REPORT 763-3*

SIGNAL LEVEL VARIATION DUE TO MULTIPATH EFFECTS AND BLOCKAGE BY SHIP'S SUPERSTRUCTURE IN MARITIME MOBILE-SATELLITE SERVICE LINKS

(Study Programme 88/8)

(1978-1982-1986-1990)

1. Introduction

The effect of multipath interference caused by sea-reflected signals is one important factor to be considered in establishing maritime satellite communication systems.

The fading characteristics depend on:

- frequency;
- angle of elevation;
- sea surface condition, especially wave height and slope (wind is an important factor);
- the shipborne antenna pattern;
- satellite and shipborne antenna axial ratio;
- the angular orientation of the polarization ellipses for the satellite and shipborne antennas;
- the shipborne antenna pointing error;
- the superstructure of the ship;
- the height of the antenna above the sea.

A theoretical estimate based on the model presented in Report 884 is given in order to predict values of fading as a function of the satellite elevation angle, sea state and antenna gain.

A summary of theoretical estimations and measured results of multipath fading depths reported so far is tabulated.

A computer simulation has been made to establish the fading resulting from reflection from a ship's superstructure. Results are given of this simulation. Attenuation factors for blocking due to column type structure are also given.

In a low *G/T* ship earth station using a passive antenna stabilizer, shipborne antenna pointing error due to random ship motion should also be considered. Experimental results and statistical analyses on this topic are given in Report 921.

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* The Director, CCIR, is requested to bring this Report to the attention of Study Group 5.

2. Characteristics of multipath fading

2.1 *General*

The purpose of the theoretical model is to provide for data on fading resulting from the effect of multipath for various parameter values. The theoretical estimation is based on a model presented in Report 884.

Account has not been taken of antenna polarization discrimination, although at low elevation angles this discrimination can have a significant effect on the characteristics of the received signal due to the polarization sense reversal at elevation angles greater than the Brewster angle (around 6° at 1.5/1.6 GHz over sea paths, see Report 1008). Neither has account been taken of fluctuations due to the atmosphere; their effect is significant when the effects due to the sea are negligible, in other words at high elevation angles.

In general, multipath fading due to sea reflection is caused by the interference between direct and reflected waves. Reflected waves coming from the sea surface are composed of a coherent component (specular reflection component) that varies with the height of antenna and an incoherent component (diffused component) that fluctuates with the motion of the sea waves. The coherent component is predominant under calm sea conditions, whereas the incoherent component is predominant under rough sea conditions.

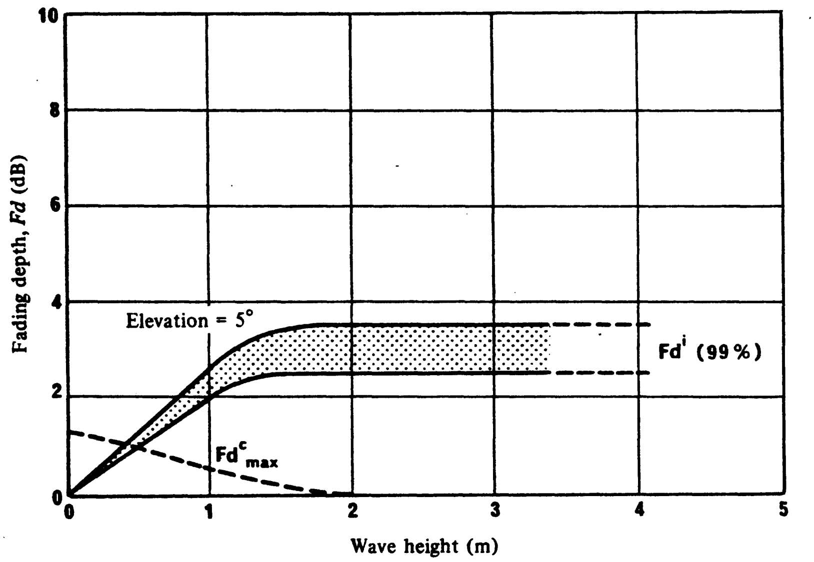
2.2 Fading depth

In practice, the fading depth for p% of the time is approximately given by the sum of the coherent fading Fd^c_{max} and the incoherent fading Fd^i according to the following expression (see also Report 884):

