Low-Noise Current Controller for Experiments with Ultracold Sodium Gases

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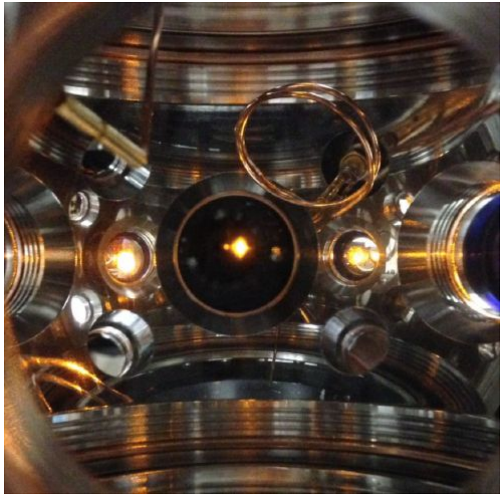
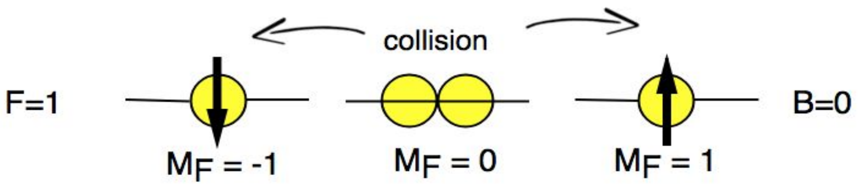
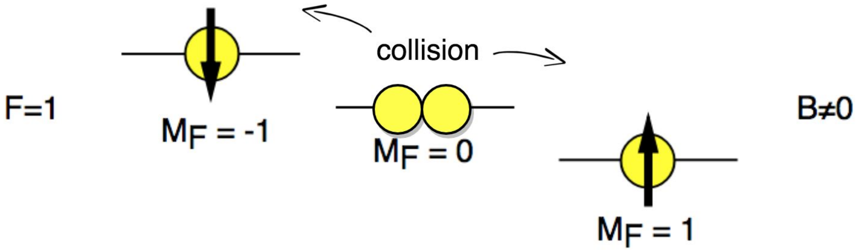
Controlling Collisions in Bose-Einstein Condensate

- Study ultracold gases of sodium
- All atoms are in ground state
- Spin-exchange collisions depend sensitively on magnetic field
- Magnetic field shifts energy level (Zeeman effect)
- Rate of collisions changes
- **Goal: Control magnetic fields to control collisions**

