International Telecommunication Union

Supplements 1, 2, 3 and 4

Handbook

Mobile-satellite service (MSS)

Supplement 1

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Supplement 4

Technical aspects of coordination among mobile-satellite systems using the geostationary-satellite orbit

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Inquiries about radiocommunication matters

Please contact:

ITU
Radiocommunication Bureau
Place des Nations
CH-1211 Geneva 20
Switzerland

Telephone:	+41 22 730 5800
Fax:	+41 22 730 5785
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SUPPLEMENT 1

System aspects of digital mobile earth stations

Summary

This Supplement provides characteristics of a digital voice-grade mobile earth station and a low *G*/*T* mobile earth station. Detailed description is also provided for an example of forward error control (FEC) for multi-path fading compensation and enhanced group call system. In § 4.2 and 4.5 of the original MSS Handbook, general explanation was presented for the basic of MSS system engineering. This Supplement is intended to provide the design principles of currently used digital MSS systems together with practical design examples.

Fundamental design examples of digital mobile earth stations

1 Introduction

This Supplement addresses a number of technical aspects to system and communications channel characteristics for digital ship earth station standards, in particular the trade-offs between system requirements for efficient space segment capacity utilization and the user requirements for small, compact shipborne equipment.

The initial maritime satellite communication system was designed to operate with ship earth stations having a *G*/*T* of -4 dB(K^{-1}). It was assumed that digital ship earth station standards introduced later would be characterized by similar or lower *G*/*T* and perhaps smaller antenna size, as summarized in Table 1 below in the case of the Inmarsat system.

TABLE 1

Summary of Inmarsat ship earth station characteristics assumed in the Supplement

Ship earth station standard	Antenna gain (dBi)	*G*/*T* (dB(K^{-1}))	System capability
A	21 to 24	–4	Full range of public correspondence
B	21	–4	Full range of public correspondence and digital data-based communications
M	12 to 15	–13 to –10	Full range of public correspondence and digital data-based communications
C	2	–23	Low data-rate messages

In the shore-to-ship direction for the same type of modulation, it would be possible to provide the same channel quality for a low *G*/*T* ship earth station as for a -4 dB(K^{-1}) *G*/*T* ship earth station by increasing the satellite e.i.r.p. per channel. However, this approach would reduce the channel capacity of the system, since maritime satellite communication systems in Table 1 were power-limited.

In the ship-to-shore direction, the same channel quality could be provided by increasing the power from a low *G*/*T* ship earth station, but this would result in a radiation hazard and the possibility of increased interference to other maritime satellites.

Therefore, it was necessary to consider more efficient modulation and coding techniques which can provide channels at the lower values of carrier-to-noise density ratio (C/N_0).

The concepts denoted in Standard B and Standard C were designed as providing transmit and receive capabilities based on digital modulation and coding techniques, whereas the Standard A system uses FM analogue modulation for telephony. In both cases an access control and signalling system was envisaged, separate from the system which existed at that time and with different channel characteristics which were expected to provide enhanced signalling efficiency and capacity. In the Standard B system, demand assignment of channels was based on forward TDM links which might be used for centralized or distributed access control within each network. Such links, coupled with ship earth station request (random access) and response (TDMA) signalling channels, also enable adaptive power control and satellite spot-beam identification procedures to be implemented. In the Standard C system, communications and signalling information were combined in forward TDM and return random access links, using ARQ techniques.

Section 2 provides the technical design basis of digital system. Link budget considerations were presented in § 3 and § 4 introduces performance characteristics of digital ship earth stations of various cases of G/T. Section 5 describes Inmarsat Standard C communications system. In § 6, a concept of enhanced group call system is introduced.

2 Design basis of digital system

2.1 System concept and application aspects

The introduction of a Standard B system was assumed to represent a means of providing a successor to Inmarsat Standard A ship earth stations for the full range of public correspondence service, including the following:

– telephony, based on digital modulation, coding and speech processing techniques, including voiceband data;

– data for low-speed service (up to around 9.6 kbit/s), including telex and facsimile.

The signalling system and numbering plan adopted for ship earth station would allow interconnection at coast earth stations between the satellite channels and the appropriate terrestrial networks for telephony, telex and data, including the capability for interworking with the integrated services digital network (ISDN).

In addition to the above basic services, it was also assumed that a Standard B system would continue to provide the other capabilities available with Standard A such as telephone and telex distress alerting, ship-to-shore high-speed data at 56 kbit/s.

It was expected that the main services requirement in terms of space segment utilization would continue to be telephony. The introduction of digital techniques would provide the opportunity for saving in satellite power and bandwidth, or a reduction in ship earth station G/T and e.i.r.p. requirements, or a combination of both.

In order to maintain the telephone channel subjective quality currently provided by Standard A (see Recommendation ITU-R M.547), it was assumed that a design objective for Standard B would be to provide good quality telephony under nominal conditions at low satellite elevation angles. Furthermore it was assumed that the satellite e.i.r.p. required to meet these objectives would be comparable to that required for Standard A. By applying voice activation and power control on forward links, the average satellite e.i.r.p. per channel would be further reduced to less than that required for Standard A.

A digital implementation of ship earth station equipment would support a wide variety of data transmission.

2.2 Voice coding techniques

Digital modulation and voice coding techniques could provide the required voice quality more efficiently than analogue modulation. The application of efficient digital voice coding methods would serve to reduce bandwidth requirements which, coupled with forward error correction (FEC) would also reduce the value of carrier-to-noise density ratio (C/N_0) which determines the satellite power requirement in the shore-to-ship direction, the most power-limited link in the system. Such techniques would also serve to minimize ship earth station e.i.r.p. requirements in the ship-to-shore direction. It was expected that the continuing development of LSI circuit technology would enable the necessary digital technique to be realized in a cost-effective manner.

One conclusion to be drawn from the comparison of available voice coding techniques was that the required speech quality objectives could be achievable with 16 kbit/s voice coding rate and a bit error ratio (BER) of around 10^{-2} to 10^{-3}, using adaptive-predictive coding (APC) or sub-band coding (SBC) as the voice coding method. This would also provide the opportunity to achieve a reduction in channel spacing to 20-25 kHz, depending on the modulation and FEC coding technique adopted.

2.3 Modulation techniques

Various digital modulation techniques which were potentially applicable to Standard B would be considered, and the resultant BER performance characteristics, bandwidth utilization efficiency and hardware complexity would be compared.

For shore-to-ship transmissions, filtered 4-PSK would be an efficient modulation technique but because of its varying amplitude characteristics, a liner (Class A) amplifier at the ship earth station would be required for ship-to-shore transmissions. However, offset 4-PSK modulation with smaller amplitude variation would be compatible with existing (Class C) amplifiers, and could be used with only minor degradations in spectral efficiency and BER performance.

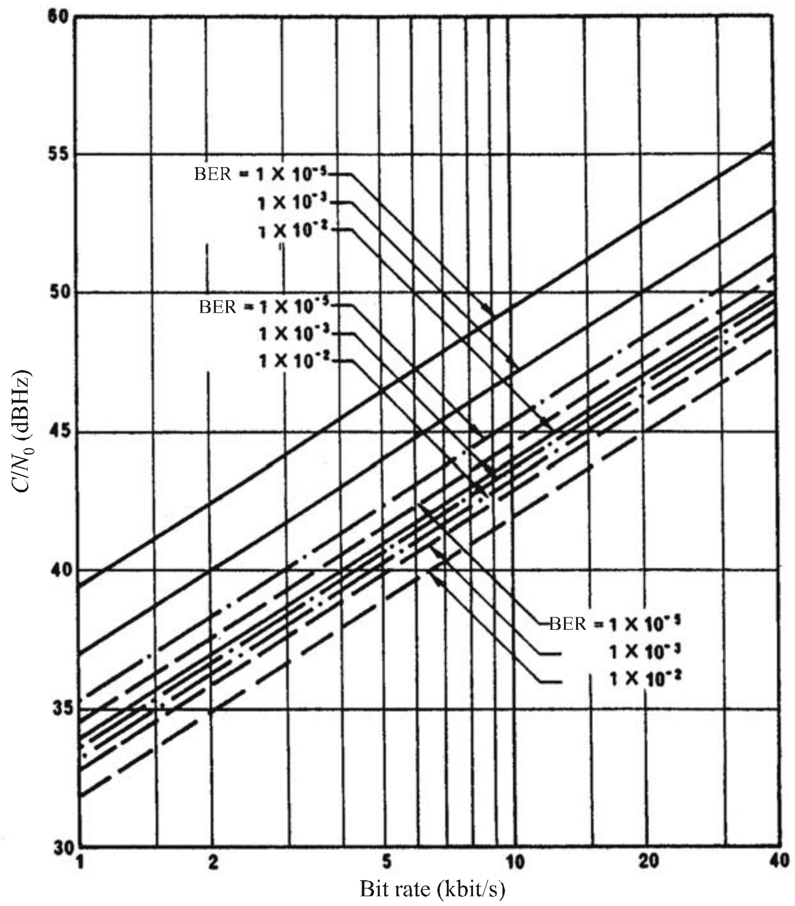
2.4 FEC techniques

The application of FEC to digital channels for voice transmission to and from ship earth stations would enable the value of C/N_0 required to meet the BER criterion derived from the speech quality objective to be reduced significantly, irrespective of the type of voice coding techniques adopted.

Figure 1 shows the C/N_0 requirement for 2-PSK or 4-PSK channels at various bit rates, without FEC and with FEC. For practical application, an additional 1 to 2 dB should be included for implementation margins, although later developments suggested that implementation margins less than 1 dB might be appropriate. It is obvious from the figure that FEC techniques are very effective in reducing the value of C/N_0 for a given bit rate.

FIGURE 1

C/N_0 as a function of bit rate



——— Without FEC

– – – – With FEC, rate 1/2 convolutional coding (k = 7), 8-level soft decision Viterbi decoding

•—•—• With FEC, rate 3/4 punctured convolutional coding, 8-level soft decision Viterbi decoding

($C/N_0 = E_b/N_0 + 10 \log R$, where R: information bit rate)

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Rate 1/2 convolutional coding (constraint length k = 7) with soft decision Viterbi decoding had been widely used in satellite systems and was thus a well-proven technique; implementation in VLSI was available. Coding gains achievable in practice were close to theoretical predictions: around 3.8 dB at 10^{-3} output BER and 5.2 dB at 10^{-5} BER.

Rate 3/4 coding with Viterbi decoding was not at that time as widely applied as rate 1/2 FEC, and required more complex processing. Practical coding gains were of the order of 2.8 dB at 10^{-3} output BER and 4.3 dB at 10^{-5} BER (i.e. about 1 dB less than rate 1/2), but the bandwidth expansion factor was reduced significantly (i.e. 1.8 dB less than rate 1/2).

The complexity of rate 3/4 coding could be significantly reduced by applying "punctured" coding techniques to the basic rate 1/2 code. This required deletion of two bits in every six coded bits in the rate 1/2 coded data stream, transmission of the remaining four bits at rate 3/4, and insertion of two additional bits at the receiver prior to rate 1/2 Viterbi decoding. Another potential application was the implementation of codecs with flexible coding rates switchable between rate 1/2 and rate 3/4. BER performance with punctured coding was only marginally inferior to non-punctured techniques, requiring 0.2 dB additional E_b/N_0 at 10^{-5} BER and essentially no degradation at 10^{-3} BER.

It was concluded that 3/4 FEC offers significant advantages for a Standard B system, providing efficient spectral efficiency and good power utilization. Rate 1/2 FEC could be appropriate to a more power-limited system, where 1 dB savings in satellite and ship earth station e.i.r.p. requirements could be achieved at the expense of less efficient bandwidth utilization.

Further it was noted that after Viterbi decoding all errors, including random errors, appear as burst errors. Also since the transmission quality of digital channels was affected differently by burst and random errors it cannot be directly determined by BER.

In addition in mobile satellite communications both random errors and burst errors due to multipath fading occur. It was, therefore, necessary to evaluate the statistical characteristics of burst errors after Viterbi decoding including the effect of multipath fading.

The output error characteristics after Viterbi decoding had been studied experimentally and statistically [Yasuda *et al*., 1988]. As a result, it was clarified that the error burst under multipath fading conditions was longer than region sandwiched between two error-free continuations of more than 20 bits. Figure 2 shows the results of the measurements by simulation models and Table 2 gives conditions not included in the figure.

