REPORT 920-2

MARITIME SATELLITE SYSTEM PERFORMANCE AT LOW ELEVATION ANGLES

(Question 88/8)

(1982-1986-1990)

1. Introduction

Maritime satellite system performance at low elevation angles is affected by, *inter alia*, a number of propagation factors. The results of tests performed by the USA and the U.S.S.R. are described in this Report, and a preliminary assessment of the system performance at low elevation angles is given.

2. USA tests

2.1 *Background*

In October 1978, an experiment to determine the extent of degradation of satellite-to-ship and ship-to-satellite signals at low elevation angles in the bands 1.5/1.6 GHz was performed by the USA using the Atlantic Marisat satellite. A MARISAT ship earth station having a G/T of -4 dB(K^{-1}) was used on-board the S.S. Mobile AERO, an 18 600-ton oil tanker, while on route from Norfolk, Virginia to Texas City, Texas, with elevation angles changing from 17° to 0°. Baseline measurements were made during the initial portion of the trip. On a straight line sailing from Tampa, Florida to Texas City, Texas on a heading of 274°, the elevation angle from the ship earth station to the satellite decreased steadily from 11° to 0.3° at an average rate of 0.3° per hour. During this 40 h period the experiment was conducted without interruption.

2.2 *Data collection*

The equipment block diagram of the measurement set-up at the ship earth station is shown in Fig. 1. An IDS-1310A data test set was used to generate either 2400 bit/s or the 1200 bit/s data for input to a DPSK modem (ICC-24LSI) or an FSK modem (GDS1200ES), respectively. The input/output point was at the data jack on the ship earth station console (VOICE/DATA). A 600 ohm variable attenuator, not shown in Fig. 1 was inserted at the data jack for the purpose of adjusting the interface level between the console and the modem. The block size for each transmit/receive test could be either 10^6 or 10^7 bit/s, taking either 7 or 70 min to complete for 2400 bit/s tests, and taking twice as long for 1200 bit/s tests. Besides direct readings from the data test set, a printer was also employed to record the bit error ratios [Fang *et al.*, 1981].

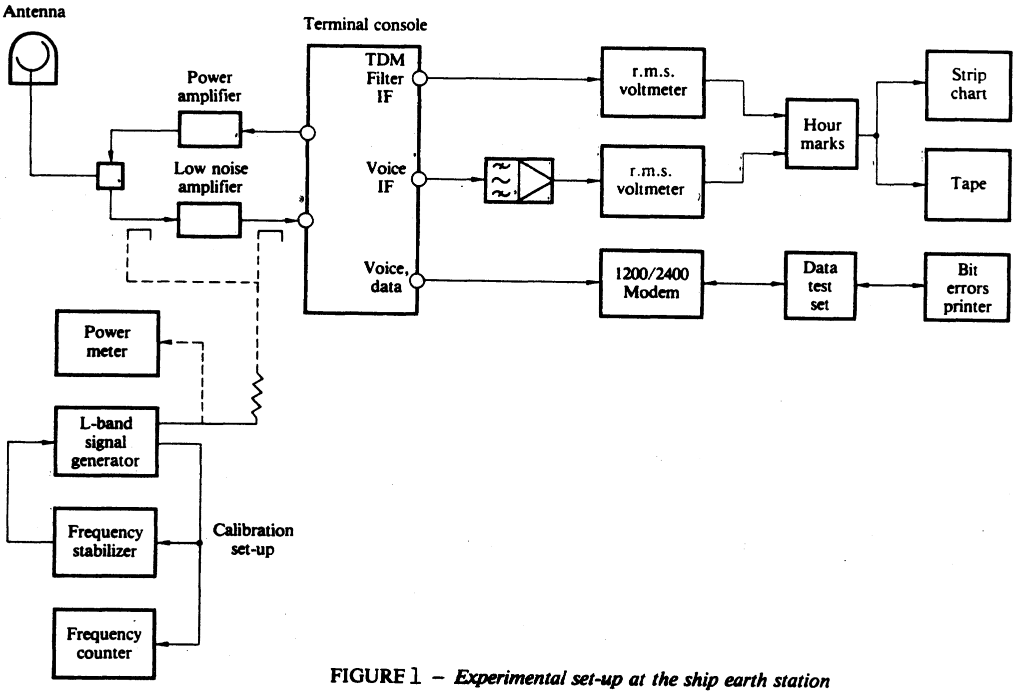

FIGURE 1 – *Experimental set-up at the ship earth station*

2.3 *Test conditions*

Signal degradations on the received TDM carriers due to atmospheric and sea surface anomalies cannot be assessed until the carrier level shifts due to the effect of demand assignment of telephone calls are resolved. To achieve this, the signal levels were measured during the earlier period of the experiment when the elevation angles were above 10°. The distribution of telephone traffic was not uniform over a 24 h period for any given day. The busy time for ship/shore and ship-ship voice communications via the Atlantic Marisat satellite was generally concentrated in early morning hours, between 0330 and 0530 EST (Eastern Standard Time) and in late morning hours, between 0830 to 1130 EST.

Throughout the entire experiment period, the weather was mild. The sky was either clear or cloudy but it never rained. The windspeed was generally under 15 knots (28 km/h).

The highest sea state during the experimental period was 4, corresponding to a wave height of about 1.2 m (4 feet), which was considered relatively calm. The sea surface was, nevertheless, fairly rough from the point of view of the microwave propagation experiment. This is because at L-band, the wavelength is about 0.2 m, which is only 1/6 of the peak amplitude of the sea waves at sea state 4.

2.4 *Experimental results*

2.4.1 *Carrier-to-noise characteristics*

Since the satellite-to-ship TDM and voice carriers are amplified by a common 1.5 GHz TWT, a redistribution of RF powers occurs whenever there is a change in telephone traffic. This is a further cause of the carrier level shifts.

Although such carrier level shifts occur on both TDM and voice carriers, the extent of the shifts is not the same. TDM carrier levels which were continuously available were measured to determine the 1.5/1.6 GHz band C/N variation as a function of elevation angle. (In actuality $(C+N)/N$ was measured in all cases. It is understood that $(C+N)/N$ is implied for measured data where C/N is written.) In addition, the voice carrier levels were measured during times of voice communication or of transmitting and receiving digital data, for the correlation of voice channel C/N and the bit error ratio of the digital signals.

