EE 124

Lab 3: Artificial Neuron

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Introduction

In this lab, the Quadratic Integrate and Fire Neuron (QIF) model was used to simulate the behavior of a single neuron. Operational amplifiers, capacitors, resistors, and a multiplier, and an n-type transistor were used to implement the QIF circuit. The purpose of this lab was to study how the input B (shown in the equation below) affects the output behavior of the circuit, such as producing bursts and spikes, by charging and discharging the capacitors.

The following equation is used to describe the QIF circuit:

$$RC * \frac{dV}{dt} = V^2 + B \qquad (1)$$

Where V is the input voltage of the Integrator, B is the input signal (pulse, ramp, DC) acting as a bias that controls the output, and RC is the time constant of an integrator. The capacitors are charged and discharged via a Schmitt Trigger. Solving for dV and integrating:

$$dV = \frac{V^2 + B}{RC} * dt$$

$$\int dV = V(t) = \left(\frac{1}{RC}\right) * \int (V^2 + B) * dt \qquad (2)$$

With this equation, a direct translation to circuitry is more feasible. For example, to achieve V^2, a multiplier can be used while a simple low pass filter, or integrator, amplifier can be used to integrate $V^2 + B$. To compensate for the attenuation due to the multiplier, an amplifier can be used at the multiplier output. This amplifier can also be used as a summer to add the bias to the signal.

Since this circuit will be cyclic, i.e. the output feeds back to the input, there is a chance for the system to be unstable. Therefore, a switch with hysteresis, such as a Schmitt trigger, can be used to reset the signal every so often. The actual reset can be accomplished with the trigger by connecting it to the capacitor in the integrator, so the capacitor can discharge once the trigger switches.

Procedure:

For a point of comparison, the QIF model was first simulated on LTSpice using behavioral voltage sources. These circuits and their simulation results are shown in the LTSpice Behavioural Models section.

As mentioned previously, to implement the QIF circuit, there are serval stages involved: 1) a multiplier plus a summing amplifier, 2) an integrator, and 3) a Schmitt trigger. Figure 1 below shows this circuit in LTSpice as well as the simulation result.

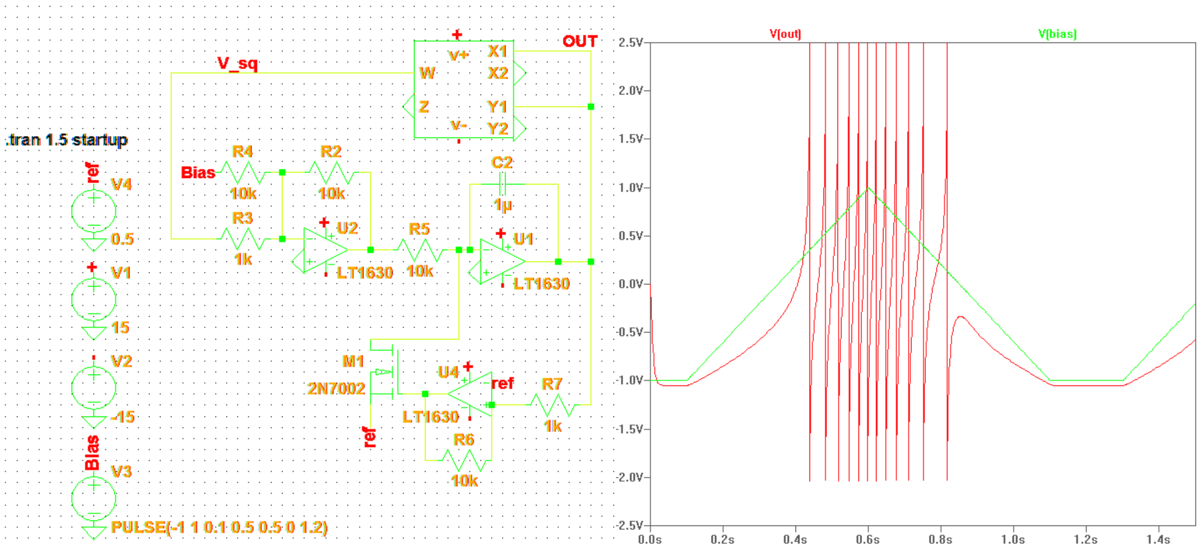


Figure 1: QIF circuit (left) and simulation (right)

As seen in Figure 1, the bias used to test this circuit was a low frequency triangle wave, and the response from the system was to generate several spikes similar to the behavior of a neuron.

In addition to the schematic from Figure 1, a similar implementation of the QIF model can be done with a Deboo integrator. Figure 2 below shows the QIF implementation using a Deboo integrator as well as the simulation result.

