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.

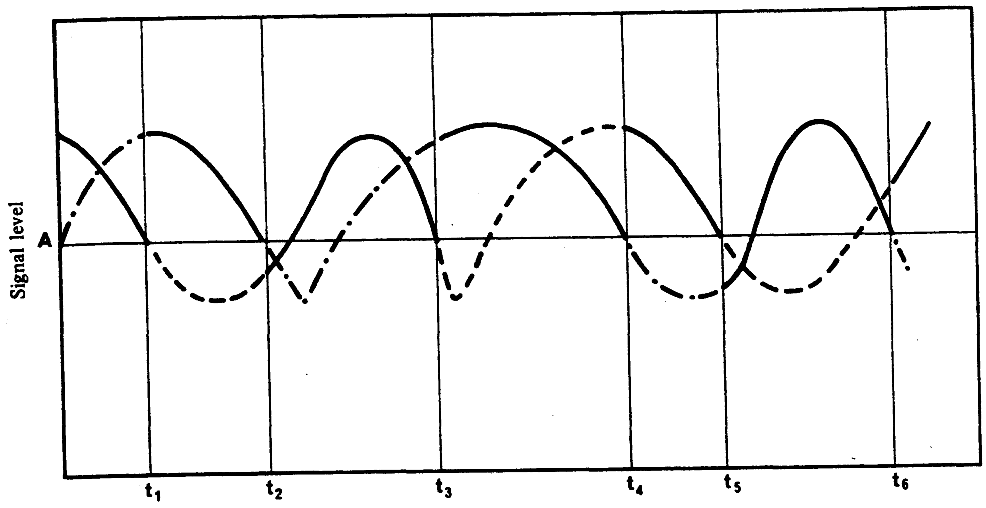


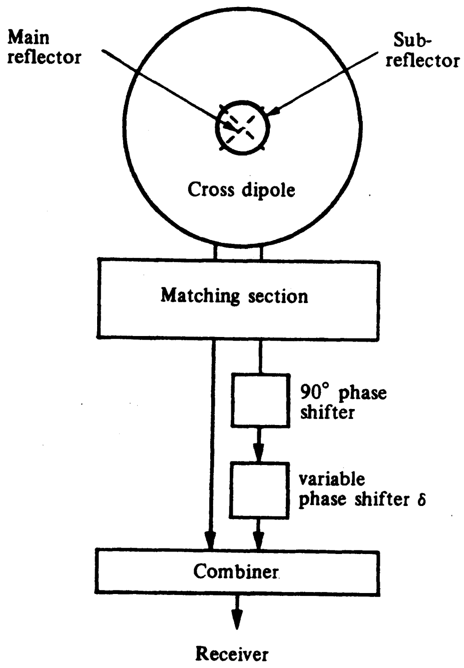
FIGURE 1 – *Principle of switch and stay algorithm*

—·—·— $r_1(t)$
– – – – $r_2(t)$
——— $R(t)$

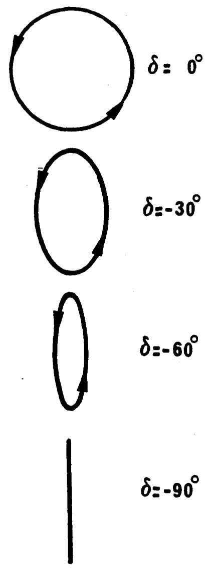
Note.– The input to the receiver is switched to the serial from which the output is rising when the input of the selected antenna falls below a pre-determined level "A".

2.2 *Polarization method*

For reflections from the sea surface at 1.64/1.54 GHz, the horizontally linear polarized wave is almost perfectly reflected, while the vertically polarized wave is reflected with fairly large attenuation at incident angles, with respect to the horizontal plane, of less than 10°. Furthermore, the phase angle of a vertically polarized wave undergoes a continuing change as the elevation angle increases, whereas the phase of a horizontally polarized wave remains unchanged at all but the highest elevation angles. Above around 6° elevation angle, the phase and amplitude relationship between the horizontal and vertical components of an incident circularly polarized wave is such that upon reflection it becomes elliptical and reversed in its sense of rotation, with its major axis nearly horizonal. (An elevation angle of around 6° is the Brewster angle at 1.5/1.6 GHz over sea paths; for more information see Report 1008.) Accordingly, if the polarization ellipse of a shipborne antenna, in the direction of the reflected wave, could be adjusted so that it always stays orthogonal to that of the reflected wave, the reflected wave can be suppressed. This principle [Shiokawa and Karasawa, 1982] can be easily applied to cross dipole fed antennas such as a short back-fire antenna. For instance, if it is arranged that the cross dipole elements are inclined by 45° with respect to the horizontal line, and the phase is adjusted by a phase shifter inserted in one of the ports of the short back-fire antenna feed as shown in Fig. 2a), the axial ratio of this antenna can be arbitrarily controlled. In this case, the major axis of the polarization ellipse is always vertical as shown in Fig. 2b).



