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5.1B MOST DESIRABLE TERRAIN, e.g., FLAT VS VALLEY LOCATION

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THE INFLUENCE OF GROUND REFLECTIONS ON THE ANTENNA DIAGRAM AT LOW ELEVATION ANGLES AND THEIR EFFECT ON RADAR GROUND CLUTTER AND INTERFERENCE

For obtaining an estimate it is assumed that ground reflections are similar for all (Yagi) elements of a phased array and they just change the radiation pattern of the single elements. This consequently yields a change of the radiation pattern of the entire array. It is furthermore assumed and deemed to be justified that the radiation pattern of a Yagi antenna can be treated in a good approximation for the present purpose, similar to the pattern of a single dipole, if one confines to radiation angles which are roughly perpendicular to the main beam of the Yagi antenna (e.g. at low elevation angles for vertically pointing Yagis).

Assume the geometry given in Figure 1. Antenna A is located at a height z_A above the ground. The direct path length between the antenna and the clutter target C is r_1, and the path length of the wave, reflected at R on the ground surface, is r_2. The horizontally stratified ground surface has the complex reflection coefficient ρ. The height of the clutter target above the ground surface is z_C, and the ground distance between antenna A and clutter target C is d.

Let E_o be field strength at C for free space propagation, and E_R the resulting field with ground reflection, then

$$\frac{E_R}{E_o} = \exp\left(-i\,\frac{2\pi\, r_1}{\lambda}\right) + \rho\cdot\exp\left(-i\,\frac{2\pi\, r_2}{\lambda}\right) \qquad (1)$$

where λ is the wavelength of the radar signal.

Let us assume some limiting values, which appear reasonable (λ = 6 m):

$$z_A < \lambda,\ z_C < 5\lambda,\ d > 250\lambda,$$

then $\alpha_1 \approx \alpha_2 = \alpha < 1.5°$. Ground reflection at R is within 100λ of antenna if $\alpha > 0.5°$, e.g. ground is assumed flat (inclination to the horizontal smaller than λ) out to several hundred meters from the antenna.

The reflection coefficient for horizontal polarization (propagation direction perpendicular to axis of dipole) is

$$\rho_h = \frac{\sin\alpha - \sqrt{\varepsilon_r^* - \cos^2\alpha}}{\sin\alpha + \sqrt{\varepsilon_r^* + \cos^2\alpha}}$$

and for "vertical" polarization (propagation direction in direction of dipole axis)

$$\rho_v = \frac{\varepsilon_r^*\sin\phi - \sqrt{\varepsilon_r^* - \cos^2\phi}}{\varepsilon_r^*\sin\phi + \sqrt{\varepsilon_r^* - \cos^2\phi}}$$

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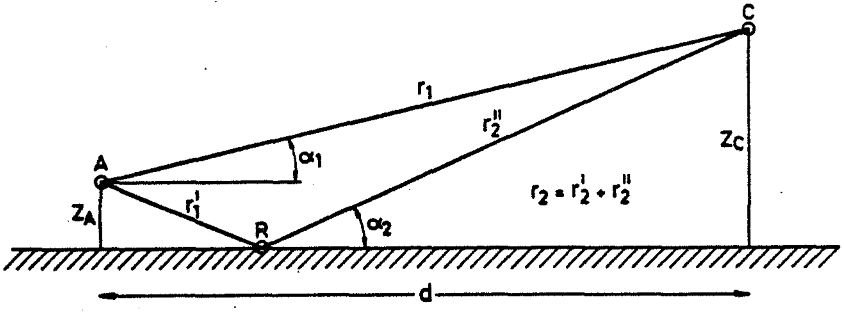

Figure 1. Geometry to calculate interference field at C of direct wave and indirect wave, reflected on the ground surface at R.

where ε_r^* is the complex permittivity given by

$$\varepsilon_r^* = \varepsilon_r - i\ 60\sigma\lambda,$$

with ε_r = dielectric constant (relative), σ = ground conductivity.