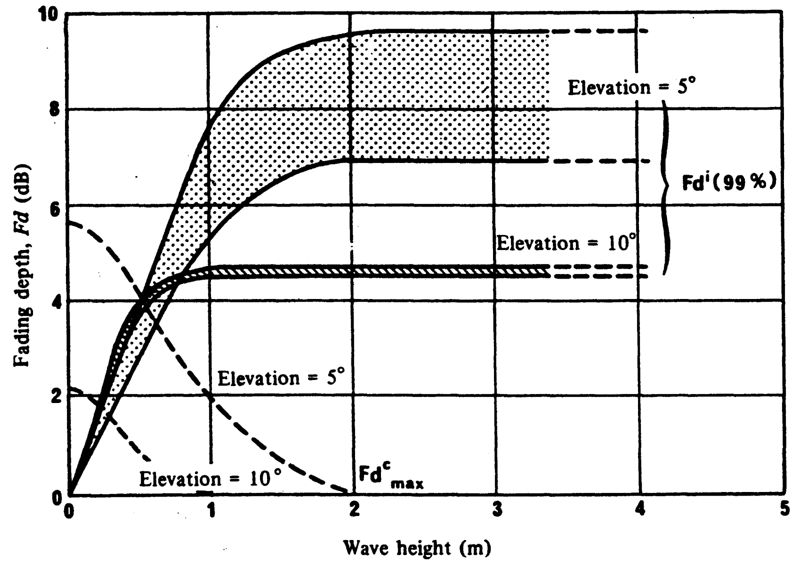
$$Fd(p\%) = Fd^c_{max} + Fd^i(p\%)$$

Fading depths for 99% of the time calculated at 1.5 GHz are given in Fig. 1 for antenna gains of 24 and 14 dB as a function of the wave height. The shaded area covers the practical range of the sea wave slope between 0.04 and 0.07. From the results it may be deduced that the fading depth due to the coherent component decreases with increasing wave height monotonically, while the fading depth due to the incoherent component increases gradually with increasing wave height and then reaches a peak value.

Figure 2 shows the fading depth for antenna gains of 24, 20, 15 and 8 dB as a function of elevation angle, with a fully developed incoherent component, due to wave heights of about 1.6-3.2 m.