a) Block diagram



b) Polarization ellipse of ship antenna

FIGURE 2 – *Short back-fire antenna with polarization method (A)*

Recently, another reduction technique applying a polarization method has also been proposed [Ohmori and Miura, 1983]. This method (polarization method (B)) makes use of the polarization characteristics of the sea-reflected wave and of the electrical characteristics of a hybrid combiner. This method is based on the difference of reflection coefficients of sea surface, as in the case of circular polarization, for cross-polarized as against co-polarized waves. In this case it is noticed that the amplitude of the cross-polarized circular component is greater than that of the co-polarized component when the elevation angle is greater than about 6°. Accordingly, by making the amplitudes of both reflected components equal and setting the phase difference to be out of phase (± 180°) with each other, it should be possible to get a direct wave without fading. In this method, a phase shifter (which is pre-programmed to optimize the phase shift at a particular elevation angle) and a power combiner are added to the ordinary circular polarized antenna equipment as shown in Fig. 3, where the direct and the reflected co-polarized components are put out on terminal T3 and the reflected cross-polarized component is put out on terminal T4. Although this method has a few disadvantages such as an increase of insertion loss due to the 3 dB power combiner loss and the increase of thermal noise temperature due to the attenuator, a large reduction effect is expected, especially when the fading is very severe.

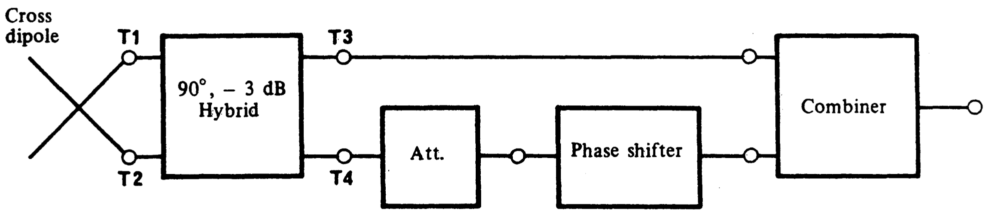


FIGURE 3 – *Configuration of polarization method (B)*

2.3 *Pattern shaping method*

It is possible to suppress the reception of a reflected signal by using a shaped pattern antenna which has low gain radiation characteristics in the direction of the sea-reflected wave. This method may be realized by an antenna array or a shaped reflector antenna. Figure 4 shows an example of the radiation pattern of a shaped pattern antenna [Ohmori *et al.*, 1980]. The radiation pattern is shaped so as to be flat in the main beam and to be suppressed in other directions. This antenna is expected to have a good reduction effect when the reflected waves come from directions away from the main beam. The shaped pattern antenna, however, has the disadvantage that the aperture efficiency of the antenna is in general comparatively low.