There are two principal differences between the performance at high and low elevation angles:

- mean C/N levels decrease as the elevation angle decreases, and
- peak-to-peak fluctuations of C/N increase with respect to its mean, as the elevation angle decreases.

At extremely low elevation angles, i.e., below 2°, the mean C/N reductions and peak-to-peak C/N fluctuations are so severe that it is impossible to identify the shifts of carrier levels due to the effect of simultaneous telephone traffic.

2.4.2 *BER versus C/N*

For an ideal bit error ratio measurement, the signal C/N should remain at a fixed level, i.e., with little or no variation while the digital data are being transmitted. The BER observed over a block size of 10^6 or 10^7 bits then provides a true measure of probability of errors with a high degree of confidence. Furthermore, if such an ideal measurement can be repeated at different elevations angles, the effect of elevation angle on BER can be readily assessed.

Unfortunately, such an ideal situation never existed during the shipboard tests. First of all, the number of telephone calls changed the C/N level from time to time. Even during a 7 min period, which was the minimum time period required for relaying a block of 10^6 bits at 2400 bit/s rate, the number of simultaneous telephone calls often changed 4 to 5 times. Furthermore, signal fluctuations were severe at low elevation angles. These fluctuations sometimes caused the C/N to fall below the threshold level required to maintain the synchronization of the digital transmission. As a result, an instantaneous drop of C/N below threshold level due to signal fluctuations would generate very large numbers of errors over a prolonged period of time. Even though C/N recovered readily to a respectable level, it took some time for synchronization to be restored.

In order to overcome these difficulties in the data analysis effort, each digital data transmission test was divided into a number of subtests based on the occurrence of sudden shifts of C/N levels. In one 3 min period, the C/N variation about the mean was 2 to 4 dB, which caused a loss of synchronization; while in the following 9 min period, the C/N varied over a 1.0 to 4.0 dB range, giving a BER of 28×10^{-4} with no loss of synchronization. The irregularity is due to the fact that the occurrences of either bit errors and loss of synchronization were random events. Statistical regularities were observable only when an adequate sample size was available, which was not always the case in the subdivisions. Furthermore, the peak-to-peak fluctuations of voice C/N sometimes exceeded 5.0 dB or more. A determination of BER in reference to a fixed value of C/N was not meaningful in such instances. The degradation of BER for elevation angles below 5° was even more serious.

The BER data for elevation angles above 5° were generally much more manageable. This was because the mean C/N was higher and peak-to-peak fluctuations of C/N were less severe, reducing markedly the possibility of synchronization loss. The results of measured BER versus the range of C/N variations during the measurement are presented in Figs. 3 and 4 for the cases of 2400 bit/s DPSK transmission at elevation angles between 5° to 11°, and between 11° and 15°, respectively; and in Fig. 5 for the case of 1200 bit/s FSK transmission at elevation angles between 5° and 11°. Also shown in the figures are curves of BER versus the mean C/N which best fit the data. The gross pattern of the BER fitting curves do follow a general class of error functions, which is consistent with theoretical predictions.

3. U.S.S.R. tests

3.1 *Background*

Experiments were performed by the U.S.S.R. on board the M/V "Magnitogorsk" (220 m length, 25 000 grt deadweight) over the period November 1979-February 1980. The objective of the tests was the collection and processing of experimental data pertaining to MARISAT system performance at low elevation angles. When the ship was operating near the Bay of Biscay and within the Gulf of Mexico, communication tests were conducted via Marisat satellites over the Indian and Atlantic Oceans respectively.

The M/V "Magnitorgorsk" is equipped with a ship earth station of -4 dB(K^{-1}) G/T which was employed for establishing communication and making tests.

3.2 *Test conditions*

The measurements were conducted under normal operation of shipborne equipment in the absence of failures of satellite or shorebased equipment.

To evaluate the system performance at low elevation angles, the data used was obtained over the periods for which the ship earth station was not affected by operation of other shipborne radio aids. Therefore no allowance is made for the possible effect of these aids in the given results.

Concerning the effect of propagation conditions, variations on a satellite-to-ship link (1.5 GHz) only were estimated. Propagation conditions on a shore-to-satellite link were believed to be stable. The ship-satellite-shore direction was not examined during the tests.

Account was taken of the effect of variations in satellite loading levels (i.e. number of simultaneously operating channels) on C/N values. Variations of C/N at the first IF were then assumed to be due to propagation conditions at low elevation angles.

Measurements were carrried out mainly on telex channels. A limited amount of data was obtained for telephone channels. In evaluating performance of the telephone channels at low elevation angles, the changes in signal levels in the telephone channels were assumed to be proportional to the relevant changes observed at the time in the telex channels. The validity of this assumption was confirmed by a series of measurements taken for the telephone and telex channels at 3° elevation angle.

3.3 *Weather effect*

During the test period, the effects of weather conditions on quality of communications via satellite were studied. The data obtained indicated that, during drizzle and rainstorm conditions, degradations of the mean C/N of about 1.5 dB and 2 dB respectively were observed.

Environmental conditions encountered were mostly favourable, so that the ship rolling and pitching did not exceed 3°-5° and 2°-3°, respectively. Such disturbances are too small to evaluate their effect on quality of satellite communications at low elevation angles.

3.4 *Experimental data*

The total number of readings processed was about 2500. Elevation angles ranged from 3° to 14°.

Experimental data were divided into two groups, each being handled separately.

The first group comprised measured C/N values on telex channels in the absence of operating telephone channels.

The second group comprised measured C/N values with both telex and telephone channels being active.

Graphic presentation of experimental and measured values of C/N ratio in accordance to the first and the second groups mentioned above is given in Figs.2 and 3 respectively. Because of the limited data for telephone channels, the r.m.s. deviations from mean C/N of telephone channels were assumed to correspond to those of telex channels at the same elevation angles.

