Resonant frequency tracking with Inferno

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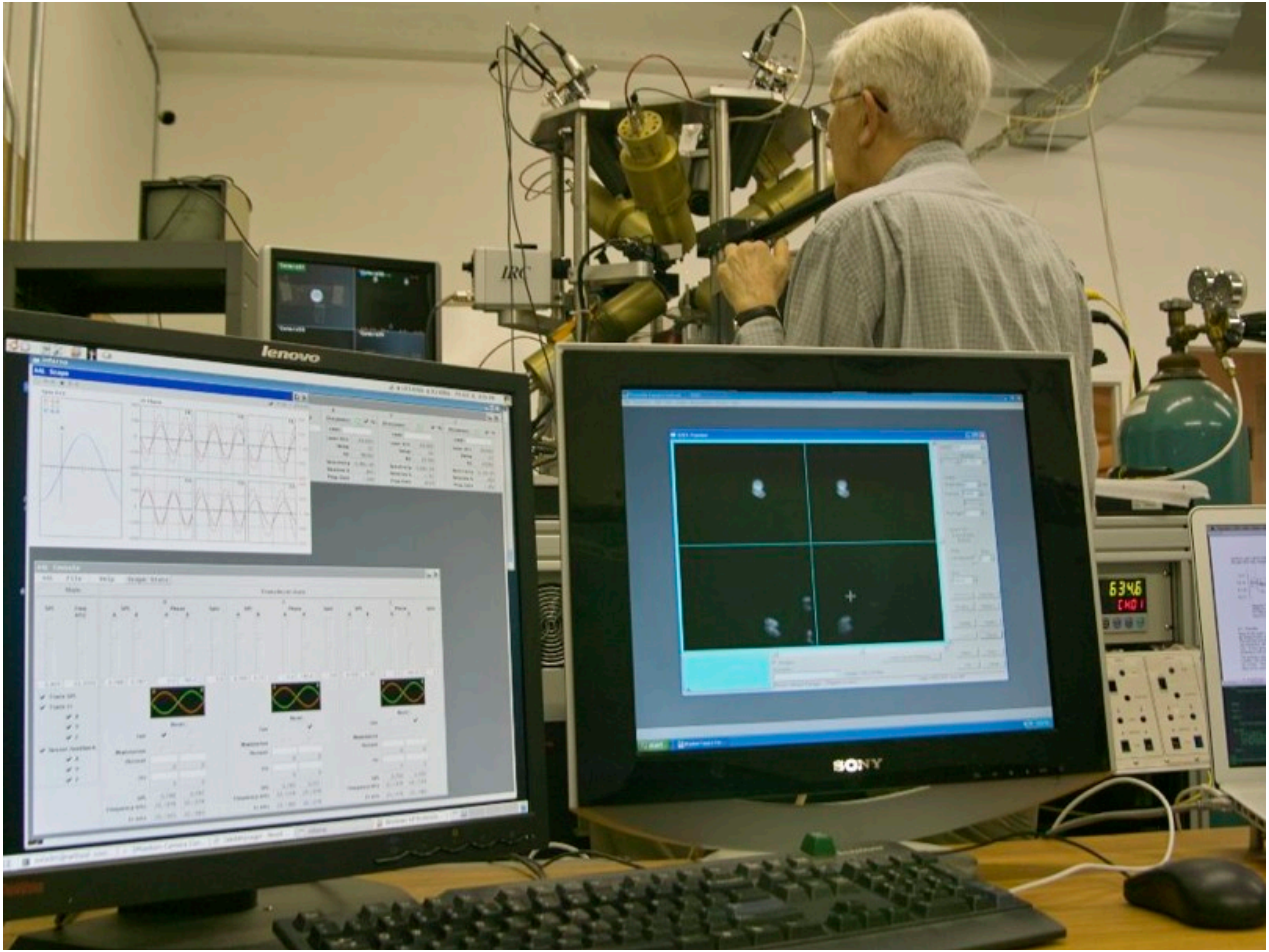

lenovo
SONY

Introduction

Aero-acoustic levitation

A method for containerless processing of molten materials at extremely high temperature.

Used in studying solid-liquid phase transitions, viscosity, recalescence, and experimental testing of material resonant frequency properties.

This talk

importance of resonant frequency tracking
introduction to the embedded system (dsPIC33F)
9p and the file system of the AAL
test environment
Inferno console

Resonant frequency tracking

Temperature dependent

Transducer thermal profile determines resonant frequency.

Higher output increases the temperature and lowers the resonant frequency.

Voltage-current phase relationship

Linear amplifiers operated in a constant voltage mode.

Transducer output power is dependent on gain, temperature, operating frequency, voltage-current phase, and resonant frequency.

Operation near resonance is optimal for maintaining equal sound pressure levels.

Sound pressure level

Measured in Torr (1 mmHg) 7.5cm from horn surface.

Matched transducer phases produce an optimal standing wave for proper position of the node and well slope for levitation.

Acoustic transducers

Solid aluminum alloy

Designed to resonate at ~22kHz.
Driven by piezoelectric transducers.
Shaped to match the impedance with air.

