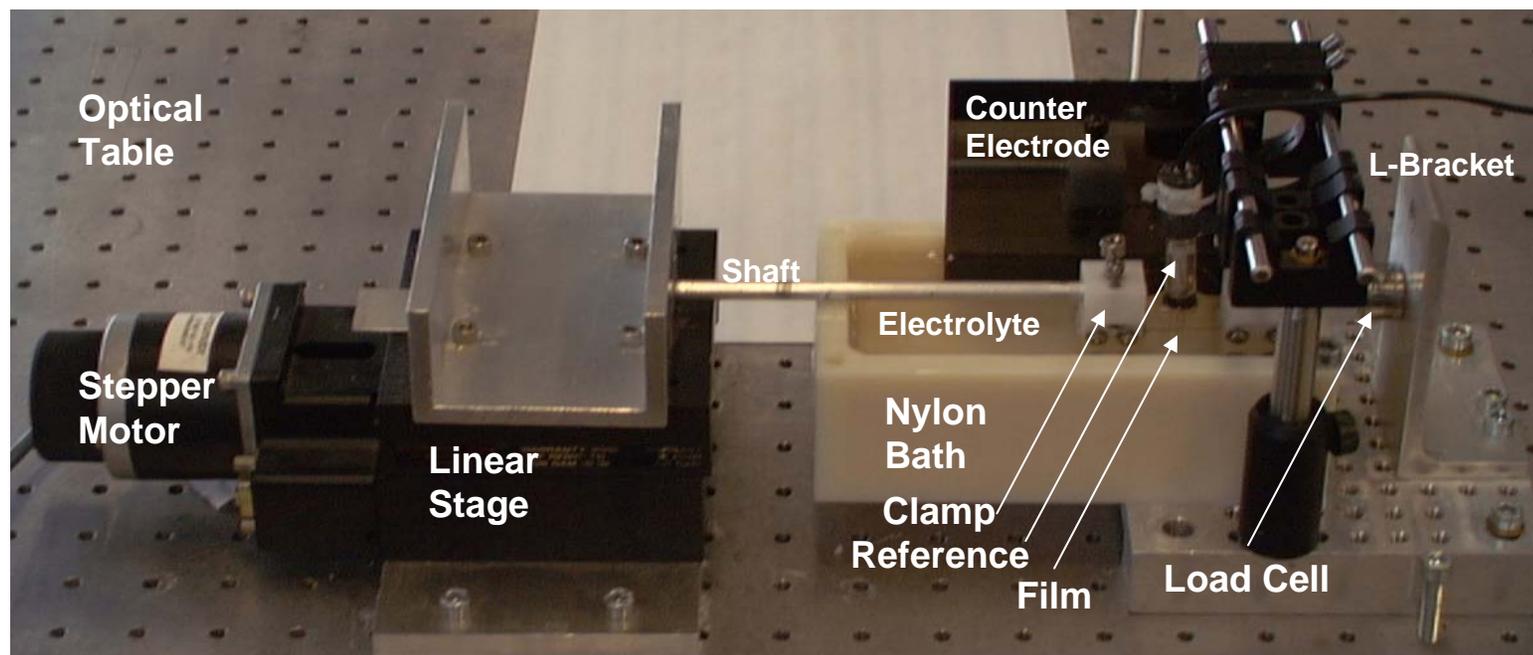
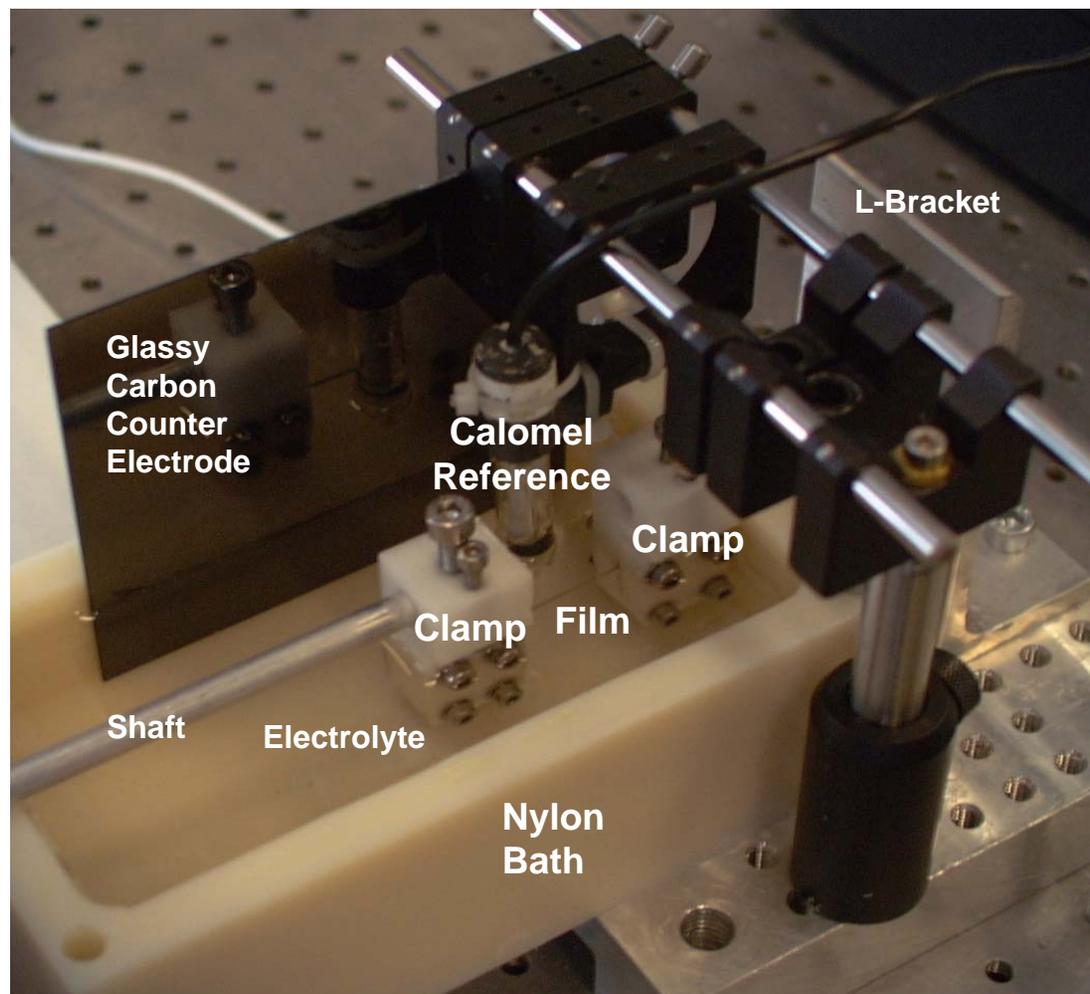


