

# 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.

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## 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.

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## 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.

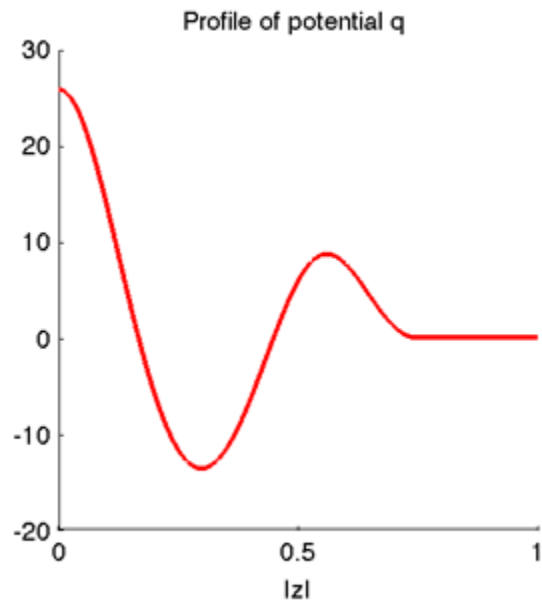
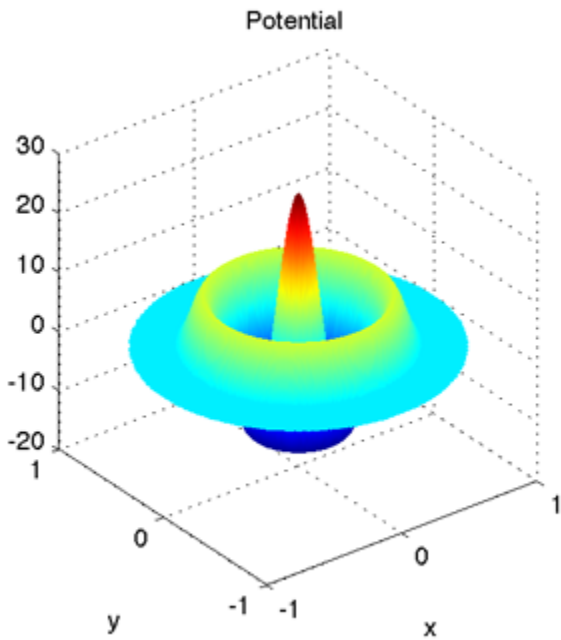
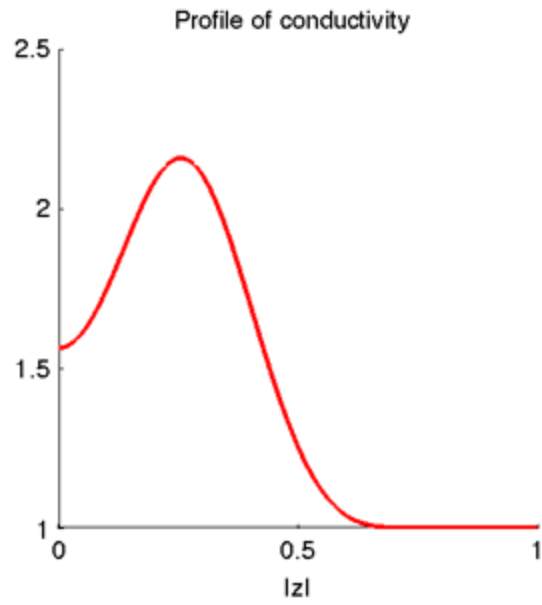
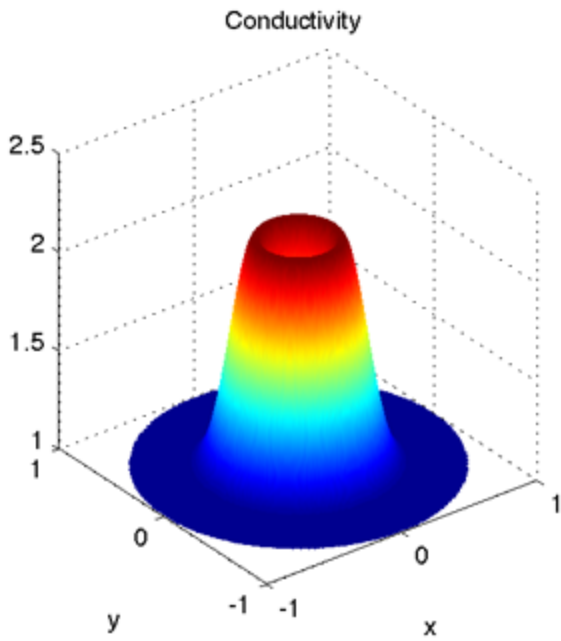
The following file defines a rotationally symmetric and smooth conductivity in the unit disc: [sigma.m](#).

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:




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## 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*.

