

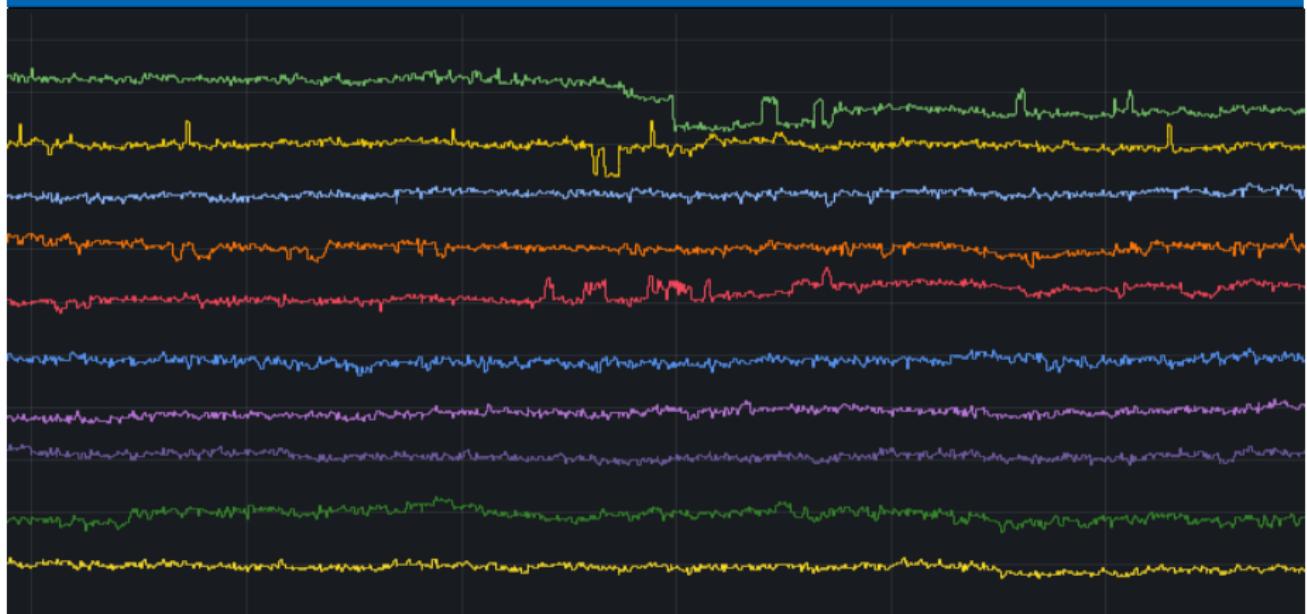
The Quest for Quiet - Tales from the Lab



TECHNISCHE
UNIVERSITÄT
DARMSTADT

P. Baus, G. Birkl

Institut für Angewandte Physik and GSI ARTEMIS



Contents



TECHNISCHE
UNIVERSITÄT
DARMSTADT

Introduction

The Project

Implementation

Laser Current Driver

Testing Voltage References

Open Source Scanner Card

LM399 vs. ARD1399



The Project

Building a Quantum Computer



TECHNISCHE
UNIVERSITÄT
DARMSTADT

Goal: Quantum computer with single atoms

- Needs lasers (dozens!)...
- and current sources...
- and voltage references...

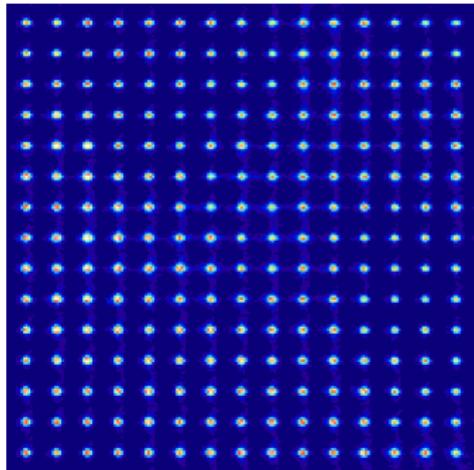


Figure: Array of 15x15 trapped neutral atoms

Contents



TECHNISCHE
UNIVERSITÄT
DARMSTADT

Introduction

The Project

Implementation

Laser Current Driver

Testing Voltage References

Open Source Scanner Card

LM399 vs. ARD1399



Diode Laser System

Requirements



TECHNISCHE
UNIVERSITÄT
DARMSTADT

Requirements:

- Low noise
- Low drift with temperature ($<1 \text{ ppm K}^{-1}$)
- Output current: up to 500 mA
- Compliance voltage: up to 10 V



Current Driver

The state of the art



TECHNISCHE
UNIVERSITÄT
DARMSTADT

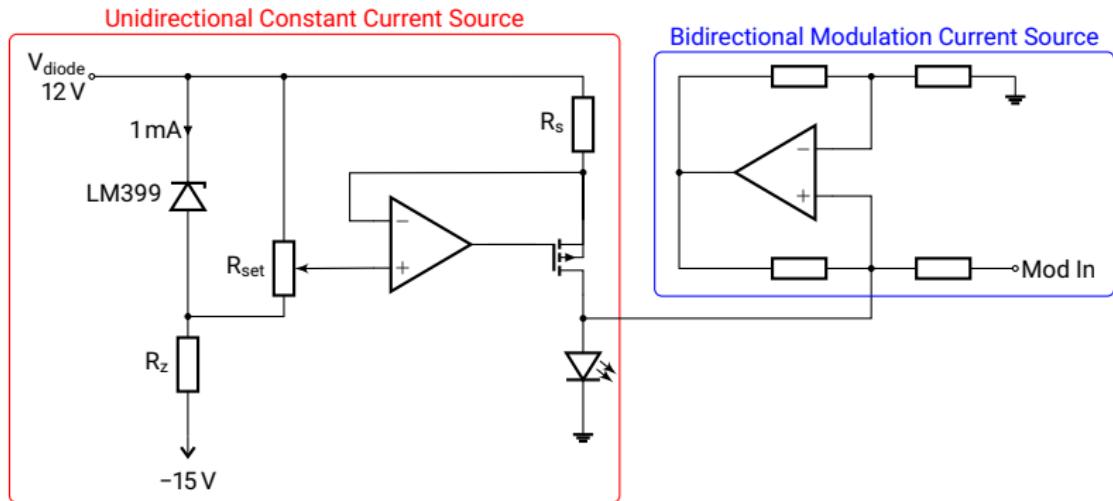


Figure: Simplified current source based on [1]



Current Driver

The state of the art



TECHNISCHE
UNIVERSITÄT
DARMSTADT

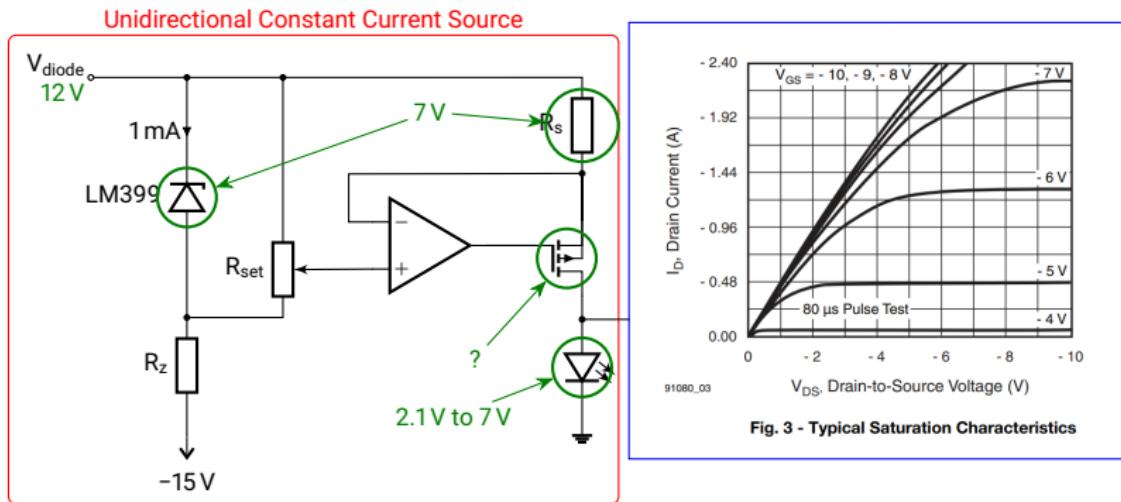


Figure: Simplified current source based on [1], inset: [2]