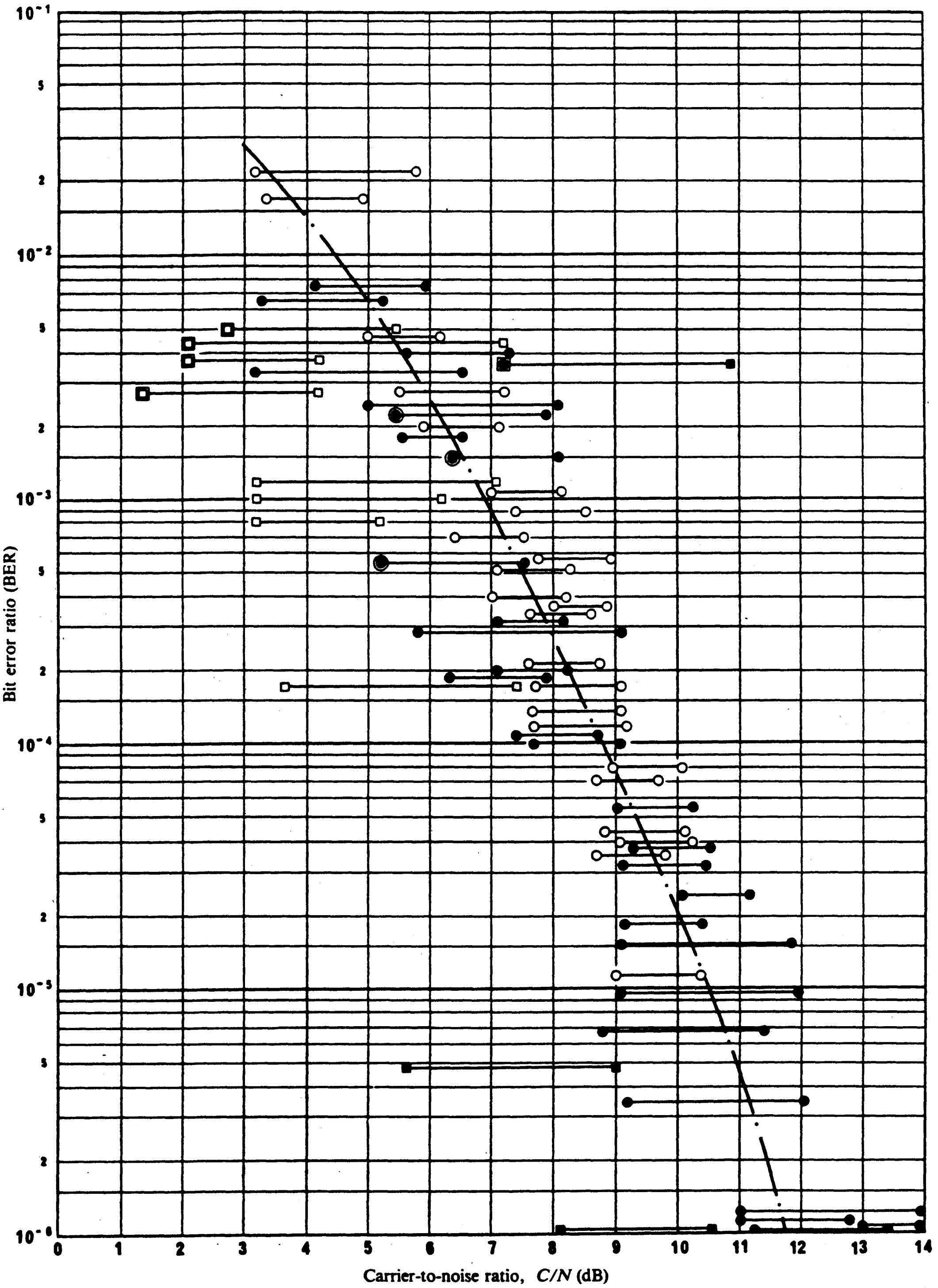

FIGURE 2 – *MARISAT 2400 bit/s DPSK data transmission measurement at elevation angles between 5° and 11°*

	Test	Elevation angle
○——○	69-73	11.2°-10.0°
●——●	74-78	10.0°-7.2°
■——■	79	7.1°-6.6°
□——□	80	6.5°-6.0°
—·—·—	fitting curve	
◉ ■ ▣	lost sync	