For $\alpha < 1.5°$, these reduce to

$$\rho_h \approx -1,$$

$$\rho_v \approx -1.$$

(The deviation from -1 is fairly negligible for low elevation angles and reasonable ground permittivity and conductivity. Using $\rho \approx -1$ in equation (1) for $r_1 \approx r_2$ elucidates the clutter reduction!)

For $z_A < z_C << d$, we obtain for the two-way (radar) case

$$\frac{E_R}{E_o} = 4 \sin^2 \frac{2\pi\ z_A \cdot z_C}{\lambda \cdot d}. \tag{2}$$

Since z_C is mostly much larger than z_A, the altitude extension of the clutter target essentially determines the clutter echo strength. Inserting the limiting values $z_A < \lambda$, $z_C < 5\lambda$, $d > 250\lambda$, equation (2) yields

$$\frac{E_R}{E_o} \lesssim 0.07\ (\hat{=} -24\ \text{dB}).$$

To illustrate: The ground reflection reduces the clutter echo strength by at least 24 dB for this fairly exposed condition of a highly elevated target (e.g., top of an antenna tower at 30 m height at 1500 m distance). A tower with 10 m height would yield a clutter strength reduced by another 20 dB.

It is evident that most of the clutter contribution comes form the top part of such targets. This is because of the quadratic altitude weighting (for $z_A \cdot z_C << \frac{\lambda d}{2\pi}$) given by (2), and because the larger the elevation α, the more the ground reflection coefficients deviate from -1. Of course the actual clutter echo strenth depends also on the total reflection coefficient of the clutter targets (has to be integrated), which, however, may not change so strongly as the height dependence given by (2). Clutter returns from localized (point or line) targets, e.g. TV towers or buildings, will be weaker than distributed (area) targets because of their r^{-4} dependence. From equation (2) it is deduced that clutter returns may get fairly strong if z_C is large. This would be, for instance, the case for mountains extending up to several hundred meters or even higher altitudes. Additionally, for such extended targets only an r^{-2} dependence applies and the target reflection coefficient can be orders of magnitude larger than for single towers or buildings.

One has to keep in mind that ρ_v deviates substantially from -1 for already very small elevation angles, which is not the case for ρ_h. It follows that in direction of the dipole axis the cancellation of direct and ground reflected wave is no more efficient, except of for very grazing elevation angles.

Similar to clutter problems with elevated targets, the reverse can happen also, namely problems with an elevated antenna. Equation (2) shows that this problem can be treated in an exactly equal way. It shows that obviously very critical clutter can occur even from fairly low targets. Part of these clutter problems can be explained by the fact that the direct radiation is fairly inefficiently cancelled by the ground-reflected radiation because of the not grazing incidence angle to the earth's surface.

Equation (2), of course, also yields an estimate for interference pick-up if one assumes a transmitter (TV, broadcast, etc.) with antenna height z_C. Again, the ground-reflected signal at low elevation angles almost eliminates, or at least strongly reduces, direct signals. Equation (2) also indicates that the ground clutter suppression improves by lowering the radar antenna; the single feed elements of the antenna (or their phase centrum), however, must not be a quarter wavelength above the ground to obtain the radiation suppression at low angles.

SUMMARY

It is shown that ground reflection very effectively cancels the radiation at grazing angles ($\alpha \lesssim 5°$) because the reflected wave suffers a phase reversal during reflection. This even can suppress low sidelobes of the array pattern which may be regarded as crucial without taking into account ground reflections. The location of an array antenna at a flat ground (extending out to several 100 m) may be sufficient, but a shallow valley should generally be preferred to eliminate the low angle radiation effects. However, high extending targets, such as radio towers or mountains in the close vicinity, will still cause considerable clutter echoes, even when optimizing the antenna array for low angle radiation suppression.