiver antenna gain} - P_{noise}$$

An example of this calculation is shown in Appendix 2.

2.2.2 Overall LEO MSS spread-spectrum system performance analysis

The performance of the spread-spectrum LEO MSS system for both the forward and return Earth-to-space and space-to-Earth links in the presence of thermal noise, interference from other users within the LEO MSS system, and interference from terrestrial mobile transmitters has been analysed and is summarized in this section. For a totally spread-spectrum system, the forward and return channels use the same transponder and frequencies, and constitute the intrasystem interference for the desired carriers to be received at the central station and at the user terminals. Accordingly, RF budgets are calculated considering all the possible interferences and the model used will serve ultimately to optimize the system design.

Appendix 2 shows the forward and return, uplink and downlink budgets using conservative values to achieve the adequate system margins.

It is instructive to follow through one complete computation of composite *CND*, including the effects of all interferers. This is done in detail in Appendix 2. The overall approach is described here.

Having computed the carrier level for each of the four links (forward uplink, forward downlink, return uplink, and return downlink), we can treat the interference on each link as the sum of all of the undesired carriers in the receiver. We compute (C/N) resulting from each source of interference and add the various equivalent noise powers. The carrier-to-noise densities combine using the familiar “reciprocal of the sum of the reciprocals” formula. Note that the noise levels are computed per Hz of bandwidth. For a 1.0 MHz bandwidth this in effect adds 60 dB to the carrier-to-noise densities and provides the “spreading” gain.

For example, let us compute the total *CND* for the forward uplink channel. We calculate the C/N_0 resulting from considering thermal noise. The desired signal in this case has a carrier level of C_f dBW. The noise due to interference from the return uplink is n times the return carrier level C_r, where n is the number of simultaneous users. Spread over a bandwidth B, this noise is:

$$N = 10 \log n + C_r - 10 \log B$$

which results in a $(CND)_1$ of $C_f - N$. On this same link, there is also interference from the other $(m - 1)$ uplink channels which have different spreading codes (m: number of spreading codes used).

The “undesired” carriers contribute

$$N_2 = 10 \log(m - 1) + C_f - 10 \log B$$

of noise, giving us

$$(CND)_2 = C_f - N_2 \qquad \text{dBHz}$$

The *CND* of the interfering land mobile systems contribute noise as a function of traffic intensity. For the case of E erlang in the forward link, $(CND)_3$ can be computed as shown in the previous section.

Next we can compute the composite C/N for the forward uplink as:

$$1/(CND) = 1/(CND)_0 + 1/(CND)_1 + 1/(CND)_2 + 1/(CND)_3$$

Note that for the combined spread-spectrum/narrow-band system, there are no “undesired” carriers or interfering mobile systems to consider.

Having computed a composite *CND* for both the uplink and downlink, an overall “up and down” composite can be computed by the same technique. This number is to be compared to the required value which is easily arrived at from the bit rate R_b and the practical value for E_b/N_0.

Thus:

$$(CND)_{reqd} = E_b/N_0 + R_b$$

Thus the *CND* margin is

$$\text{Margin} = (CND) - (CND)_{reqd}$$

Appendix 2 shows a complete analysis for an interference traffic level of 0.05 E. The link budget shown there includes the effect of elevation angle on interference margin. That is, for a given level of interference traffic, an elevation angle can be found for which there is a positive operating margin for the LEO system. For any MSS user terminal within the cone defined by the specified elevation angle, operation with a positive margin is possible.

The analysis can be repeated for different values of interference traffic to produce values of service area as a function of interference. Inspection of the example produced by this analysis method shows how a spread-spectrum LEO MSS degrades gracefully with increasing interference.

