Internal Diode for Frequency Selective EIT Contrasts

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Problem

Impedance imaging has low sensitivity in regions deep within the interior of a body. Inserting a current source, such as a capsule swallowed and then tracked through the gastrointestinal tract, would improve sensitivity near the source. We conducted simulation and tank-model experiments to evaluate whether harmonics from diode conduction would be detectable when used in a body.

Why use Diodes?

A circuit element with a non-linear V-I relationship, such as a diode (Figure 1), produces harmonics at multiples of the input frequency f when driven with sinusoidal inputs. Our concept is that harmonics could be detected in the measured voltages from a diode placed within the body using an EIT system. In this case, the diode will act as a source at the first harmonic $2f$, turning EIT into a source localization problem which can give higher resolution.

Since the harmonics are small, the EIT current sources would need to be sufficiently harmonically pure, in order to separate the the diode-produced harmonics from those of the current source. In this paper, our goal is to evaluate the feasibility of the concept; we study the harmonic to fundamental ratio v_{2f}/v_f which would be used to detect the source.

Math and Simulations

We study an EIT measurement system with 16 electrodes around the circumference of a tank or chest operating at 1 kHz. 2D models were constructed in EIDORS using Netgen to estimate the voltage V across a diode located near the centre of a cylindrical domain (Figure 2). V was simulated for a range of geometries and EIT drive levels, as well as expected measurement amplitudes. The FEM system matrix $\mathbf{A}$ may be reduced to a minimal resistor network [1].

$$\begin{bmatrix} \mathbf{v}_a \\ \mathbf{v}_b \end{bmatrix} = \mathbf{A} = \begin{bmatrix} \mathbf{B} & \mathbf{C}^\mathsf{T} \\ \mathbf{C} & \mathbf{D} \end{bmatrix} \begin{bmatrix} \mathbf{i}_a \\ 0 \end{bmatrix} \quad (1)$$

The upper-left triangle of the reduced matrix, $\widetilde{\mathbf{A}} = \mathbf{B} - \mathbf{C}^\mathsf{T}\mathbf{D}^{-1}\mathbf{C}$, gives the resistor values between nodes: the four electrodes and two nodes at the ends of the diode. Resistor values were selected to minimize the fitting error between ideal resistor values and available values within tolerances ($\pm 0.1\%$). This procedure is available as an EIDORS tutorial [2].