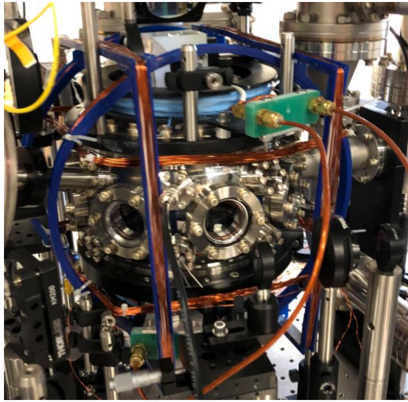


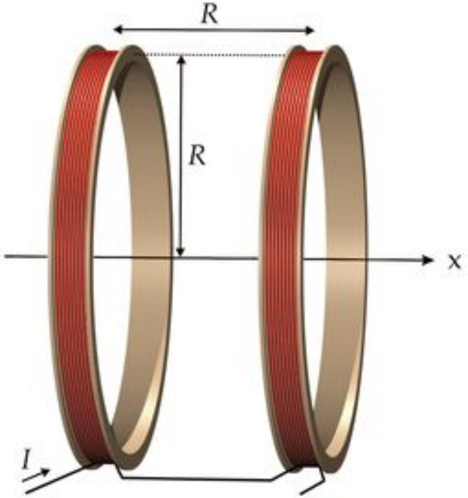




Controlling Magnetic Field

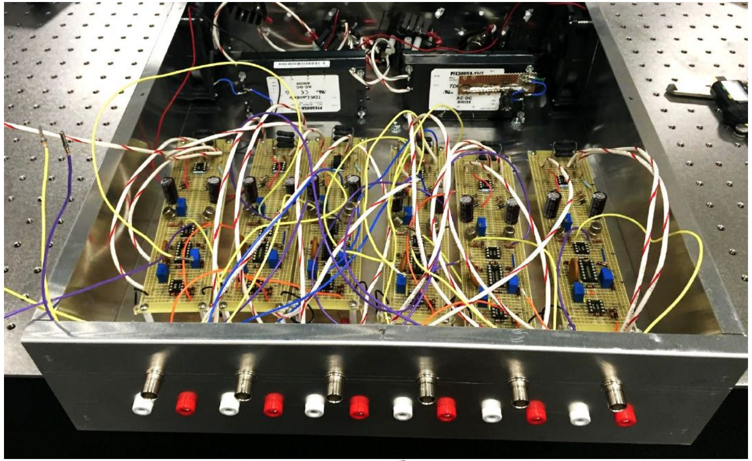
- Control magnetic field by changing current through Helmholtz coils
- Helmholtz coils are pairs of thin coils with radius=distance that create uniform magnetic field in the center
- Coil frame was 3-D printed by former REU student
- Coils allow us to cancel out other fields (earth, nearby magnets)
- Coils allow us to control collisions by applying arbitrary magnetic fields

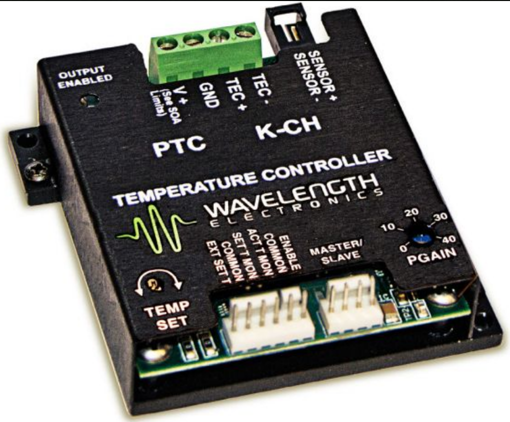




The Idea - Use a Temperature Controller (TC)

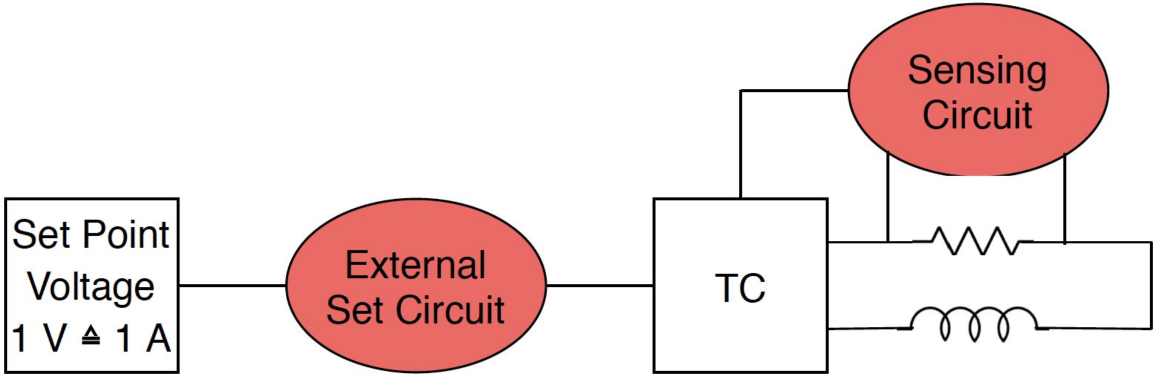
- Currently using homebuilt current supply -- fast but noisy
- Difficult to find commercial current supply
  - Bipolar, active stabilization, remote current programming, fast (ms)
- TC meets these requirements
  - Used PTC5K-CH from Wavelength Electronics, capable of supplying ±5 A
- TC expects to sense a temp and adjust a current
- Challenge: convert current data into fake temperature data





