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A Strong-Scatter Theory of Ionospheric Scintillations for Two-Component Power Law Irregularity Spectra

Abstract:
We extend the phase screen power law theory for ionospheric scintillation to account for the case where refractive index irregularities follow a two-component power law spectrum. This two-component model includes, as special cases, an unmodified power law and modified power law with an outer scale. As such, it provides a useful framework for systematically investigating the effects of a spectral break or outer scale on the scintillation statistics. Using this spectral model, we solve the 4th moment equation governing the intensity fluctuations for the case of two-dimensional field-aligned ionospheric irregularities. A specific normalization is invoked to exploit the self-similar properties of the problem to achieve a universal scaling: i.e. different combinations of perturbation strength, propagation distance, and frequency produce the same results. The numerical algorithm is novel in that it employs highly-specialized quadrature algorithms and a Python library for arbitrary-precision floating-point arithmetic (Mpmath). These advancements enable simulation of significantly stronger scattering conditions than previously possible, enabling us to validate via simulation the statistical moments predicted by the asymptotic strong scatter theory.

On the basis of theoretical considerations and numerical simulations we make the following observations which are valid in the asymptotic strong scatter limit. Suppose p1 and p2 are the slopes of the low-frequency and high-frequency components of the phase spectral density, respectively. An unmodified power law spectrum is the special case with slope p=p1=p2. For steeply sloped spectra (p>3) in the absence of a spectral break or outer scale the scintillation index approaches a quasi-saturation state exceeding unity, S4→((p-1)/(5-p))1/2, as the strength of scatter increases. On the other hand, the presence of a spectral break or outer scale with p1<3 causes the S4 index to recede from its maximum with increasing perturbation strength to ultimately saturate at unity. In general, when p1<p2<3 the limiting behavior of S4 is dictated by the high frequency portion of the irregularity spectrum (i.e. the influence of an outer scale becomes insignificant), whereas when 3<p1<p2 it is dictated by the low frequency portion of the irregularity spectrum (i.e. the contribution from scales sizes smaller than the Fresnel scale becomes insignificant). For the case p1<3, p2>3, irregularity scales sizes both smaller and larger than the Fresnel scale contribute to the intensity statistics. For an unmodified power law, the correlation length of intensity fluctuations decreases with increasing perturbation strength according to a power law with exponent -1/(p-1) when p<3 and -1/(5-p) when p>3. The variation of this exponent as a function of p is symmetric about the result for p=3. However, when a spectral break or outer scale is present and p2>3 this symmetry is broken. In this case the intensity correlation length decreases with increasing perturbation strength according to the same power law exponent (-1/2) regardless of the high frequency spectral slope.