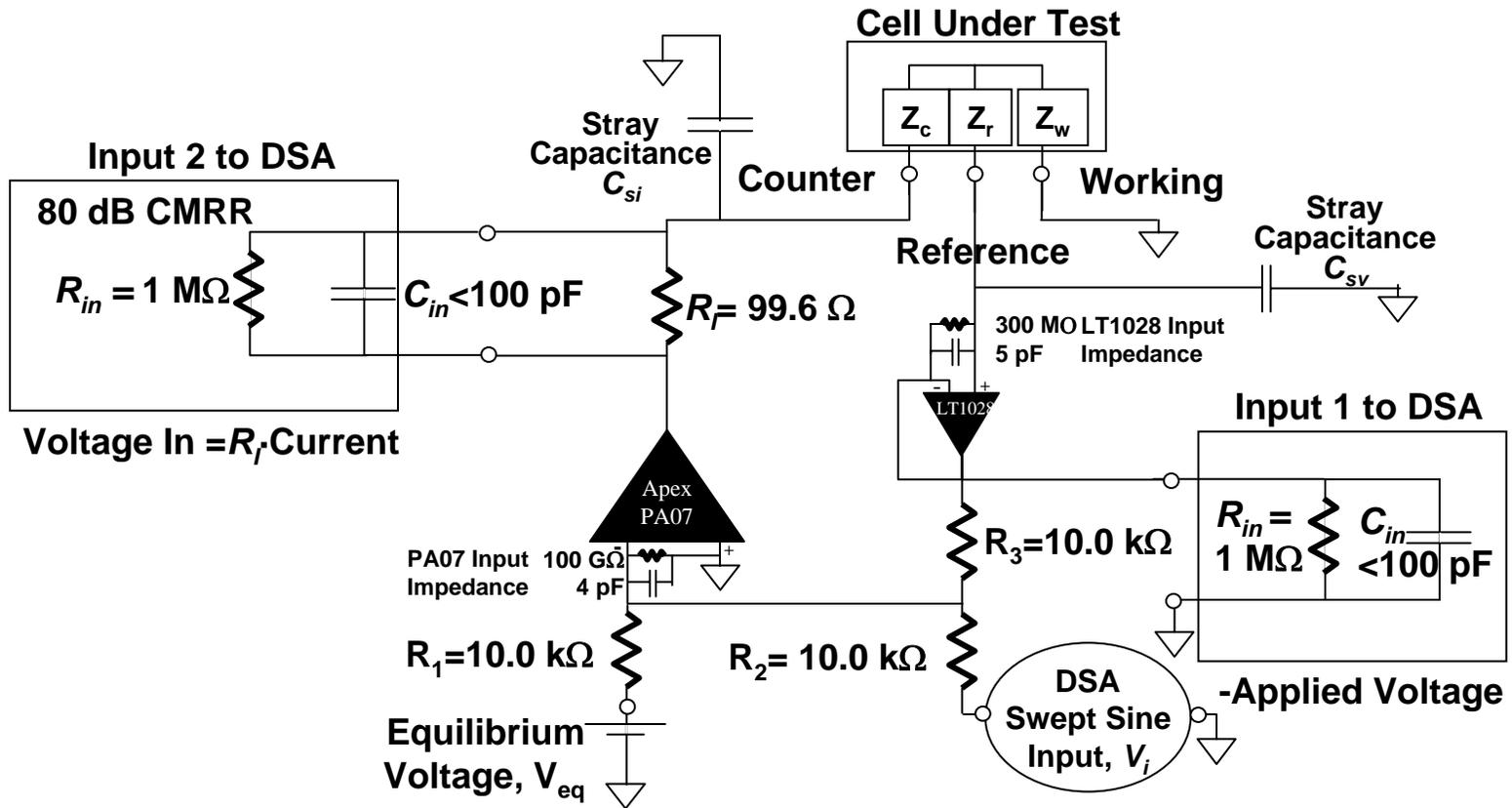
**Figure 1:** Diagram of the experimental apparatus for measuring polypyrrole admittance. Strain to current and stress to current are measured by switching connections to the DSA.



