Electrical Impedance Tomography: Computation and Applications

Part 1: What is EIT, and Why Should we Care?

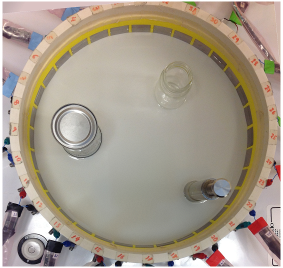
Melody Alsaker

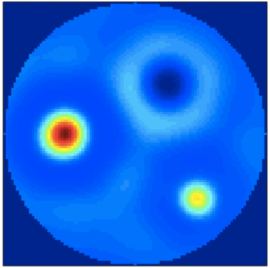
Jyväskylä Summer School 2026

August 2026

"Seeing" with Electricity

In the usual isotropic (direction-independent) model, electrical conductivity is represented by a positive scalar field $\sigma(x) > 0$, which quantifies how readily a material conducts electrical current.





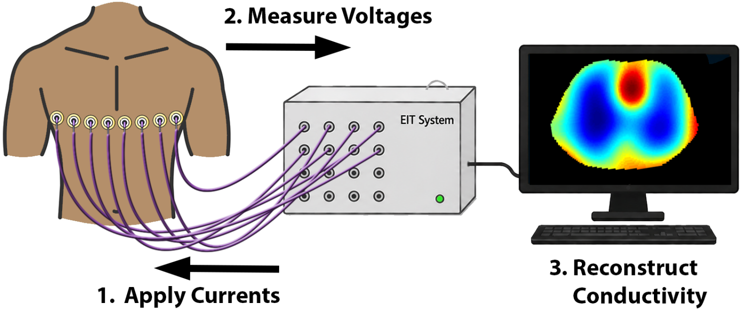
Red = high conductivity
Blue = low conductivity

The usual goal in EIT is to "see" the electrical conductivity distribution inside a target using only surface measurements.

Basic EIT Workflow

The usual EIT strategy is:

1. Apply AC current through electrodes on the surface.
2. Measure resulting surface voltages on the electrodes.
3. Use this boundary data to reconstruct the interior conductivity σ.



Why Should we Care About EIT?

- Low-cost, simple equipment compared to CT and MRI
- Portable, bedside-compatible, even wearable
- Uses safe, non-ionizing measurement energy
- High temporal resolution and fast reconstruction algorithms provide real-time functional imaging potential

Image: Hamilton Medical LinkedIn page

But there is a tradeoff

EIT images have low spatial resolution and are strongly affected by modeling and measurement errors.

Comparison with CT and MRI

	CT	MRI	EIT
Applied energy	X-rays	Magnetic fields and RF pulses	Electrical current
Main contrast	X-ray attenuation	Proton density and relaxation	Electrical conductivity
Equipment cost	High	Very high	Low/moderate
Portability	Limited	Very limited	Good
Continuous monitoring	Poor	Limited	Excellent
Spatial resolution	High	High	Low
Ionizing radiation	Yes	No	No

Key Point

EIT does not try to compete with CT and MRI as an anatomical imaging modality. It occupies a different niche.

What is Electrical Conductivity?

Basic facts about electrical conductivity:

- SI units: siemens per meter: $\frac{\mathrm{S}}{\mathrm{m}} = \frac{1}{\Omega \cdot \mathrm{m}}$
- Electrical conductivity is an intrinsic material property and *does not* depend on the size or shape of an object.
- Electrical conductivity *does* depend upon temperature and the frequency of the alternating current.

Electrical Conductivity of Materials

Approximate electrical conductivities of selected materials near room temperature:

Material	Conductivity σ (S/m)
Quartz	10^{-18}
Dry air	10^{-14} to 10^{-12}
Window glass	10^{-10}
Ultra-pure water	5.5×10^{-6}
Intrinsic silicon	4.3×10^{-4}
Seawater	4.5 to 5.5
Stainless steel	0.14×10^{7}
Silver	6.30×10^{7}

Sources:

- Wikipedia
- S. Mitchell, *An Introduction to Materials Engineering and Science*, 2004
- https://www.engineeringtoolbox.com

Where Biological Materials Fit In

Ordinary physical materials have conductivities on the order of $\sigma \approx 10^{-18}$ to 10^{7} S/m. Biological tissues have conductivities on the order of $\sigma \approx 10^{-2}$ to 10^{0} S/m.

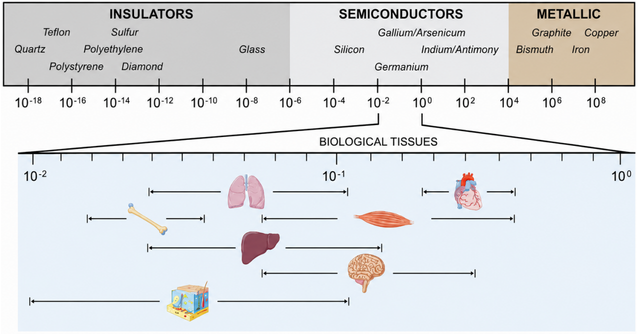


Image adapted from Solazzo et al., 2019

EIT allows us to "see" these conductivity contrasts between various materials or biological tissues.

Conductivity, Resistivity, Resistance, and Impedance

These related quantities are often used somewhat loosely in EIT terminology.

Material properties

- **Conductivity** σ describes how readily a material carries current. It is independent of geometry and is commonly used in mathematical models of medical EIT.
- **Resistivity** $\rho = \frac{1}{\sigma}$ is the reciprocal of conductivity and is commonly used in geophysical electrical resistivity tomography.