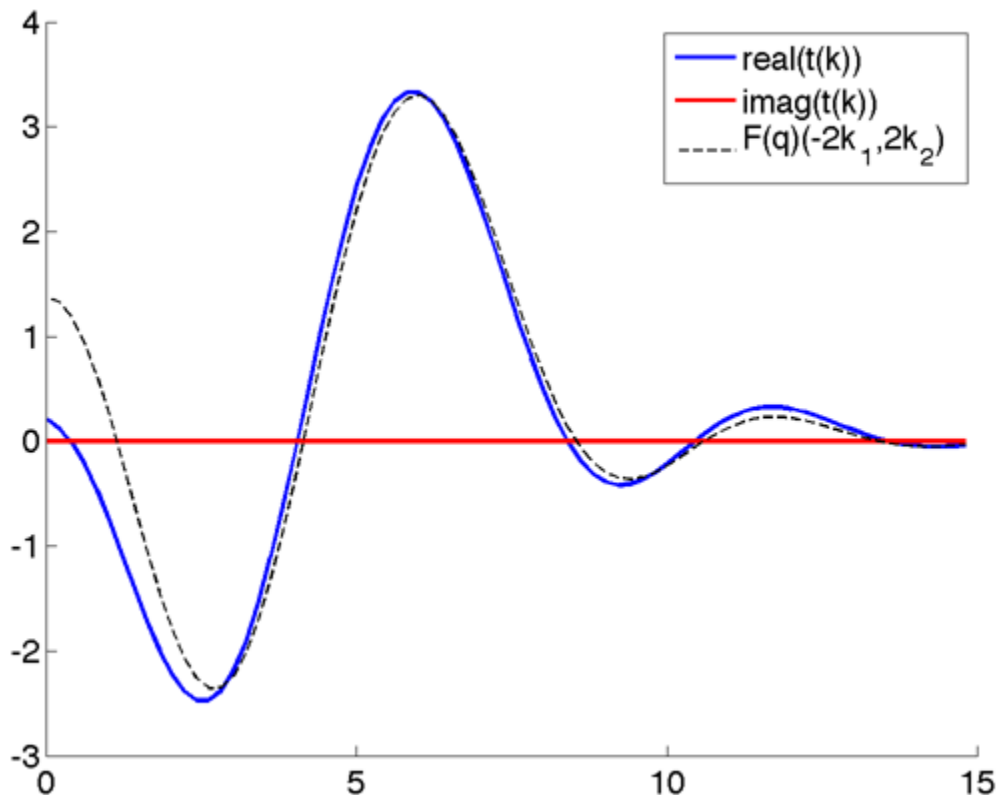
The result will be saved to a file called 'data/tLS.mat'. Here 'LS' refers to the use of the Lippmann-Schwinger equation in the computation of the complex geometric optics solutions. *tLS\_comp.m* needs these files:

[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  $128 \times 128$ . 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.

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## 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 \(617 KB\)](#)

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## 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](#).

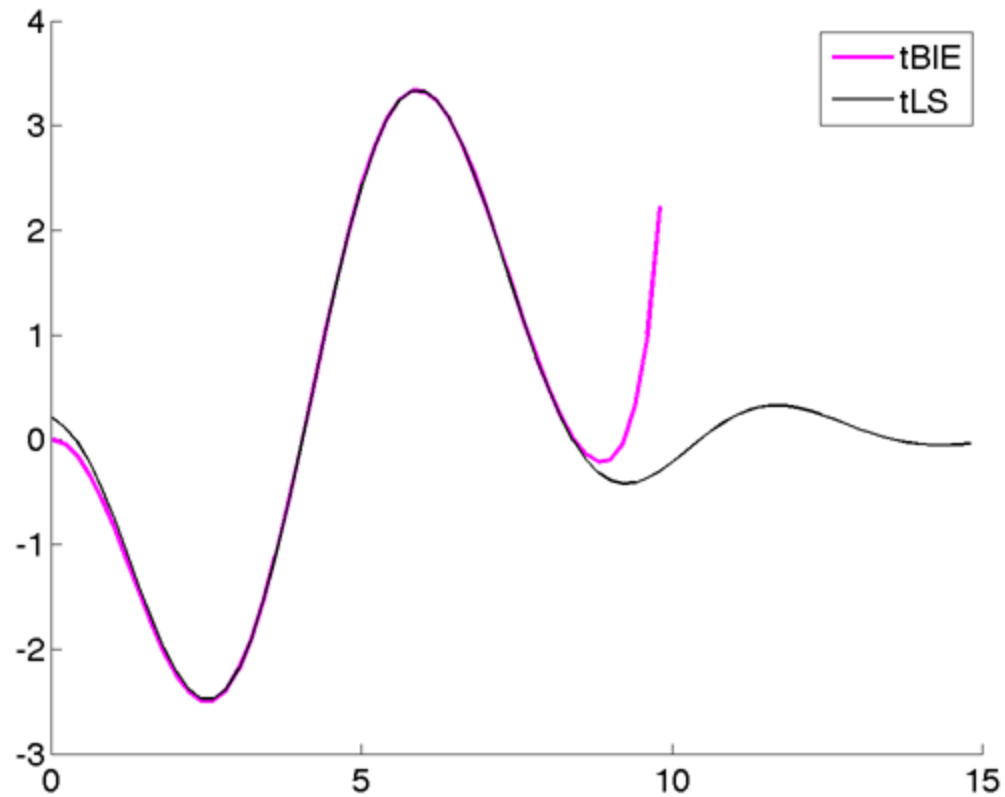
Here [Hk\\_comp.m](#) computes the matrices and [H1.m](#) is an auxiliary function. Note that the order  $N_{\text{trig}}$  of trigonometric approximation (in other words, the number of basis functions used) has been chosen in the routine [DN\\_comp.m](#) above and saved to disc for later reference.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