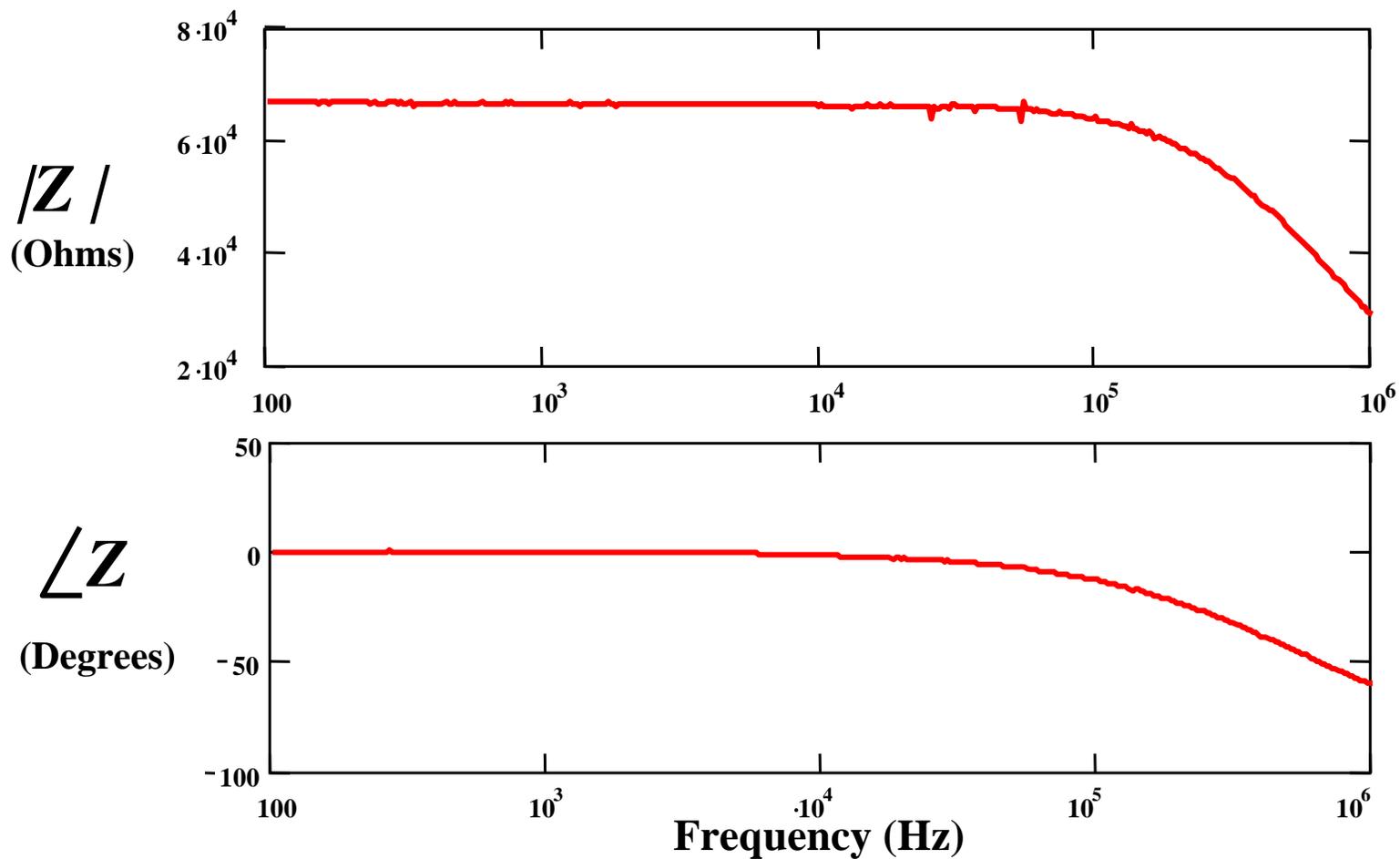
**Figure 2a:** A photograph of the bath in which electrical and mechanical tests of polypyrrole films are performed, and of the stepper motor and linear stage used to apply displacements to the film. A second counter electrode, placed symmetrically about the film relative to the first, is not shown.



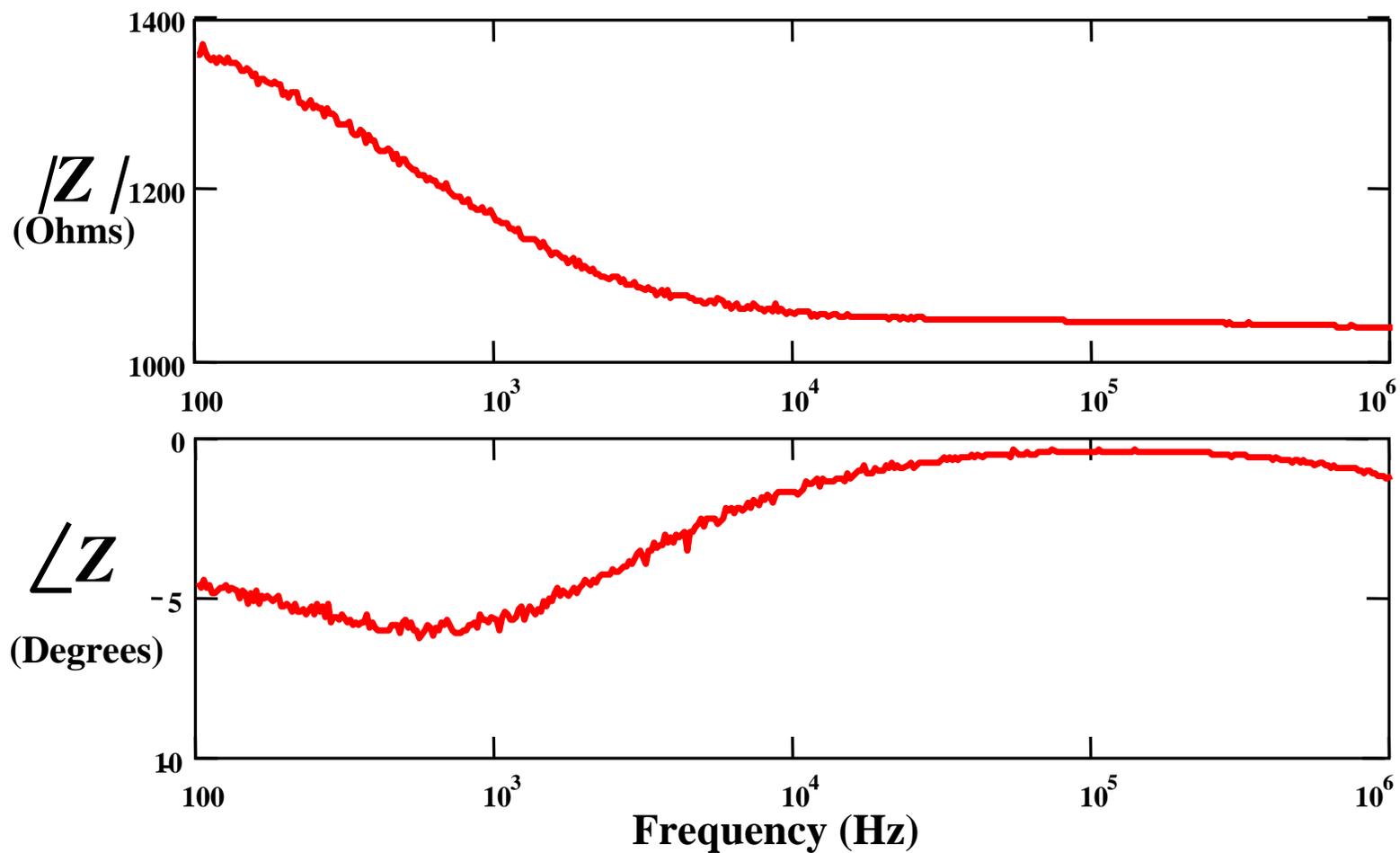
**Figure 2b:** A closer view of the bath, showing the positioning of the clamps, the reference electrode and the film. A second identical counter electrode on the near side of the film has been removed.