(a) Antenna gain: 24 dB



(b) Antenna gain: 14 dB

FIGURE 1 – *Fading depth as a function of the wave height*

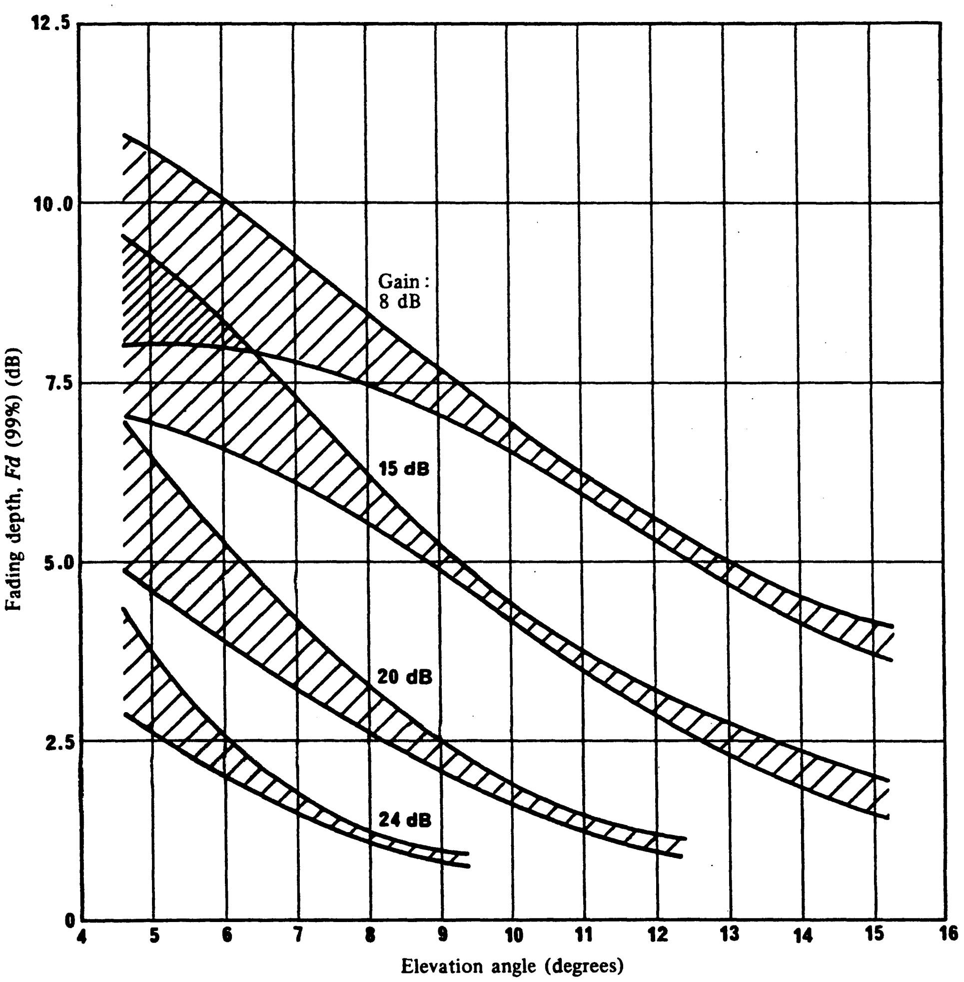


FIGURE 2 – *Fading depth for 99% of the time as a function of elevation angle with wave height from 1.6 m to 3.2 m*

2.3 Fading spectrum and fade duration statistics

The frequency spectrum bandwidth of temporal amplitude variations increases with increasing wave height and elevation angle. According to the calculations, taking the antenna height variation due to the ship motions (rolling/pitching) into account, the frequency corresponding to the spectral power density of –10 dB relative to the flat portion of power spectrum (hereafter denoted as –10 dB spectral bandwidth) ranges from 0.3 Hz to 5 Hz when the significant wave height is from 0.5 m to 5 m, the elevation angle is from 5° to 10°, and the ship velocity is less than 30 knots.

Figure 3 shows the probable range of -10 dB spectral bandwidth of multipath fading at 1.5/1.6GHz, obtained by the theoretical fading model (see Rep. 884) as a function of the elevation angle under ordinary conditions of maritime satellite communications, namely, wave height of 1-5m, ship velocity of 0-20 knots, and rolling/pitching of 0-30°.

Error pattern in digital transmission systems generated by multipath fading is usually of the burst type. Accordingly, a firm understanding of the fade duration statistics of the burst-type fading is required in order to apply the data interleaving together with the forward error correction to effect a considerable improvement in channel bit-error-performance. Mean values of fade duration, <T$_D$>, and fade occurrence interval, <T$_P$>, defined in Figure 4 can be estimated from fading spectrum. A simple method predicting the mean values from the -10 dB spectral band width can be available in Rep. 884.

Predicted values of <T$_D$> and <T$_P$>for 99% of the time at elevation angles from 5° to 10° are 0.05 to 0.4 seconds for T$_D$ and 5 to 40 seconds for <T$_P$>. The probability density function of <T$_D$>and <T$_P$> at any percentages ranging from 50% to 99% approximates to an exponential distribution.