2.2.3 A means of reducing potential interference to a LEO MSS spread-spectrum system from high-power, narrow-band emitters

The above calculations assume that all the interfering signals are spread across the spectrum as noise. In this case mobile system base stations will appear to the LEO MSS system as high power narrow-band jammers. There are well-known techniques for combating the effects of such jammers. The technique is to locate the jammer in frequency and then attenuate the jammer with a notched filter. With digital signal processing, it is easy to locate the narrow-band, high-power jammers in the frequency spectrum. One computes the fast Fourier transform (FFT). The signals in question are confined to a band of 1 MHz. By translating the signal down to the band from d.c. to 1 MHz, the signals are well within the frequency range for which digital signal processing chips can compute the FFT as fast as the signals are received in a pipeline processor. Clipping the few sharp peaks that will appear when high-power, narrow-band signals are present is the same as using notched filters. The signals can then be converted back to the time domain by an inverse FFT. The computation could be done by a common signal processor chip set used for cross correlating, Doppler tracking, and Fourier transforms. As the notched filters produce a small distortion of the desired signal, they would probably be used only against the more severe interferers. If there are no more than the equivalent of ten such filters, then there should be no problem with signal detection after the inverse FFT.

For a particular interval of time, we must find the probability that some number of the base stations will transmit during that interval. The data intervals are short compared to the mean holding time of the average land mobile user. Thus it is appropriate to consider the probability of k transmissions being initiated in any mean holding time interval. If, during that interval, k transmissions are initiated, then at some instant of time within that holding time interval, all k will be transmitting simultaneously.

The appropriate formula for the probability of k transmissions in a time interval t given n potential users is

$$p = \binom{n}{k} p^k \, q^{(n-k)}$$

where:

n:	total number of active users
k:	number of transmissions in the designated interval
p:	probability that a station is active in the interval t
$q = (1 - p)$:	probability that a station is inactive
$\binom{n}{k}$:	binomial coefficient.

Since the proposed narrow-band interference rejection system will reject only those base stations that present the maximum signal to the satellite, we wish to compute the probability of exceeding some number of active stations in a given time interval for several cases. For example, if 200 stations have power above the clipping threshold, the probability that more than 10 stations will be active simultaneously (and thus will be clipped) is 5%. If 150 stations have sufficient power to exceed the clipping threshold, the probability that more than 10 stations will be clipped is only about 0.1%.

When the FFT and clipping technique is applied, distortion will result if too many signals are clipped. The distortion of the individual equivalent notched filters is additive. Thus one must set the clipping threshold to eliminate the higher powered base stations and not clip the mobile stations. This can be done without hampering the feasibility or efficiency of the system.

APPENDIX 1

Typical spread-spectrum LEO MSS and land mobile system parameters

Typical spread-spectrum MSS system parameters are shown in Tables 1 and 2. A message input at a certain bit rate is encoded to produce a coded message of a certain symbol rate. Each symbol is “chipped” to produce the output spread-spectrum signal at the chip rate. The resulting spectrum is then filtered to eliminate out-of-band emissions.

TABLE 1

System parameters for a typical LEO MSS totally spread-spectrum system

Orbital altitude, h	1 300 km	
Range at 5°, d	3 753 km	
Orbital period, T	111.6 min	
Overhead pass, T_p	21 min	
Message bit rate, R_b	1 400 bit/s	
Coded symbol rate, R_s	2 800 bit/s	
Chips per symbol, R_c	255	
Output filter Roll-off factor	1.4	
Error probability, P_c	10^{-5}	
Required E_b/N_0, $(E_b/N_0)_r$	2.3 dB theoretical	4.0 dB practical
No. of simultaneous users, N_u	4	
No. of CDA codes, N_c	4	
e.i.r.p. of user	3 dBW (up)	–2.3 dBW (down)
e.i.r.p. of CDA	8.5 dBW (up)	4.0 dBW (down)

