Improving the robustness of the iterative solver in state-space modelling of guitar distortion circuitry

Ben Holmes and Maarten van Walstijn

bholmes02@qub.ac.uk, m.vanwalstijn@qub.ac.uk

Abstract

In the simulation of nonlinear Virtual Analogue models, the iterative solver is typically the most computationally expensive algorithm. In an attempt to reduce this expense, two methods are proposed to be used in conjunction with Newton's method, which aim to improve efficiency and robustness. These methods are derived using information specific to the system, exemplified using two circuits: a diode clipper and the Dallas Rangemaster guitar pedal (Figures 1 and 2). Comparison of computational expense between the proposed and existing methods show competitive performance and some exploitable properties.

Proposed Methods

Two methods were developed for gradient based iterative solvers, and applied to Newton's method. Both methods exploit how the Nodal DK-method represents the nonlinear function to be solved in the form

$$\boldsymbol{v}_{\mathrm{n}}[n] = \boldsymbol{p}[n] + \boldsymbol{K}\boldsymbol{f}(\boldsymbol{v}_{\mathrm{n}}[n])$$

where v_n is the nonlinear voltage, p is the contributions from the linear portion of the model, $f(v_n)$ is a function that represents the nonlinear behaviour of components, and K is a state space coefficient matrix. This equation can be decomposed to a function which emphasises it's construction from linear and nonlinear terms:

$$\boldsymbol{g}(\boldsymbol{v}_{\mathrm{n}}[n]) = \underbrace{\boldsymbol{p}[n]}_{constant} + \underbrace{\boldsymbol{K}\boldsymbol{f}(\boldsymbol{v}_{\mathrm{n}}[n])}_{nonlinear(g_{\mathrm{n}})} - \underbrace{\boldsymbol{v}_{\mathrm{n}}[n]}_{linear(g_{\mathrm{l}})}$$

This decomposition is illustrated in Figure 3. Both methods utilise the separation between the linear and nonlinear terms. The first method applies a cap to the step size to reduce overshoot. The cap is derived by comparing the gradient of the linear and nonlinear parts of the function so that

$$\partial \boldsymbol{g}_{\mathrm{n}} / \partial \boldsymbol{v}_{\mathrm{n}} = \partial \boldsymbol{g}_{\mathrm{l}} / \partial \boldsymbol{v}_{\mathrm{n}}$$

The magnitude of the voltage at which these values are equal is applied as the cap. These values are marked on Figures 3 and 4 as V^{tr} (transitional voltage).

The second method finds a new initial iterate for the solver. This is found using the inverse of the nonlinear term, removing the implicit nature by ignoring the linear term. This yields

$$\boldsymbol{v}_{\mathrm{n}}^{\mathrm{NI}} = \boldsymbol{f}^{-1}\left(-\frac{\boldsymbol{p}}{\boldsymbol{K}}\right)$$

where v_n^{NI} is the new initial iterate.