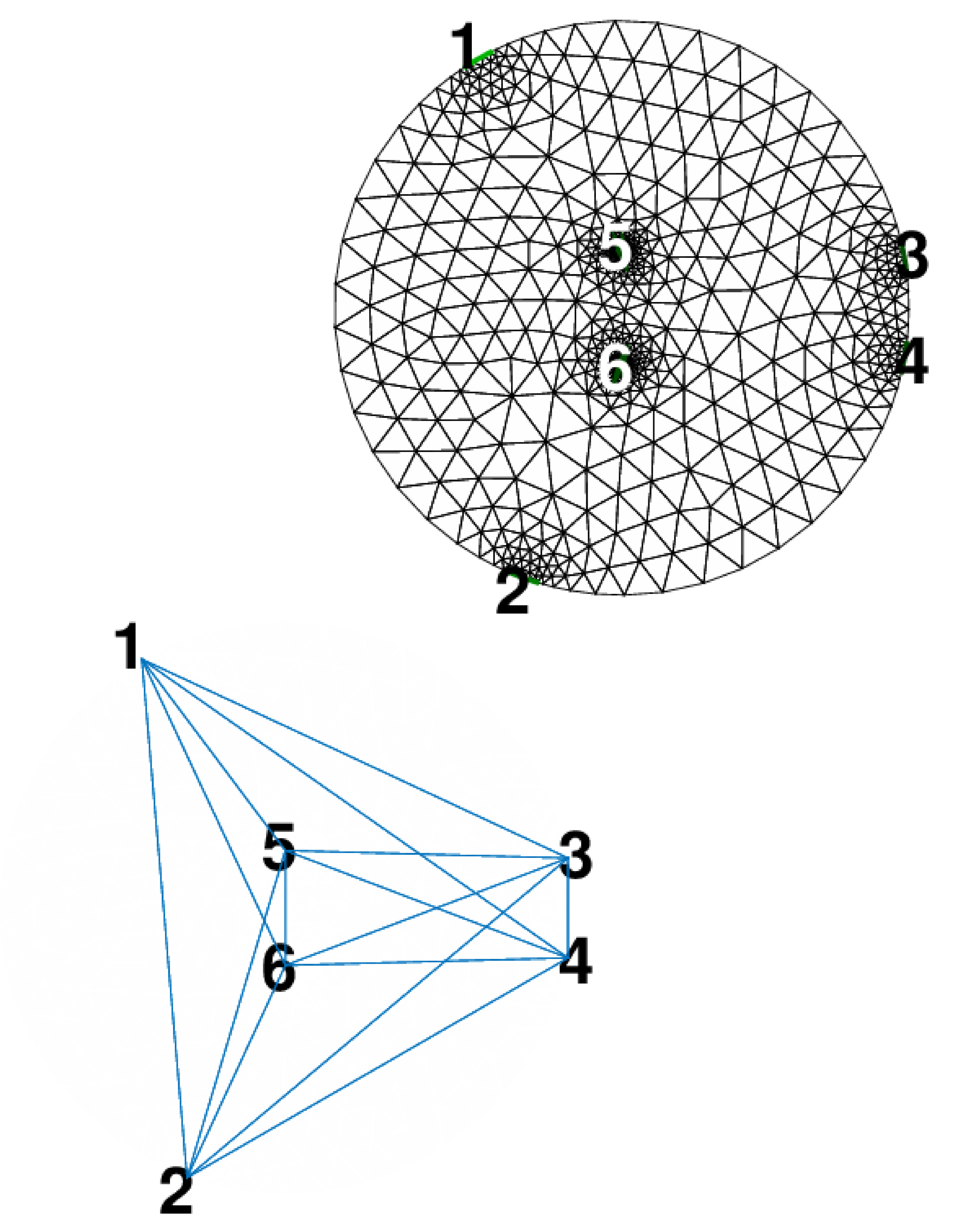

Figure 2: (above) 2D FEM simulation mesh and (below) reduced model as a 15 resistor (blue), 6 terminal (numbered) network, a diode is inserted between terminals #5 and #6 in the interior

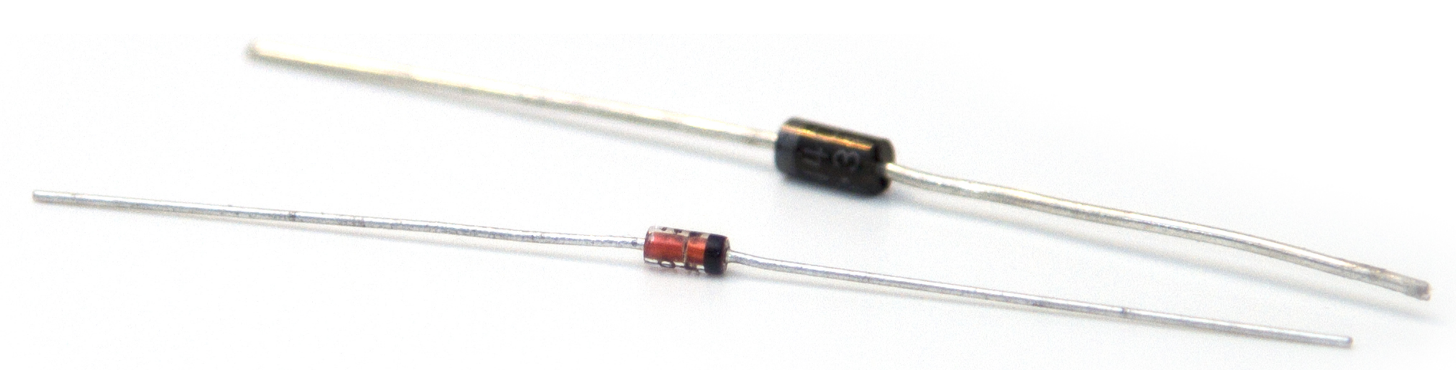

Figure 1: Diodes as connected between nodes 5 and 6 in Figure 1; examples similar to the BAT42 Schottky diode (above in black with a silver band) and 1N34A germanium diode (below in orange with a black band); licensed CC BY-NC [3]