Current Driver

Our solution

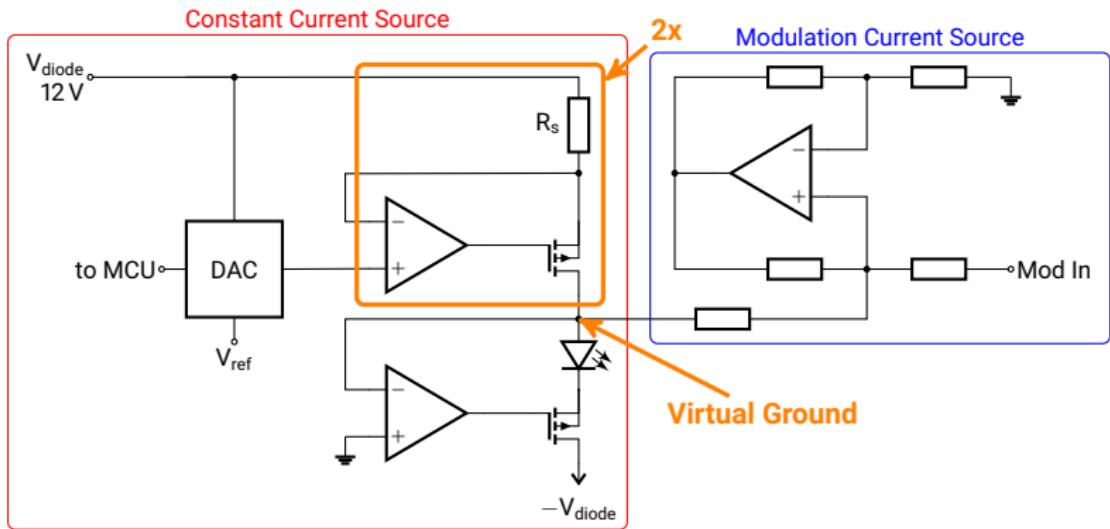


Figure: Simplified current source, APQ design

Current Driver

Noise Source



TECHNISCHE
UNIVERSITÄT
DARMSTADT

Sources of Noise:

- Wideband
 - Reference noise can be filtered
 - Op-amp must be low noise (AD797)
- Low frequency noise
 - Dominated by reference noise
 - LM399 vs. ADR1399 vs. LTZ1000
 - Popcorn noise!
 - References need to be tested.
Each and every one!?

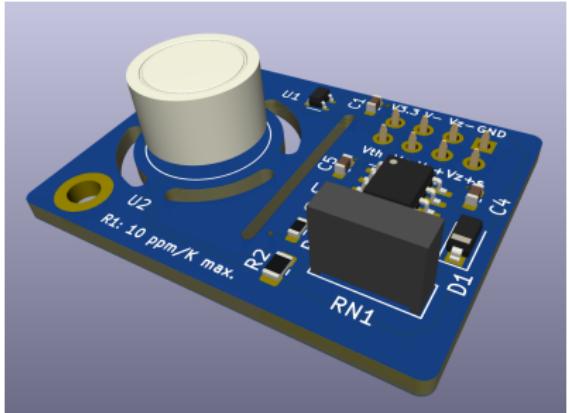


Figure: LM399 -15 V reference, Available at [3]



Testing Voltage References



TECHNISCHE
UNIVERSITÄT
DARMSTADT



Figure: Test setup for voltage references. Images taken from: [4]

- 10 measurants every 18 s (2×10^5 relay operations @ 1000 h)
- Keithley 2000-SCAN is rated at 1×10^5 to 1×10^8 operations



Testing

Corona and Home Office



TECHNISCHE
UNIVERSITÄT
DARMSTADT



Figure: Reverse engineering the 2000-SCAN protocol



Testing

Open Source Scanner Card



TECHNISCHE
UNIVERSITÄT
DARMSTADT

- 10- or 20-channel scanner card
- All solid state relays
- Silent
- iCE40 FPGA-based to meet timing requirements of the K2002
- Fully compatible with DMM6500 and Model 200x
- Open source toolchain

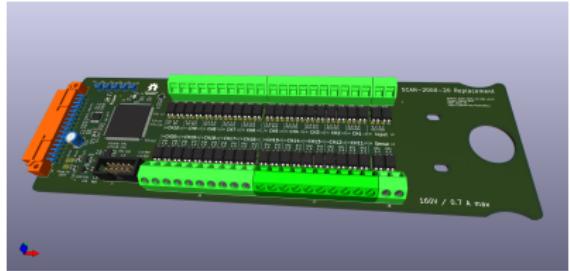


Figure: Available at [5]

