REPORT 921-2

SYSTEM ASPECTS OF DIGITAL SHIP EARTH STATIONS

(Study Programme 17A/8)

(1982-1986-1990)

1. Introduction

This Report addresses a number of technical aspects related 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 present maritime satellite communication system is designed to operate with ship earth stations having a G/T of -4 dB(K^{-1}).It is assumed that digital ship earth-station —————————— standards introduced in the future will be characterized by similar or lower G/T and perhaps smaller antenna size, as summarized in Table I below in the case of the INMARSAT system.

TABLE I – *Summary of existing and potential INMARSAT ship earth-station characteristics*

Ship earth-station standard	Antenna gain (dBi)	G/T (dB(K^{-1}))	Service capability
A	21 to 24	-4	Full range of public correspondence
B	21	-4	Full range of public correspondence and **digital data-based** services
B variant	12 to 15	-13 to -10	(Under study)
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 are power-limited, at least in the foreseeable future.

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 is 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 new concepts denoted in Table I by standard B and standard C are envisaged as providing transmit and receive capabilities based on digital modulation and coding techniques, whereas the current standard A system uses FM analogue modulation for telephony. In both cases a new access control and signalling system is envisaged, separate from the existing system and with different channel characteristics which are expected to provide enhanced signalling efficiency and capacity. In the standard B system, demand assignment of channels is based on forward TDM links which may 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 are combined in forward TDM and return random access links, using ARQ techniques.

Variants of the new concepts are also under investigation. Annex I describes a digital ship earth-station development similar to the envisaged standard B system with G/T values of -10 dB(K^{-1}) and -4 dB(K^{-1}). Annex II describes the performance of a low G/T ship earth-station ($G/T = -13$ dB(K^{-1})) with a 2400 bit/s vocoder channel. Annex III discusses the concept of enhanced group call system. Annex IV presents experimental results on the forward error correction (FEC) as a means of multipath fading compensation. Annex V describes a statistical evaluation method for a passive antenna stabilizer.

Annex VI describes a communication system concept which relies on an adaptive coding scheme suitable to data-only mobile earth stations (e.g. maritime, aeronautical, and land mobile with a G/T of -24 dB(K^{-1})). A detailed description of the coding scheme is given in Report 509, Annex II. The communication system under consideration is based on TDM in the forward link and CDMA in the return link.

Annex VII describes in more detail the proposed INMARSAT Standard C system.

2. Follow-on system (Standard B)

2.1 *System concept and service aspects*

The eventual introduction of a standard B system is assumed to represent a means of providing a successor to INMARSAT standard A ship earth stations for the full range of public correspondence services, including the following:

- telephony, based on digital modulation, coding and speech processing techniques, including voice-band data;
- data for low-speed services (up to around 9.6 kbit/s), including telegraphy, teletex and facsimile;

The signalling system and numbering plan adopted for ship earth stations 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 is also assumed that the 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, multi-channel operation, plus a range of data services at 16 kbit/s and above.

It is expected that the main service requirement in terms of space segment utilization will 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 547), it is assumed that a design objective for standard B would be to provide good quality telephony under nominal conditions at least equivalent (subjectively) to the standard A companded FM system, with acceptable voice quality under adverse propagation conditions at low satellite elevation angles. Furthermore it is 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 services. The definition of the telegraphy and signalling systems is under study by INMARSAT.

2.2 *Voice coding techniques*

Report 509 indicates that 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 is expected that the continuing development of LSI circuit technology will enable the necessary digital techniques to be realized in a cost-effective manner.

One conclusion to be drawn from the comparison of available voice coding techniques is that the required speech quality objectives could be achievable with 16 kbit/s voice coding rate and a bit error ratio (BER) of arround 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.

Currently available information suggests that the subjective speech quality obtainable with lower rate vocoder techniques is not yet sufficient for the desired quality objectives, and that further study and development is required in this area. However, these systems demonstrate a useful potential for reductions in satellite power and bandwidth requirements at coding rates around 9.6 kbit/s or less, and could thus be applied to future maritime and perhaps other mobile satellite communications services. As an example, 9.6 kbit/s APC could be applied to the -10 dB(K^{-1}) variant of the Standard-B System and is expected to provide acceptable voice quality for public correspondence.

2.3 *Modulation techniques*

Report 509 considers various digital modulation techniques which are potentially applicable to standard B, and compares the resultant BER performance characteristics, bandwidth utilization efficiency and hardware complexity.

For shore-to-ship transmissions, filtered 4-PSK would be an efficient modulation technique but because of its varying amplitude characteristics, a linear (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 (see Report 708).

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 applications, an additional 1 to 2 dB should be included for implementation margins, although more recent developments suggest that implementation margins less than 1 dB may be appropriate in the future. 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.

Rate 1/2 convolutional coding (constraint length $k = 7$) with soft decision Viterbi decoding has been widely used in satellite systems and is thus a well-proven technique; implementation in VLSI is available. Coding gains achievable in practice are 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 is not currently as widely applied as rate 1/2 FEC, and requires more complex processing. Practical coding gains are 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 is reduced significantly (i.e. 1.8 dB less than rate 1/2).

The complexity of rate 3/4 coding can be significantly reduced by applying "punctured" coding techniques to the basic rate 1/2 code. This requires deletion of 2 bits in every 6 coded bits in the rate 1/2 coded data stream, transmission of the remaining 4 bits at rate 3/4, and insertion of 2 additional bits at the receiver prior to rate 1/2 Viterbi decoding. Another potential application is the implementation of codecs with flexible coding rates switchable between rate 1/2 and rate 3/4. BER performance with punctured coding is 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 may be concluded that rate 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 is noted that after VITERBI decoding all errors, including random errors, appear as burst errors. Also since the transmission quality of digital channels is 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 is, 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 were studied experimentally and statistically (Yasuda et al., 1988). As a result, it is clarified that the error burst under multipath fading conditions is longer than that of Gaussian noise addition. Here, error burst is defined as the error burst region sandwiched between two error-free continuations of more than 20 bits. Figure 2 shows the results of the measurements made by simulation models and Table II gives conditions not included in the figure.

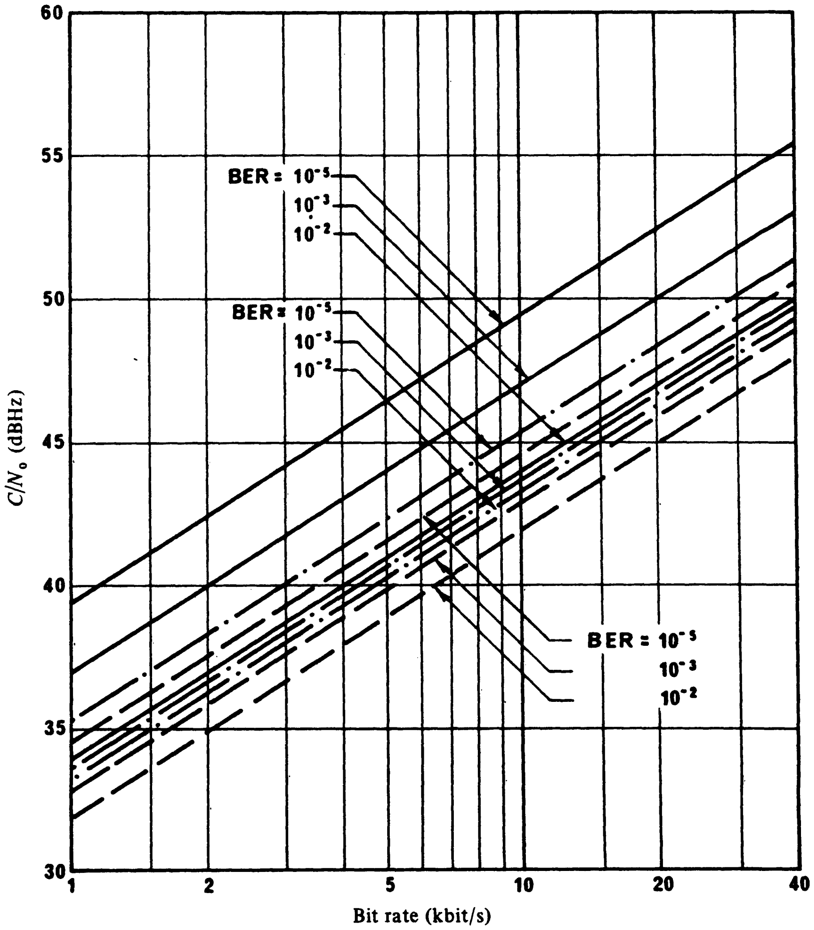


FIGURE 1 – C/N_0 *as a function of bit rate*

———: 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)

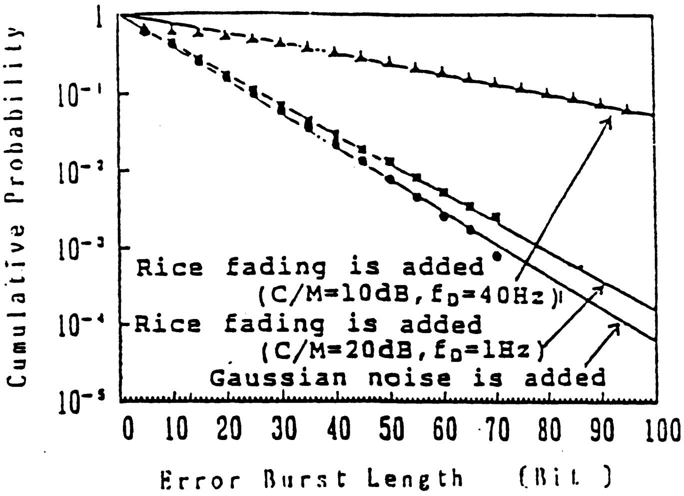


FIGURE 2

Measured cumulative distribution of error burst length

TABLE II

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 currently being studied 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 directions. Full voice activation on shore-to-ship carriers and power control depending on ship earth station elevation angle gives an overall average satellite e.i.r.p. requirement of the order 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.

The same basic channel design can also be used to provide data at 9.6 kbit/s (with rate 1/2 FEC giving 10^{-5} BER) and at 16 kbit/s (rate 3/4 FEC, 10^{-3} BER which can be improved by the use of ARQ by the end users). Sub-band signalling fields within the channel frame, constituting a 96-bit signal unit per 80 ms frame, are used for service addressing (ship-to-shore), supervisory functions after call set-up and to provide additional signalling capacity for future ISDN connections.

Call set-up is performed by means of out-of-band signalling channels, transmitted as appropriate by the network coordination station (NCS), coast earth station (CES) and ship earth station (SES).

3. Low G/T, data only, system concept (Standard C)

The ship earth-station characteristics inherent in standard A and the envisaged standard B concept may not be optimum for smaller vessels which constitute a large proportion of the maritime community, in particular where voice-grade communications are not required and where space for equipment installation is limited.

The standard C concept could enable satellite communications facilities to be extended to such vessels, by means of a relatively simple, compact ship earth station providing message-based capabilities at a channel rate of 600 bit/s. The ship earth station would be characterized by an unstabilized and unsteered antenna system. Potential applications for the system include both-way distress alerting, reception of safety messages, transmission of meteorological data, public correspondence and ship polling, with the following message services:

- text in the appropriate alphabet selected by the user;
- graphics and facsimile;
- information and control instructions for user peripherals such as voice-synthesis equipment.

In view of the projected low *G/T* of the standard C ship earth station, efficient modulation and coding techniques need to be adopted in order to minimize satellite and ship earth-station e.i.r.p. requirements. The choice of technique should also be compatible with anticipated antenna characteristics, channel bit rates and system efficiency.

