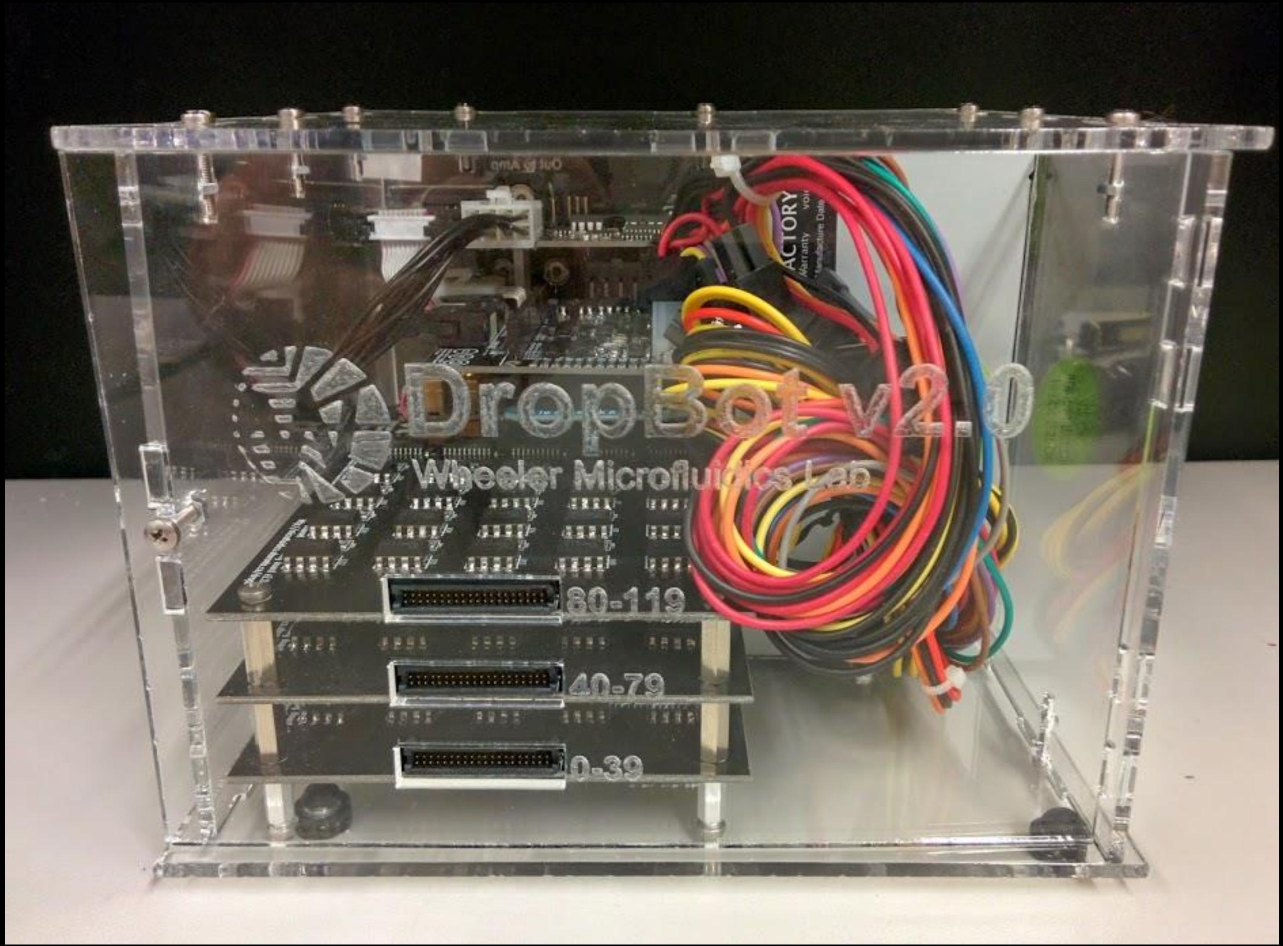
Wheeler Microfluidics Lab

DropBot System Overview

Ryan Fobel
PhD Candidate

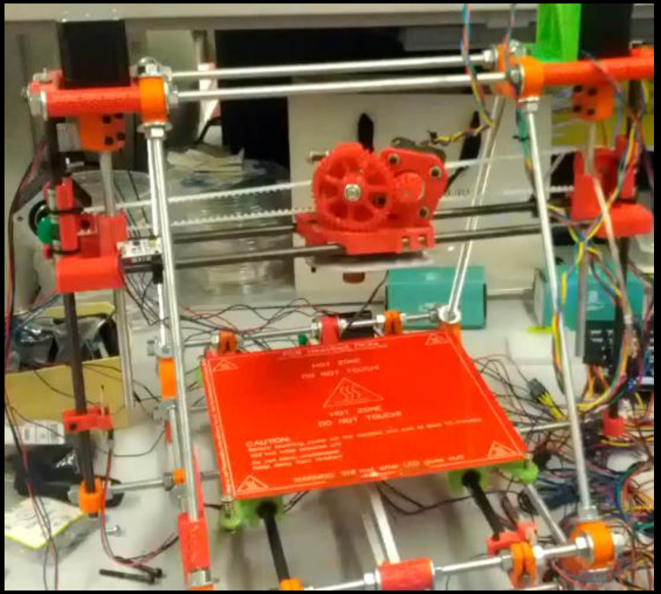


open source hardware

University of Toronto

Philosophy of open-source hardware

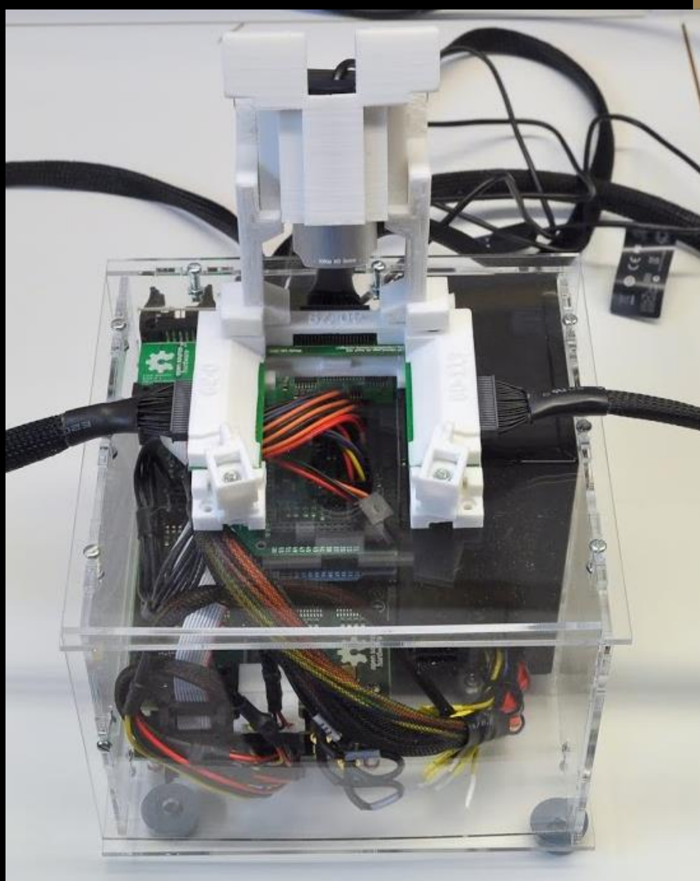
- Don't re-invent the wheel
- Goals/concepts familiar to scientists (peer-review, living design/documentation evolves over time, improved by community)
- When commercial DMF instruments come along, they are likely to be closed appliances