Overview of Circuit

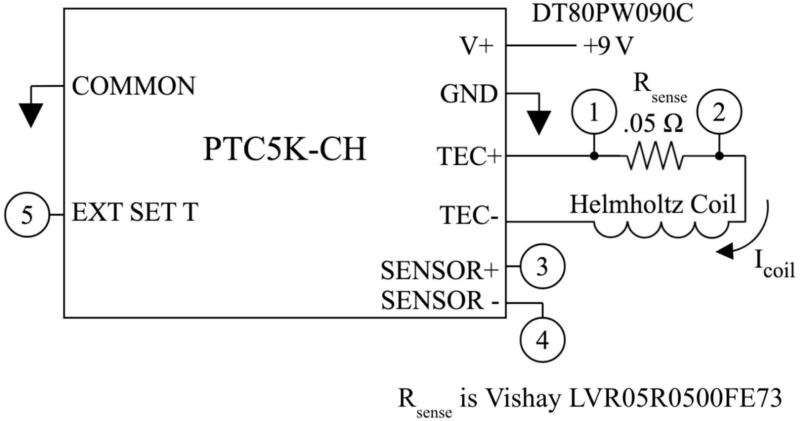
- Set point signal passes through external set circuit to tell TC what the desired voltage is
- TC sends current through Helmholtz coils
- Sense resistor is used to measure the current
- Feedback from the sensing circuit allows TC to compare the actual voltage with the set voltage and make an adjustment if needed

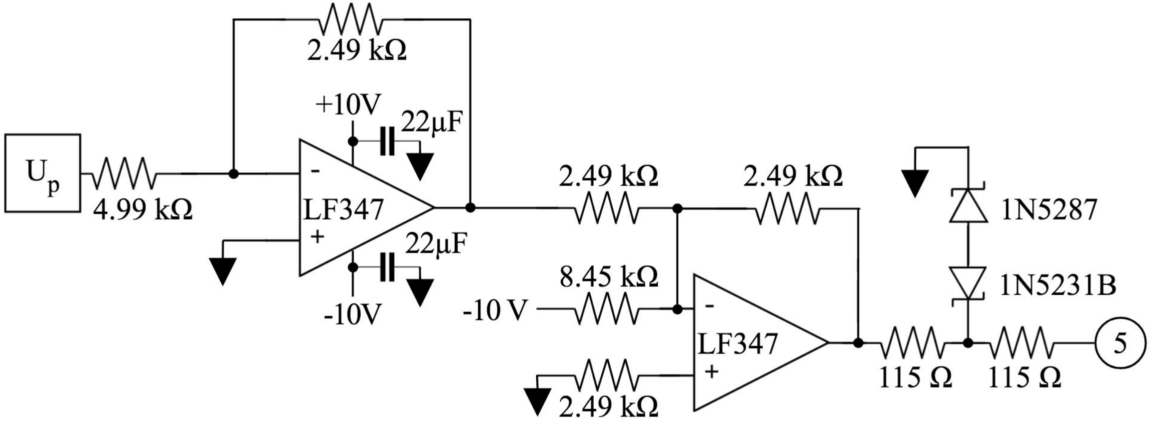


External Set Point Circuit

- Reacts to external set point programming voltage from LabView program
  - for testing used function generator
- Converts a range of -5 V … 5 V to 0.5 V … 5.5 V (a range the TC can interpret)

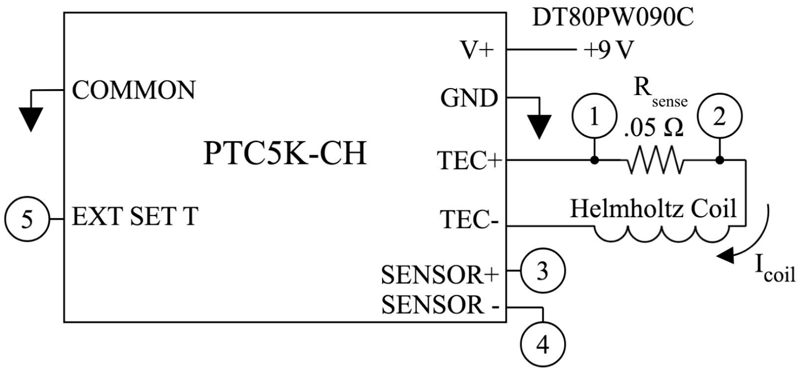
- Includes protection diodes in case of voltages surges



