

magnETHical

MASTER THESIS: BUILDING A 25 MHz NMR SPECTROMETER

Maximilian Stabel

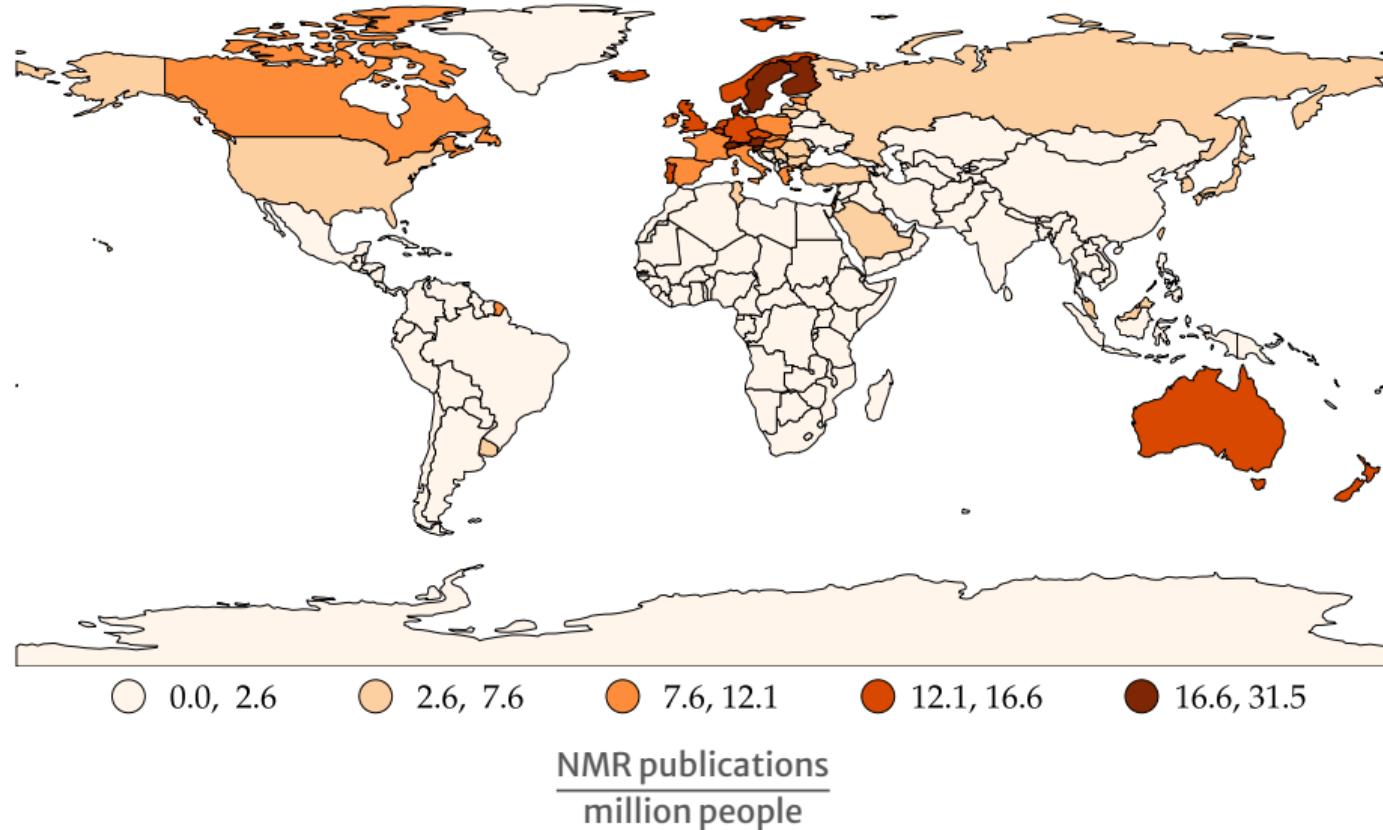
September 30, 2023

ETH Zürich

“What I cannot create, I do not understand”

—Richard Feynman

There is not a lot of NMR research in the Global South



Nuclear Magnetic Resonance

- Nuclei absorb radio waves at a certain frequency when inside a magnetic field
- The nuclei emit radio waves at that same frequency when excited this way
- $f \sim B_0$ and surroundings

NMR is used across various fields

- Research (Structure Analysis, Drug Discovery, ...)
- Medicine (Imaging, Diagnosis, ...)
- Industry (Process Control, Drug screening, ...)
- Education (Quantum Mechanics, Quantum Computing, ...)

