



analogNeuron: Stimulus-Dependent Spike Threshold Neuron Circuit

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Abstract

In a variation of the spiking leaky-integrator model, proposed by Jones, Johnson, and Ratnam [1], the spiking threshold is not a constant value, but a dynamic time-varying variable. Specifically, upon spiking an action potential, the threshold would jump up by a fixed amount to a higher level, before decaying to a baseline threshold level. Upon optimizing two additional parameters, this dynamical threshold model produces spike trains that match experimental spike trains of *in vivo* sensory neurons and *in vitro* cortical neurons much better than a simple leaky-integrator model.

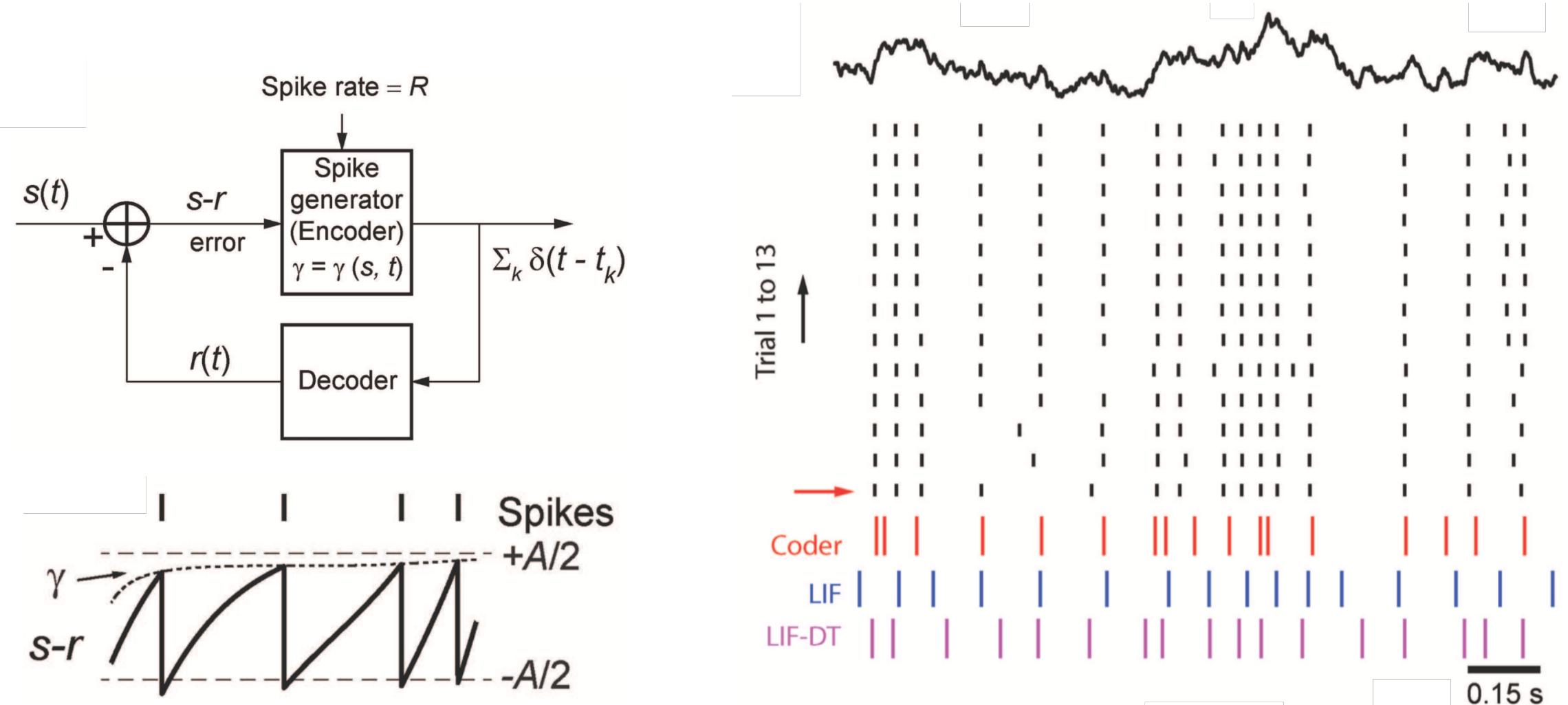
One interpretation for this dynamic threshold assumes that neurons try to encode the stimuli they receive via their spike trains; the dynamic threshold is a neuron's internal copy of the effects of its spikes on post-synaptic neurons, i.e. internal decoder of its spike train.

