TERRAIN FOR SUPPRESSING INTERFERENCE BY SEA REFLECTION ON VOR

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Abstract Conditions required to select a suitable terrain for suppressing interference in VHF omnidirectional range (VOR) signal caused by reflected waves from the sea are studied. The geometrical theory of diffraction (GTD) is applied to estimate the amount of the interference. The comparison with measured results shows our methods reasonable and indicates that proper selection of a VOR site brings forth a remarkable reduction of interference.

1. Introduction

VOR is a navigation aid providing azimuth information to aircraft in the 108-118 MHz frequency range. Many VORs in Japan are placed close to the sea. Signal fluctuations and degradation caused by the interference with reflected waves from the sea often deteriorate performance of these stations. About 10 stations have various restrictions due to such interference. Improvement in the radiation pattern of a VOR antenna has been proposed to cope with the problem [1]. However, it was found not cost effective since the antenna system proposed was much more sophisticated than conventional one.

We noted that interference is influenced not only by an antenna radiation pattern but by the terrain conditions between the antenna and a receiving point. This fact suggests that interference may be reduced by proper selection of antenna site. The propagation models derived from terrain profiles have proved to be useful in expressing the propagation characteristics and relations between the terrain and interference [2].

Several conditions required to the propagation model for suppressing interference are reported here. The GTD is applied to make a numerical evaluation on the amount of the interference reduction. Simple formulas relating the amount of interference to the constituents of a terrain are obtained and they give the best terrain for interference reduction. Flight measurements were made to compare measured results with the computed ones.

2. Propagation modeling

Propagation paths from a VOR station located close to the coast to a receiving point is shown in Fig. 1. A propagagion model representing a terrain profile is introduced to study the influence of the terrain on Ed and Er in Fig. 1. As one of propagation models, a knife edge one has been proposed which is obtained by substituting the highest hill shadowing the propagation paths (see Fig. 1). The GTD is applied to a knife edge model, shown in Fig. 2, to compute the field at the receiving point. The field is composed of a direct, reflected, diffracted and diffracted reflected field, Egd, Egr, Edd and Edr respectively, as shown in Fig. 2. Egd is given by

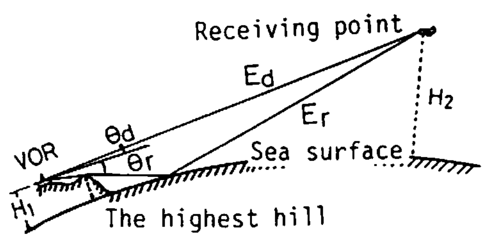

Fig. 1 Propagation paths

$$Egd = F(\theta d) \exp(-jkr_d)/r_d \qquad (1)$$

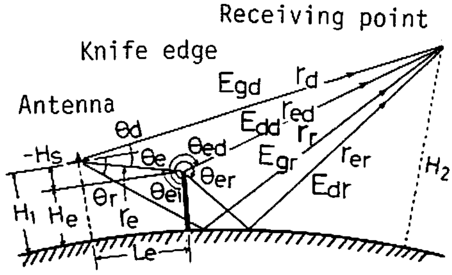

Fig. 2 Propagation model

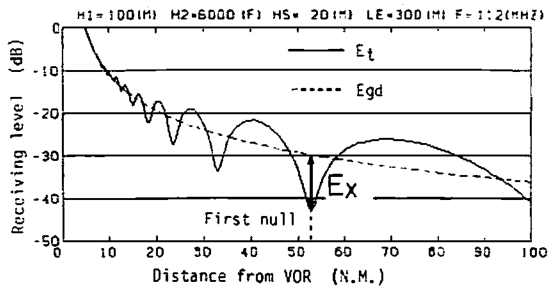

Fig. 3 Signal fluctuation by interference

where F(θd) is the radiation pattern of a VOR antenna, which can be derived from [3], and k is the propagation constant. Edd is expressed as

$$Edd = F(\theta e)\,\frac{\exp(-jkr_e)}{r_e}\,Ds(r_{ed},r_e,\theta ed,\theta e)\sqrt{\frac{r_e}{r_{ed}(r_e+r_{ed})}}\,\exp(-jkr_{ed}) \qquad (2)$$

where $Ds(r_{ed},r_e,\theta ed,\theta e)$ is the diffraction function given in [4]. Egr and Edr are obtained with similar procedures. The total field at the receiving point, Et, is given by adding these four terms.

