AC Transport Option for the PPMS

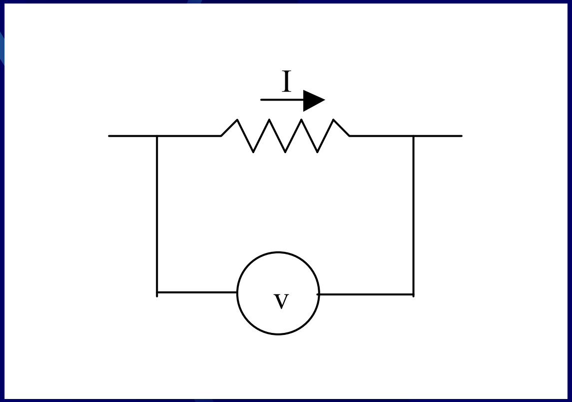
31 October, 2002

Outline

- Basics of electrical transport measurements
- QD ACT Hardware
- Performing ACT Measurements
- Basic Troubleshooting

Electrical Resistance

- Resistance: ratio of voltage across a sample to the current through the sample
- Ohm's law: R=V/I=constant
  - Constant is independent of V
  - Could depend on temperature



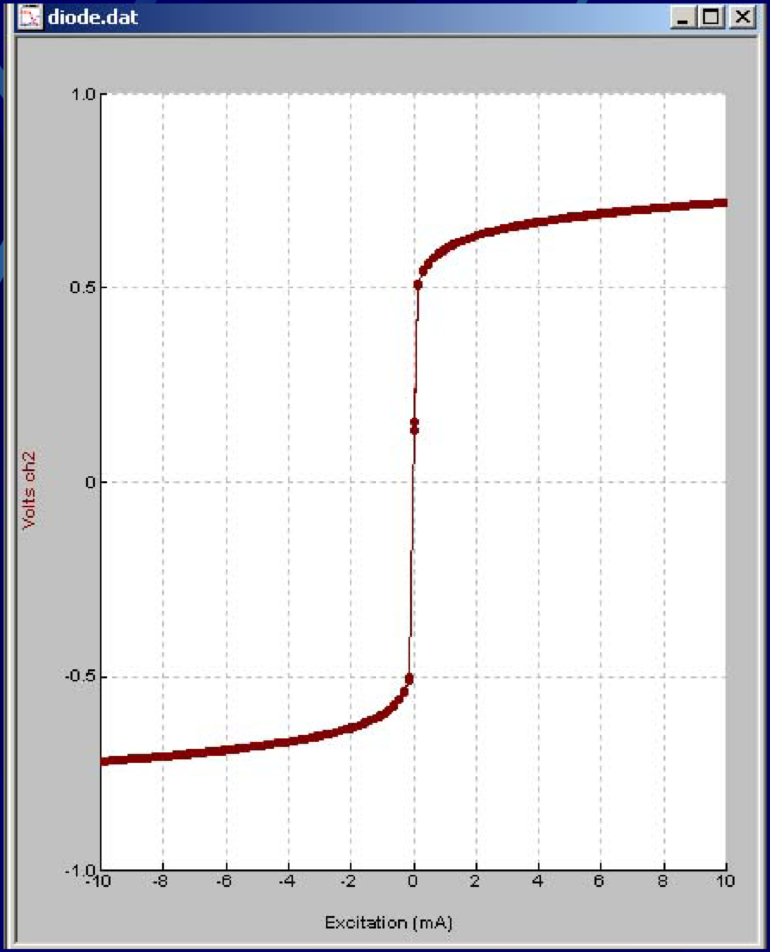
- Samples which obey Ohm's law are called resistors

Resistivity vs. Resistance

- Resistance: R, quantity measured by instrument. Depends on sample geometry.
- Resistivity: ρ, intrinsic material property.
- Given one, the other is calculated from using sample geometry
- Very important probe in solid state physics
- $R = \rho * L/A$
- L = length of sample, A = cross sectional area

IV Curve

- Measure V as I is varied
- Straight line for a resistor
- Curved line, possibly hysteretic, for interesting samples