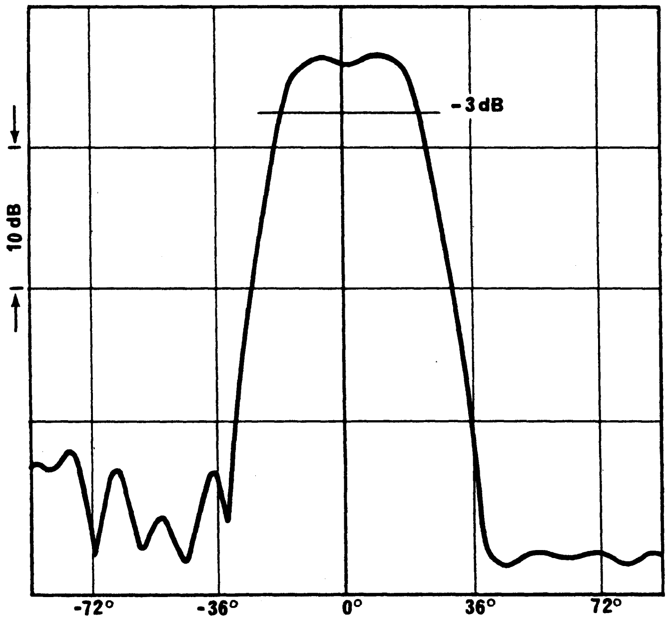
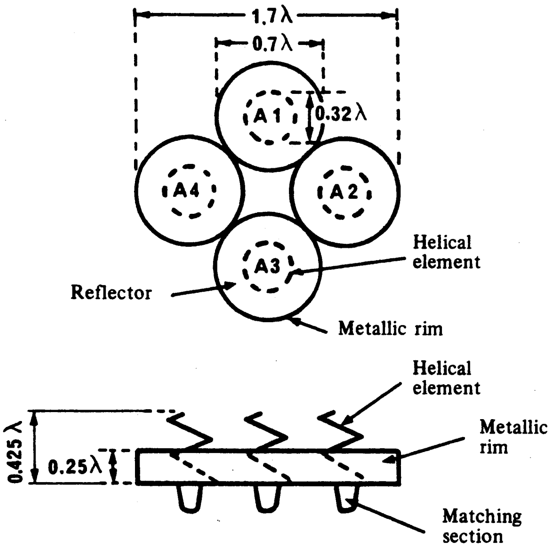


FIGURE 4 – *Radiation pattern of shaped pattern antenna*

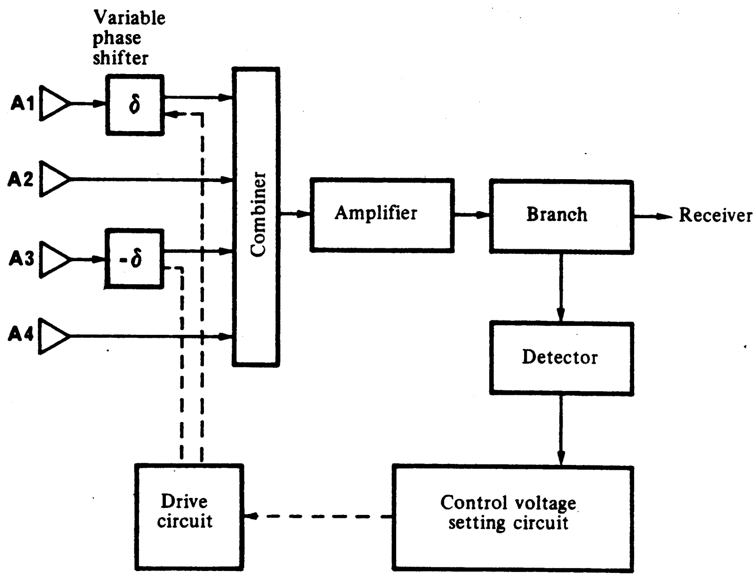
Gain: 16 dBi (1.54 GHz)

2.4 *Maximum level tracking method*

If the radiation characteristics of an antenna in the direction of the reflected wave are controlled so that the received signal intensity is always maintained at a higher level, the fading could be substantially suppressed. This principle [Shiokawa and Karasawa, 1982] can be easily applied to an antenna array. The phase of a variable phase shifter inserted in the feed circuit for each antenna element is varied by a small amount by changing its control voltage in order to see whether the resultant signal level increases or not. The phase has to be adjusted at a rate sufficiently fast to track the speed of the fading. If the signal level increases, the control voltage is allowed to change continuously in the same direction. If not, the polarity of the control voltage has to be reversed to control the variable phase shifter in the opposite direction. Fading can be reduced by repeating this operation. Figure 5 shows a block diagram illustrating an example of this method applied to a quad-helix antenna.



