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Effects of Sandstorms on Microwave Propagation

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Low rainfall volume suggests the promise of long paths using higher microwave frequencies for radio communication in desert areas. The pursuit of this promise gives rise to the need for understanding the effects of sandstorms on microwave propagation. First, a distinction should be made between large sand grains and fine sand dust.[1] Sand grains of greater than about 0.2-mm diameter are driven by the wind as a low-flying cloud with a height of less than about 2 meters above the ground. This limited height is expected to be lower than most antenna heights of a microwave station. On the other hand, dust-like sand particles can rise in dense clouds to a height of one kilometer or more. This latter type of sandstorm, which is essentially a misnomer for dust storm, may lie in the terrestrial and earth-space paths of microwave radio; hence, path attenuation data are required. Precise calculation is hampered by the uncertainty about the dielectric constant and the size distribution of sand particles. However, useful analysis and frequency dependence of the sandstorm effects can be obtained without precise knowledge of these parameters.

The relation between microwave attenuation and optical visibility will be of interest because visibility provides a convenient measure of dust density. The visibility is inversely proportional to the optical attenuation coefficient. A proportionality constant of 15 dB* will be assumed for the visibility distance in the following calculations. Sand

* This constant is simply 10 $\log_{10}$ of the measured median 0.031 of normalized difference in luminance between the sky and a mark located at the visibility distance (Ref. 2).

particles will be assumed as spheres of 0.01- to 0.1-mm radius with a dielectric constant in the range of 2.5 $(1 - j\,0.01)$ to 10 $(1 - j\,0.01)$. The assumed dielectric constant of 2.5 is that of dry soil.[3] The loss tangent of 0.01 and the other assumed dielectric constant of 10 are believed to be probable upper limits for sand particles in a desert environment. The Rayleigh approximation is valid at centimeter wavelengths, whereas the very-large-sphere approximation can be used at optical wavelengths.

The attenuation coefficient of a sandstorm is simply the sum of extinction cross sections $C(a)$ of sand spheres

$$\alpha = \int_0^\infty N\,(a)\;C\,(a)\;da, \tag{1}$$

where $N\,(a)\,da$ is the number density within the range of radii $(a, a + da)$. Assuming a single sand radius a in meters, this attenuation coefficient can be written as[4,5]

$$\alpha = \frac{3.25\;SQ_{ext}}{a}\;\text{dB/m}, \tag{2}$$

where $Q_{ext} = C/\pi a^2$ is the normalized extinction cross section, and $S = (4/3)\pi a^3 N$ is the fraction of sand in the atmospheric volume. Since $Q_{ext} = 2$ at optical wavelengths, the number of sand particles per cubic meter becomes

$$N = \frac{\alpha_0 a}{6.5\left(\dfrac{4}{3}\,\pi a^3\right)}, \tag{3}$$

where α_0 is the optical attenuation coefficient in dB/m.

The effective refractive index of a scattering medium is[5]

$$\tilde{m} = 1 - iS(0)\;2\pi N k^{-3}, \tag{4}$$

where k is the free space phase constant and $S(0)$ is the forward scattering function. Within the Rayleigh approximation, we have[4]

$$S(0) = ik^3\left(\frac{\epsilon - 1}{\epsilon + 2}\right)a^3 + \frac{2}{3}\,k^6\left(\frac{\epsilon - 1}{\epsilon + 2}\right)^2 a^6, \tag{5}$$

where ϵ and a are, respectively, the dielectric constant and the radius of the spherical scatterer. The second term in eq. (5) is negligible at centimeter wavelengths for the sand particle sizes under consideration. Substituting eqs. (3) and (5) into eq. (4) gives the phase shift and attenuation coefficient for centimeter waves.

$$k(\text{Re}\;\tilde{m} - 1) = \frac{3k}{13}\,\alpha_0 a\left[\text{Re}\left(\frac{\epsilon - 1}{\epsilon + 2}\right)\right]\left(\frac{180}{\pi}\right)\text{DEG}/m \tag{6}$$

$$k(\mathrm{Im}\ \tilde{m}) = \frac{3k}{13}\alpha_0 a\left[\mathrm{Im}\left(\frac{\epsilon - 1}{\epsilon + 2}\right)\right](8.68)\ \mathrm{dB/m}. \tag{7}$$