Diode Clipper

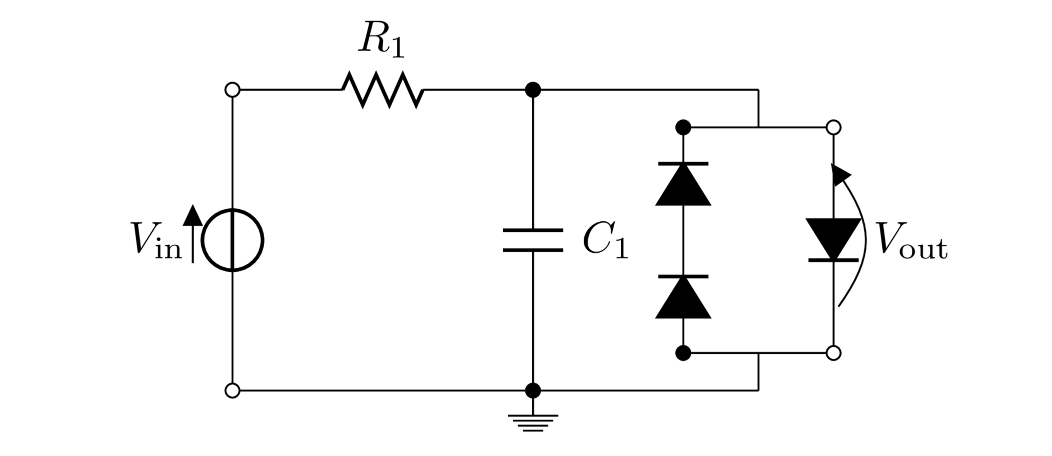

Figure 1: Diode clipper schematic

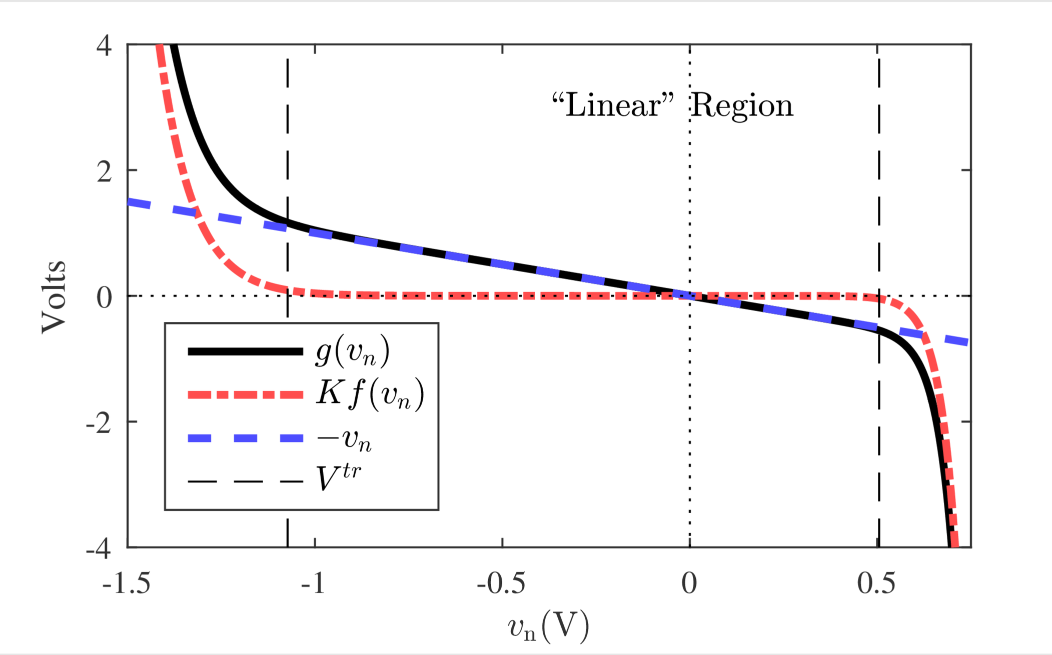

Figure 3: Decomposed diode nonlinearity showing the nonlinear function, it's decomposition into -v_n and Kf(v_n), and the points where the gradients of the components are equal, V^{tr}.