For typical ship motion characteristics currently applied to standard A designs, the maximum antenna gain for an unstabilized standard C antenna would be of the order of 2 dBi. In the shore-to-ship direction a satellite e.i.r.p. of 20 dBW could then support a channel bit rate of 600 bit/s; an increase in e.i.r.p. would enable higher bit rates to be achieved. In the ship-to-shore direction, practical limitations on ship earth station transmit amplifiers cause the channel rate to be restricted to around 600 bit/s.

At these bit rates an efficient modulation technique would be 2-PSK, with rate 1/2 convolutional coding as the basic FEC technique to improve the system margin. For the ship-to-shore direction, sensitivity to potential interference could be minimized by the use of block coding, linked with an inner convolutional code. In both cases the fading margin due to multipath effects would be significantly reduced by means of interleaving, which would disperse error bursts into a random pattern correctable by FEC, as opposed to improving the antenna discrimination. This would incur transmission delays of up to 20 s, and would thus result in an inability to provide real-time communications such as telephony in the future, although such a capability for small ship earth stations is envisaged for a standard B variant, e.g. as described in Annexes I and II.

Measurements of FEC performance with antenna systems of the standard C type are reported in Annex IV, 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 data links of a standard C system with continuous transmissions.

As an alternative to FDMA/2-PSK modulation in the ship-to-shore direction, the use of code division multiple access (CDMA) may provide some advantages which are further discussed in Annex VI.

The use of FEC in a maritime satellite link is mainly necessary to combat multipath effects at low elevation angle. This leads to the implementation of a communication system with protocols and coding overheads that are more powerful than necessary for much of the time. Furthermore, a coding scheme that is efficient in a multipath environment may exhibit reduced efficiency under non-faded conditions. One way to minimize the protocol and coding overheads when the link is good and still be able to cope with the most unfavourable link conditions is to use an adaptive coding scheme (see Annex VI).

A description of the INMARSAT Standard C system based on the above concepts is given in Annex VII.

4. Link budget considerations

4.1 *Multipath fading characteristics*

The currently envisaged standard B and, in particular, standard C ship earth-station concepts indicate a general trend towards smaller antenna systems which, in view of their reduced directivity, would be more susceptible than standard A to multipath fading effects.

Figure 3 shows a simple multipath fading model derived from theoretical considerations and from measurement data (see Annexes I and II to this Report, and Reports 884 and 763). 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, as described in Report 1048.

4.2 *Pointing/tracking error characteristics*

Pointing/tracking errors for a passively-stabilized ship earth-station antenna, due to ship motion, have been studied in Japan. Experimental results and a statistical analysis of the measurement data are given in Annex V. This information could be used to determine link budget losses for representative antenna systems.

4.3 *Link budget examples*

Example link power budgets for a voice channel BER objective of 10^{-3} are shown in Table III for a standard B ship earth station (case 1: $G/T = -4$ dB(K^{-1})) and the standard B variant 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.

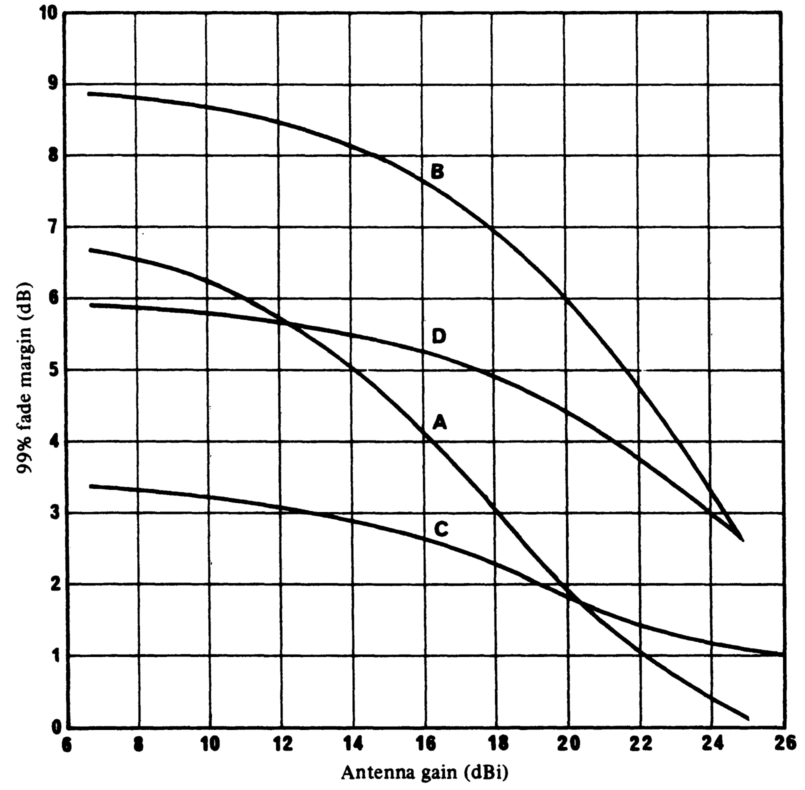


FIGURE 3 - *Multipath fading characteristics (99% time Rice-Nakagami fading)*

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)

TABLE III – *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)	188.4	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
Ship-to-satellite (1.64 GHz):		
– SES 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-shore (4.20 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
– CES 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)

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

Although these example link budgets are not strictly in accordance with the method described in Report 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 existing standard A system.

5. Areas for further study

Continuing study is required on the following aspects:

- speech quality objectives for the reduced G/T SES's;
- 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.

REFERENCES

YASUDA, Y., KOMAGATA, H. and HAGIWARA, E. [1988] - An experimental study on VITERBI decoder output error characteristics (in Japanese). Trans. IEICE Japan, J71-B, 2, 229-237.

ANNEX I

PERFORMANCE CHARACTERISTICS OF A DIGITAL VOICE-GRADE SHIP EARTH STATION

This annex 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).

1. System design

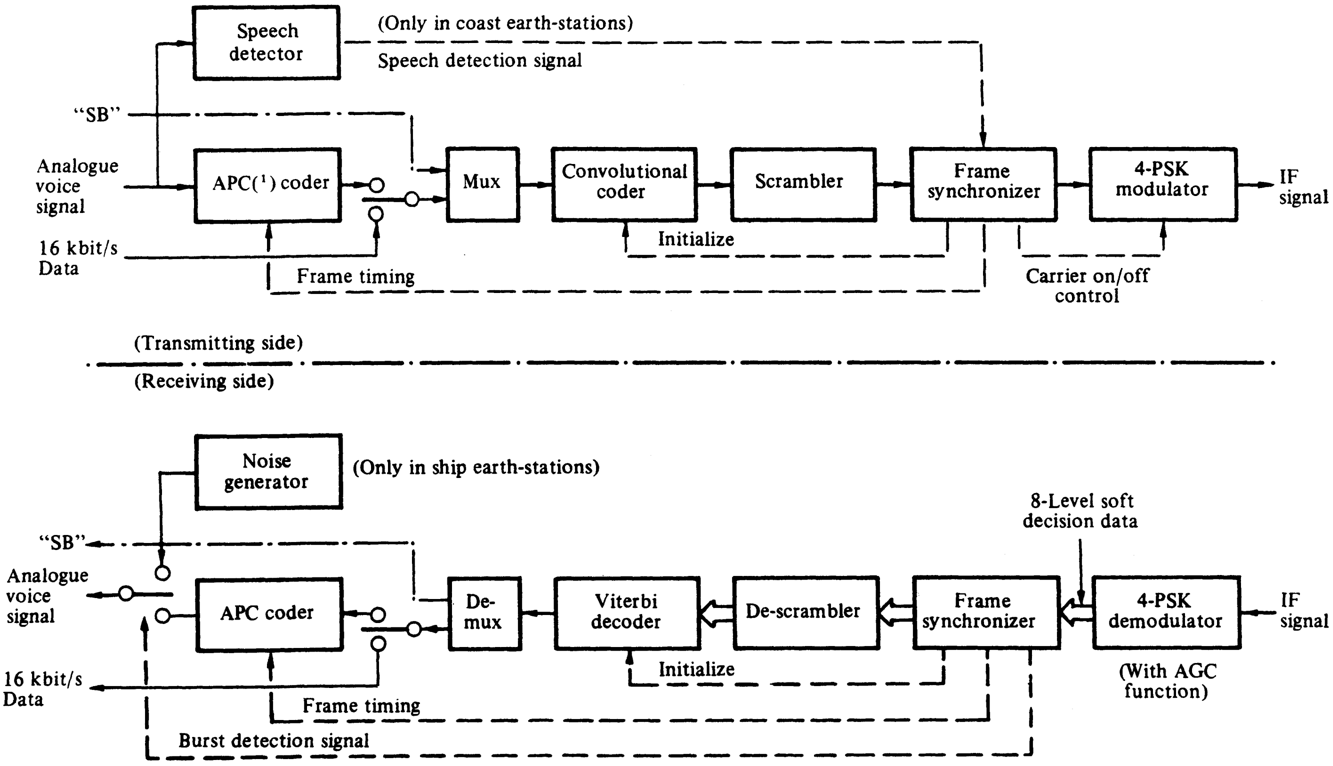
The digital ship earth station system described here has been designed to be used in the INMARSAT system and to operate in the SCPC mode at carrier spacings of 20 kHz.

Table IV 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 coded data including bits for signalling control and 1.6 kbit/s additive data for frame synchronization.

Table IV Major parameters of the digital communication channel

Information bit rate	16 kbit/s and 9.6 kbit/s
Voice coding	APC-MLQ (Adaptive Prèdictive 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 4 shows the functional block diagram of the 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-to-ship direction.



(¹) APC: adaptative predictive coding.

FIGURE 4 - *Functional block diagram of communications unit*

2. 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 the first field experiment for the initially-designed ship 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 stations). 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 at., 1982]. Table V shows major parameters of the high gain and medium gain antennas.

Table V - 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 -3dB beamwidth	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 ship 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 re-growth of the modulated signal due to the nonlinearity of the HPA.

In the field experiment, the E_s/N_o (E_s: energy per transmission bit, there are two bits per symbol for QPSK, N_o: one-sided noise power espectral density) and the number of bit errors were measured every second for the specific time span, and the measured data were stored in the computer memory as a function of time. It was observed that the measured E_s/N_o varies according to the time in the measuring time span under the same transmit e.i.r.p. condition. This variation of E_s/N_o is caused by the level variation of the received signal and/or variation of the noise floor in the satellite transmission channel.

The examples for the performance of BER, which was calculated from the measured number of bit errors per second, versus E_s/N_o is shown in Figures 5 and 6. Dotted points in these figures are the raw data obtained for every second, while circular points indicate the mean value of the BER averaged over the measuring time span (15 minutes) for the same E_s/N_o.

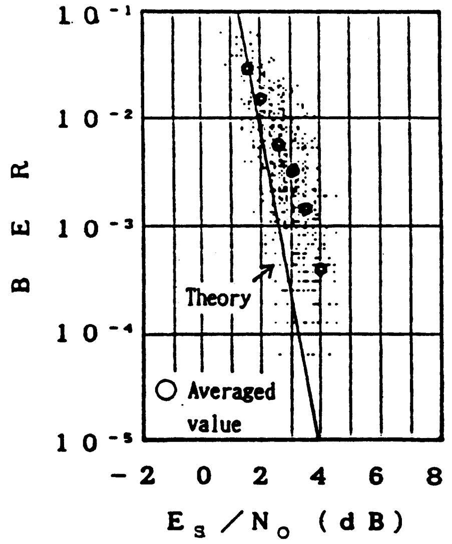
Figure 5 (a) is for the case of offset QPSK (OQPSK) with the Class-C HPA at the SES elevation angle of 10 degrees, while Figure 5 (b) is for the conventional QPSK with the linear HPA also at 10 degrees of SES elevation angle.