**Build an accessible
NMR spectrometer**

Preview

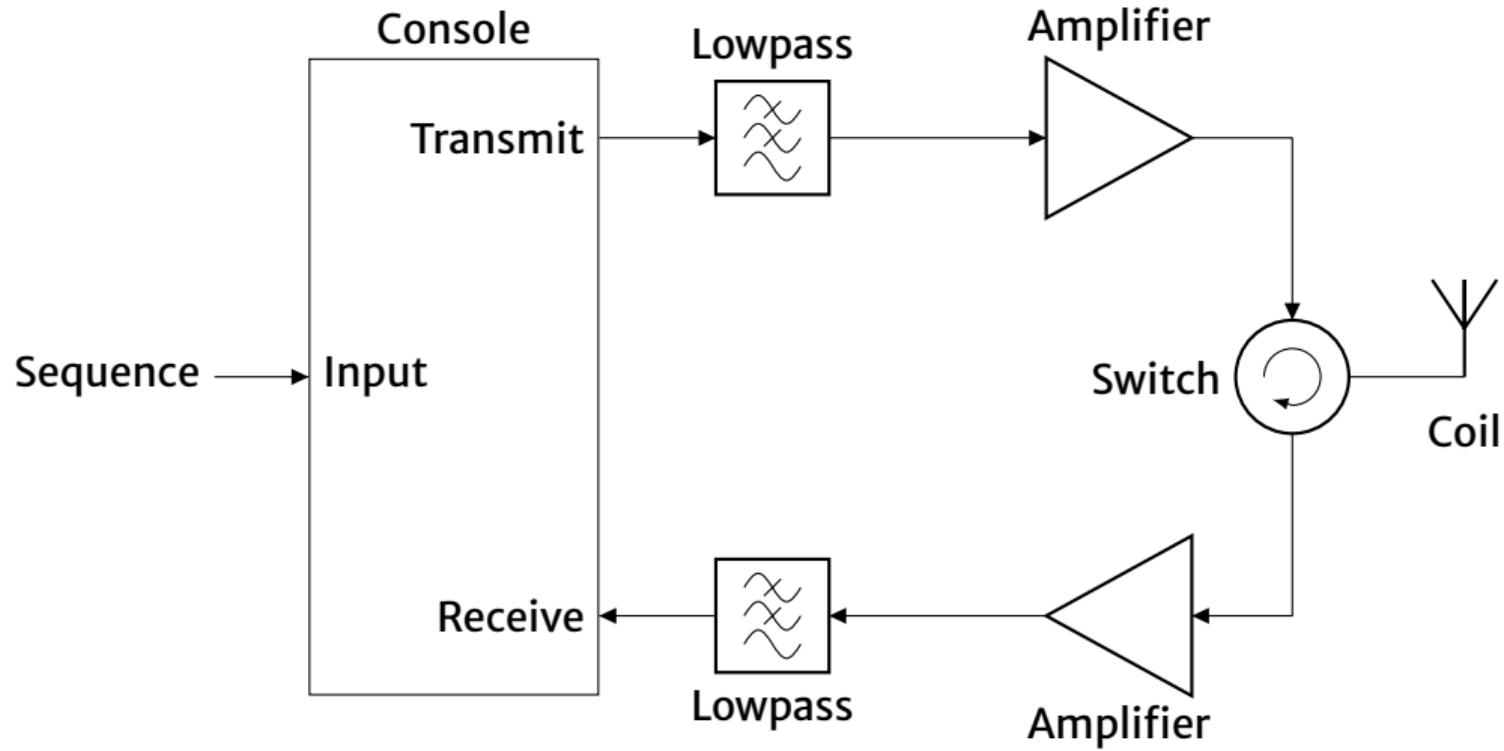
The parts

The complete setup

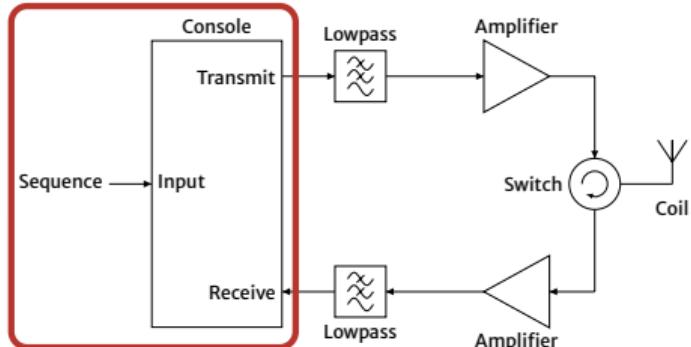
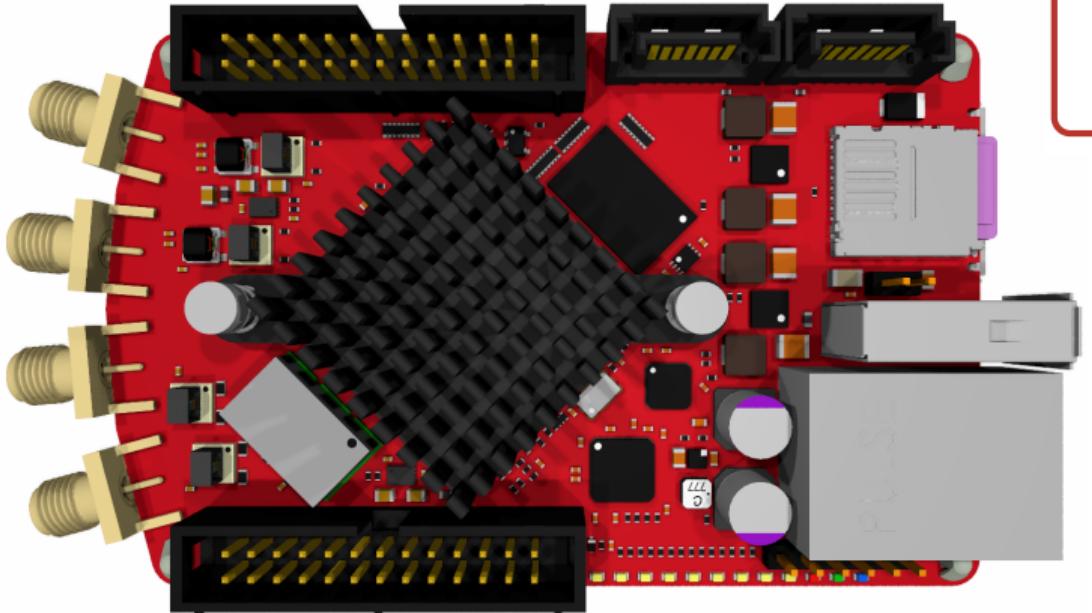
Experimental Results

THE PARTS

Our goal is to build an accessible NMR spectrometer

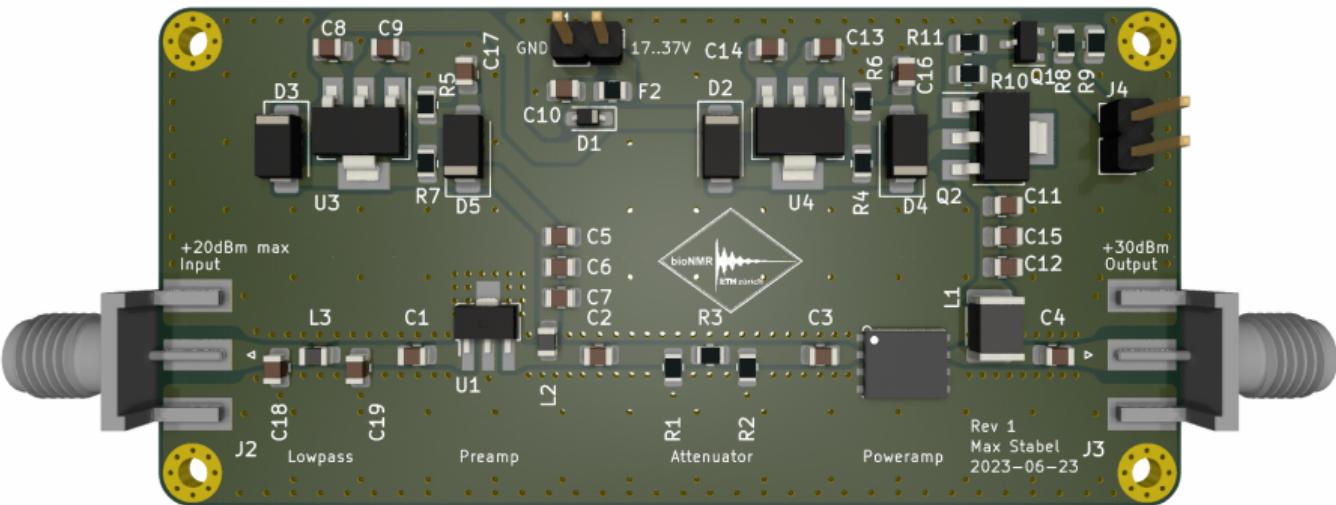
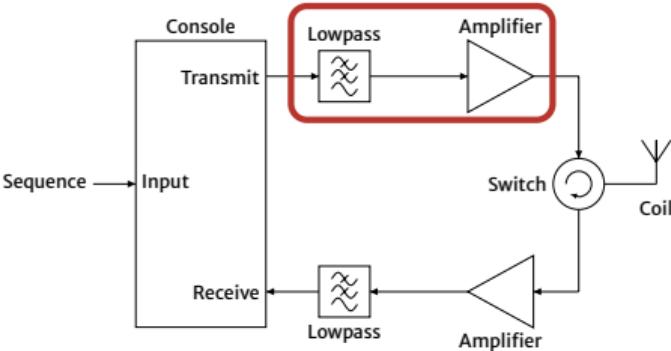


The console
is a ready-made FPGA board*

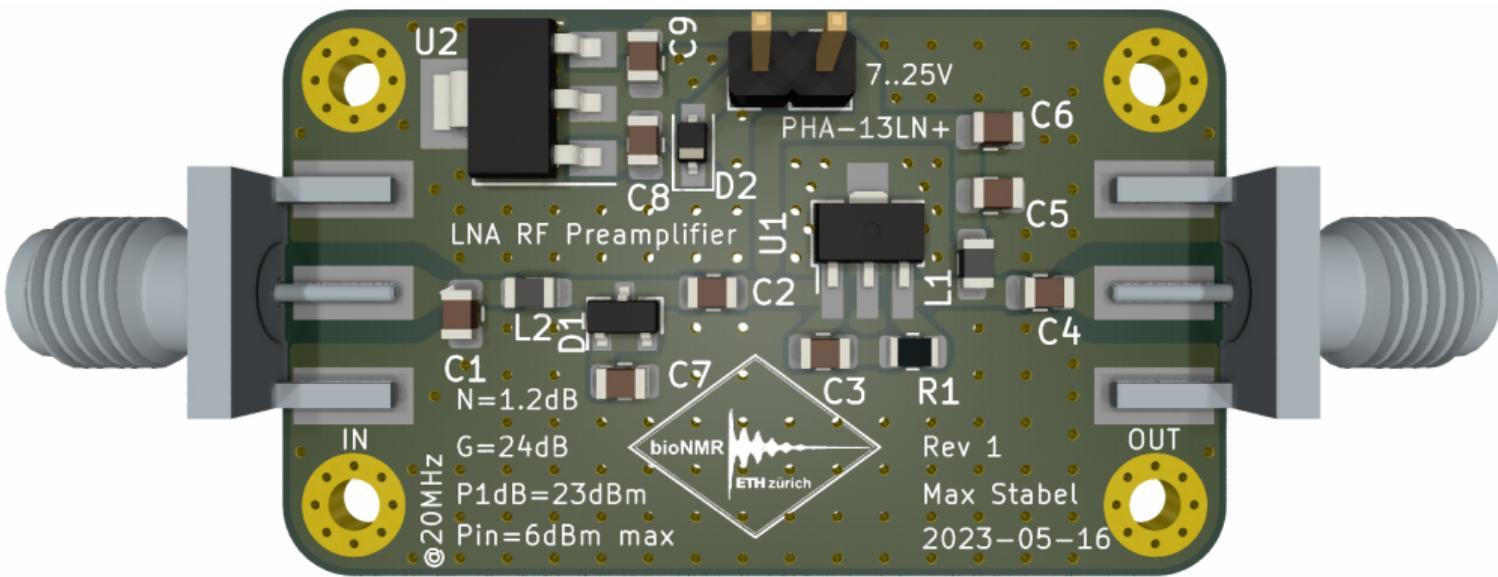
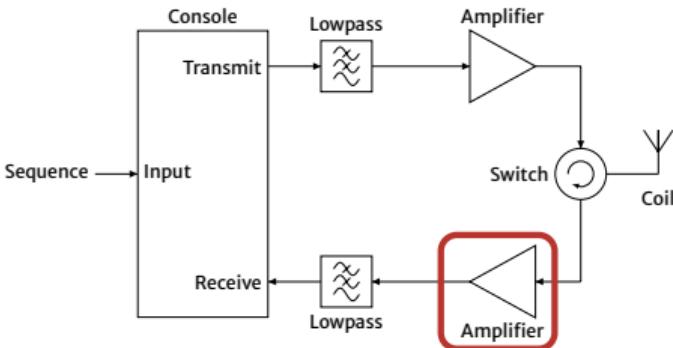


