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A UNIFIED ANALYSIS OF GROUND-WAVE PROPAGATION OF USEFUL AND INTERFERING SIGNALS

Summary

The ground-wave consists of three components and no general analysis is applicable to the engineering practice. Here, the geometrical model is extended to all cases of ground-wave propagation and simple approximate formulas are derived, in agreement with general theory. The propagation of useful or interfering signals as well as of narrow-band noise can be determined by the unified approach. A very simple novel criterion for distinguishing the dominant component of the ground-wave is also formulated.

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It has been known for a long time that the general analysis of radio-wave propagation over earth surface leads to very complicated nonlinear relations. It is customary to present the field intensity at a given distance from the transmitting antenna as the free-space field intensity E_o multiplied by a nonlinear factor F:

$$E = E_o \cdot F = \sqrt{30\ PG} \cdot \frac{1}{d} \cdot F \qquad [V/m] \qquad /1/$$

where: P – the radiated power of the transmitter [W],
G – the power-gain ratio of the transmitting antenna,
d – the distance between transmitting and receiving antenna [m].

Evidently the problem can be reduced to expressing analytically the attenuation factor F, which depends upon the wave-length and – polarization, the path geometry and electric constants of the ground. However, no general expressions are known so far and only one attempt to elaborate a set of simple formulas and curves has been published /Bullington I1I, 1947/, with the indexing "above 30 Megacycles". It is therefore justified to maintain that no unified approach to the analysis of the groundwave propagation exists as yet.

Thanks to results by Wise, Burrows I2,3I and Norton I4,5I it is possible to decompose the ground-wave into three independent components with different modes of propagation /fig.1/:

a/ the space wave /which consists of direct and reflected wave/ propagating along with the rules of geometrical optics;

b/ the surface wave approximately governed by the diffraction theory with account to the energy absorption in the ground.

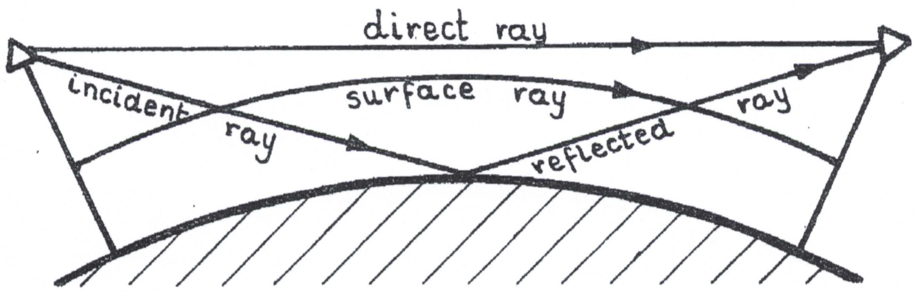

Fig.1. Decomposition of the ground-wave

This is conventionally shown by the approximate equation I1,5I :

$$E = E_o \left[1 + Re^{-j\Delta} + /1-R/\ Ae^{-j\Delta} + \dots\right] \qquad /2/$$

where: R – the reflection coefficient of the ground,

Δ – the phase difference introduced by the path difference of direct and reflected rays,

A – the surface-wave attenuation factor.

The reflection coefficient R is given by well-known Fresnel's formulas, viz.

– with the vertical polarization:

$$R_v = \frac{\varepsilon'_z \sin\gamma - \sqrt{\varepsilon'_z - \cos^2\gamma}}{\varepsilon'_z \sin\gamma + \sqrt{\varepsilon'_z - \cos^2\gamma}} \qquad /3a/$$

– with the horizontal polarization:

$$R_h = \frac{\sin\gamma - \sqrt{\varepsilon'_z - \cos^2\gamma}}{\sin\gamma + \sqrt{\varepsilon'_z - \cos^2\gamma}} \qquad /3b/$$

where: $\varepsilon'_z \triangleq \varepsilon' - j60\lambda\sigma$

$\varepsilon' \triangleq \frac{\varepsilon}{\varepsilon_0}$ - the dielectric constant of the ground relative to unity in free space,

λ - the wavelength /m/ ,

σ - the conductivity of the ground /S/m/

$\gamma \triangleq \arctan \frac{h_t + h_r}{d}$ - the elevation angle of incident or reflected wave,

h_t - the elevation of the transmitting antenna /m/,

h_r - the elevation of the receiving antenna /m/.