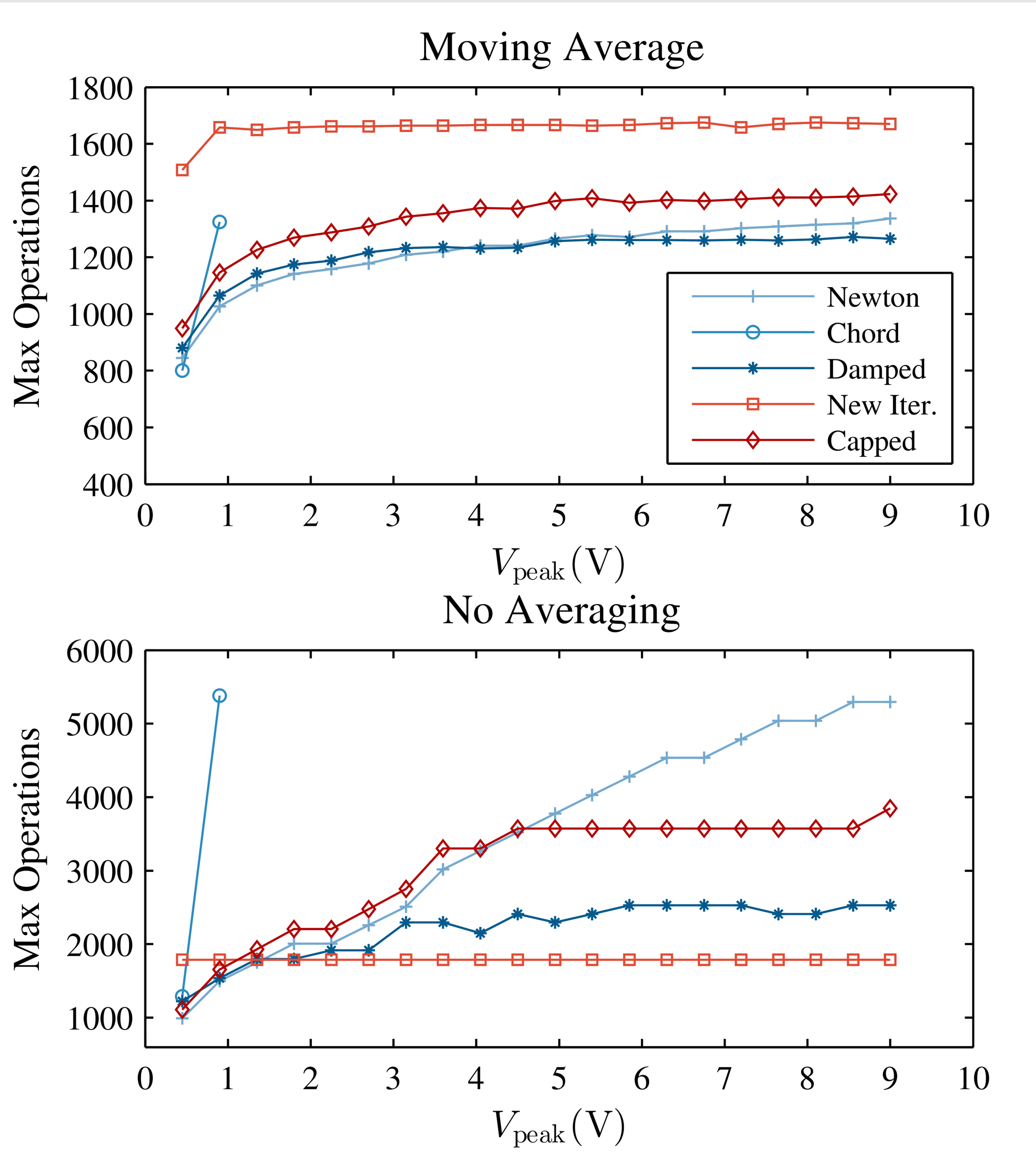

Figure 5: Computational operations of each iterative method solving the diode clipper

Performance

The proposed methods were compared against the following iterative solvers: Newton's method; Damped Newton's method; Chord method; Secant method. Each method was compared using the number of operations it required to find the root of the function. Figures 5 and 6 show the number of operations relative to peak input voltage. A moving average filter was applied to simulate an audio buffer.