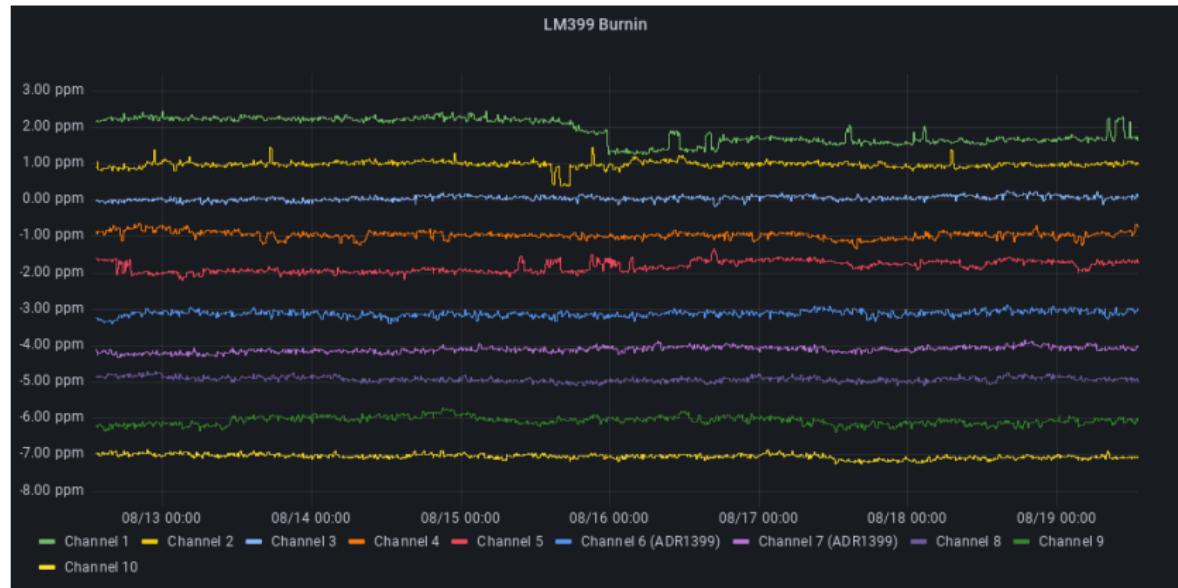


Test results

LM399 vs. ARD1399



TECHNISCHE
UNIVERSITÄT
DARMSTADT



Test results

In numbers



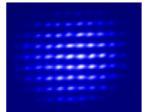
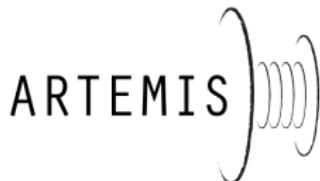
TECHNISCHE
UNIVERSITÄT
DARMSTADT

Our experience with the LM399/ARD1399:

- All diodes are tested over 1000 h
- Tested over 100 LM399 samples
- Tested around 10 ADR1399 (100 more on order)
- LM399 popcorn noise is about **0.4 ppm to 0.6 ppm**
- Around **40 % to 50 %** of the LM399s show excess popcorn noise and get tossed
- ADR1399 shows (nearly) no popcorn noise

Is the ADR1399 the future? - Time will tell. See you in a few months.





ATOME-PHOTONEN-QUANTEN
Prof. Dr. Gerhard Birkl
Institut für Angewandte Physik
Fachbereich Physik



TECHNISCHE
UNIVERSITÄT
DARMSTADT

Thank you very much for your attention!



Bundesministerium
für Bildung
und Forschung

HFHF



Bibliography I



TECHNISCHE
UNIVERSITÄT
DARMSTADT

-
- [1] K. G. Libbrecht and J. L. Hall.
A low-noise high-speed diode laser current controller.
Review of Scientific Instruments, 64(8):2133–2135, 1993.
 - [2] Vishay Siliconix.
IRF9610 Datasheet, 2021.
Rev. C.
 - [3] Patrick Baus.
LM399 Sub-ppm Voltage Reference.
https://github.com/TU-Darmstadt-APQ/Voltage_reference,
2019.



Bibliography II



TECHNISCHE
UNIVERSITÄT
DARMSTADT

- [4] Keithley 2002 8.5 Digit Multimeter with Scanning.

<https://www.tek.com/en/products/keithley/digital-multimeter/2002-series>.

Accessed: 2012-08-26.

