IMPROVEMENT OF IN-BAND AMPLITUDE DISPERSION BY BEAM TILTING ON RADIO LINKS WITH STRONG GROUND-REFLECTION

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1. Introduction

On overwater paths where stationary ground-reflected waves exist, heavy fading commonly occurs. Severe signal distortion due to in-band amplitude characteristics caused by ground-reflected waves severely degrades the transmission quality. A number of techniques including space diversity reception, multi-carrier transmission[1], and various fading countermeasures have been tried to overcome the heavy fading effects.

This paper examines a new technique called beam tilting for overcoming heavy fading. It was found that the recieved power level and XPD charactristics were substantially improved because beam tilting reduced the intensity of ground-reflected waves[2]. This paper also presents a theoretical technique of evaluating the improvement of in-band linear amplitude dispersion (LAD) by tilting the receiving antenna beam upward to reduce interference caused by sea surface reflected waves. Propagation tests, which were carried out during periods without deep fading, confirm the improvement due to beam tilting. Based on these test results, this paper proposes a method of evaluating the LAD improvement effect in heavy fading periods. Such an evaluation method is indispensable for system design.

2. In-band linear amplitude dispersion

The distribution of received power x (normalized by averaged power) under fading can be approximated by gamma distribution. The probability density function f(x) of the received power can be expressed by the following formula[3]:

$$f(x)= \{\lambda^{\lambda}/\Gamma(\lambda)\} \cdot x^{\lambda-1} \cdot \exp(-\lambda \cdot x) \tag{1}$$

where λ is the parameter.

Generally, it can be assumed that the received power at each frequency in a transmission band follows the same distribution. The distribution of LAD F(z) is given by the correlation coefficient $\rho(\Delta f)$ (frequency correlation function) of the received power at the frequency separation Δf[3].

$$F(z)=\frac{1}{B(\lambda,\lambda)} \int_{0}^{\sin^2(\theta/2)} u^{\lambda-1} \cdot (1-u)^{\lambda-1} du \tag{2}$$

$$B(\lambda,\lambda)=\Gamma(\lambda)^2/\Gamma(2\lambda) \tag{3}$$

$$\tan\theta=\sqrt{4\{1-\rho(\Delta f)\} z/(1-z)^2} \tag{4}$$

The frequency correlation function $\rho(\Delta f)$ of the three ray model, which consists of direct, duct, and ground-reflected waves, is expressed by the following formula[4][5]:

$$\begin{aligned}\rho(\Delta f) = [&X^2+Y^2+Z^2+XY\cdot\cos(2\pi\Delta f\,\ell_1/c)\cdot\exp\{-0.5(2\pi\Delta f\,\sigma_1/c)^2\}\\ &+ZX\cdot\cos(2\pi\Delta f\,\ell_2/c)\cdot\exp\{-0.5(2\pi\Delta f\,\sigma_2/c)^2\}\\ &+YZ\cdot\cos\{2\pi\Delta f(\ell_1-\ell_2)/c\}\cdot\exp\{-0.5(2\pi\Delta f/c)^2(\sigma_1^2+\sigma_2^2)\}\\ &-(a_0^4+a_1^4+a_2^4)]\ /\ \{X^2+Y^2+Z^2+XY+YZ+ZX-(a_0^4+a_1^4+a_2^4)\}\end{aligned}\tag{5}$$

where $X=a_0^2+\sigma_{a0}^2$, $Y=a_1^2+\sigma_{a1}^2$, $Z=a_2^2+\sigma_{a2}^2$, $\Delta f=f_1-f_2$, and

c : light velosity
ℓ_1 : average value of path length difference between direct and ground-reflected waves
ℓ_2 : average value of path length difference between direct and duct waves
σ_1, σ_2 : standard deviations of ℓ_1 and ℓ_2
a_0, σ_{a0}: average value of amplitude of direct wave and its standard deviation
a_1, σ_{a1}: average value of amplitude of duct wave and its standard deviation
a_2, σ_{a2}: average value of amplitude of ground-reflected wave and its standard deviation.

$\ell_1, \ell_2, \sigma_1, \sigma_2$, a_0, σ_{a0}, a_1, σ_{a1}, a_2, σ_{a2} can be determined from the conditions of the propagation path[6]. The beam tilting effect can be evaluated as the reduction in intensity of the ground-reflected waves in Eq.(5).

