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Data-Driven Compact Modeling of Bipolar Junction Transistors with Recurrent Neural Networks

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Introduction

Objective: Evaluate critically the capability of discrete-time RNN (DTRNN) to substitute for physics-based compact models in circuit simulation.

Approach taken: Start with a specific case study; compare the performance of a DTRNN model of an NPN Bipolar Junction Transistor (BJT) against that of the SPICE Gummel Poon (SGP) model.

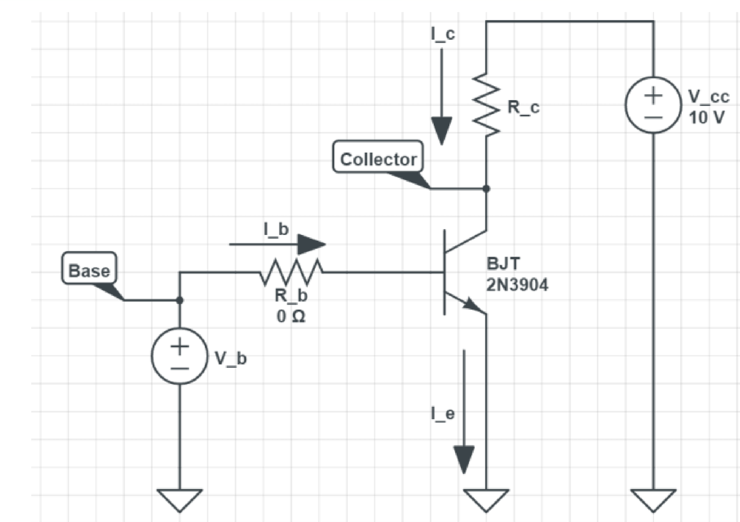
Motivation: Analysis and design of large-scale or complex circuits routinely involves compact semiconductor device models to reduce unnecessary computational burden in simulations and design optimization. Numerical, data-driven approaches demonstrate exciting potential to automate and accelerate compact model development and calibration.

Approach

Experiment Details

This figure shows the setup used to generate training data. It includes two input voltages $\mathbf{V_b}$ and $\mathbf{V_{cc}}$, a load resistor $\mathbf{R_c}$, and the device-under-test (NPN model 2N3904).

$\mathbf{V_b}$ and $\mathbf{V_c}$ denote the base and collector voltages, respectively. $\mathbf{V_{cc}}$ is a constant 10 V and $\mathbf{R_b}$ is fixed at 0 Ohms. $\mathbf{V_b}$ and $\mathbf{R_c}$ are varied.