We design a circuit to simulate this spiking leaky-integrator-with-dynamic-threshold model, implement it through breadboarding, mill it onto a PCB board, and show that it behaves as expected.

Motivation for a Time-Varying Threshold

(according to Jones, Erik and Ratnam [1])

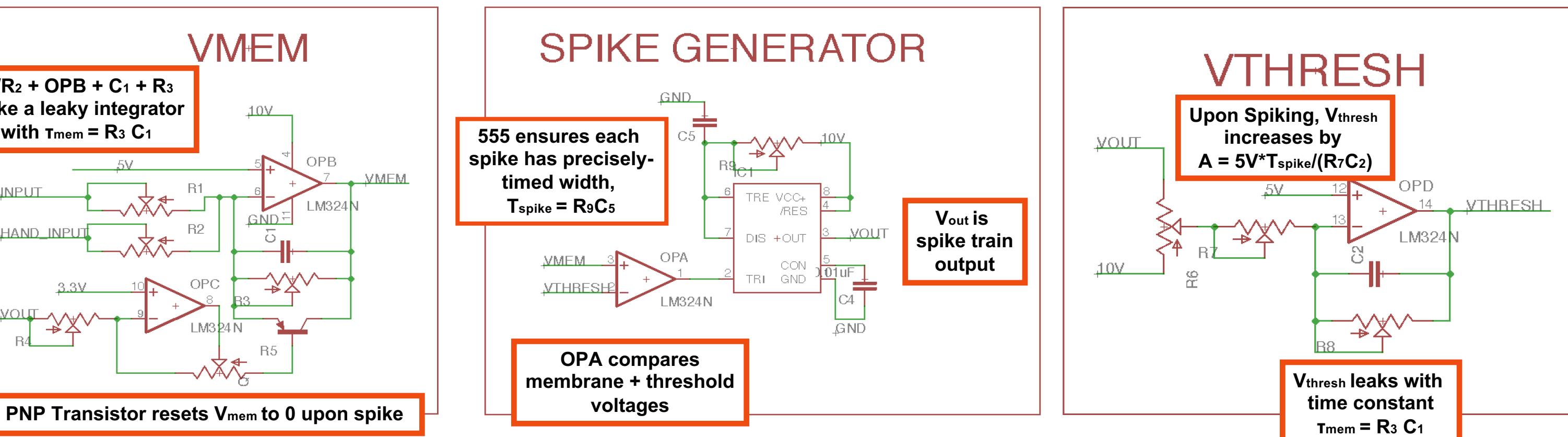
- Low Spike Rate desired; each spike costs energy (ATP)
- High Spike Rate desired; more spikes => better signal representation
- Dynamic signal-dependent neural threshold optimizes trade-off
 - Mimics a post-synaptic membrane (a low-pass filter) as internal decoder.
 - Sets the average firing rate (the energy constraint).
 - Provides an internal copy of the coding error to the spike-generator, which emits a spike when the error equals or exceeds a spike threshold
 - Matches empirically recorded spike trains better than Leaky Integrate and Fire model



Spiking Algorithm

- (1) Leaky Integrator: $\tau_m \frac{dV_m}{dt} = -V_m + RI(t)$
- (2) Spikes: when $V_m > V_{\text{thresh}}$, set V_m to 0; emit spike
- (3) Vary Threshold: when spike occurs, set V_{thresh} to $V_{\text{thresh}} + A$; decay exponentially with time constant τ

