

EIT with the D-bar method: smooth and radial case

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This page contains the computational Matlab files related to the book [Linear and Nonlinear Inverse Problems with Practical Applications](#) written by **Jennifer Mueller** and **Samuli Siltanen** and published by SIAM in 2012.

You can order the book at the [SIAM webshop](#).

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This page is related to a smooth and rotationally symmetric conductivity.

Introduction

The D-bar method is a reconstruction method for the nonlinear inverse conductivity problem arising from Electrical Impedance Tomography. This page contains Matlab routines implementing the D-bar method for a smooth and rotationally symmetric conductivity.

Note carefully that although we use the rotational symmetry of the conductivity to speed up some computations, the reconstruction process including the solution of the D-bar equation is two-dimensional, not one-dimensional.

Please download the Matlab routines below to your working directory and run them in the order they appear.

Definition of the example

The first example concerns a rotationally symmetric and smooth conductivity that equals one near the unit circle. Outside the unit disc the conductivity has value 1.

The following file defines a rotationally symmetric and smooth conductivity in the unit disc: [sigma.m](#).

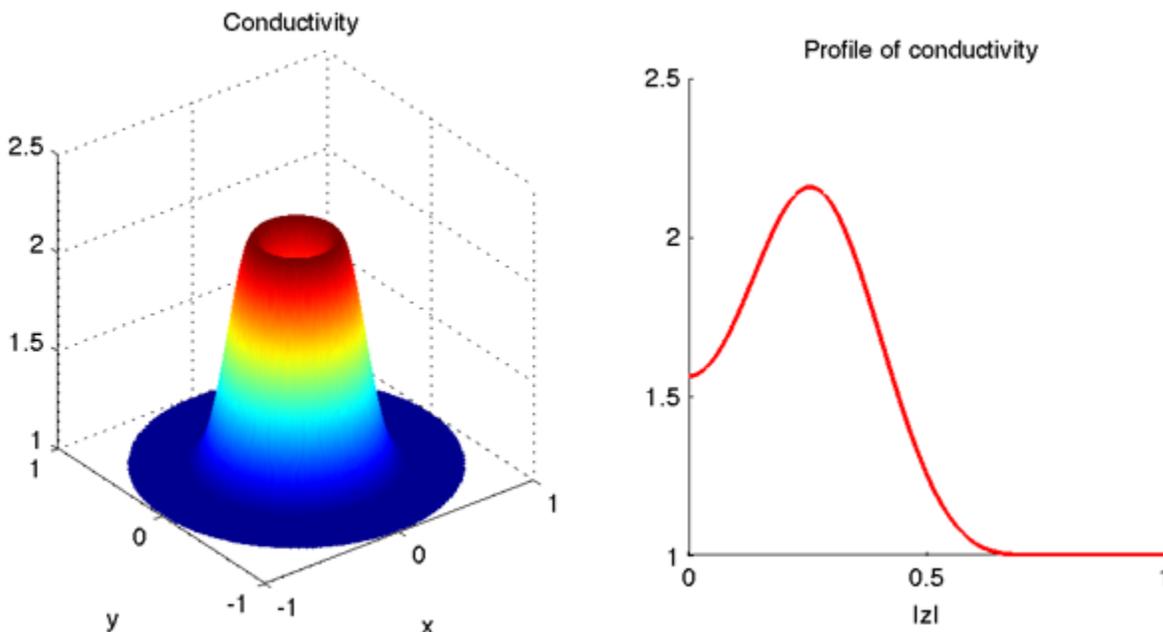
Furthermore, this file implements the Schrödinger potential related to the conductivity: [poten.m](#).

