Microwave PWE Propagation and Scattering From Atmospheric Turbulence

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Atmospheric microwave propagation in the presence of clear air turbulence can have significant differences from normal propagation due to the mean (background) gaseous refractivity $n(\vec{r})$, because turbulence modifies the instantaneous refractivity and produces small scale spatial gradients which affect EM wave propagation. This paper discusses methods to create 3D spatial realizations of turbulent refractivity fields, $n_t(\vec{r})$, which are then used in a parabolic wave equation (PWE) model to propagate EM waves beyond-line-of-sight (BLOS). The turbulent n_t is based on a modified 3D von Kármán spectrum that is scaled by a local C_N^2 profile computed from high-resolution radiosonde measurements.

The microwave modified refractivity $N \equiv 10^6(n-1)$ can be expressed in terms of mean N_o and random N_t components: $N = N_o + N_t$, where the ensemble average $< N >= N_o$ and $< N_t >= 0$. To propagate an EM field through the turbulent refractivity N, a sub-wavelength 3D spatial realization N_t is computed and used by the PWE model. The stochastic N_t is computed by 2D convolution of a spatial, white zero-mean Gaussian field with the modified von Kármán wavenumber spectrum:

$$S(k_r, k_z) = \frac{0.0555 C_N^2}{[K^2 + L_o^{-2}]^{4/3}} e^{-K^2/K_m^2}, K^2 = k_r^2 + k_z^2, K_m = 4.6/L_i$$

Here the inner (L_i) and outer (L_o) spectral scales specify the equilibrium turbulence region. The refractivity turbulence structure constant C_N^2 provides a scaling parameterization for N_t and is computed from the large scale ($> L_o$) atmospheric properties. A turbulence threshold is computed from the mean (background) atmosphere, based on a critical Richardson number R_c, such that turbulence is only present when the Richardson number $Ri < R_c$.

The approach used in this paper is distinct from previous PWE methods which employ a 1D phase screen model, in that a 2D refractivity field N is generated at sub-wavelength spatial scales at each PWE range step. This technique uses the background (mean) refractivity N_0 down to spatial scales of the outer scale L_o, combined with the stochastic N_t down to spatial sizes of the inner scale L_i. Thus, the PWE method accounts for the large scale refraction/diffraction corresponding to N_o and the forward scatter caused by the smaller spatial scales of N_t. This latter effect can produce significant effects on BLOS propagation.

Examples of PWE propagation in the presence of turbulence will be shown for X-band and MMW frequencies in coastal and marine environments. Forward scatter coupling to elevated ducts will be shown and the physical mechanisms responsible for this coupling will be discussed.