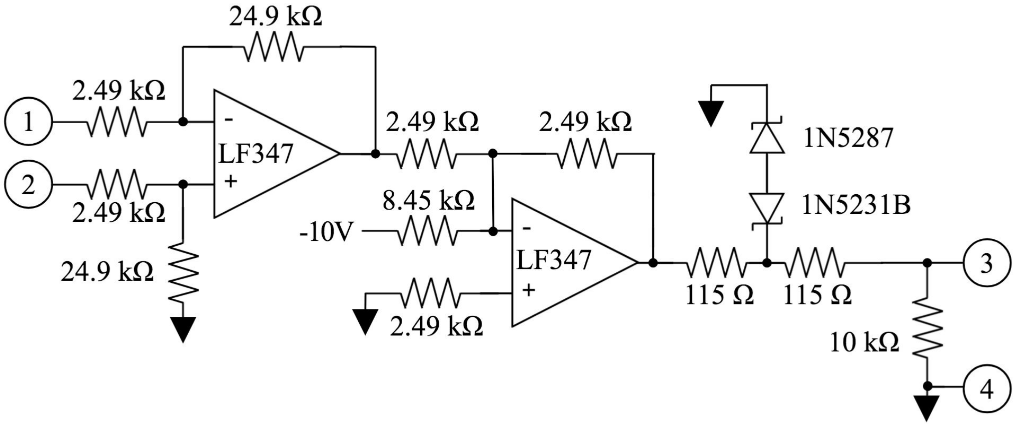


Sensing Circuit

- Senses current and presents fake temp to TC
- The sensing circuit appears as a 10 kΩ thermistor
- Use .05 Ω sense resistor to sense current
- Need -5 A … 5 A output from TC to result in 0.5 V … 5.5 V drop across 10kΩ resistor