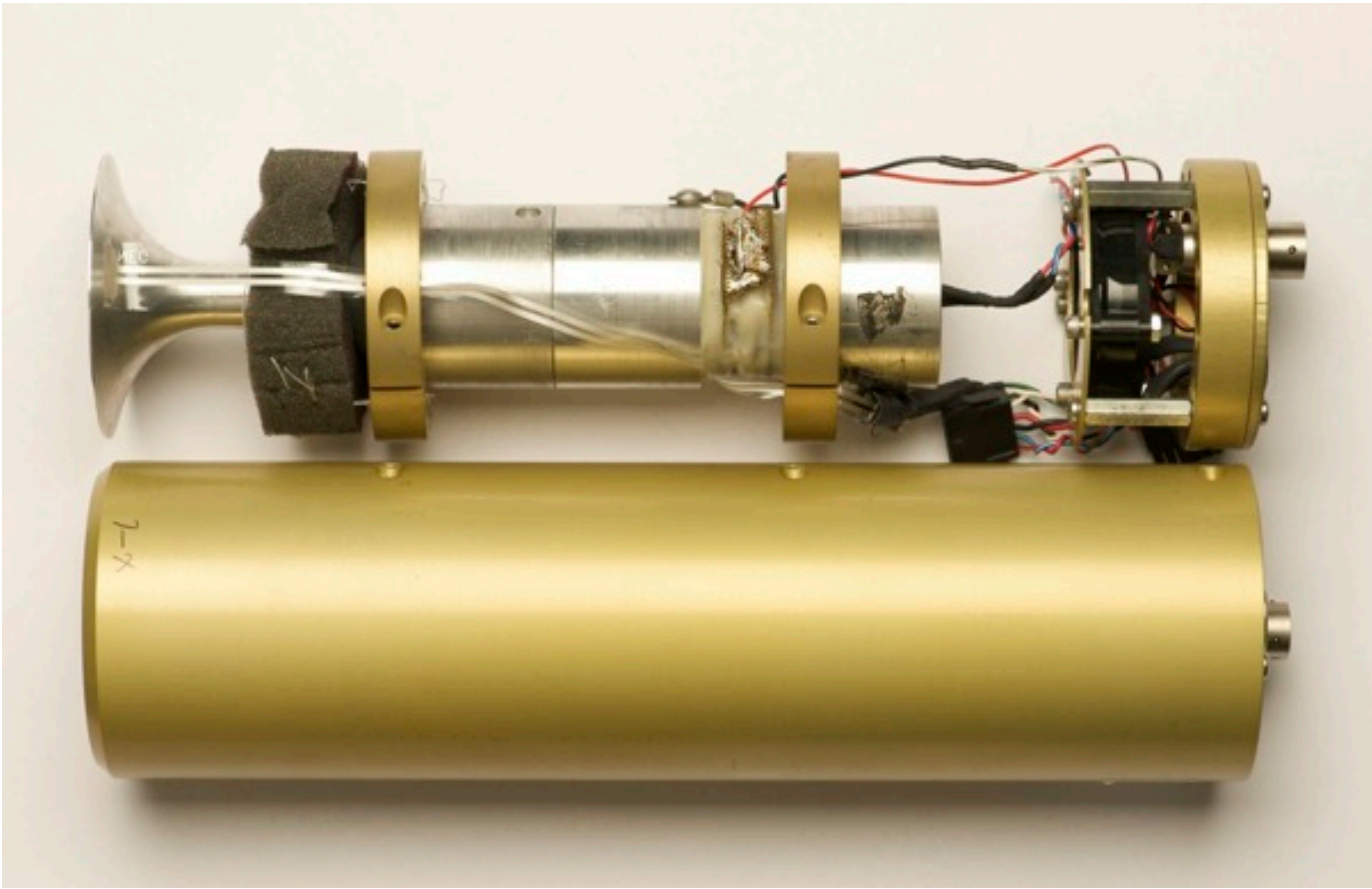
Manufacturing process introduces variations in mass and core responsiveness.
Optimal pairs matched on an axis, a set of three pairs installed in the AAL.

Acoustic transducers

Prior AAL versions

Piezoelectric film pickup mounted on the underside of the horn.

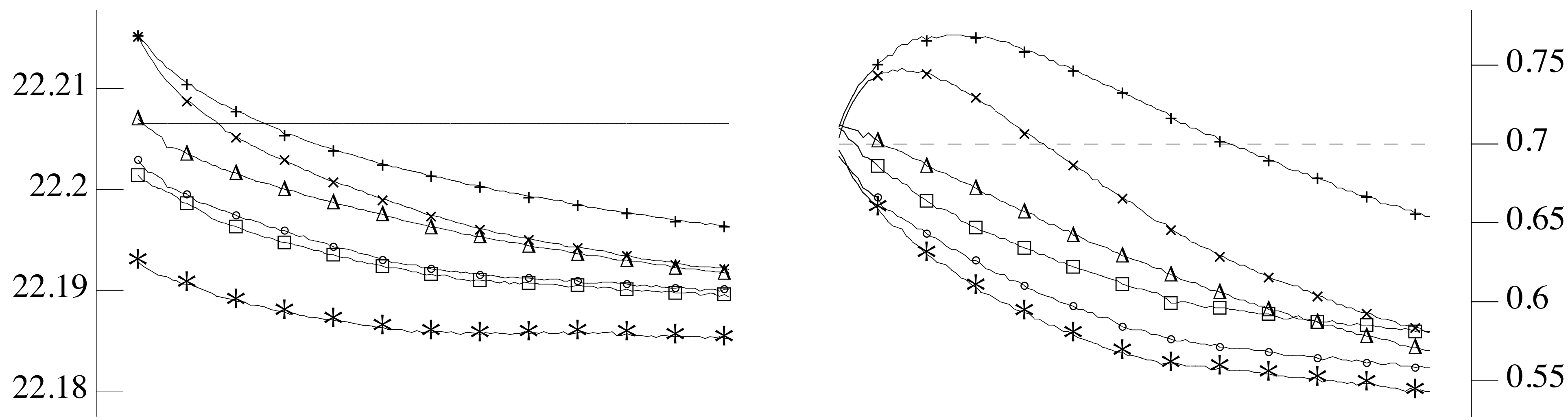
Proper placement proved problematic.



Operating frequency

Thermal profile

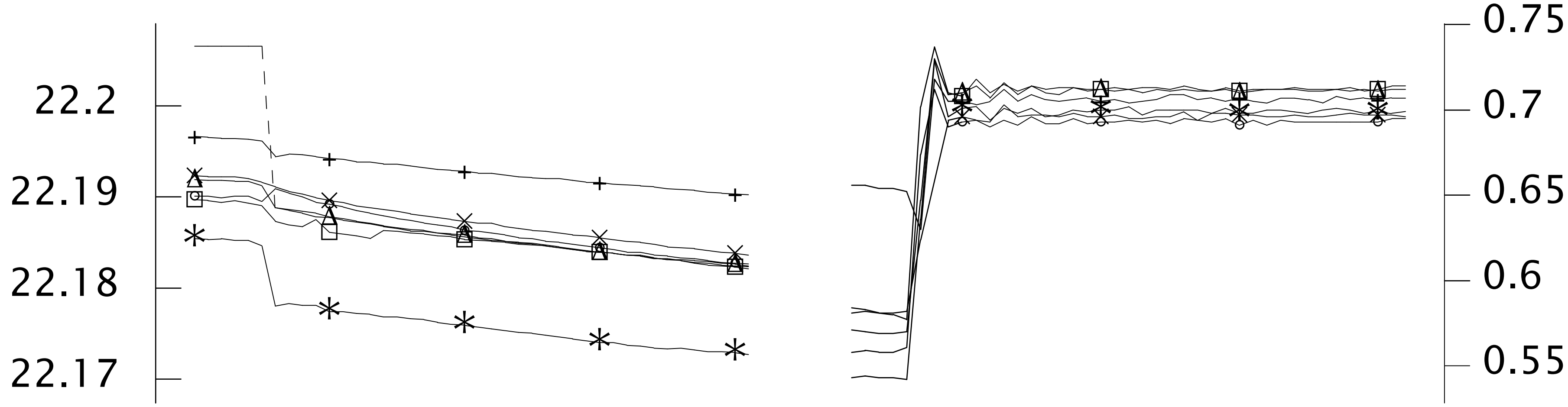
- Resonant frequency drops proportionally to the transducer temperature increase.
- Voltage-current phase measurements important for determining output power.
- Tracking resonant frequency of all six transducers allows for an average to be set as the operating frequency.
- Enabling:
  - consistent SPL is maintained
  - fan cooling control
  - longer experimental run times