a) Quad-helix array antenna



b) Block diagram

FIGURE 5 – *Quad-helix antenna with maximum level tracking method*

2.5 *Beam offset method*

If the beam axis of a ship antenna could be varied slightly with satellite direction, fading due to sea reflection could be suppressed by the general characteristics of the ship antenna so that the degradation of antenna gain in the direction of the reflected wave would be generally greater than the boresight error. This is achieved by utilizing a program tracking antenna system. It would also be possible to reduce the fading by the polarization characteristics of the ship antenna. Figure 6 shows the measured polarization ellipse of the short back-fire antenna [Yamada *et al.*, 1981]. From this figure, if the cross-dipole is arranged to be inclined by 45° with respect to the horizontal line, the major axis of the polarization ellipse in the vertical plane is nearly vertical and the degradation of axial ratio becomes bigger as the angle, with respect to the beam centre, becomes larger. On the other hand, the major axis of the sea-reflected wave is nearly horizontal, in the case of an elevation angle lower than about 10°, as shown in § 2.2. Therefore, the relation between both polarization ellipses approaches more closely the orthogonal condition (see § 2.2) compared to the case where beam offset is not applied.

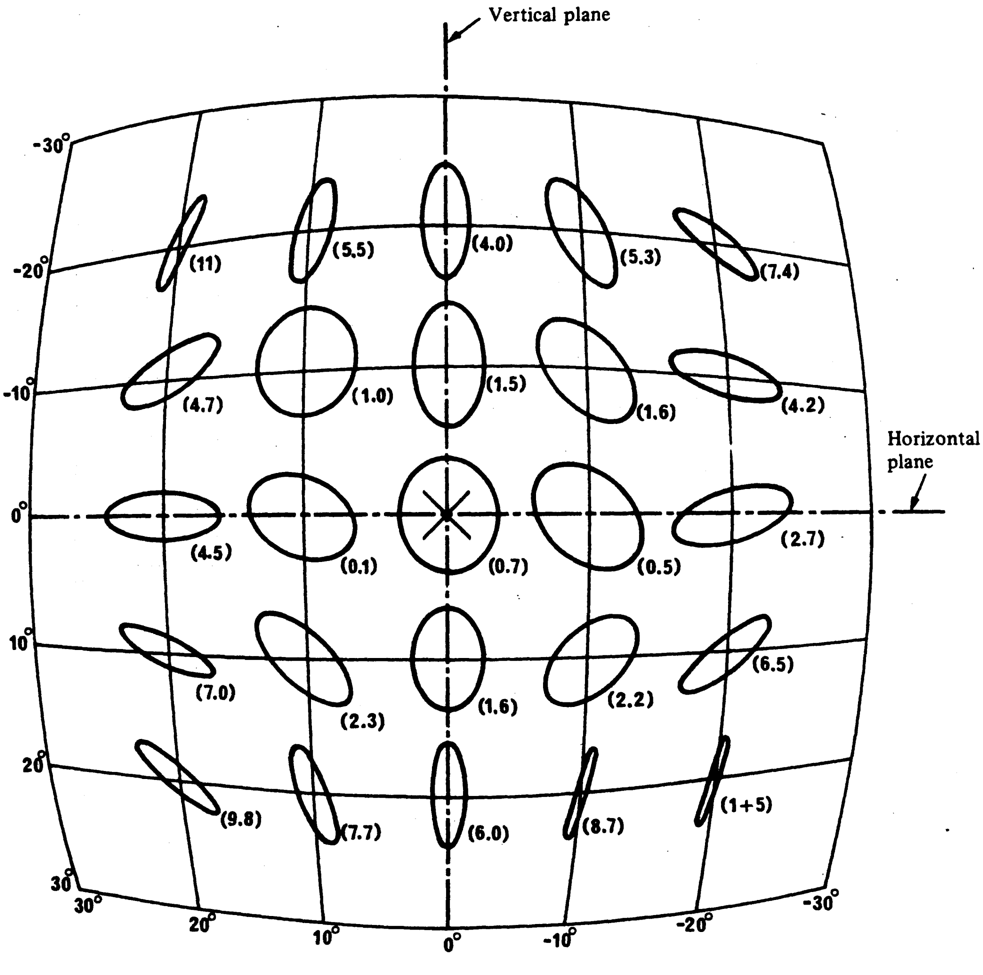


FIGURE 6 – *Polarization ellipse of short back-fire antenna*

(antenna gain: 12 dBi)

3. Field experimental results on reduction effects

3.1 *Space diversity*

A space diversity experiment [Kozono and Yoshikawa, 1981] applying the switch-and-stay algorithm was carried out by setting up two 20 cm diameter short back-fire antennas on a small vessel under conditions with wave heights of about 1 to 1.5 m. These antennas were located with a 3 wavelength separation in the vertical direction. Figure 7 shows the space diversity effect obtained by a simulation in which the switching operation has been carried out by computer. From this figure, it can be noticed that the cumulative time distributions through each branch are nearly equal to each other and these distributions almost correspond to a I_0 distribution with C/I of 6.25 dB. It is also noticed that the fading depth of about 8 dB at an elevation angle of 9° can be reduced to about 5 dB in the case where the threshold level is −5 dB.