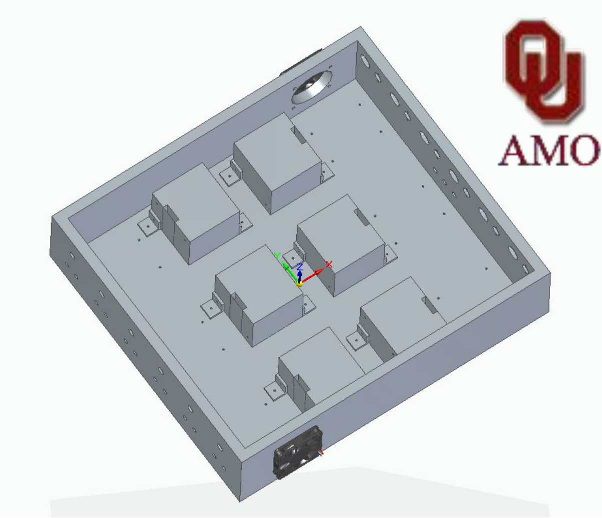


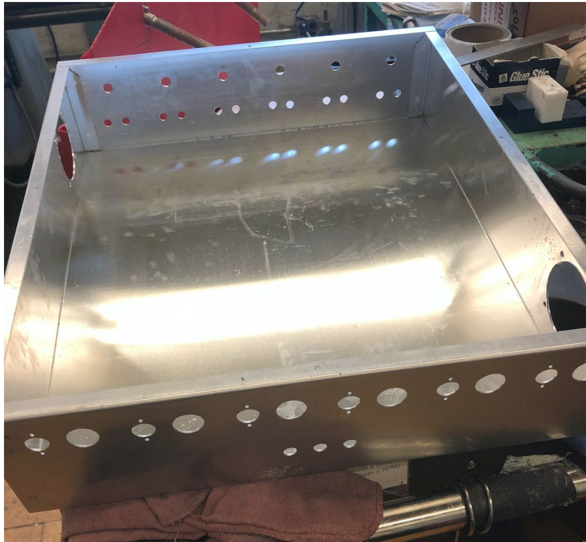
R_{sense} is Vishay LVR05R0500FE73



Making the Enclosure

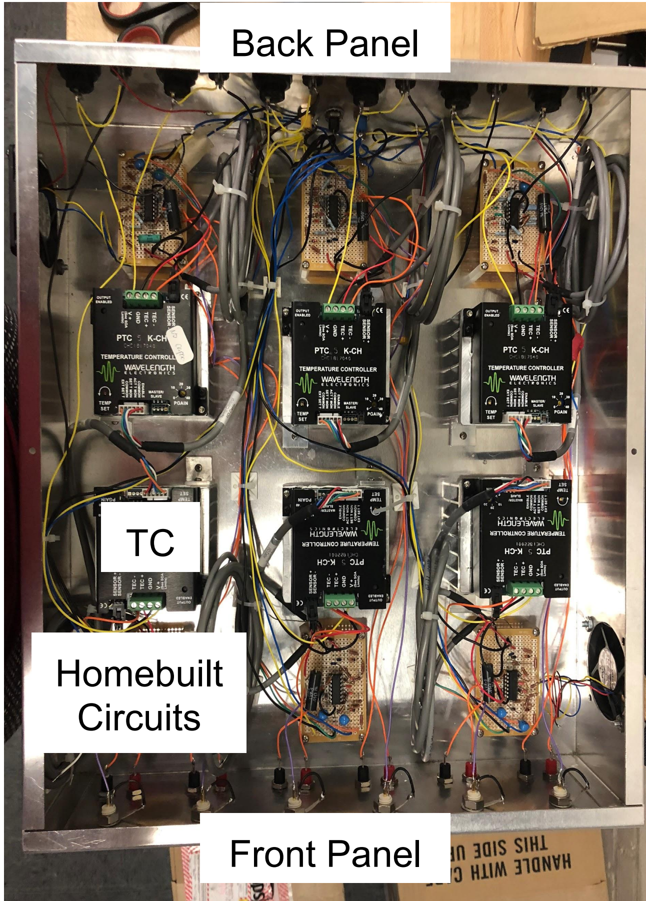
- Built 6 copies of each circuit
- Used solid edge to design CAD drawing
- Built box in student shop
- Cut heat sinks and made own L-brackets to fasten TC to box





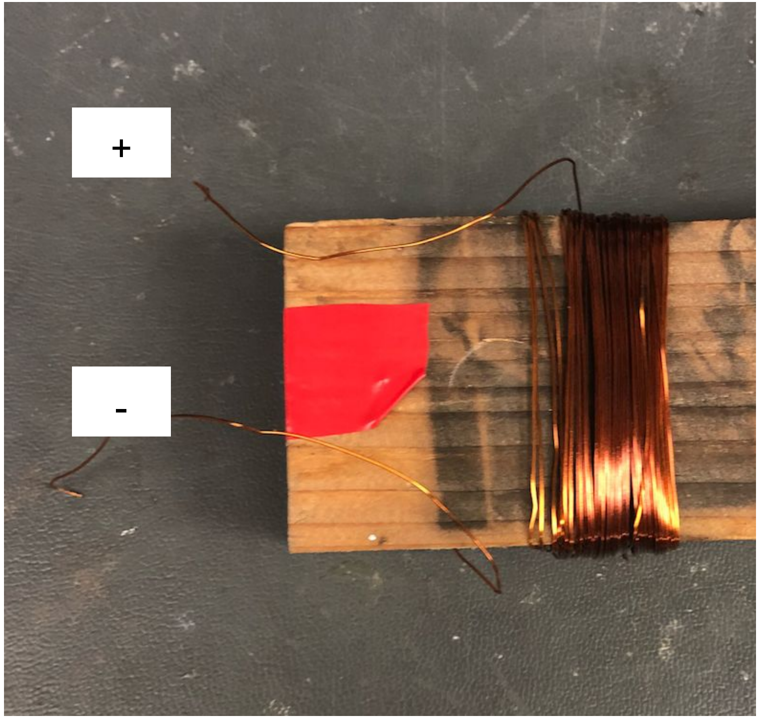
Layout

- Front Panel:
  - 6 set point inputs (BNC)
  - 6 pairs of coil outputs (banana)
- Back Panel:
  - Low current, +10 V, ground, -10 V power supply for op amps and fans (banana)
  - High current, +9 V power supply for each TC (4 pin DIN)