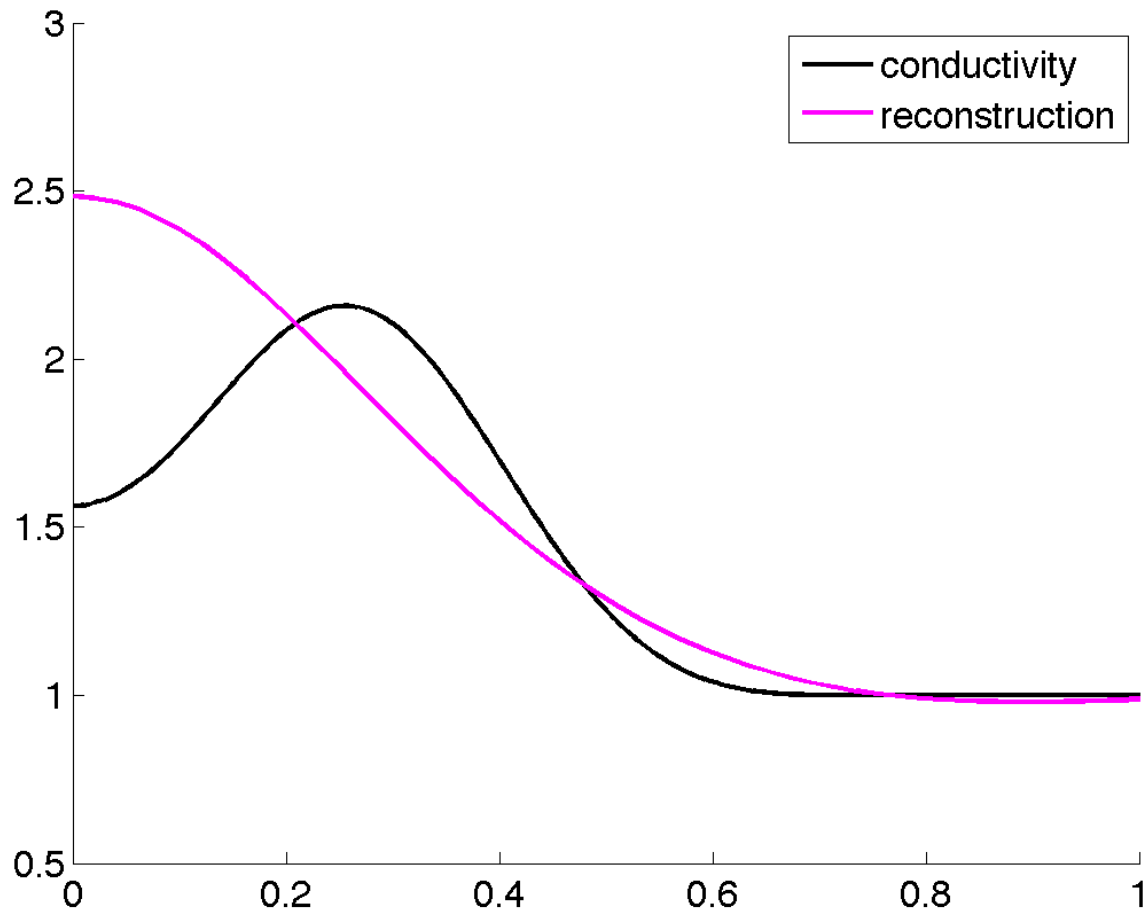
Note how the magenta line (computed using the boundary integral equation) diverges for  $|k| > 8$ . However, the values of the magenta line for  $k$  near zero are very accurate.

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## Reconstruction from scattering transform using the D-bar method

Now we are ready to reconstruct the conductivity. Download the routines `tBIErecon_comp.m` and `DB_oper.m`, and run `tBIErecon_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.