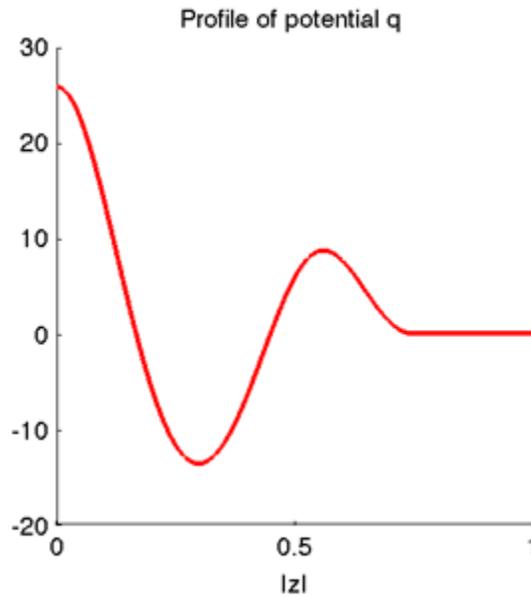
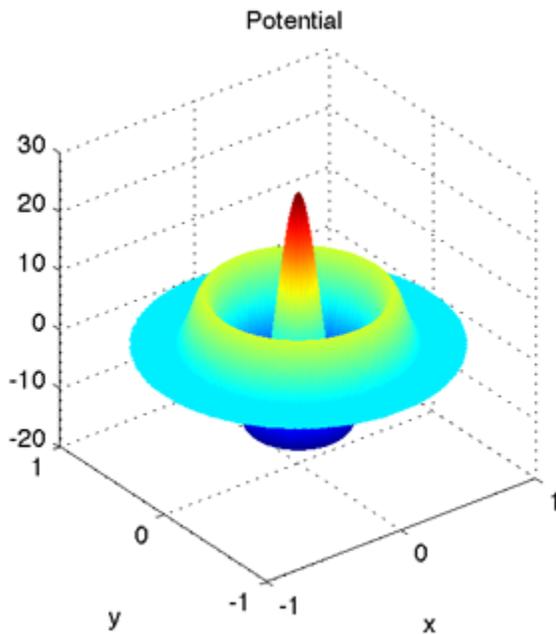
The Laplace operator appearing in the definition of the potential is implemented by finite differences in [poten.m](#).

The following routines plot the conductivity and the potential, respectively: [sigma_plot.m](#), [poten_plot.m](#).

Please run the plot commands before continuing to make sure that everything is working properly.

You should see something like this:





Computation of the scattering transform via the Lippmann-Schwinger equation

Next we define a set of points in the k -plane for evaluating the scattering transform $t(k)$.

Because of the rotational symmetry of this example, it is enough to choose k -values along the positive real axis: the scattering transform is known in this case to be rotationally symmetric and real-valued. Why? See [proof](#).

So please download and run this file: [kvec_comp.m](#).

The above file *kvec_comp.m* defines a set of k -points and saves them to a file called 'data/kvec.mat'. (Note that *kvec_comp.m* creates a subdirectory called 'data'. If you already created it before, Matlab will show a warning. However, you don't need to care about the warning.)

When running the example for the first time you might just use the file *kvec_comp.m* as it is. Later you might want to modify it to choose a different set of k -values.

Now that we have decided on the k -points, it's time to evaluate the scattering transform. Here we do it first by 'cheating', or by knowing the actual conductivity, because then there are no ill-posed steps involved. Later we will compute the scattering transform also honestly from (simulated) EIT measurements. This is the file that evaluates the scattering transform $t(k)$ at the k -points: [tLS_comp.m](#).