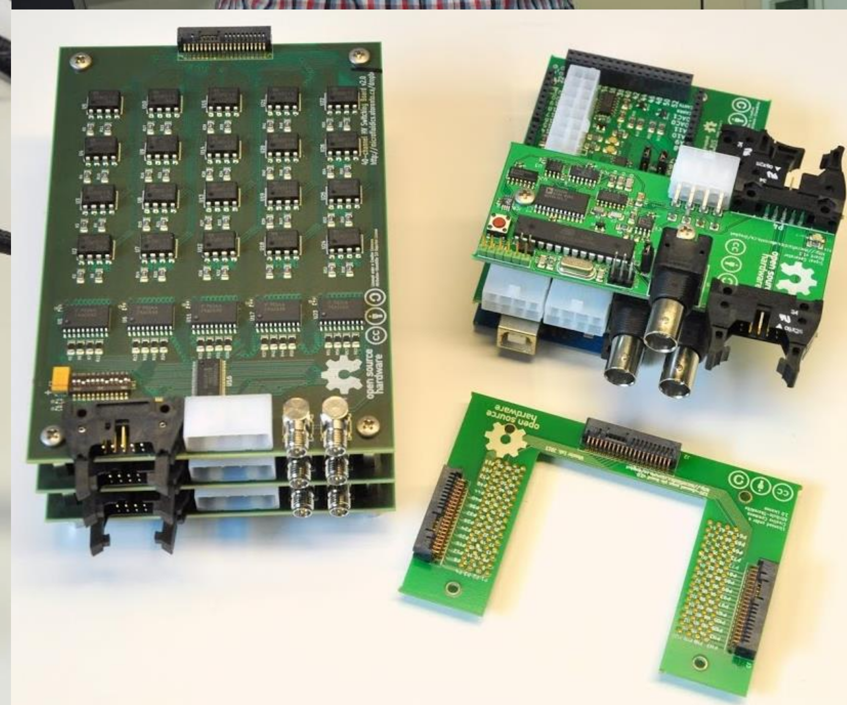


http://www.reprap.org

http://www.arduino.cc

- 1st photos of a DropBot system in the wild!
- Hopefully more to come soon…



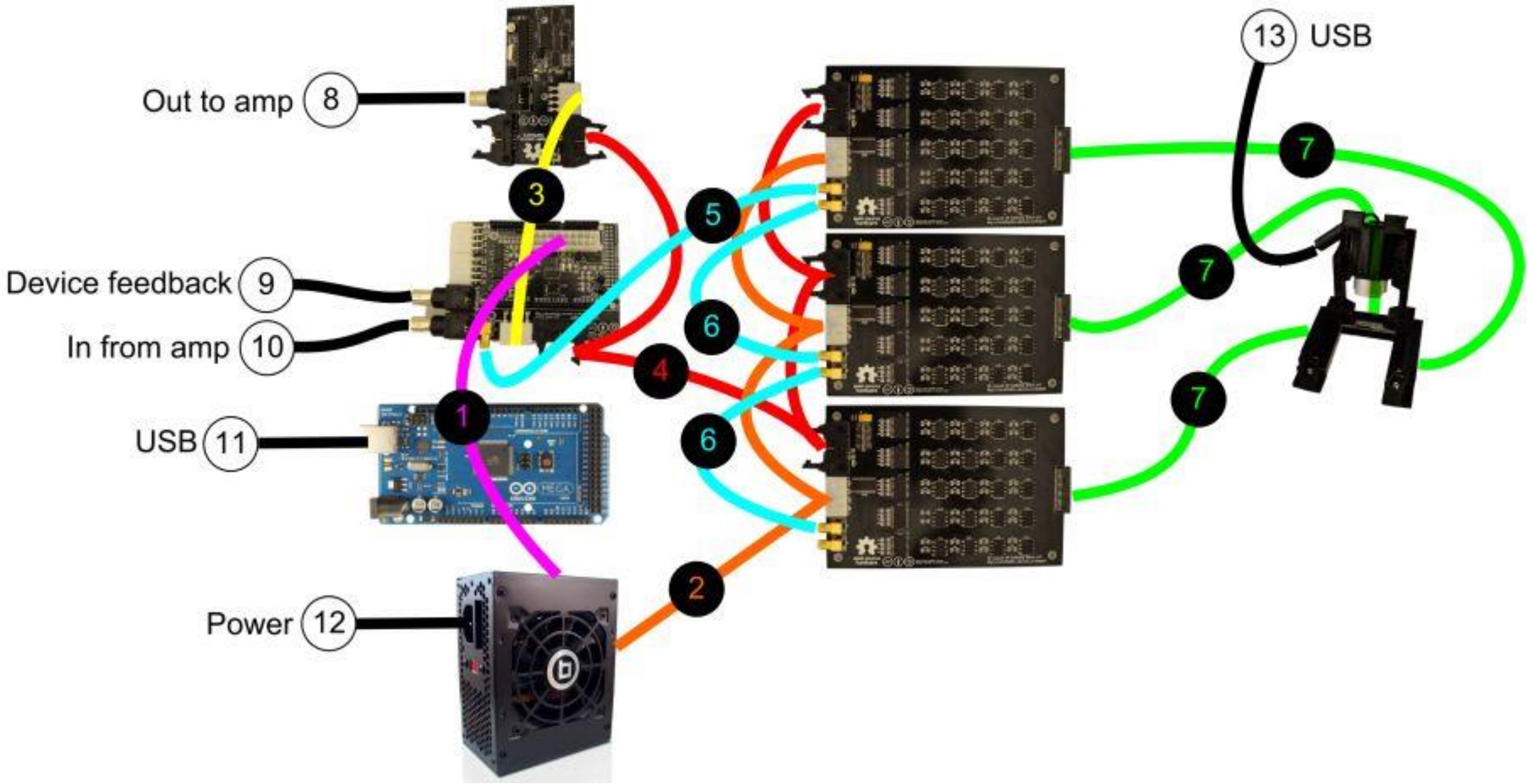


Markus Haapala and Tiina Sikanen
Faculty of Pharmacy
University of Helsinki

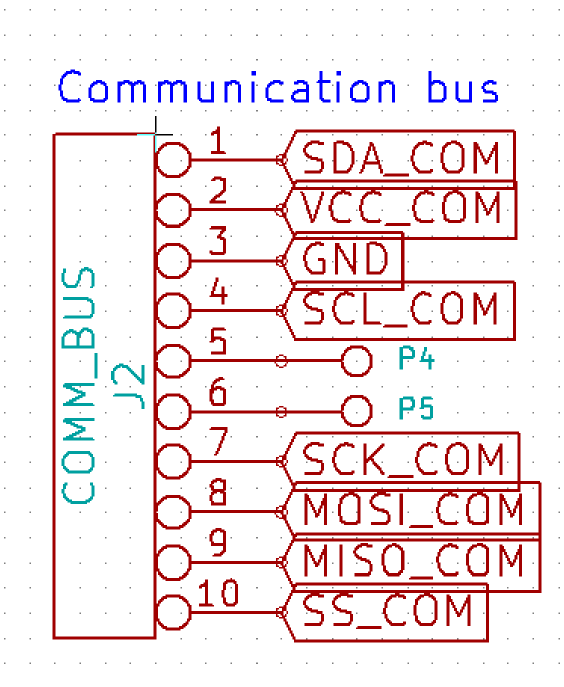
Modular and easy to extend

- modular/decoupled hardware (40 to >1000 channels)
- ARDUINO and python™ based
- software plugin architecture
- can integrate with existing hardware
- I^2C/power (+/-12V, +5V, +3.3V) breakouts (i.e., to add sensors/actuators)