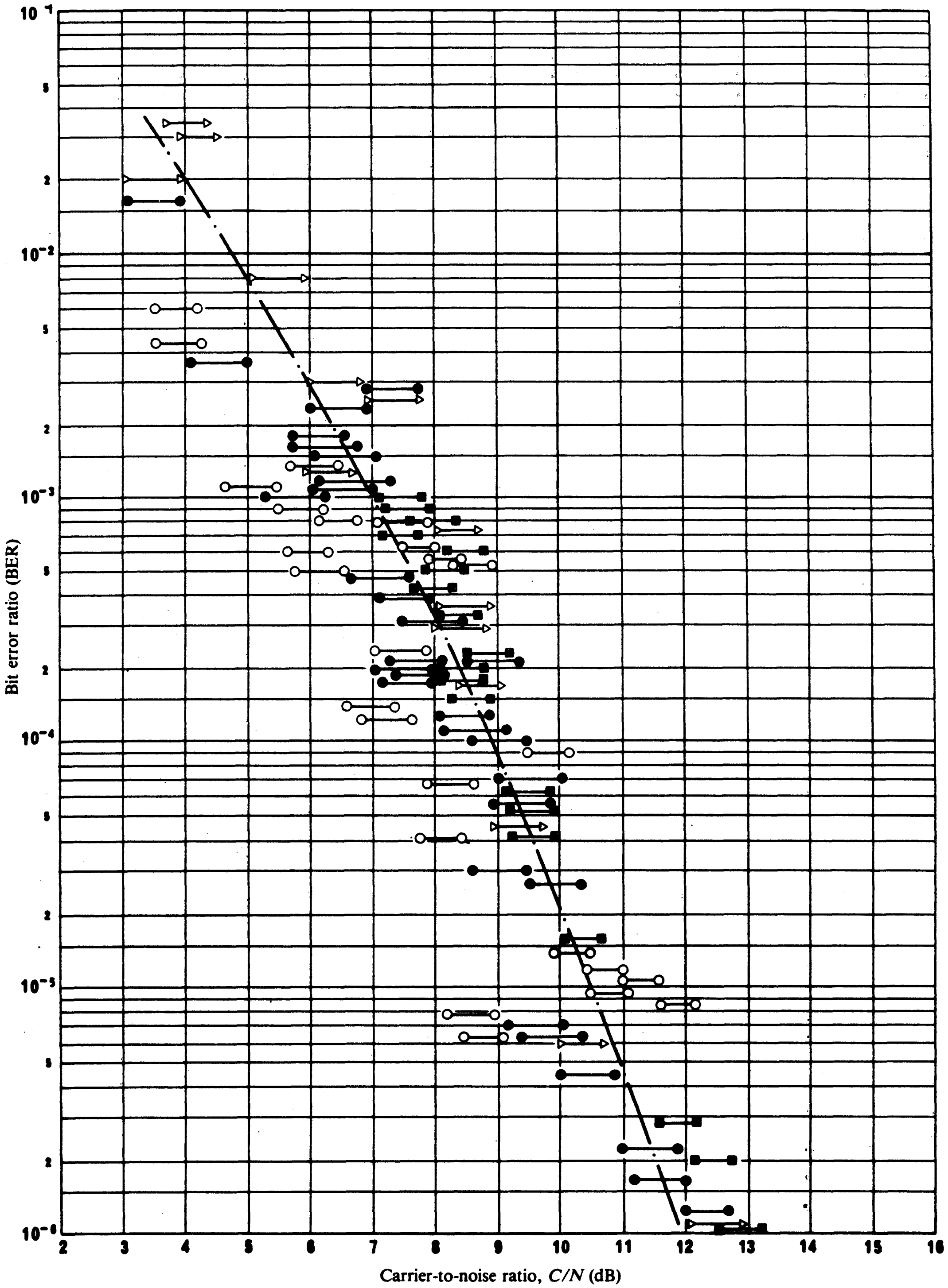

FIGURE 3 – *MARISAT 2400 bit/s DPSK data transmission measurement at elevation angles between 11° and 15°*

	Data test runs	Elevation
■——■	9-32	14°-15°
○——○	33-38	15°-14°
●——●	39-49	14°-13°
▷——▷	50-64	13°-11°
—·—·	fitting curve	

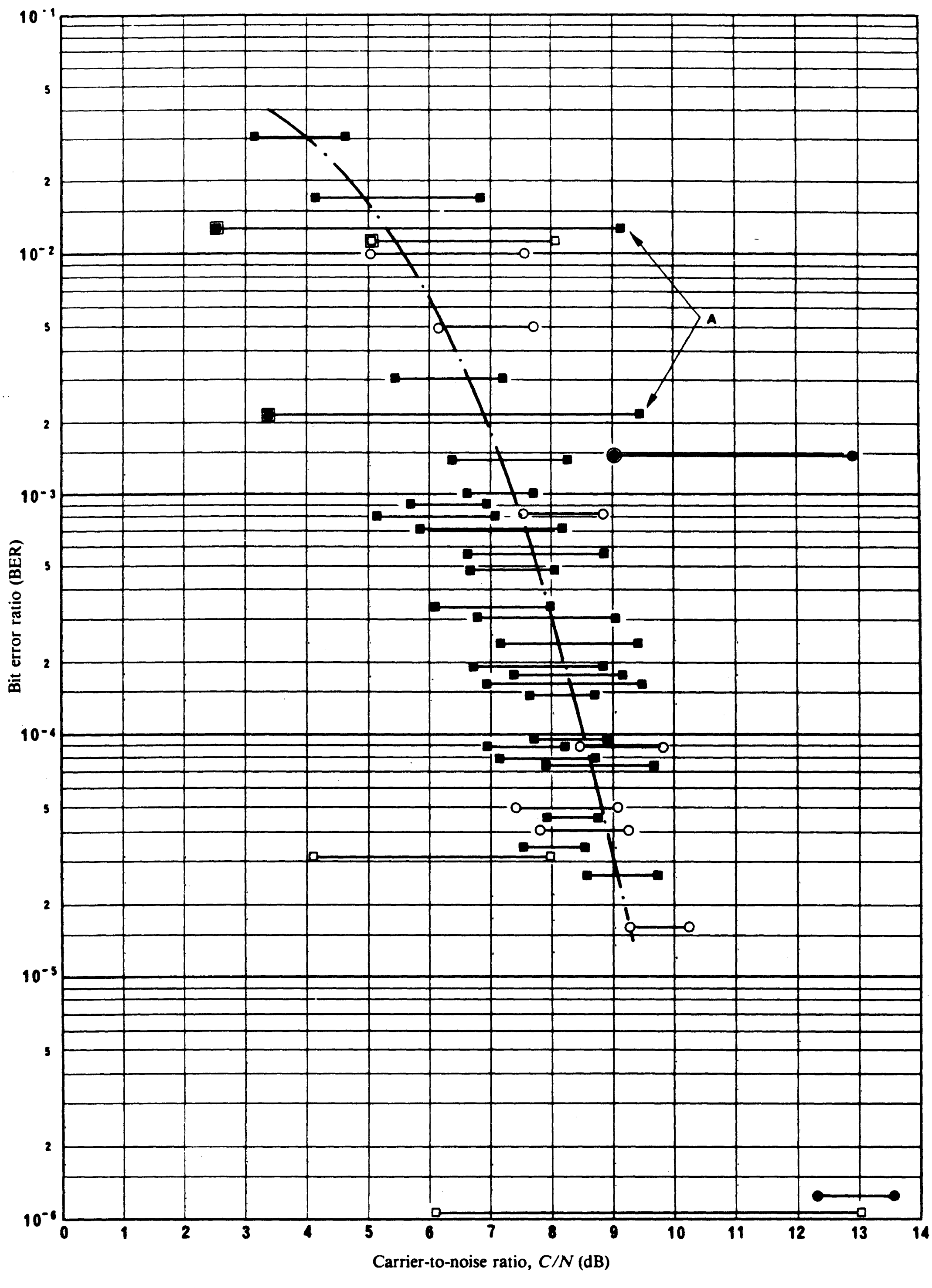

FIGURE 4 – *MARISAT 1200 bit/s FSK data transmission measurements at elevation angles above 5°*