TABLE 2

System parameters for a typical spread-spectrum/narrow-band system

Orbital altitude, h Range at 5°, d Orbital period, T Overhead pass, T_p	1 300 km 3 753 km 111.6 min 21 min
Forward link	
Uplink frequency Forward channel, N_c e.i.r.p. of ground station Channel bit rate, r_b Coded symbol rate, r_s Modulation	149.9-150.05 MHz 1 15 dBW 14 000 bit/s 28 000 bit/s OQPSK
Downlink frequency e.i.r.p. of satellite	400.15-401 MHz 13 dBW
Return link	
Uplink frequency Number of simultaneous users, N_u e.i.r.p. of user Message bit rate, R_b Coded symbol rate, R_s Chip rate, R_c Modulation	148-149.9 MHz 7 5 dBW 1 200 bit/s 2 400 bit/s 1 000 000 bit/s QPSK
Downlink frequency e.i.r.p. of satellite	137-138 MHz 8 dBW

Tables 3 and 4 are examples of link budgets for typical spread-spectrum LEO MSS systems. There may be some differences between communication parameters in these tables and those in Tables 1 and 2, but the values shown are nevertheless typical and representative of actual practical values.

TABLE 3

Typical spread-spectrum system link budget for a totally spread-spectrum system

	Forward		Return	
	Up	Down	Up	Down
Net P_t (W)/channel	0.1	2.0	2.0	1.0
G_t (dBi)	16	2.0	1.0	3.0
e.i.r.p. (dBW)	6.0	5.0	3.0	3.0
Space loss, L_s (dB)	147.37	146.76	147.37	146.76
Polarization loss, L_p (dB)	2	2	2	2
Reception loss, L_r (dB)	0.5	2	0.5	2
G_r (dBi)	3.0	1.0	3.0	16
Carrier level (dBW)	–140.87	–144.76	–143.87	–131.76
T_s (dBK)	26.3	27.0	26.3	24.8
G_t/T_s (dB(K^{-1}))	–23.3	–26	–23	–3.3
C/N_0 (dB(Hz))	61.45	56.85	58.45	72.07
R_b (bit/s)	8 334	8 334	4 167	4 167
E_b/N_0 available	22.24	17.64	22.25	35.87

TABLE 4

Typical spread-spectrum/narrow-band system link budget

	Forward		Return	
	Up	Down	Up	Down
P_t (dBW)	–1	11.2	4	–14
Elevation	5	10	10	5
G_t (dBi)	16	1.9	1	3
e.i.r.p. (dBW)	15	13.1	5	–11
L_s (dB)	147.46	154.9	146.3	146.74
L_p (dB)	2	3	3	2
L_r (dB)	0.5	0.5	0.5	0.5
G_r (dBi)	3	1	1.9	16
Received level (dBW)	–131.96	–144.3	–142.9	–144.24
T (dBK)	33.47	28.61	33.47	33.6
C/N_0 (dB(Hz))	63.17	55.69	52.23	50.76
C/N_{users} (dB(Hz))			50.46	
r_b (bit/s)	14 000	14 000	1 200	1 200
E_b/N_0 (dB)	21.7	14.23	21.4	19.97
$(E_b/N_0)_t$ (dB)		13.51		15.5
Margin (dB)		9.11		11.1

APPENDIX 2

Example calculations demonstrating the application of certain sharing methodologies

1. Example of analysis of interference induced by a spread-spectrum LEO MSS system on a land mobile system

Using the parameters shown in Appendix 1 and using the equations found in Annex 1, we can compute separation distances for various situations.

1.1 Analysis of interference induced by MSS user terminals on land mobile receivers

In the case of a land mobile service receiver being subject to interference from a MSS user terminal, we substitute 2 W into the above referenced equation to get a separation distance of 8 km. Land mobile stations may be subject to short bursts of radio frequency energy from spread-spectrum user terminals within an 8 km radius. Assuming a uniform distribution of 1 million users over the usable (5° elevation) footprint of the LEO satellite, only 6 of those users would be in the local region of the station subject to interference. If those 6 terminals were to transmit once per day, and if every transmission were received at a level above receiver sensitivity, then a potential for interference would exist less than 0.0007% of the time. Since the 100 ms burst from a spread-spectrum MSS station is probably too short to break squelch, no interference would be apparent to an inactive receiver. For an active receiver, one whose squelch is already opened by a desired signal, a 100 ms burst might be noticed, but it would not be considered harmful to radiotelephone traffic.