*Red Pitaya SDRlab 122-16

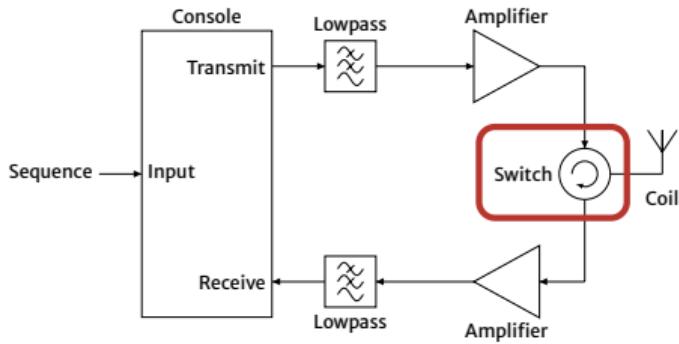
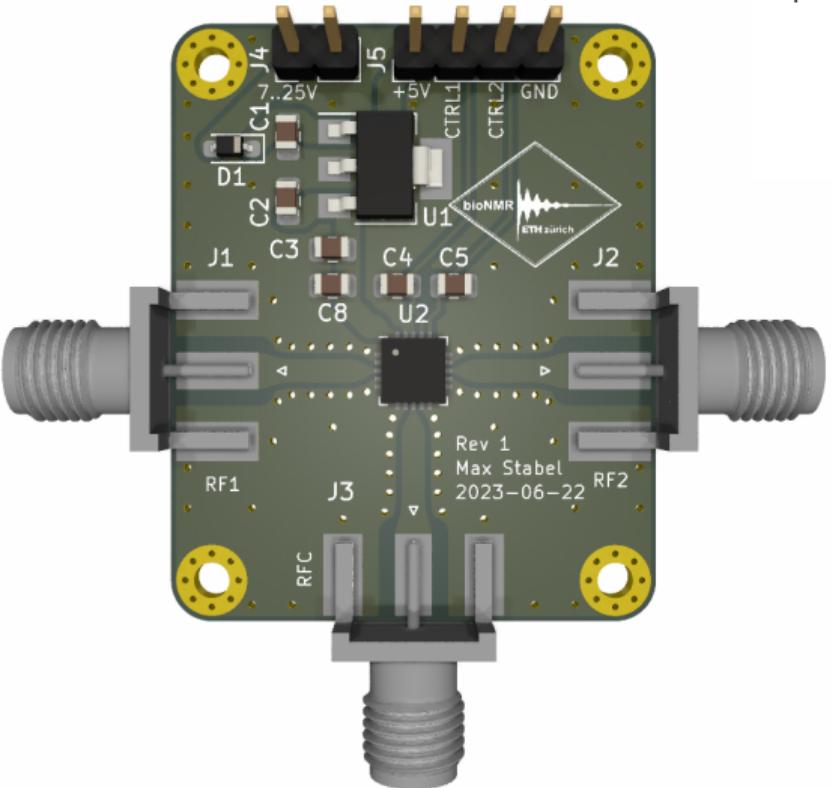
The power amplifier has two stages



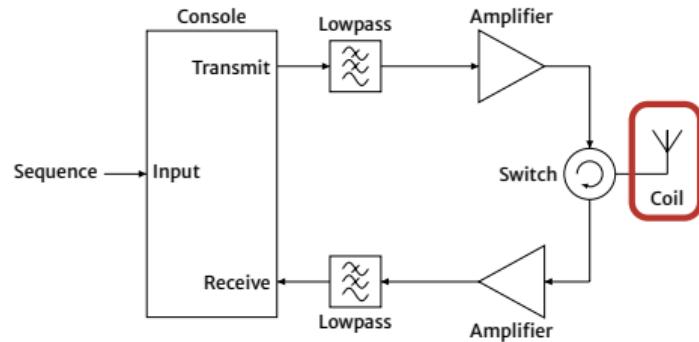
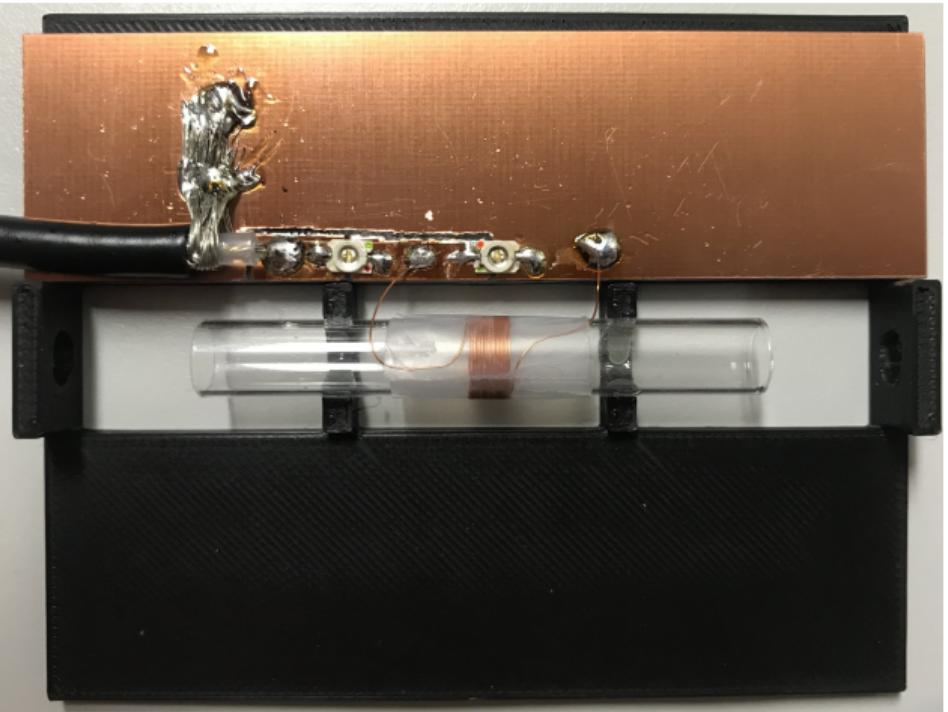
The low-noise amplifier had instability issues



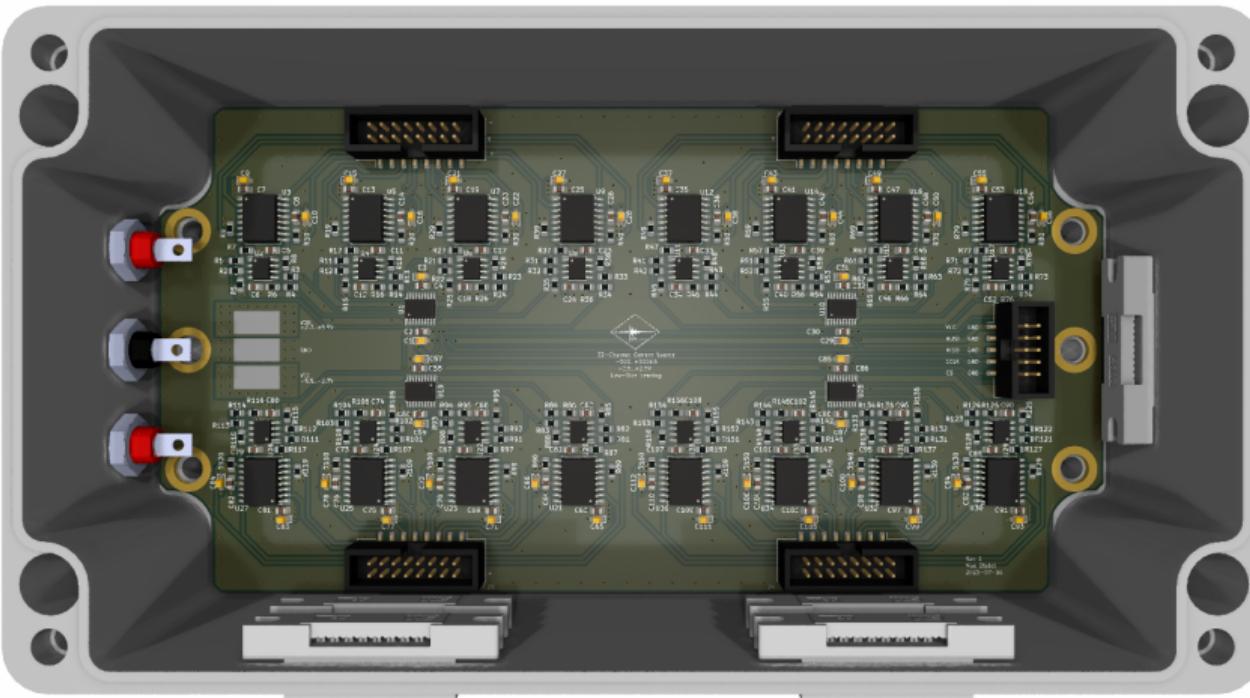
We use a transistor-based active switch



The probe



A 32-channel current supply is designed but untested



THE COMPLETE SETUP

Our NMR is affordable ...