Fig. 3 shows an example of computed results. The solid curve shows the field strength of the total field Et. Owing to the interference, the curve fluctuates as the receiving point approaches to the antenna. The dashed curve represents Egd, the field strengh without the terrain and interference. In order to estimate the amount of interference readily, Ex, the ratio of Et to Egd at the first null, as shown in Fig. 3, has been employed. Ex implies the amount of reduction due to the interference. The reason of selecting the first null is that the level of Et there is the lowest in the range from the station to the range limit.

3. The terrain and interference variables, H_1, H_2, Le and He. In the propagation model, there are four variables, H_1, H_2, Le and He. Though H_2 generally ranges from 5,000 to 40,000 feet, the radiation angles θd and θr (see Fig. 1) at the first null varies only 0.05 degree or less. This means that the variation of H_2 gives little effect on the signal level at the first null. Therefore, three variables, H_1, Le and He, are important in the following consideration.

Fig. 4 shows the relation among Ex and the constituents of the model, where $Hs=He-H_1$. The dashed curve represents the receiving level without taking account of the knife edge. The figure shows that every solid curve

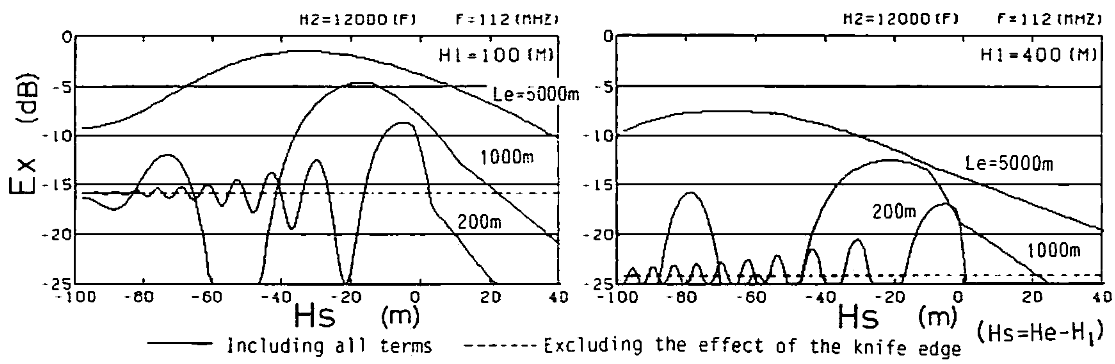

Fig. 4 Relations between interference and the terrain constituents

has a maximum point or the best point for interference suppression. The reduction of Ex at the left side of the maximum (the direction of decreasing Hs) owes much to the fact that the shadowing effect by the knife edge is small and hence the interference is large. The reduction at the right side of the maximum is caused by that the knife edge blocks not only the reflected field but the direct field. At the left side of the maximum point, when Le=200m or 1000m, Ex is fluctuating with respect to the dashed curve. This is due to the diffraction by the knife edge.

The plots show that when Le=5000m, the interference at the maximum point is reduced by 15 to 17 dB compared to the one without the terrain effect.

Fig. 5 indicates the relation among the interference level at the maximum point, Exmax and Le, H_1, where Le is logarithmically scaled. From the figure, the following approximate equation is obtained,

$$Exmax \cong 6.91\log Le - 11.61\log H_1 - 2.8 \quad (dB) \quad (H_1 \geq 150m). \qquad (3)$$

Fig. 4, shows that the amount of Hs at the maximum point, Hsmax, Le and H_1 are also related by an approximate equation given by,

$$Hsmax \cong Le(0.0133\log Le - 0.0087\log H_1 - 0.04) \quad (m) \quad (H_1 \geq 150m). \qquad (4)$$

Eq. (4) gives a condition required to the most suitable terrain for interference reduction. Eq. (3) yields the interference level when a suitable terrain is chosen. The equation shows that H_1 is more effective than Le to increase Exmax, because the coefficient of log H_1 is larger than that of log Le.

When H_1 is small ($H_1 \leq 100m$), explicit relations among the constituents are not available due to the curvature of the earth.

From Fig. 4 and Eqs. (3),(4), several important suggestions for suppressing interference are derived.

(1) Large Le is preferable. It can expand the range of Hs for attaining enough suppression.
(2) Small H_1 is favourable. H_1 is more effective than Le in reducing interference.