It has been suggested that an upper limit for a non-uniform distribution of spread-spectrum user terminals in the vicinity of mobile stations might be 50 times the uniform value cited above. The resultant potential for interference exists for less than 0.04% of the time.

Thus, sharing between MSS LEO user terminals and land mobile receivers is practical with an appropriate consideration for the separation distance recommended above. Within this separation distance, land mobile receiver performance is expected to be only minimally impacted due to the short burst nature and low duty cycle of MSS transmissions.

1.2 Analysis of interference induced by MSS CDA stations on land mobile service receivers

For spread-spectrum LEO control and data acquisition (CDA) stations, substituting 8.5 dBW for MSS e.i.r.p. into the formula shown in § 2.1 of Annex 1 yields a separation distance of about 11 km which will protect *other services* from the CDA transmissions.

Sharing between MSS LEO CDA stations and land mobile receivers is practical with an appropriate consideration for the separation distance recommended above. Because of the directive nature of the steerable CDA antenna, a nearby mobile receiver will be minimally affected by harmful interference for most CDA antenna elevation angles even if it is within the separation distance.

2. Example of computation of total noise induced by the land mobile service on a spread-spectrum LEO MSS

Typical spread-spectrum LEO MSS systems with overall system parameters as shown in Appendix 1 use 1 MHz of a 1.9 MHz band of frequencies at 148.0-149.9 MHz for the Earth-to-space link. Of the approximately 3 700 total land mobile users in the United States of America, it is reasonable to assume that about 50% are in service at any one time. Assuming a uniform distribution of users over the band and a voice activity factor of 33%, we could expect to have approximately 321 simultaneous users at any time within the United States of America.

A land mobile system normally has one base station and a number of mobile terminals. Base stations have up to 100 W of power. The mobile terminals usually operate with 5 to 10 W. Since the base and mobile stations transmit alternately, a practical assumption is that the average power of all such transmissions is 30 W.

Using the method described in § 2.2.1 of Annex 1, we can compute the effect of these land mobile transmitters on typical spread-spectrum LEO MSS systems. The results of the calculations are summarized in Tables 5, 6, 7 and 8.

It may be of interest to note that when values from Appendix 1 are substituted into the integral for P_{TOT}, the result is

$$P_{TOT} = 2.18 \, N_i \, A$$

or

$$\text{Noise/Hz} = 10 \log(2.18 \, N_i) - \text{A(dB)} - 10 \log(\text{bandwidth}) - 3 \text{ dB polarization loss}$$

$$= 10 \log(2.18 \, N_i) - 201$$

Table 5 shows the power induced by a land mobile system for various values of interference traffic. Values from this table will be used in the example computation of link budget. Tables 6 and 7 show operating margin for a given level of traffic in erlang and a specific value for user-satellite elevation angle. By computing this link budget table for different traffic assumptions and adjusting the elevation angle for non-negative operating margin, Table 8 can be created. Table 8 shows the graceful degradation that a spread-spectrum system will experience in the presence of increasing interference. It should be noted, however, that this performance is highly dependent upon the radiation pattern of the satellite antenna.

3. Experimental measurement of total noise induced by the land mobile service on a spread-spectrum LEO MSS

An experimental French satellite, S80/T, was launched in August, 1992, into an orbit close to one suitable for a LEO MSS system (altitude 1 300 km). Signals in the 148.0-149.9 MHz band received by the satellite are repeated in the 137.0-138.0 MHz band. Experiments conducted with spread-spectrum signals have validated the link budget analysis.