FIGURE 2

Measured cumulative distribution of error burst length

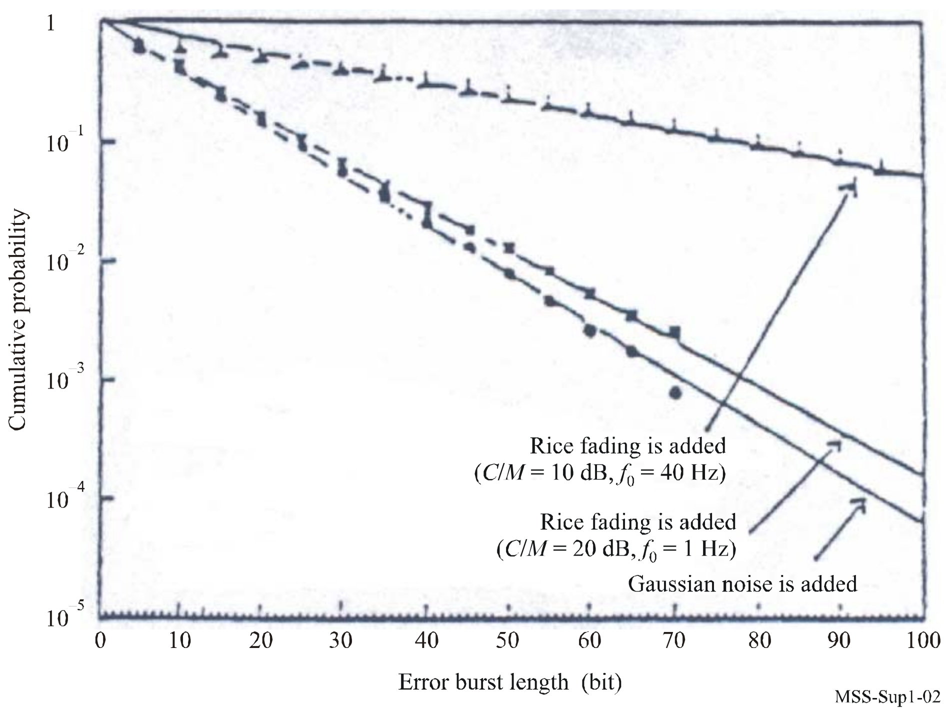


TABLE 2

Major parameters of the measured system

Information bit rate	16 kbit/s
Viterbi decoding	– constraint length: 7 – coding rate: 1/2

2.5 Standard B design example

The following design example describes the Standard B system concept being studied at that time by Inmarsat.

The basic telephony channel uses 16 kbit/s APC voice coding with offset-QPSK modulation and rate 3/4 FEC, to give an effective channel rate of 24 kbit/s over the SCPC satellite link in both directive channel rate of 24 kbit/s shore-to-ship carriers and power control depending on ship earth station elevation of 15-16 dBW per carrier with –4 dB(K^{-1}) ship earth station *G*/*T*. The corresponding ship earth station maximum e.i.r.p. required is 34 dBW for operation to Inmarsat first-generation satellites. Minimum channel separation is 20 kHz to provide for acceptable channel BER performance in the presence of adjacent channel interference.

Table 3 shows the basic parameters of the telephone signal transmission channel of the digital ship earth station system. The system employs 16 kbit/s (switchable to 9.6 kbit/s) voice coding using adaptive predictive coding with maximum likelihood quantization (APC-MLQ) [Yatsuzuka *et al*., 1986], rate 3/4 (switchable to rate 1/2) punctured convolutional coding/soft decision Viterbi decoding [Yasuda *et al*., 1984] and offset-QPSK (OQPSK, switchable to QPSK). The transmission bit rate is 24 kbit/s which results from the 22.4 kbit/s additive data for frame synchronization.

TABLE 3

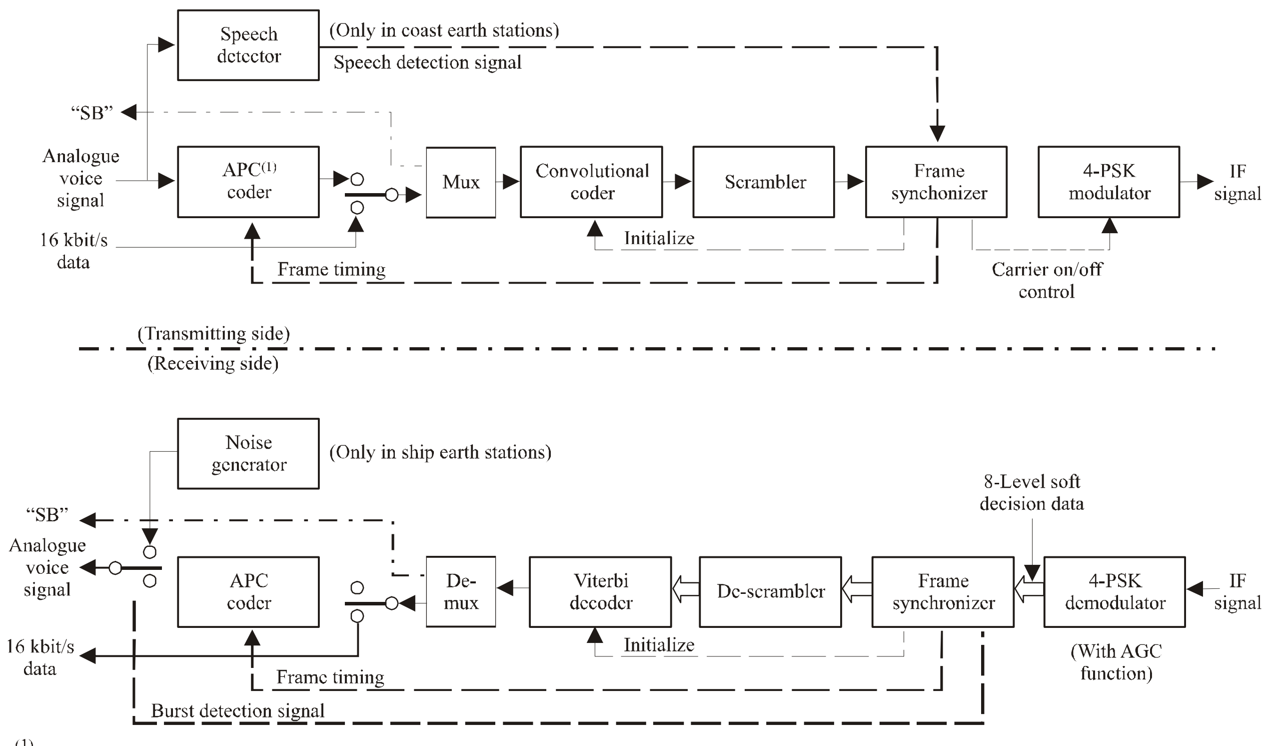
Major parameters of the digital communication channel

Information bit rate	16 kbit/s and 9.6 kbit/s
Voice coding	APC-MLQ (adaptive predictive coding with maximum likelihood quantization)
FEC	Rate 3/4 and 1/2 punctured coding (K = 7)/ 8-level soft decision Viterbi decoding
Modulation	Offset QPSK and QPSK
TX/RX filters	Square root raised-cosine Nyquist filter with 60% roll-off for OQPSK 40% roll-off for QPSK
Transmission bit rate	24 kbit/s
Carrier spacing	20 kHz (minimum)
Operation mode	Voice activation operation in shore-to-ship direction

Figure 3 shows the functional block digital communications unit for the system. In addition to the APC-MLQ codec, the FEC codec and the modem, a speech detector which performs voice activation in the shore-to-ship direction is used in the coast earth station, and a noise generator is provided in the ship earth station to provide a more natural listening environment. Voice activation will allow efficient use of satellite power in the satellite-ship direction.

FIGURE 3

Functional block diagram of communications unit



(1) APC: adaptative predictive coding.

2.6 Advanced areas of system design

The study was required on the following aspects for advanced areas of system design:

– speech quality objectives for the reduced *G*/*T* SESs;

– interconnection with the terrestrial networks;

– telegraphy and signalling arrangements;

– further development and subjective assessment of possible coding techniques, particularly at bit rates around 9.6 kbit/s and below;

– effects of increased multipath fading, with particular regard to modulation and coding methods;

– effects of ship motion on ship earth station antenna performance characteristics.

3 Link budget considerations

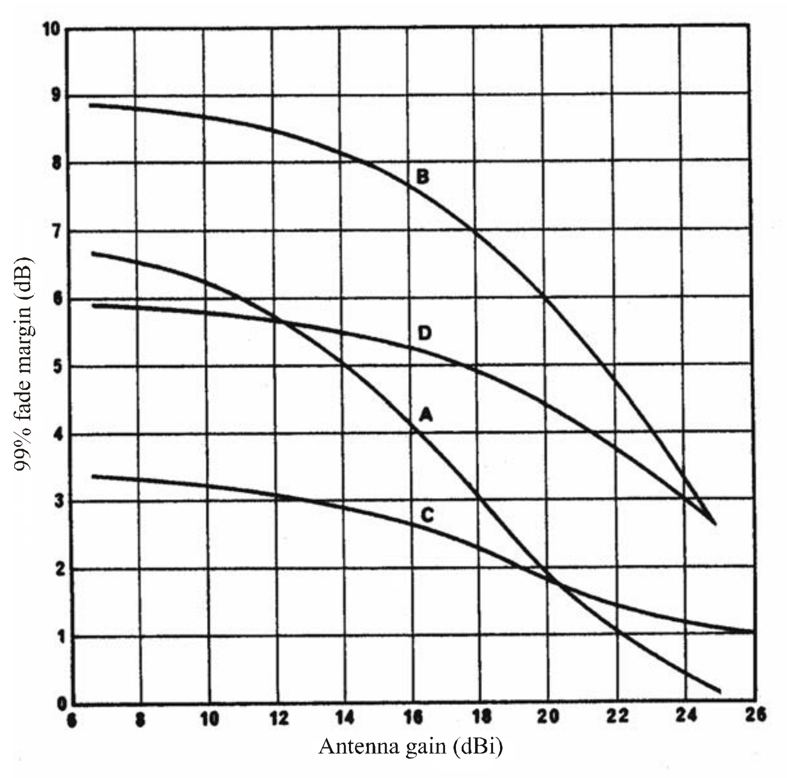
3.1 Multipath fading characteristics

The Standard B and, in particular, Standard C ship earth station concepts indicated a general trend at that time towards smaller antenna system which, in view of their reduced directivity, would be more susceptible than Standard A to multipath fading effects.

Figure 4 shows a simple multipath fading model derived from theoretical considerations and from measurement data (see § 5 of this Supplement). The model is based on antenna directivity for gains in the range 7-25 dBi, and shows fade margins (99% of the time under Rice-Nakagami fading conditions) for “moderate” sea states at 5° and 10° elevation. Also shown is the potential advantage provided by the application of multipath fading reduction (polarization shaping technique) to the antenna system.

FIGURE 4

Multipath fading characteristics
(99% of time Rice-Nakagami fading)



Curves A: 10° elevation angle
B: 5° elevation angle
C: 10° elevation angle with multipath fading reduction (polarization shaping)
D: 5° elevation angle with multipath fading reduction (polarization shaping)

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3.2 Pointing/tracking error characteristics

Pointing/tracking errors for a passively-stabilized ship earth station antenna, due to ship motion, had been studied in Japan. This information could be used to determine link budget losses for representative antenna systems.

3.3 Link budget examples

Example link power budgets for a voice channel BER objective of 10^{-3} are shown for a Standard B ship earth station (Case 1: $G/T = -4$ dB(K^{-1})) and the Standard M system (Case 2: $G/T = -10$ dB(K^{-1})) operating through an Inmarsat second-generation satellite. In the latter case, the potential link quality (C/N_0) improvements due to multipath fading reduction (polarization shaping) are also indicated.

Although these example link budgets are not strictly in accordance with the method described in Report ITU-R M.760, they do indicate that digital modulation and coding techniques provide the opportunity for significant savings in satellite and/or ship earth station transmit power requirements compared to the Standard A system.

NOTE 1 – Values in parentheses for Case 2 show the case using multipath fading reduction technique.

4 Performance characteristics of a digital voice-grade ship earth station

This section presents an example of concept of such a ship earth station employing efficient digital communication technologies [Hirata *et al*., 1984], and its performance characteristics based on the results of a field experiment using two types of antenna system (medium gain and high gain).