For a given visibility, the above equations show a linear dependence on the particle radius. For two particle sizes, eqs. (6) and (7) have been plotted for 11 GHz vs visibility and optical attenuation in Figs. 1 and 2. It is seen that, for a relatively poor visibility of 0.1 km, the calculated attenuation for this uniform sandstorm is less than 0.03 dB/km, whereas the calculated phase shift is in the range 1.5 to 35 DEG/km. Some beam displacement or broadening could take place if there were strong density gradient in the sandstorm. Significant attenuation at 11 GHz will certainly occur for a very poor visibility of 10 meters or less.

It is of interest to compare our calculations with recently published 10-GHz measurements[6] on dust using an open resonator. Substituting eq. (3) into eqs. (6) and (7), the refractive index and the loss tangent of a dust medium can be obtained

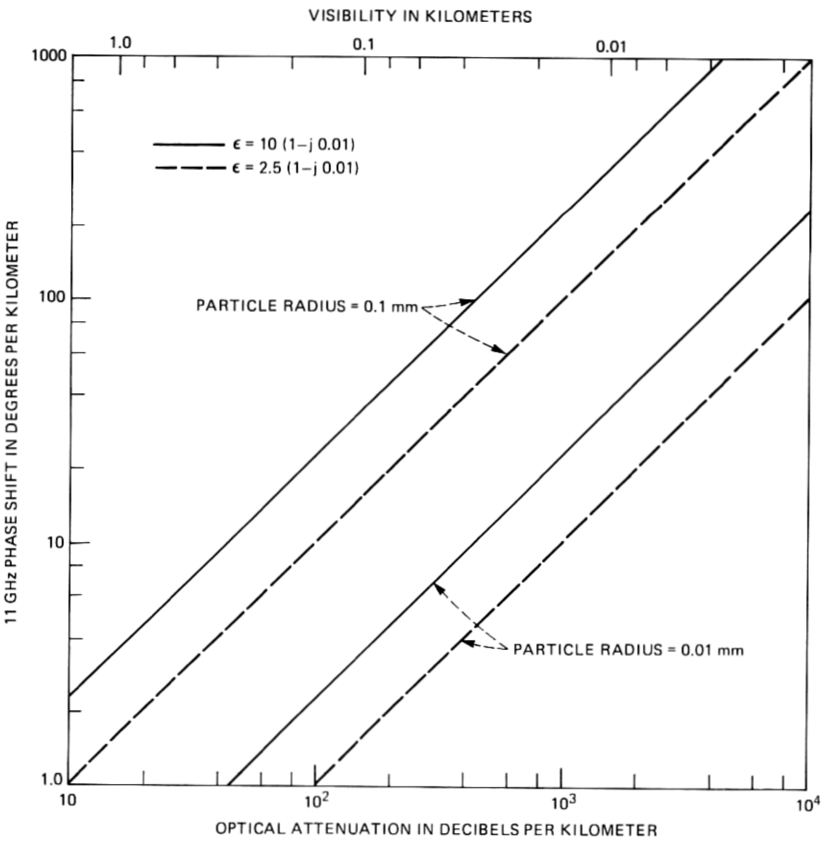

Fig. 1—Calculated 11-GHz phase shift by uniform sandstorm.