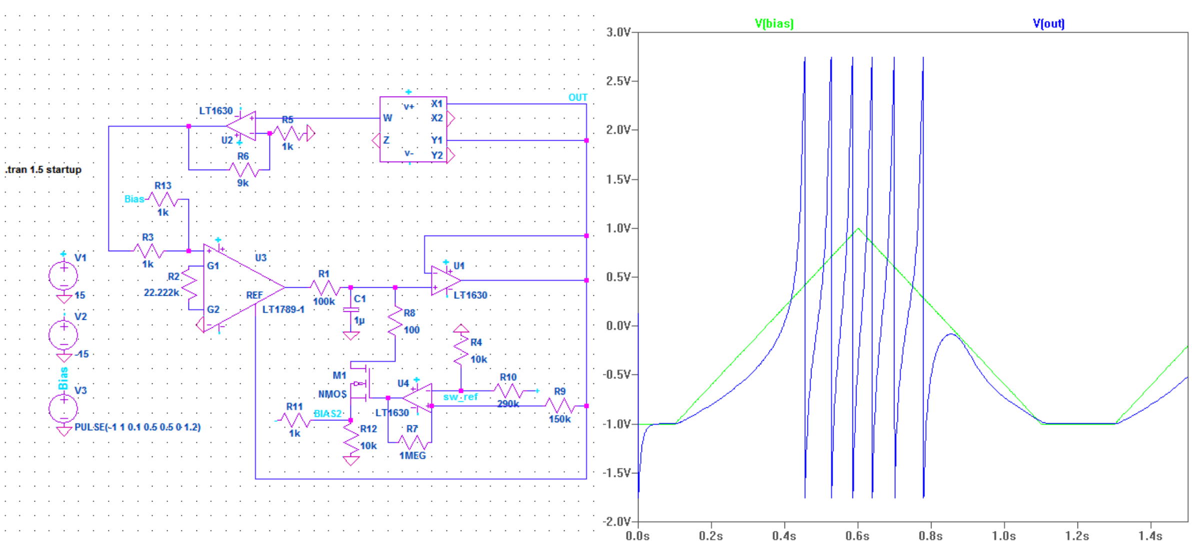


Figure 2: QIF model and simulation with a Deboo integrator

Although proven that a Deboo integrator can be used, the circuit from Figure 1 was built due to a lack of required parts. Figure 3 shows the physical prototype and settings used to create the QIF model. For this prototype, as in the simulation, LT1630 amplifiers were used along with the AD633 from analog devices. Instead of the 2N7002, however, the 2N7000 was used, and bypass capacitors were added to the supply pins of the multiplier to cut down ambient noise due to a jumper wire.

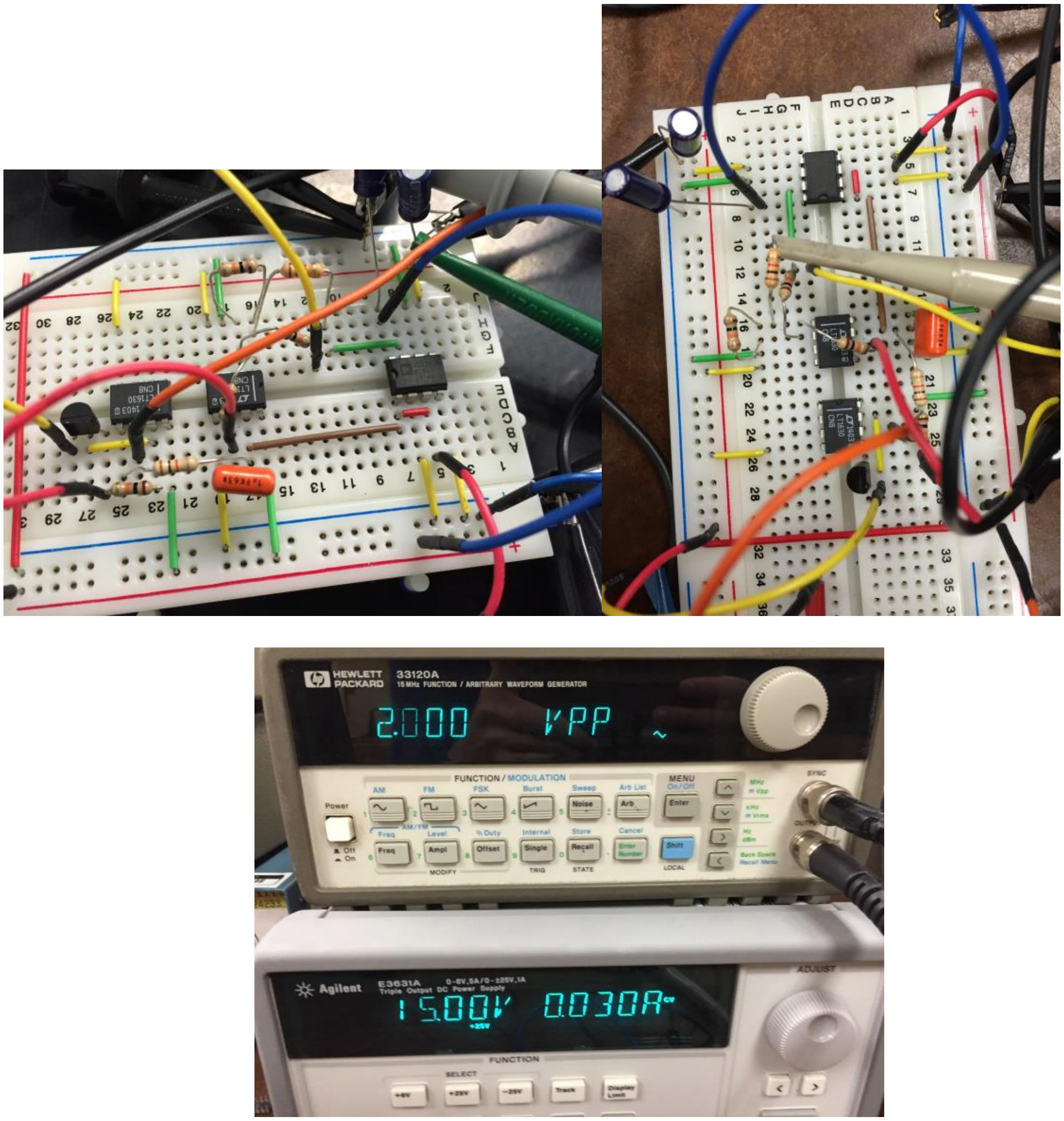


Figure 3: QIF model (top) and settings (bottom)

As in the simulation, a 0.5 Hz triangle wave was fed to the circuit; however, unlike the simulation, the source of the FET was instead connected to a 0.1V source.