Connection diagram

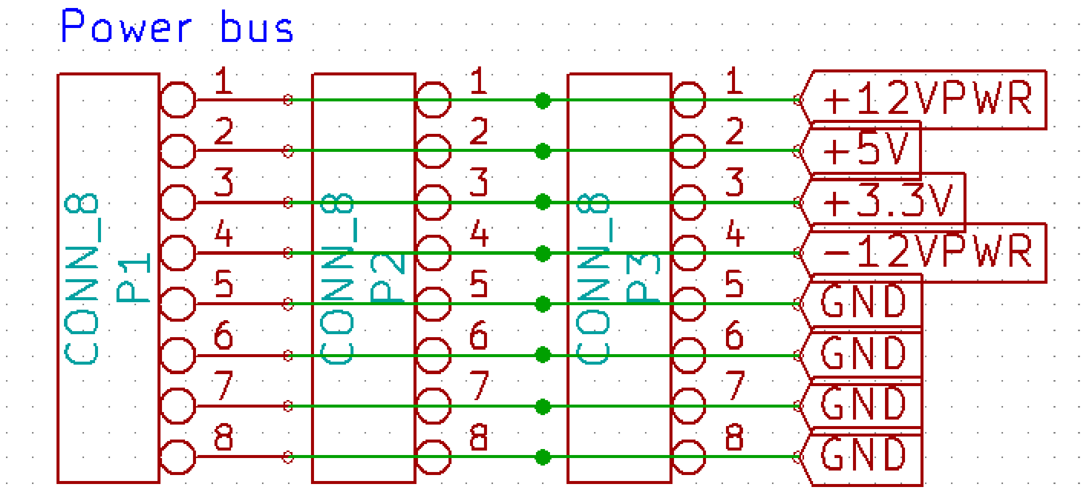


Communication bus (i^{2}c and SPI)



- I2c multiple devices can share same 4 wires (<400kbs)
- SPI requires cable select wire for each slave (>4 Mbps)

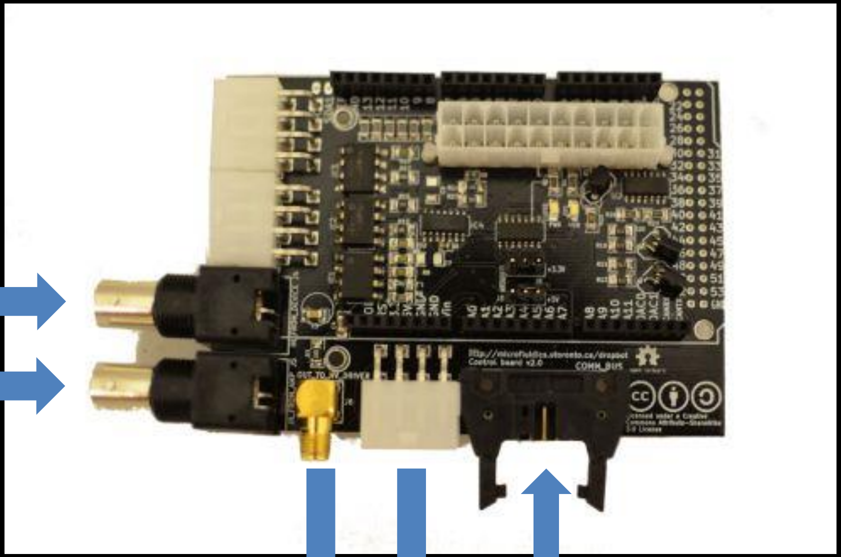
Power bus



- Power external hardware (sensors/actuators) with several Amps (depends on PSU)

System components

Control board



Measure current through device

Measure amplifier output

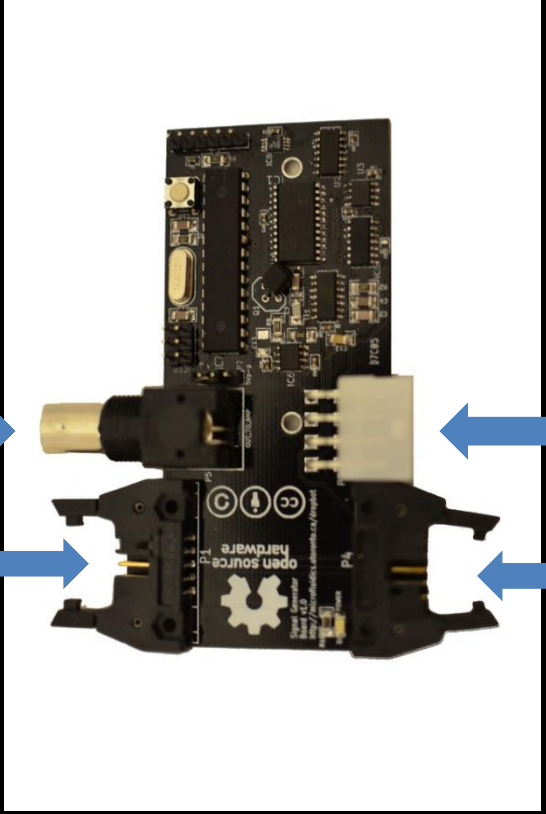
HV signal

Power to other boards

Comm. with other boards

- shield for an Arduino Mega 2560
- communication with the computer (over USB)
- impedance-measurement (estimating drop position, velocity, etc.)
- control of other system hardware (signal generator board, high-voltage switching boards, other custom hardware modules)

Signal generator board



- produces sine waves at voltages up to 20 Vpk-pk and frequencies ranging from 100 Hz to 50 kHz
- communicates with the control board over the communication bus ribbon cable