Tracking frequency and SPL

Consistent output

Measuring the voltage, current, and voltage-current phase of a transducer allows for tracking of the running system without the mic input.



AAL

Chassis

Seven controller boards:

- one communication controller board
- six transducer controller boards

Frame

The frame consists of:

- six piezoelectric transducers, two per axis
- three position sensors coupled with 808nm diode lasers
- gas flow control and meter
- ceramic nozzle and heater
- cameras and pyrometer
- two CO_2 lasers

Embedded system

Chassis

Controller boards are based on a dsPIC33F and Xilinx XC9536XL CPLD.

Single dsPIC33F firmware version for all seven boards.

Position sensors

Axial feedback control to dampen sample movement.

Provides real-time stability control.

Feedback and configuration parameters controlled through simple serial protocol.

9p on 16-bit dsPIC33F

Port

- Plan 9 from User Space as reference
  - lib9
  - lib9p

Serial interface

- UART interrupt handler sniffs for Tversion message.
- Switches to DMA interrupt handler:
  - 4-byte size field
  - remaining message length
  - verified and processed in the main loop

- Interface for programatic control of the system.

File system

- One-level directory

```
% lc /n/aal
ctl    status t1err  t2err  t3err  t4err  t5err  t6err
data   t1     t2     t3     t4     t5     t6
stats  t1ctl  t2ctl  t3ctl  t4ctl  t5ctl  t6ctl
```

Back plane communication

Serial bus

- Leverages dsPIC33F's 9-bit mode for address detection.

Modified Fcall

- Not all messages are required to be a transaction.
- Most messages write values on the transducers controllers.
- AAL_Tdata requires a response.
  - A board is marked as offline if it does not respond over a period of time.

Position Sensors

One per axis

dsPIC33F based board modulates an infrared laser.
Samples signals from a two-dimensional position sensing detector.
Calculates velocity and sends phase correction data to transducer controllers.

Serial interface

Transmits 250 packets per second of phase change data.
Maximum throughput of ~4000pps possible, transducer Q-factor limited.

Testing environment

Hardware Probes

Voltage and current probes to validate phase and RMS (or Pk-Pk) values.

Software measurements, stats from transducer controllers

dsPIC33F measurements from ADC and V-I phase.

All testing reads from *data* or *stats* files.

ID	Ai	Fi	Phi	Mper	Mfreq	Flags	Vo	PhiV	Io	PhiI	F
t1	3100	222000	0	0	0.00	132	507	2922	209	0	0
t2	3100	222000	2048	0	0.00	132	538	2892	265	0	0
t3	3100	222000	0	0	0.00	132	502	3146	248	0	0
t4	3100	222000	2048	0	0.00	140	535	2636	160	0	1
t5	3100	222000	0	0	0.00	140	495	0	393	3150	1
t6	3100	222000	2048	0	0.00	140	592	0	404	3140	1

Transducers

Gain

Output tests run to verify SPL produced at specified voltage.

Frequency

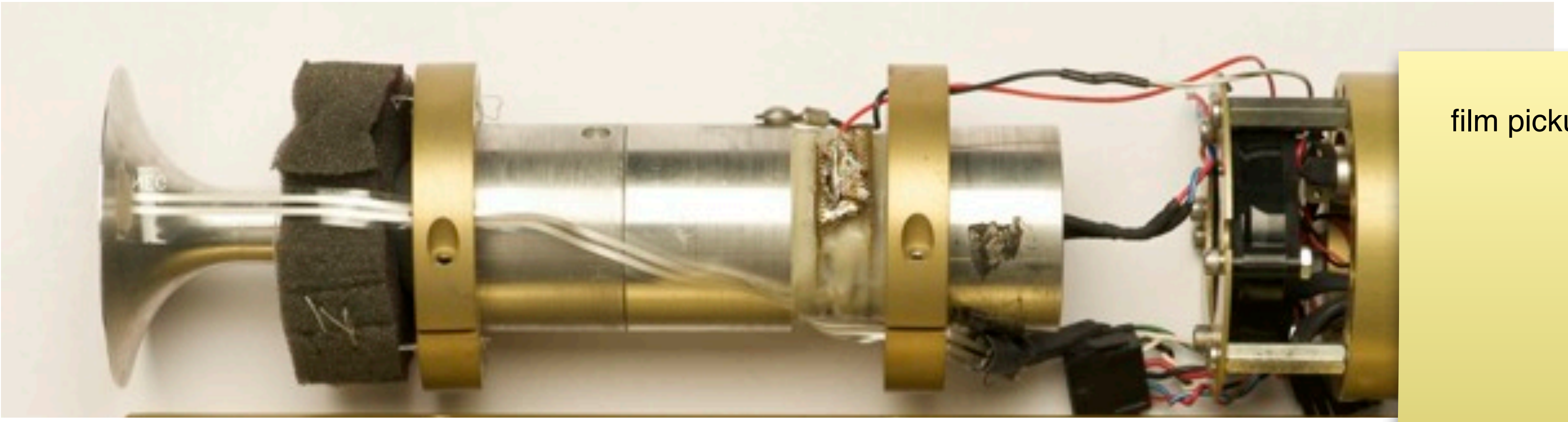
Sweep at constant gain to check V-I phase.

Phase

Verify that changes are synchronized for valid position and spin control.

Feedback

Remember the piezoelectric film pickup?



film pickup, it’s gone.