Results:

Figure 4 below shows the output of the circuit and the bias signal on an oscilloscope. It can be seen that the result was very similar to the simulation. Unfortunately, the signal would swing down to -15 V.

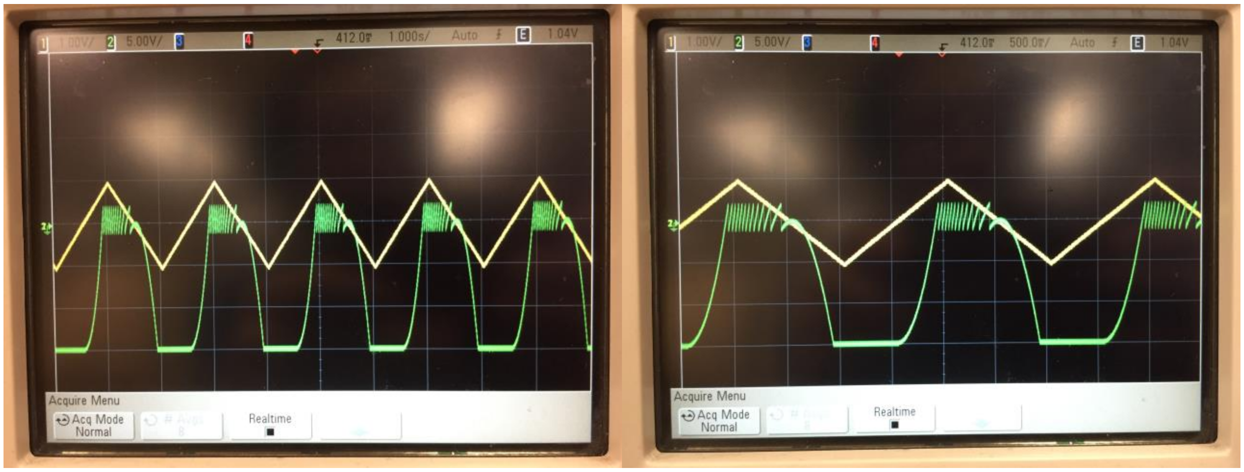


Figure 4: QIF model output signal. On the right, a zoomed in version, so the spikes are clearer.

If an offset in the triangle wave was introduced such that the wave never falls below 0 V, the circuit responds differently as shown in Figure 5. Here, it can be seen that the output continuously spikes. However, if a triangle wave was generated such that there are periods of 0 V between each triangle, a much more similar behavior to the simulation might be observed.

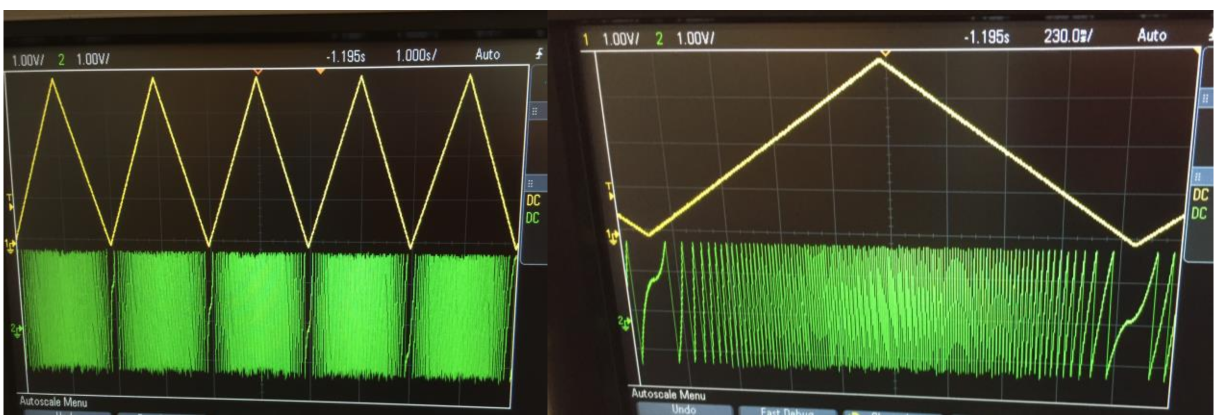


Figure 5: Model response to the same triangle wave with an offset. On the right, a zoomed in version to observe response at a single period.