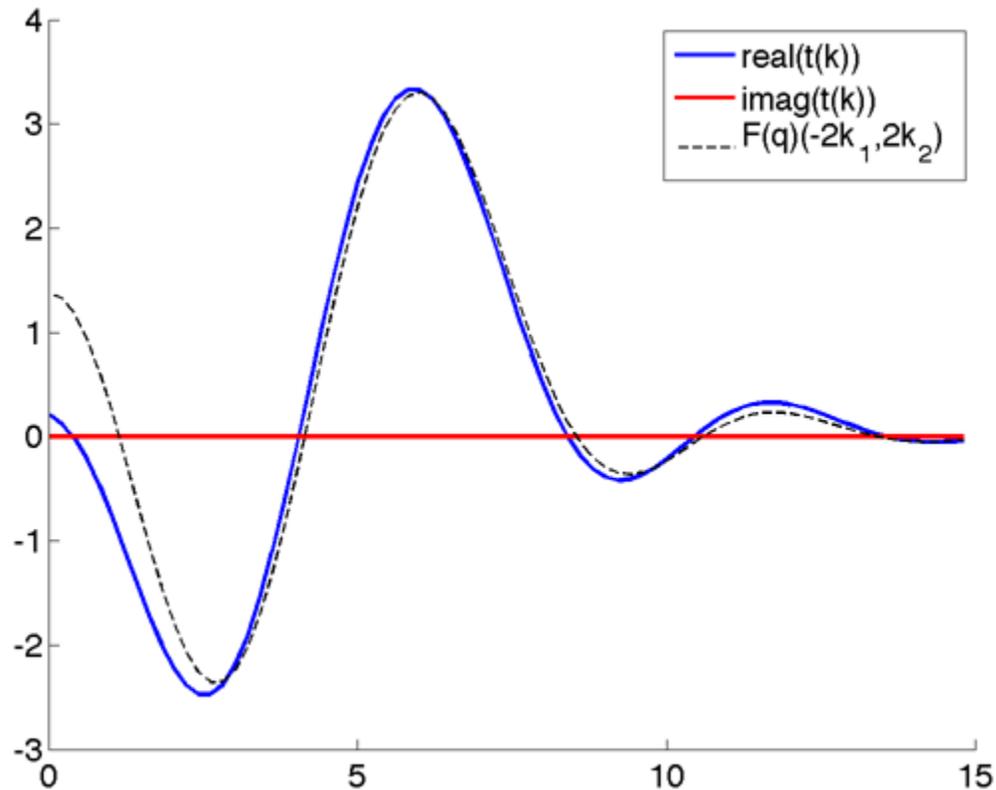
The result will be saved to a file called 'data/tLS.mat'. Here 'LS' refers to the use of the Lippmann-Schwinger equation in the computation of the complex geometric optics solutions. *tLS_comp.m* needs these files:

[green_faddeev.m](#), [g1.m](#), [GV_grids.m](#), [GV_LS.m](#), [GVLS_solve.m](#), [GV_project.m](#), [GV_prolong.m](#)

In the names of the above files, 'GV' refers to Gennadi Vainikko, a numerical analyst who invented the periodization-based algorithm used here for solving Lippmann-Schwinger type equations.

It is interesting to compare the linear and nonlinear Fourier transform. To that end, we compute the Fourier transform of the potential q using the routines [Fq_comp.m](#) and [gaussint.m](#).

After running the files *tLS_comp.m* and *Fq_comp.m*, you can plot the results using [tLS_plot.m](#). You should see something like this:



In the above image, the scattering transform is not quite approaching the value $t(0)=0$ as k tends to zero, although we know from theoretical results that this should be the case. Why such an error at zero? This is because we only used the value $M=7$ for constructing the grid, which was then of size 128×128 . The Faddeev fundamental solution has a $\log(|k|)$ singularity at the origin, and the Lippmann-Schwinger type approach has always difficulties near the origin. You can either use as big M value as your patience and computer memory allows, or you can use the boundary integral equation approach below to compute $t(k)$ for k near zero.

The rule of thumb is: The Lippmann-Schwinger approach for computing $t(k)$ is good for k somewhat away from the origin, and the boundary integral approach for computing $t(k)$ is good (only) for k near zero.

Simulation of EIT data

Since the conductivity is rotationally symmetric, the Dirichlet-to-Neumann map can be approximated by a diagonal matrix in the Fourier basis. Why? See [proof](#).

The diagonal elements have been precomputed and are simply given as a data file [DN1eigs.mat](#).

The DN matrix is constructed by the routine [DN_comp.m](#).

For details of the computation of the matrix elements, see

Mueller J L and Siltanen S 2003,

Direct reconstructions of conductivities from boundary measurements,
SIAM Journal of Scientific Computation **24**(4), pp. 1232-1266. [PDF \(617 KB\)](#)

Computation of the scattering transform via the boundary integral equation

We need to build matrices for the single layer operators S_k parametrized by the complex number k . This is done by the routines [Hk_comp.m](#) and [H1.m](#).