It is shown in these figures that the BER versus E_s/N_o performance of the OQPSK modem is a little better than the QPSK modem under perfect synchronization conditions. However, in addition to this, it should be noted that the synchronization loss (sync. loss) at the demodulator and/or the frame synchronizer was caused more often in OQPSK than in QPSK particularly for E_s/N_o values of less than 1 dB.

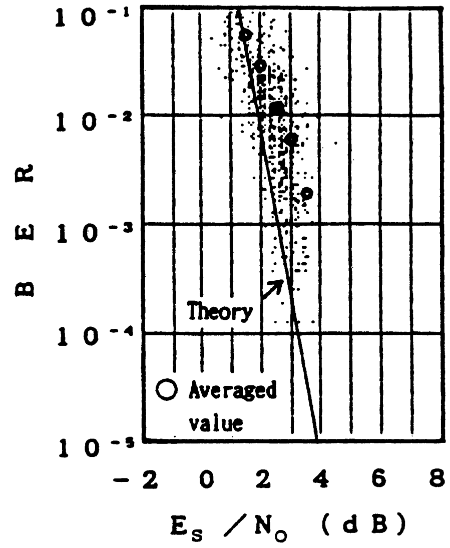
The BER performance for high gain antenna and medium gain antenna systems are compared in Figures 6 (a) and (b). It is observed from these figures that the variance of E_s/N_o and BER is large for the medium gain antenna system due to multipath fading. Because of this a large power margin is required for the medium gain system when operating at low elevation angles.

When rate 1/2 FEC coding (and 9.6 kbit/s voice coding) is emplowed instead of rate 3/4 FEC coding the required satellite and SES e.i.r.p., in theory, should be reduced by around 2 dB. In the field experiment, however, this was not well verified because synchronization loss occured more often in the rate 1/2 FEC system (particularly in the case of the OQPSK), due to the lowered operational E_s/N_o, than for the rate 3/4 FEC system.

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.



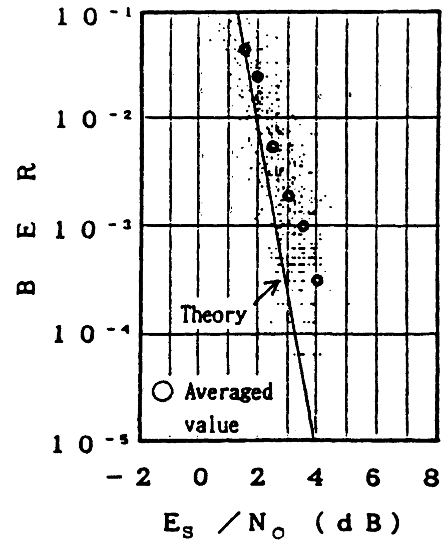
(a) Offset QPSK with Class-C HPA



(b) QPSK with linear HPA

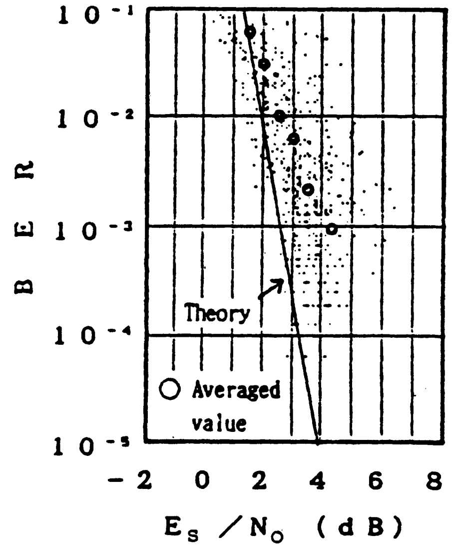
Figure 5 - BER vs. E_s/N_0 performance of offset QPSK and QPSK

(ship-to-shore link, SES elevation = 10°, high gain antenna, FEC: rate 3/4)



(a) High gain antenna system

(satellite 1.5/1.6 GHz band e.i.r.p. = 12 dBW)



(b) Medium gain antenna system

(satellite 1.5/1.6 GHz band e.i.r.p. = 20 dBW)

Figure 6 - BER vs. E_s/N_0 performance of high gain and medium gain antenna systems

(shore-to-ship link, SES elevation = 7.5°, offset QPSK, FEC: rate 3/4)

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ANNEX II

PERFORMANCE OF AN EXPERIMENTAL LOW *G/T* SHIP EARTH STATION

1. Introduction

This Annex presents some results from tests carried out with an experimental low *G/T* SES (-13 dB(K^{-1})) of the standard B type which uses a wide beamwidth antenna and digital modulation techniques.

These tests were aimed at demonstrating the practicability of this type of SES, and at evaluating its performance at a bit rate of 2400 bit/s (suitable for vocoded speech operation [Holmes, 1982] over the present generation of maritime satellites both in conditions prevailing at high elevation angles, essentially unfaded, and in the multipath fading conditions prevailing at low elevation angles.

The tests therefore consisted of two distinct parts:

- land-based tests, with transmissions in the 6 GHz-1.5 GHz direction, via the INMARSAT Atlantic Ocean Region (AOR) satellite Marecs-A, to establish the base-line performance of the SES over an actual satellite link;
- tests using the "stored channel method" to evaluate the performance of the modulation system (modem) in different fading environments and so determine the link margins available for 2400 bit/s (vocoder) operation.

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).

2. Tests using the Marecs-A satellite

Land-based tests were conducted during the last quarter of 1982 using Marecs-A and the British Telecom International Coast Earth Station (CES) at Goonhilly Downs, Cornwall. The low *G/T* SES was also sited at the CES, giving an elevation angle to the satellite of 29° i.e. effectively unfaded conditions. Measurements were made in the 6 GHz to 1.5 GHz band (shore-to-ship) direction of transmission. A repeated 511 bit pseudo-random sequence was transmitted over the link at 2400 bit/s and measurements were made of BER for different values of carrier-to-noise density ratio (C/N_0), the BER being evaluated over 10^6 bits. The C/N_0 at the SES was varied by adjusting the e.i.r.p. of the CES. The equipment configuration used during these tests is shown in Fig. 7.

3. Tests using the stored channel method

The stored channel simulator was driven by pre-recorded tapes. These tapes can be produced synthetically, by using theoretical fading models or by recording actual measurements of satellite transmissions. The technique is described in [Hagenauer and Papke, 1980] and was previously used in the multipath tests carried out by the Federal Republic of Germany (see Report 762).

In order to have available appropriate recordings for the modem tests, the wide beamwidth SES antenna was mounted (unstabilized) on board the German Research Vessel RV GAUSS, and during March 1983, tape recordings were made at elevation angles between 25° and 4° from high level (28 dBW) CW transmissions from Marecs-A.

Two signals representing the amplitude and phase variations of the multipath signals were recorded during each test.

These recorded tapes as well as synthetic tapes generated by the DFVLR were used to assess the modem performance under non-fading (Gaussian) as well as under fading (Rice-Nakagami and Rayleigh) conditions.

Table VI gives details of the RV GAUSS and summarizes the sea and wind conditions prevailing during the recording of the test tapes. For further details see [Hagenauer *et al.*, 1984].

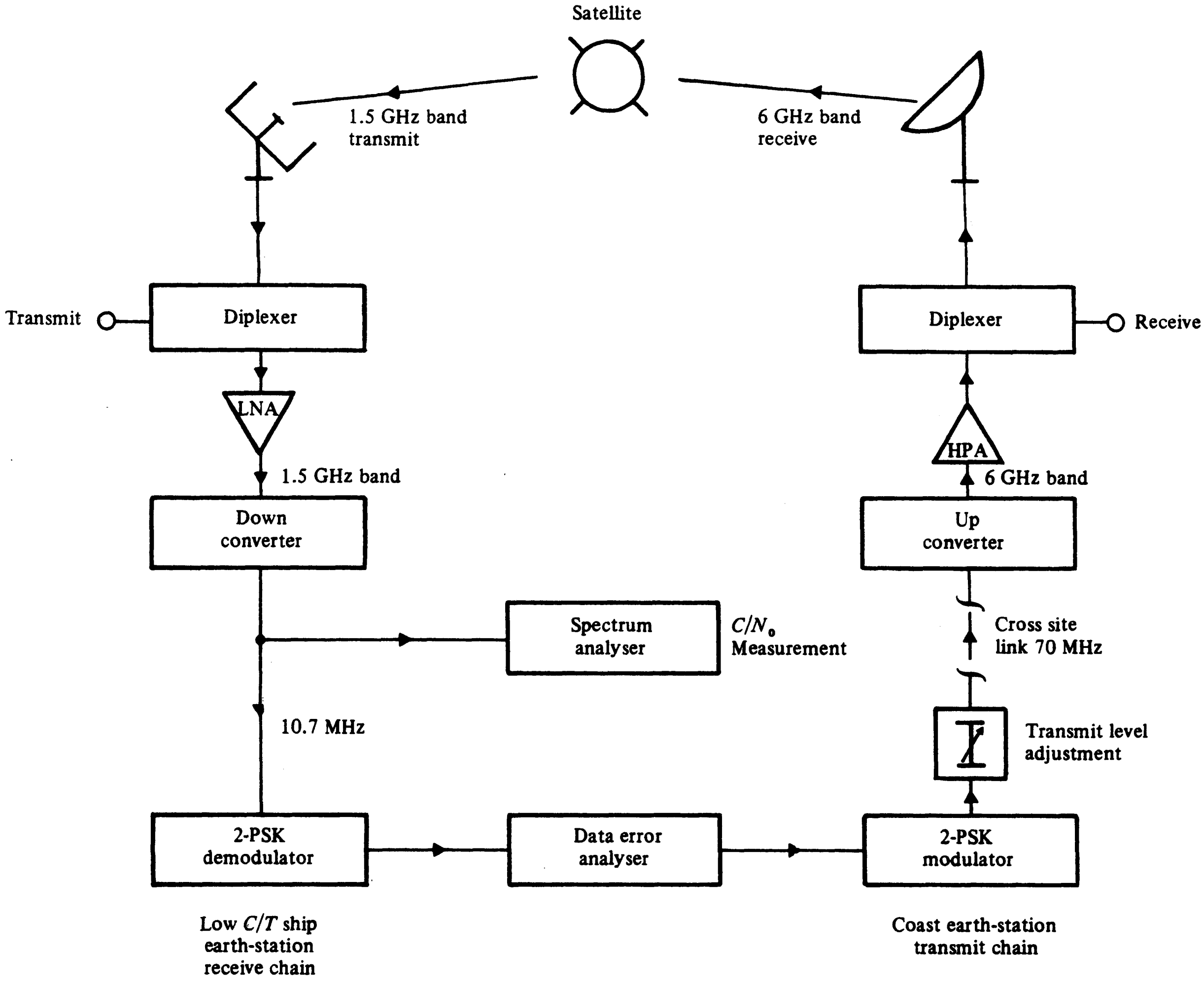

FIGURE 7 – *Equipment configuration for test in the shore-to-ship direction of transmission*

TABLE VI

Ship RV GAUSS Length: 68.86 m Width: 13.09 m Grt: 1599 t			
Satellite	Marecs A Atlantic Ocean Region 26° W		
Test Tape No.	1	2	3
Elevation angle (degrees)	26	10	4
Wave height (m)	< 1	3.5	4.5
Wind force (knots)	< 5	26	35
Measured C/M (carrier to multipath) (dB)	16.5	11	10
Antenna height above sea surface: 12 m			

As in the land-based tests, measurements were made of BER as a function of C/N_0. The equipment configuration used during these tests is shown in Fig. 8.