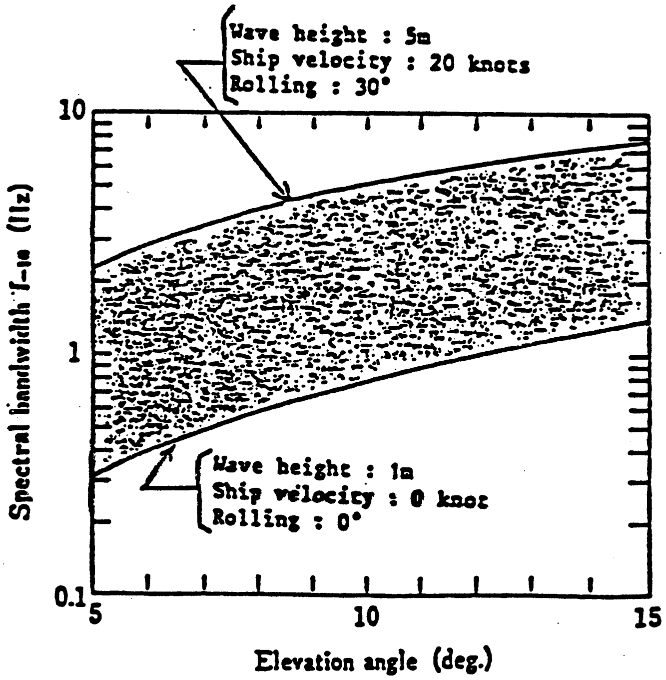
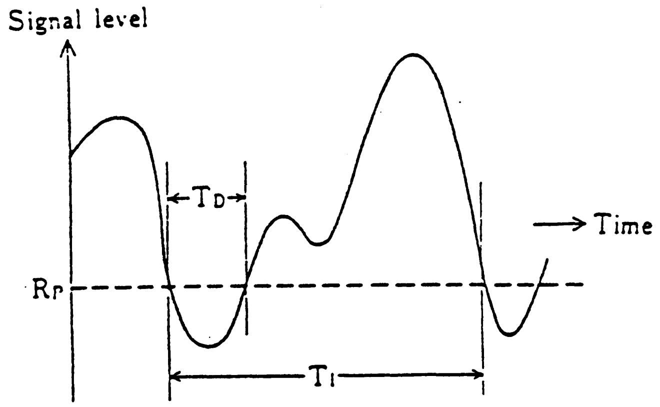


Fig.3 -10dB spectral bandwidth of 1.5 GHz multipath fading due to sea reflection as a function of the elevation angle.



Rp : signal level for a given % of the time

Fig.4 Fade duration and fade occurrence interval.

3. Summary of multipath fading statistics

Table I gives a summary of theoretical estimations and measured results of multipath fading depths contained in this Report. The table also shows some results of measurements carried out using an experimental low *G/T* ship earth station (see Annex II to Report 921).

The figures shown in Table I indicate that the theoretical model is borne out well by experimental results.

TABLE I – *Theoretical and measured multipath-fading statistics for 99% of the time*

Antenna gain (dB)	Elevation angle (degrees)	Wind force (knots)	Wave height (m)	Fade depth (dB)		Source notes
				Theoretical	Measured	
0	6		0.5	5.0(note1)	6.9	(8)
0	6		0.5	12.2(note2)	12.8	(8)
	4	35			12	
3	8	27			13	(1)
	19	20			10.5	
	4	35			14	
5	8	27			14	(1)
	19	20			8	
	4	35			11	
11	8	27			10	(1)
	19	20			6.5	
14	5		1.5-3.2	7-9		(2) (3)
14	5		1.5-3		6-10	(4)
15	5		1-4		7-10	(5)
13	4		4.5		7.2	(6)
14	10		1.5-3	4.5-5		(2) (3)
15	10		0.5-3		4-5	(5)
13	10		3.5		6.2	(6)
20	5		1.6-3.2	5-7		(3)
20	5		3		4.8	(7)
24	5		1.6-3.2	2.5-4		(2) (3)
24	5		1.6-3.2		1.5-3	(4)
20	10		1.6-3.2	1.5-2		(3)
20	10		3		2.8	(7)
24	10		1.6-3.2	1		(2) (3)

(1) [Hagenauer *et al.*, 1984]; Report 921, Annex II.

(2) Report 884, Fig. 4.

(3) Report 763, Fig. 2.

(4) [Ohmori et al., 1985]

(5) [Karasawa et al., 1986]

(6) Report 762, Fig. 11.

(7) Report 763-2 [1986], Table V

(8) [Higuchi and Shinohara, 1988]
note 1: fixed at a middle position of antenna height pattern
note 2: fixed at a minimum position of antenna height pattern

Table II summarizes data of fade duration statistics.

Table II Fade duration statistics

(a) Measurement parameters

Data no.	Antenna gain (dBi)	Elevation angle (degrees)	Wind force (knots)	Wave height (m)	Ship velocity (knots)	Rolling /pitching (degrees)	Source notes
1	15.5	5		0.5	11	1	(1)
2	15.5	10		3.0	11	5	(1)

(1) [Karasawa and Shiokawa, 1987]

(b) Measured data

Data no.	Threshold level		T_D (seconds)		T_I(seconds)	
	Time rate (%)	Fade depth (dB)	Mean	Standard deviation	Mean	Standard deviation
1	50	0	1.29	1.53	2.56	2.16
	90	4.0	0.55	0.54	5.61	5.41
	99	9.3	0.30	0.24	29.0	28.5
2	50	0	0.26	0.32	0.52	0.47
	90	2.0	0.13	0.13	1.29	1.61
	99	4.0	0.078	0.072	7.29	10.8

4. Prediction of influence from ship's superstructure

4.1 *Reflections from ship's superstructure*

Reflections from the ship's superstructure, which are mainly coherent with the direct signal, will cause fading in the received signal.