4.1 Results of field experiment [Yasuda *et al*., 1987]

A field experiment was carried out using the Inmarsat satellite over the Indian Ocean (INTELSAT V MCS-A), following earth station system [Kashiki *et al*., 1985]. The ship earth station equipment was installed on a sailing vessel which weighs 701 tons.

Two types of ship earth stations were tested in the experiment by employing a high gain antenna and a medium gain antenna. The high gain antenna was an 85 cm diameter parabolic antenna with a gain of 20 dBi and provided a G/T of -4 dB(K^{-1}), (similar to Inmarsat Standard A ship earth station). The medium gain antenna was a 40 cm diameter modified short backfire antenna with a gain of 15 dBi and provided a G/T of -10 dB(K^{-1}), which incorporates a fading reduction function based on polarization shaping [Shiokawa *et al*., 1982].

TABLE 4

Example link budgets for digital voice-grade ship earth stations

Coast earth station elevation angle: 5°
Ship earth station elevation angle: 10°

Shore-to-ship link		
Ship earth station standards	**Case 1**	**Case 2**
Shore-to-satellite (6.42 GHz):		
– CES nominal e.i.r.p. (dBW)	52.0	60.0
– free-space path loss (dB)	200.9	200.9
– atmospheric absorption (dB)	0.4	0.4
– satellite G/T (dB(K^{-1}))	–14.0	–14.0
– up-path C/N_0 (dBHz)	65.3	73.3
– satellite C/IM_0 (dBHz)	60.5	68.5
Satellite-to-ship (1.54 GHz):		
– satellite nominal e.i.r.p. (dBW)	13.0	21.0
– free-space path loss (dB)	188.9	188.4
– atmospheric absorption (dB)	0.2	0.2
– SES G/T (dB(K^{-1}))	–4.0	–10.0
– down-path C/N_0 (dBHz)	49.0	51.0
Overall unfaded C/N_0 (dBHz)	48.6	50.9
Fading loss (dB)	2.0	4.4 (2.7)
Overall faded C/N_0 (dBHz)	46.6	46.5 (48.2)
Ship-to-shore link		
Ship earth station standards	**Case 1**	**Case 2**
Shore-to-satellite (6.42 GHz):		
– CES nominal e.i.r.p. (dBW)	31.0	26.0
– free-space path loss (dB)	188.9	188.9
– atmospheric absorption (dB)	0.2	0.2
– satellite G/T (dB(K^{-1}))	–12.5	–12.5
– up-path C/N_0 (dBHz)	58.0	53.0
– satellite C/IM_0 (dBHz)	69.0	69.0
Satellite-to-ship (1.54 GHz):		
– satellite nominal e.i.r.p. (dBW)	–7.4	–2.4
– free-space path loss (dB)	197.2	197.2
– atmospheric absorption (dB)	0.4	0.4
– SES G/T (dB(K^{-1}))	32.0	32.0
– down-path C/N_0 (dBHz)	55.6	60.6
Overall unfaded C/N_0 (dBHz)	53.5	52.2
Fading loss (dB)	2.0	4.4 (2.7)
Overall faded C/N_0 (dBHz)	51.5	47.8 (49.5)

Table 5 shows major parameters of the high gain and medium gain antennas.

TABLE 5

Major parameters of high gain and medium gain antennas

	High gain antenna	**Medium gain antenna**
Antenna type	85 cm diam. Parabolic	40 cm diam. Modified short backfire
G/*T*	–4 dB(K^{-1})	–10 dB(K^{-1})
e.i.r.p. (max. value)	34 dBW for Class-C HPA 31 dBW for linear HPA	26 dBW
Antenna gain	20.5 dBi	15 dBi
Antenna –3 dB beam width	14°	32°
Antenna axial ratio (beam-centre)	1.8 dB	1 dB
Transmitter output power	25 W (Class-C HPA) 15 W (linear HPA)	20 W (linear HPA)

As for the high power amplifier for the earth station transmitter, either a Class-C HPA with power control capability or a linear GaAs FET HPA [Okinaka *et al*., 1985] was employed for the high gain antenna, while a linear HPA was employed for the medium gain antenna. When a Class-C HPA was used, offset-QPSK modulation was applied to avoid the spectrum regrowth of the modulated signal due to the nonlinearity of the HPA.

In conclusion, the experimental results have demonstrated that digital techniques using forward error correction and voice coding are effective for systems employing medium gain antennas as well as for high gain antennas.

4.2 Performance of an experimental low *G*/*T* ship earth station

This section presents background of tests carried out with an experimental low *G*/*T* SES –13 dB(K^{-1})) of the Standard M type which uses a wide beam width antenna and digital modulation techniques.

This work was performed jointly by the United Kingdom Home Office (now the Department of Trade and Industry), British Telecom International (BTI) and the German Aerospace Research Establishment (DFVLR).

These tests were aimed at demonstrating the practicability of this type of SES, and at evaluating its performance at a bit rate of 2 400 bit/s over the present generation of maritime satellite both in conditions prevailing at high elevation angles, essentially unfaded, and in the multipath fading conditions prevailing at low elevation angles.

Some results from the tests are given Hagenauer *et al*. [1984].

5 Inmarsat Standard C communications system

5.1 Overview

The Standard C communications system was designed to permit the fitting of two-way satellite communications system on board the smallest vessels. It was also accepted for fitting as an alternative to Standard A SESs for satisfying the requirements of the 1988 amendments to the 1974 SOLAS Convention for the GMDSS within the Inmarsat satellite coverage area. Standard C terminals fitted on ship to which the 1974 SOLAS Convention applies are required to meet the IMO performance standards for Inmarsat Standard C SESs capable of transmitting and receiving direct-printing communications (IMO Assembly Resolution A663(16)).

The system offers a two-way message-based communications application that has been designed to interface with the International Telex Network and a wide range of terrestrial data networks. In addition, an oceanwide broadcast only application known as Enhanced Group Call, is carried by the Standard C communication channels.

5.1.1 Briefly the Standard C system is described as follows:

a) the G/T is –23 dB(K^{-1}) utilizing a small omnidirectional antenna which permits design of very small equipment;

b) digital packet transmission techniques are used with TDM shore-to-ship and TDMA ship-to-shore for both signalling and message data;

c) good error correction performance at low carrier to noise densities is expected by use 1/2 rate convolution coding and interleaving;

d) an inter-station (CES and NCS) link permits data exchange for system control purposes;

e) operation in a spot beam environment is facilitated by automatic identification of the satellite spot beam when first turned on.

5.1.2 These techniques permit the following applications to be carried

a) International telex

b) Text broadcasts

c) Interactive data exchange and database interrogation

d) Priority connection for distress purposes.

5.2 Design implications

The adoption of –23 dB(K^{-1}) G/T restricts the system offered to very low data rates and has the following major design implications:

a) the forward and return data rates are restricted to 600 bit/s which, with 1/2 rate convolutional coding and interleaving, permits a high packet success rate to be achieved;

b) for the shore-to-ship direction, a relatively high satellite e.i.r.p. of 21 dBW is needed.

5.3 Link budgets

A Standard C link analysis differs from a typical satellite link analysis, because of the ARQ nature of the Standard C system. In a typical system, there is a defined threshold level of C/N_0 which defines a quality of service and is a deemed a limit of acceptability; the percentage of time in excess of this threshold is the availability. In Standard C, C/N only affects the number of retransmissions, and hence message delay and the system capacity.

The link budgets presented in Table 6 and Table 7 are termed "worst case", and this is defined as:

– SES and CES at 5° elevation;

– minimum values for G/T and e.i.r.p.;

– worst-case transponder loading (i.e. fully loaded transponder and channel having the lowest carrier/intermodulation ratio);

– 99% of time acceptability.

It should be noted that the C/N_0 will be better for most cases, for most of the time.

TABLE 6

"Worst-case" forward link budget
Forward link: 99% of time

Coast earth station e.i.r.p.	(dBW)	60.4
Path loss	(dB)	200.9
Absorption loss	(dB)	0.4
Satellite G/T	(dB(K^{-1}))	–15.0
Mean uplink C/N_0	(dBHz)	72.7
Mean satellite C/I_0	(dBHz)	54.8
Satellite mean e.i.r.p.	(dBW)	20.4
Path loss	(dB)	188.5
Absorption loss	(dB)	0.4
SES G/T	(dB(K^{-1}))	–23.0
Mean downlink C/N_0	(dBHz)	37.1
Nominal unfaded C/N_0	(dBHz)	37.0
Interference loss	(dB)	0.5
Total RSS random loss (99%)	(dB)	2.0
Overall C/N	(dBHz)	34.5
Required C/N_0	(dBHz)	34.5
Margin	(dB)	0.0

TABLE 7

Return link: 99% of time

		MCS	MARECS
Ship earth station e.i.r.p.	(dBW)	12.0	12.0
Path loss absorption loss	(dB)	189.0	189.0
Absorption loss	(dB)	0.4	0.4
Satellite G/T	(dB(K^{-1}))	–13.0	–11.0
Mean uplink C/N_0	(dBHz)	38.2	40.2
Mean satellite C/I_0	(dBHz)	49.0	49.0
Transponder gain	(dB)	150.9	150.9
Satellite mean e.i.r.p.	(dBW)	–26.5	–26.5
Path loss	(dB)	197.2	197.2
Absorption loss	(dB)	0.5	0.5
CES G/T	(dB(K^{-1}))	32.0	32.0
Mean downlink C/N_0	(dBHz)	36.4	36.4
Nominal unfaded C/N_0	(dBHz)	34.1	34.7
Interference loss	(dB)	0.5	0.5
Total RSS random loss (99%)	(dB)	1.7	1.7
Overall C/N_0	(dBHz)	31.9	32.5
Required C/N_0	(dBHz)	31.5	31.5
Margin	(dB)	+0.4	+1.0

5.4 Signal processing system

5.4.1 Signal processing features

Because of the low gain SES antenna, both forward and return links are energy limited, as may be seen from the link budgets. Half-rate convolutional encoding (constraint length $k = 7$) is used to provide forward error correction which can provide in the region of 5 dB coding gain in an unfaded link.

A given bit of information passing through the encoder only has an effect on a group of 14 consecutive symbols, and since the fading bandwidth is very low, all 14 symbols would be equally involved in a fade. To counter the above situation, encoded symbols are assembled into a block before transmission. They are then transmitted in a different order to that in which they were assembled. The effect of this process is to spread transmission of the 14 symbols associated with a given data bit over a length of time which is large compared with a fade duration.

Therefore only some of the 14 symbols may be corrupted due to one typical fade, and the redundancy built in to transmitted symbol stream allows reconstruction of the original data stream.

The above is true for the continuous mode forward TDM channels, and the quasi-continuous SES message channel. For the burst mode SES signalling channel, interleaving is not applied because the bursts are too short for it to have any useful effect.

Scrambling of data has been applied to all the channels. Although it is not necessary for energy dispersal due to the low bit rate it is necessary to ensure adequate symbol transitions for the demodulator clock recovery. Message with a high pattern content (e.g. tabulations) can interact in the interleaver to produce much longer sequences without symbol transitions than might be expected with random data.

5.4.2 Signal processing effects

A relatively short ($k = 7$) constraint length has been selected to allow use of maximum likelihood decoding techniques (such as the Viterbi algorithm).

It is in the nature of convolution decoders to generate errors in burst, and different implementations of different decoder algorithms can produce a wide variation of error burst characteristics.

As the Standard C system is basically a packet system with ARQ, the prime performance parameter is packet error rate. Packet error rate in practice is highly dependant upon burst error rate but almost independent of the number of bits in a burst. For this reason bit error rate is not a useful metric for the Standard C mobile channels.

As a baseline for defining performance limits, a Viterbi decoder has been assumed operating on 3 bit soft decision samples.

5.5 FEC performance

Measurements of FEC performance with antenna systems of the Standard C type are reported as a means of compensating for multipath fading effects. These measurements show that it will be necessary to use FEC with interleaving in order to improve channel error performance on faded links of a Standard C system with continuous transmissions. The performance of coded DECPSK transmission over the Standard C maritime channel was measured by means of the DFVLR channel-simulator test set-up with a modem of new design using a COSTAS-loop combined with an AFC loop (automatic frequency control), in order to recover carrier and data of the DECPSK signal channels (Rayleigh-channel, Rice-Nakagami-channel with $C/M = 6.3$ dB) as well as for a representative selection channels includes the worst case of 4° elevation angle for all tested antennas C3, C5, C11, C14 and the 19° elevation test for antennas C3 and C11 (Standard C antennas with gains in decibels as indicated). The details are provided in Report ITU-R M.762 and [Hagenauer *et al*., 1984].