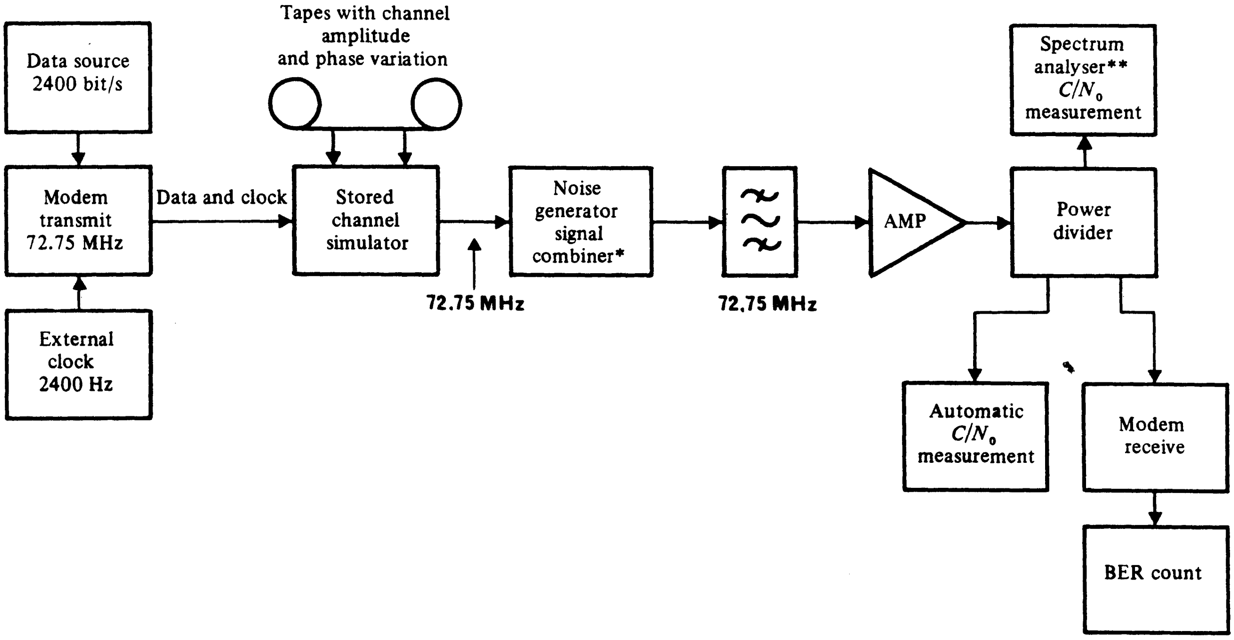

FIGURE 8 – *Equipment configuration for test, using the stored channel simulator*

* The noise generator and signal combiner have the capability to vary the signal and noise independently, allowing the value of C/N_0 to be set for each series of BER measurements.

** The spectrum analyser shown here is similar to the one employed during the land-based tests for C/N_0 measurements. It was used here for comparison with the automatic C/N_0 measurements. In all cases the results obtained from the two methods of measurement were within ±0.5 dB of each other.

4. SES hardware

A full description of the SES hardware is given in [Mecrow *et al.*, 1983]. The main component parts relevant to this Report are the SBF antenna (see § 2 of the main Report and Annex I to Report 922) and the two phase PSK modem. The modem employs a residual carrier modulation technique (deviation ± 1 rad) with the data Manchester-encoded [Subramaniam, 1978].

5. Test results

5.1 *Land-based tests*

The results of the land-based tests are shown in Figs. 9 and 10. In Fig. 9, BER as a function of C/N_0 is plotted as curve D. Throughout the measurements, short-term variations of up to 1.5 dB were observed in the carrier level received from the satellite. This was due to variations in satellite loading which was an average of 12 channels during the tests. Measurements of C/N_0 were therefore made by taking an average of at least 10 measurements over a period of about 2 min before and after each test run. The resulting accuracy of C/N_0 measurements is estimated to be within ± 1.5 dB. The scatter of the results shown in Fig. 9 at low values of C/N_0 is thought to be due to the dominance of varying intermodulation products occurring in the satellite transponder.

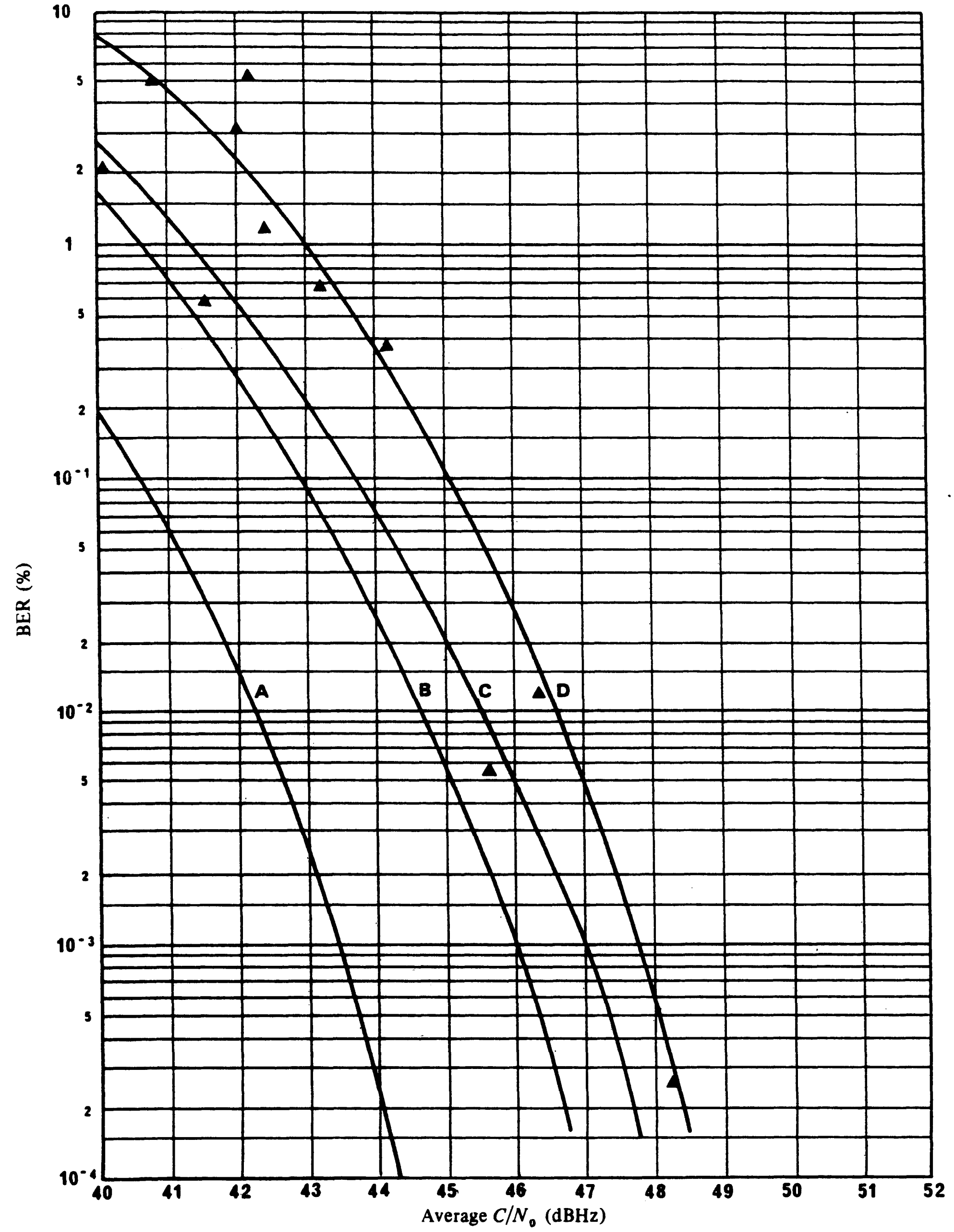

FIGURE 9 – *Measurements of percentage BER for different values of C/N_0 at 2400 bit/s in an effective unfaded (Gaussian) channel*

Curves A: theoretical curve for CPSK

B: back-to-back performance of the modem with the addition of Gaussian noise

C: channel simulator results using a recorded tape (1), elevation angle = 25°, C/M = 16.5 dBi

D: ▲ results of satellite tests carried out at Goonhilly in the shore-to-ship direction

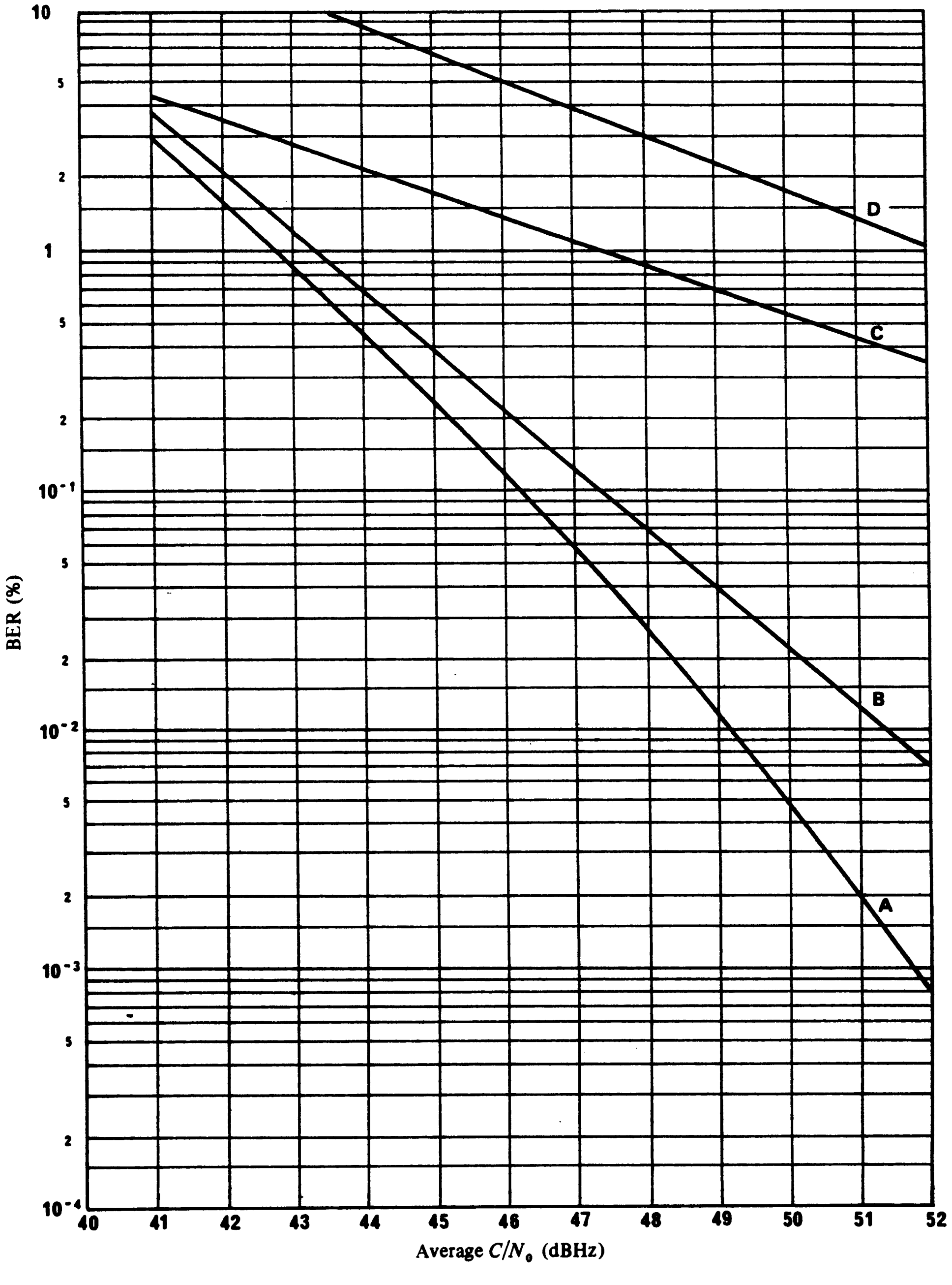

FIGURE 10 - *Measurements of percentage BER for different values of C/N_0 at 2400 bit/s in a fading (Rice-Nakagami and Rayleigh) channel*

Curves A: recorded tape (2), elevation angle = 10°, C/M = 11 dB

B: recorded tape (3), elevation angle = 4°, C/M = 10 dB

C: synthetic fading (equivalent Rice-Nakagami), C/M = 6 dB

D: synthetic fading (equivalent Rayleigh), C/M = 0

5.2 *Stored channel (simulator) tests*

The results of the stored channel (simulator) tests are shown in Figs. 9 and 10.