High-voltage switching board

Communication with other boards

Power

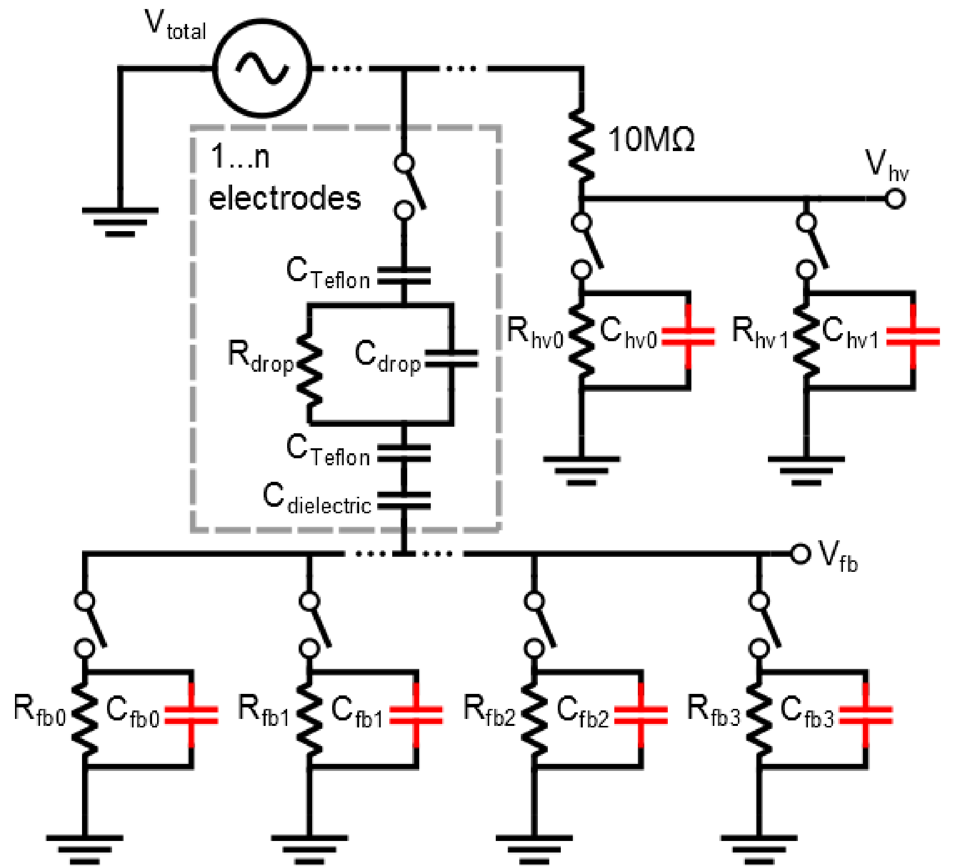
HV signal from amplifier

HV signals to DMF electrodes

- controls the on/off state of the DMF electrodes (2 solid state relays per channel)
- Each board controls 40-channels and multiple boards can be daisy-chained together to create a DropBot system with >120 channels

Features

Quantitative, dynamic impedance measurement over wide range of conditions



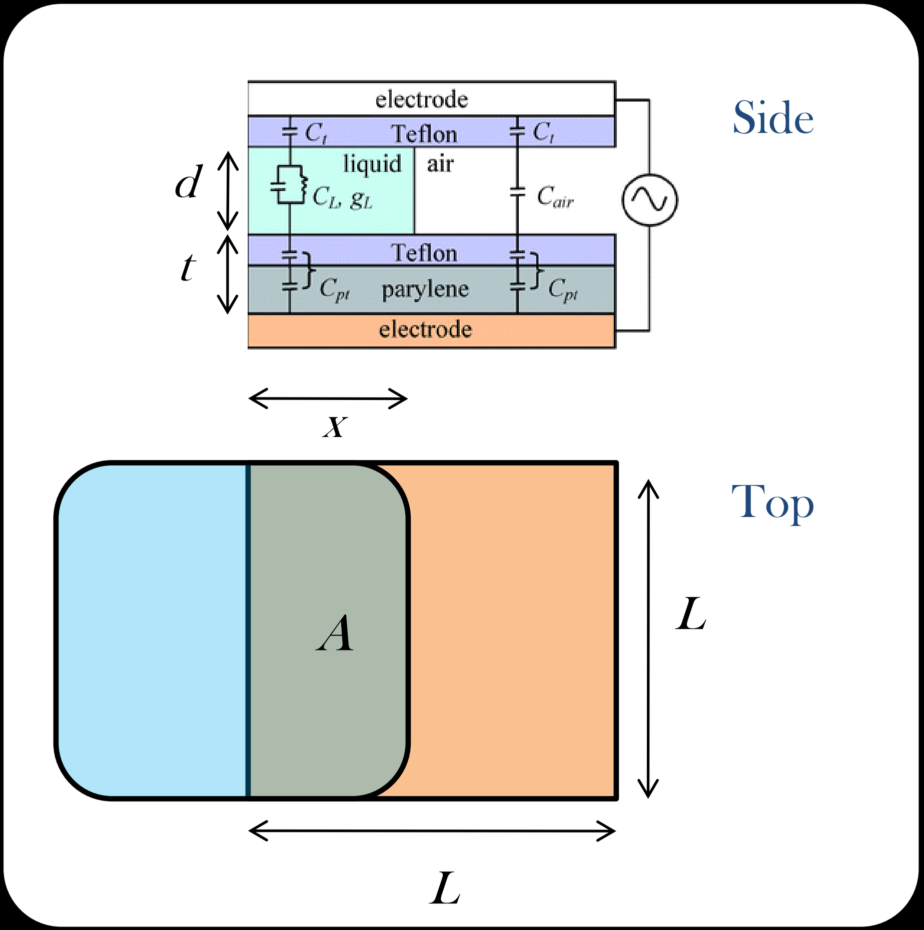
- Typically work over range of frequencies from 100 Hz to 20 kHz
- Range of dielectrics require operating voltages of 20 V to >500 V_{RMS}
- Need to compensate for amplifier loading, parasitic capacitance, etc.

Fobel et al., *Appl. Phys. Lett.. 102,* 2013

Impedance sensing gives us lots of useful, quantitative information

Closed-loop control and real-time measurement[1] of:

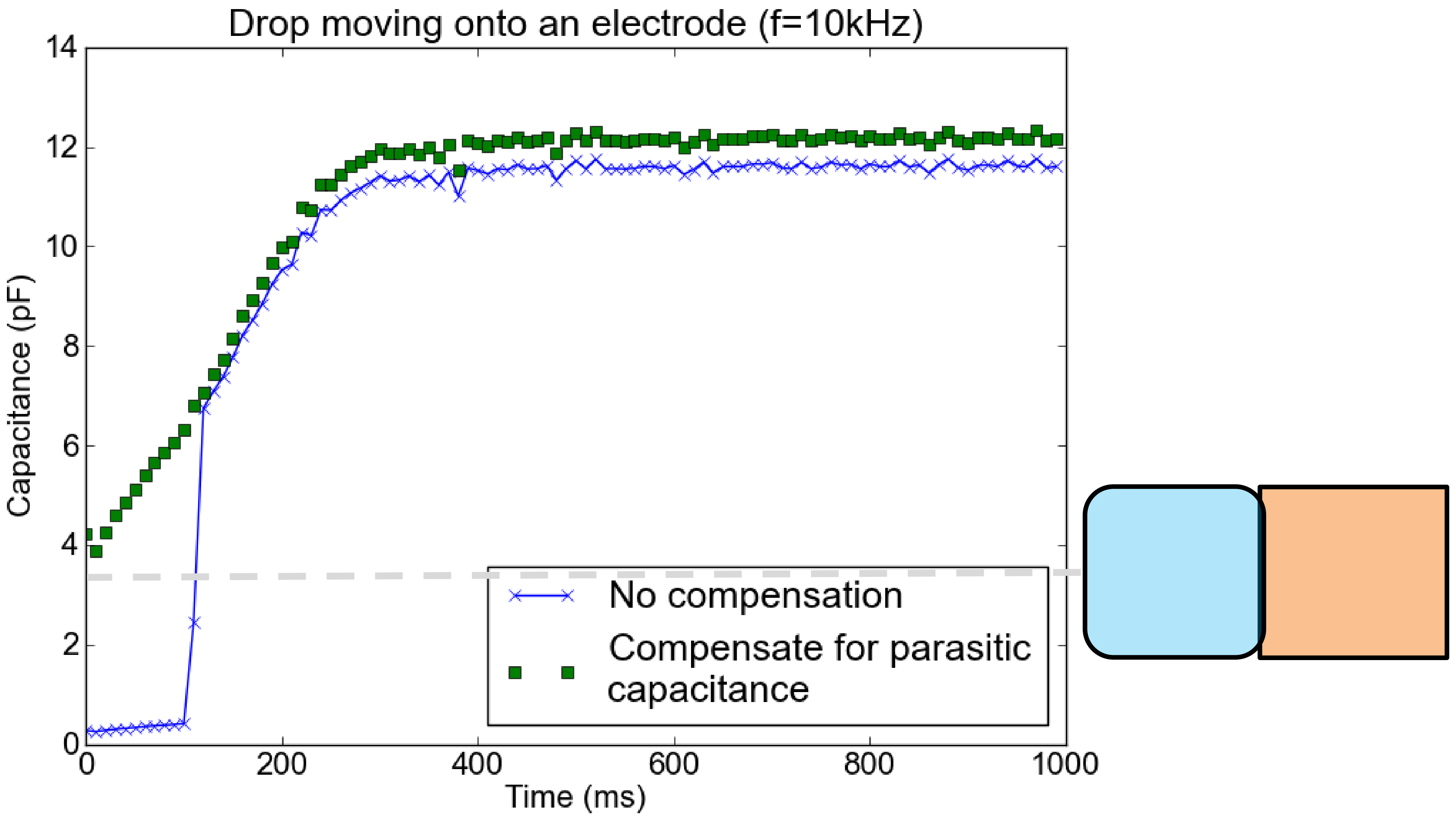
- actuation voltage
- drop position
- instantaneous velocity
- measured voltage and capacitance allows for calculation of force using electromechanical model[2]