Calibration

V-I phase verification

```
log = $home/tests/run.log
fn s {
    ts = ‘{date -n}
    ID=‘{echo t$1}
    delta=‘{echo $2}
    PkV=‘{echo $3}
    PkI=‘{echo $4}
    measure=‘{cat $ID}
    Ai=‘{echo $measure | awk ’{print $2}’}
    Fi=‘{echo $measure | awk ’{print $3}’}
    Vo=‘{echo $measure | awk ’{print $8}’}
    PhiV=‘{echo $measure | awk ’{print $9}’}
    Io=‘{echo $measure | awk ’{print $10}’}
    PhiI=‘{echo $measure | awk ’{print $11}’}
    echo $ts $ID $Ai $Fi $Vo $PhiV $Io $PhiI $delta $PkV $PkI >>
    $log
}
cd /n/aal
echo freq 221900 > ctl
echo gain 2920 > t6ctl
# record transducer 6 measurements
# delta in µs
# ouput voltage and current recorded in volts from a scope
 s 6 7.2 2.98 .184
```

Resonant frequency equations

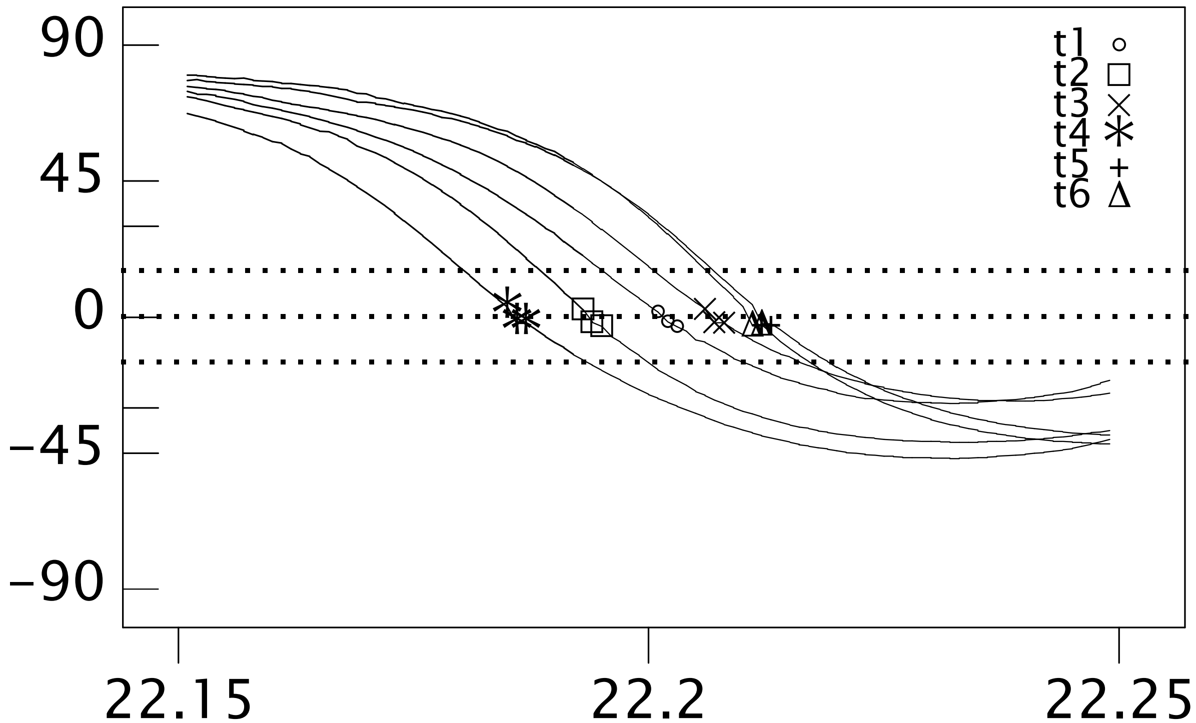
Measured values during calibration

Voltage and current RMS (or Pk-Pk), and phase.

Data from controller board

All testing reads from *data* or *stats* files.

Commands sent to *ctl* file.



$$\phi_c = \mathrm{Sign}\left(\phi_I - \phi_V\right) \cdot \left(1 - \frac{(\phi_I + \phi_V)}{\mathrm{Fosc} \cdot 2} \cdot \omega\right) \cdot 180$$

Resonant frequency equations

Power output

Maintain a set point for SPL 7.5cm from transducer horn.

$$P = \frac{V \cdot I}{100} \cdot \cos(\phi)$$

$$\mathrm{SPL} = A_{\mathrm{spl}} \cdot \sqrt{P_s}, P_s = \left(\frac{\mathrm{SPL}}{A_{\mathrm{spl}}}\right)^2$$

Reset DAC gain

Maintain SPL set point

$$V_C = A_g \cdot G + B_g$$

$$V_n = V \cdot \sqrt{\frac{P}{P_s}}, V_{\mathrm{Cn}} = V_c \cdot \sqrt{\frac{P}{P_s}}$$

Resonant frequency equations

Limbo function

Feedback for consistent SPL.

```
splgain(spl: real, tp: ref Tprofile, ts: ref Tstats): real
{
   ng := 0.0;
   V := math->fabs(ampvolt(tp, ts));
   P1 := math->fabs(amppower(tp, ts));
   if(P1 != 0.0) {
        P2 := math->fabs(splpower(spl, tp));
        V2 := V * math->sqrt(P2/P1);
        Vc2 := V2/tp.Av;
        ng = (-tp.Bg + Vc2)/tp.Ag;
   }
   return ng;
}
```