6 Enhanced group call system

6.1 Overview

The enhanced group call (EGC) system is a global data broadcast system for commercial group calling, global paging (FleetNET™) and the dissemination of maritime safety information (SafetyNET™). The system is part of Inmarsat's Standard C System and makes use of Standard C common channel TDMs for the transmission of shore-to-ship messages.

The International Convention for the Safety of Life at Sea, 1974, as amended in 1988, requires that every ship be provided with a radio facility for reception of maritime safety information by the Inmarsat enhanced group calling system if the ship is engaged on voyages in any areas of Inmarsat coverage but in which an international NAVTEX application is not provided. The SafetyNET application provides the maritime safety information, including shore-to-ship distress alerts, NAVAREA navigation and meteorological warnings as well as routine weather forecasts may be selectively received by vessels technique. EGC receivers carried on ships to which the 1974 SOLAS Convention applies, are required to meet the IMO performance standards for EGC equipment (IMO Assembly Resolution A. 664)16)).

The FleetNET^{TM} system allows shore-based commercial users to selectively call groups or individual vessels with pre-assigned IDs.

6.2 System description

EGC messages are transmitted on Standard C common channel (NCS) TDMs along with Standard C signalling traffic. This allows EGC terminals to be based on a compact, low cost, low *G*/*T* receiver since use is made of the very robust modulation and coding techniques employed for the Standard C System. The receivers may be self contained, stand alone units, or integrated with Standard C or Standard A SESs. Integration with a Standard C SES doses not necessarily require a second receiver, since the Standard C receiver is monitoring the common channel TDM when it is not engaged in traffic. EGC messages are forwarded from the terrestrial network to the Standard C NCS via a Standard C CES.

The operational bandwidth of the EGC system extends from 1 530 to 1 545 MHz with a 5 kHz channel spacing. Adjacent ocean regions will have different frequencies for the EGC carriers. The frequencies of these carries are stored by the receivers so that they may automatically retune once a vessel leaves one ocean region and enters another. Receivers are capable of storing many channel frequencies to allow for expansion and compatibility with future spot beam satellite payloads.

6.3 Addressing techniques

There are three basic methods of addressing EGC receivers, these are:

– unique ID addressing (FleetNET^{TM});

– group ID addressing (FleetNET^{TM}); and

– area addressing (SafetyNET^{TM}).

EGC receivers that are capable of receiving commercial FleetNET^{TM} messages have a unique 24 bit identity and a number of 24 bit group identities. The group identities are downloadable and erasable over the satellite link. Addressing within the SaftyNET^{TM} application is performed exclusively on the basis of geographical area. Two types of geographical area addressing are possible:

a) predefined geographical areas, such as NAVAREAs, WMO areas, NAVTEX coverage areas and SAR areas;

b) absolute areas are defined in terms of a coordinate and a latitudinal and longitudinal extension (rectangular area addressing), or a coordinate and a radius in nautical miles (circular area addressing).

Receivers may be automatically updated an external navigational instrument and operators may select other areas of interest such as those lying on the vessels expected course.

6.4 Summary

The EGC system provides an effective means for disseminating maritime safety information and for the transmission of shore-to-ship commercial group calls and paging messages. Vessels equipped to receive EGC messages only need a simple low cost receiver, or alternatively, a suitably equipped Inmarsat Standard A or Standard C SES may be used.

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SUPPLEMENT 2

Methodology for the derivation of interference and sharing criteria for the mobile-satellite services

Summary

This Supplement provides a methodology to derive interference sharing criteria for mobile satellite services. Since the desired and interference signal levels vary depending upon many factors, the interference criteria is derived for two percentages of time, one for long term performance and the other for short term performance. The basis for criteria on total interference is explained in § 3 of this Supplement. The interference criteria for both service links and feeder links are also explained in this Supplement. In addition, different propagation factors to be considered in the derivation of interference criteria are also given. Some elements on the coordination threshold and coordination distances are described.

A method to derive interference sharing criteria for mobile satellite services

1 Introduction

A mobile-satellite system (MSS) can utilize a wide variety of channels in order to provide services that fulfil various communication needs of aircraft, ship or land mobile earth stations. Network control data, facsimile, video and voice communications channels may be provided. The performance and link characteristics associated with these channels may differ and consequently, the tolerance of each communication to interference may differ. This Supplement proposes a structured approach for developing interference and sharing criteria for the mobile-satellite service. The statistical aspects are reviewed and methodologies are described for the determination of maximum permissible total and single-entry interference power levels.

2 Statistical considerations

In MSS, the desired signal and noise power levels vary with operating and environmental conditions in such a manner that system performance is best portrayed as a statistical parameter. Interfering signal power levels vary for similar reasons. Consequently, interference criteria should be specified with two components:

a) a threshold that defines a limit on interfering signal power; and

b) a percentage of time and for land mobile-satellite service (LMSS), a percentage of locations, that defines the probability of exceeding the interference threshold. Criteria should be developed for at least two percentages of time and locations in order to control the variability of interference and absolute levels of performance.

"Long-term" criteria are used to establish the maximum permissible interference that should not be exceeded for more than X% of the time and if appropriate, for LMSS, Y% of locations. The percentages of time (and locations) correspond with those for the long-term performance objective (e.g. 10%-50%). These interference levels and the long-term desired signal and noise power levels define the long-term system performance.

"Short-term" criteria are used to establish the maximum permissible interference that should not be exceeded for more than a small percentage (M%) of the time (and, for LMSS, N% of locations).

Long- and short-term permissible interference criteria should be developed for both total interference (i.e. the total from all sources) and single-entry interference (i.e. from one source).

3 Basis for criteria on total interference

Performance objectives for communication circuits are specified in terms of baseband performance thresholds and associated percentages of time and locations for which the thresholds are to be exceeded. These objectives can be converted to ratios of the desired signal power to the sum of noise and equivalent-noise-like interfering signal powers. System link power budgets associated with the percentages of time and locations specified in the performance objectives can be computed for representative systems to determine the achievable performance in the absence of inter-system interference (e.g. as in Report ITU-R M.760). Furthermore, permissible levels of inter-system interference must be included in a statistical manner in these link power budgets in order to compare the required and achieved levels of performance. The following equation defines this relationship, assuming that the total effect of multiple interfering signals is noise-like.

$$\frac{C}{(N+I)_t}(p) = \left[\left(\frac{N}{C} + \frac{I}{C} \right)_{mob} + \left(\frac{N}{C} + \frac{I}{C} \right)_{fdr} \right]^{-1} (p) \qquad (1)$$

where the symbols "*mob*" and "*fdr*" denote service link (i.e. 1.5/1.6 GHz link) and feeder link parameters, respectively, and:

$C/(N+I)_t(p)$: ratio (numerical) of desired signal power to the total noise plus total interference power, to be exceeded for all but p' of the time and locations

N/C: ratio (numerical) of total intra-system noise power to desired signal power (relates to performance achieved in the absence of inter-system interference)

I/C: ratio (numerical) of aggregate interfering signal power to desired signal power.

The system performance in the absence of inter-system interference (i.e. N/C values in equation (1)) is limited by various intra-system performance degradations (e.g. receiver thermal noise, inter-modulation noise, etc.). Additional intra-system degradations occur in systems employing frequency reuse (e.g. among satellite antenna spot beams). Thus, as has been the case for the fixed-satellite service, different interference criteria may be applicable to systems employing frequency reuse. In any case, the performance degradation attributed to the permissible level of interference should not exceed some fraction of the intra-system degradation in order to assure that the system designer and operator has good control over performance.

There is precedent in the Earth exploration-satellite and meteorological-satellite services for setting the long-term allowance for interference at 25% or more of the total noise plus interference power level. The fixed-satellite service (FSS), for which orbit and spectrum resources are in high demand and use, allows 35% of the long-term total *noise* in a FDM/FM telephone channel to result from inter-system interference, or 30% in the case of systems employing frequency reuse (Recommendations ITU-R S.353 and ITU-R S.466). These percentages are comprised of up to 10% from terrestrial fixed network interference and the remainder of 20% to 25% from fixed satellite network interference. However, in considering the use of such ratios of interference power to total noise plus interference power for the mobile-satellite services, the impact on performance and system capacity (for a given performance level) should be carefully evaluated.

The link performance can be degraded to levels associated with a performance threshold by fading of desired signals or by increases of the interfering signal levels. Performance margins should be designed so that interference does not degrade link below the performance objectives.

4 Development of the interference budget

4.1 Budgeting between feeder links and service links

Fixed-satellite service allocations are typically used for feeder links; thus, each half of a channel (uplink or downlink) is subject to different interference environments and may have different interference criteria.

Short-term interference considerations also affect the C/N and C/I requirements of mobile-satellite circuits. Short-duration shadowing and multipath effects may control the C/N and C/I budgets, in the service link at 1.5/1.6 GHz, especially for networks in the land mobile-satellite service. As well, if feeder links above 10 GHz are used short-term fading due to rain attenuation may control the feeder-link noise and interference budgets.

A fundamental design consideration in developing mobile-satellite systems is that the net C/N (including C/I contributions) should be largely established by the service links; i.e. the feeder links should only provide a small degradation (trade-offs in system design, e.g. to take into consideration the very low availability of feeder link e.i.r.p. in the space-to-Earth direction in early systems, have necessitated compromising this design consideration).

4.2 Criteria for service links

The desired signal power levels at 1.5/1.6 GHz generally experience wide and rapid variations. The same is true of interfering signals at these frequencies, which generally vary independently of the desired signals. Thus, given the performance requirement for a service link (i.e. derived using equation (1), the performance objective, and the budgeting between feeder and service links), the permissible aggregate interference level could be determined in a statistical analysis of desired and interfering signals. Further, given an assumed number of interferers, a statistical analysis could be performed to determine permissible single entry levels of interference. Annex 1 of Report ITU-R M.1179 describes how these interference budgets could be determined. A description of coordination thresholds for these links is discussed in § 7.

4.3 Criteria for the feeder links

In the feeder downlink, the desired signal power level generally experiences the same variations as the service uplink signal when the transponder is used in the quasi-linear region. Therefore, the methodology used for the feeder downlink should be similar to that for the service uplinks.

In the feeder uplinks, where the desired signal is within about 1 dB of its mean value for large percentages of the time (e.g. >95%), simplifying assumptions can be made in deriving the interference criteria. Specifically, the permissible "long-term" total interference power levels can be based on analyses of performance expected for the mean value of the desired signal. The "short-term" interference criteria can be established from an analysis of "unfaded" performance because of the small joint probability of interference increasing to levels experienced for only small percentages of time while the desired signal is also faded to levels existing for only small percentages of time. Section 6 provides a method for determining feeder uplink interference criteria based on these assumptions.

5 Derivation of interference criteria

This section of the supplement considers the derivation of interference criteria for the service links operating at 1.5/1.6 GHz and feeder downlinks.

5.1 Introduction

Mobile-satellite systems operating in the 1.5/1.6 GHz portion of the spectrum will need to accommodate a large range of service requirements that include both varying (analogue and digital)modulation techniques, a variety of bandwidths and data rates, and a variety of transmitter power levels. There are significant variations in the e.i.r.p., bandwidth and performance margins among the various channels used in the service links provided in mobile-satellite systems. Each type of link should be evaluated separately. However, it is anticipated that several types of links will be seen to have similar interference criteria.

5.2 Interfering services to be considered

Interference to the service links of a mobile-satellite system operating in the 1.5/1.6 GHz bands will be caused by emissions of space stations and mobile earth stations operating in other mobile-satellite systems. Interference to the service links operating in certain portions of the 1.5/1.6 GHz bands will also be experienced from emissions of systems in the fixed service operating in specific geographical areas. Interference to feeder downlinks can be experienced from other services operating in these bands.

5.3 Propagation factors

The service link signals of mobile-satellite systems are primarily affected by reflection and scattering from the surrounding terrain (e.g. the ground, the oceans and buildings), by shadowing from obstructions (e.g. buildings and trees) along the Earth-space path, and by diffraction from nearby obstacles. These links are also affected, but to a much lesser extent at 1.5/1.6 GHz, by the ionosphere, the troposphere, and by precipitation. Recommendations ITU-R P.680 and ITU-R P.681 describe the propagation effects experienced in maritime and land environments at frequencies above 100 MHz, respectively. Aeronautical environments are also being studied in Recommendation ITU-R P.682. Of the three types of operating environments, the propagation effects on land mobile-satellite links are the most severe.