Circuit Schematic

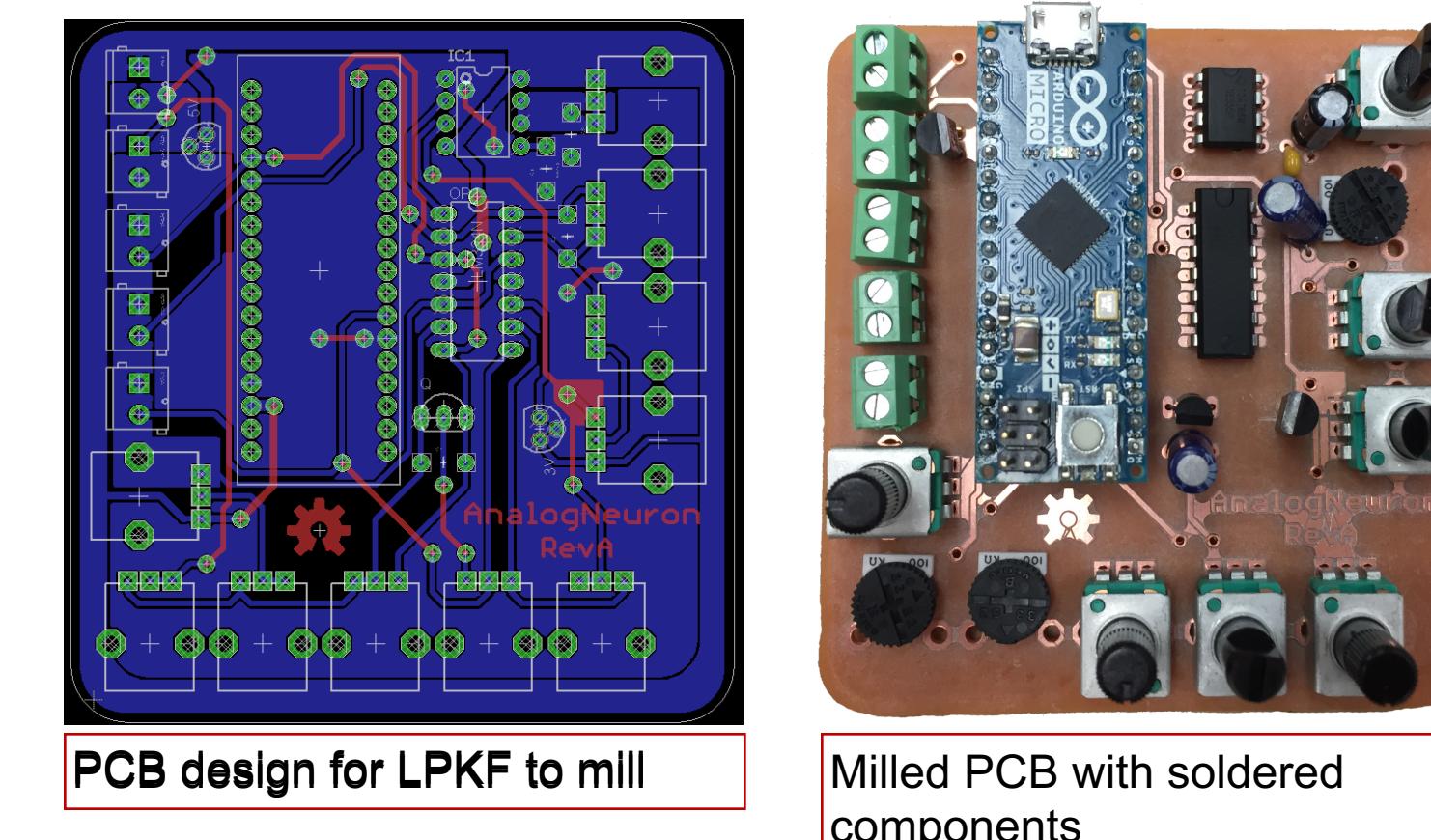


For our circuit, $\tau_m \approx 0.130$ sec; $A \approx 0.81$ V; $\tau \approx 1.65$ sec