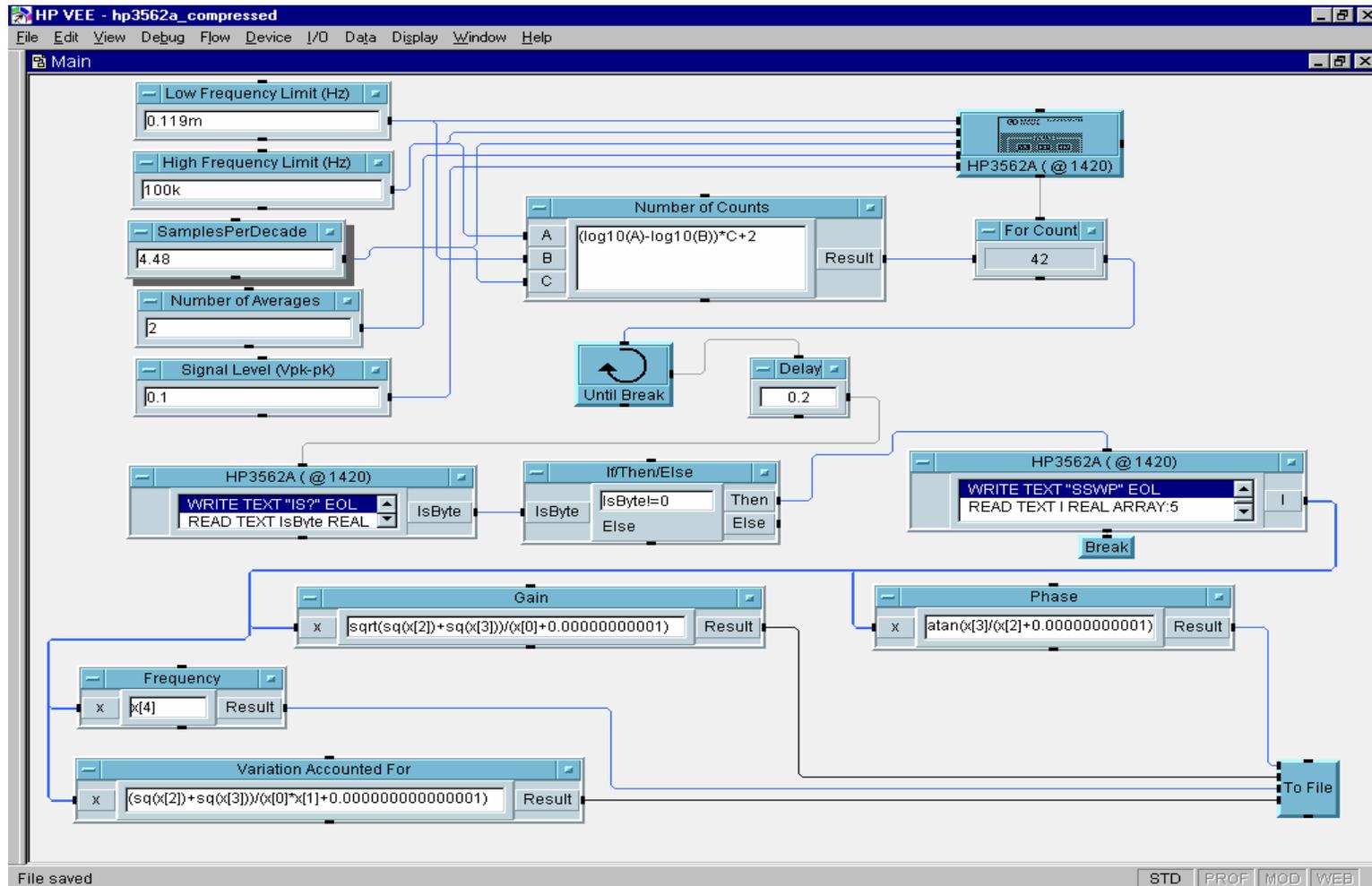
**Figure 3:** Diagram of the potentiostat circuit with the HP3542A DSA (dynamic signal analyzer) connected. The open circles represent inputs and outputs to the potentiostat. The DSA input impedances and some of the parasitic capacitances are shown. CMRR is the Common Mode Rejection Ratio of the DSA inputs. The admittance is the ratio of amplitudes of Input 2 to Input 1 multiplied by  $\exp(i \cdot \text{phase difference})$