The statistics of propagation loss depend on the local environment. Theoretical studies and measurements made for links show that multipath signals are Rayleigh distributed. The mean power of the multipath signals relative to the power of the unattenuated line-of-sight (LoS) signal is dependent on the antenna radiation pattern, the elevation angle of the antenna, and the characteristics of the physical media from which the multipath signals are scattered. If the receiving antenna does not completely discriminate against the multipath signal and the LoS signal is not severely attenuated, then the distribution of the envelope of the received signal may be modelled by the Rice-Nakagami distribution function. Measurements have also shown that the distribution of the LoS signal power under conditions of shadowing (e.g. by trees or other obstacles) is suitably approximated by a log-normal distribution. Thus, for all environments, the statistical variation of the envelope of the received signal may be modelled as a compound process. The fluctuations of the instantaneous received signal power can be modelled as a Rice-Nakagami process in which the amplitude of the “constant” signal is assumed to be a log-normal process. A rather comprehensive discussion of the mathematical details of this compound process is given in Recommendation ITU-R P.1057.

However, it should be noted that those mathematical models might not be accurate enough, especially in the region of extremely high or low signal levels where the probability of occurrence of such levels is very low.

Interfering signal levels will be affected by similar propagation factors. Nevertheless, the line-of-sight (LoS) interference level can be used as a representative value for most ~ of the time in cases where we consider the interference from other mobile-satellite networks, provided that the elevation angle of the desired and interfering signal paths are not too low (e.g. <5°).

In considering short-term interference criteria, short-term increases of the interference levels due to multipath mechanisms should be taken into account, especially in cases where the mobile earth station is over the sea. Increases of up to 5 dB over the LoS level may be experienced from such effects.

The analyses should take into account the effects of differences between the elevation angles of the desired and interfering signals or the earth station antenna discrimination and the consequential differences in the distribution functions of desired and interfering signals. Elevation angles must be considered when the sharing criteria are applied, but the effects of earth station antenna discrimination can be encompassed in the interference criteria. Furthermore, the effect of intra-system *noise* must be included.

The total interference levels can be determined by convolution of the probability density functions of the assumed individual interference entries. These relationships between required performance and aggregate and single entry interference levels can be used to determine the permissible levels of interference to service links.

6 Derivation of permissible single-entry interference criteria for feeder uplink

6.1 Allocation of interference criteria among space and terrestrial services

Earth-to-space frequency allocations used for the mobile-satellite service, generally require sharing among mobile-satellite systems, sharing with systems in terrestrial services and, in some cases, sharing with systems in other space services. An initial division of the short-term (enhanced) and long-term (near-median) interference criteria can be made to establish separate interference budgets for the space service and terrestrial service. This procedure facilitates the determination of appropriate sharing criteria and coordination thresholds for space and terrestrial systems, which are generally present in differing numbers and which might-pose interference potentials of different severity.

The following equations can be used for this subdivision:

$$I_s(x) = I(x) \cdot \frac{A_s}{100} \tag{2}$$

$$I_t(x) = I(x) - I_s(x) \tag{3}$$

where:

I_s: interference (W) budget for space service

I_t: interference (W) budget for terrestrial service

A_s: per cent of total interference power budget allocated to the space service

$I(x)$: total permissible level of interference power (W) to be exceeded for no more than x% of the time, where x is associated with the long-term performance objective.

$$I_s(p_s) = I(p) - I_t(x) \tag{4a}$$

$$I_s(p_t) = I(p) - I_s(x) \tag{4b}$$

$$p_s = p(a_s/100) \tag{5a}$$

$$p_t = p - p_s \tag{5b}$$

where:

p: percentage of time associated with the short-term interference criterion

p_s: percentage of time that space services may exceed the interference threshold

p_t: percentage of time that terrestrial services may exceed the interference threshold

a_s: portion (%) of the percentage of time p allocated to the space services

$I(p)$: total interference power (W) to be exceeded for no more than p% of the time (i.e. short-term interference criterion).

In equations (2) and (3), the long-term interference criteria are subdivided on a power basis among space and terrestrial service interference categories. This is justified in that these long-term space and terrestrial interference levels can be expected to be present simultaneously.

The short-term interference criteria are subdivided in equations (4) and (5) on a percentage-of-time basis among space and terrestrial service interference categories. Short-term enhanced interference levels are not likely to occur simultaneously for both space and terrestrial services owing to the uncorrelated mechanisms that cause these enhancements. However, the interference from the space services at its long-term level must be considered when the short-term interference budget is established for the terrestrial services; likewise, from the terrestrial services to the space services. Thus, in equations (4a) and (5a) the long-term interference associated with the space service is assumed to be additive with the short-term interference associated with the terrestrial service.

Values for the-interference power apportionment (I_s and I_t) and time apportionment (p_s and p_t) in equations (2) to (5) should be selected so as to correspond with the relative interference levels that can be expected from a typical environment of terrestrial and space service interferers in order to minimize constraints resulting from adoption of sharing criteria.

6.2 Considerations for the establishment of sharing criteria

6.2.1 Single-entry interference criteria

Subdivisions of the total interference and time allowances for space and terrestrial interferers can be made to establish appropriate permissible levels of interference from individual interferers (i.e. "single entry" interference). Equations (6) and (7) below can be used for this purpose:

$$I_{X'}(x) = \frac{I_X(x)}{n} \tag{6}$$

$$I_{X'}(p_{X'}) = \frac{I_X(p_X)}{y_n} - \left(I_{X'}(20) \cdot \frac{1-y}{y} \right) \tag{7a}$$

$$p_{X'} = \frac{p_X}{y_n} \tag{7b}$$

where prime (′) parameters denote single-entry values and:

- $I_x(x)$: total permissible interference power level (W) budgeted for space or terrestrial services to be exceeded for no more than X% of the time
- $I_x(p_x)$: total permissible interference power level (W) budgeted for space or terrestrial services to be exceeded for no more than p_x% of the time
- n: effective number of space or terrestrial interferers
- y: the fraction of interferers at an enhanced level, $0 < y < 1$.

Equations (6) and (7) are similar in nature to equations (2) to (5). Long-term interference allowances are subdivided on a power basis and short-term interference allowances are subdivided on a percentage-of-time basis. In equation (7), only some of the interference entries are assumed to be enhanced to their short-term values and are, therefore, uncorrelated. While these interference entries are at an enhanced level, all other entries are assumed to be at their long-term levels. The sum of these long-term levels is assumed to be ($n – y_n$) times the long-term single entry interference allowance.

7 Coordination thresholds and sharing criteria for 1.5/1.6 GHz links

7.1 Coordination among satellite systems

Potential interference among satellite systems is examined in the course of coordination under RR Article 11 to determine what, if any, design or operating constraints are necessary to ensure that interference will remain below acceptable levels. Single entry permissible interference levels define the minimum acceptable levels of interference for use in coordination. RR Appendix 8 prescribes a method for determining when this coordination should be conducted. Coordination is triggered when a small increase in link noise temperature is predicted under worse-case conditions (i.e. a 6% increase). As a practical matter, the low discrimination of mobile earth station antennas at 1.5/1.6 GHz would almost always trigger coordination under this procedure, provided that a mobile earth station from one system has line-of-sight visibility to the satellite of the other system. Thus, this visibility condition appears to be a practical approach for determining when coordination should be conducted among mobile-satellite systems operating at 1.5/1.6 GHz, except when the satellite coverage areas are completely separated.

7.2 Interference caused to satellite receiver by terrestrial stations

Criteria for sharing near 1.6 GHz among transmitting stations in the terrestrial services and receiving space stations can be developed from the aggregate long-term permissible level of interference budgeted for this interaction (see Annex l to Report ITU-R M.1173).

Coordination is not used as a method for governing this interference interaction. Instead, applicable sharing criteria have the form of e.i.r.p. and antenna input power and pointing limits on the terrestrial stations. The aggregate interference from terrestrial stations can be expected to have a low temporal variability, thus assuring that the relatively stringent long-term interference criteria will dominate the sharing when the method of Annex l is applied. These sharing criteria have been developed for other bands on the basis of assumptions as to the deployment and characteristics of the terrestrial stations.

7.3 Coordination distances

Criteria for sharing between mobile earth stations and terrestrial stations can be developed in accordance with the protection area concept. The high temporal variability of propagation losses over terrestrial signal paths generally requires that both short-term and long-term interference criteria be applied. Coordination areas can be computed for land and ship mobile earth stations using the method of RR Appendix 7. For aircraft earth stations, coordination areas can be constructed using coordination distances based on line-of-sight propagation paths between the aircraft and terrestrial station. Assuming that an aircraft earth station may be operated at altitudes as high as 12 km, and that the refraction of the atmosphere causes a 4/3 effective Earth radius, the LoS distances would be 450 km and 900 km with respect to other stations on the ground or in an aircraft, respectively. Allowing for somewhat higher atmospheric refractivity, the coordination distances for aircraft should be taken to be 500 km and 1 000 km for sharing with terrestrial stations located on the ground and in aircraft, respectively. Further study of coordination distances is required.

SUPPLEMENT 3

Interference and noise problems for maritime mobile-satellite systems using frequencies in the region of 1.5 and 1.6 GHz

Summary

This Supplement explains the potential interference and noise problems for maritime mobile satellite systems in 1.5/1.6 GHz frequency band based on theory as well as practical measurements and experiments. In § 2, different kinds of interference sources to maritime mobile satellite systems are identified. In the remaining sections, interference from ship borne maritime satellite transmitters to different victim systems is explained.

Interference and noise problems for maritime mobile-satellite systems using frequencies in the region of 1.5 and 1.6 GHz

1 Introduction

Operational maritime mobile-satellite systems will employ at least frequencies in the region of 1.5 and 1.6 GHz for the satellite-to-ship and ship-to-satellite links respectively. This supplement gives results of a theoretical investigation of the potential interference to a maritime mobile-satellite system from different sources and of the interference caused to other systems from the maritime mobile-satellite systems at such frequencies. Results of practical electromagnetic (EM) noise measurements in harbours and on-board ships at sea are summarized. Finally, consideration is given to other sources of noise at these frequencies such as extra-terrestrial noise and receiver noise temperature.

2 Interference to maritime satellite systems

2.1 Interference from radar altimeters

Radar altimeters can interfere with the shipboard satellite receivers when aircraft with operating altimeters are in the shipboard antenna beam. It is understood however that the number of radar altimeters operating in this band is diminishing. Radar altimeter operation may be restricted to the high end of the allocated band to reduce the chances and duration of interference.

2.2 Interference from aeronautical satellite systems

An aircraft transmitter of an aeronautical satellite system is not expected to cause interference to a maritime satellite system shipboard terminal, even while radiating into the main beam of the shipboard antenna.

2.3 Interference from out-of-band radar emissions

The air search radar such as the AN/SPS-29 can be considered a potential radio-frequency interference problem. This EM noise source can be suppressed by the insertion of a simple commercially available RF coaxial filter at the transmitter. Similarly the interference from 10 cm surface search radar can also be suppressed with a simple commercially available waveguide filter located at the transmitter output. There was no evidence of Band 9 noise originating from 3 cm surface search radars used by government and merchant ships.

2.4 Interference from existing shipborne communications equipment and associated high voltage insulators

HF ship transmitter emissions may lead to interference in satellite channels of ship earth stations. The results of theoretical and experimental assessment of this effect are shown below.

2.4.1 Theoretical aspects

A criterion for identifying the extent to which the HF transmitter emissions can affect the ship earth station operation is the susceptibility threshold of the ship earth station receiver. The threshold of susceptibility is assumed to be receiver sensitivity level calculated for the corresponding frequencies, f_{SR}, which are capable of producing spurious responses and may be represented by the following expression:

$$f_{SR} = \frac{pf_{LO} \pm f_{IF}}{q} \pm \frac{B_R}{2q} \tag{1}$$

where:

- f_{LO}: local oscillator frequency (MHz)
- f_{IF}: first intermediate frequency (MHz)
- B_R: dB bandwidth at the first intermediate frequency (MHz)
- p, q: harmonic number of local oscillator and interfering signal, respectively ($p, q = 0$, 1, 2…, etc.).