1. Fobel et al., *Appl. Phys. Lett.* 102 (2013).

2. Chatterjee et al., *Lab on a Chip.* 9 (2009).

Compensation for parasitic capacitance



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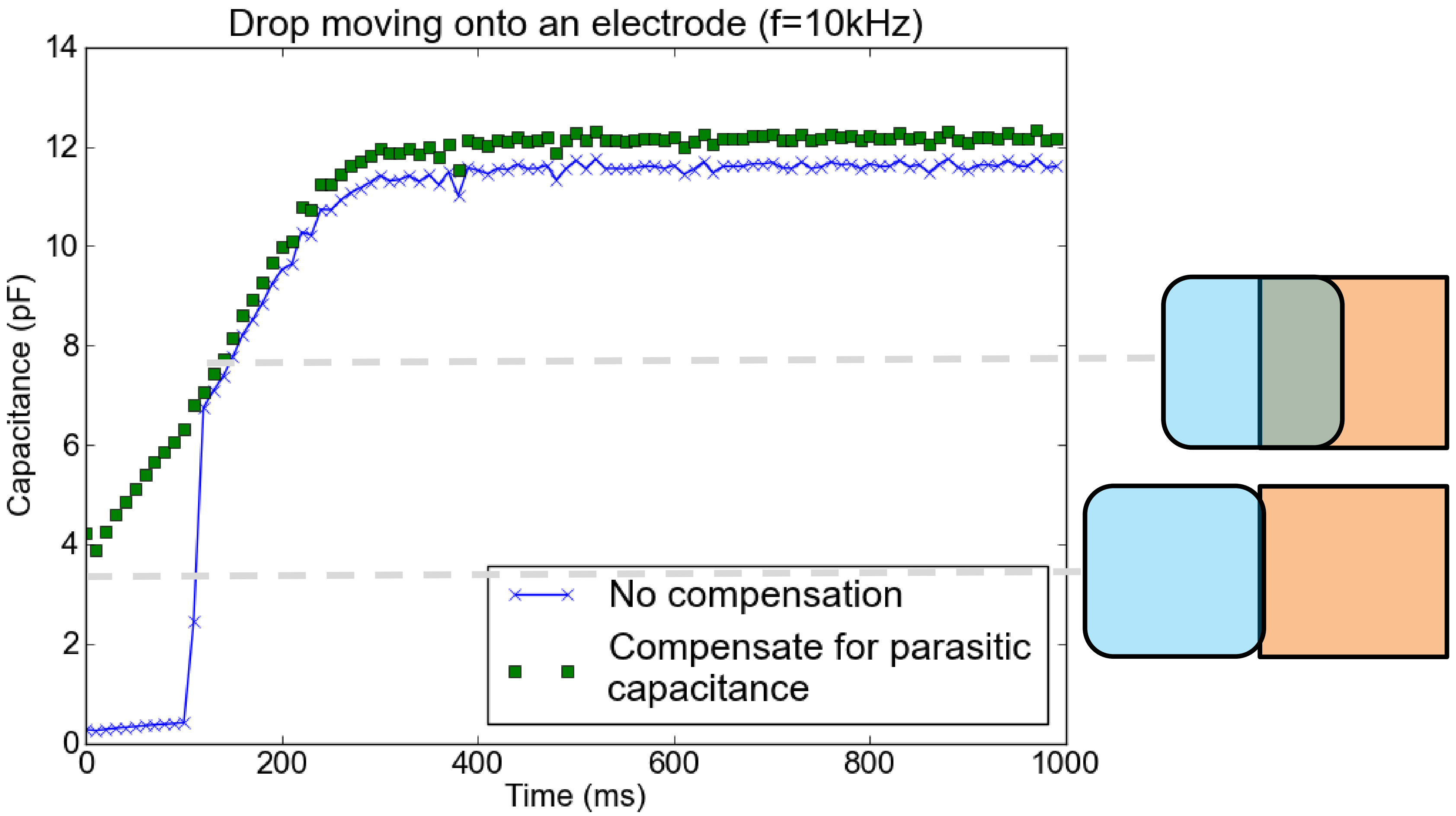