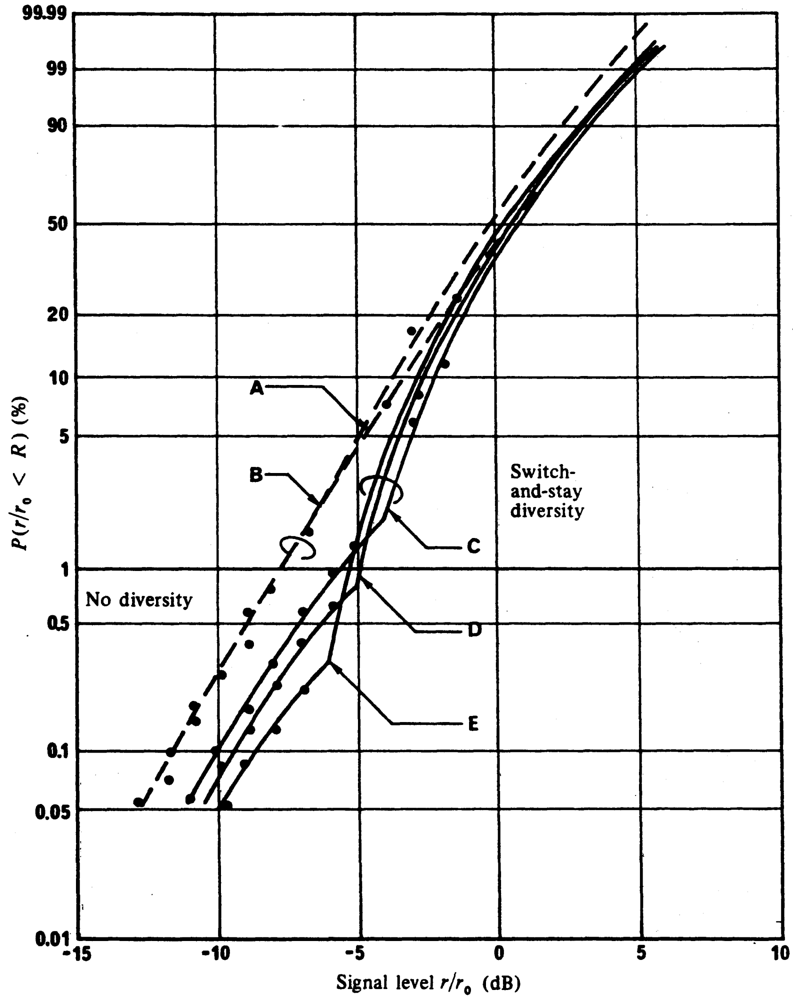


FIGURE 7 – *Fading reduction effect of space diversity method*

Frequency: 1.5 GHz
Short back-fire antenna
Antenna separation: Δh = 0.6 m

Curves A: branch 1
B: branch 2
C: S = –4 dB
D: S = –5 dB
E: S = –6 dB
S: threshold level

3.2 *Polarization method*

For polarization method (A), field experiments [Shiokawa and Karasawa, 1982] have been made using a short back-fire antenna with an aperture diameter of 33 cm, which was located on the deck of a ferry receiving signals from the Marisat satellite. This antenna had a gain of about 13.5 dBi, an axial ratio of about 0.7 dB without fading reduction and a beamwidth of about 38°. Figure 8 shows the cumulative time distribution of the fading reduction effect for a wave height of about 70 to 80 cm corresponding to "rough" sea conditions. It can be seen that the fading depth corresponding to 99% of the time is decreased from 5.1 dB to 2.5 dB by the use of this fading reduction technique. However, there is a polarization loss of about 1 dB.