The receiver spurious response susceptibility threshold at the receiver input, $P_R(f_{SR})$, can be expressed as:

$$P_R(f_{SR}) = P_R(f_{OR}) + I \log \frac{f_{SR}}{f_{OR}} + J \tag{2}$$

where:

- $P_R(f_{OR})$: receiver fundamental sensitivity (dBm)
- f_{OR}: receiver fundamental frequency (MHz)
- I, J: constants for characterizing receiver off-tune rejection (dB/decade and dB respectively).

The interference signal power produced by HF transmitters emissions at ship earth station receiver input, $P_1(f_{SR})$, is determined for transmitter fundamental harmonics in accordance with the following equation:

$$P_1(f_{SR}) = P_T(f_{OT}) + A \log n + B - L_c \tag{3}$$

where:

- $P_R(f_{OT})$: fundamental power (dBm)
- n: harmonic number of transmitter frequency (f_{OT}) relative to receiver spurious response frequency (f_{SR}), $n = f_{SR}/f_{OT}$
- A, B: constants for characterizing transmitter harmonic emission levels (dB/decade and dB respectively)
- L_c: coupling loss (dB) including propagation, receiver antenna and transmitter antenna effects.

In more detail, L_c can be expressed as:

$$L_c = 10 \log \eta_{af} + 20 \log \frac{\lambda}{4\pi r} + 10 \log \gamma + 10 \log \beta + 10 \log G(\theta, \varphi, \lambda) + 10 \log \eta_f \qquad (4)$$

where:

η_{af}: transfer constant of transmitter antenna feeder link

λ: wave length (for corresponding harmonic) (m)

r: distance between SES antenna and HF transmit antenna (m)

$G(\theta, \varphi, \lambda)$: SES receiver antenna gain referred to azimuth, θ, and elevation, φ

η_f: *i* receiver feeder efficiency

β, γ: constants for characterizing the effects of antenna polarization mismatch and of physical obstructions.

Equations (1) and (2) were applied to calculate receiver susceptibility threshold for spurious response frequencies most close to HF transmitter operating frequencies. Initial data used in the calculation were as follows:

$f_{OR} = 1\,538$ MHz $\qquad f_{LO} = 1\,351$ MHz

$f_{IF} = 187$ MHz $\qquad P_R(f_{OR}) = -139$ dBm

$B_R = 8.5$ MHz $\qquad I = -20$ dB/decade

$P = 0$ $\qquad J = 80$ dB.

Results of the calculation are shown in Table 1.

TABLE 1

Spurious response susceptibility thresholds

q	**f_{SR} (MHz)**	**$P_R(f_{SR})$ (dBm)**
8	13.37 ± 0 53	–22.6
10	18.70 ± 0.42	–20.7
11	17.00 ± 0.39	–19.9
5	37.00 ± 0.85	–26.7
7	26.71 ± 0.61	–23.8

The spurious response frequencies as given in Table 1 are the first IF sub-harmonics of ship earth station receive system.

Using equation (3), interference power of spurious response frequencies was calculated and compared with the obtained values of receiver susceptibility threshold. The calculation was performed for those HF transmitter frequencies, f_{OT}, which are capable of producing interference at the receiver spurious response frequencies. It was assumed that $P_T(f_{OT}) = 500$ W, $A = –70$ dB/decade (see Note 1), $B = –20$ dB, and free-space loss over a distance of 10 m was used for L_c.

NOTE 1 – The value of A in future calculations can be taken as –60 dB/decade without impairing the quality of reception.

Results of the calculation are shown in Table 2.

TABLE 2

Spurious response interference power

f_{OT} (MHz)	n	$P_1(f_{SR})$ (dBm)	$P_1(f_{SR})/P_R(f_{SR})$ (dB)
4.670 ± 0.1062	5	–27.0	–4.4
6.2333 ± 0.1417	3	–9.5	+11.2
17.00 ± 0.3864	1	+24.7	+44.6
8.50 ± 0.1932	2	+3.6	+23.5
12.4666 ± 0.2833	3	–15.5	+11.2
13.3571 ± 0.3035	2	–0.3	+23.5

TABLE 3

Interference power at SES receiver fundamental frequency $P_1(f_{OR})$)

f_{OT} (MHz)	N	$P_1(f_{OR})$ (dBm)	$P_1(f_{OR})/P_R(f_{OR})$ (dB)
6.2 to 13.2	248 to 124	–102 to 82	–11 to 9

The above interference values are for only the first sub-harmonics of the ship earth station IF. It should be noted that equations (2) and (3) do not take into account non-linearities in active receiver or transmitter components that can affect the relative susceptibility or emission levels for different harmonics.

2.4.2 Experimental results

During the experimental period, $(I + N)/N$ levels were measured to identify the effect of HF transmitter emissions. Interference was produced by the HF transmitter emissions at the frequencies selected within the band shown in Table 2. Noise levels and interference-plus-noise levels were determined for 20 kHz bandwidth in the first IF channel of the ship earth station.

The ship earth station antenna was directed towards the HF transmit antenna located at 8.6 m distance. The transmitter was operating in A1A emission mode, the emitted power being 1.5 kW.

Shown in Table 4 are results of processing of measured $(I + N)/N$ values.

TABLE 4

Mean $(I + N)/N$ vs. HF transmitter operating frequencies

f_{OT} (MHz)	4.68	6.23	8.35	12.51	13.2	16.75
$(I + N)/N$ (dB)	0	20	18	23	17	16

The measured interference in Table 4 does not compare directly with the calculated interference in Table 2. Any inconsistency is due to a number of factors not taken into account in calculating Table 2 values, e.g. frequency dependent effects on L_c.

The interference in the receive channel was narrow-band in nature, with its level dependent upon directing the ship earth station antenna towards HF transmit antenna.

Throughout the experiment period, the effect of HF transmitter emissions on the quality of telephone and telex message reception was examined at f_{OT} = 12.502 MHz which causes interference at the receive frequency 1 537.75 MHz (satellite channel). Values of $(I + N)/(C + N)$ were determined.

No troubles were experienced with reception of reference telex messages with $(I + N)/(C + N) \leq -1$ dB. It should be noted that this ratio may reach 15 dB at low elevation angles.

The quality of telephone message reception was judged to be satisfactory, with $(I + N)/(C + N) \sim 2$ dB,

where:

I: interference sign level

N: noise

C: wanted carrier signal level.

Should the $(I + N)/(C + N)$ value measured in the first IF channel be equal to or exceed 5 dB, the telephone channel was completely blocked due to the interference.

3 Potential interference from shipboard maritime satellite transmitters

3.1 Interference to aeronautical satellite systems

One study has shown that interference from a shipboard transmitter of a maritime satellite system may occur only when the aircraft satellite receiver is within 4 nm of the ship and is within the main beam of the maritime satellite transmitter.

3.2 Interference to collision avoidance systems

Spurious emissions from shipboard transmitters are potentially capable of interference to experimental collision avoidance systems. Limits on spurious emission should be established to eliminate insofar as practicable the source of interference.

3.3 Out-of-band interference to other radiocommunication services

Satellite ship terminal transmitters may generate intermodulation, harmonic and other forms of spurious emissions which could cause harmful interference to other services operating above, between and below the 1.5 and 1.6 GHz maritime mobile satellite service bands. Limits on spurious emissions from satellite ship terminals should be determined which would eliminate insofar as practicable such interference. Studies on the values of limits should recognize practical equipment limitations.

3.4 In-band interference to the fixed service

In accordance with the provisions of No. 5.359 of the Radio Regulations, the band 1 540 to 1 660 MHz is also allocated to the fixed service to certain Administrations in Regions 1 and 3.

The potential interference from shipborne transmitters to the fixed service studied in Report ITU-R M.917, Annex I.

4 Electromagnetic compatibility

An in-harbour and at-sea electromagnetic compatibility survey was made on board the *American Alliance* for a maritime satellite shipboard terminal operating in the 1 500 to 1 600 MHz band.

4.1 Field strength

Measurements of field strength 1 m from the radar transmitter cabinets in the storage room showed that the cabinet radiation was not excessive.

Field-strength measurements at the above deck locations showed levels that were either equivalent to or less than the levels measured in the storage room.

Radar interference to the shipboard terminal was influenced by the relative location of the antennas. On the *American Alliance*, the separation between the maritime satellite antenna and the radar Band 9 antenna was 9.2 m, and for the Band 10 antenna it was 7.4 m. Closer spacing might justify the requirement for an additional low pass filter.

4.2 Interference to radars

The test for shipboard satellite terminal interference to the Band 9 and Band 10 radars as installed on the *American Alliance* showed that this should not be a problem with 15 W power from the shipboard satellite transmitter. One 1.2 m (4 feet) diameter parabolic dish reflector, containing a right-hand circular polarization feed, was used. The antenna gain was 24 dB at 1 559 MHz.

5 Extra-terrestrial noise

Table 5 summarizes the effects of extra-terrestrial radio noise sources on a system at 1500 MHz.

TABLE 5

Extra-terrestrial radio source characteristics at 1500 MHz

Source		Sun	Moon	Jupiter	Casseopia	Galactic centre
Source size (Sr)		1.35×10^{-4}	1.07×10^{-4}	Point source	Point source	1.9×10^{-3} ($2.6 \times 1.4°$)
Power flux-density ($W/(m^2 \cdot Hz)$)		9.3×10^{-21}	–	–	2.2×10^{-23}	
Apparent temperature (K)		10^{-5}	250	2×10^{3}	–	162
Antenna temperature (K)	20 dB antenna gain	107	0.21	<1	0.24	15
	10 dB antenna gain	11	2.1×10^{-2}	$<10^{-1}$	2.4×10^{-2}	7
	3 dB antenna gain	2	2.1×10^{-3}	$<2 \times 10^{-2}$	4.8×10^{-3}	2 (estimated)

6 Atmospheric noise from absorption

An absorbent medium, such as oxygen and water vapour in the atmosphere, emits thermal noise that can be described in terms of apparent sky temperature. At 1600 MHz the temperature varies from 80 K to 2 K between elevation angles from 0° to 90°. At a 10° elevation angle the sky temperature is about 10 K.

7 Noise of satellite ship terminal receiver

The noise temperature of a satellite ship terminal receiver will depend mainly on the type of preamplifier stage and the feeder loss between the antenna and pre-amplifier. Typically the pre-amplifier would be mounted immediately behind the antenna to minimize feeder loss. In such a configuration a transistor pre-amplifier can provide a receiver noise temperature of the order of 225 K and an uncooled parametric amplifier of the order of 55 K.

8 Man-made noise

Data have been recorded in harbour and at sea for approximately ten different classes of ships. All of the significant electromagnetic noise sources of Band 9 (1535 to 1660 MHz) which were measured were determined to be broadband in character relative to the link bandwidths contemplated for future maritime mobile-satellite system design. The broadband noise was intermittent and generally having a duration much shorter than a typical message element envisaged for a maritime satellite system.

The predominant sources of serious Band 9 electromagnetic noise were found to be associated with electrical equipment operating intermittently in ports or in close proximity. This noise is generally broadband in character. A high percentage of these intermittent sources originated as broadband impulsive noise from ignition circuits associated with dockside and shipboard unloading apparatus. The same noise category was frequently evident for automobiles and trucks on highways and bridges adjacent to harbours, ports and canals. Also evident at ports is a component of city ambient noise which varies in amplitude from port to port, and also depends upon the time of the day. This noise varies in magnitude by 20 dB depending on whether it is measured on a normal working day or on weekends and holidays, when it is lower in magnitude. Occasionally evident while near or in port were radio-frequency interference noise power density levels 20 to 30 dB above the ambient receiver noise power density level far a 3 dB noise figure receiver. This increase in apparent ambient noise level may seriously affect link thresholds. Beyond radio line-of-sight of any port, radio-frequency interference should not affect receiver sensitivity especially for new ships.

8.1 Interference from automobiles on an expressway

The peak amplitude of the noise emanating from the Brooklyn Expressway with heavy traffic was recorded to be about –150 dB(mW/Hz) within Band 9. For this test, a 20 dB gain horn antenna was used, oriented in the direction of the noise source. Under certain operating conditions, man-made noise from automobile traffic may impair receiver sensitivity level.

8.2 Ship-yard

Extremely high peak amplitudes of noise of –141 dB(mW/Hz) were recorded from the Boston Navy Yard which was in full operation at the time. This noise is a combination of city ambient noise and of broadband electromagnetic noise from industrial equipment. A 20 dB gain horn antenna was used, oriented in the direction of the noise source. Under certain operating conditions ship-yard noise may impair receiver sensitivity levels in Band 9.