	Test	Elevation angle
■——■	66	11.2°
○——○	67,68	11°
●——●	77	8.4°-7.6°
□——□	81	6.0°-5.0°
·—·—·	fitting curve	
▣ ▣ ◉	lost sync	
A	radar mast blockage	

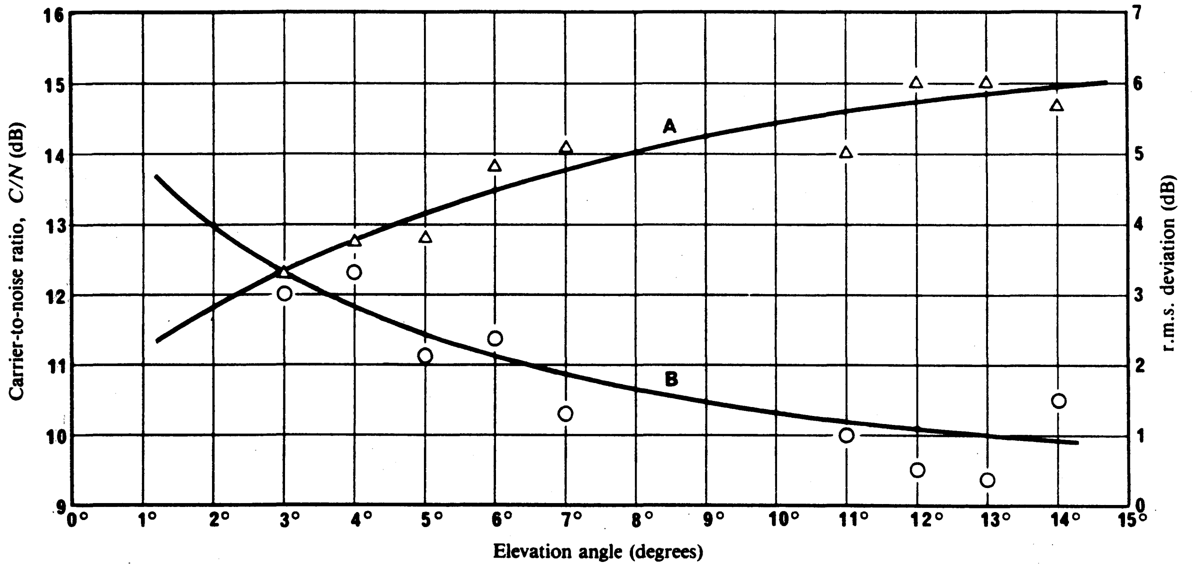

FIGURE 5– *Received carrier-to-noise ratio (C/N) and root mean square deviation (r.m.s.) from mean C/N of telex channels at different elevation angles (no active telephone channels)*

○, △: experimental data
Curves A: *C/N*
B: r.m.s. deviation

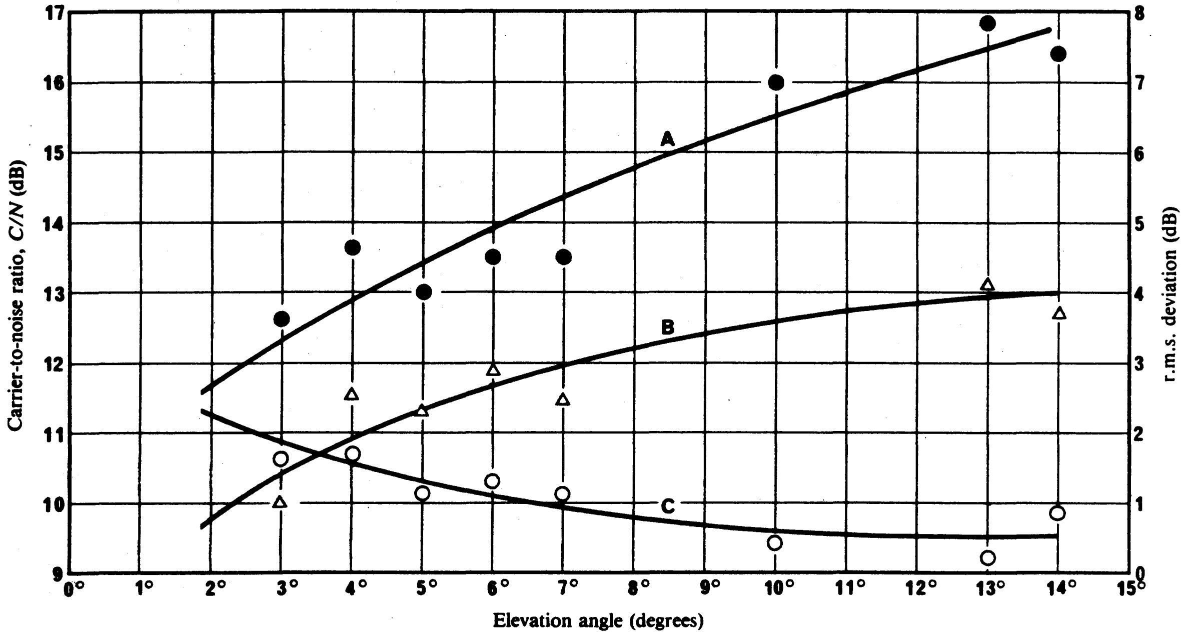

FIGURE 6 – *C/N and r.m.s. deviation from mean C/N in case of simultaneous operation of telex and telephone channels at different elevation angles*

○, ●, △: experimental data
Curves A: *C/N* of telephone channel
B: *C/N* of telex channel
C: r.m.s. deviation

3.5 *Minimal values of elevation angles for telephone and telex services*

In order to determine minimal values of elevation angles, certain threshold values of *C/N* for telephone and telex channels were assumed. The criterion for telex channel quality was assumed to be a BER of 10^{-5} for 99% of the time. A speech intelligibility of 99% was adopted as the criterion for telephone channels.

The best-fit curves shown in Figs.2 and3 were used to determine areas of marginal values of *C/N* (99% probability) in telex and telephone channels for various levels of satellite loading and different elevation angles.

Shown in Figs.4, 5 and 6 respectively are the areas of marginal values of *C/N* for:

- telex channels in the absence of telephone channel loading in the satellite;
- telex channels with telephone channels in operation;
- telephone channels.