The phase difference Δ can be expressed as:

$$\Delta = 2\pi \cdot \frac{1}{d} \left[\sqrt{d^2 + /h_t+h_r/^2} - \sqrt{d^2 + /h_t-h_r/^2} \right] \qquad /4a/$$

or approximately, when $/h_t+h_r/ \ll d$:

$$\Delta = \frac{4\pi}{\lambda d} \cdot h_t\, h_r \;/\; 1 - \gamma^2 + \ldots \;/ \qquad /4b/$$

Unfortunately, no exact and general expression for the surface-wave attenuation factor A is known so far. Apart from scientific-level theories /major publications by Sommerfeld, Fock, van der Pol and Bremmer/ much work has been done in order to facilitate practical calculations in the plane-earth range by means of the concept of "numerical distance" [3,4]. The validity of the plane-earth approximation is usually assumed to be limited by the distance:

$$d_p = 80000 \cdot f^{-1/3} \qquad /5/$$

where: d_p - /m/

f - frequency of the radio-wave /MHz/

Excluding the near-zone, where the surface-wave approaches the free-space wave, the main part of A over plane-earth can be presented as:

$$A = \mathrm{const} \cdot \frac{1}{d} \qquad /6/$$

where the constant does not depend on the distance d, leading to the $1/d^2$ slope of the field intensity E.

We will, however, modify the traditional approach to the surface-wave analysis by transfering the well-established geometrical theory of the space-wave propagation over plane earth.
In the latter case /fig.2/, a very simple approximation by Vvedensky

I6I is valid up to the horizontal distance:

$$|E| = 4\pi\sqrt{30PG} \cdot \frac{h_t h_r}{d^2} = E_o \cdot \frac{4\pi h_t h_r}{d} \quad [V/m] \qquad /7/$$

with the same $1/d^2$ relation.

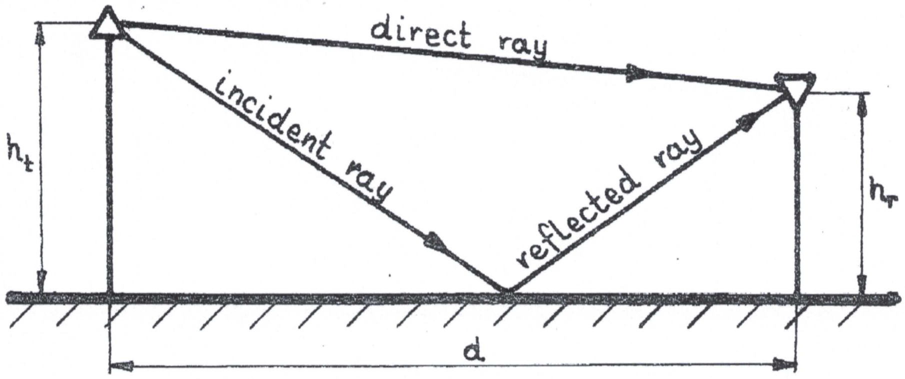

Fig.2. Geometrical propagation of the space wave over plane-earth.

In order to /formally/ express the surface-wave field intensity in a fashion similar to /7/, we approximately evaluated /6/ after lengthy calculations based on I2,4I. The obtained result apparently does not comply with the numerical distance method, because:

$$A = \frac{/R + 1/^2 \lambda}{8\pi j \cdot \sin^2\gamma} \cdot \frac{1}{d} \qquad /8/$$

where both R and γ still depend on the distance d.