LTSpice Behavioural Models:

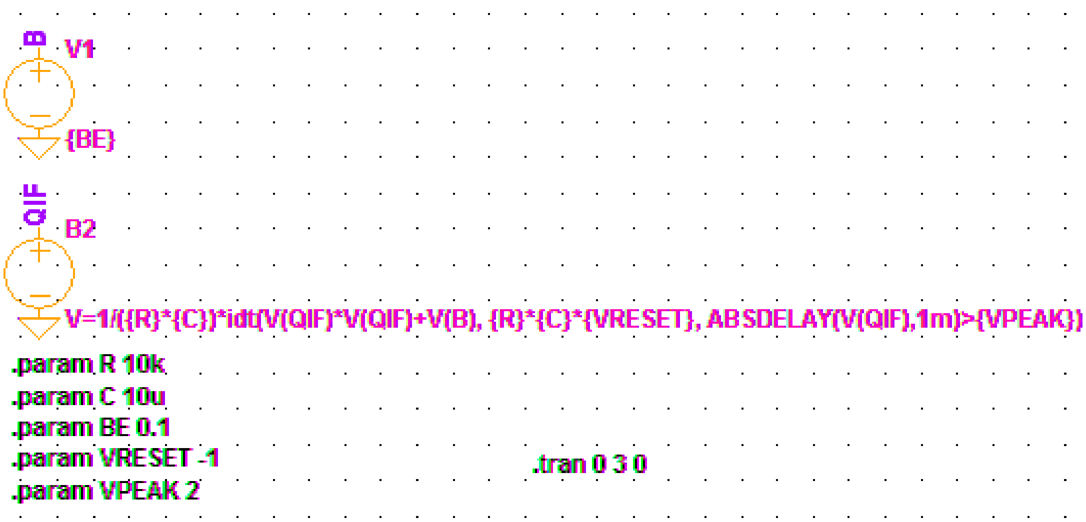
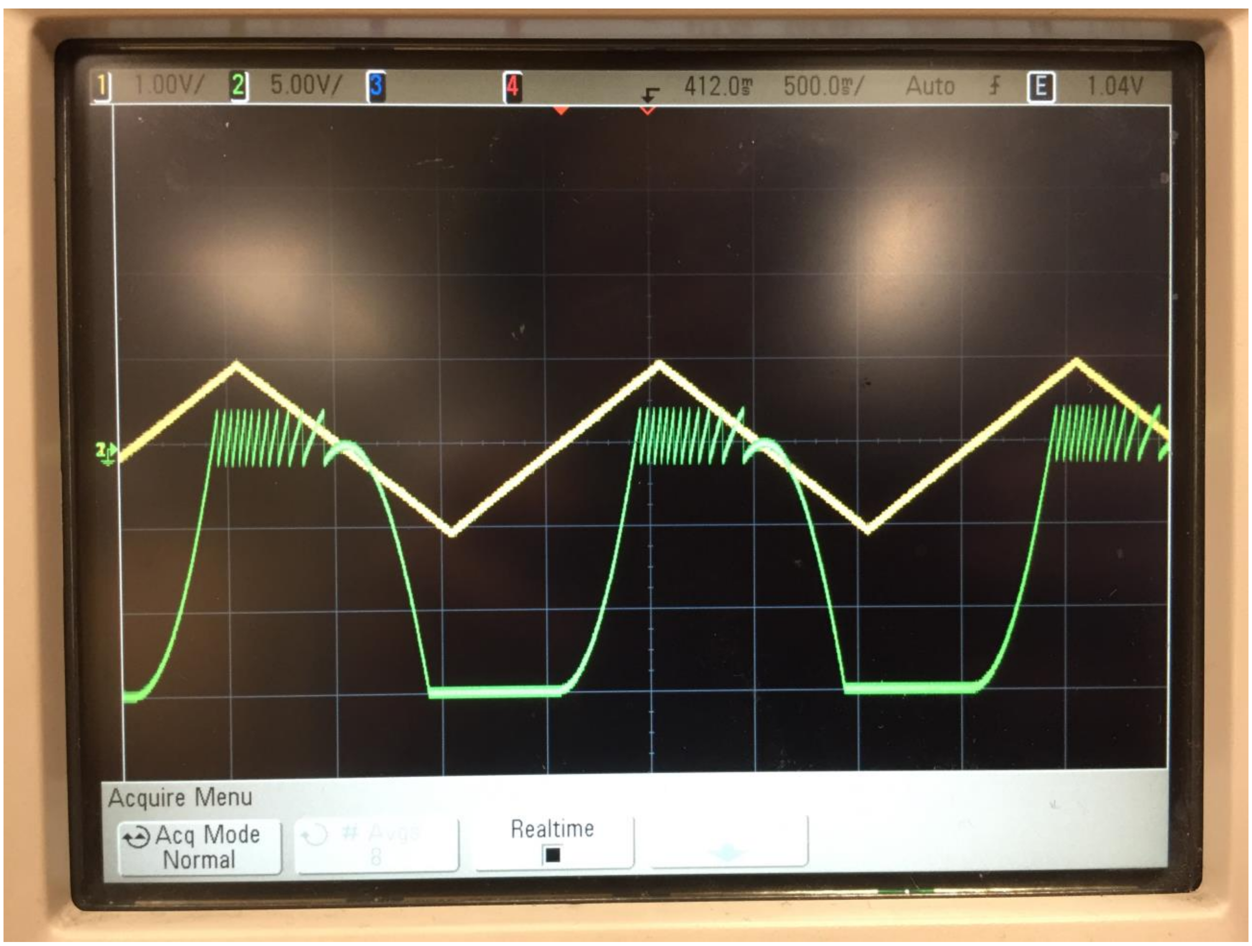