The threshold values of *C/N* are plotted with an allowance being made for possible degradation due to precipitation.

3.6 *Experimental results*

From analysis of Figs.4 to 6 it can be determined that the required quality of communications of telex channels can be achieved, given certain conditions of external disturbances, if the elevation angle exceeds 4.5°.

A speech intelligibility of 99% for telephone channels can be achieved for at least 99% of the time when the elevation angle exceeds 12.5°. At lower elevation angles, rainstorms may degrade the communication quality, e.g. at 10° elevation angle, intelligibility will be 98% for isolated words and 92% for isolated syllables; at 8° elevation angle the intelligibility drops to 88%.

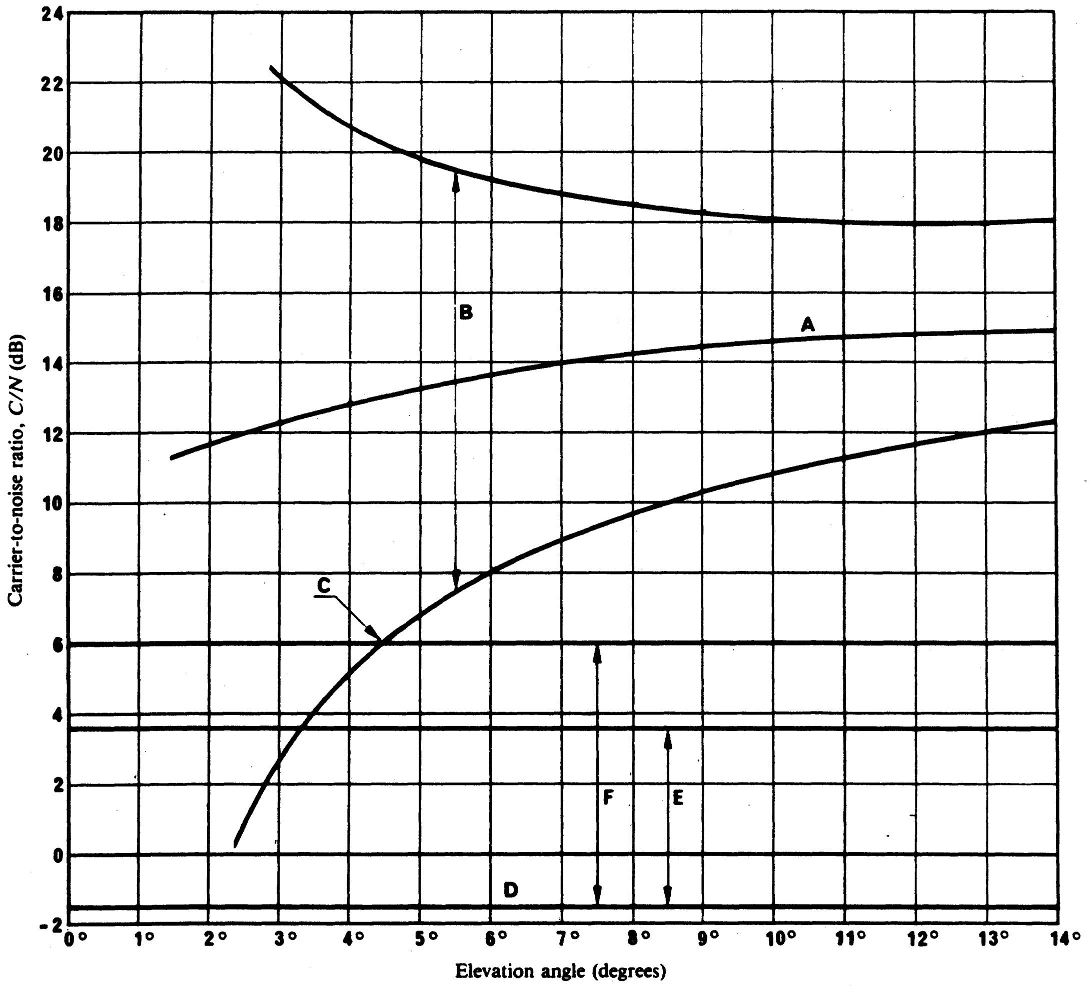

FIGURE 7 – *Area of marginal values of C/N of telex channels at various elevation angles (no telephone loading in the satellite)*

A: mean *C/N*
B: *C/N* marginal value area
C: critical value of elevation angle
D: threshold *C/N* for telex channel (– 1.5 dB)
E: drizzle, 5.25 dB maximum degradation
F: rainstorm, 7.5 dB maximum degradation