Resonant frequency equations

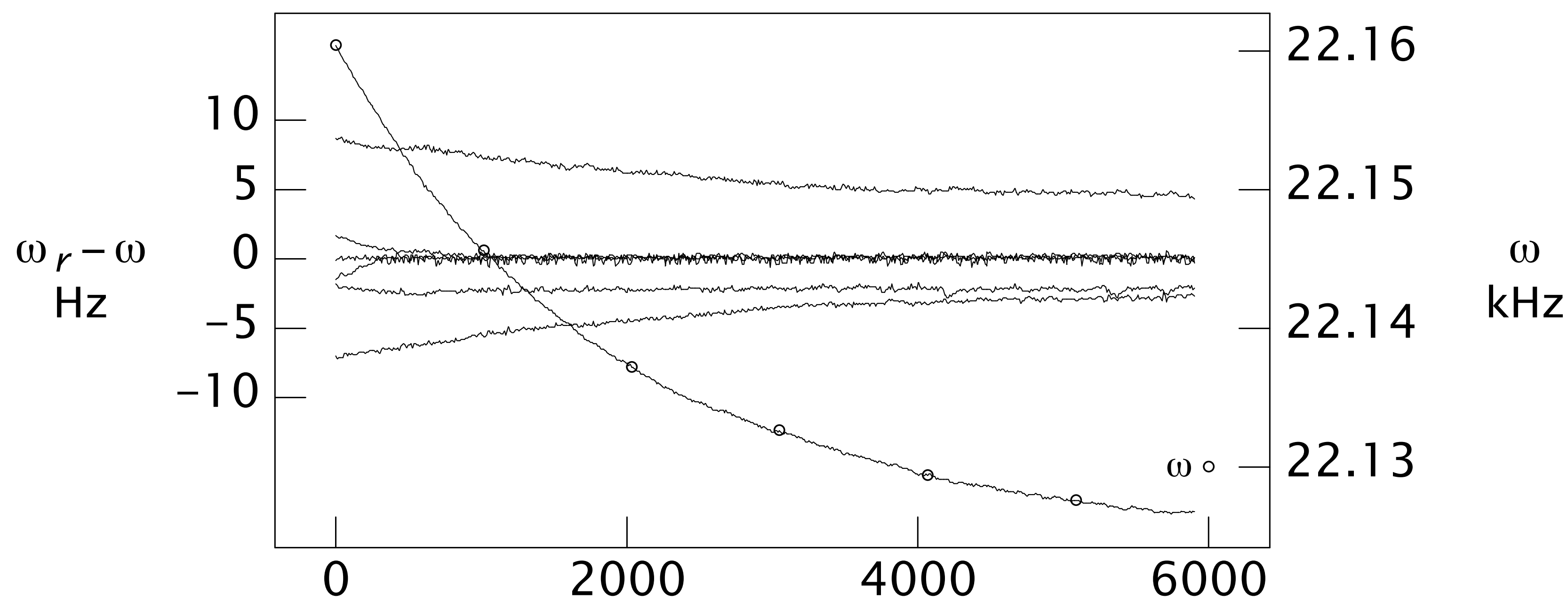
Frequency tracking

Average all transducers resonant frequency to set the operating frequency.

$$\omega_r - \omega = A_3\phi^3 + A_2\phi^2 + A_1\phi + A_0$$

Fan

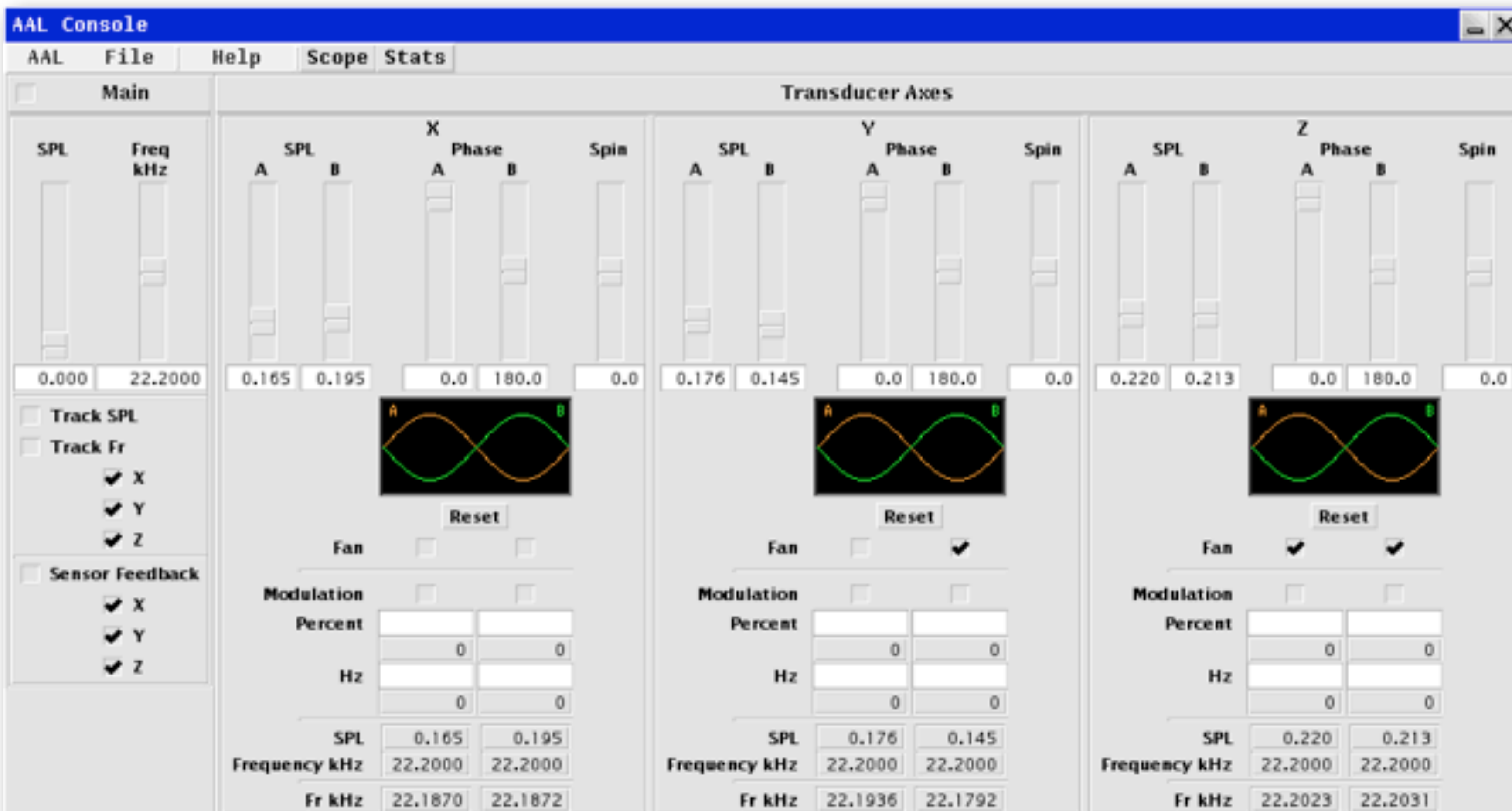
Turned on when resonant frequency is bellow the average to cool transducers.
Turned off when resonant frequency is above the average, let the transducer heat to lower frequency.



Inferno console

Stats from transducer controllers

All testing reads from *data* file.
Commands sent to *ctl* file.



Inferno console

Stats from transducer controllers

Tstats populated from *data* file.
Measured and calculated values displayed.