	600 MHz [†]	mini-circuits	<i>magnETHical</i>
Power Amplifier	50 000	323.49	36.01
Switch	-	82.06	20.05
Probe	100 000	-	≈15.00
Low-Noise Amplifier	50 000	409.38	73.11
Shim Driver	-	-	257.08
Console	200 000	-	662.53
Magnet	1 000 000	-	≈9000.00
Sum			10 142.80

[†]estimated costs

Prices incl. VAT [CHF]

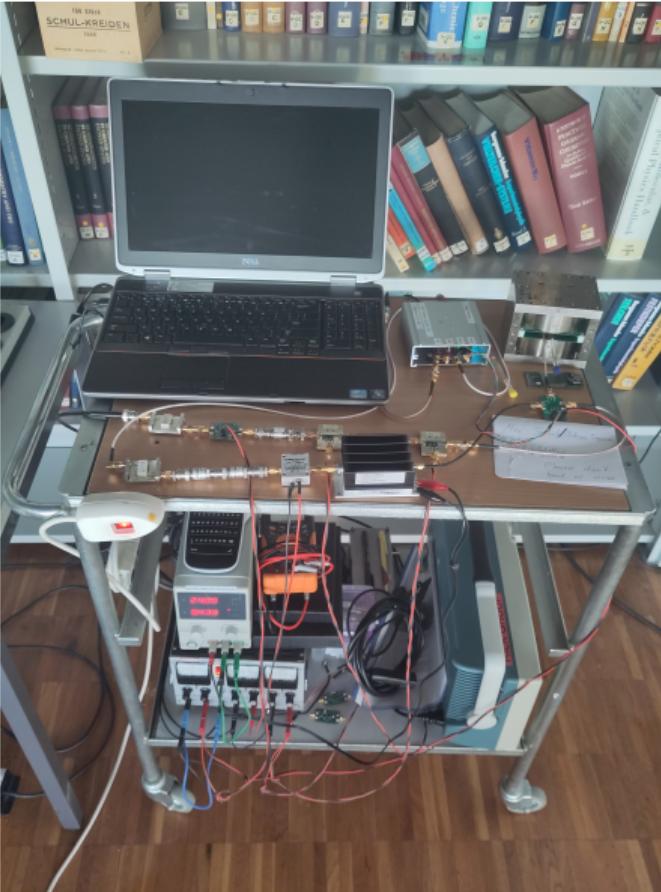
... competitive ...

	Superconducting	Benchtop	<i>magnETHical</i>
Price [k CHF]	200–18 000	50–150	≈10
Frequency [MHz]	300–1200	40–125	25
Resolution [Hz]	≈0.2	0.2–1	≈2.5/50 [†]
Weight [kg]	600–15 000	25–150	≈5