Test Coil vs. Lab Coil

- Test coil is thinner gauge wire
- Both have resistance of 1 Ω
- Test coil: $L \approx 1.5 \times 10^{-4}$ H
- Lab coil: $L \approx 3.6 \times 10^{-3}$ H
  - Inductance is off by an order of magnitude
- Need to verify response time with higher inductance

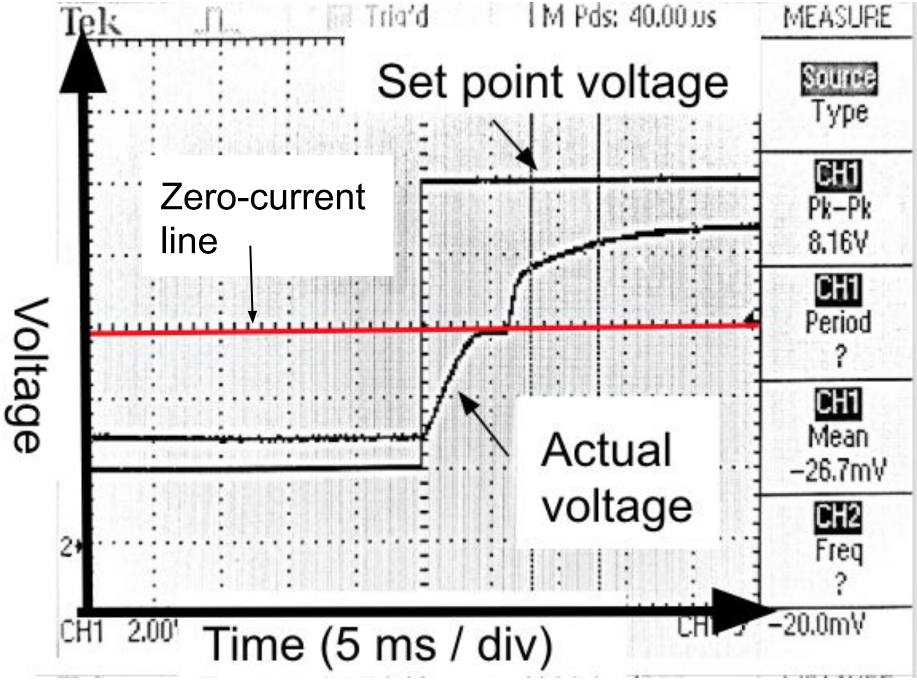


What is a PI Controller

- Feedback loop that automatically adjusts the output to reach a certain set point (e.g. cruise control)
- P = Proportional
  - Represents the difference between current actual value and set value
- I = Integral
  - Represents the difference between past actual value and set value
  - Output becomes larger the longer the measurement deviates from set point

Testing

- Applying a square wave from function generator
- Actual voltage follows set point but not quickly
- There is a delay when the TC switches from driving positive current to negative current
- Signals are centered on zero-current line, voltages are scaled differently and offset