8.3 Dockside noise

Broadband impulsive noise, originating from combustion engine ignition circuits used with dockside unloading apparatus, was found to exist at all ports. The recorded peak amplitude of the noise at Narragansett Bay, five miles From Portsmouth, Rhode Island (United States of America), is about –137 dB(mW/Hz) within the maritime mobile-satellite receive band. Noise levels of –150 dB(mW/Hz) have been recorded from ships' cranes. A 20 dB gain horn antenna was used oriented in the direction of the noise sources.

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SUPPLEMENT 4

Technical aspects of coordination among mobile-satellite systems using the geostationary-satellite orbit

Summary

In this Supplement different technical aspects involved in the coordination among mobile-satellite systems using the geostationary satellite are explained. In § 1.2, a brief summary of RR Article 9 coordination procedures is given. The relevance of different stages of satellite design in the facilitation of coordination is explained. The different parameters relevant to the coordination of satellite systems are explained in § 2. The coordination methodology involved in the coordination of two satellite systems in cocoverage and non-cocoverage cases is also given in this supplement. Finally, the impact of technological evolution on future coordinations is described briefly.

Technical aspects of coordination among mobile-satellite systems using the geostationary-satellite orbit

1 Introduction

1.1 Objectives and scope

Before an administration notifies the Radiocommunication Bureau (BR) of new or revised frequency assignments for a mobile satellite system, it must first comply with its obligations under the advance publication and coordination procedures specified in Article 9 of the Radio Regulations (RR). The objective of these procedures is to ensure that the proposed assignments will not cause or suffer unacceptable interference with existing and planned space and terrestrial systems.

The RR Article 9 procedures prescribe the sequence of interactions between the applicant administration and affected administrations and with BR; they do not address the technical aspects of coordination. The purpose of the present report is to deal with the technical aspects of coordination by describing those system design and operational parameters that can be adjusted to achieve the objective of the RR Article 9 procedures and by illustrating how these parameters might be adjusted in practical cases.

The discussion and the illustrations are confined to systems designed to use the mobile-satellite service (MSS) allocations in the 1525-1559 MHz (down-link) and 1626.5-1660.5 MHz (up-link) bands and do not deal with the coordination of such systems with terrestrial stations.

1.2 Summary of RR Article 9 – Advance publication and coordination procedures

The advance publication procedure described in Section I of Article 9 of the RR takes place before the formal coordination procedure described in Section II of that Article. It requires the administration proposing new or revised frequency assignments for a satellite system to supply BR with the information about the network characteristics listed in RR Appendix 4 so that it can be published for review and comment by any administration as to the effect on its space radio-communication services.

The RR stipulate that if such comments are received within a period of four months from publication, the administration proposing the new or revised assignments is obligated first to explore all possible means of reducing interference to acceptable levels by adjusting the design and deployment of the proposed system. If no such means can be found, it may then seek the cooperation of the potentially affected administrations in finding a solution.

The coordination procedure and the conditions under which it must be applied are given in Section II of Article 9 of the RR. The principal condition is that coordination is required if interference from the new system would increase the equivalent noise temperature T in another satellite system beyond an amount ΔT under worst-case conditions defined in RR Appendix 8.

The interference power threshold which triggers coordination under RR Appendix 8 may be lower than that considered acceptable by a particular service provider. Hence, it may still not be necessary to modify the design and operating characteristics of that system to accommodate reduction of the received interference.

If system adjustments are necessary in order to meet the criteria for acceptable interference agreed to by the administrations involved, the available options are then identified during the coordination process. They include relocation of one or more space stations or changing the emissions, frequency usage, or other technical and operational characteristics of the systems as described in § 2.

1.3 Importance of satellite system development stage

Before discussing how adjustment of the design and operating parameters of the systems involved can reduce intersystem interference, it should be noted that the extent to which the parameters of a given system can be adjusted depends on the specific characteristics of that system and on its stage of development. Four stages in the development of a satellite system can be distinguished:

– *Initial concept and design:* The design plan for the system has proceeded to the point where preferred values of the technical parameters required by RR Appendix 4, including orbital location and frequency, have been decided.

– *Implementation:* This stage includes the detailed design and construction of the satellite and its associated earth stations and ends with the launch of the satellite. Several years are normally required.

– *Operation:* At this stage, the satellite has been built, launched, and is operating from a particular orbital location with its associated Earth segment.

– *Second generation or replacement satellite system:* During the useful life of the first-generation satellite in a system, a replacement satellite is normally designed and constructed. By the time it is launched, an extensive array of earth stations is in place, and a number of associated transmission parameters may have to be retained in order to preserve continuity of service.

The greatest opportunity for adjusting any of the design and operating parameters exists during the initial concept and design stage. Often, an applicant's network may already have entered its implementation stage before the coordination procedure has reached the point where agreements can be made. The other potentially affected systems may be in any of the four stages.

Systems in the implementation stage may still afford opportunities for the adjustment of their planned design and operating parameters to reduce interference, but these opportunities diminish as the launch date approaches.

Systems in the operation stage have many parameters that are either fixed or can only be changed at significant cost. Nevertheless, some systems are designed to have built-in flexibility during operation such as beam repointing, transponder gain settings, programmable passbands, etc. In general, mobile satellite systems have significant flexibility to resolve interference problems through adjustments to frequency plans, as a minimum, regardless of where the system is in the development cycle from concept to operation.

Replacement satellites for an existing system have some of the flexibilities of the preceding three stages. Although a number of transmission parameters may have to be retained, the opportunity does exist to incorporate design changes to reduce potential interference. Adjustments to earth stations are practical only over a substantial period of time, in conjunction with schedules for maintenance, refurbishment, or replacement or termination of obsolete services.

1.4 Link inhomogeneities in mobile-satellite systems

The adjustment of system parameters to meet interference criteria may be made more complex when there are large inhomogeneities among the MSS links to be considered. For example, between links operating with Earth-coverage satellite antennas and links operating with spot beam satellite antennas.

In addition to these link inhomogeneities, mobile satellite systems may have to accommodate a range of RF carriers reflecting differences in message type, message data rate or baseband bandwidth, modulation method, multiple access technique and other parameters.

2 Coordination parameters

The system design and operating parameters to be considered in the course of coordination include virtually any parameter that may affect the interference between systems. The parameters reviewed in this section are as follows:

– criteria for permissible and accepted interference;

– transponder frequency and polarization plans;

– carrier frequency plans;

– satellite antenna coverage and service areas;

– earth station antenna discrimination;

– earth station power control;

– transponder gains and satellite e.i.r.p.;

– satellite positions;

– operational schedule.

2.1 Criteria for permissible and accepted interference

Two types of interference levels are defined in the RR for use in the coordination of frequency assignments between administrations. "Permissible interference" is that which complies with quantitative interference and sharing criteria contained in the RR or in ITU-R Recommendations or in special agreements as provided for in the RR. "Accepted interference" is interference at a higher level than that defined as permissible interference and which has been agreed upon between two or more administrations without prejudice to other administrations. Report ITU-R M.1179-1 presents a method for determining permissible levels of interference.

When used as the “interference objectives” in overall system planning, the interference criteria of interest apply to the total or aggregate interference from all sources, both intrasystem and intersystem. However, since coordination is usually carried out on a bilateral basis, the interference criteria used in coordination is for single entries of intersystem interference. The single-entry criteria should be chosen so that, if they are met individually by each interfering system, the total interference will not exceed the levels specified by the aggregate interference criteria for intersystem interference.

In the absence of ITU-R Recommendations specifying single-entry interference criteria for permissible intersystem interference, each administration in a coordination action is free to specify the levels of permissible and accepted interference it believes are necessary to protect the channels of its system. However, these levels may be subject to reconsideration during the coordination. Coordination will be facilitated by flexibility in two areas: the ratio of the aggregate to the single-entry level of interference, and the difference between the criteria for accepted interference and the criteria for permissible interference.

It may be possible to relax the single-entry interference criteria in situations where the assumed ratio of aggregate-to-single-entry interference power is conservatively high, as long as the aggregate interference criteria are met.

In the case of accepted versus permissible interference, the actual links in some systems may provide larger performance margins than the representative links upon which permissible interference is based. This could enable later acceptance of higher aggregate levels of interference while still meeting link performance objectives. However, peak capacities or link margins in power-limited satellites are reduced as aggregate interference is increased. Acceptance of relaxed criteria for aggregate interference power is of course strictly a matter to be decided during coordination and should not be relied upon when planning systems prior to coordination.

2.2 Transponder frequency and polarization plan

The transponder frequency and polarization plan for a satellite system describes the passbands of the transponders and the polarization of the receiving and transmitting antennas to which each of the transponders is, or can be, connected. The transponder passbands may partially overlap (e.g. for non-overlapping beams in a multibeam satellite). In principle, transponder frequency/polarization plans can be chosen to facilitate both intrasystem and intersystem frequency reuse.

In practice, however, there is no regular or standard transponder frequency/polarization plan for the MSS. Moreover, although polarization discrimination may provide some reduction in interference in certain cases, mobile earth stations cannot usually be designed to take advantage of this theoretical improvement due to a number of factors, including antenna performance deficiencies, depolarization associated with multipath and requirements for interoperability among systems.

Nonetheless, the opportunity exists during advance publication and coordination, for administrations to redefine the transponder plan of a system in order to reduce interference with respect to other systems. Likewise, it may be possible to negotiate constraints on the use of the existing transponder plan of an operating system in order to meet the criteria for accepted interference.

For example, when it is foreseen that unwanted signals from another system might unacceptably load the feeder down-link transmitters, it may be possible to negotiate carrier frequency plan constraints (see § 2.3) for the interfering system or transponder plan constraints for the interfered-with systems to alleviate the problem. The loading level statistics can be predicted and used to determine the degree to which it is necessary to constrain the carrier or transponder frequency plans.

For transponders equipped with programmable passbands, it may be possible to accept constraints on passband settings to remedy transponder loading problems. This is a particularly promising technique for multiple-beam satellites insofar as the constraints may be needed only for some of the beams. Another advantage is that programmable passbands allow changes to be made in the transponder plan even in the operational stage.

2.3 Carrier frequency plans

The carrier frequency plan of a satellite system designates which frequencies within the passbands of the transponders are to be used for each type of carrier to be provided by the system. Mobile satellite systems typically use several types of carriers for several types of earth stations. Consequently, when interference between two such systems is analysed, there are a large number of link combinations to be considered.

For example, some satellites will support on the order of greater than ten different types of carriers, some of which will be transmitted by more than one type of mobile earth station. This task of evaluating interactions between all links may be facilitated by the use of computer software.

In a typical sharing situation, some of the possible co-channel interactions between links may be found to comply at the outset with criteria for permissible levels of interference. If the number of problem links is small (e.g. one or two) carrier frequency planning is an option to be strongly considered.

As an example, consider a co-channel sharing difficulty between a single link and some of the links in the other system. A simple operational constraint may be accepted where the problems interactions are avoided by agreeing to observe the necessary channel assignment constraints. This can be accomplished in systems using demand assigned multiple access (DAMA) by implementing appropriate frequency assignment safeguards in the DAMA software.

Links that cannot share frequencies on a co-channel basis will require adherence to carrier frequency plans that assure prescribed amounts of frequency offset with respect to their problematic counterparts. Again, the solution may be implemented in the form of channel assignment software controls within the system frequency plan.

2.4 Satellite antenna coverage and service areas

The service area(s) of a satellite system are the geographic areas within which the earth stations associated with the system are intended to operate with specified signal-to-noise performance and specified protection against interference from other systems. The coverage area is the geographic area within which the signal-to-noise performance meets specifications. In single-beam satellite systems, the coverage area generally encompasses the entire service area. In multiple beam systems, the individual beam coverages will be smaller than the service area but collectively will encompass it.

The discrimination available from satellite antennas in cases of systems with non-overlapping service areas may be sufficient to allow unconstrained co-channel sharing. In other cases, the interactions between each beam in one system and the various types of links and mobile earth stations in the other system must be individually considered. The satellite antenna beam(s) of one system are considered against the service area(s) of the other.

Reference radiation patterns for representative antennas are often used in interference analyses; however, in many cases, actual radiation patterns may offer greater discrimination than reference patterns. In some cases, it may be possible to design satellite antennas that have substantially reduced side-lobe levels in the direction of the non-overlapping service areas of other systems.