Figure 9 curve C shows the performance of the modem in an effectively unfaded (Gaussian) channel using the channel simulator and a tape recording (tape 1) made on the RV GAUSS at an elevation angle of 26° with a measured carrier-to-multipath power ratio (C/M) of 16.5 dB.

For comparison, Fig. 9 also shows: curve A, the theoretical performance of CPSK in an unfaded channel, curve B, the back-to-back performance of the modem with the addition of Gaussian noise and in curve D, the results of the land-based tests carried out at Goonhilly. As mentioned in § 5.1, the effects of intermodulation product must be borne in mind when comparing the Goonhilly results with other measurements.

Figure 10 curves A and B show the modem performance in fading Rice-Nakagami conditions obtained using tape recordings (tapes 2 and 3) made on the RV GAUSS at elevation angles of 10° and 4° with a C/M of 11 dB and 10 dB respectively. Curves C and D show the modem performance using synthetic tapes equivalent to a Rice-Nakagami channel with a C/M of 6 dB and a Rayleigh channel with a C/M of 0.

6. **Discussion of results**

In considering the implications of these results for an operational low G/T system it is assumed that the satellite e.i.r.p. per voice channel is as provided by the present generation of maritime satellites, and a BER of 2% is taken as the criterion (vocoder operation) for assessing the link margins which would be required to provide 99% availability in multipath fading environments.

Considering first the curves in Fig. 9, the modem performance in an effectively Gaussian channel, some difference can be seen between the results obtained via the satellite link and those from the channel simulator. At worst the difference is about 1.5 dB at the lower values of C/N_0. This is within the measuring accuracy that was attributed to the land-based tests (see § 4.1) and allowances must be made for the fitted curve due to the scatter of results which was obtained at low values of C/N_0 and the possibility of bit errors being introduced by the CES high power amplifier (HPA) and satellite transponder. In general it is considered that the two sets of results compare favourably and that a C/N_0 value of about 41 dBHz can be taken as that required for a BER of 2% in unfaded conditions.

Measured SES C/N_0 as a function of CES e.i.r.p., shows that a C/N_0 of 50 dBHz was measured at the SES for a CES e.i.r.p. of 55 dBW. The e.i.r.p. of 55 dBW, measured at Goonhilly CES (during its pre-operational phase) was found to be the e.i.r.p. required to provide the satellite power at 1.5 to 1.6 GHz (measured by Southbury NCS, United States of America) equivalent to that provided for an INMARSAT standard A SES voice channel. However, this figure of 50 dBHz would be reduced by about 4 dB under full satellite loading (30 channels compared to the average of 12 observed during the tests), and by a further 1.4 dB for edge of coverage (EOC) conditions (elevation angle 5° as compared to the 29° at which the measurements were made). Taking these factors into account the available unfaded C/N_0 at edge of coverage (EOC) would be 44.6 dBHz.

Table VII shows the modem C/N_0 required for 2% BER performance under various fading conditions and indicates the link margins available when compared to the calculated EOC C/N_0 available.

It should be noted that although the wide beamwidth SES antenna was mounted unstabilized on the RV GAUSS, and wave heights of up to 4.5 m were experienced, the measured C/M value did not drop below about 10 dB.

7. **Conclusions**

It is concluded that with a link of an average C/N_0 of > 44 dBHz this experimental low G/T ship earth station ($G/T = -13$ dB(K^{-1})) could support 2400 bit/s vocoded speech, with a BER not greater than 2% for 99% of the time in all but the worst-case theoretical fading conditions. Under such conditions, fade reduction or forward error correction (FEC) techniques could be applied, although this would add to SES equipment complexity and cost.

Furthermore from the experimental results obtained with this wide beamwidth (47° at 3 dB) unstabilized antenna under realistic fading conditions at edge of coverage, it may also be concluded that only minimal requirements for antenna elevation pointing are necessary. This would significantly reduce the complexity and cost of above deck equipment.

TABLE VII

Fading conditions	Measured C/N_0 required for 2% BER (dBHz)	Calculated available C/N_0 at EOC (dBHz)	Link margin (dB)
Tape 2: C/M = 11 dB elevation angle 10°	41.6	44.6	3
Tape 3: C/M = 10 dB elevation angle 4°	42	44.6	2.6
C/M = 6 dB (synthetic Rice-Nakagami)	44.2	44.6	0.4
C/M = 0 (synthetic Rayleigh)	49.6	44.6	−5

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ANNEX III

ENHANCED GROUP CALL SERVICE

1 INTRODUCTION

The enhanced group call (EGC) service is a global data broadcast service for commercial group calling, global paging (FleetNET^{TM}) and the dissemination of Maritime Safety Information (SafetyNET^{TM}). The service is part of INMARSATs 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 service is not provided. The Safety NET Service 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 in specific geographic areas through the use of a flexible area addressing 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} service allows shore based commercial users to selectively call groups or individual vessels with pre-assigned IDs.

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 does 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 service extends from 1530 to 1545 MHz with a 5 kHz channel spacing. Adjacent ocean regions will have different frequencies for the EGC carriers. The frequencies of these carriers 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.

3 LINK BUDGET

The 1.5/1.6 GHz band link budget for the EGC service is shown in Table VIII. The link budgets shown are for the MARECS and INTELSAT-V MCS satellites and the second generation INMARSAT satellites. The common channel carrier TDM power is approximately 3 dB higher than a Standard-A voice carrier. The TDM is BPSK modulated at 1200 symbols per second (600 bits/s data rate before encoding). FEC Coding is rate 1/2, constraint length 7 convolutional with full frame interleaving and a frame length of 10368 symbols (8.64s). A pair of 64 bit unique words are included in each frame to aid synchronization and ambiguity resolution.

TABLE VIII

	Units	MARECS/ INTELSAT V	INMARSAT 2
Satellite EIRP (5°)	dBW	21.4	21.0
Free space path loss	dB	188.5	188.5
Absorption loss	dB	0.4	0.4
Receiver G/T[1]	dB/K	-23.0	-23.0
Mean downlink C/No	dBHz	38.1	37.7
Mean unfaded C/No	dBHz	38.0	37.6
Interference loss	dB	0.5	0.5
Random loss (99%)	dB	2.2	1.6
Overall C/No	dBHz	35.4	35.5
Required C/No	dBHz	34.5	34.5
Margin[2]	dB	0.9	1.0

Note 1: Minimum G/T based on a stand alone EGC or Standard-C receiver at 5° satellite elevation.

Note 2: Link margin greater than 0.9/1.0 dB for 99% of time.

4 ADDRESSING TECHNIQUES

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

i) unique ID addressing (FleetNET™);
ii) group ID addressing (FleetNET™); and
iii) area addressing (SafetyNET™).

EGC receivers that are capable of receiving commercial FleetNET™ messages have a unique 24 bit identity and a number of 24 bit group identities. The group identities are downloadable and eraseable over the satellite link. Addressing within the SafetyNET™ service is performed exclusively on the basis of geographical area. Two types of geographical area addressing are possible;

a) Pre-defined geographical areas, such as NAVAREAs, WMO areas, NAVTEX coverage areas and SAR areas;
b) Absolute areas are defined in terms of a co-ordinate and a latitudinal and longitudinal extension (rectangular area addressing), or a co-ordinate and a radius in nautical miles (circular area addressing).

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

5 SUMMARY

The EGC service 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.

ANNEX IV

FORWARD ERROR CONTROL (FEC) AS A MEANS OF MULTIPATH FADING COMPENSATION

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 [Hagenauer *et al.*, 1984]. The BER was evaluated for convolutionally and block coded transmission over synthetic channels (Rayleigh-channel, Rice-Nakagami-channel with $C/M = 6.3$ dB) as well as for a representative selection of stored standard C channels recorded on the ship "Gauss" (C/M between 8 dB and 14 dB). The set of stored 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). See Report 762 and [Hagenauer *et al.*, 1984].

The realized coding schemes were:

- Viterbi decoding of convolutional codes of rate 1/2, constraint length 7, with and without channel state information (fading depth information from AGC is used in the decision-making process in the FEC decoder); decoder realized in hardware;
- Reed-Solomon codes (15 : 9 : 3), Berlekamp-Massey decoder realized in software on-line in a main-frame computer [Lutz, 1984].

Interleaving was used with different interleaver sizes. The self-synchronizing de-interleaver was realized in a microprocessor.

An example of the performance of FEC with a Viterbi decoder, for the 11 dB antenna (C11), is shown in Fig. 11. The measurements show that with rate 1/2 convolutionally coded transmission at an elevation angle of 4° a BER of 10^{-5} can be achieved with E_b/N_0 in the range from 12.5 dB to 15.5 dB corresponding to a net coding gain of 18.5 to 20.5 dB.

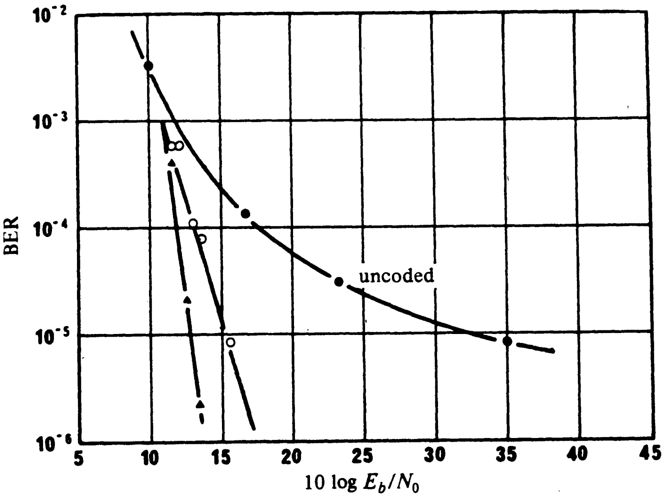

FIGURE 11 – *Measured performance of interleaved Viterbi decoding (C11 antenna, 4° elevation)*

Channel: stored, C11, 4° elevation
Modulation: binary DECPSK
Modem: COSTAS/AFC
Data rate: channel 1200 bit/s
inform. 545 bit/s
Interleaver size: 60 x 80
Decoder: Viterbi rate 1/2
constraint length 7

Decoder mode:
o YH, AN
▲ YH, AH
YH: variable for decisions/hard decisions
AN: no channel state information
AH: hard decision on channel state

Antenna:
C11: standard C type with 11 dB gain

Measurements with a 3 dB antenna showed that at an elevation angle of 19° a BER of 10^{-5} requires an E_b/N_0 of 9.5 to 10.5 dB; the corresponding net coding gain is between 4.5 and 7.5 dB [Hagenauer *et al.*, 1984].

For rate 1/2 block code transmission over stored channels, necessary E_b/N_0 values ranged from 12 dB to 18 dB which correspond to net coding advantages from 6 dB to 17 dB. Compared to convolutional codes the realized simple block coding scheme was somewhat inferior, but it can be concluded that equivalent results will be achieved by using more powerful block coding. A comparison between block and convolutional codes is shown in Table IX.