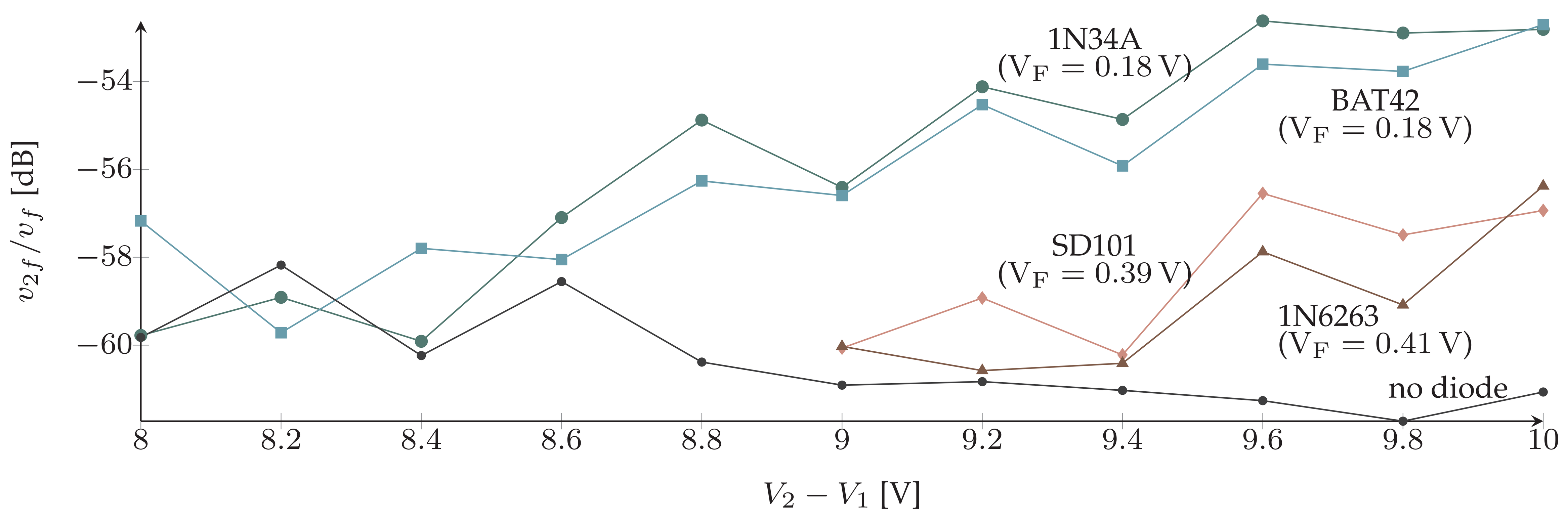

Figure 3: Ratio of magnitudes, fundamental frequency v_f and first harmonic v_{2f}, compared to maximum input voltage $V_2 - V_1$ at 9 mm spacing for a variety of passive low-dropout diodes; 1N34A germanium and BAT42 Schottky diodes exhibit stronger second harmonics

Experimental Results

A resistor mesh was constructed using resistance values from the tank simulation with a diode node spacing of 9 mm. Across nodes 1 and 2, a 1.0 kHz sine wave with varying amplitude was applied. A spectrum analyzer was placed across nodes 3 and 4 and the $1f$ and $2f$ harmonics were recorded. Different models of diodes were tested, these were selected based on their low forward voltage characteristics.

Results (Figure 3) show that although only small signals were produced by the diodes, it was still possible to detect the diode presence as long as input voltages were high enough. Signal strength increased with increasing applied EIT voltage, and decreasing diode forward voltage.

Discussion

Our study investigated whether the harmonics from internal diodes produce enough signal to distinguish them. Even for low-dropout (~0.2 V) passive diodes, the required boundary stimulation voltages was > 10 V, which limits its practical application in humans. Industrial or geophysics ECT/ERT have reduced electrical safety requirements that may allow sufficient forward voltage. Active circuits such as “super diodes” offer an alternative, but need a virtual ground and power which make their implementation challenging. Other passive components such as inductors or capacitors may prove to be effective, but were not evaluated in this work.

References

References

[1] Adler A, Lionheart WRB *EIT2016* Stockholm, Sweden, 2016

[2] Boyle A, 2017 **eidors.org/tutorial/model_reduction**

[3] Martin Bircher, CC BY-NC diode image (unmodified) **www.e-style.ch**