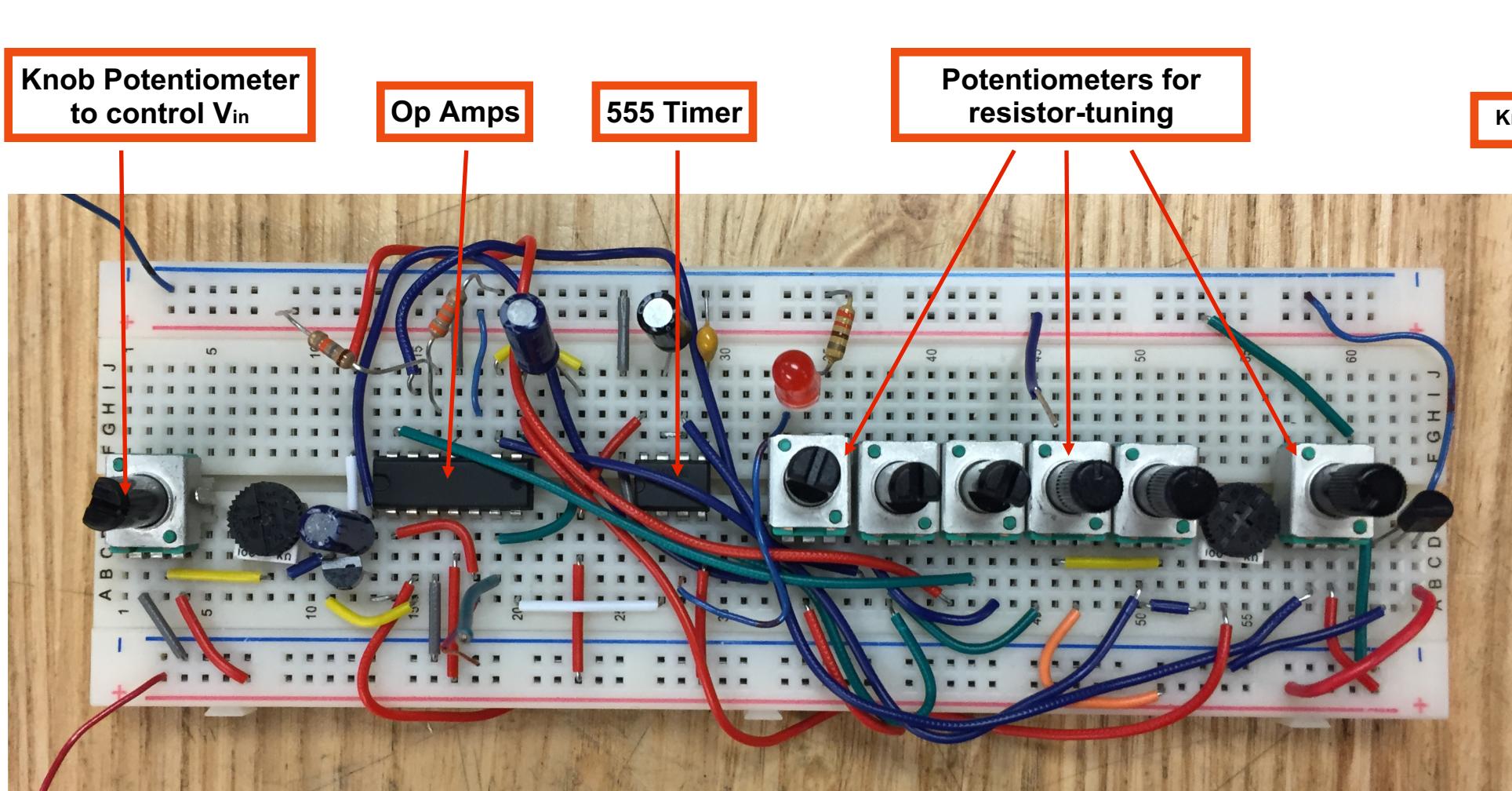
Advantages of Analog Computation

- Simulating differential equations is depressingly slow on software
- Physical realization of model