Figure 6.. LTSpice Behavioral Model of a QIF neuron with 1/RC=10, Vpeak=2V, Vreset=1V, and B=.1



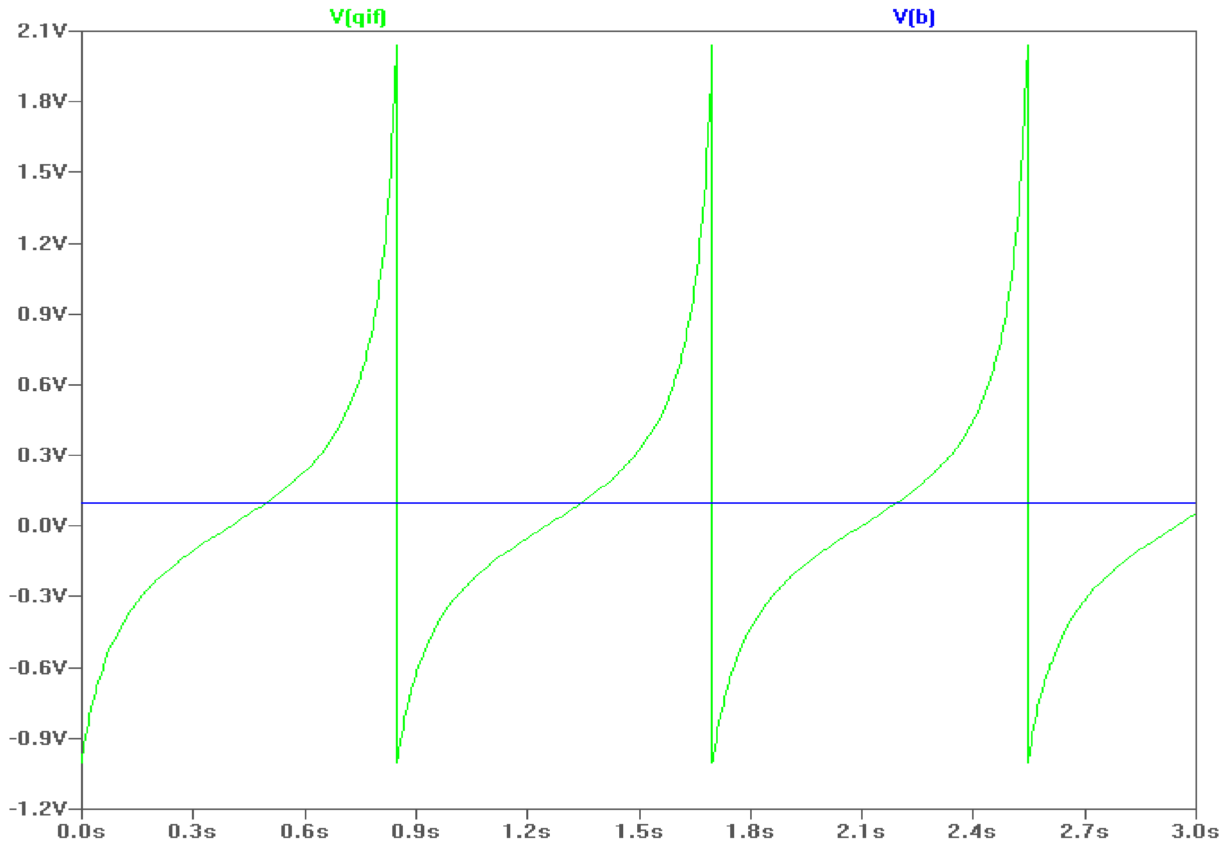


Figure 7. Transient response a QIF neuron with 1/RC=10, Vpeak=2V, Vreset=-1V, and B=.1

Figure 8. LTSpice Behavioral Model of a QIF neuron with 1/RC=10, Vpeak=2V, Vreset=-1V, and B a pulse that goes to -1V from .1V at 800ms.