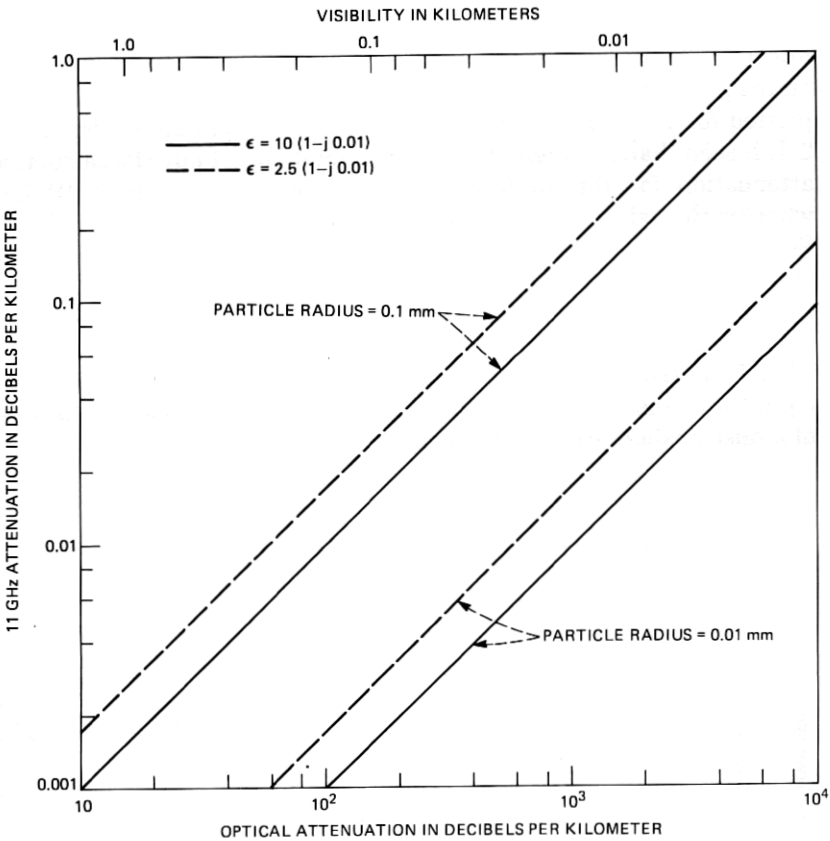

Fig. 2—Calculated 11-GHz attenuation by uniform sandstorm.

$$\text{Re}\,\tilde{m} - 1 = 0.579\;W\left[\text{Re}\left(\frac{\epsilon - 1}{\epsilon + 2}\right)\right]10^{-3} \tag{8}$$

$$\tan\delta = 1.157\;W\left[\text{Im}\left(\frac{\epsilon - 1}{\epsilon + 2}\right)\right]10^{-3}, \tag{9}$$

where W is the weight in Kg/m^3 and a specific gravity of 2.6 is assumed. For a given W, the refractive index and the loss tangent are independent of the particle size. Equations (8) and (9) have been plotted along with the measured data of Ref. 6 in Figs. 3 and 4, respectively. The measured refractive indices of both sand and clay dust lie within the range of calculated values. The measured loss tangent for sand dust agrees with the calculated values within the limits of measuring error, whereas that for the clay dust is higher by an order of magnitude. The moisture content of the clay dust in Ref.