**Figure 4:** Impedance of a Ag/AgClO<sub>4</sub> reference electrode. A 10 mV applied potential is used to measure the impedance against a 50x50 mm stainless steel electrode placed 10 mm from the reference tip, and all immersed in 0.3 M tetraethylammonium hexafluorophosphate in propylene carbonate.



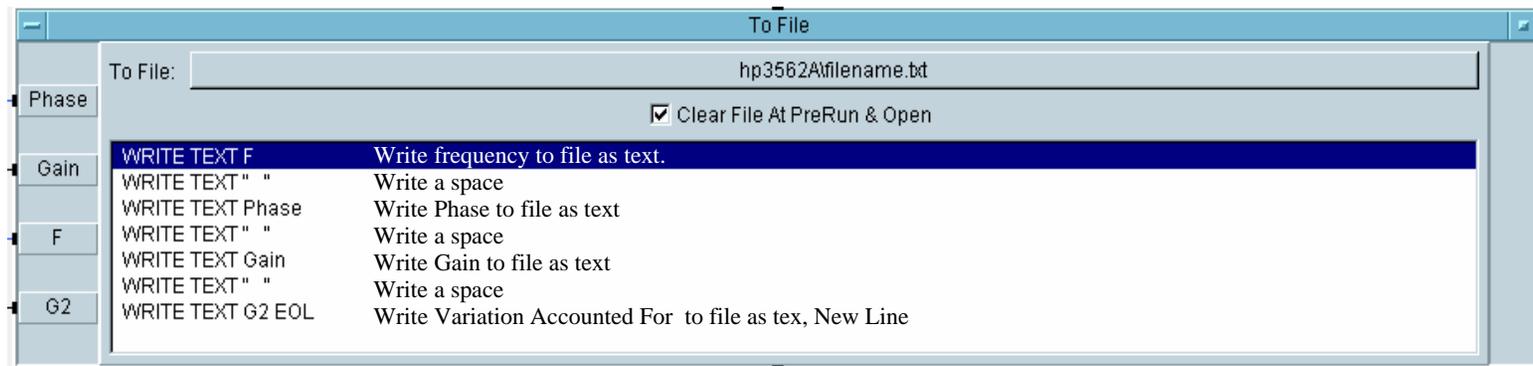
**Figure 5:** Impedance of a calomel reference electrode. A 10 mV applied potential is used to measure the impedance against a 50x50 mm stainless steel electrode placed 10 mm from the reference tip, and all immersed in 0.3 M tetraethylammonium hexafluorophosphate in propylene carbonate.



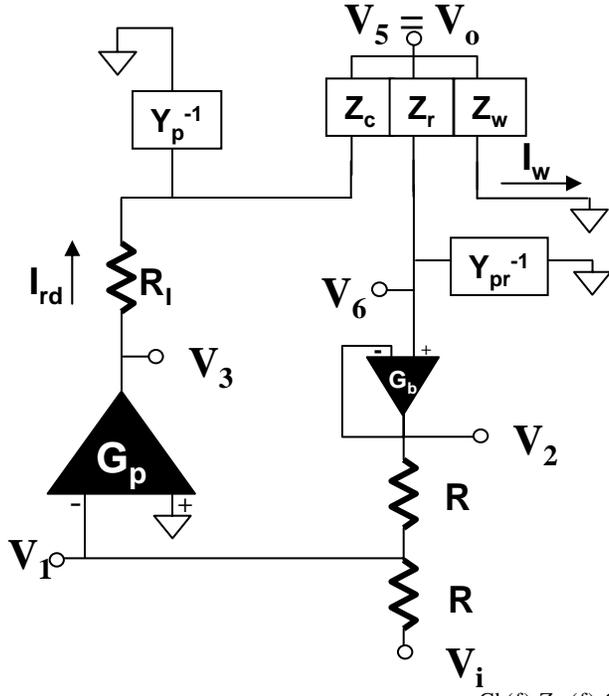
**Figure 6:** The HP VEE program used to control the dynamic signal analyzer, acquire data, and compute gain, phase and variation accounted for.

