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## Analytic model for electromagnetic fields in the bubble regime in non-uniform plasma

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We consider a model of a strongly nonlinear plasma wakefield (a bubble) excited by an intense laser pulse or a relativistic electron bunch propagating in plasma with transverse inhomogeneity. Assuming an arbitrary shape of the electron sheath on the border of the bubble, we obtain a second-order ODE for the boundary of the bubble. We find two approximations when this equation is significantly simplified. Assuming small thickness of the electron sheath, we develop the lowest-order perturbation theory for the components of electromagnetic fields inside and outside the bubble. Unlike previous models, we derive simple explicit expressions for the components of electromagnetic fields not only in the vicinity of the center of the bubble, but in the whole volume of the bubble (including areas of driving or accelerated bunches) as well as outside it. Moreover, we apply the results to the case of radially non-uniform plasma. The obtained results are verified with 3D particle-in-cell simulations which show good correspondence to our model.

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