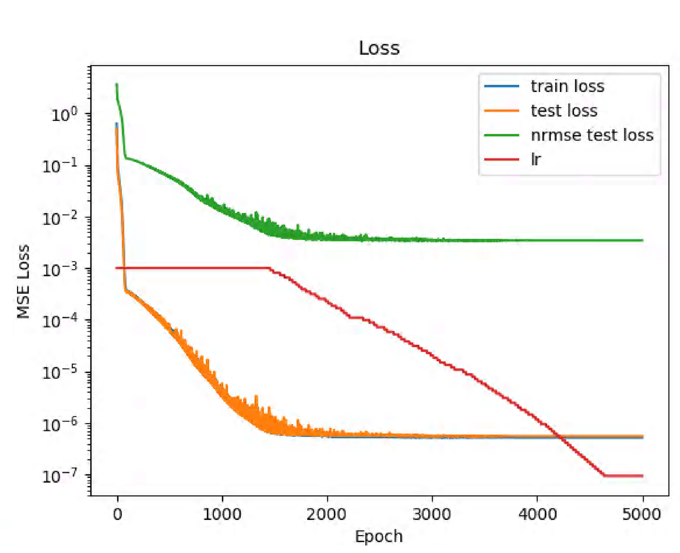
RNN Model

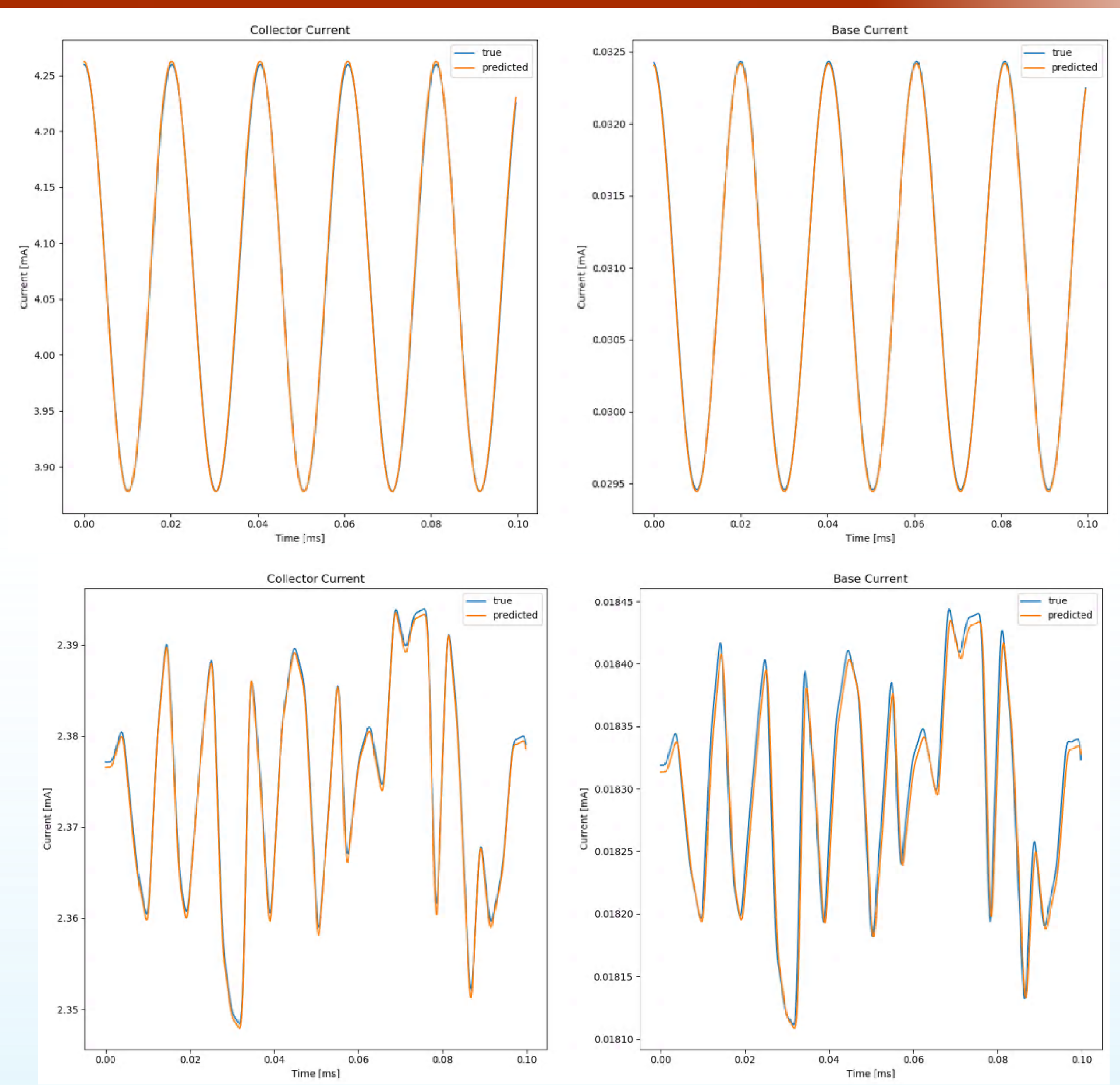
The inputs to the RNN will be $\mathbf{V_b}$ and $\mathbf{V_c}$ and the outputs will be $\mathbf{I_b}$ and $\mathbf{I_c}$. We use a basic discrete-time RNN. A **tanh** activation function is used, and the model output is taken from a linear layer.

$$h_t = \tanh(W_{ih}x_t + b_{ih} + W_{hh}h_{t-1} + b_{hh})$$
$$y = h_t A^T + b$$

W and **A** are weight matrices and **b** is a vector containing the bias terms. **x** are the model inputs. **h** are the hidden states. The dimension of **h** is a hyperparameter. The subscript indicates the time index.

Results



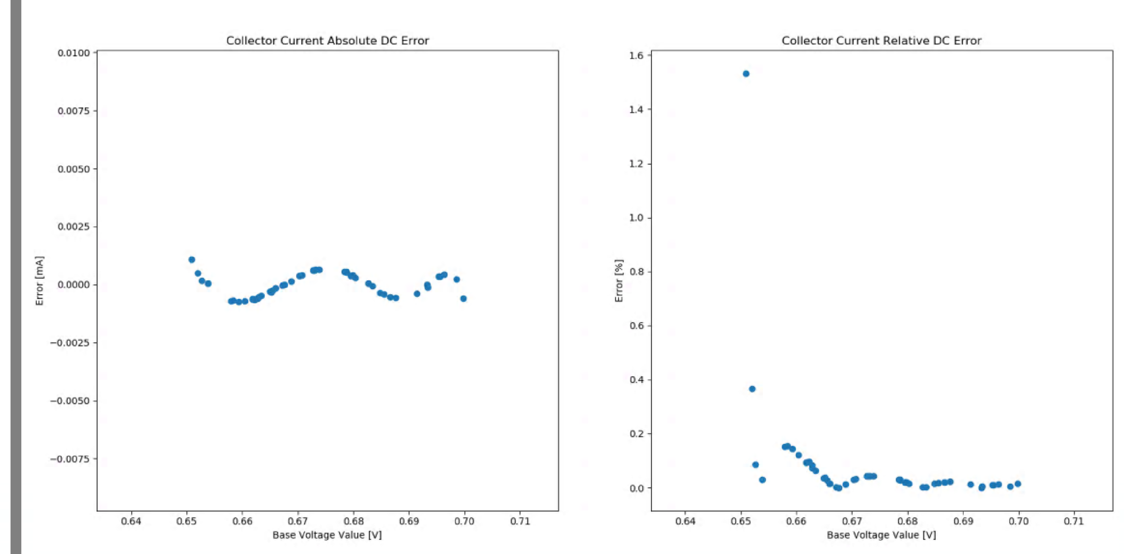


Top Left: Loss function for model trained and tested on sinusoidal samples.

Top Right: True (blue) and predicted (orange) currents for a sinusoidal waveform.

Bottom Right: True (blue) and predicted (orange) currents for a piecewise linear waveform.

Analysis



- The DTRNN model achieves a small loss when the load resistor is constant.
- The figure shows absolute and relative DC errors vs. $\mathbf{V_b}$ for a model trained and tested on sinusoidal data.
- The average relative error is 0.1%. However, the absolute DC error, while very small, has a distinct pattern that requires further investigation.

Conclusion

It is challenging to optimize a DTRNN to represent both the large signal transient response of the device and its small signal AC response with comparable accuracy.

The results suggest that a DTRNN may be a useful temporary model that is used to represent an emerging device with reasonable accuracy until the physics-based model can be developed.

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