Compressive near-field imaging in the ULF/VLF

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Ultra-low- and very-low-frequency (ULF/VLF) radiation has significant penetrative capability, even in conductive materials. As a result, it offers the possibility of imaging *through* obscuring objects and structures. Existing transmitters in these bands (with global-scale range), as well as local environmental sources such as lightning, produce source fields which are scattered by the objects of interest. These scattered fields can be transduced and the resulting information can potentially be used to form images of the scattering objects.

Given the extreme wavelengths involved, the scattering problem can accurately be described as quasistatic near-field and modeled as purely static dipolar scattering, with full separation of the electric and magnetic responses. Analysis of the dipole scattering operator reveals that plane-to-plane direct imaging can be represented as a two-dimensional convolution. Nine convolution kernels emerge (one for each of the possible vector-component couplings), but they take one of two functional forms—one for vector-component-preserving scattering and one for component-changing scattering. The component-preserving kernels appear as (using the x-to-x coupling as an example)

$$K_{xx} = \left(\frac{1}{4\pi}\right)\frac{2x^2 - y^2 - z^2}{(x^2 + y^2 + z^2)^{5/2}} - \frac{\delta(x)}{3},$$

while the component-changing kernels appear as (x-to-y)

$$K_{yx} = \left(\frac{1}{4\pi}\right)\frac{3xy}{(x^2 + y^2 + z^2)^{5/2}}.$$

The convolution-based representation then admits an MTF-style resolution analysis. This analysis reveals that the direct imaging resolution via dipolar near-fields falls off inversely with the plane-to-plane distance.

This result highlights the limited applicability of direct imaging and suggests the need for model-based indirect imaging methods. Such an approach will necessarily be undersampled in practical applications as a result of sensor cost to achieve requisite sensitivity. We have been investigating compressed sensing (CS) approaches that utilize prior knowledge about object sparsity in some domain as a regularization method for improving inversion of the underdetermined problem and will report on our progress.