	Code	Description
	WRITE TEXT "RST" EOL	Reset
	WRITE TEXT "ESQW" EOL	Enable Sweep Service Request (Interrupts during measurement for data transfer)
	WRITE TEXT "SSIN" EOL	Swept Sine mode
StartFreq	WRITE TEXT "LGSW" EOL	Log sweep mode
	WRITE TEXT "AB" EOL	Display two plots
	WRITE TEXT "FRSP" EOL	Measure frequency response
	WRITE TEXT "FRQR" EOL	Display Frequency Response on HP3562A Screen
	WRITE TEXT "SF"	Input Start Frequency
	WRITE TEXT StartFreq	Start Frequency Value (From test box)
	WRITE TEXT "HZ" EOL	Units of Hertz
StopFreq	WRITE TEXT "SPF"	Input Stop Frequency
	WRITE TEXT StopFreq	Stop Frequency Value (From text box)
	WRITE TEXT "HZ" EOL	Units of Hertz
	WRITE TEXT "RES"	Input Frequency Measurement Resolution
	WRITE TEXT ResPerDec	Start Frequency (From text box)
	WRITE TEXT "P/DC" EOL	Units of points per decade
	WRITE TEXT "SRLV"	Input Signal Level
ResPerDec	WRITE TEXT SignalLevel	Value of Signal Level (From text box)
	WRITE TEXT "V" EOL	Units of Voltage
	WRITE TEXT "AU1" EOL	Auto-scale channel 1 up and down
	WRITE TEXT "AU2" EOL	Auto-scale channel 2 up and down
	WRITE TEXT "A" EOL	Highlight Figure A on the Display
	WRITE TEXT "MGLG" EOL	Choose units of Log Magnitude for Display A
	WRITE TEXT "B" EOL	Highlight B
Averages	WRITE TEXT "SWDN" EOL	Scan Frequency from High to Low
	WRITE TEXT "PHSE" EOL	Display Phase in Degrees on B
	WRITE TEXT "AB" EOL	Choose both A and B
	WRITE TEXT "XASC" EOL	Autoscale the X-axes of Displays A and B
	WRITE TEXT "YASC" EOL	Autoscale the Y-axes of Displays A and B
	WRITE TEXT "NAVG"	Input the Number of Averages
	WRITE TEXT Averages EOL	Write Value (From text box)
SignalLevel	WRITE TEXT "STRT" EOL	Start the Frequency Scan
	WRITE TEXT "SSWP" EOL	Send First Data Point
	READ TEXT I REAL ARRAY:5	Read First Data Array of Length 5

**Figure 7:** The code used to set-up and begin the HP3562A measurement. (Top left icon in Figure 6).



**Figure 8:** The code used to write frequency, gain, phase and variation accounted for to file in HP VEE.



**Figure 9:** Equations describing the effects of parasitic admittances and finite operational amplifier gains on potentiostat output. The circuit diagram at left defines the variables employed.

$$V2(f) := \frac{-G_b(f) \cdot Z_w(f) \cdot G_p(f) \cdot V_i}{(A(f) \cdot Y_p(f) + B(f)) \cdot Y_{pr}(f) + C(f) \cdot Y_p(f) + 2 \cdot (Z_w(f) + Z_c(f) + R_i) \cdot (1 + G_b(f)) + Z_w(f) \cdot G_p(f) \cdot G_b(f)}$$

$$V3(f) := -G_p(f) \cdot \frac{(V_i + V2(f))}{2}$$

$$A(f) := 2 \cdot (Z_w(f) \cdot R_i \cdot Z_c(f) + Z_c(f) \cdot R_i \cdot Z_r(f) + Z_r(f) \cdot Z_w(f) \cdot R_i) \cdot (1 + G_b(f))$$

$$B(f) := 2 \cdot (Z_w(f) \cdot R_i + R_i \cdot Z_r(f) + Z_c(f) \cdot Z_r(f) + Z_c(f) \cdot Z_w(f) + Z_w(f) \cdot Z_r(f)) \cdot (1 + G_b(f))$$

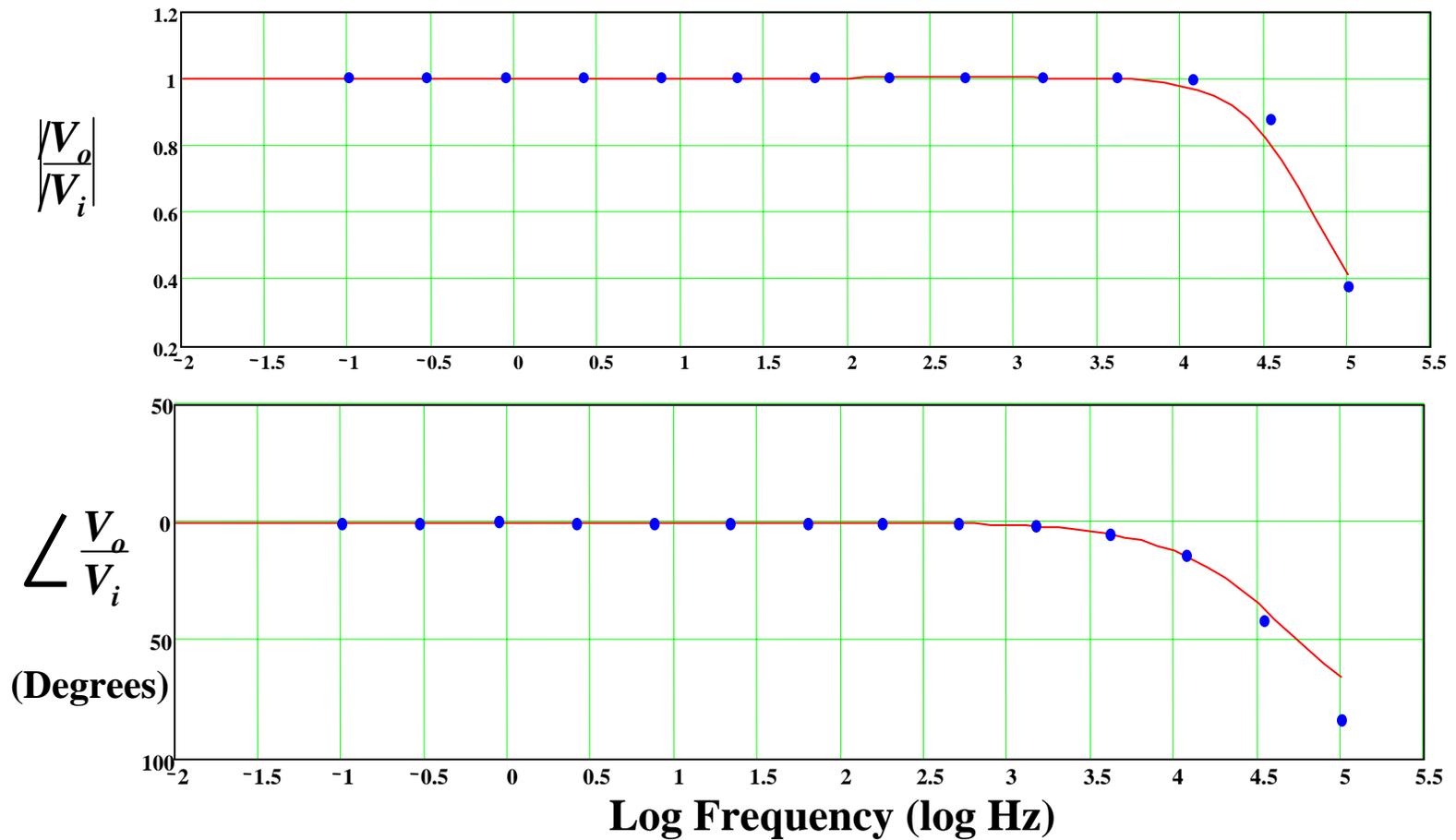
$$V6(f) := V2(f) \cdot \frac{(1 + G_b(f))}{G_b(f)}$$