[†]with/without shims

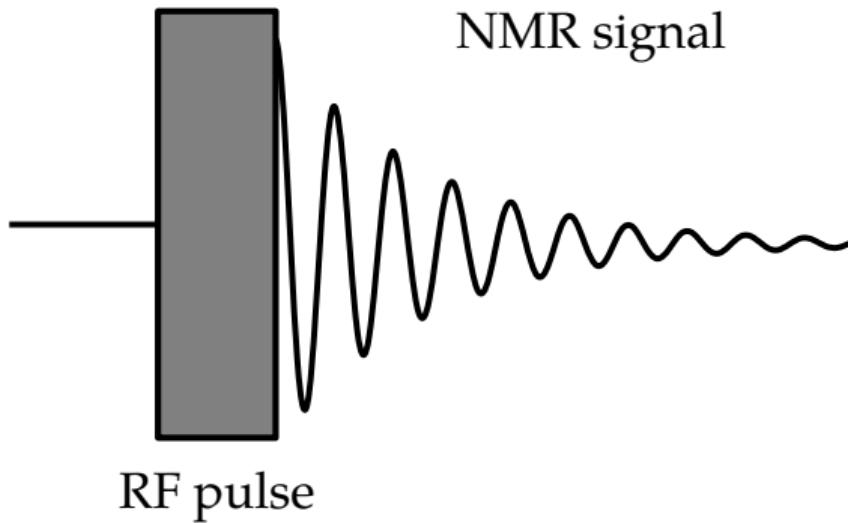
For 5mm standard NMR tubes

... and portable



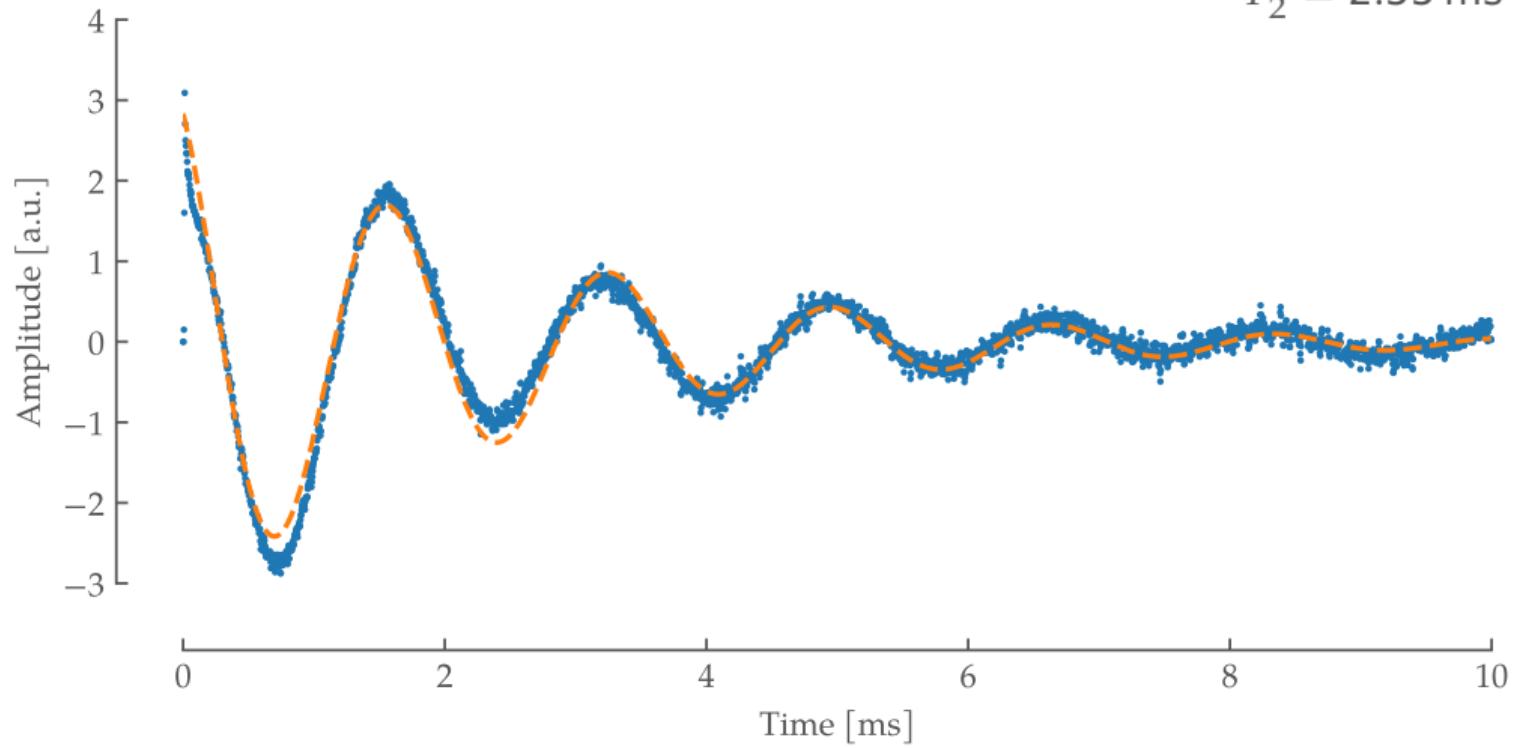
EXPERIMENTAL RESULTS

Simple Pulse Sequence

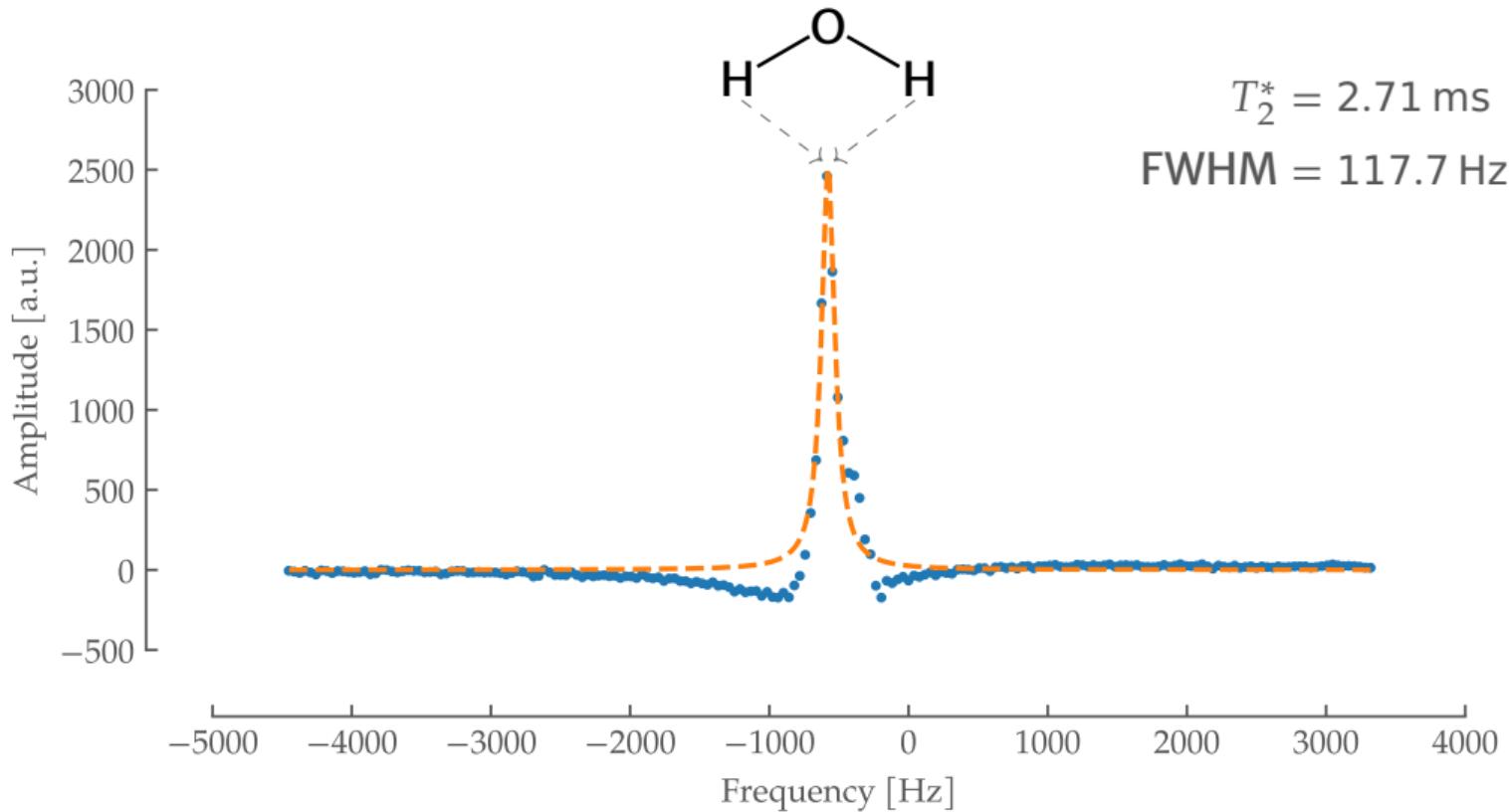


We can already see a water FID

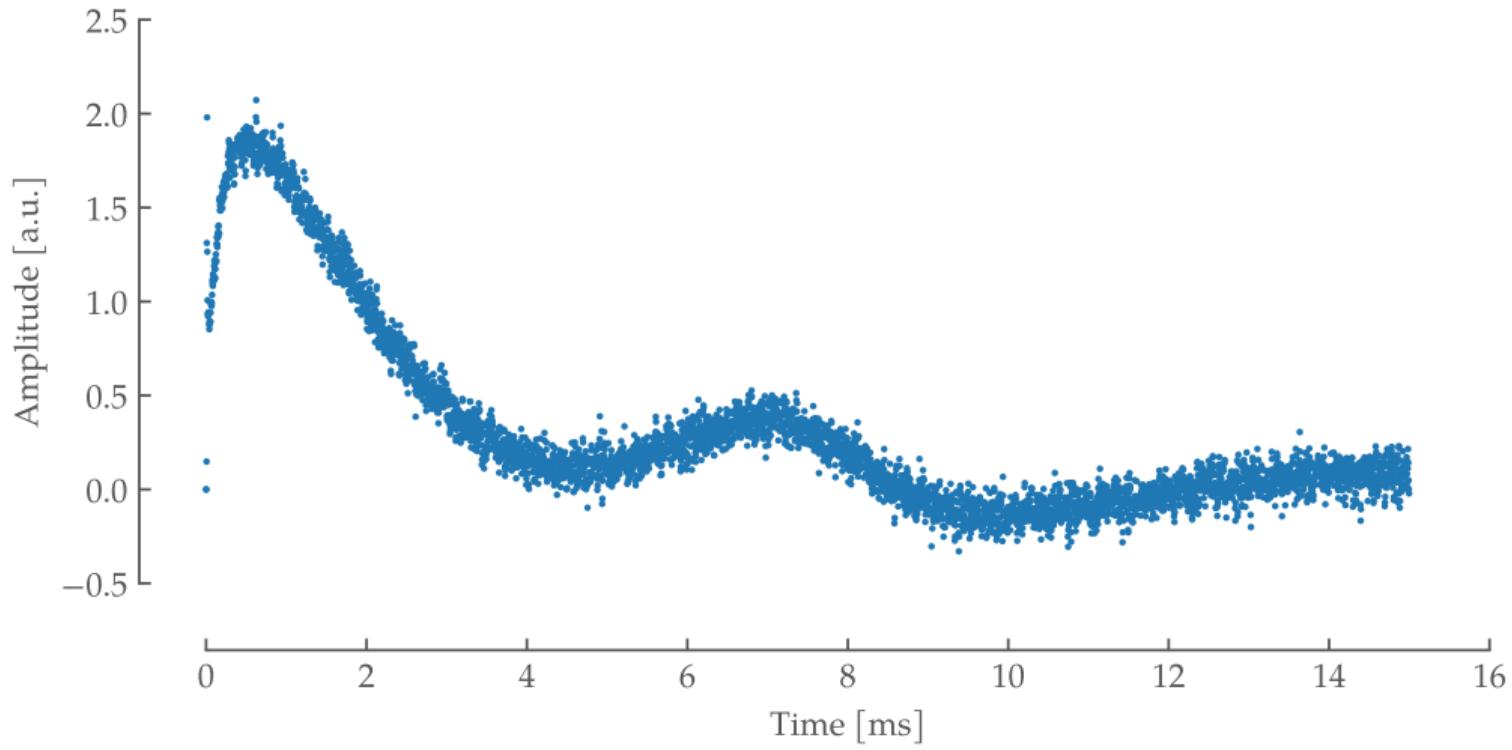
$$T_2^* = 2.55 \text{ ms}$$



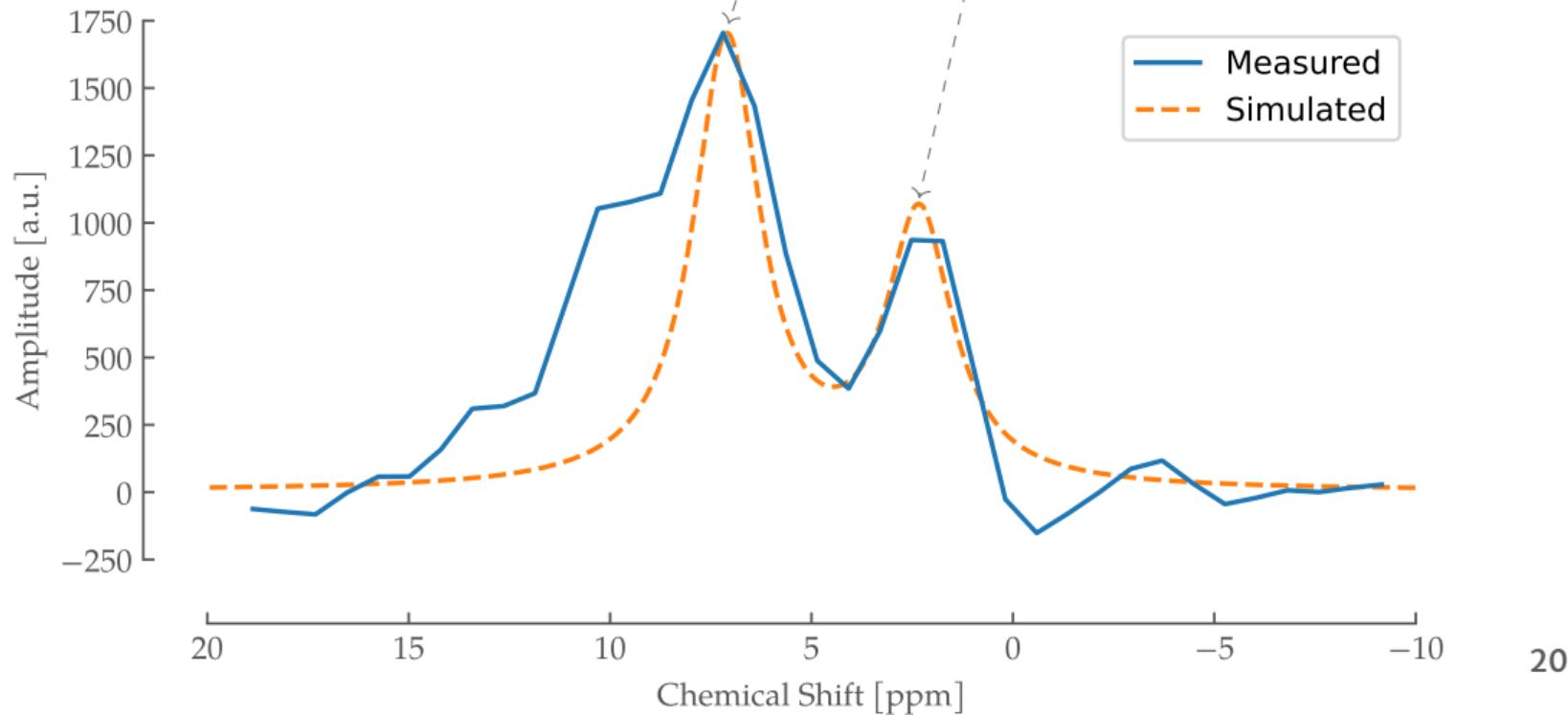
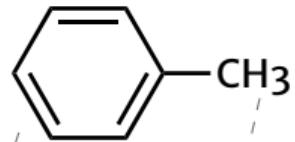
...and do a Fourier transform