The fading depth depends on a number of parameters:

- shape of the ship;
- location of the ship antenna;
- antenna directivity and side lobe level;
- axial ratio and orientation of the polarization ellipse, both for the satellite and the ship antenna;
- elevation and azimuth angle.

An oil tanker of approximately 230 000 tons deadweight (see Fig. 5) was chosen as a sample ship for a computer prediction of ship reflections. This type of ship was expected to give strong reflections because of its large open deck space in front of the antenna. The reflecting surface on the ship deck was modelled as a set of plane surface elements with infinite conductivity. The on-axis axial ratio of the ship antenna was assumed to be 1 dB and that of the satellite antenna to be 2 dB.

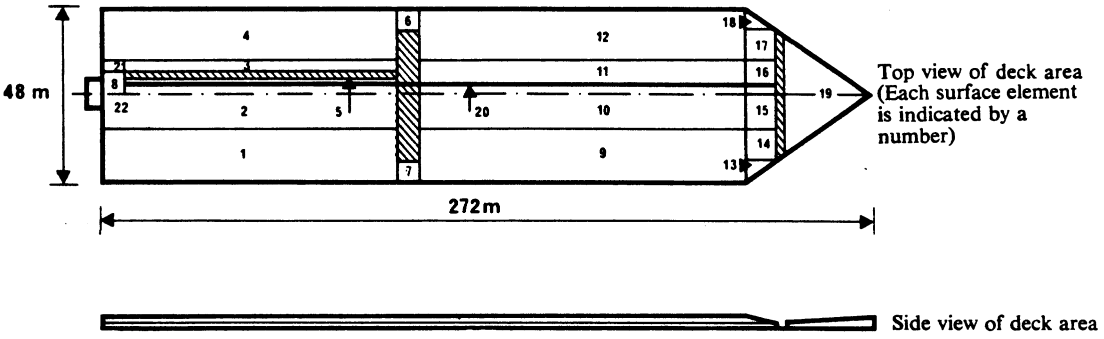


FIGURE 5 – *Diagram od tanker used for simulation of ship's reflectors*

In Fig. 6 the signal levels predicted by the computer are presented as a function of the elevation angle for two values of assumed directivity, 20 dB and 24 dB. The effect of antenna pointing error is shown, corresponding to a loss of 1 dB. The corresponding pointing angle errors are −5.4° in elevation for the 20 dB antenna and −3.4° for the 24 dB antenna.