4. Measurement To compare with the computed results, measurement was conducted on Miyako VOR located near Miyako-city in the Tohoku district. Radial flights were made to the VOR at an altitude of 7000 feet, taking a course of 90 degrees. Fig. 6 shows the location and the terrain profile of the station. Fig.7 shows the received signal level. The dotted curve is the computed results and the agreement between measured and computed results

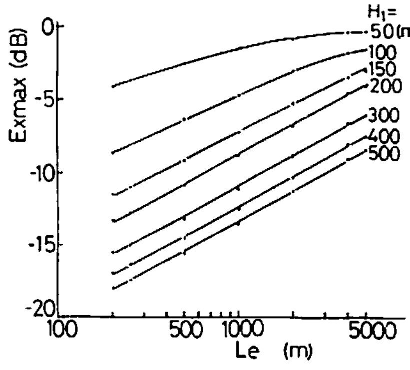

Fig. 5 Minimum interference level and the terrain constituents

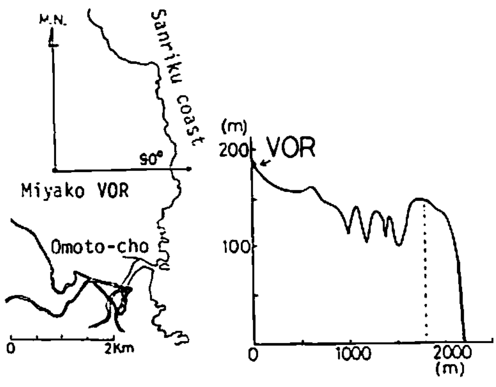

Fig. 6 Location of Miyako VOR and the terrain profile

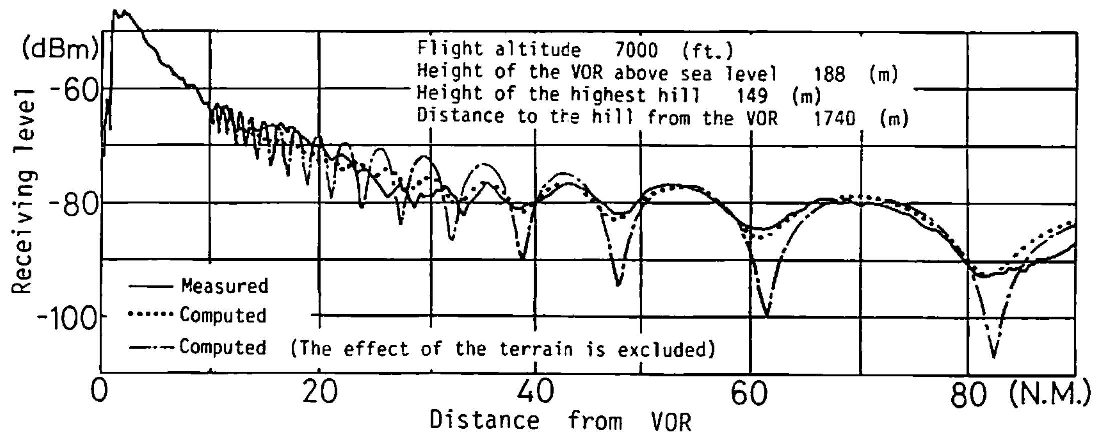

Fig. 7 Signal fluctuation of Miyako VOR

is good, which shows the validity of our analysis. Let us apply Eq. (4) to Miyako VOR to estimate the terrain. As Le=1740m, H_1=188m, then Hsmax = -29m. Compared to Hs (-39m), it is seen that the height of Miyako VOR is a little higher than the most effective position.

The dots and broken curve is a computed result in which the effect of the terrain is not included. This curve and the measured result show that the terrain effect improves the receiving level by about 14 dB at the first null. This improvement is quite remarkable compared to 5 dB obtained by a special antenna with improved radiation pattern described in [1].

5. Conclusions A propagation model for a terrain has been derived to express propagation characteristics from a VOR antenna to a receiving point when the antenna is placed close to the sea. The GTD is applied to make a numerical analysis on the relation between the terrain and the amount of interference due to the sea.

The analysis has revealed the conditions required of the terrain in minimizing the interference. Simple equations, relating the interference to the variables composing the model are also obtained.

It is obvious that selection of a site may fail to obtain an optimum terrain satisfying the conditions mentioned above. However, the method enables us to choose an effective terrain for interference reduction and to predict the amount of the interference. Therefore, when a new VOR is to be installed or a new air route is to be provided, this method contributes much to choose an appropriate location for suppressing the interference.

References

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