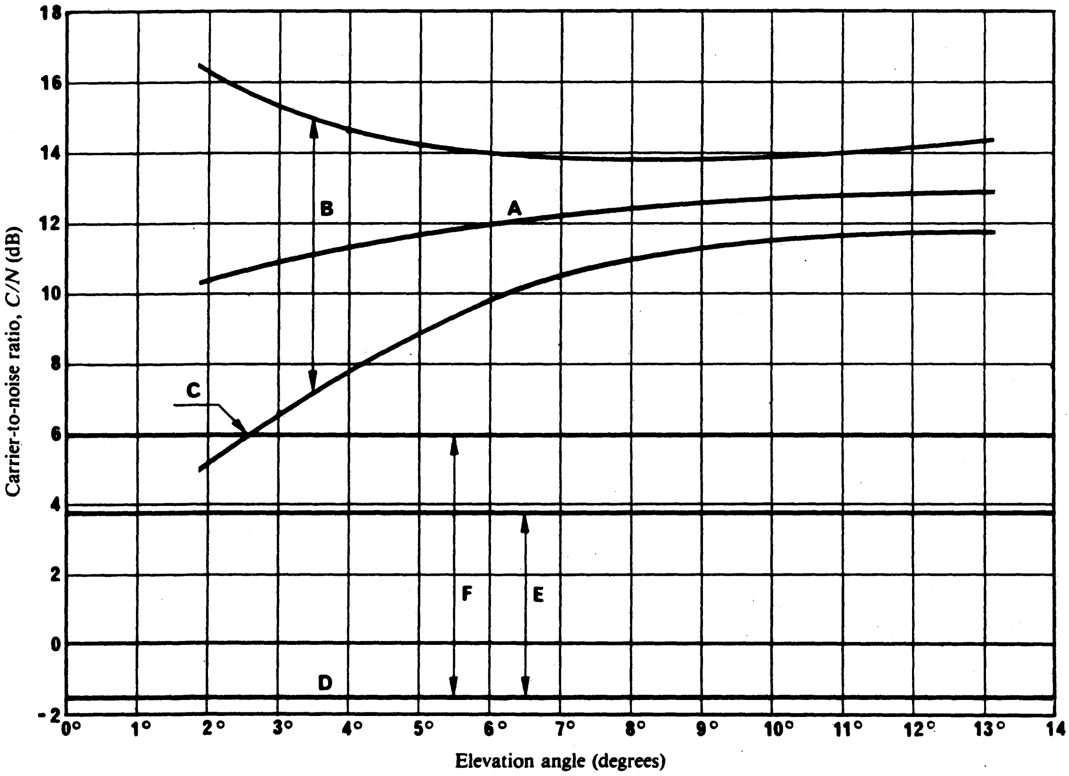

FIGURE 8 – *Area of marginal values of C/N of telex channels at various elevation angles (active telephone channels)*

A: mean *C/N*
B: *C/N* marginal value area
C: critical value of elevation angle
D: threshold *C/N* for telex channel (– 1.5 dB)
E: drizzle, 5.25 dB maximum degradation
F: rainstorm, 7.5 dB maximum degradation

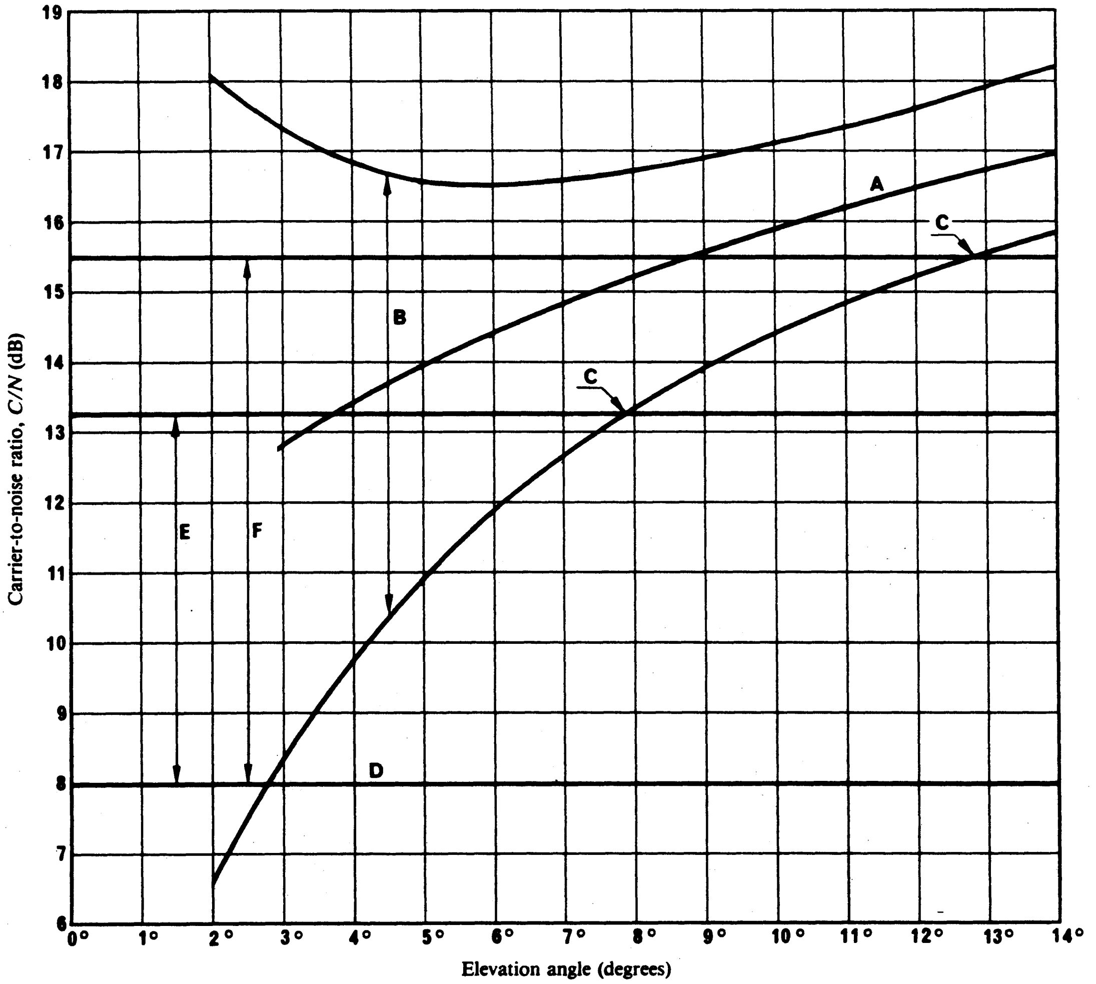

FIGURE 9 – *Area of marginal values of C/N of telephone channels at various elevation angles*

A: mean *C/N*
B: *C/N* marginal value area
C: critical value of elevation angle
D: threshold *C/N* (8 dB)
E: drizzle, 5.25 dB maximal degradation
F: rainstorm, 7.5 dB maximal degradation

3.7 *Background (new tests)*

Experiments were performed by the USSR on board the M/V "Michael Kalinin" (122 m length, 4980 grt deadweight) over the period 26 May-14 July, 1984. The objective of the tests was the determination of Inmarsat satellite telex channel performance at low elevation angles. The ship was cruising on the Baltic Sea, North Sea, Bay of Biscay and Mediterranean Sea. During the tests, *C/N* levels were measured in the coverage areas of the Atlantic Ocean Marecs-A satellite and the Indian Ocean Intelsat-V satellite, with elevation angles changing from 7° to 46° and from 4° to 16°, respectively.

