

## Ultrafast, Full-Wave Microwave Breast Tomography

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One of the lingering problems associated with microwave tomography or inverse problems is the long computation times. To perform a full reconstruction, it is necessary to compute multiple forward solutions along with the Jacobian matrix at each iteration. The latter provides a series of sensitivity maps depending on the associated transmit and receive antennas used at that moment. Numerous strategies have been employed such as not computing the Jacobian at each iteration and using the adjoint method to compute it [1]. The introduction of FDTD was a significant improvement over other forward solvers, as was the use of multi-processor computers and GPU's for the computations [2]. These have all been useful in exploring the nature of the problem, but have only made minor upgrades in improving the computation time.

We have introduced two innovations which have made dramatic progress in reducing the computation time. The first involves employing the discrete dipole approximation as the forward solver. The DDA has been known to be a fast solver alternative for some time, but its efficiencies are most often only available for situations where the domain is primarily dielectric – i.e. without large, high contrast scatterers such as metal antennas. One common example is for modeling field propagation through disperse clouds of particles in space. Serendipitously, the combination of our monopole array with a lossy coupling medium produces equivalent desired effects. The second involves a judicious choice of the reconstruction and forward solution meshes as part of utilizing the adjoint method. Much of the insight for this advance comes from observing the distributions of the separate rows of the Jacobian plotted on the reconstruction parameter mesh. These sensitivity maps are essentially vector-vector multiplications of the forward solutions generated from transmission from both the associated transmit and receive antennas. In this way, we have reduced the time to compute the Jacobian matrix to roughly 1/200<sup>th</sup> of a second. The combination of the two advances allows us to recover images in under 6 seconds while reducing the memory requirements by over a factor of 20.

For the forward solver, a key observation with the DDA is that the complete forward solution matrix can be formulated as a block-Toeplitz matrix once the diagonal terms have been separated from it. These blocks can then be padded into circulant matrices which have unique properties related to convolution theory. Their multiplication times a vector, as performed in conjugate gradient-like iterative forward solver techniques, can utilize the FFT to dramatically speed up the calculations. The synergism of all of these features makes for a very efficient forward solution which can be readily transformed to 3D applications where needed.

The benefits for a faster and less computationally heavy algorithm are obvious. Being able to construct images quickly on a simple laptop computer may open opportunities for deployment in under-resourced settings in developing countries. On a pragmatic level, it means that reconstructions can be more readily repeated to assess and optimize different imaging parameters. While the overall algorithm is still heavily parallelizable, these advances bring this portion of the imaging problem down to a level that is more accessible to researchers with the potential for reaching more end users and patients.

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## References

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