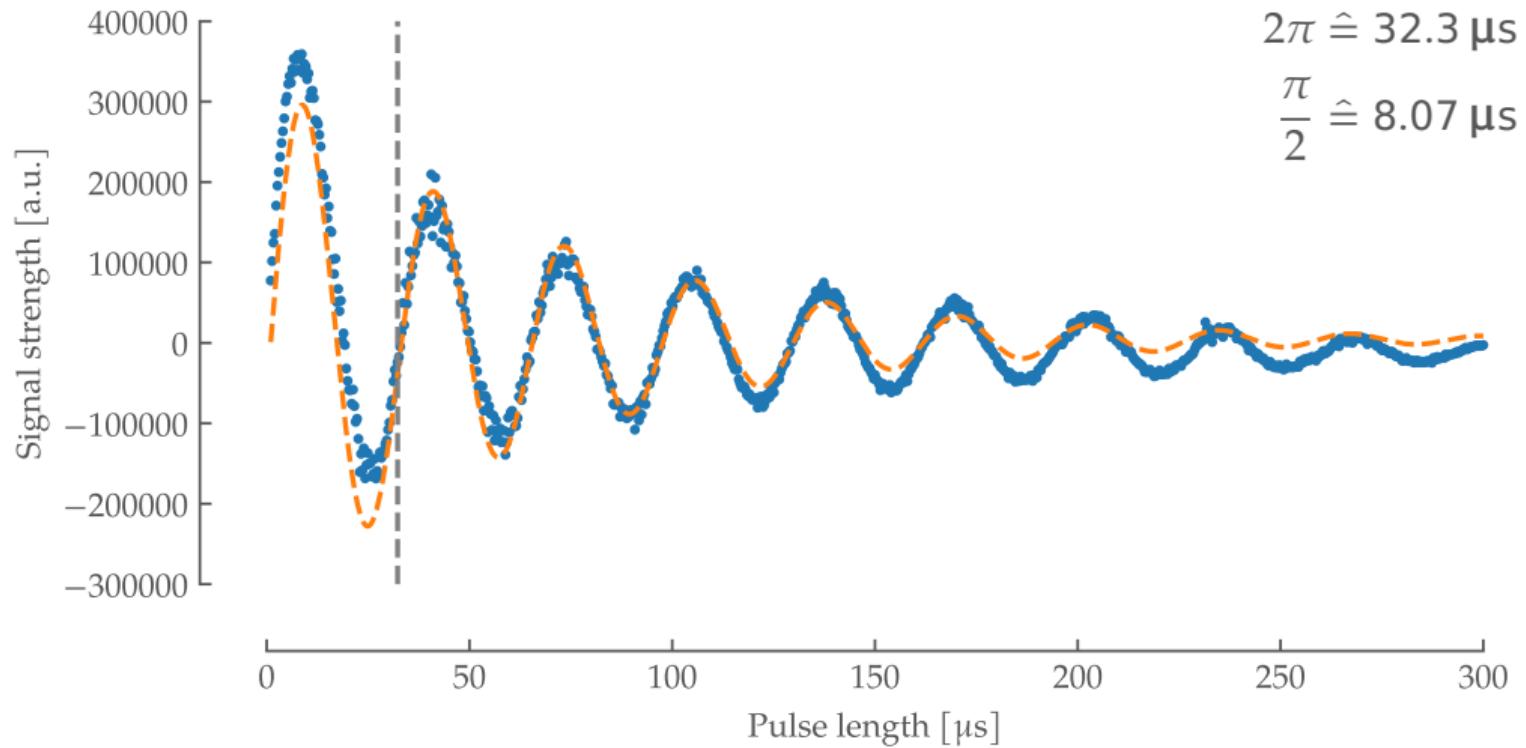
Toluene also has a visible signal



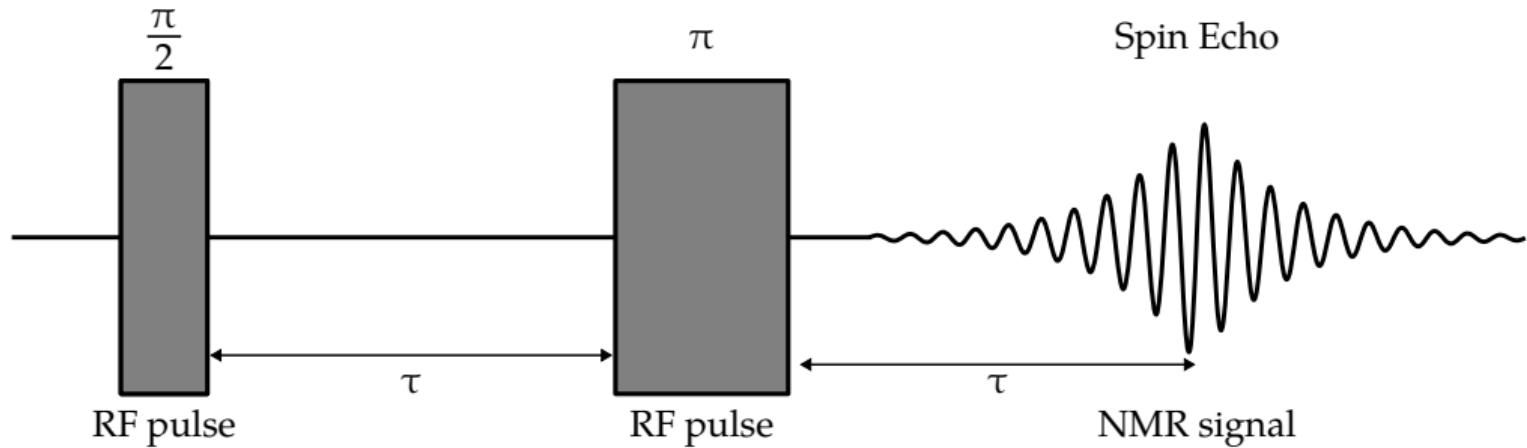
We can even see the chemical shifts
of the Toluene peaks!



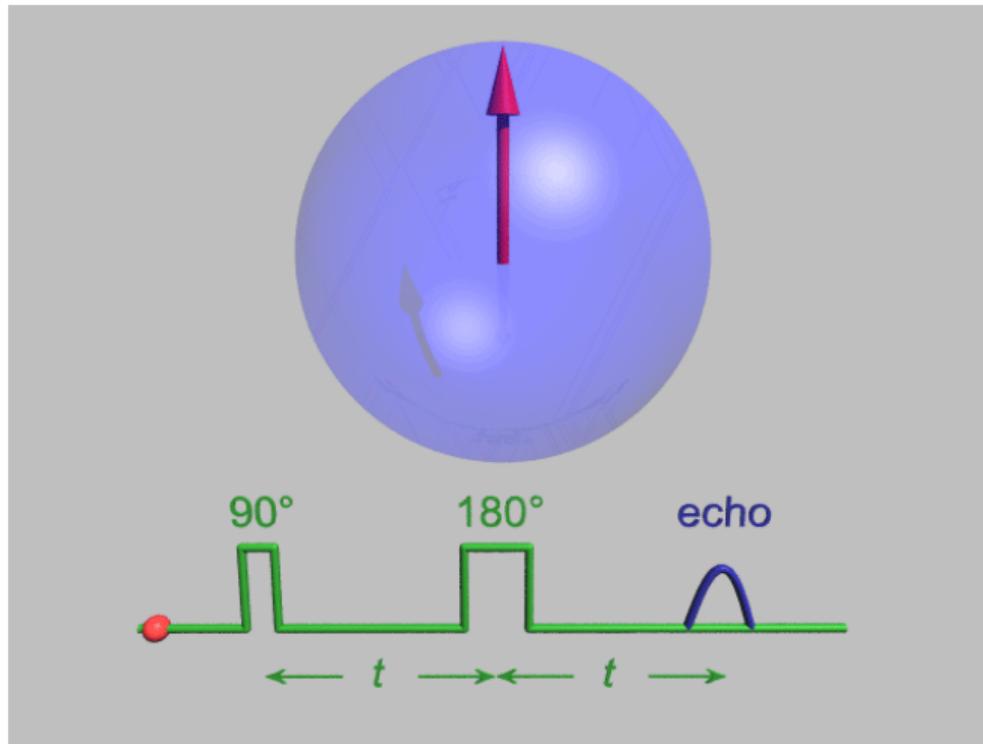
Rabi nutation (pulse calibration) of water