Object / measurement quantities

- **Resistance** $R = \frac{V}{I}$ describes opposition to current and depends on both material properties and geometry (V = voltage, I =current).
- **Impedance** $Z = \frac{V}{I}$ is the AC generalization of resistance; it also depends on frequency of the current and includes phase information.

Clinical thoracic EIT often reports relative "impedance changes," even when the inverse problem is formulated in terms of conductivity.

What Makes EIT so Hard?

Now that we know what EIT measures, let us return to the tradeoff introduced earlier:

EIT images have low spatial resolution and are strongly affected by modeling and measurement errors.

Suppose the pattern of measured voltages changes. What caused it?

- A conductivity change near an electrode?
- A different change deep inside the target?
- Electrode motion or a change in electrical contact?
- Measurement noise?

The Fundamental Difficulty

All of these effects can alter the measured voltage pattern, but the measurements do not directly identify the underlying cause or its location.

Boundary Measurements Mix Interior Information

- Electrical current spreads throughout the target rather than traveling along a single narrow path.
- Each measured voltage is influenced by conductivity across a broad region of the interior.
- Conductivity changes in different locations can produce similar patterns of boundary voltage change.

Key Point

The measurements contain spatial information, but they do not come with spatial labels. It's all mixed up together!

A Deep Difference from X-Ray CT

The comparison with CT reveals an important difference in measurement geometry.

	X-ray CT	EIT
Measurement field	Narrow X-ray beams	Distributed electrical current field
Geometry	Approximately straight paths, known in advance	Diffuse, curved current paths throughout the target
Effect of the unknown	Attenuation changes the beam intensity but not its path	Conductivity changes the internal current distribution itself

Key Difference

CT measures attenuation along known paths. In EIT, the unknown conductivity also reshapes the measurement field used to image it.

The Nonlinearity of EIT

For a *known* conductivity σ and specified applied currents, predicting the resulting boundary voltages is a linear forward problem.

In EIT reconstruction, however, σ is the unknown.

Important Distinction

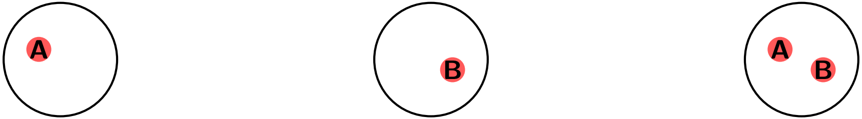
The mapping $\quad F : \sigma \longmapsto \text{(boundary voltages)} \quad$ is nonlinear in σ.

While we have an exceptionally well-developed modern numerical toolkit for linear problems, nonlinear reconstruction is much more challenging.

Nonlinear reconstruction requires linearization, iteration, or a specialized nonlinear method. . . not merely the solution of one fixed linear system.

Where does Nonlinearity Come From?

Let σ_0 be a background conductivity, and let A and B represent two local conductivity changes.



A alone B alone A and B

If $F(\sigma)$ denotes the predicted boundary voltage data, then in general

$$\underbrace{F(\sigma_0 + A + B) - F(\sigma_0)}_{\text{effect of both changes}} \neq \underbrace{F(\sigma_0 + A) - F(\sigma_0)}_{\text{effect of } A} + \underbrace{F(\sigma_0 + B) - F(\sigma_0)}_{\text{effect of } B}.$$

Key Point

When A is present, it redistributes the current throughout the target. Adding B to this altered current field therefore produces a different voltage change than adding B to the background alone.

Fine Detail Leaves a Weak Boundary Signature

- Localized conductivity features produce broad, diffuse effects on the boundary voltages.
- Small-scale features and changes far from the electrodes often produce only small changes in the data.
- Sensitivity and spatial resolution are not uniform throughout the target.

Practical Consequence

Different conductivity distributions can produce boundary data that are almost indistinguishable once realistic noise is included.

Real Data and Models Are Limited

Measurement limitations

- A finite number of electrodes and current patterns
- Electronic noise and interference
- Imperfect or changing electrode contact

Modeling limitations

- Uncertain target shape or electrode locations
- A 2D model of a 3D target
- Motion or material behavior omitted from the model

Why This Matters

The reconstruction algorithm can mistake any of these discrepancies for a conductivity change.

The Central Reconstruction Tradeoff

EIT is a Severely Ill-Posed Inverse Problem

Small errors in the measured data or mathematical model can cause large errors in a naive reconstruction.

Practical reconstruction therefore requires **regularization**: deliberately limiting the information we try to recover so that errors are not severely amplified.

- Too little regularization: noise and modeling errors become image artifacts.
- Too much regularization: real conductivity features become blurred or suppressed.

The Goal

Adequately and reliably recover the information required by the application. . . do not aim to see every fine detail of the interior!

Why EIT Remains Compelling

EIT sits at an unusual intersection of mathematical difficulty and practical promise.

Mathematical challenge

EIT brings together inverse problems, PDEs, numerical analysis, optimization, and experimental design.

Its limitations remain active research problems rather than merely settled technical details.

Practical promise

The measurement hardware is comparatively simple, safe, portable, and low-cost.

Better reconstructions could therefore have an outsized impact in medicine and industry.

Why We Keep Working on It

The challenge keeps EIT intellectually compelling; the potential payoff keeps mathematicians, engineers, clinicians, and industry committed to making it work.