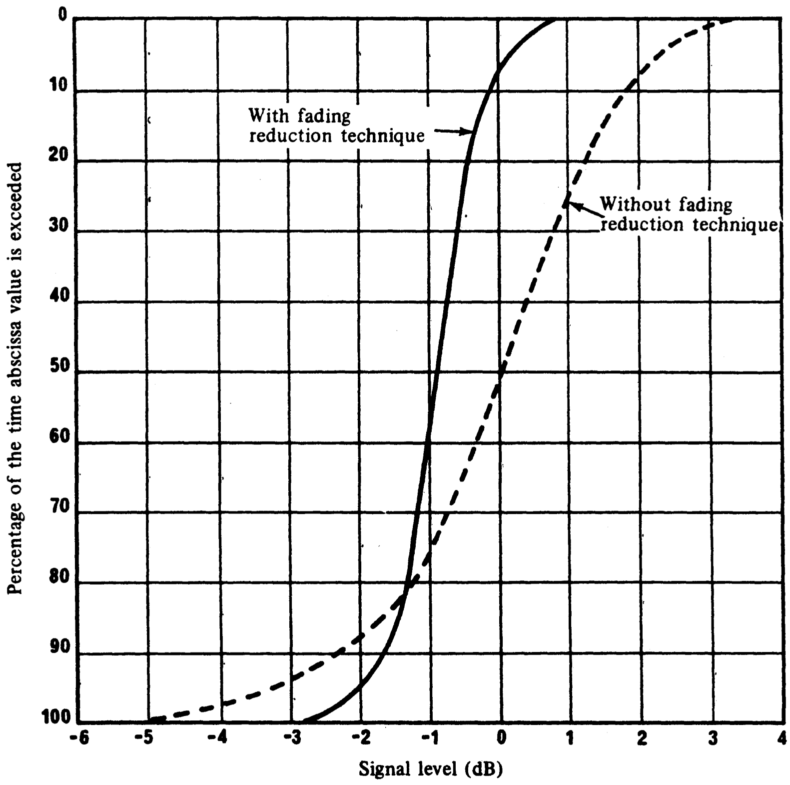
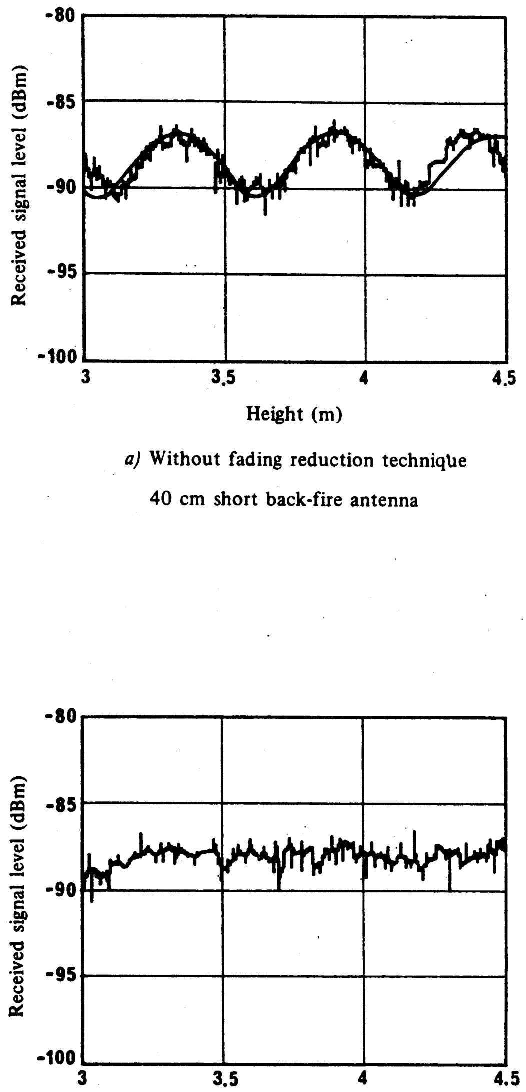


FIGURE 8 – *Fading reduction effect of polarization method (A)*

Elevation angle: 11.2°
Wave height: 70-80 cm

For polarization method (B), experiments [Ohmori and Miura, 1982] have also been performed on the sea shore receiving pilot signals from Inmarsat with elevation angles of about 10°. The antenna used in these experiments was a short back-fire antenna, with electrical characteristics which were almost the same as those of the experiments for polarization method (A). Figures 9a) and 9b) show height-gain patterns of the ordinary short back-fire antenna where the value of additional attenuator was fixed at infinity and the short back-fire antenna with fading reduction technique, respectively. The results show that the spatial fading (height-gain pattern fading) is almost completely eliminated.