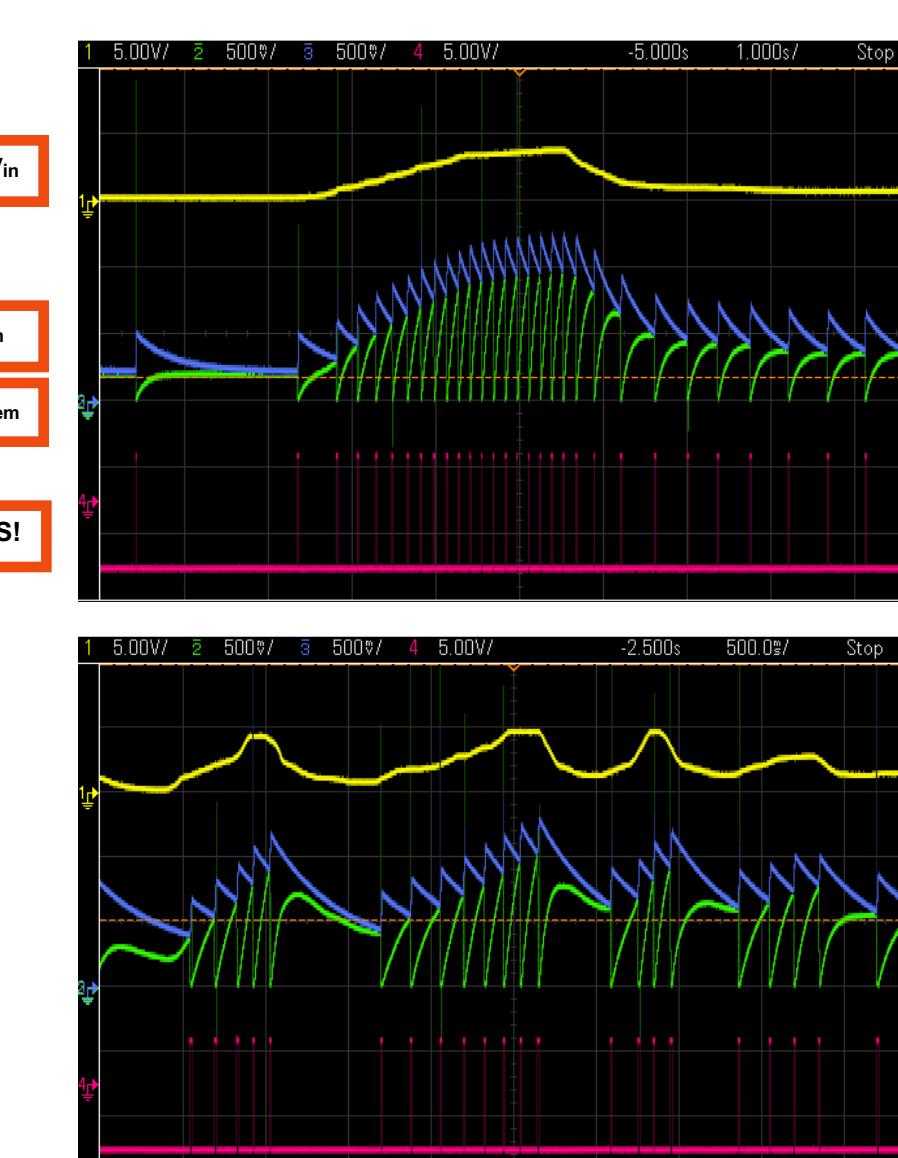
PCB Fabrication Process



Bread-Barded Circuit ...



and behavior



Future Steps

- Feed in INCF spike-prediction data[2] as input—compare output spikes with actual empirical ones
- Optimize parameters for most accurate spikes
- Debug PCB — and make it open source for the world to use and see!