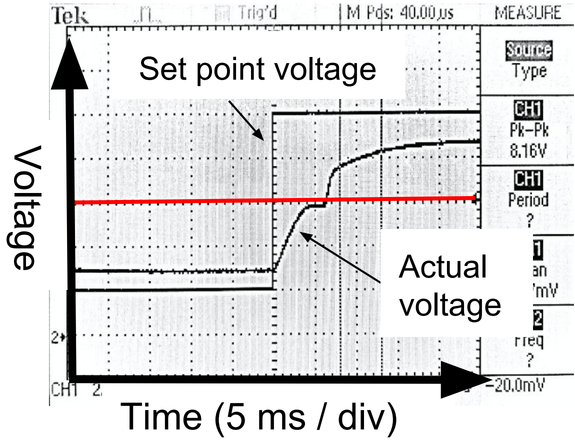


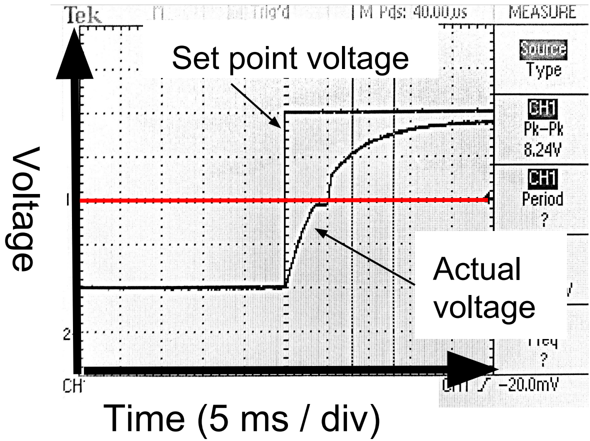
Adjusting Proportional Gain

- Gain is an amplification of a signal
- Want the actual voltage to reach the set point voltage quickly
- TC is capable of P gains between 5 and 40 A/V
- Even at max P gain the signal is overdamped, want an overshoot
- Looking for a solution to drive P gain past 40 A/V

Top image: 5 A/V

Bottom image: 40 A/V



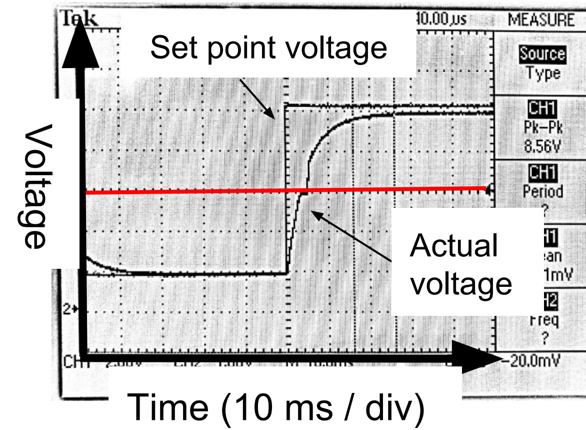


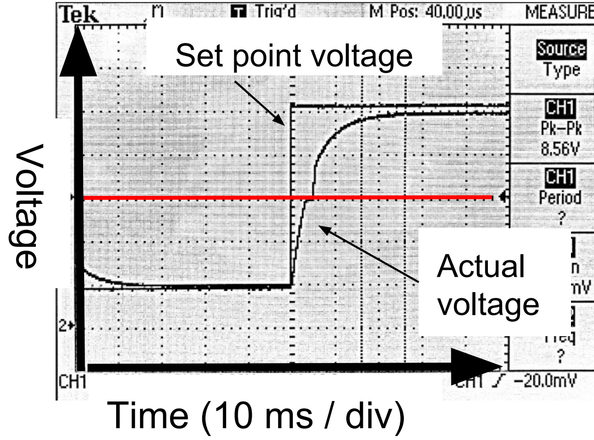
Adjusting Integral Gain

- A smaller integral time constant corresponds to larger integral gain
- Changed capacitor in TC to lower integral time constant
- That change had no impact on gain
- Looking for a solution to increase further, may modify circuit board on TC