- [5] Patrick Baus.

Keithley SCAN2000 SSR Replacement.

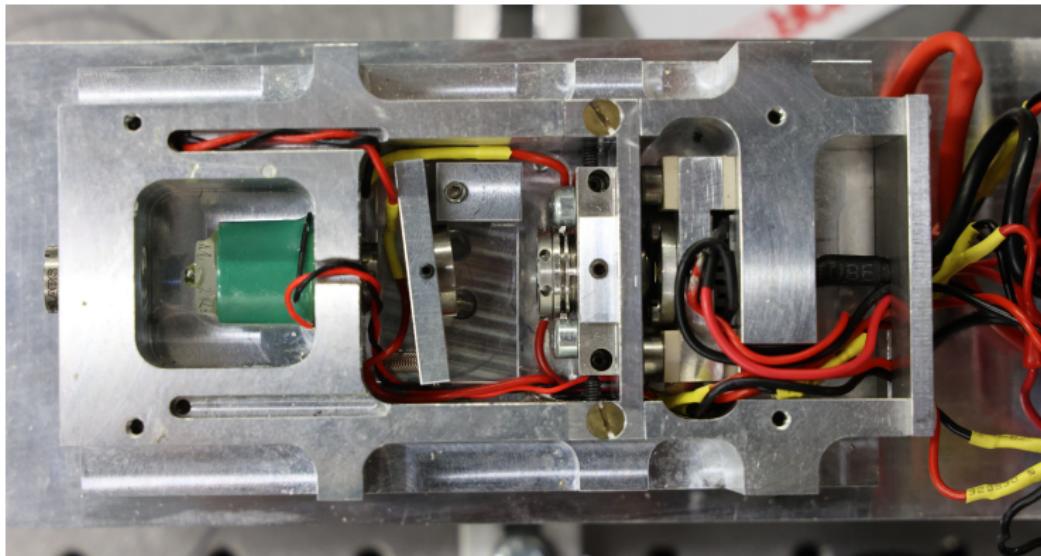
<https://github.com/PatrickBaus/SCAN2000>, 2022.



Laser Resonator



TECHNISCHE
UNIVERSITÄT
DARMSTADT



Current Driver

Comparison with commercial alternatives



TECHNISCHE
UNIVERSITÄT
DARMSTADT

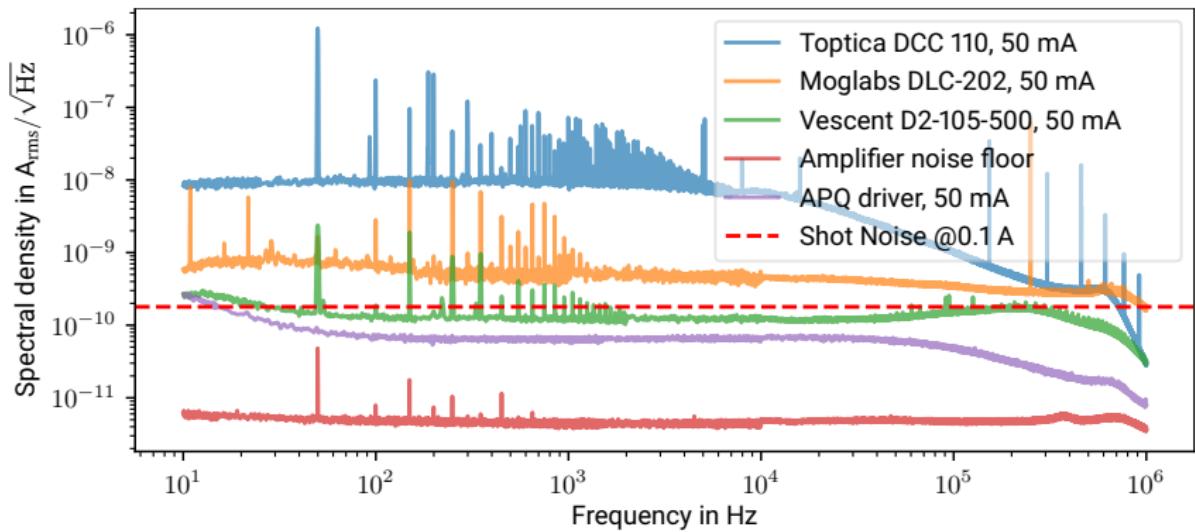


Figure: Current noise spectral density of different commercial drivers