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Parabolic Wave Equation Model for Ducted Environments

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Abstract

The goal of this work is to develop a numerical EM tool based on a parabolic wave equation (PWE) model that can accurately predict propagation losses over a wide range of frequencies, geometries, atmospheric and ocean conditions, including very small elevation angles. The code is specifically written for accurate field computations in ducted environments for low grazing angle air-to-ground links (typically less than 4-5^o). It can run as a hybrid model with upper atmosphere is modeled using fast simpler models and lower marine atmospheric boundary layer is simulated by a discrete mixed Fourier transform-based PWE. It also include a Monte Carlo module that allows statistical estimation of realistic effects of varying sea surface, and turbulence by providing both the coherent and incoherent components of the field.

1 Introduction

Parabolic wave equation (PWE) based EM computational tools have been used extensively for problems with narrow paraxial/propagation angles, marine/littoral applications in particular. Lower atmospheric ducts create inhomogeneous conditions that complicates proper computation of the EM field but the approximations inherent in the PWE allow fast accurate EM field computations as long as most of the signal propagates within the paraxial angle [1, 2]. PWE codes such as Advanced Propagation Model (APM) are used in these scenarios [3, 4].

The PWE model developed here is also a discrete mixed Fourier transform-based PWE code and incorporates all the previous improvements such as [5–7] that enables incorporation of surface roughness, terrain profiles, and full 2-D refractivity (*M*) profiles.

The code focuses on low-grazing angle air-to-ground links. Some improvements to previous codes include:

- More accurate grazing angle computation using curved-wave spectral (CWS) estimation due to bent wavefront under non-standard conditions, evaporation ducts in particular [8].
- Improved surface impedance computations due to better grazing angle modeling.
- Incident field extraction from the total electric field that improves clutter and radar scattering computations.
- Hybrid GIT model for sea surface backscattering calculations [9].
- Hybrid PWE capability, that splits the domain into full PWE lower domain that contain the marine atmospheric boundary layer with complicated *M* variations and an upper domain that can be analytically or numerically solved using fast methods for high sources [2].
- Capability to compute coherent and incoherent portions of the EM field due to sea/rough surface variations and turbulence.

The schematics of sea clutter computation is given in Fig. 1. The ducting environment that can be characterized trilinear surface-based duct, evaporation ducts computed using Navy Atmospheric Vertical Surface Layer Model (NAVSLaM) [10] or any field-measured M-profile is coupled with the necessary radar and terrain profile parameters. These are fed into 2 successive PWE runs. The first is a split-step simple fast Fourier transform (FFT) based one that allows the code to compute the surface grazing angle using CWS or ray trace at each range, that allows accurate surface impedance boundary layer calculations [8]. Then a DMFT-based PWE is run to compute the total E-field. The field incident on the sea surface is then extracted and fed into backward RCS module that use hybrid GIT model [9].

Scintillation and fading codes compute the coherent and incoherent portions of the EM field. An improved scintillation computation model given in [11] is used here enabling fast accurate scintillation calculations even for high frequencies and under different turbulence outer scale lengths using relatively large PWE step size resulting in fast Monte Carlo analysis even when small scale turbulence effects are incorporated.

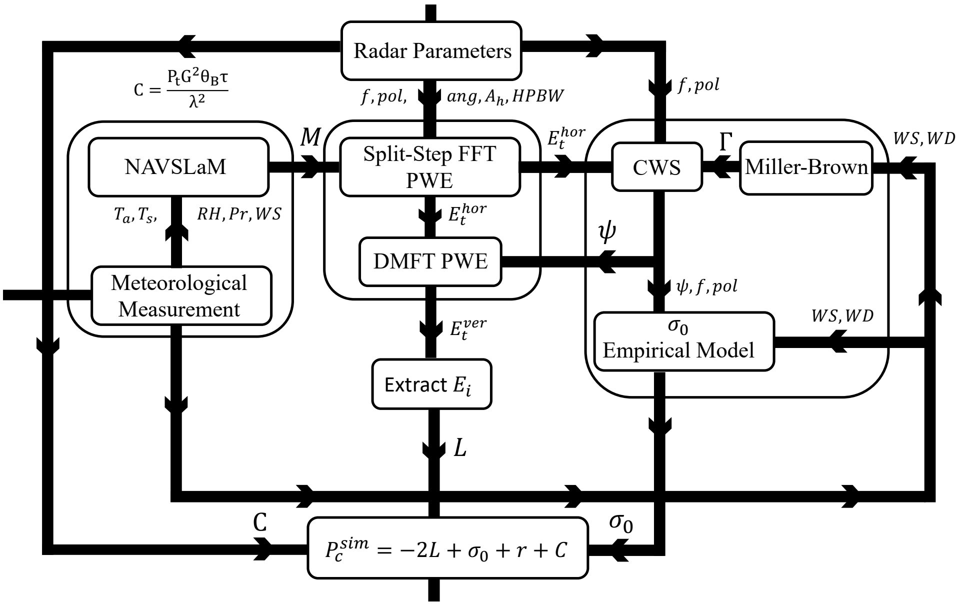


Figure 1. Main schematics of the PWE code for a surface clutter computation example.