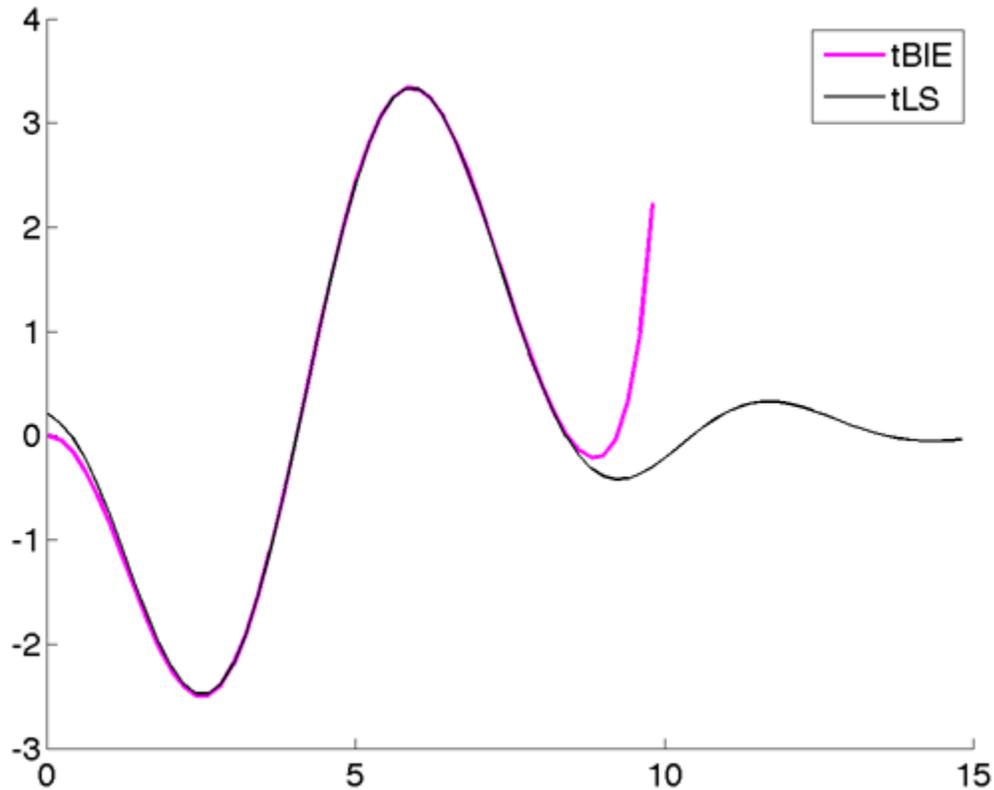
Here [Hk_comp.m](#) computes the matrices and [H1.m](#) is an auxiliary function. Note that the order N_{trig} of trigonometric approximation (in other words, the number of basis functions used) has been chosen in the routine [DN_comp.m](#) above and saved to disc for later reference. The routine [Hk_comp.m](#) loads N_{trig} from file.

Running the routine *Hk_comp.m* is computationally the most demanding task on this page. Do not be surprised if it takes 10 minutes or more.

Note that we save time by not running *Hk_comp.m* for too large values of $|k|$. Namely, the ill-posedness of the EIT problem has the effect that the boundary integral equation cannot be solved for $|k|$ exceeding a certain threshold value R ; for k values satisfying $|k|>R$ the computation will produce numerical garbage.

Once *Hk_comp.m* has been run, we can solve the boundary integral equation for the traces of the complex geometric optics solutions. This is done by the routine *psi_BIE_comp.m*, and the result is saved to a file in the subdirectory 'data'. The next step is to evaluate the scattering transform by integration over the boundary using the routine *tBIE_comp.m*.

We are now ready to plot the result and compare it to the scattering transform computed using the Lippmann-Schwinger equation approach. Run the file *t_plot.m*, and you should see something like this:

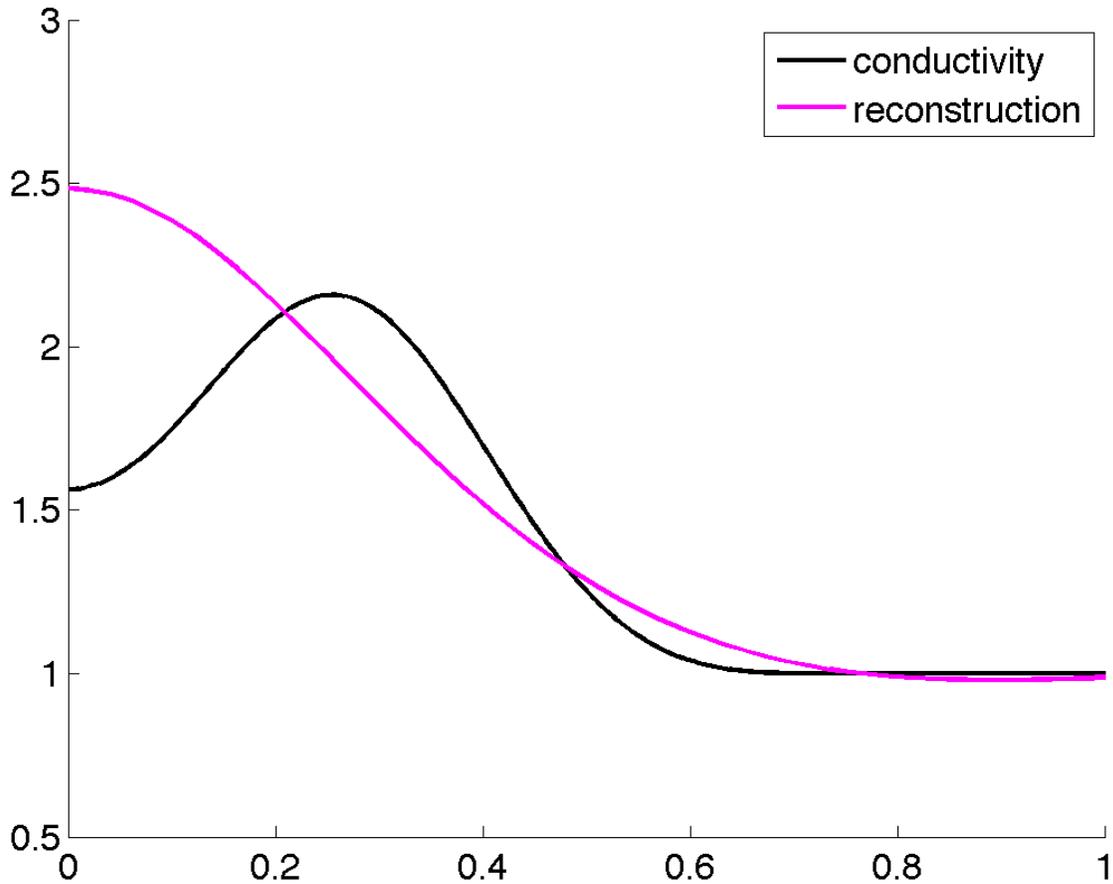


Note how the magenta line (computed using the boundary integral equation) diverges for $|k|>8$. However, the values of the magenta line for k near zero are very accurate.

Reconstruction from scattering transform using the D-bar method

Now we are ready to reconstruct the conductivity. Download the routines *tBIRecon_comp.m* and *DB_oper.m*, and run *tBIRecon_comp.m*.

You can look at the reconstruction using the routine *recon_plot.m*. You should see something like this:



Here we used $R=4$, so the reconstruction is not very close to the original. Try setting $M=8$ and $R=7$ in *tBIErecon_comp.m* and see what *recon_plot.m* produces then.

Note carefully that although we used the rotational symmetry of the conductivity to speed up some of the above computations, the solution of the D-bar equation is a two-dimensional process, not one-dimensional. We did choose the reconstruction points along the positive x_1 -axis for convenience, but any planar point x could be chosen. Also, note that the reconstruction at one x point is completely independent from the reconstruction at another point, so the D-bar method allows region-of-interest imaging and trivial parallelization.

You can experiment with the truncation radius R . When you use tBIE computed using the boundary integral equation, you can take R up to 7 with no problems. However, when R is so large that the bad-quality parts of the above magenta plot are being used, the reconstruction will be bad.

You can take the experiment further by using tLS instead of tBIE; then you can push the reconstruction to higher values of R . Also, you can replace the low-quality tLS values near $k=0$ with the higher-quality tBIE.