AAL Stats

	X A	X B	Y A	Y B	Z A	Z B
Freq kHz	22.2000	22.2000	22.2000	22.2000	22.2000	22.2000
DAC Gain	3100	3100	3100	3100	3100	3100
Vo	507	538	502	535	495	592
Io	209	265	248	160	393	404
ϕV	2923	2891	3143	2634	0	0
ϕI	0	0	0	0	3150	3140
% Gain	15.76	15.76	15.76	15.76	15.76	15.76
Amp Voltage 10x V	2.349	2.493	2.326	2.479	2.294	2.743
Amp Current mA	96.830	118.373	111.844	77.897	167.237	171.411
Measured I-V Phase	-21.687	-23.420	-9.772	-37.340	9.393	9.934
True I-V Phase	-7.687	-9.420	4.228	-23.340	23.393	23.934
Gain vs Voltage	500.28	494.27	453.00	530.83	484.27	592.77
Amp Power	2.255	2.911	2.595	1.773	3.521	4.298
Resonant Frequency	22.1870	22.1872	22.1936	22.1792	22.2023	22.2031

Inferno console

Stats from transducer controllers

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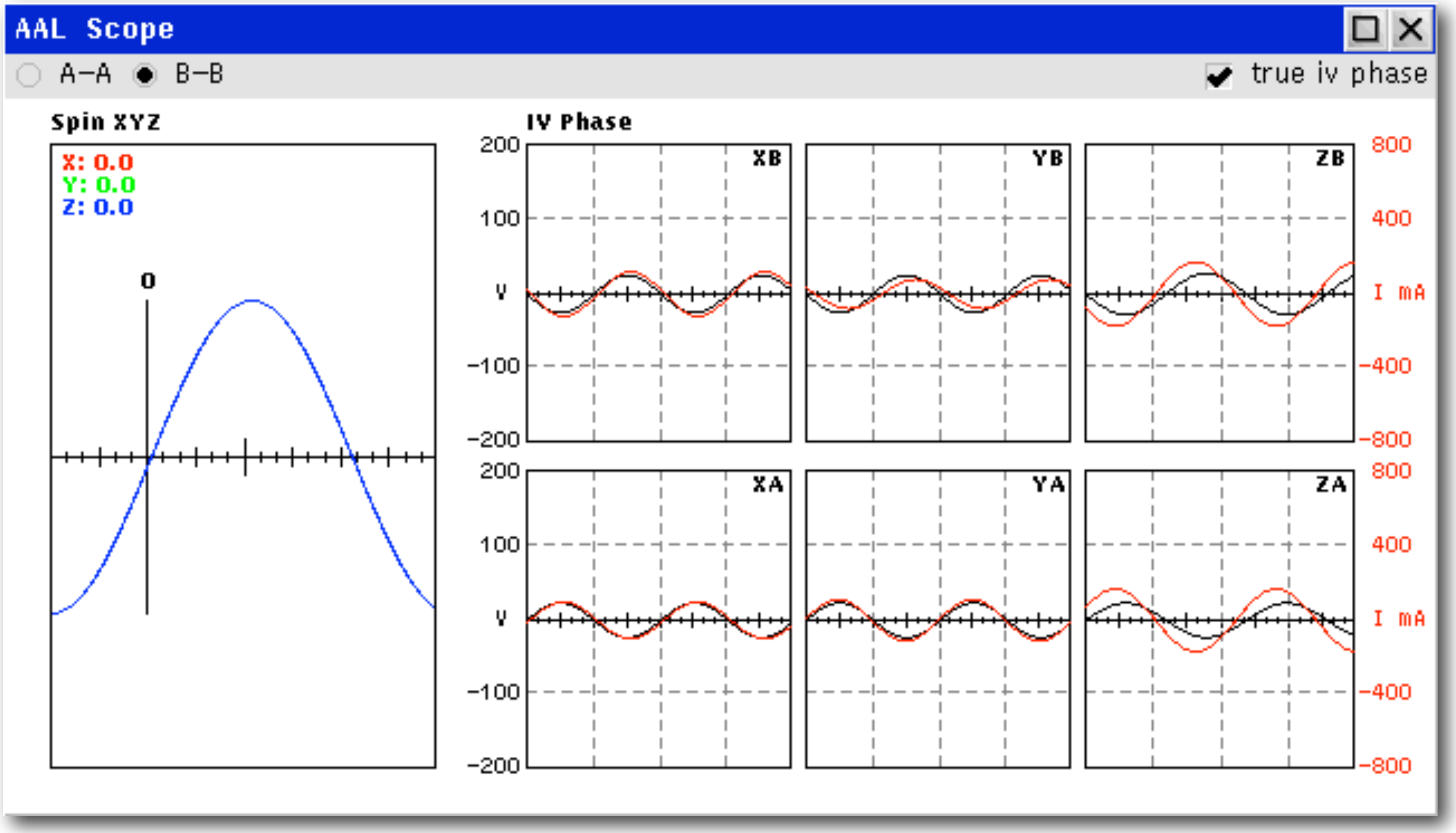
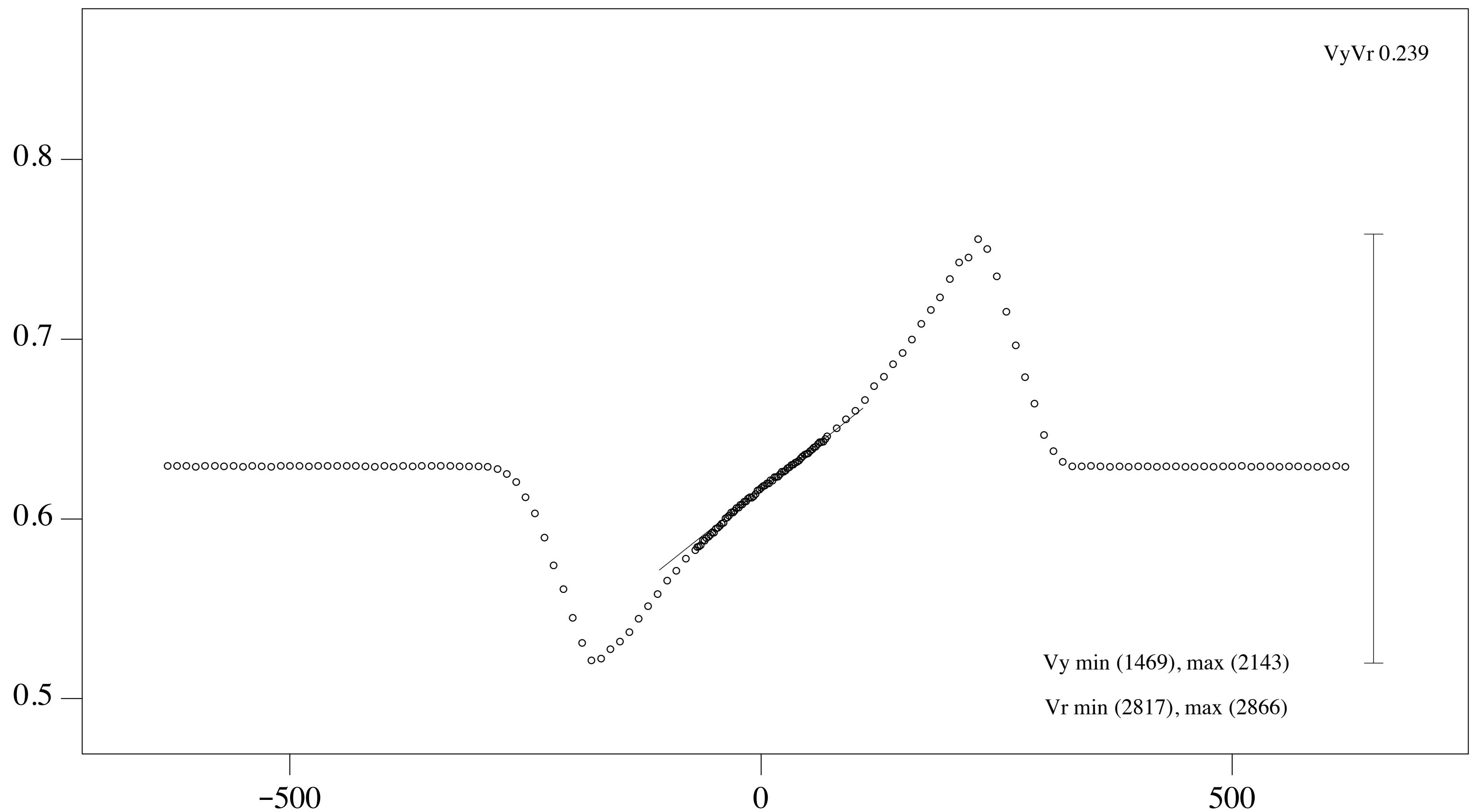