$$C(f) := [2 \cdot (Z_w(f) + Z_c(f)) \cdot R_i \cdot (1 + G_b(f))]$$

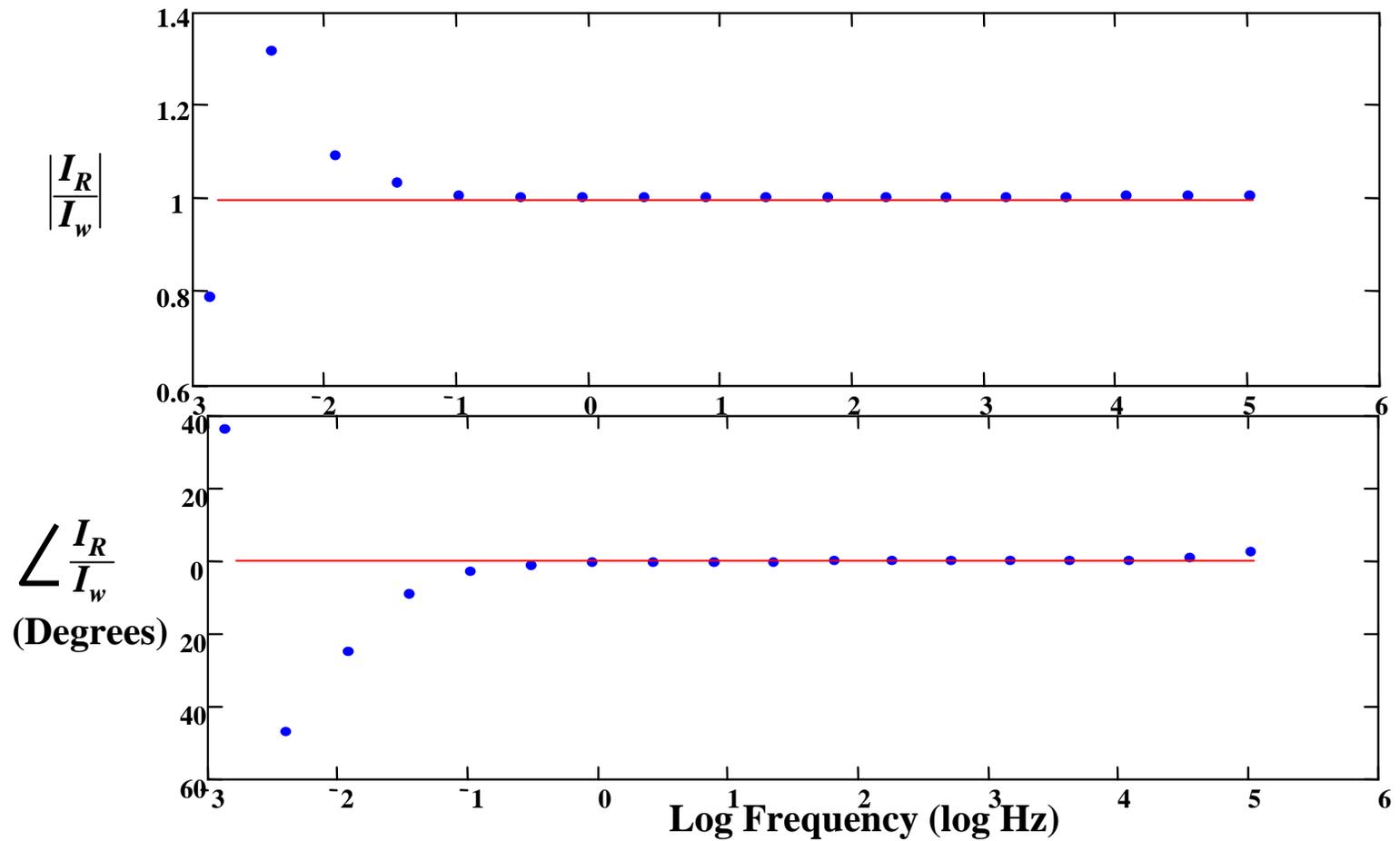
$$I_{rd}(f) := \frac{(Z_w(f) + Z_r(f)) \cdot (1 + G_b(f))}{[G_b(f) \cdot (1 + R_i \cdot Y_p(f)) \cdot Z_w(f)]} \cdot V2(f) \cdot Y_{pr}(f) + \frac{[2 \cdot V2(f) \cdot (1 + G_b(f)) - G_p(f) \cdot Y_p(f) \cdot Z_w(f) \cdot G_b(f) \cdot (V_i + V2(f))]}{[2 \cdot G_b(f) \cdot (1 + R_i \cdot Y_p(f)) \cdot Z_w(f)]}$$