Multiple-beam satellites may also offer opportunities for obtaining higher satellite antenna discrimination to facilitate coordination. The increased discrimination can be achieved for systems in the following ways:

– rearrangement or repositioning of beams, so long as the composite service area remains properly covered;

– decreasing the beam dimensions so as to accelerate the fall-off of gain with increasing off-axis angle;

– repositioning the entire beam array through scan angle or rotational angle adjustments;

– repositioning beams and decreasing their numbers, possibly with some sacrifice to performance at the fringe of the composite service area;

– minimization of gain specifically towards the affected service area(s) of the other system through optimization of the antenna design.

2.5 Earth station antenna discrimination

Reference radiation patterns for representative earth station antennas are often used in coordination. However, measured patterns may be used but with some caution because the distortion of the far-field radiation pattern that may be caused by objects near the antenna (e.g. cars and trucks) must be taken into account. In coordination, it is necessary to consider the service area for each type of mobile earth station with respect to the beam(s) in the other system.

2.6 Earth station power control

Some types of mobile earth stations may implement power control, such that their up-link e.i.r.p. levels are under the control of the system in which they are working. Systems that also utilize linear transponders could possibly accept some constraints in the algorithms for commanding mobile earth station power levels. In some cases, transponder gain can be adjusted to compensate for this constraint. It may be possible to identify modest constraints on e.i.r.p. that can effectively reduce the interference that is either caused or received. This assessment is made on a carrier-by-carrier and beam-by-beam basis.

2.7 Transponder gains and satellite e.i.r.p.

In cases where total power levels from unwanted signals from mobile earth stations operating in other systems might load the satellite return link as a result of overlap in the carrier frequency plans, it may be necessary to constrain transponder gain settings in order to minimize the power drain caused by that loading. However, routine practices for adjusting transponder gain may preclude the option of special adjustments.

Similarly, in order to assure adequate reception at mobile earth stations, the satellite e.i.r.p. levels used in the service down links in the forward direction should be maintained at or above predetermined levels. However, when the traffic level through the satellite is far below the peak system capacity level, unnecessarily high down link e.i.r.p. levels can occur. Down-link interference can be limited by adjusting the gain settings to constrain the maximum e.i.r.p. used in the down-link carriers. For a given type of down link, the range between minimum and maximum e.i.r.p. cannot be reduced below a certain amount due to the need for tolerances in the control of feeder up-link e.i.r.p. levels and transponder gain.

2.8 Satellite positions

Interference on the links to and from mobile earth stations is not greatly reduced as the satellite spacing is increased, until the spacing is greater than one-half the half-power beamwidth of the earth stations. Nonetheless, it may be possible to eliminate problem interactions involving medium- or high-gain earth station antennas by adjusting orbital spacing. For low gain earth stations, clearly the ability to do this is much more limited.

Orbital position can also improve satellite isolation under the following exceptional circumstances:

– for a satellite using an earth-coverage antenna beam, it may be possible to maintain coverage of the service area from alternate orbital positions while reducing the coverage area overlap with the other system’s service area(s);

– for planned satellites using multiple beams, it may be possible to reduce or eliminate overlaps between the coverage area(s) of one system and the service area(s) of another to the extent that coverage can be varied with changes in satellite position.

2.9 Operational schedule

If peak traffic loads in two systems do not occur at the same time, it may be possible to accept time-shared access to common segments of the spectrum. This may be facilitated by the use of an interconnecting communications link between the two systems.

3 Coordination methodology

As noted earlier, the RR Article 9 procedures for advance publication and coordination only provide methods for determining when the procedures are to be applied, which administrations are affected, the kinds of information to be exchanged, and the sequence and timing of the information exchanges. The methodology for deciding whether it is necessary to adjust the technical and operational parameters of the systems involved in the coordination process is left to the discretion of the participating administrations. This section illustrates possible methodologies for use during the technical coordination.

3.1 Assumptions

It is assumed that at least some frequency assignments proposed for a new mobile satellite system "B" must be coordinated with those of a mobile satellite system "A" already in coordination or operation. Although system "B" may have to be coordinated with more than one other system, and occasionally multilateral coordination meetings may be held, the coordinations are usually carried out on a bilateral basis.

It is also assumed that both the mandatory and the more detailed information on system characteristics listed in RR Appendix 4 have been furnished for system "A" and that corresponding information for system "B" has also been published. Flexibility for the adjustment of these system characteristics during the coordination process will depend on the stage of development of the system as described in § 1.3 previously.

System "B" is assumed to be in either the late concept and design or early implementation stage, whereas system "A" is assumed to be in either the late implementation or operative stage. Thus, the administration responsible for system "B" (the "applicant administration") will generally have more flexibility for parameter adjustment than the administration for system "A" (the "affected administration"). Even so, the affected administration also has responsibilities to make feasible adjustments.

3.2 The coordination process

As in the case of the fixed-satellite service (FSS), the MSS coordination process can be divided into three phases:

Phase 1 – Assessment of the interactions of the transmissions of the involved systems ("A" and "B") against predetermined interference criteria: If unacceptable levels of interference are anticipated, it will be necessary to move ahead to phase 2; otherwise the administrations can agree that no adjustments to the system design parameters are needed.

Phase 2 – Adjustment of technical and operational system parameters which could facilitate a complete or partial resolution to the interference problems identified in phase 1. However, any adjustments made during this phase should not require either system to constrain its current or planned mode of operation, nor its type, distribution or quality of services.

Phase 3 – Consideration and negotiation of further adjustments and constraints of system parameters to either or both systems if interference problems have not been resolved during phase 2. Such changes could affect the operating flexibility and future growth options of either or both systems.

3.3 Identification of significant interactions

To carry out the first phase of the coordination, it is necessary to identify where interference between systems "A" and "B" is most likely to occur. Each band or band segment common to both systems must be examined for each satellite beam in the two space segments. All possible operational configurations must be considered.

In examining the various links in the two systems as defined in § 1.4, it is desirable first to compare their relative vulnerability to interference and the comparative impact on interference levels of adjusting link parameters.

3.3.1 Feeder link versus service link

In principle, the coordination can involve altering various parameters of the feeder links or service links. Generally, it is first desirable to concentrate on coordinating the service links. This is because feeder links generally employ relatively large earth station antennas with higher adjacent satellite discrimination and interference is more highly dependent on the service link parameters.

3.3.2 Forward versus return service link

Because of the large differences in the transmitting and receiving characteristics of a satellite and a mobile earth station, adjustments of most of the parameters described in § 2 may affect the forward and return service links differently. Some will affect only the forward (space station-to-mobile earth station) or the return (mobile earth station-to-space station) link.

3.4 Adjustment of technical and operational parameters

Table 1 summarizes the general practicality and benefit of making parameter adjustments and constraints during the coordination process. Practicality is referred to stage of development, and benefit is described separately for the forward and return links of the two systems.

To illustrate how the parameters for the service links may be adjusted in the second and third phases of coordination, two basic cases are considered:

– non-cocoverage case: the satellite networks serve separate geographical areas;

– cocoverage case: the satellite networks have overlapping service areas.

Based largely on which of these two cases applies to systems “A” and “B”, and whether the principal interference is expected to be encountered on the forward or return link, one can make a rough evaluation of the practicality and benefit of the various system parameter adjustment options.

3.4.1 Non-cocoverage case

If system “A” and system “B” cover different service areas, and it has been determined that there will nonetheless be an interference problem, administration “B” may want to first concentrate on the design of the spacecraft antenna. The objective would be to alter or constrain the satellite antenna coverage so that it more closely matches the service area and also achieve greater intersystem isolation in the direction of the service area of system “A”. This is only practical in the design and perhaps the early implementation stage of system “B”. Adjustment of the spacecraft antenna coverage of system “A”, whose satellite is assumed to be in the late implementation or operation stage, is generally practical only in the event that the satellite employs programmable or steerable spot beams.

TABLE 1

General practicality and benefit of accepting constraints or adjustments on system parameters

	Practicality relative to stage of system development				**Interference reduction benefit**	
Parameter to be adjusted	Concept and design	Implement	Operation	2nd gen/replace satellite	Forward link	Return link
Criteria for acceptable interference	M-H	M-H	M-H	M-H	M	M
Transponder frequency passbands	M-H	M	L*	M-H	L	M
Polarization	M-H	M	L	L	L	L
Carrier frequency plans	H	H	M	M	H	H
Satellite antenna coverage	H	M	L	H	CC:L NCC:M-H	CC:L NCC:M-H
Satellite service areas	L	L	L	L	CC:L NCC:M	CC:L NCC:M
Mobile earth station antenna discrimination	M	L-M	L	L	L	L-M
Earth station e.i.r.p. (power control)	M	M	L-M	M	M	M
Transponder gains and satellite e.i.r.p.	M	M	M	M	M	L
Satellite position	M	L-M	L	L	CC:L NCC:L-M	CC:L NCC:L-M
Operational schedule	L-M	L-M	L-M	L-M	H	H

Key: H = High; M = Moderate; L = Low or None; CC = Cocoverage; NCC = Non-cocoverage

* Only if programmable passbands are used.

In non-cocoverage cases where unacceptable interference from system “B” to system “A” is predicted only in the forward link, one or both may change its satellite e.i.r.p. in order to achieve satisfactory carrier-to-noise plus interference power ratios without unduly sacrificing performance.

In some of the non-cocoverage cases, discrimination may be improved by changing the proposed position of satellite “B” or the existing position of satellite “A” to increase the orbital spacing between them. Given the limited directivity of most mobile earth station antennas, this option will have only a moderate effect on the interference between systems “A” and “B” and would thus be considered as a last resort. However, to overcome an interference problem, moving the satellite may be attractive in that it might have little impact on the development cost or schedule of system “B”.

For the non-cocoverage case some of the options described in § 2 may not be necessary if most of the required isolation can be provided by satellite antenna discrimination. If, however, the interference problem is severe the administrations may have to resort to frequency interleaving or other options.

3.4.2 Cocoverage case

In the cocoverage case, total achievable isolation between systems on the service links is clearly less than that in the non-cocoverage case since the same geographical region (or a portion thereof) will be serviced by both systems “A” and “B”. If system “B” is still in the design stage, and unacceptable intersystem interference is expected, it may be decided to consider changes to the frequency/polarization plan in order, for example, to interleave transponder passbands with those of system “A”.

Also, changes to carrier frequency plans may be considered to reduce intersystem interference. Channel interleaving can reduce the required protection ratio between systems and carrier placement can be planned so as to reduce intermodulation. Interleaving the two systems’ channels (perhaps in conjunction with adjusted satellite e.i.r.p.) may be enough to resolve the interference problem.

In the cocoverage case, design alterations affecting the satellite antenna coverage serve little or no purpose in either the forward or return service links unless an administration chooses to limit or change its service area in the case of partial cocoverage. The benefit of this is low.

4 Impact of technological evolution on future coordinations

Many of the advances in technologies that are being made to improve mobile satellite system performance may also enhance the compatibility between mobile satellite systems and improve coordination outcomes. Hence, the capabilities of the orbit/spectrum resources for accommodating future requirements are generally increasing.

Spectrally efficient modulation methods and low-rate voice codecs should result in reduced channel bandwidths or greater interference tolerance which will allow more flexible frequency planning. Multiple access techniques such as code division multiple access (CDMA) employing spread spectrum modulation may result in higher interference tolerance for mobile satellite systems.

Transponder linearization will reduce intrasystem noise (e.g. intermodulation) and the resulting increase in margins may enable acceptance of higher levels of interference power. Multiple-beam satellite antennas with smaller beams and reduced side-lobe levels will enable better matching of the coverage areas to service areas resulting in increased intersystem isolation. Future flexible spot beam planning concepts should enable dynamic frequency and power allocation to beams while ensuring efficient spectrum usage.

Widespread use of medium-to-high gain mobile earth station antennas may improve compatibility where adequate satellite separation is possible. Although not necessarily aimed at improving coordination, these advances may offer a bonus by enhancing intersystem compatibility. As a result, future coordination may be eased.

5 Conclusions

During advance publication and coordination of frequency assignments for mobile satellite systems, detailed analysis may identify interactions producing unacceptable interference. Several design and/or operating parameters can be adjusted at various stages of development to alleviate the identified interference; however, it should be noted that with existing systems, certain satellite parameters cannot be changed until the replacement stage.

New technology is anticipated to offer greater performance in terms of capacity, and might also improve intersystem compatibility and reduce the need for administrations to make adjustments during coordination. Responsibility rests with all mobile satellite system operators to incorporate flexibility into their designs and operations so as to facilitate the coordination process.

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