Acoustic Squeeze
1 Hz

Sensors calibration

Alignment tests

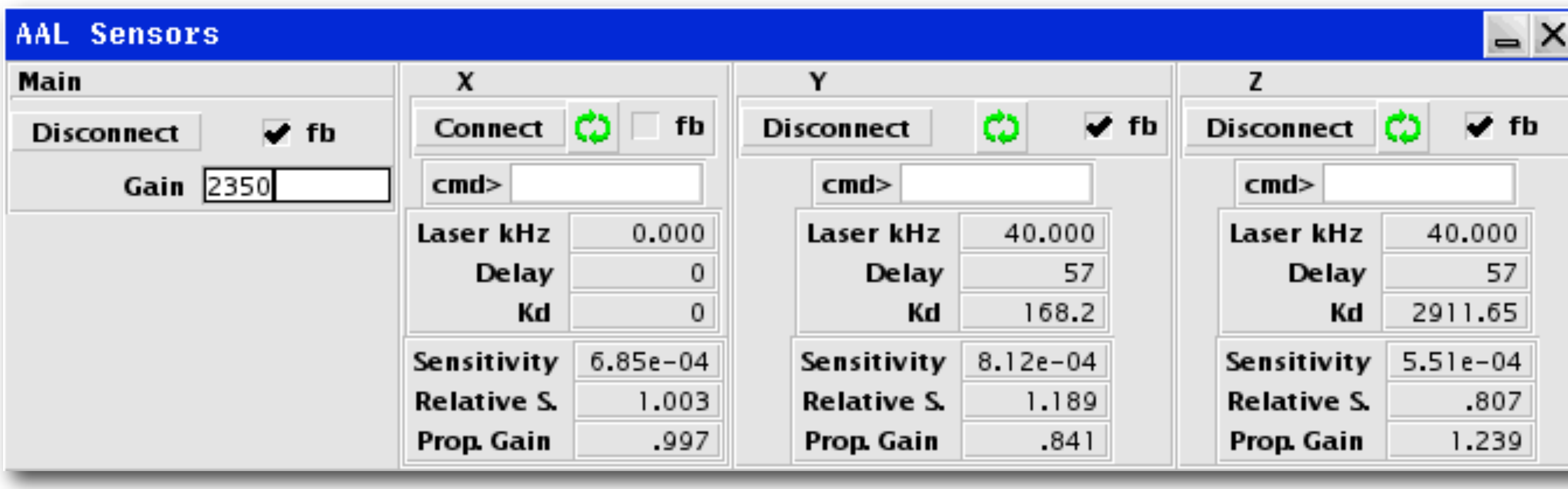
Verification of laser and detector alignment performed with a simple Limbo programs.
The axis slope and sensitivity calculation is used to calibrate the feedback system.