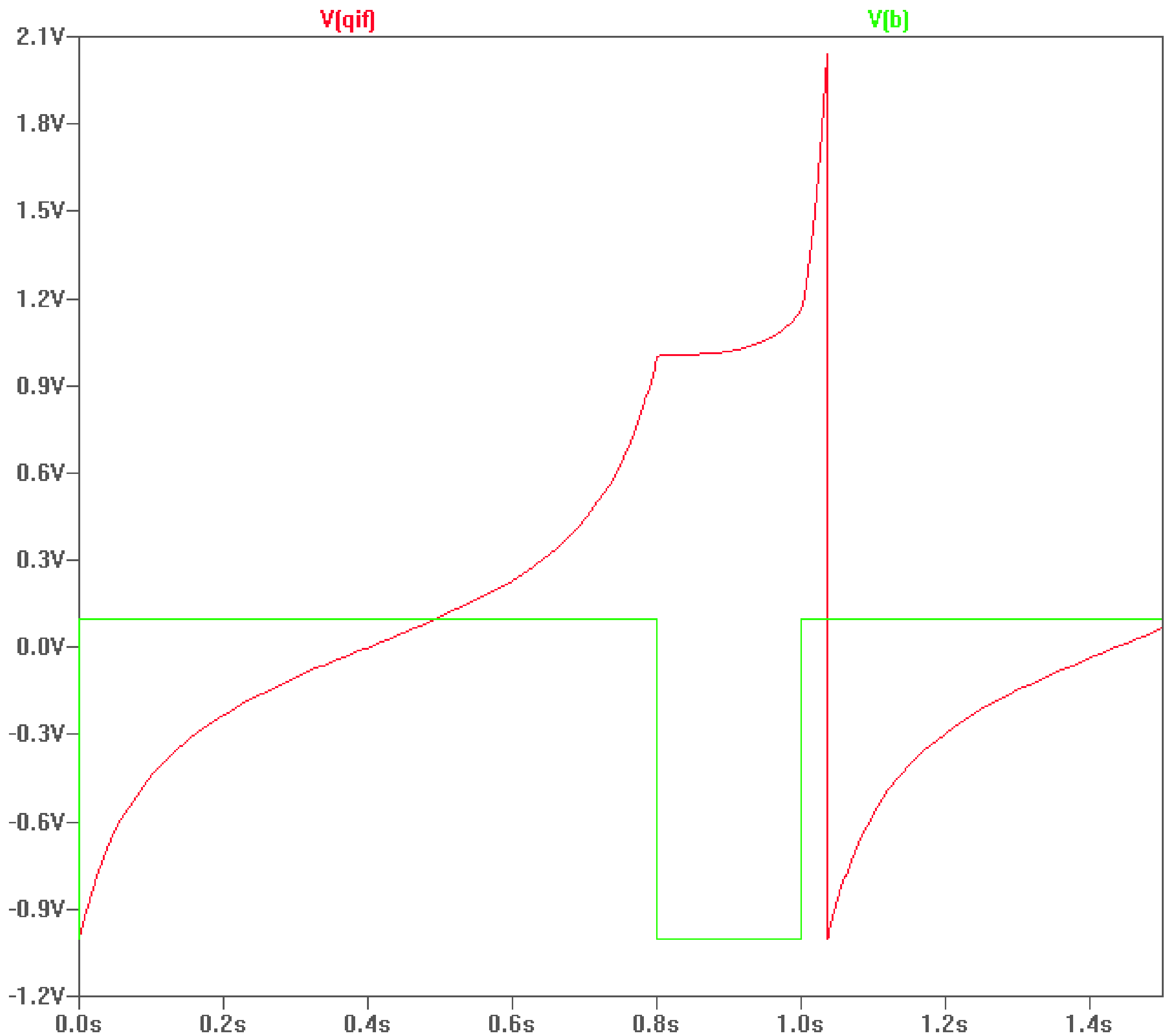


Figure 9: response of a QIF neuron with 1/RC=10, Vpeak=2V, Vreset=-1V, and B a pulse that goes to -1V from .1V at 800ms.

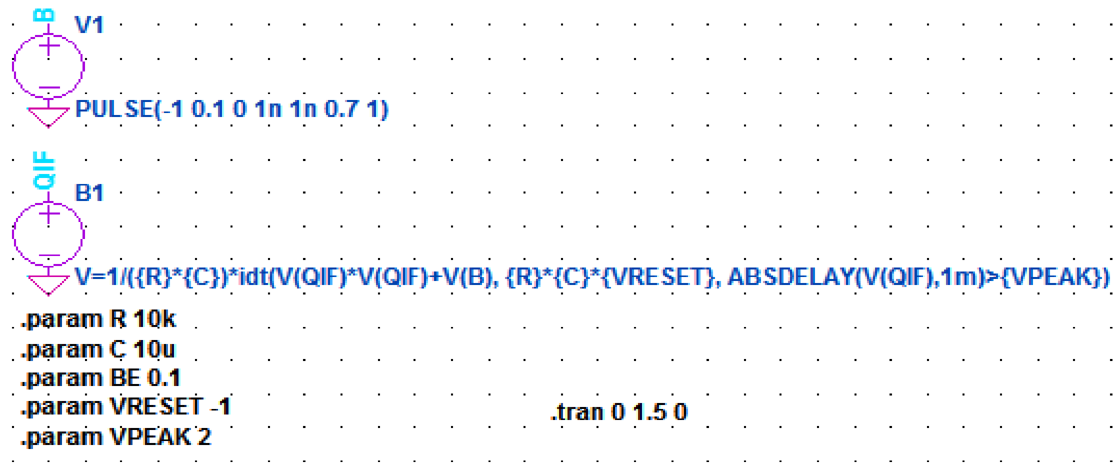


Figure 10: LTSpice Behavioral Model of a QIF neuron with 1/RC=10, Vpeak=2V, Vreset=-1V, and B a pulse that goes to -1V from .1V at 700ms.