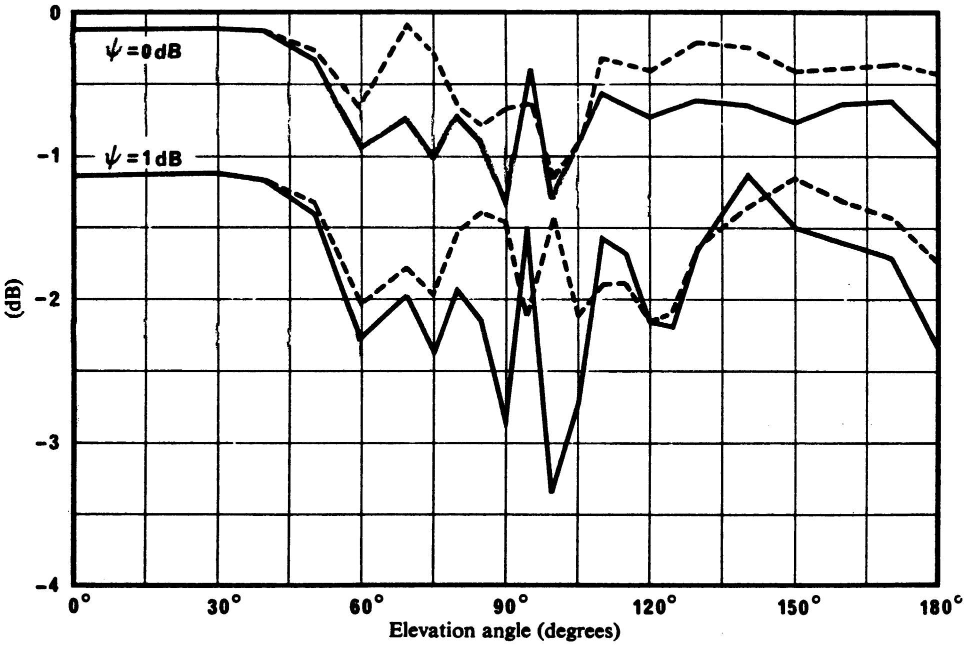


FIGURE 6 – *Computer predicted fading depth versus elevation angle for an oil tanker of 230 000 tons deadweight*
(ψ = pointing loss)

——— 20 dB directivity

– – – – 24 dB directivity

The variations within the elevation angle range 9° to 11° are caused by interference between reflections from the various parts of the deck.

For this particular example, the predicted multipath effect from a ship's superstructure:

- decreased to zero when the ship heading was more than 14° off the bearing of the satellite,
- changed less than one dB when the height of the antenna above the deck varied.

4.2 *Blocking by ship superstructures*

Blocking is caused by ship superstructures such as the mast and various types of antennas. The geometry is shown in Fig. 7. Attenuation due to blocking depends on various parameters such as diameter of column, distance between antenna and column and size of antenna. Based on experimental data reported so far, attenuation due to blocking caused by a column type structure can be obtained.

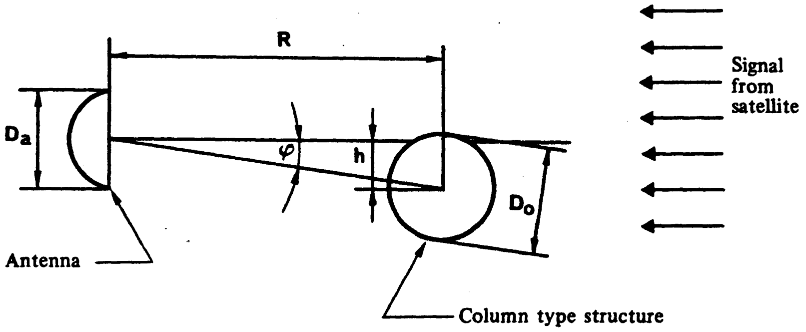
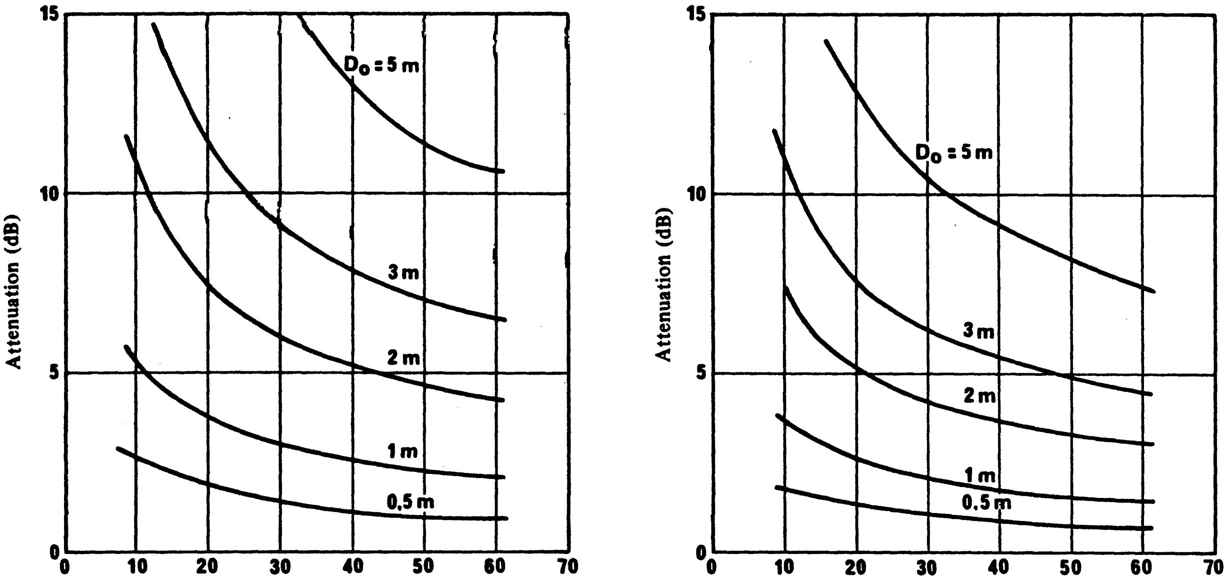