Dallas Rangemaster

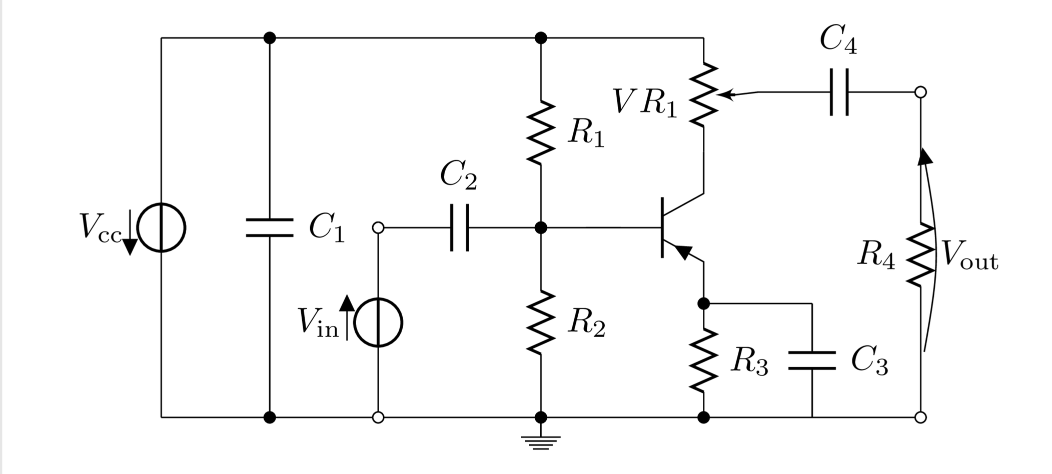

Figure 2: Dallas Rangemaster schematic

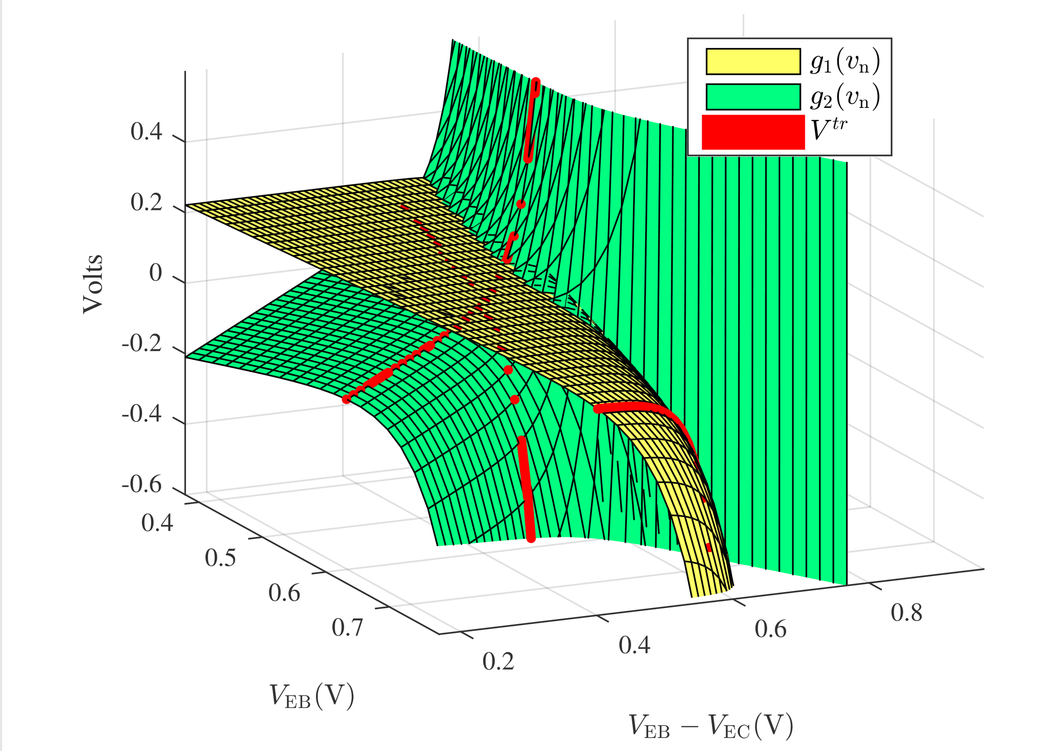

Figure 4: Decomposed BJT nonlinearity, showing the nonlinear function and the points where the gradients of the components are equal, V^{tr}.