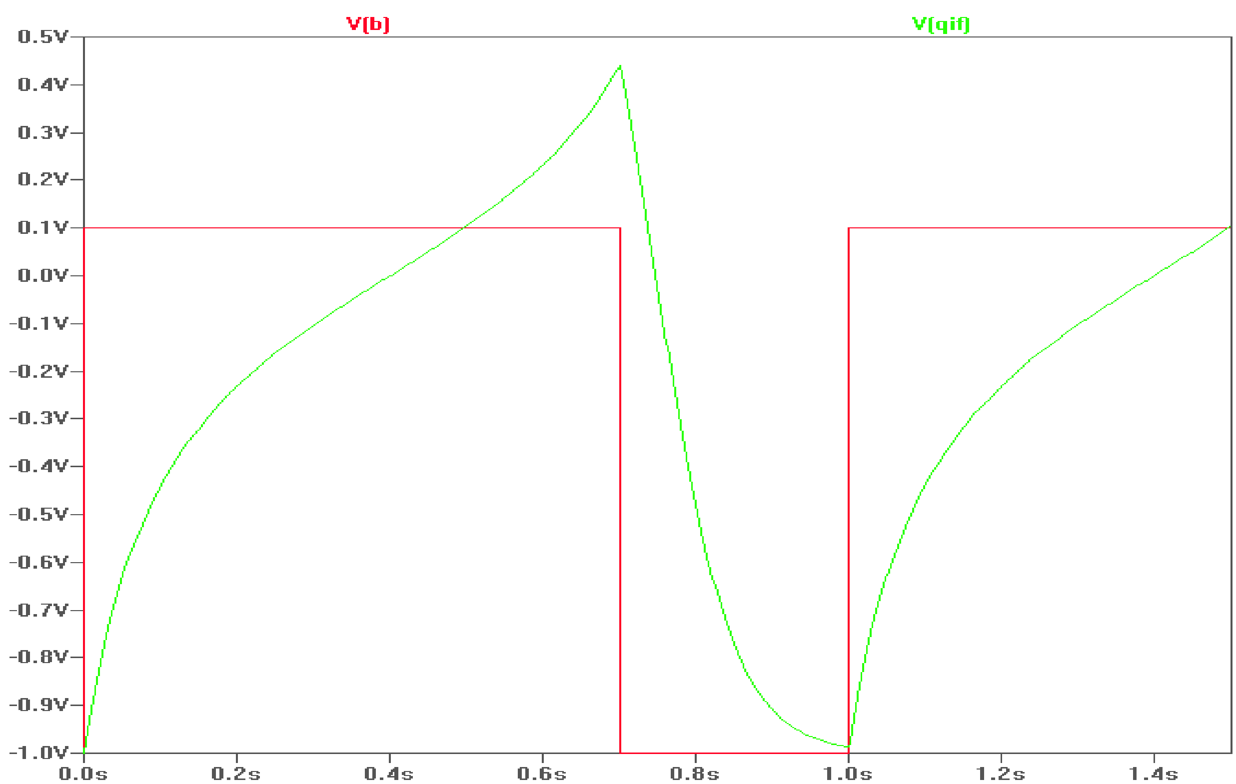


Figure 11: Transient response of a QIF neuron with 1/RC=10, Vpeak=2V, Vreset=-1V, and B a pulse that goes to -1V from .1V at 700ms.

Figure 12: LTSpice Behavioral Model of a QIF neuron with 1/RC=100, Vpeak=2V, Vreset=-1V, and B a slow ramp that goes from -1V to 1V and back every 2s.