FIGURE 7 – *Geometry of blocking*

Estimated attenuation due to blocking caused by a column-type structure is given in Fig. 8 for antennas of 20 dB and 14 dB gain.



(a) Antenna gain: 20 dB

(b) Antenna gain: 14 dB

FIGURE 8 – *Estimated attenuation due to blocking*

Figure 9 shows blockage effects caused by a column structure with near placed low-gain antenna.

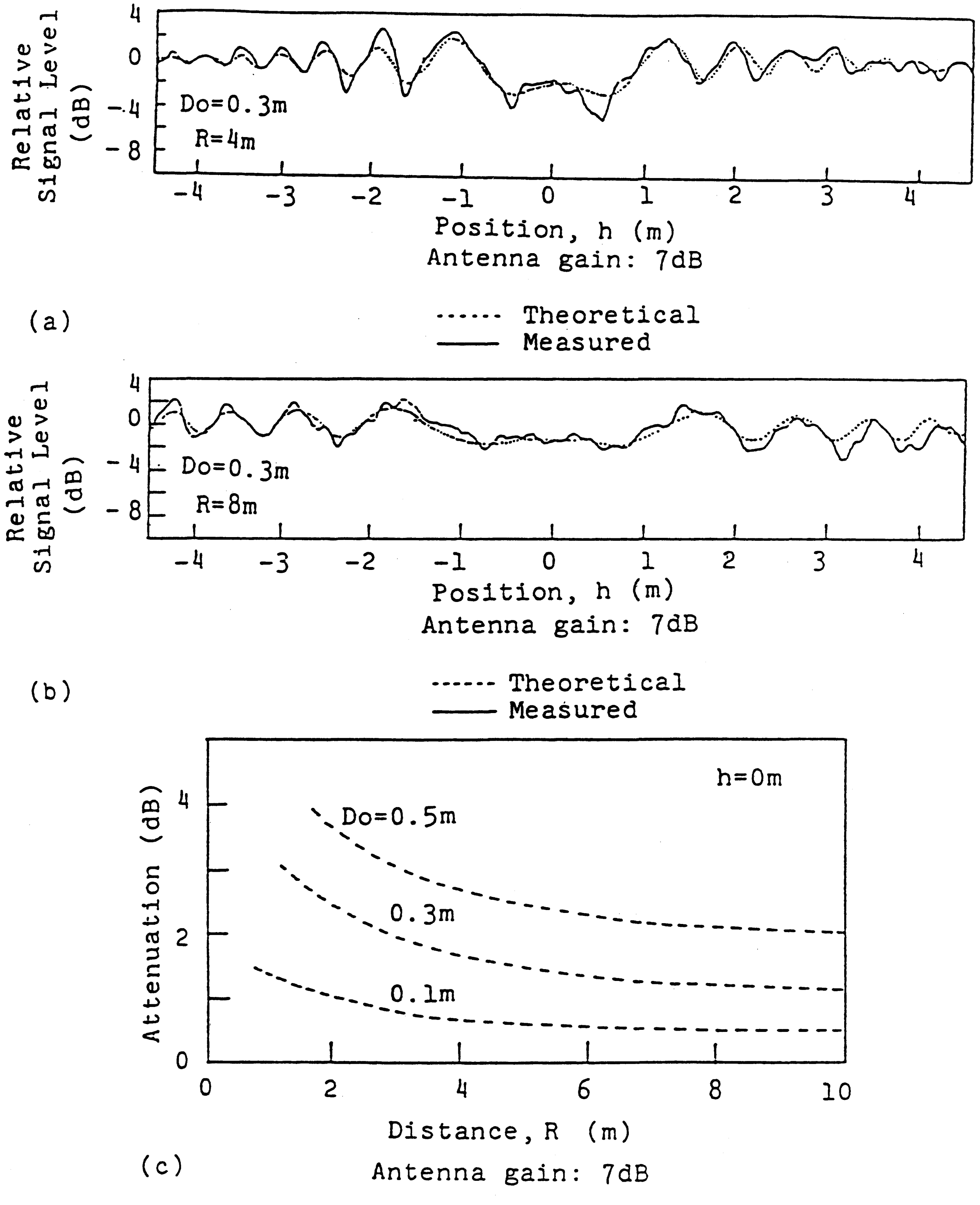


FIGURE 9

<u>Blockage effects caused by a column structure with near placed low-gain antenna</u>

5. Conclusions

The results obtained by the theoretical model given in § 2 enable fading due to the multipath effect to be predicted for a wide range of parameter values. It has been shown that fading due to the coherent component, namely height pattern fading, decreases with increasing wave height monotonically, while fading due to the incoherent component increases gradually with increasing wave height and reaches a peak value at around a wave height of 1.6 m. Fading depth generally increases with decreasing elevation angle and antenna gain.

For low elevation angles the coherent (specular) component of the reflection may predominate while the incoherent (diffuse) component dominates for higher elevation angles.

The experimental results described above show that the multipath effect increases with decreasing satellite elevation angle and antenna gain. Maximum fading depth containing both coherent and incoherent components appears at wave heights around 1.6 m and the dependency of fading depth on wave height is small at wave heights ranging from 0.8m to 3.2 m.

Experimental measurements of multipath fading depths are typically within 1 dB of those given by theoretical estimations. Therefore it can be concluded that the theoretical model is borne out well by measured results.

Reflections from the superstructure of a large oil tanker were studied. The results show that fades of the order of one dB may be expected for antenna gains in a range of 20 to 24 dB, assuming small pointing errors and for the antenna aligned along the axis of the ship. Blocking by the ship superstructure was also studied. Attenuation due to blocking by a column-type structure is presented as functions of distance, diameter of a column and size of antenna.

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CCIR Documents

Report 884.

REPORT 1048-1

FADING REDUCTION TECHNIQUES APPLICABLE TO SHIP EARTH-STATION ANTENNAS

(Question 88/8)

(1986-1990)