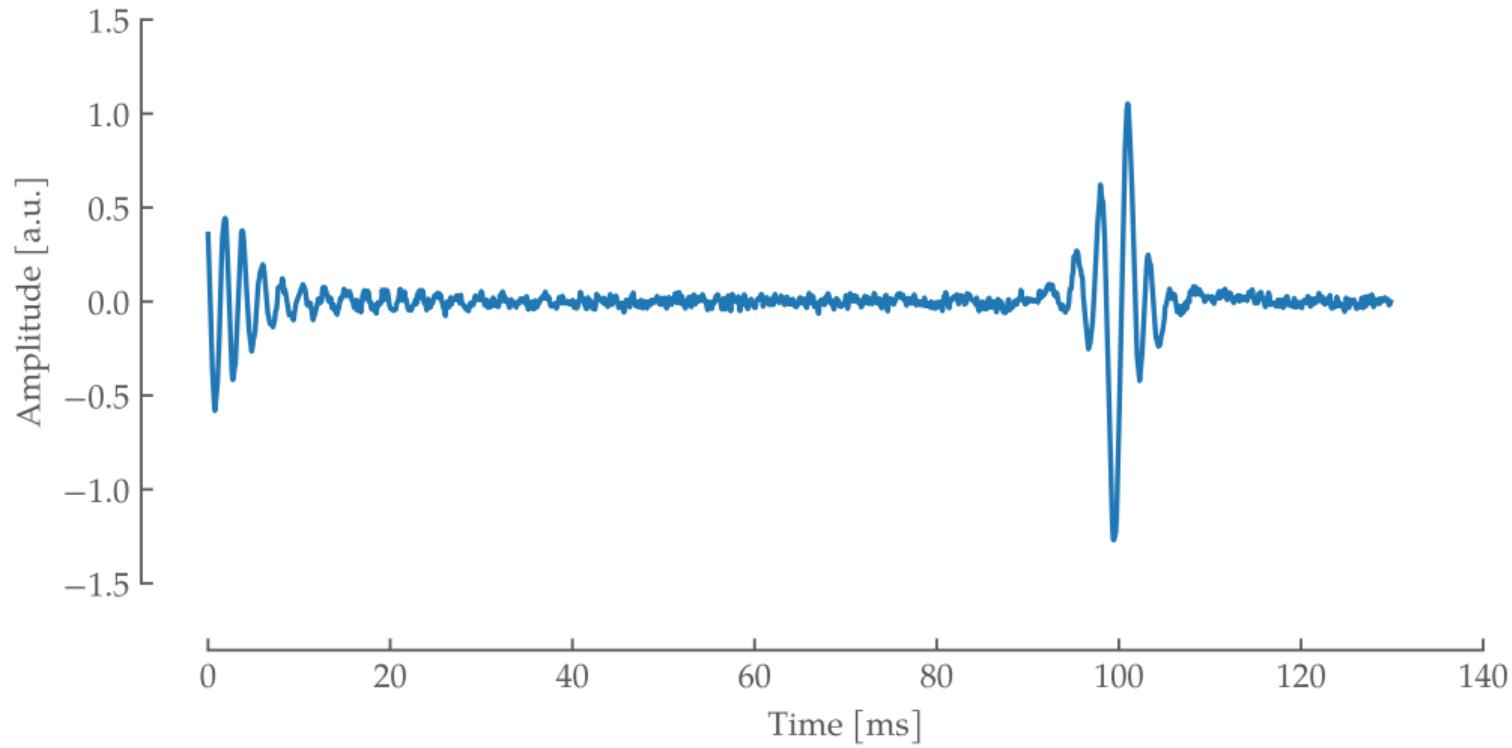
Spin Echo Sequence



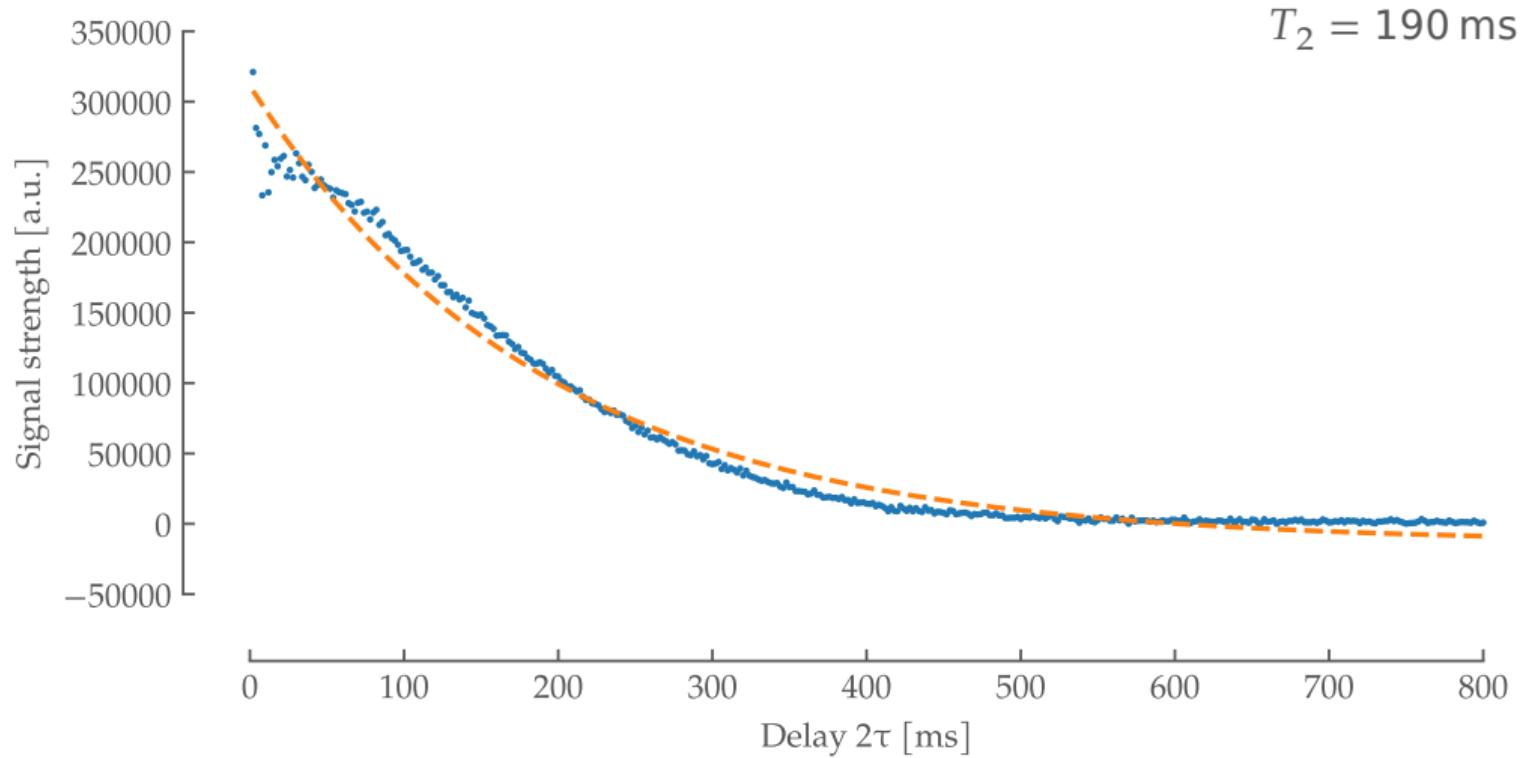
Spin Echo Animation



Spin Echo Measurement



T_2 decay of water



Demo time!

Review

- Why?
- The parts
 - Console
 - Amplifiers
 - Switch
 - Probe
- Capture & Process Software
- Experimental Results
- Demonstration

Outlook

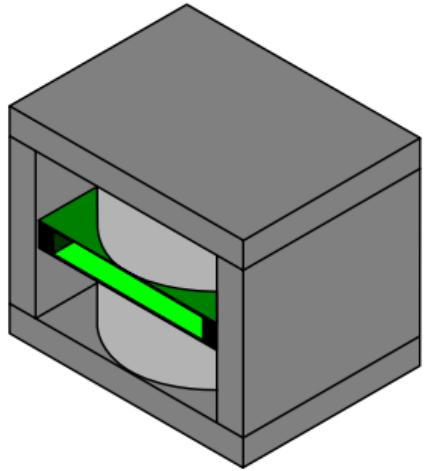
- Shim Driver
- Shielding
- Improve any part individually
 - Cheaper Magnet
 - Better Probe
 - Software (CIC compensation filter, frequency adjustment during pulse, ...)
- Investigate temperature stability
- Sell it to NexMR (or do Photo-CIDNP ourselves)

“I have not yet lost that sense of wonder, and of delight, that this delicate motion should reside in all ordinary things around us, revealing itself only to him who looks for it.”

“There the snow lay around my doorstep — great heaps of protons quietly precessing in the Earth’s magnetic field.”

— E.M. Purcell

Thank you!