Further investigation showed, however, that this double dependence tends to cancel out and we arrive at a simple approximation

$$|A| = \frac{2\pi}{\lambda d} \cdot h_m^2 \qquad /9/$$

Extending the idea of Bullington I1I we introduce here the parameter h_m /m/ denoting the apparent elevation of the antennas and given by:
- with the vertical polarization

$$h_m^2 = \frac{\lambda^2}{4\pi^2} \cdot \frac{\varepsilon'^2 + (60\lambda\sigma)^2}{\sqrt{(\varepsilon'-1)^2 + (60\lambda\sigma)^2}} \qquad /10a/$$

- with the horizontal polarization

$$h_m^2 = \frac{\lambda^2}{4\pi^2} \cdot \frac{1}{\sqrt{(\varepsilon'-1)^2 + (60\lambda\sigma)^2}} \qquad /10b/$$

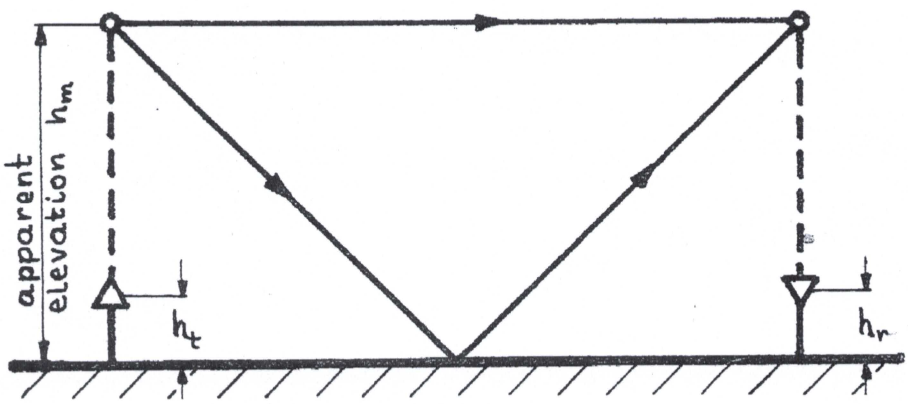

Fig.3. Geometrical model of the surface-wave propagation over plane-earth.

Thus, a new model of the surface-wave propagation /fig.3/ closely reminds the space-wave case; the same applies to the new expression for the surface-wave field intensity:

$$|E| = 4\pi \sqrt{30\ PG}\ \frac{h_m^2}{d^2\lambda} \qquad [V/m] \qquad /11/$$

It is possible to show that equation /11/ is sufficiently exact /for practical purposes/ within the range of distances:

$$\frac{250\ h_m^2}{\lambda} < d < d_p \qquad /12/$$

where the left hand expression is the boundary of the near zone.

Notice that equation /11/ actually describes the rectlinear part of basic curves of ground-wave propagation /fig.4/, to be found in CCIR graphs /Recommendation 368/. With the analytic form of /10/ we are not limited by any specific selection of ground parameter values ε', σ . Beyond the plane-earth boundary d_p the graphs are still indispensable, because exact formulas are too complicated.

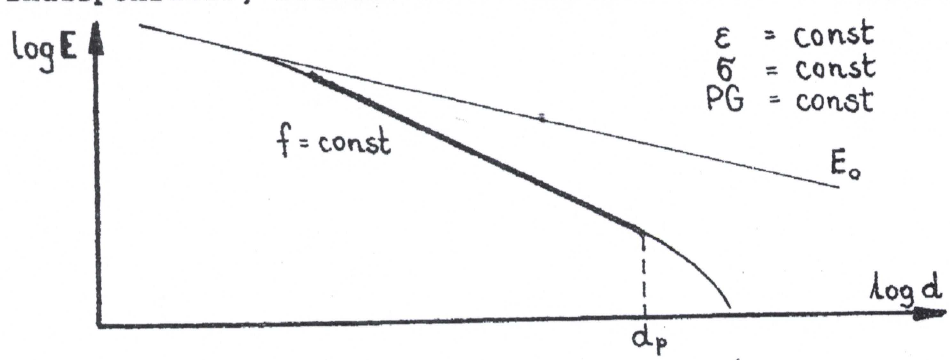

Fig.4. Typical shape of one curve in the graph of the surface-wave propagation

Continuing the theoretical research by Burrows and Bullington we now infere that the summation law of space and surface components is also very simple. This law, partly visible in /2/, can be formulated in the extended geometrical model by introducing corrected elevations h_1 and h_2 of the transmitting and receiving antenna as follows:

$$h_{1/2} = h_m + j\, h_{t/r} \qquad /13a/$$

or with absolute values:

$$h_{1/2} = \sqrt{h_m^2 + h^2_{t/r}} \qquad /13b/$$

Therefrom a general equation results for the tricomponent ground-wave intensity within a range similar to /12/:

$$|E| = 4\pi \sqrt{30\ PG} \cdot \frac{h_1\, h_2}{d^2} \quad [V/m] \qquad /14/$$

The upper limit of distance ensuring the validity of /14/ may be larger than d_p and depends somewhat upon which is the dominant component of the ground-wave - this problem is the object of our current research.