1. Introduction

For low G/T systems, the effect of multipath fading due to sea surface reflection is a severe problem, especially at low elevation angles as pointed out in § 5 of Report 921. This Report surveys possible fading reduction techniques for low G/T ship earth-station antennas and presents field experimental results on the reduction effects. The antennas reported in these tests are described in more detail in Report 921.

2. Survey on fading reduction techniques

The following methods are possible as fading reduction techniques applicable to low G/T ship earth-station antennas:

- diversity method,
- polarization method,
- pattern shaping method,
- maximum level tracking method,
- beam offset method.

2.1 *Diversity methods*

Diversity techniques such as space, polarization and frequency diversity have already been used practically in radiocommunication systems subject to severe fading. The space diversity technique needs two or more antennas, while other diversity techniques can be effected using a single antenna. In any case, the fading reduction effect largely depends on the correlation of signals with different properties, such as frequencies, polarization and time difference. Figure 1 shows the principle of space diversity with a switch and stay algorithm [Kozono and Yoshikawa, 1981]. As is seen in this figure, the diversity output results in $R(t)$, when signal levels through antenna 1 and antenna 2 are $r_1(t)$ and $r_2(t)$, respectively. With this technique, the greatest reduction effect is expected when the correlation of the signals between the two antennas is lowest. In practice, it may not be possible to set up the antennas with the optimum spacing of a half wavelength.

Frequency diversity can produce a good reduction effect when the path difference between the direct and reflected waves is greater than one wave length of the difference frequency between two frequencies used. Assuming that the height of the ship antenna is 15 m, the elevation angle is 5° and the frequency separation is 15 MHz, which is the maximum separation with the current 1.6 GHz band maritime mobile satellite service allocations, then, at the most, the path difference is only 0.14 wave length of the difference frequency. Therefore, frequency diversity does not seem practicable at this stage, because of the limited separation of the two frequencies. However, if the frequency band were to be widened in the future, this method could be applicable.