3.8 *Environmental conditions*

Environmental conditions throughout the experiment period may be summarized as follows:

– Weather :	clear, sunny, no precipitation
– Wave height :	1-2m
– Motions of ship :	roll : 1-2° with a period of about 20 s pitch: 0 average

3.9 *Main characteristics of the equipment used*

Main characteristics of the equipment used were as follows:

3.9.1 *Standard A ship earth-station (Volna-S)*

– Antenna height :	15 m above the sea
– Beamwidth :	10°
– *G/T*:	-4 dB(K^{-1})

3.9.2 *Test receiver and recorder*

– Receiver :	Selective microvoltmeter SMV-8
– Recorder response :	0-150 Hz

3.10 *Experimental results*

The results of processing statistical data obtained for the Atlantic and Indian Ocean regions are shown in Figs. 7 and 8, respectively.

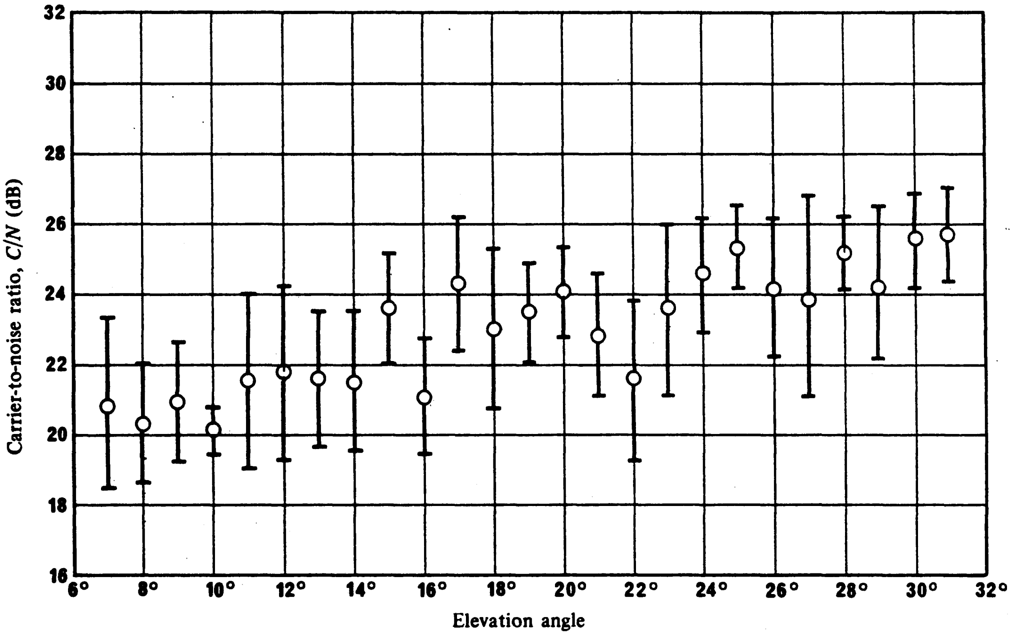

FIGURE 10 – *Atlantic Ocean data*

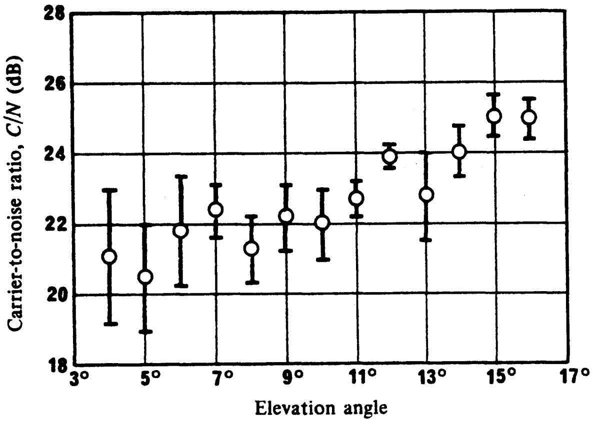

FIGURE 11 – *Indian Ocean data*

Examination of the results showed that mean C/N levels were 21-22 dB at elevation angles of 5-6°, with the C/N variations about the mean being 4-5 dB for 95% of the time. The experimental data was extrapolated (see Note) to determine the C/N values and their variations for lower elevation angles for the same percentage of time. The estimated values of C/N are 20.5, 20.3, 20 and 19.5 dB for elevation angles of 4°, 3°, 2° and 1°, respectively, with the C/N variations ranging from 3.6 dB for a 4° elevation angle to 5.5 dB for 1° elevation. Calculations were also made to obtain the C/N variations for 99% of the time. The estimated C/N variations are 5.5, 6, 7.5 and 8 dB for elevation angle of 4°, 3°, 2° and 1°, respectively. Estimation was made of minimal C/N occurring in the worst case of degradation due to precipitation referred to in Figs.4 and 5. The minimal C/N values were found to be 8.0, 7.0, 5.5 and 3.0 dB at elevation angles of 4°, 3°, 2° and 1°, respectively. Shown in Table I is BER performance calculated for the estimated minimum C/N.

Note. – Validation of the extrapolation method will be provided for a future meeting of Study Group 8.

TABLE I

Elevation angle (degrees)	Minimum C/N (99% of the time) (dB)	BER (¹) (99% of the time)	Minimum C/N (99% of the time) (dB)	BER (¹) (99% of the time)
4	8.0	3×10^{-3}	12.5	1×10^{-6}
3	7.0	7×10^{-3}	11.3	2×10^{-5}
2	5.5	3×10^{-2}	10.0	2×10^{-4}
1	3.0	6×10^{-2}	9.0	8×10^{-4}

(¹) BER values include anticipated degradation of 2 dB due to hardware design and operational factors.

4. Conclusion

Minimum elevation angles from ship-to-satellite were determined at which the satellite communication system is still capable of providing the needed quality of communciations. Sufficient communication quality can be achieved at elevation angles of about 5°. It should be recognized, however, that the values obtained are of preliminary nature, since the analysis was limited. Further study of ship earth station performance at low elevation angles is required.

REFERENCES

FANG, D. J., TSENG, F. T. and CALVIT, T. O. [January, 1982] Elevation angle propagation measurement of 1.5 GHz satellite signals in the Gulf of Mexico. *IEEE Trans. Ant. Prop.*, Vol. AP-30, 1.