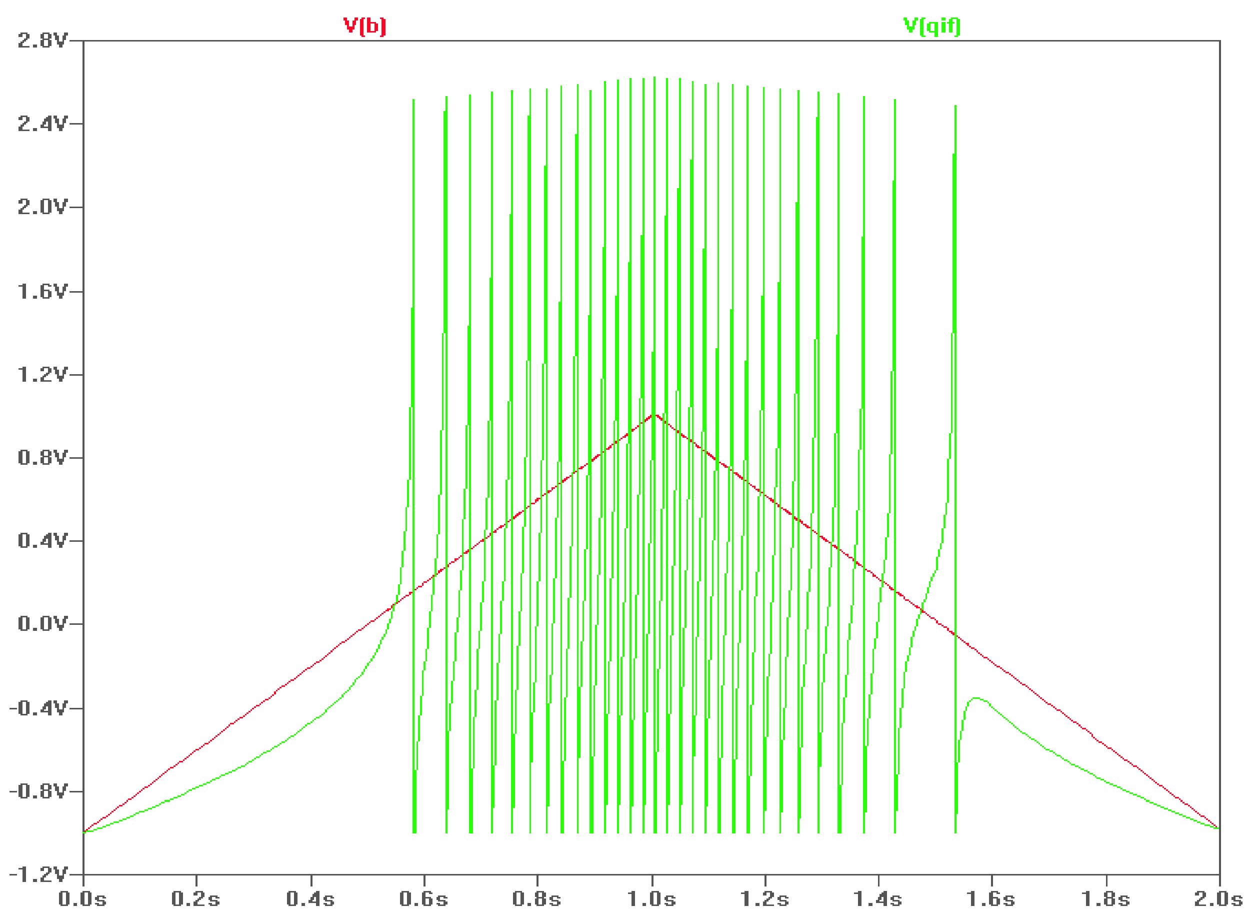


Figure 13: resonse of a QIF neuron with 1/RC=100, Vpeak=2V, Vreset=-1V, and B a slow ramp that goes from -1V to 1V and back every 2s.

Figure 14: LTSpice Behavioral Model of a of a QIF neuron with 1/RC=10, Vpeak=2V, Vreset=.5V, and B a slow ramp that goes from -1V to 1V and back every 2s.

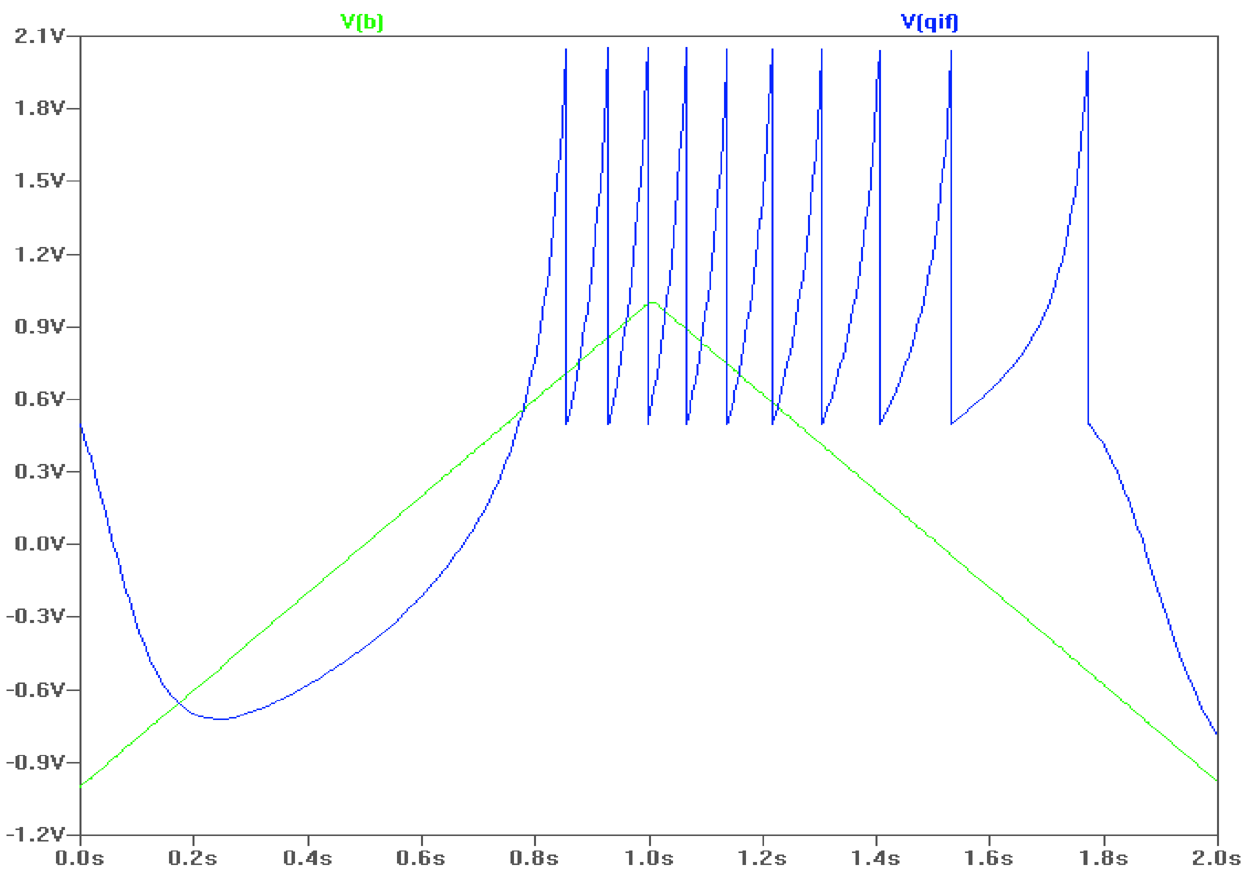


Figure 15: Transient response of a QIF neuron with 1/RC=10, Vpeak=2V, Vreset=.5V, and B a slow ramp that goes from -1V to 1V and back every 2s