TABLE IX – *Comparison of block and convolutional codes with respect to interleaver volume, decoding effort and measured E_b/N_0 for BER = 10^{-5} at 1200 bit/s channel rate (COSTAS/(AFC) modem)*

Channel	Code (¹)	Interleaver volume (bit/s)	Decoding effort operations/infobit (²)	Measured E_b/N_0 for BER = 10^{-5} (dB)
Rayleigh synthetic 1 Hz	Block	48·60 = 2880	8.3	27
	Convolutional	48·60 = 2880	128	22.5
C3 antenna 4° elevation stored	Block	48·60 = 2880	8.3	17
	Convolutional	80·60 = 4800	128	13.2
C3 antenna 19° elevation stored	Block	48·60 = 2880	8.3	12
	Convolutional	80·60 = 4880	128	10.5

(¹) Block code: Reed-Solomon (RS) code (15 : 9 : 3), hard-decision decoding.
Convolutional code: rate 1/2, constraint length 7, YHAH Viterbi decoding.

(²) 1 operation for RS decoding means 1 multiplication + 1 addition in GF (2^4) (GF: Gallois field).
1 operation for Viterbi decoding means 1 addition + 1 table look-up of fixed point numbers.

It can be concluded that under the worst-case conditions (hemispherical antenna C3, 4° elevation angle) the mean E_b/N_0 to achieve 10^{-5} BER has to be in the range of 13 dB to 17 dB. The lower value can be achieved with more sophisticated Viterbi-decoding and an interleaving delay of 4 s. For the upper E_b/N_0 value a fairly simple Reed-Solomon decoder with interleaving delay of 2.4 s can be used. Compared to uncoded transmission, net coding advantages of 9 dB to 13 dB have been achieved. These results show that it is necessary to use FEC on standard C satellite data communication systems with continuous transmission to compensate for the multipath effects.

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ANNEX V

METHOD OF STATISTICALLY EVALUATING SHIP MOTION INFLUENCE ON MARITIME MOBILE SATELLITE COMMUNICATIONS

1. Introduction

A shipborne antenna system mounted on a passive gravity-stabilized platform was recently studied for low *G/T* ship earth stations such as INMARSAT standard C [Sandrin and Carpenter, 1983]. In such cases, the received signal level is randomly affected by the antenna off-beam gain because the antenna motion may be directly influenced by random ship motion. Therefore, the performance of such an antenna system mounted on a passive stabilizer should be statistically evaluated as the received signal level fluctuation margin.

This Annex describes a method of statistically evaluating passive antenna stabilizer performance for obtaining the fluctuation margin of the received signal level due to antenna off-beam gain changes on the basis of experimental results and statistical analysis [Satoh *et al.*, 1984].

2. Evaluation of ship motion influence

The experimental area was near Japanese waters. The vessel used for the experiment was in the 200-ton class. Roll motion analysis is discussed here because this mode is a dominant ship motion. Roll was measured with a vertical gyroscope.

A typical recording of a series of instantaneous roll motions (X) for a period of 5 min is shown in Fig.12. The measured cumulative probability distribution (CPD) of (X) is shown in Fig.13. This is the probability that (X) does not exceed a specified level (X_s). The coordinates in Fig. 13 are scaled so that the Gaussian CPD appears as a straight line. It is found that the measured values agree well with a zero-mean Gaussian distribution. The Gaussian CPD is expressed as follows:

$$p(X < X_s) = (1 + \mathrm{erf}(X_s/\sqrt{2}\,\sigma_s))/2 \qquad (1)$$

where:

σ_s : standard deviation of ship motion; and

erf(x) : error function.

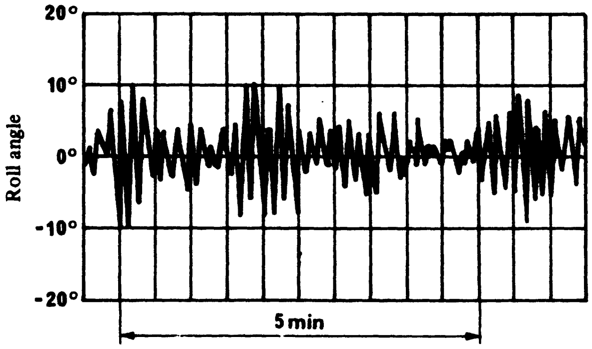

FIGURE 12 – *Typical ship roll motion recording*

Ship speed: 10 knots

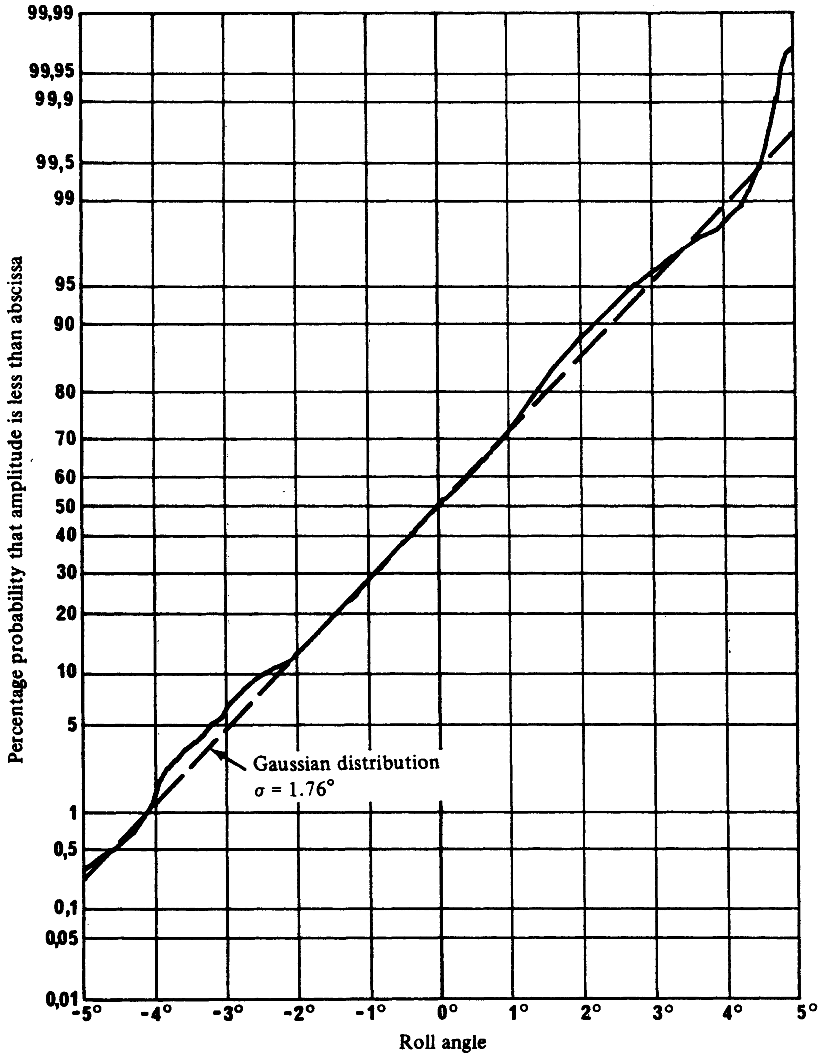

FIGURE 13 – *Measured cumulative probability distribution of instantaneous roll motion*

——— : Measured values

– – – –: Calculated values

Wave height: approximately 1 m

The passive gravity stabilizer illustrated in Fig. 14 was studied as a means of suppressing the shipborne antenna fluctuation due to such random ship motion. Measured stabilizing effects of the passive stabilizer when the ship motion is Gaussian distributed are shown in Fig.15. It is shown that antenna motion is considerably suppressed, and that the stabilized antenna motion approximates to a Gaussian distribution with zero mean.

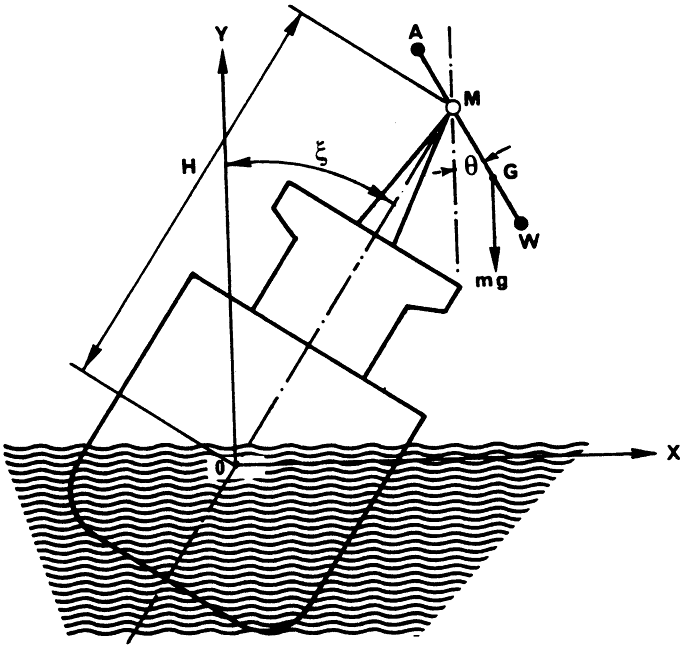

FIGURE 14 – *Configuration of passive gravity-stabilizer*

A: antenna
W: counterweight
M: universal joint
G: centre of gravity

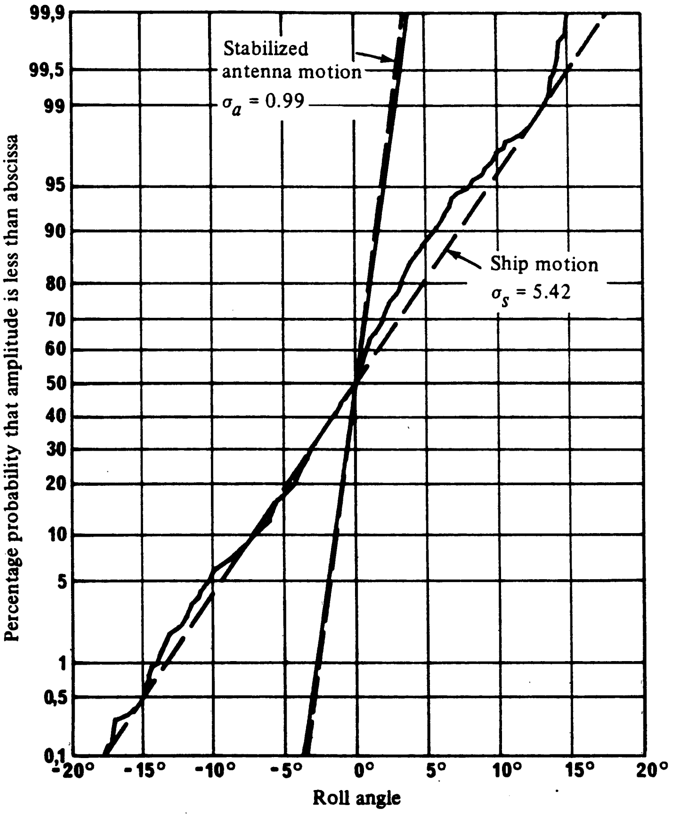

FIGURE 15 – *Measured stabilized antenna motion*

———— : Measured values

— — — : Calculated values

Wave height: approximately 5 m

If p_l denotes the probability of CPD for the stabilized antenna motion over a short interval of time, the maximum antenna motion angle, X_a, can be calculated by the following relation from equation (1):

$$X_a = \sqrt{2}\ \sigma_a \cdot \mathrm{erf}^{-1}(2p_l - 1) \tag{2}$$

where:

σ_a : standard deviation of the stabilized antenna motion; and

$\mathrm{erf}^{-1}(x)$: inverse function of the error function.

For example, for p_l = 99%: $X_a = 2.4\ \sigma_a$. The antenna directivity at X_a (degrees) from the beam centre is equivalent to the maximum received signal level reduction due to antenna motion with a stabilizer at the probability p_l within a short interval of time. The relationship between standard deviation σ_s and σ_a depends on the design of the passive stabilizer.