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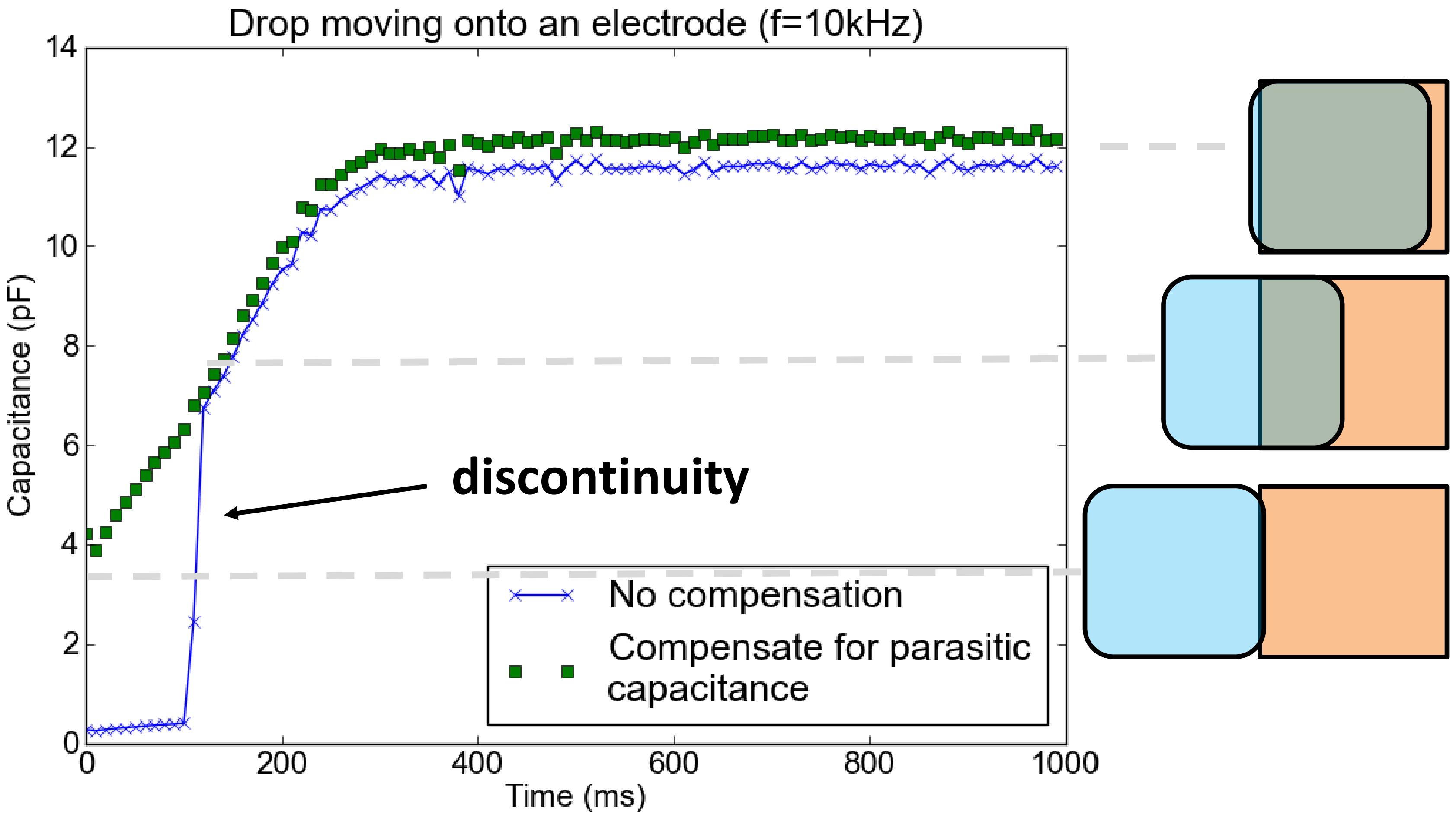

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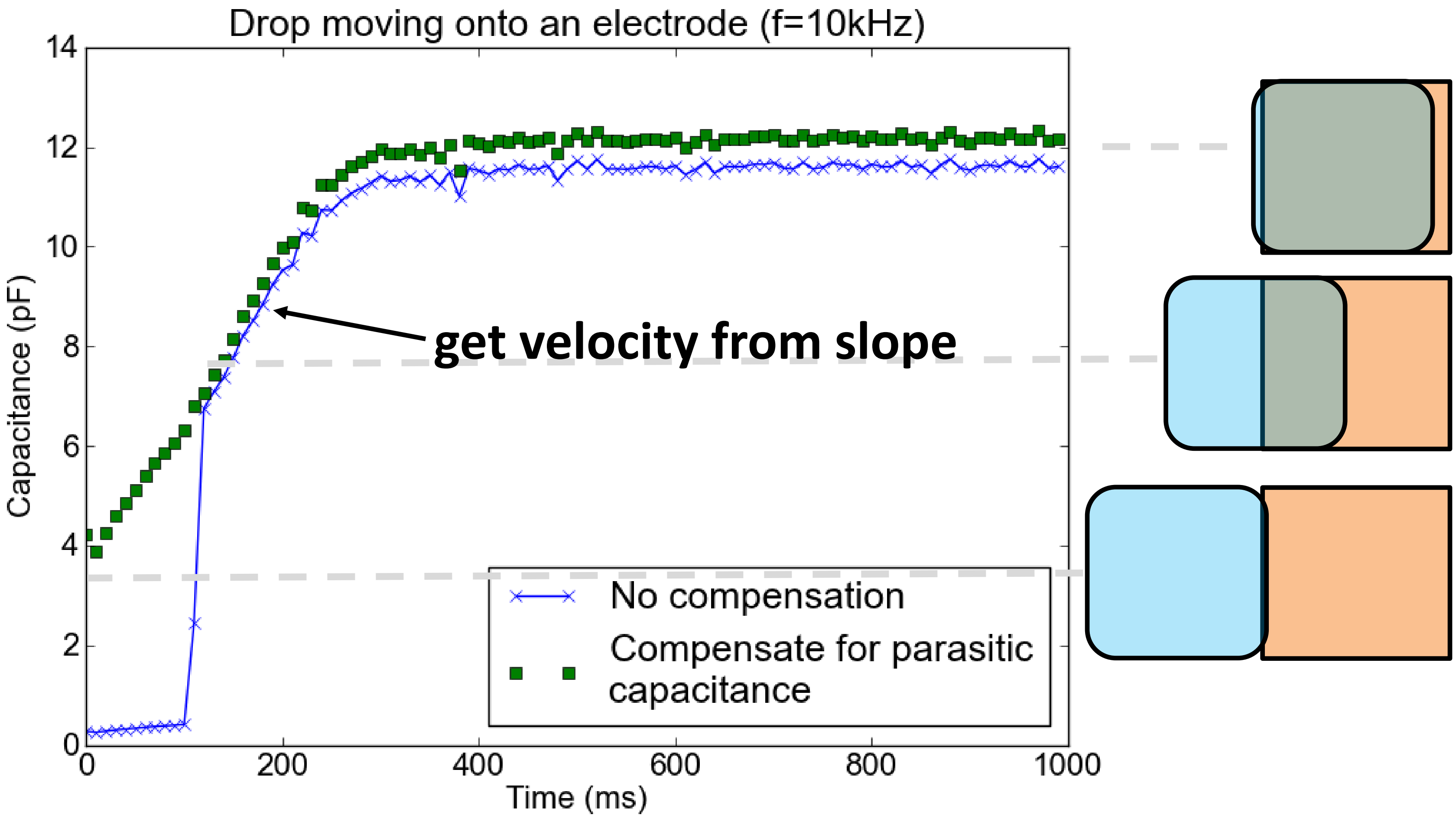
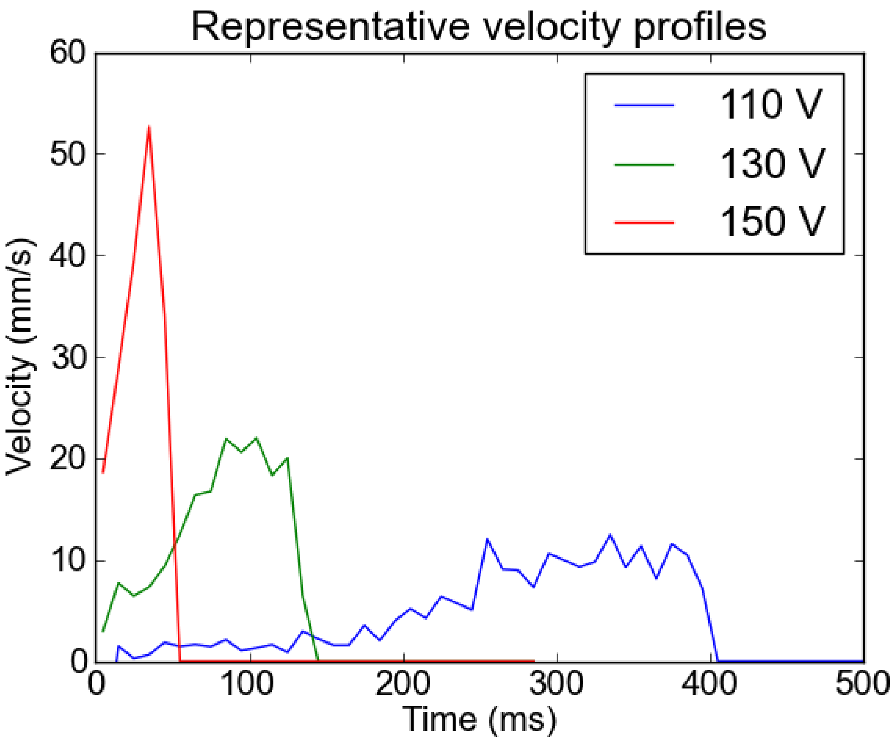