a) Without fading reduction technique
40 cm short back-fire antenna

b) With fading reduction technique
Reduction short back-fire antenna

FIGURE 9 – *Fading reduction effect of polarization method (B)*

Experiments were also carried out with similar equipment to that above on a medium size ship (1 700 tons) through ETS-V satellite [1989]. The data was obtained using a fixed amount of additional phase shift, which corresponded to the calculated value assuming specular reflection and is almost independent of elevation angles. Figure 10 shows the cumulative time distribution of the fading reduction at elevation angles of about 6°. The fading depth related to the 50% mean value of about 11 dB corresponding to 99% of the time has been reduced to about 1.4 dB. It is verified that this method is valid for low elevation angles with a maximum improvement around 6°.

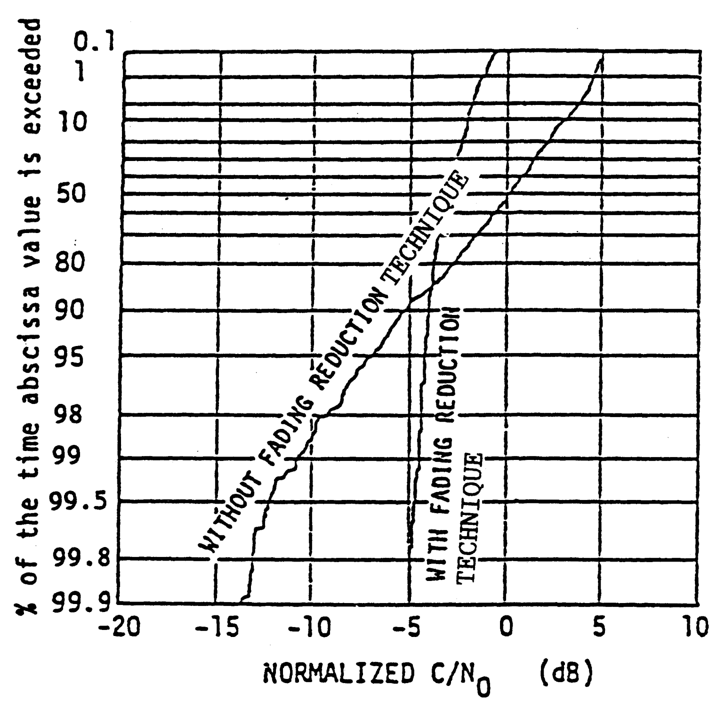


FIGURE 10

Cumulative time distribution of received signal level

40 cm short back-fire antenna
Elevation angle: 5.9°
Wave height: 1.0-1.1 m

3.3 *Maximum level tracking method*

A field experiment [Shiokawa and Karasawa, 1982] has been carried out on a beach to receive a signal from a signal source on a hill separated by a bay. In this experiment, a quad-helix antenna was used. This antenna was composed of four elements of two-turn helices as shown in Fig. 5a) and had a gain of about 13 dBi and an axial ratio of about 1.0 dB [Shiokawa *et al.*, 1981]. The elevation angle was 7.5° and the wave height was 15 to 20 cm corresponding to "moderate" sea conditions. The receiving antenna was fixed at the minimum point of the height pattern to evaluate the worst case where the received signal level is least. Figure 11 shows the cumulative time distribution of the received signal intensity. The fading depth of about 11 dB corresponding to 99% of the time has been reduced to about 7.5 dB.