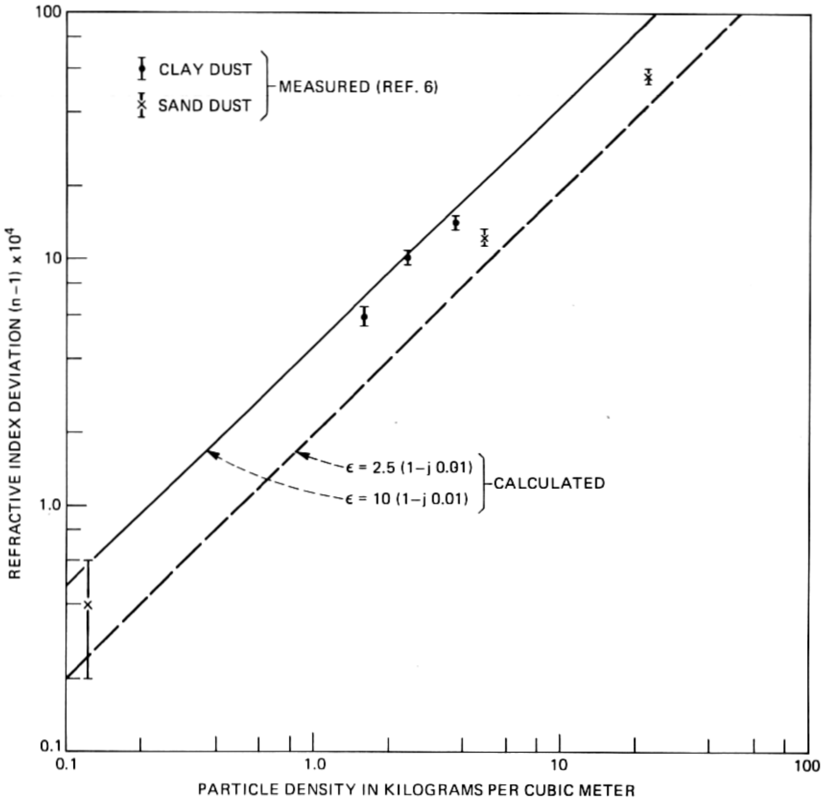

Fig. 3—Comparison between measured and calculated refractive indices for uniform dust precipitation.

6 is unknown. One notes that most particle densities ($\gtrsim 1$ Kg/m^3) used in the aforesaid measurement are so high that their optical visibilities are less than one meter.

An important result of our calculation is the linear dependence on frequency in eqs. (6) and (7). This property implies that if effects of a sandstorm at 4 and 6 GHz are negligibly small, then at 11 GHz they will also be small. One notes the sharp contrast between the above prediction and the rain attenuation which increases very rapidly from 6 to 11 GHz. Large rain drops have diameters of several millimeters; furthermore, liquid water has a much larger dielectric constant and much larger loss tangent.

Since the particle size and density of a sandstorm are larger near the ground than at a greater height, there appears to be an incentive for using large antenna heights. It also follows that satellite microwave communication is expected to encounter less sandstorm effects than terrestrial microwave networks.

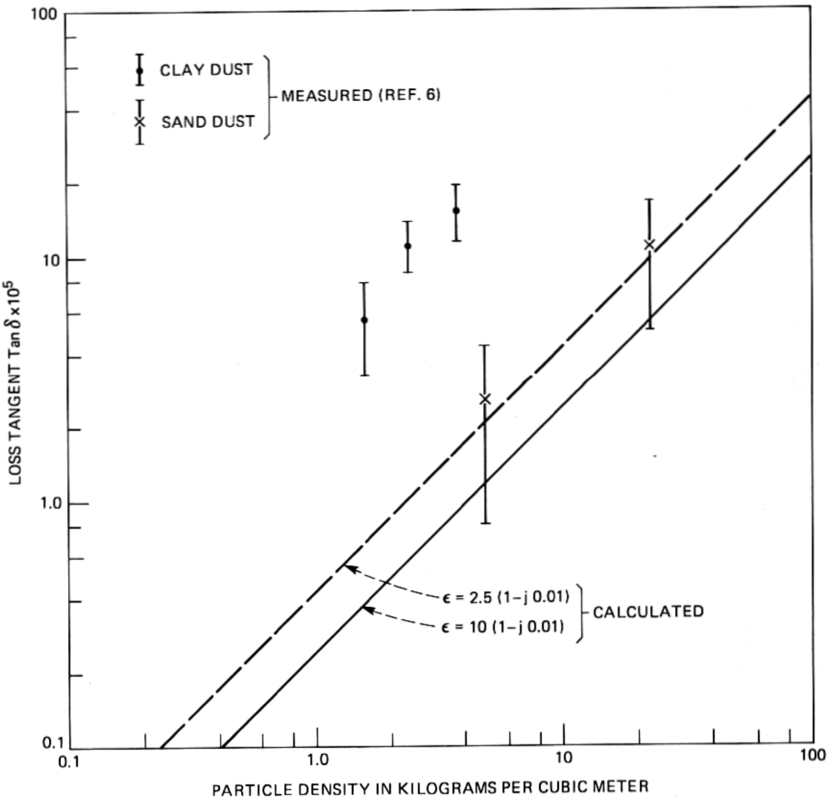

Fig. 4—Comparison between measured and calculated loss tangents for uniform dust precipitation.

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NOTE ADDED IN PROOF

A very recent paper[7] indicated an upper limit of 0.15 mm for measured radii of particles collected during sandstorms at Khartoum, Sudan.

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