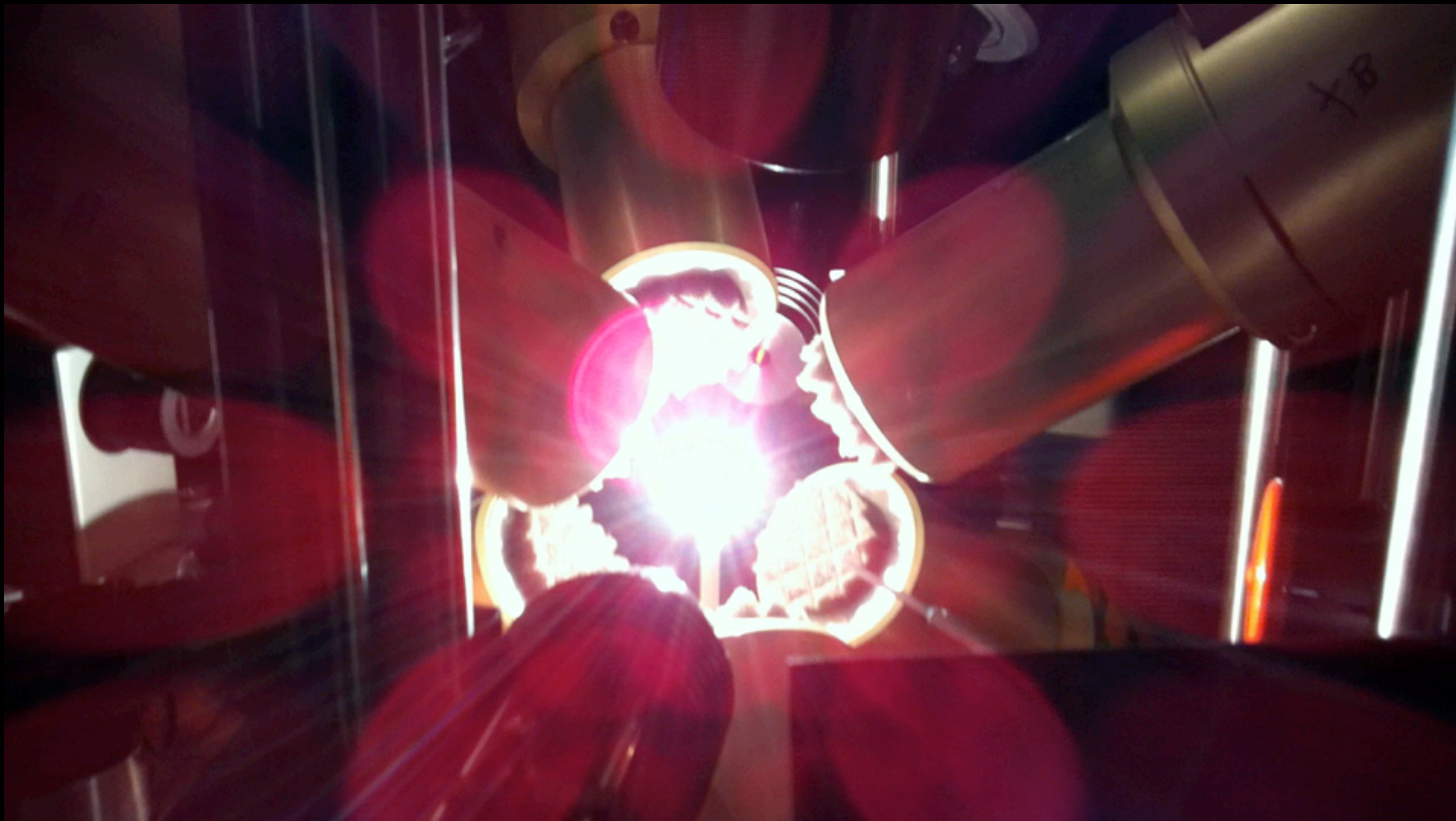
Inferno console

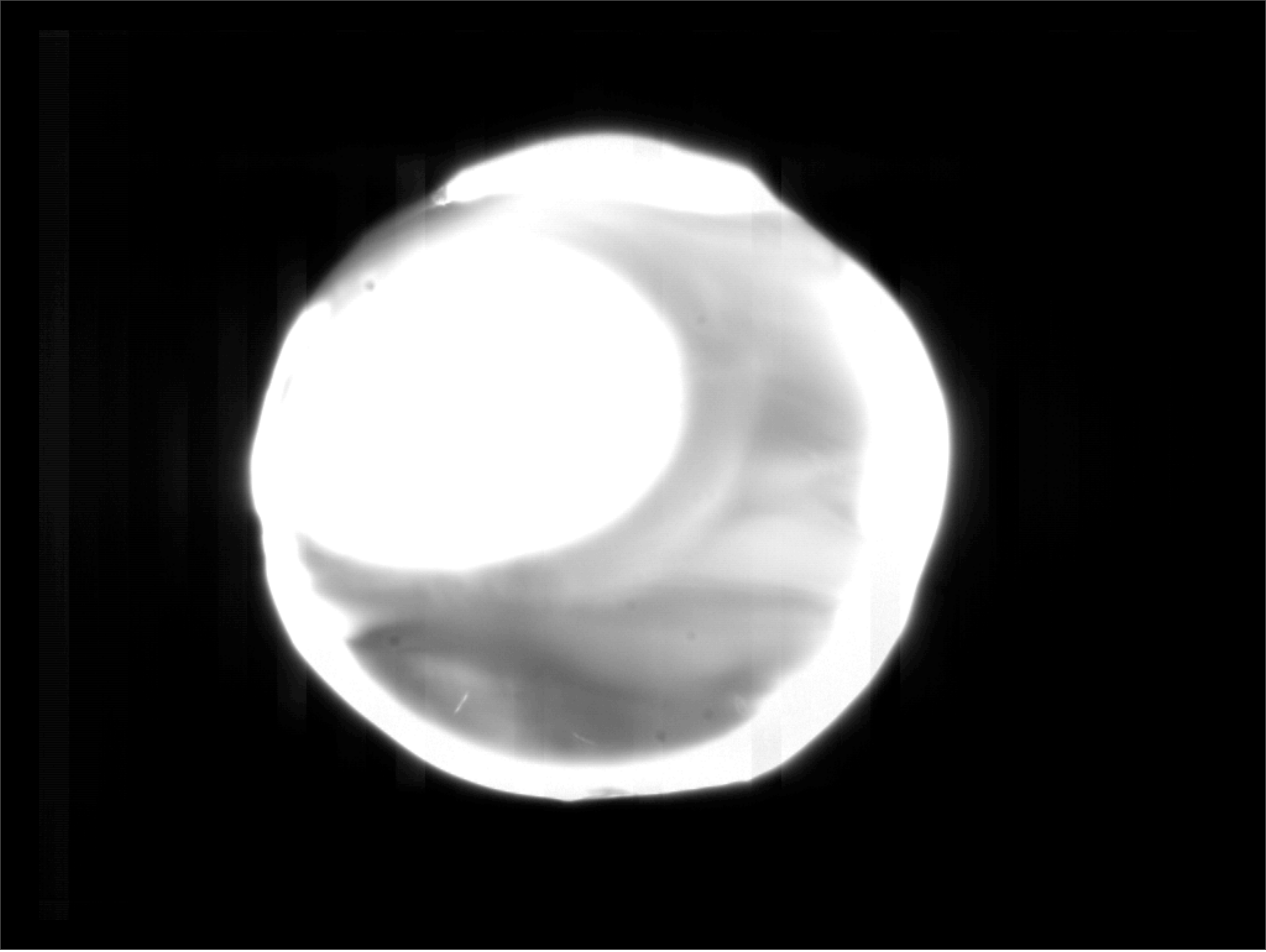
Sensor feedback

Three network connections to sensors
Add parameters for relative sensitivity and proportional gain.



Clips





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