*magn***ETH**ical

Find everything on

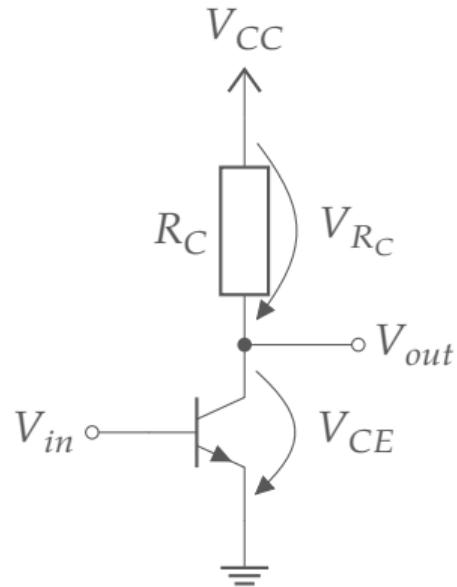


[https://gitlab.ethz.ch/mstabel/
nmr-spectrometer](https://gitlab.ethz.ch/mstabel/nmr-spectrometer)

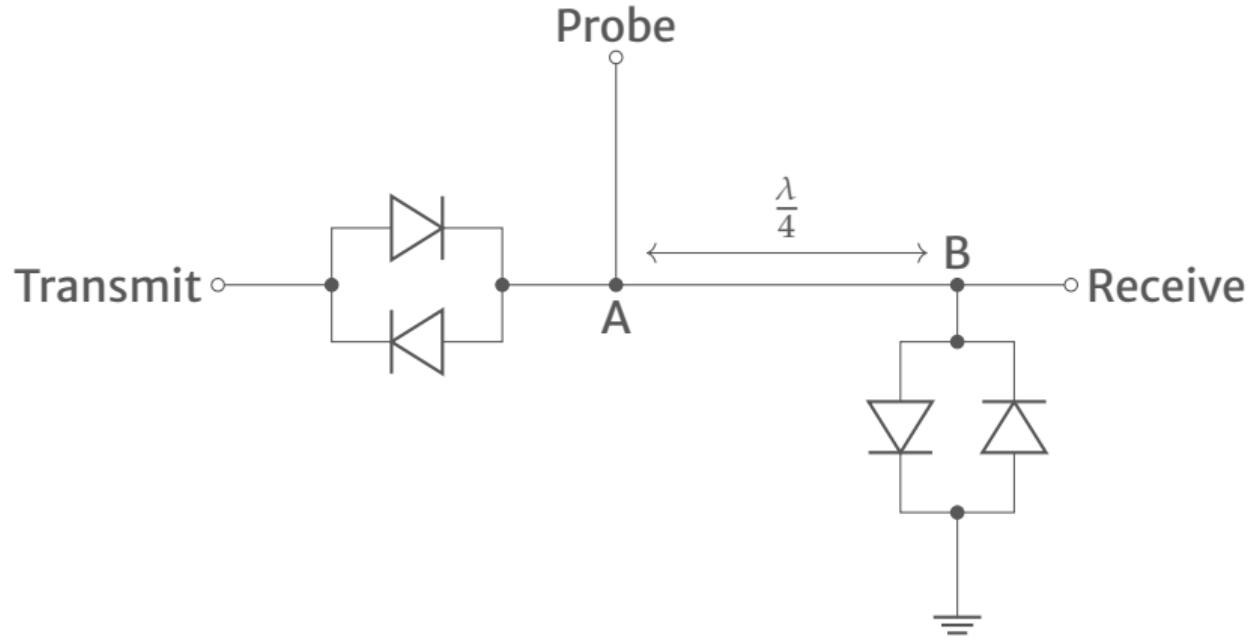
Backup

An amplifier is basically just a transistor

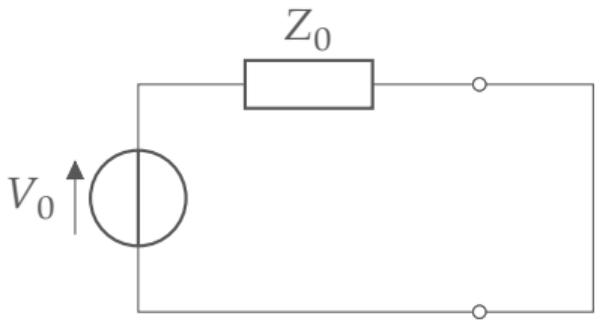
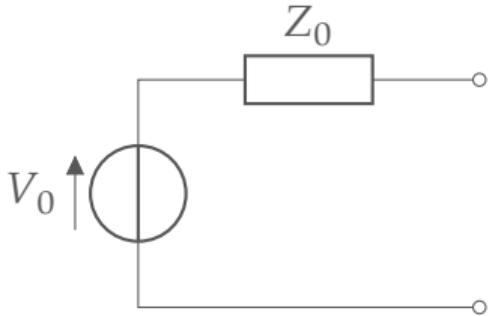
- Transistor:
voltage-controlled current source
- higher voltage → higher current
 - higher voltage V_{R_C}
 - lower voltage V_{CE}
 - 180° phase shift



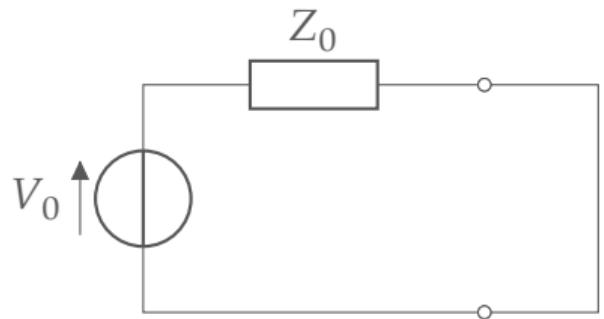
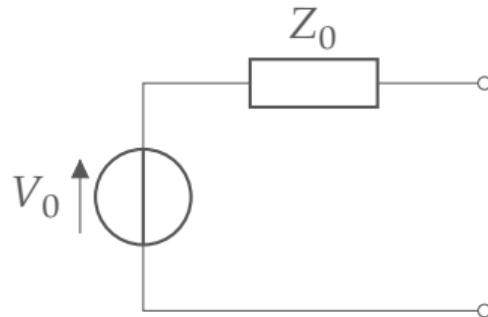
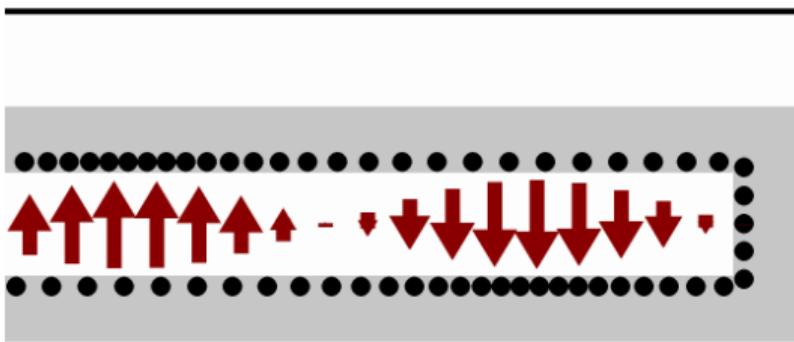
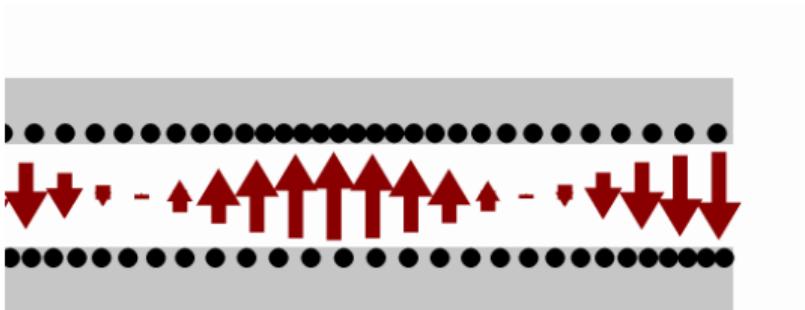
The passive approach leaked too much power



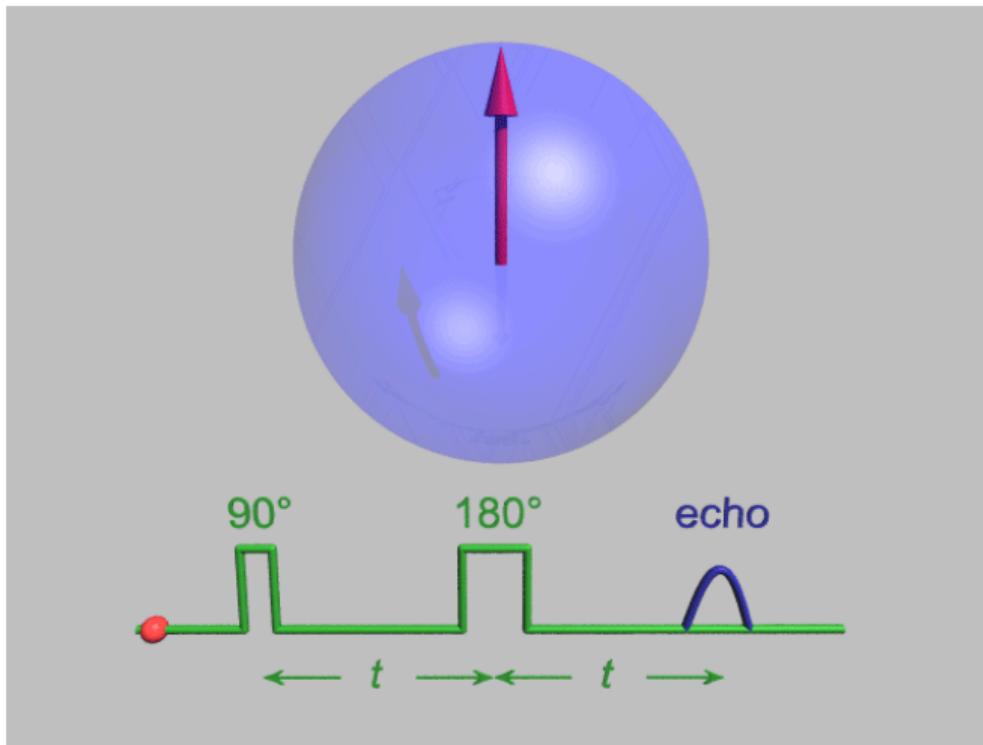
A transmission line transforms impedance



A transmission line transforms impedance



T_2 Decay Animation



MaRCoS