TABLE 5

Example computation of power induced by land mobile systems

Voice factor = 0.3 N_e = 321

Traffic (E)	N_i at 1% (2.3 σ)	P_{TOT} (dB(W/Hz))	Carrier-to-noise density	
			Forward	Return
0.05	22	–184.3	47.93	42.41
0.09	40	–181.7	45.34	39.82
0.13	57	–180.2	43.79	38.28
0.18	74	–179.1	42.69	37.17
0.23	90	–178.2	41.83	36.31
0.27	106	–177.5	41.13	35.61
0.32	121	–176.9	40.54	35.03
0.36	136	–176.4	40.04	34.53
0.4	150	–176.0	39.62	34.10

TABLE 6

Example link budget showing operating margin for specified interference traffic and user terminal elevation angle

Simultaneous users	4
Forward channels	4
RF band (kHz)	1 000
International traffic (E)	0.05
Elevation angle (degrees)	12

	Forward		Return	
	Up	Down	Up	Down
P_t (W)	0.11	1.26	1.58	0.30
G_t (dBi)	18.00	2.50	1.00	0.30
e.i.r.p	8.50	3.50	2.99	–2.30
L_s (dB) (at 12°)	145.87	145.18	145.87	145.18
L_p (dB)	2.00	2.00	2.00	2.00
L_r (dB)	0.50	1.00	0.50	1.00
G_r (dB)	3.50	2.00	3.50	19.00
Carrier (dBW)	–136.37	–142.67	–141.89	–131.48
T_s (K)	450.00	500.00	450.00	475.00
G_r/T_s (dB(K^{-1}))	–23.03	–24.99	–23.03	–7.77
C/N_0 (dB(Hz))	65.69	58.94	60.18	70.35
R_b (bit/s)	8 334	8 334	4 167	4 167
E_b/N_0 (dB)	26.48	19.73	23.98	34.16
C/N_0	65.69	58.94	60.18	70.35
Users *CND*	59.49	59.78	55.23	55.23
Channels *CND*	55.23	55.23	48.47	48.17
Interference *CND*	47.93	100.00	42.41	100.00
Composite U&D	46.88	52.73	41.22	47.37
Fwd & Rtn	45.88		40.27	
Required E_b/N_0	4.0		4.0	
Required *CND*	43.21		40.20	
Margin	2.67		0.08	

TABLE 7

Link budget showing operating margin for specified interference traffic for a typical spread-spectrum/narrow-band system

	Forward		Return		Interf.
	Up	Down	Up	Down	Up
P_t (dBW)	–1	11.2	4	–14	
Elevation (degrees)	5	10	10	5	
G_t (dBi)	16	1.9	1	3	
e.i.r.p. (dBW)	15	13.1	5	–11	
L_s (dB)	147.46	154.9	146.3	146.74	
L_p (dB)	2	3	3	2	
L_r (dB)	0.5	0.5	0.5	0.5	
G_r (dBi)	3	1	1.9	16	
Received level (dBW)	–131.96	–144.3	–142.9	–144.24	–124(1)
T (dBK)	33.47	28.61	33.47	33.6	
C/N_0 (dB(Hz))	63.17	55.69	52.23	50.76	
C/N_{users} (dB(Hz))			50.46		
C/N_{interf} (dB(Hz))					41.1
r_b (bit/s)	14 000	14 000	1 200	1 200	
E_b/N_0 (dB)	21.7	14.23	21.4	19.97	
$(E_b/N_0)_t$ (dB) with interference	13.51		9.17		
Margin with interference (dB)	9.11		4.77		

(1) If higher total interference is received, on-board narrow-band filtering is performed.

TABLE 8

Results of link budget analyses for various interference levels

Traffic (E)	Minimum elevation angle (degrees)	Service area (thousands of km^2)
0.0	0	32 345
0.05	12	21 456
0.09	25	10 094
0.13	35	5 694
0.18	43	3 570
0.23	51	2 175
0.27	60	1 159
0.32	70	475
0.36	90	0