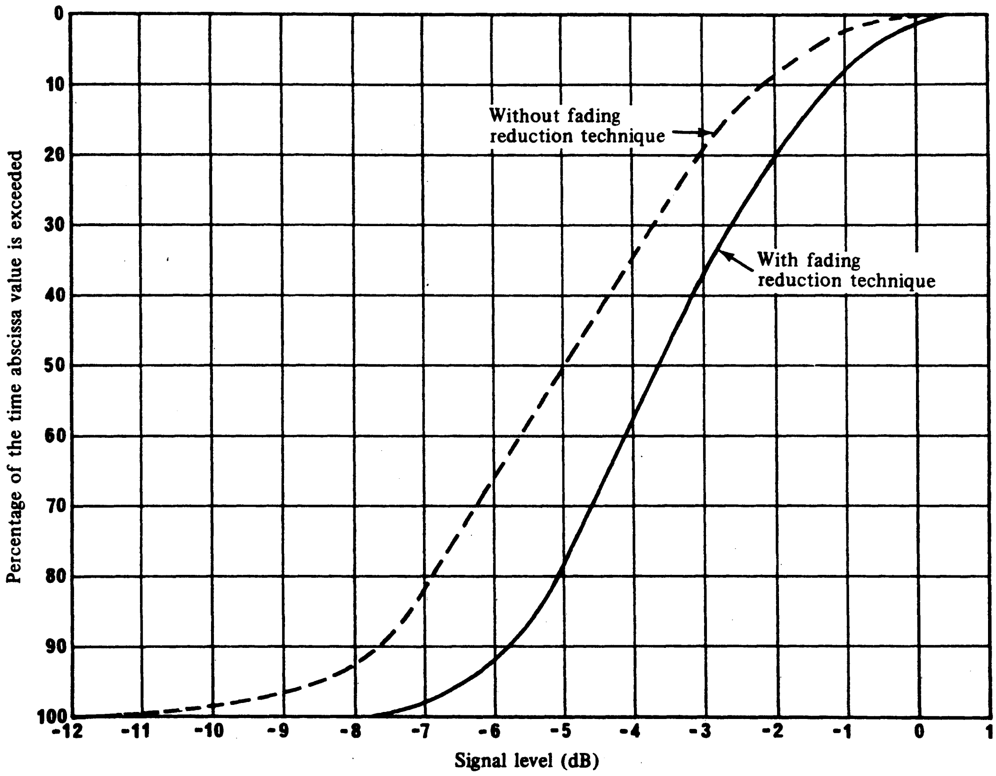
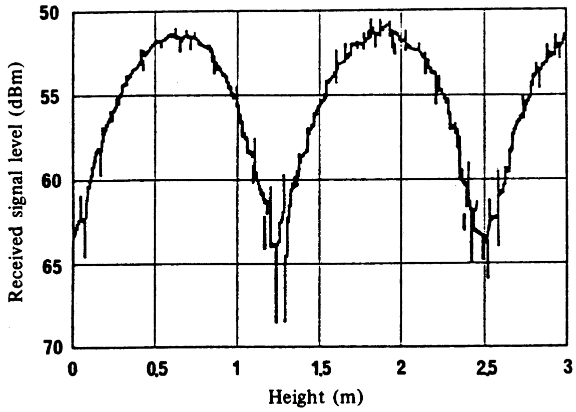


FIGURE 11– *Fading reduction effect of maximum level tracking method*

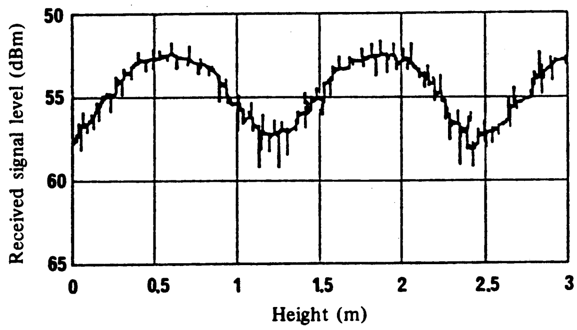
Elevation angle: 7.5°
Wave height: 15-20 cm

3.4 *Pattern shaping method and beam offset method*

Field experiments [Ohmori *et al.*, 1980] were performed on the sea shore to confirm the fading reduction effect of a combined reduction method using both the pattern shaping method and beam offset method. In this experiment, the shaped beam antenna which is presented in § 2.3 was used. Figure 12 shows the experimental results against height, Fig. 12a) is for the case of an ordinary antenna with antenna gain of about 16 dBi and Fig. 12b) is for the case of a shaped pattern antenna with a beam offset of 15°. From this figure, it can be seen that the reflected waves are fairly well suppressed.



a) Without fading reduction technique



b) With fading reduction technique

FIGURE 12 – *Fading reduction effect of pattern shaping method and beam offset method*

4. Conclusion

Some fading reduction techniques have been surveyed and experimental field results for the reduction effects have been presented. It is concluded that the adoption of fading reduction techniques is very effective for enabling significant signal degradation due to sea surface reflection to be avoided, especially for low *G/T* ship earth-station antennas.

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