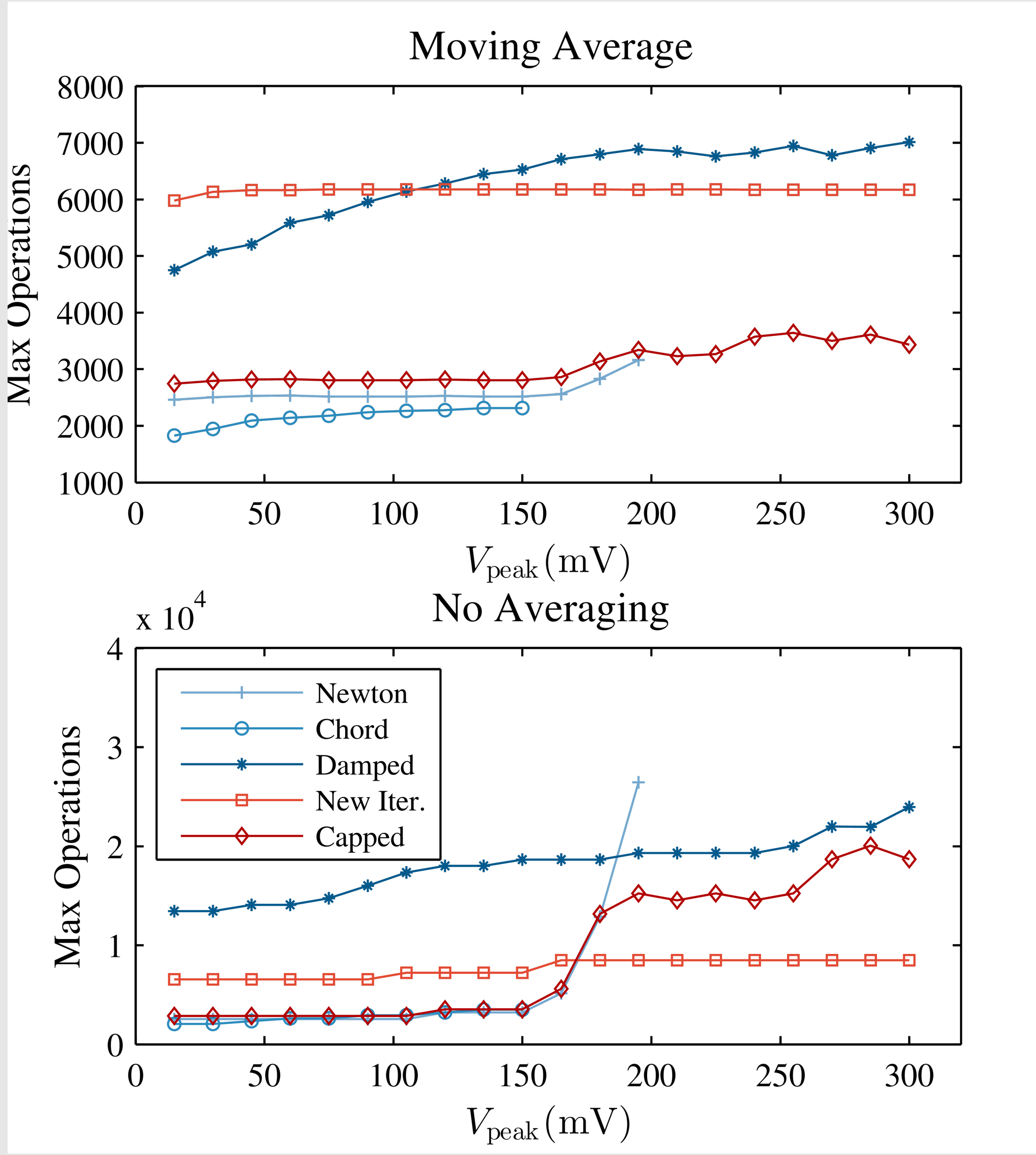

Figure 6: Computational operations of each iterative method solving the Dallas Rangemaster

Conclusion

Both methods showed similar levels of efficiency and improved robustness over the most robust method currently used, Damped Newton's method. Additionally, the uniform behaviour of the new initial iterate allows accurate prediction of the required computation, which may be further exploitable.

Sonic Arts Research Centre, School of Electronics, Electrical Engineering and Computer Science, Queen's University Belfast