The long interval distribution for the standard deviation of ship motion, σ_s, should be determined to evaluate the received signal level fluctuation margin for designing a link budget.

It is well known that the envelope of Gaussian variations with zero mean is Rayleigh distributed. A measured CPD of the roll motion envelope for half amplitude, R, within a short interval of time is shown in Fig. 16. The coordinates in Fig. 16 are scaled so that the Rayleigh CPD appears as a straight line. The short interval CPD of R agrees well with the Rayleigh distribution. The root mean square of R, (R_{rms}) for the Gaussian random process with zero mean and standard deviation σ_s is expressed as follows:

$$R_{rms} = \sqrt{2}\ \sigma_s \tag{3}$$

Therefore, the long interval distribution of σ_s can be evaluated by the long interval distribution of R_{rms}.

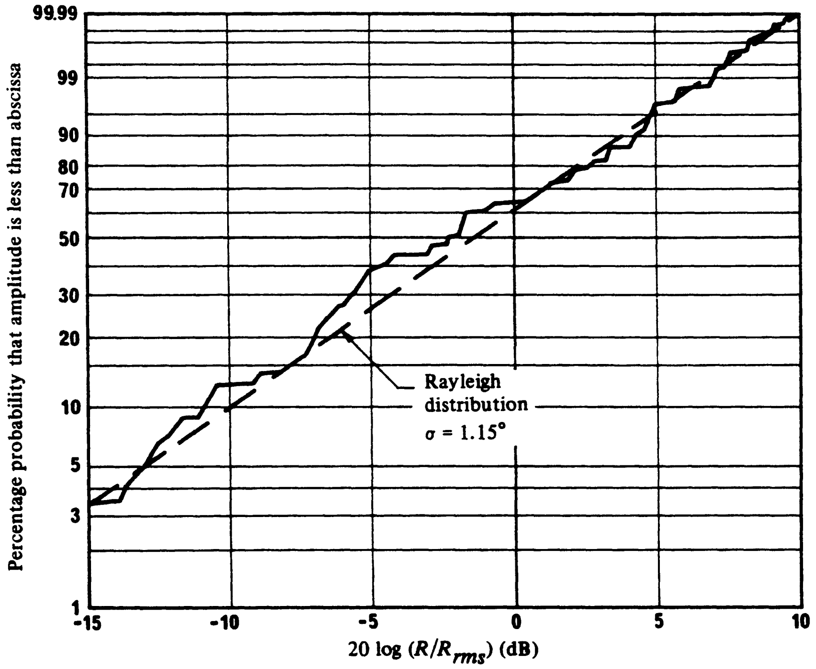

FIGURE 16 – *Measured cumulative probability distribution of roll amplitude envelope within short interval of time*

——— : Measured values

— — — : Calculated values

The long interval distribution of R_{rms} has been studied for a long time and it has been approximated by a log-normal distribution [Jasper, 1956]. However, according to recent studies of long interval distribution during a season, it is known that a Weibull distribution agrees better with measured values for a wider range of probability than a log-normal distribution [Nishinokubi and Kawashima, 1976]. Nevertheless, the long interval distribution of R_{rms} should be studied further. Here a Weibull distribution is assumed in discussing the statistical evaluation method.

The Weibull distribution is employed in the field of ship stress technology. The probability distribution function is expressed as follows:

$$p(x) = q(x/k)^{q-1} \cdot \exp(-(x/k)^q)/k,\ x > 0 \tag{4}$$

where q and k are experimentally determined parameters. The CPD function is then given by:

$$p(R_{rms} < R_0) = 1 - \exp(-(R_0/k)^q) \tag{5}$$

Using equations (3) and (5), the maximum standard deviation of ship motion σ_{s0} related to $R_{rms} = R_0$ for CPD $= p_2$ can be expressed as follows:

$$\sigma_{s0} = R_0/\sqrt{2} = k(-\ln(1 - p_2))^{1/q}/\sqrt{2} \tag{6}$$

According to experimental evaluations of ship roll motion (wave heights around 1 m), during the winter season near Japanese waters, the values of parameters q and k are approximately 1.9 and 5, respectively [Nishinokubi and Kawashima, 1976]. The long interval CPD of R_{rms} is then shown in Fig. 17, where the coordinates are scaled so that log-normal CPD appears as a straight line. For example, for P_2 = 99% the maximum standard deviation of ship motion σ_{s0} can be estimated to be less than about 8° during the season of severest ship motion.

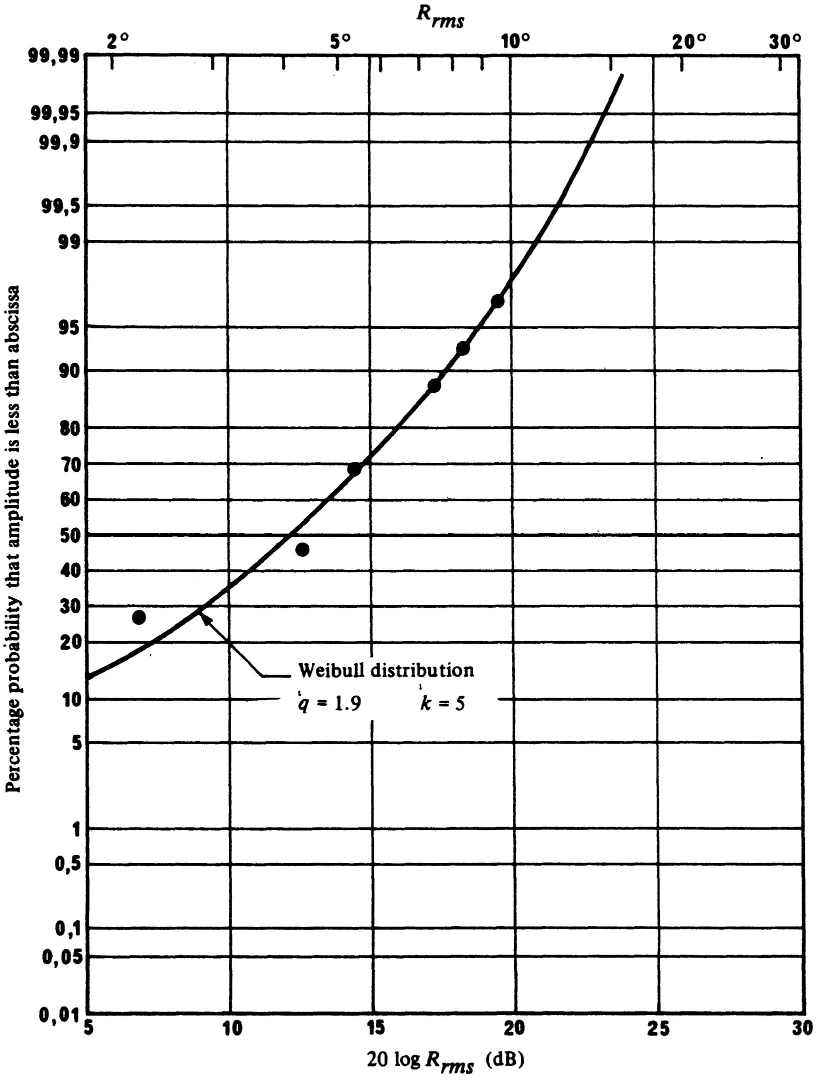

FIGURE 17 – *Measured cumulative probability distribution of root mean square of roll amplitude envelope during winter season near Japanese waters*

●: Measured values

Wave height: 5-10 m

The maximum standard deviation of the stabilized antenna motion is σ_{a0}. The relation between σ_{a0} and σ_{s0} is experimentally determined, and is dependent on the design of the passive stabilizer. The resultant reduction of the received signal due to antenna off-beam gain change, may then be regarded as the fluctuation margin for designing a maritime mobile satellite communication link budget.

3. Conclusion

Passive stabilizer performance for the development of a low G/T ship earth station requires statistical evaluation. The fluctuation margin of received signal level due to random antenna motion can then be estimated by the instantaneous and long interval cumulative probability distribution functions of ship motion, antenna directivity and stabilizer performance.

A statistical treatment for passive stabilizer performance will be useful in designing a shipborne antenna system and link budget for a future maritime mobile satellite communication system using simple low G/T ship earth stations.

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ANNEX VI

A DATA-ONLY COMMUNICATION SYSTEM FOR MOBILE SATELLITE SERVICES

1. Introduction

This Annex describes data-only communication system, named PRODAT, potentially suitable for application in the fields of the three mobile satellite services, i.e. aeronautical-, maritime- and land-mobile satellite services. The PRODAT system is currently being implemented by the European Space Agency as part of the PROSAT programme which is a test and demonstration programme relating to future mobile satellite communication services. The PRODAT system design is based on the experimental data that were gathered during the first phase of the PROSAT programme. The system will be used during the second phase to perform demonstrations and long-term evaluation of data-only communication services suitable for low G/T mobile earth stations in the three fields of application mentioned above.

The PROSAT phase 1 experiments demonstrated that the aeronautical, maritime and land mobile satellite "channels" are different. However, at system, level their behaviour is very similar: the channel is good for most of the time, but under certain conditions (e.g. low elevation angle or environment in the land mobile case) it can be very bad. In order to minimize the protocol and coding overheads when the channel is good and still be able to cope with most of the unfavourable conditions, it is necessary to find a communication system which adapts itself to the channel characteristics. This is one of the basic design criteria that has been used to define the PRODAT system. The coding and ARQ schemes used in PRODAT for both forward and return links are well adapted to the propagation conditions that low G/T PRODAT mobile earth stations ($G/T = -24$ dB(K^{-1})) will have to face.

2. PRODAT system

2.1 Frequencies

The mobile terminals have the capability to operate over the full maritime and aeronautical allocation but the frequency band used for PRODAT trials is limited to the part of the satellite maritime mobile band usable with MARECS.

Mobile to satellite : 1638.6 MHz 1644.5 MHz
Satellite to mobile : 1537.75 MHz 1542.5 MHz

2.2 Mobile antennas (see baseline pattern in Figure 18)

The mobiles will be either equipped with one antenna and a diplexer or two antennas separated by about 80 cm.

The baseline radiation diagram is hemispherical with a gain between 0 and 2 dBi.

The polarisation is right hand circular with an ellipticity ratio better than 5 dB.

2.3 Mobile transmitter characteristics

- The RF power is 10 dBW (+1 dB/-1 dB)
- The transmitter is activated only when a messages has to be transmitted.
- The modulation is direct sequence spread spectrum. The chip rate is 266.7 KHz. The symbol rate is 300 baud.
- Maximum frequency error ± 300 Hz.

2.4 Mobile receiver characteristics

The receiver locks on a continuous TDM transmitted by the satellite and monitors the signalling slots. For the purposes of PRODAT trials, the receiver parameters are:

- TDM symbol rate 750 baud
- Frame duration: 1 second
- Modulation BPSK
- The nominal flux density of the satellite TDM on earth is -133 dBW/m^2.