$$I_w(f) := \frac{V5(f)}{Z_w(f)}$$

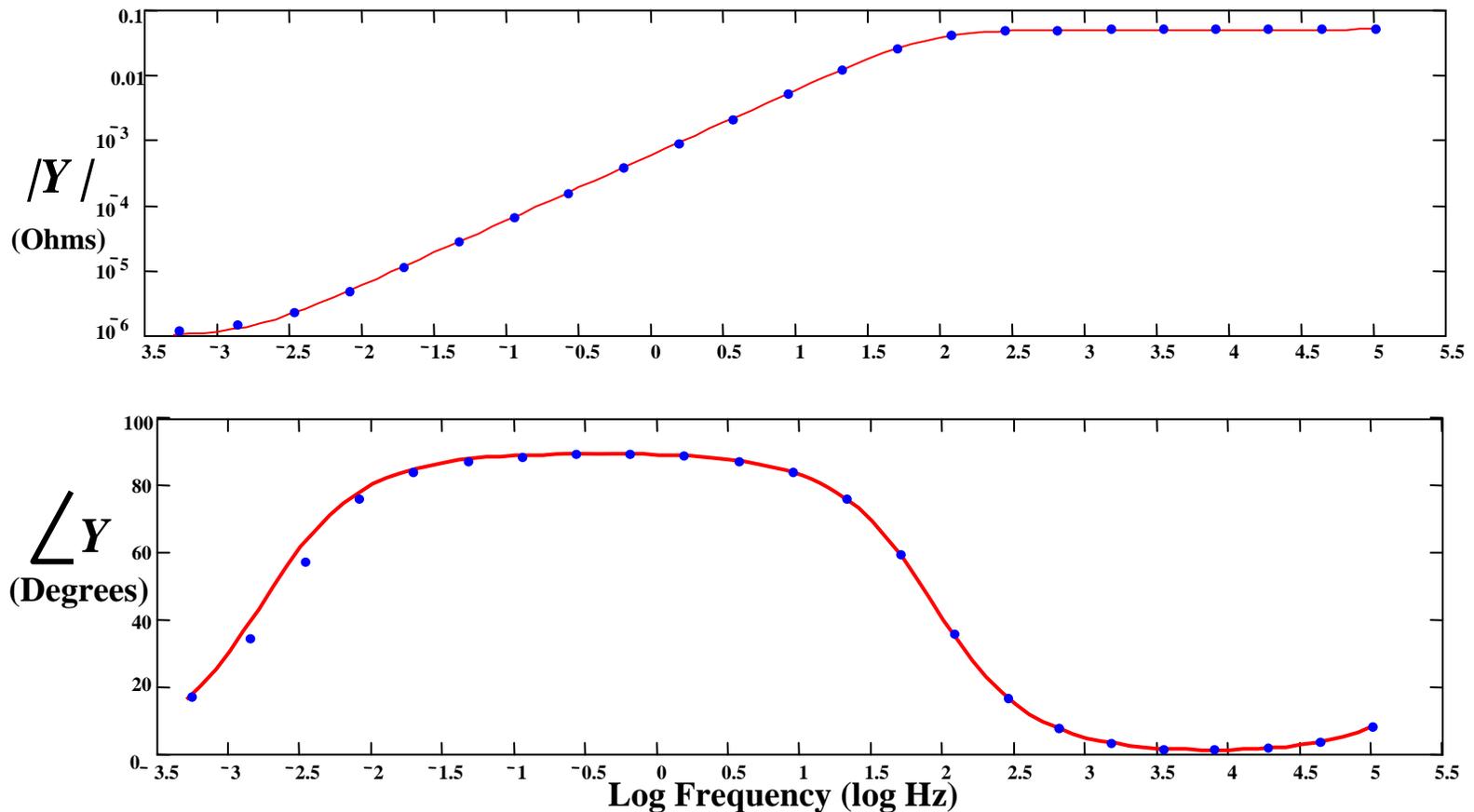
$$V5(f) := V3(f) - I_{rd}(f) \cdot R_i - \left[ I_{rd}(f) - \left[ -G_p(f) \cdot \frac{(V_i + V2(f))}{2} - I_{rd}(f) \cdot R_i \right] \cdot Y_p(f) \right] \cdot Z_c(f)$$



**Figure 10:** Ratio of actual output potential by the potentiostat to command input. The blue dots indicate measured values, while the red line is the response predicted using the equations in Figure 9, which account for the finite gains of the operational amplifiers used in the potentiostat, and for parasitic impedances.



**Figure 11:** Ratio of current,  $I_{rd}$ , measured across  $R_i$ , to actual current,  $I_w$ , across the working electrode (Figure 9) impedance,  $Z_w$ . The blue dots indicate measured values, while the red line is the predicted response. The currents are equal until 100 mHz, at which point finite common mode rejection of the DSA affects measured currents, as discussed in Section 9.2.4.2.4, and accounted for in Figure 12.



**Figure 12:** Measured and predicted admittance from an  $RC$  test circuit ( $R=20.1 \Omega$ ,  $C=94.6 \mu\text{F}$ ). The blue dots indicate measured admittance values, while the red line is the predicted response, which accounts for the finite gains of the operational amplifiers used in the potentiostat, and parasitic impedances, using the equations in Figure 9, and additionally the finite common mode rejection of the Dynamic Signal Analyzer.



**Figure 13:** Image of the Java user interface used to set film length, run stress/strain experiments, and maintain isotonic conditions.