3. Outline of propagation test

The propagation test was carried out over a 93.8-km overwater path, where stationary ground-reflected waves are present, between Nagata and Hanase radio relay stations in Kagoshima prefecture, Kyushu[7]. The test was carried out for a one month period in November 1983. The heights of the transmitting and receiving antennas were about 700 m above sea level. The path difference between direct and ground-reflected waves is 7.7 m when the Earth's effective radius factor K is assumed to be 4/3. From the transmitting station, a 4550±30-MHz frequency swept signal was transmitted using a parabolic reflector antenna 3.3 m in diameter which was set at the horizontal polarization. The frequency swept signal was scanned by a 25-Hz sinusoidal wave. Half of the 3-dB antenna beam width θ_{3dB} was 0.75° . A block diagram of the measurement is shown in Fig.1. One of the receiving antenna beams was tilted 0.4 ° upward in order to reduce the intensity of ground-reflected waves. The amplitude ratio of direct and ground-reflected waves was 0.5 without tilting. Employing the tilting, the ratio was reduced to 0.3.

4. Measured results of LAD

The received power distribution at the center frequency of a transmission band is shown in Fig.2 for both tilted and non-tilted cases. They are approximated by gamma distributions with $\lambda=3-5$. As deep fadings did not occur during the test period, both distributions are almost the same. Figure 3 shows the frequency correlation function of the received power measured in the test. The pitch of the function is 38 MHz, which corresponds to a 7.9-m path difference between direct and ground-reflected waves. The value of the pitch is approximately the same as the case of K=4/3. The solid line is the calculated result by Eq.(5). The frequency correlation function with beam tilting varies much less than that without beam tilting.

Over long-span overwater paths, the multi-carrier transmission method is used [1], and the frequency band width of a single carrier is 12.5 MHz. Figure 4(a) compares the measured LAD against the LAD calculated by Eq.(2) for a band width of 12.5 MHz. The measured result shows that a 0.1 % LAD is decreased 6 dB by beam tilting. The calculated result shows a 5-dB decrease, which agrees quite closely with the measured result. Figure 4(b) shows the LAD in a 50-MHz band for both measured and calculated values. According to these results, there is even closer agreement between the calculated and measured distributions.

5. Evaluation of the beam tilting effect for heavy fading

Thus, the propagation test results have verified the evaluation method for the beam tilting effect in periods with little deep fading. This section will consider the beam tilting effect for deep fading, in which the variation in received power is approximated by a gamma distribution of $\lambda=1$. The $\lambda=1$ case is important for the system design because this represents the worst case.

Figure 5 shows the estimated LAD improvement values for different tilt angles over the propagation test path. The tilt angle is normarized by half the width of a 3-dB beam width. The standard for this factor is the LAD value in dB when the tilt angle equals zero. The improvement factor is defined as the ratio of the standard (dB) and the LAD (dB) with beam tilting. The frequency separation Δf is 12.5 MHz, and percent value is changed one decimal place at a time from 1 to 0.0001. The tilt angle range considered in this section is less than θ_{3dB}, so both received power distributions can be approximated by the same distribution. The result with $\lambda=5$, which corresponds to the measured data, is also plotted. Over the propagation path, the LAD improvement factor at $\theta_{3dB}=1$ is 70-90 % for $\lambda=1$ by beam tilting. In case of $\lambda=5$, the improvement is 40-50 %.

6. Conclusion

It has been shown that beam tilting effectively improves LAD, because the reflected wave interference is reduced. In other words, as the frequency correlation function of the received power is flattened by beam tilting, the LAD is improved. An evaluation method for the LAD improvement factor in the tilt angle range within θ_{3dB} was also proposed. Much more improvement can be expected when the tilt angle is further increased and the intensity of ground-reflected wave is reduced to a lower level. For a precise evaluation, a more precise model must be developed which considers the difference in distributions of received power at the frequency separation Δf.

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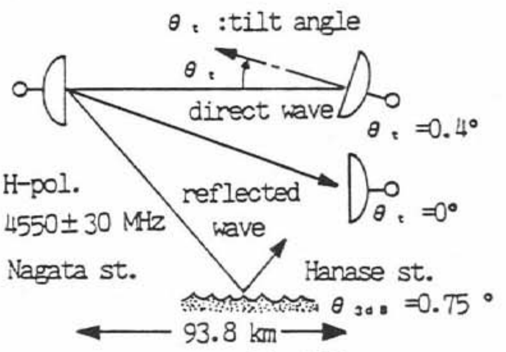


Fig.1 Measurement blockdiagram.