It is essential that h_m is determined analytically by /10/. It is also possible to analytically cross-check /14/ by extending and completing the equation by Burrows in I2I:

$$E = E_0 \cdot \frac{4\pi\, j\, h_t\, h_r}{\lambda\, d} \cdot \left[1 + \frac{/a-jb/\lambda}{4\pi\, j\, h_t}\right] \cdot \left[1 + \frac{/a-jb/\lambda}{4\pi\, j\, h_r}\right] \qquad /15/$$

where a, b are given by lengthy formulas.

The evidently simple form of equations /10/, /13/, /14/ predestinates them for practical calculations with technical accuracy. The complete verification of the accuracy of new formulas has been undertaken by the authors and requires comprehensive numerical tests. Of course, exact theories of ground-wave propagation are not challenged by this unified analysis.

The principal advantage of the outlined approach is its conceptual and applicational simplicity. Although the above mentioned original theoretical results /especially these by Burrows/ implicitely lead to unified analysis, no trials as yet are known to develop it and to introduce it to the engineering practice.

The unified method is very useful for determining the radio-signal propagation not very far from the transmitter. Narrow-band noise propagation and interfering signals in radio communication systems can also be analyzed this way.

Another, so far completely unknown *), advantage of our analysis is the simple criterion for determining the d o m i n a n t component of the ground-wave. Specifically, we find from /13/ and /14/:

if $h_m^2 \gg h_t \cdot h_r$ - the surface-wave is dominating and /11/ applies;

if $h_m^2 \ll h_t \cdot h_r$ - the space-wave is dominating and /7/ applies.

With the surface-wave, actual elevations of the antennas up to the approximate limit:

$$\sqrt{h_t \cdot h_r} < \frac{h_m}{3} \qquad /16/$$

do not influence the propagation, see fig.5. When the space-wave dominates, the polarization and ground parameters do not affect the field intensity. Further examination of these criteria will also be soon performed.

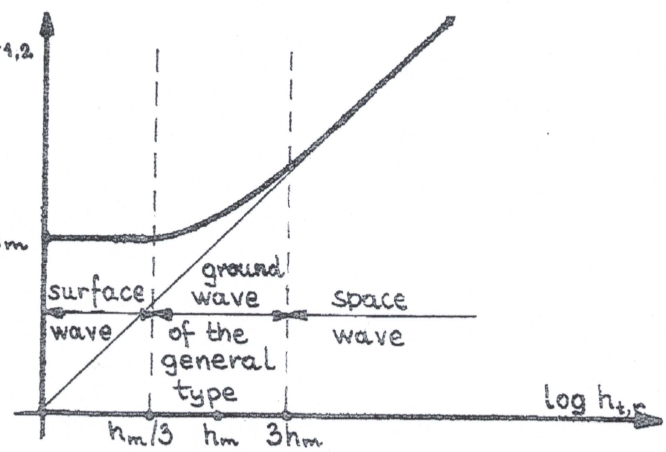

Fig.5. The type of the ground-wave as influenced by the antennae elevation.

Proposed formulas and criteria substantially facilitate the practical analysis of /shorter distance/ ground-wave propagation. The method is applicable to the analysis of useful and interfering signals. Radioelectric narrow-band disturbances /noise/, if originating from a point source and propagating not far therefrom, are

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*) except for a mention in one co-author's paper of 1973, I7I.

also apprеximately determined by same approach.

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Анализ распространения поверхностной волны полезного и мешающего сигналов

Общий анализ распространения поверхностной волны дает очень сложные зависимости. В докладе оговорена геометрическая модель для всех случаев распространения этой волны, благодаря которой получены простые приблизительные формулы, пригодны в инженерной практике и позволяющие определять доминирующую компоненту. Они пригодны при определению распространения полезного и мешающего сигналов, а также узкополосного шума.