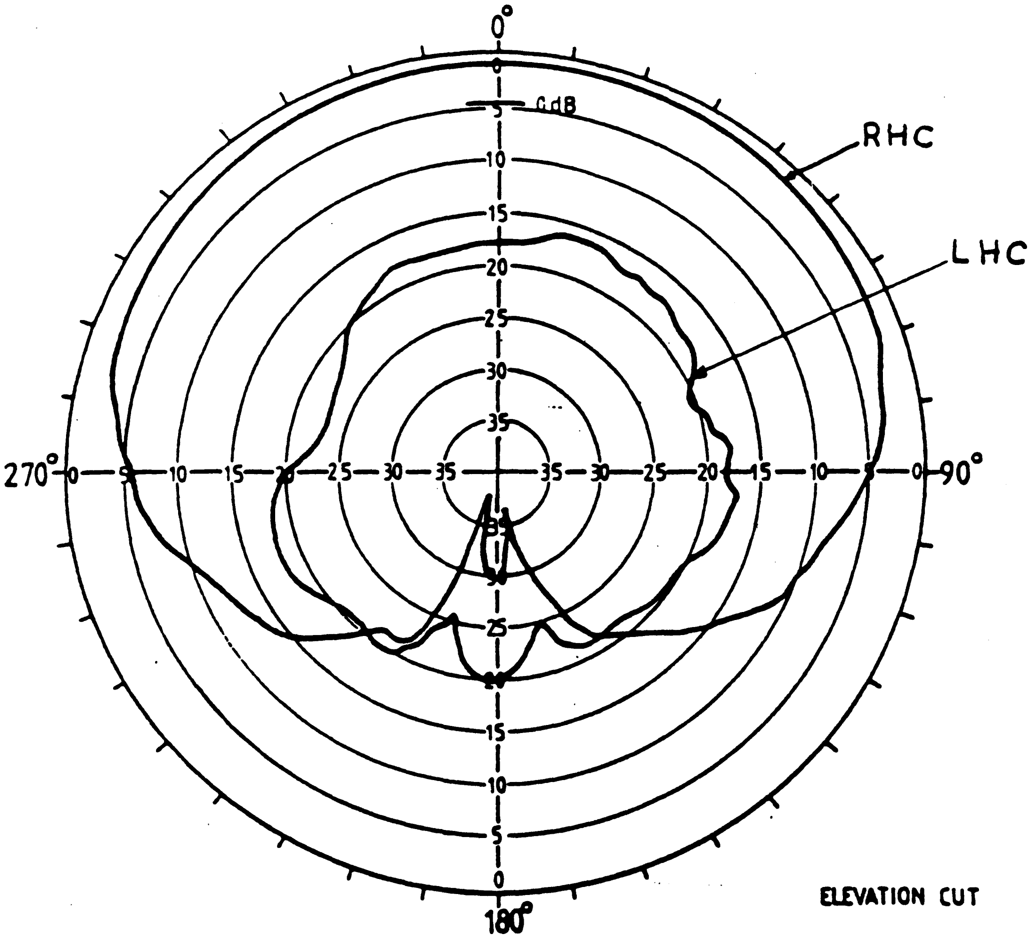

FIG. 18 - TYPICAL ANTENNA DIAGRAM

The main characteristics of the forward TDM are:

Signalling rate:	1500 Bd
Frame duration:	1.098 s
Data rate (per channel):	46 bits

The coding is based on short block GF (2^4) Reed-Solomon codes and message redundancy is introduced following an automatic repeat request (ARQ) scheme.

2.5 *Return link*

The return link is a digital link from mobile stations to the network management system through the satellite. The data from mobile stations are transmitted according to a code division multiple access (CDMA) scheme.

The main characteristics of the return CDMA are as follows:

Number of codes:	32
Signalling rate (per channel):	300 Bd
Data rate (per channel):	150 bits
Chip code length:	889

The coding is organized in a way similar to that of the forward link.

2.6 *Communication functions*

The PRODAT system will provide the following functions:

- transmitting of messages from fixed user to mobile user and *vice versa*, and from mobile-to-mobile users;
- transmitting of messages to multiple mobile users;
- dialogue between a fixed user and a mobile user;
- request/reply function;
- periodic polling of mobile stations;
- paging.

Each user will not necessarily have access to all functions.

For the purpose of PROSAT phase 2 demonstrations, the network management system will provide interfaces to the public data network, public telephone and telex networks.

2.7 *Coding scheme and ARQ function*

The PRODAT system is based upon the use of a bi-dimensional coding scheme and the implementation of an ARQ scheme.

The information is organized in "blocks", each block being a set of extended RS (16 : 12) code vectors (vertical coding). Each code vector occupies a TDM slot. The symbols of the code vectors are elements of the Gallois Field GF (2^4) containing 4 signalling bits each. The vertical coding is used to correct random errors. A detailed description of the coding scheme is given in Report 509, Annex II.

2.8 *Return link CDMA*

The selected access scheme in the return link is CDMA. The modulated signal is spread using a 127 Gold code tiered by a 7 bit Barker sequence. The modulation by the spreading code is 2-PSK, and the chip rate is 266.7 kHz. The maximum cross correlation peak is less than −13 dB (with respect to the autocorrelation peak) and the mutual interference degradation less than 2 dB.

The advantages that CDMA will provide are as follows:

- improved protection against interfering signals;
- improved efficiency in the performance of the random access channel (two signals spaced by one or two chips can be distinguished);
- better efficiency of the return data link with respect to TDMA (no need for guard times to avoid signal garbling);
- spreading of intermodulation products in the return transponder of the satellite (hence the possibility of accommodating higher signal dynamics or improving the link performance);
- improved frequency re-use capability for satellite multi-beam antennas; and
- less peak power than for TDMA in the ship earth-station transmitter.

2.9 *Channels*

The following channels are provided in the forward TDM frame:

S0:	unique work
S1:	signalling channel (access)
S2:	sub-multiplex for backward sub-channel (acknowledgement)
S3:	signalling channel (access)
D001-017:	data channels (17)

In the return link 30 CDMA codes are used, each code being associated to a particular channel:

RA1:	random access call channel
D051-062:	data channels (12)
D101-117:	backward sub-channels (17)

Backward sub-channels are used to transmit acknowledgement messages.

2.10 *Synchronization (return link)*

Transmissions on any particular channel, except the random access channel, occur once the channel is assigned to a given mobile station. Therefore only one mobile station is transmitting during the assignment period in a particular channel.

3. PROSAT phase 2 programme

As part of the second phase of the PROSAT Programme, PRODAT activities providing for communications system trials have been initiated. This has involved the procurement of a network control system, located at the Villafranca satellite control facility and providing an interface between the public data and public telex networks and the MARECS Atlantic satellite. There is also an interface with the SITA network at Villafranca.

In addition, approximately thirty mobiles covering the three mobile satellite service categories have been procured. Trials started in May 1987 and continue until December 1988. During the trials aside from purely technical matters eg. link quality, aspects of service and user reaction, but excluding tariff matters, will be explored.

ANNEX VII

INMARSAT STANDARD-C COMMUNICATIONS SYSTEM

1. INTRODUCTION

The Standard-C communications system has been designed to permit the fitting of modern two-way satellite communications systems on board the smallest vessels. It has also been 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 ships 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 service 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 service known as Enhanced Group Call, is carried by the Standard-C communication channels.

1.1 Briefly the Standard-C system may be described as follows:

(a) the G/T is -23 dB(K^{-1}) utilising 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 of 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.

1.2 These techniques will permit the following services to be carried.

(a) International Telex
(b) Text Broadcasts
(c) Interactive data exchange and database interrogation
(d) Priority connection for distress purposes

2. DESIGN IMPLICATIONS

The adoption of -23 dB(K^{-1}) G/T restricts the service 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.

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 deemed a limit of acceptability; the percentage of time in excess of this threshold is the availability. In Standard-C, C/N_0 only affects the number of re-transmissions, and hence message delay and the system capacity.

The link budgets presented in Tables X and XI 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 X

"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
Absorbtion 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
Absorbtion 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_0	(dBHz)	34.5
Required C/N_0	(dBHz)	34.5
Margin	(dB)	0.0

TABLE XI

Return Link: 99% of time

		MCS	MARECS
Ship Earth Station e.i.r.p.	(dBW)	12.0	12.0
Path Loss	(dB)	189.0	189.0
Absorbtion 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
Absorbtion 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

4 SIGNAL PROCESSING SYSTEM

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 (e.g. see Report 921).

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 the 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 (see Report 384) it is necessary to ensure adequate symbol transitions for the demodulator clock recovery. Messages 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.

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 convolutional 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 independant 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 STANDARD-C CHANNELS

A number of different types of channels are used in the Standard-C system and these are described below:

5.1 NCS Common Channel

The NCS common channel is transmitted continuously by the NCS. The channel operates at 1200 symbols/s with a fixed length frame of 8.64s. The information is scrambled, interleaved and half rate convolutionally encoded on a frame by frame basis. The information rate is therefore 600 bit/s.

In each frame, 591 bytes are available for packets and 48 bytes are reserved for a bulletin board. This bulletin board is used to transfer information concerning SES usage of associated SES signalling channels.

5.2 CES TDM Channel

The CES TDM channel is used for the forward link when communiating with an SES. Its structure is identical to that of the NCS common channel described above, and is used for carrying call set-up signalling, shore-to-ship message, acknowledgements, and call clear down signalling.

A CES may operate more than one CES TDM channel and each channel may be demand assigned by the NCS.

5.3 SES Signalling Channel

The SES signalling channel is used both by the NCS and by the CES mainly for return link signalling purposes. One to four SES signalling channels are associated with a forward TDM, channel.

Access by SESs to SES signalling channel is by means of a slotted Aloha scheme with the addition of a mechanism for reserving slots in the channel.

Slot timing is based on the TDM frame of 8.64s. Each frame time is divided into 14 slots for current generation satellites and 28 slots for future generation satellites.

Information transmitted in a slot is scrambled and half rate convolutionally encoded.

The transmission rate is 600 symbol/s for current generation satellites and 1200 symbols/s for future generation satellites. Each slot can carry 120 information bits. The bursts transmitted in the slots do not have dedicated acquisition preambles in order to maximize the utilization of the channel.

More than one SES transmitting in the same slot results in a 'collision' as seen at the receiving CES. In order to minimize the time elapsed before an SES is aware that its transmission was not successful, the bulletin board in the forward TDM is used to feedback the results of SES transmissions.

5.4 SES Message Channel

SES message channels are used by SESs to transmit their messages to the chosen CES. An SES signalling channel is used during the call setup phase of the transfer, but the message itself is sent on an SES message channel assigned by the CES.

Access to the channel by SESs is on a TDM basis. The destination CES instructs each SES waiting to transmit, the time at which it may start transmitting. Once assigned a start time, an SES will transmit all of its message without interruption.

The information to be sent is formatted into fixed sized packets and placed into frames. More than one frame size is available although the size will be fixed for a particular transmission. A frame may contain between 1 and 5 packets depending on its size. Each packet in turn contains 127 bytes of information.

The frames are scrambled, interleaved and half rate convolutionally encoded on a frame by frame basis. Before transmission, an acquisition preamble is added. Transmission rate is either 1200 symbols/s or 600 symbols/s according to the particular satellite transponder being used.

5.5 Interstation Links

Each CES offering Standard-C services has a bidirectional link with the NCS of the same region. This link is used to transfer announcements and EGC messages from a CES to the NCS for the subsequent transmission on the NCS common channel. In addition, signalling is exchanged on this link to ensure synchronization of access to SESs and for the allocation of CES TDM channels by the NCS.

The channel uses the link access procedures of CCITT Recommendation X.25 (Red Book). The transmission rate is 1200 bit/s and, no error correction techniques are employed other than those included in X.25.

5.6 Inter-Region Link

Each NCS is linked to the other NCSs by an inter-region link channel. This channel is used primarily to update other regions of any registration activity by SESs in a particular region.

This link uses automatic dial-up voice band data channels over the PSTN. The link layer procedures of CCITT Recommendation X.25 (Red Book) are used for interchange of information. These links operate at 600 bit/s, using CCITT V22 full duplex modems.

6. STANDARD-C TYPES

- Type 1	Capable of providing for Standard-C communications only
- Type 2	Capable of providing Standard-C communications and reception of Enhanced Group Call (EGC) transmissions when not engaged in communications using the only one receiver (common EGC/SGDC receiver)
- Type 3	Capable of providing for Standard-C communications and EGC simultaneously by using two receivers.