Fobel et al., *Appl. Phys. Lett.. 102,* 2013

Instantaneous velocity



$$|Z| = \frac{1}{2\pi f C} = \frac{d}{2\pi f \varepsilon_0 \varepsilon_r A}$$

$$|Z| = \frac{k}{A} \quad \text{, where } k = \frac{d}{2\pi f \varepsilon_0 \varepsilon_r}$$

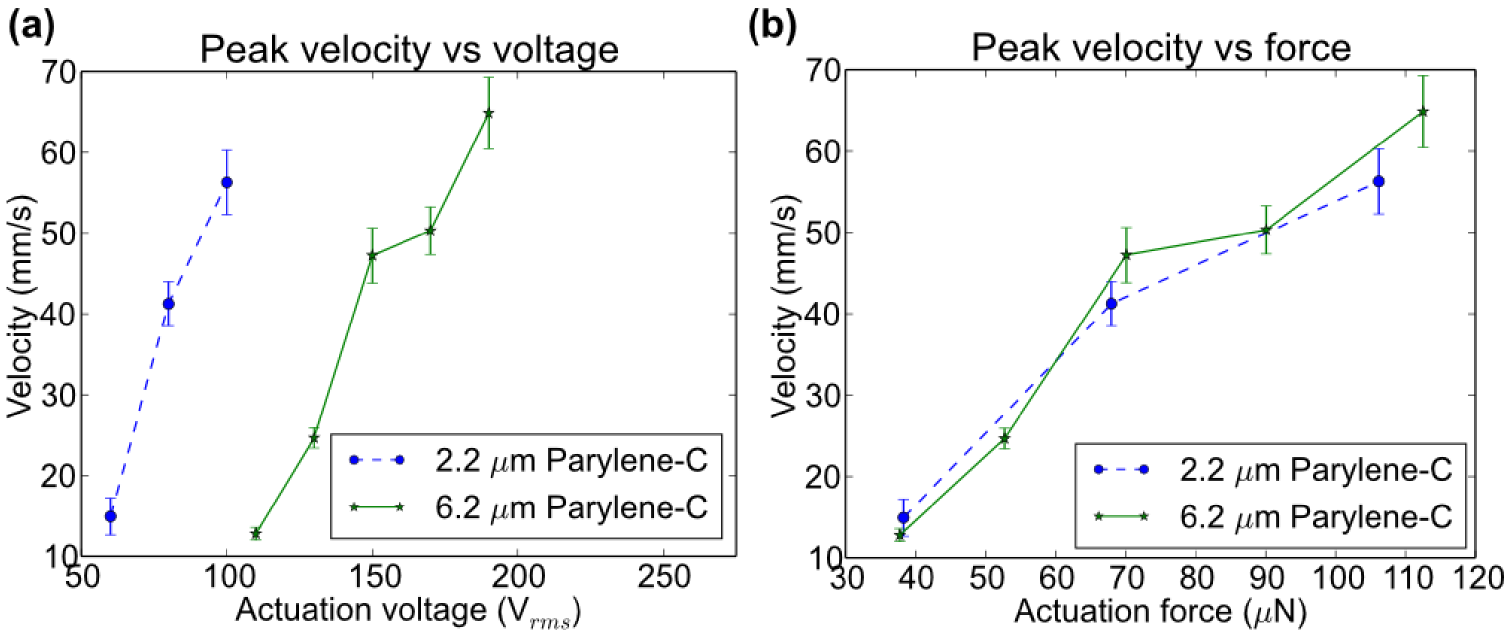
$$x = \frac{k}{|Z|w}$$

$$\text{Velocity} = \frac{dx}{dt} = -\frac{k}{|Z^2|}\frac{d|Z|}{dt}$$

- Quantitative metric describing device performance, changes to dielectric/surface

Fobel et al., *Appl. Phys. Lett.. 102,* 2013

Normalize voltage by electrostatic force



- Easily operate/compare devices with different dielectrics/geometries

Fobel et al., *Appl. Phys. Lett.. 102,* 2013

New in v2.1

- Switching boards now have their own microcontroller chip (no added cost, easier to solder, opens up new possible features)
- All boards 2 layers - scan make on single PCB panel (<$200)
- Easier to solder by hand
- In system programming
- New case layout (easier to access cables, etc.)

Check parts list

Participant materials checklist

Quantity	Description
1	FTDI Serial/USB cable
1	BNC to alligator clip cable
1	USB A-B cable
1	Arduino Mega 2560
1	Extension module proto board
1	Signal generator power cable
1	Communication bus ribbon cable
23	Machine screw (M3, .5mm pitch, 16mm)
4	Machine screw (M3, .5mm pitch, 12mm)
19	Machine screw (M3, .5mm pitch, 8mm)
34	Thin hex nut (M3, .5mm pitch, 1.8mm height)
4	Rubber foot (1/4" hole, 1/8" deep)
2	Female threaded hex standoff (M3, .5mm pitch, 20mm)
4	Female threaded hex standoff (M3, .5mm pitch, 12mm)
8	Male/female threaded hex standoff (M3, .5mm pitch, 15mm)
2	SMA cable assembly (50 ohm, RG 174, 100mm)
1	SMA cable assembly (50 ohm, RG 174, 200mm)
6	Jumper wires for flashing Arduino bootloader
1	Set of 3D printed parts for the 120-channel device connector
1	Set of laser cut parts for the case
1	Set of laser cut parts for the 120-channel device connector
1	Phillips #1 screwdriver
1	USB key

Assembly and calibration

Assembly

- Step 1: Install the Microdrop software
- Step 2: Install the control board plugin
- Step 3: Install the Arduino Mega 2560 driver
- Step 4. Flash the control board firmware
- Step 5. Set the control board jumpers
- Step 6. Burn a bootloader onto the signal generator board
- Step 7. Flash the signal generator board firmware
- Step 8. Set the signal generator board jumpers
- Step 9: Assemble the case
- Step 10: Build the signal generator power cable and communication bus ribbon cable
- Step 11: Connect all PCBs and stuff the case
- Step 12: Assemble the 120-channel device connector

System calibration

- Signal-generator board calibration
- Control board calibration

Assembling cases and device holder

3D printing:

- makexyz.com
- variability in printers, printing parameters, etc.
- $40-60 for device holder
- Make sure you clean up parts before fitting together (file, pliers)

Laser cut acrylic case:

- T-slot connectors

Assembly and calibration

Assembly

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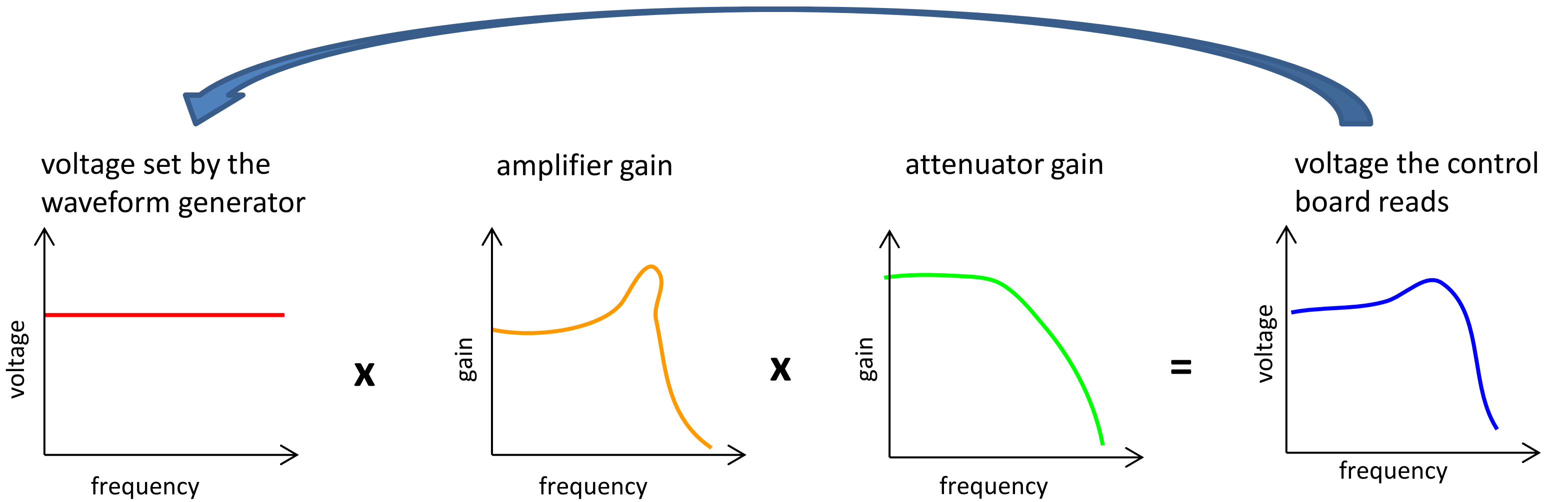
System calibration

- Signal-generator board calibration
- Control board calibration

Amplifier-gain compensation

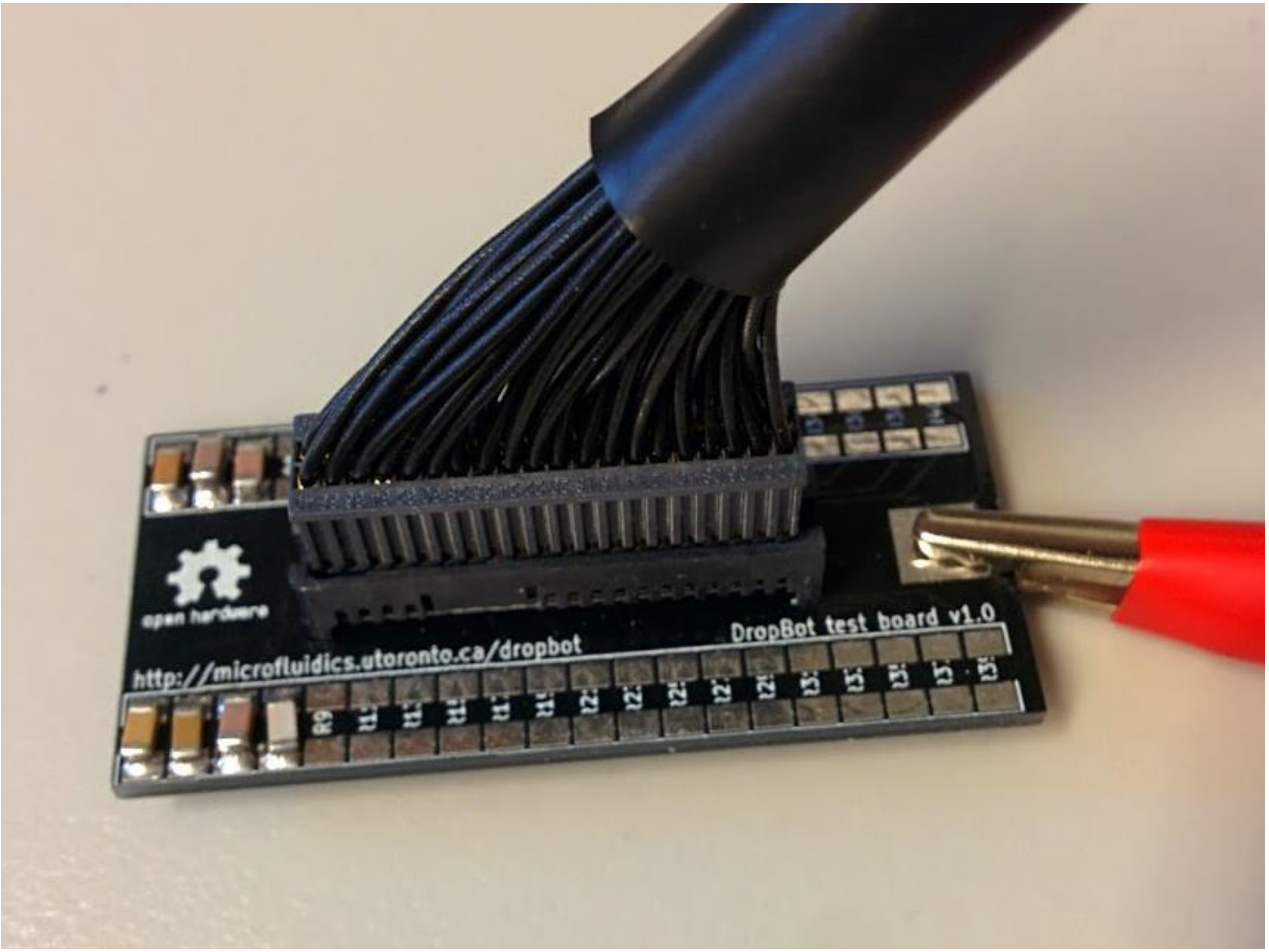
Feedback (i.e., auto-adjust input voltage to get the output we want)



Determined by resistors and parasitic capacitance of PCB (does not change)

Voltage applied to the device (changes with voltage, frequency, number of switches on, location of drops, etc.)

Test board


open hardware
http://microfluidics.utoronto.ca/dropbot
DropBot test board v1.0

Getting PCBs

- Besides the amplifier, PCBs are the major cost of the system
- Cheapest way is to solder them yourself
- Can also have the boards assembled by a 3rd party (we've used Gold Phoenix; let me know if you're interested in getting a quote from them as I think you may be able to reuse our stencil and save $200/board design).

Getting involved

- Even if you're not planning to write software or modify the hardware, there are lots of ways to make valuable contributions:
  - join the mailing list
  - report bugs
  - write/improve documentation (wiki)
  - suggest new features
  - spread the word!