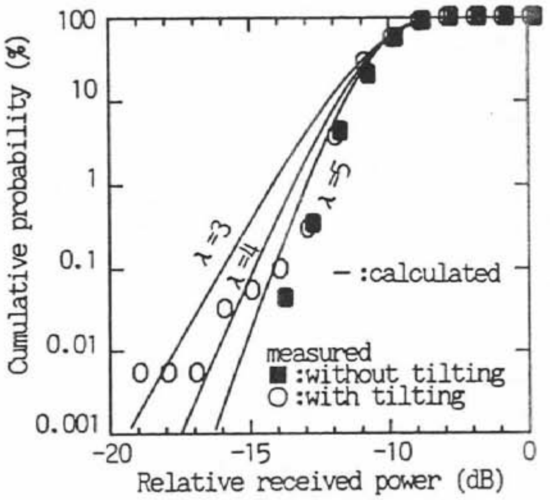


Fig.2 Cumulative received power distribution.

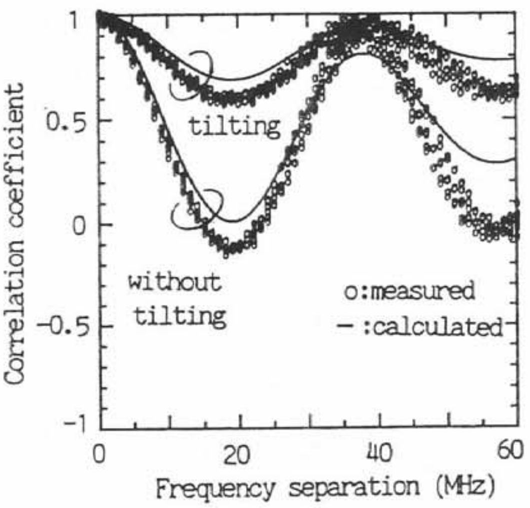
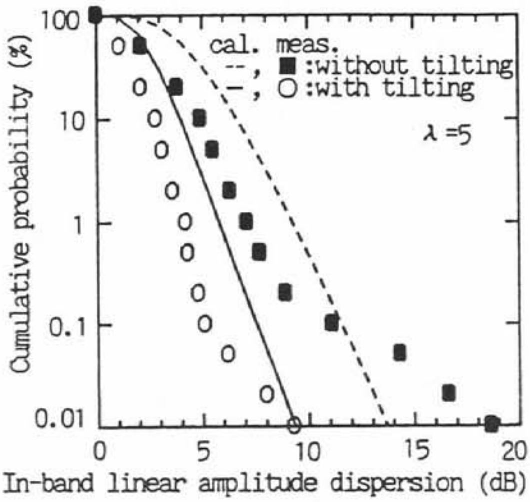
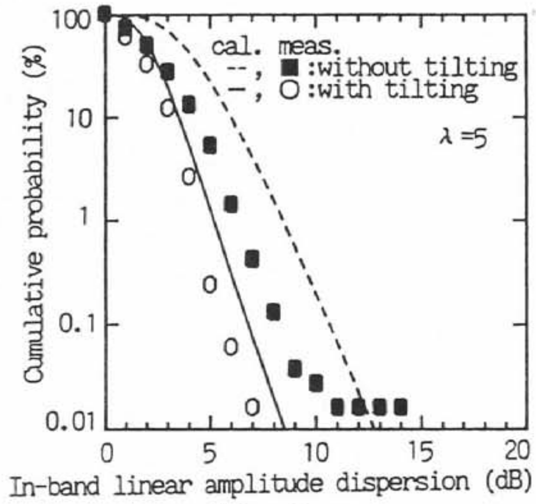


Fig.3 Frequency correlation
characteristics for received power.



(a) Δf=12.5 MHz



(b) Δf=50 MHz

Fig.4 Cumulative distribution of
in-band linear amplitude dispersion.

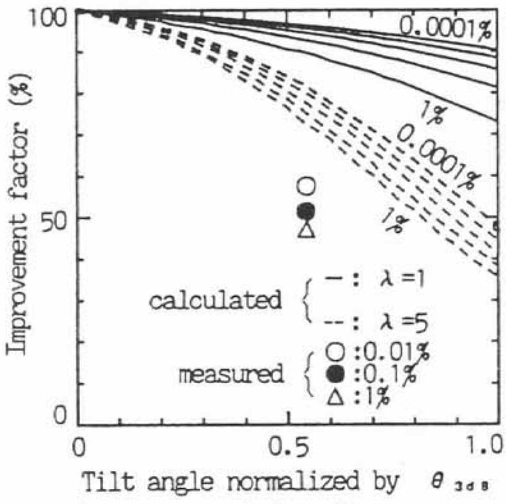


Fig.5 Improvement factor for
in-band linear amplitude dispersion.