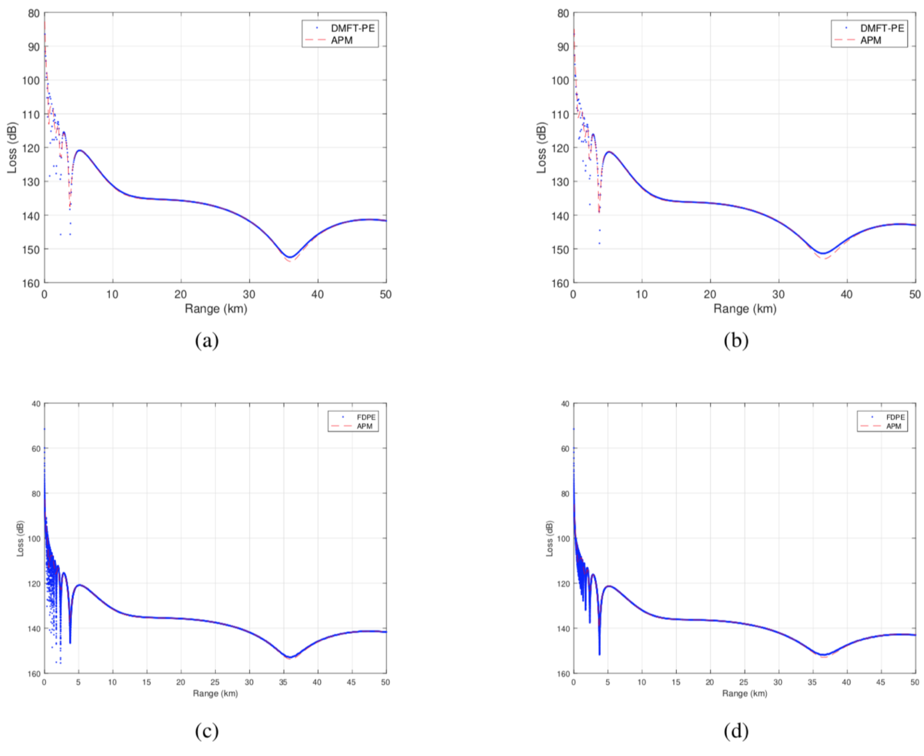
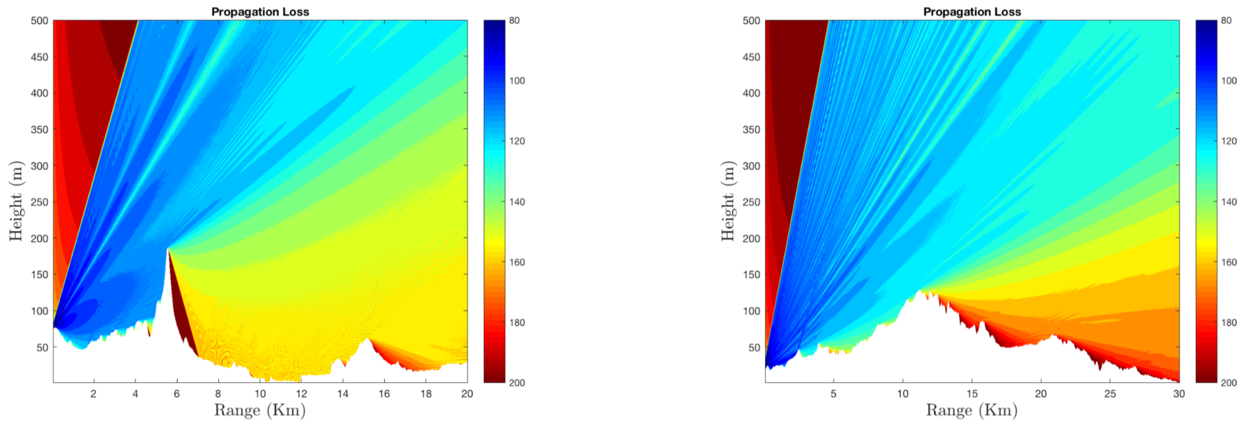


Figure 2. Propagation loss of a 10 GHz signal propagating in an evaporation duct of height 20 m at a height of 10 m for (a) horizontal and (b) vertical polarization using DMFT-PWE (blue line) and (c) horizontal and (d) vertical polarization using FD-PWE (blue line). In all plots the red dashed line represents loss obtained using the Advanced Propagation Model (APM).

2 Examples

The code is compared to APM and the results are given in Fig. 2 for a number of 10 GHz simulations performed under different ducting and polarizations. They show a good match to the APM.

The code can do both step function approximation or piecewise linear shift map (PLSM) depending on the terrain slope and slope change [6]. The code is tested for propagation around Sugarloaf Mountain and Campbell Hill, OH using digital elevation maps of the two cases under standard atmosphere (0.118 M-units/m slope). For Sugarloaf Mountain the slope can up to 15^o and require switching to the staircase model whereas PLSM works well for the entire Campbell Hill region. Sea surface roughness can be mod-



(a) (b)

Figure 3. Propagation loss of a 2.4 GHz signal propagating under standard atmosphere (0.118 M-units/m slope) for (a) Sugarloaf Mountain, Ohio and (b) Campbell Hill, Ohio where each terrain is represented through their digital elevation maps.

eled by Miller-Brown and Ament type boundary conditions but sea surface realizations can be simulated and statistical EM field properties can be extracted. Since max slope can be higher than 15^o for rough seas, staircase model is mostly used for these.

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