Top image: .01 μF

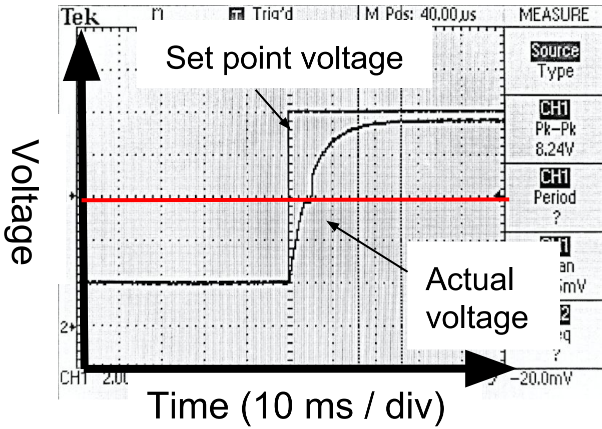
Bottom image: .1 μF

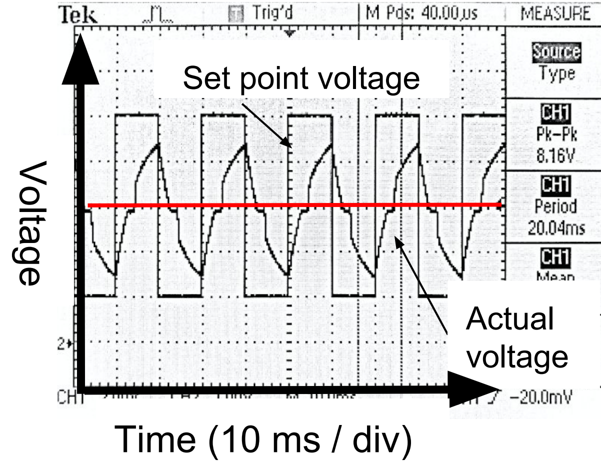




Square Signal

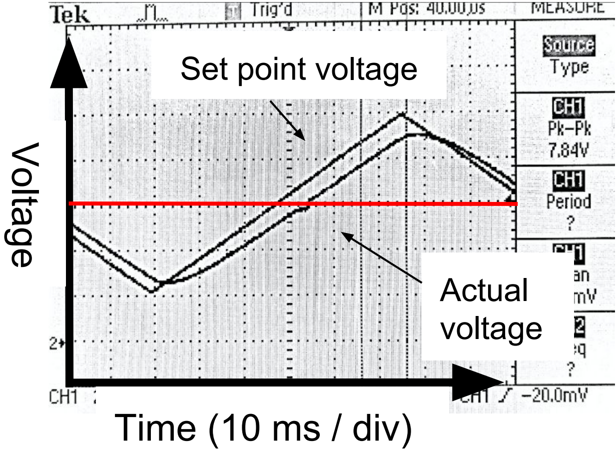
- Signal at 85% of set point after 10ms, 95% after 20ms
- With fast frequency the signal never reaches a stable point
- This test is worse case test, in lab experiments we will only make small adjustments

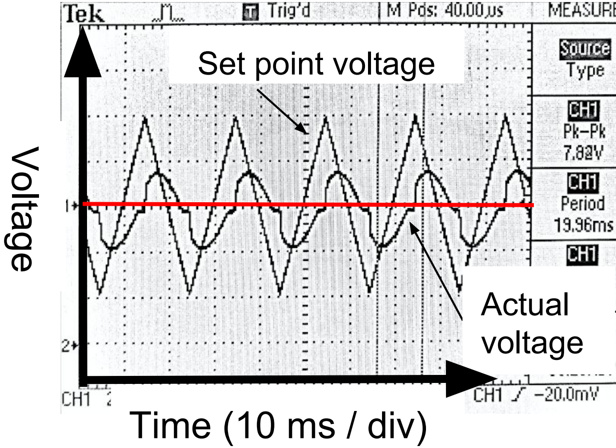




Triangle Signal

- Signal reaches 90% of set point only 4ms after set point reaches maximum
- TC can react more quickly to less abrupt changes
- More realistic test because in lab there will be ramps applied





Conclusions and Outlook

- Succeeded in building a low-noise and low-cost current controller with the required features
- Gained knowledge of physics and applicable skills in electronics and machining
- Will incorporate current controller into experiment with ultracold sodium gases
  - Should result in lower noise and thus more precise measurements
- Will write short paper detailing this controller and submit to *The Review of Scientific Instruments*

Questions?