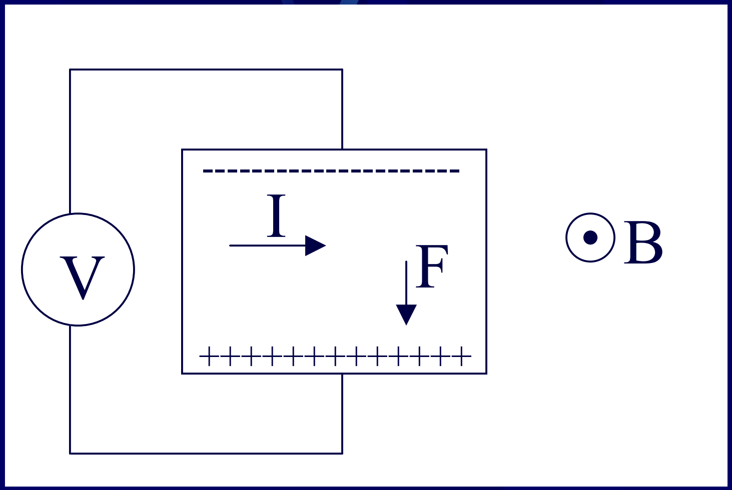
IV Curve from 2 opposing diodes in parallel

Critical Current

- Critical current: maximum current a superconductor can carry before becoming normal (resistive)
- Useful figure of merit for superconductors
- Similar to IV curve-look for the part where the voltage goes up suddenly

Hall effect

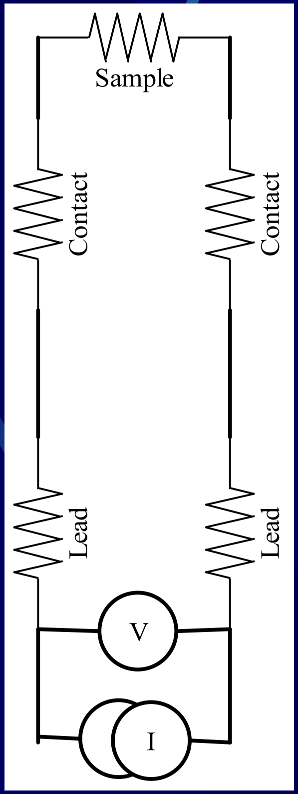
- Voltage that is perpendicular to both the current and applied magnetic field
- Interesting probe of physics of charge carriers (can determine sign of charges)



Drawn for positive charge carriers

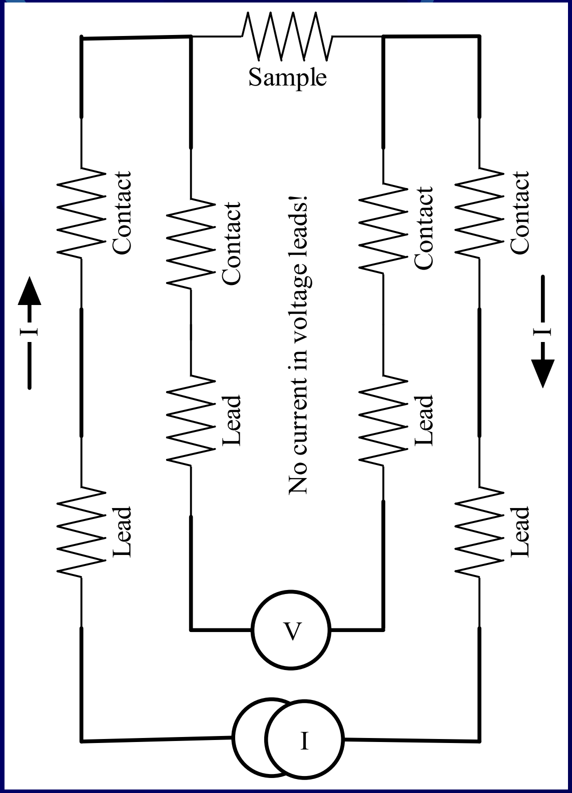
Lead and contact resistance

- Problem: don't want to measure resistance of leads and contact resistance when performing electrical transport measurements
- Solution: 4 probe measurement



4 probe measurement

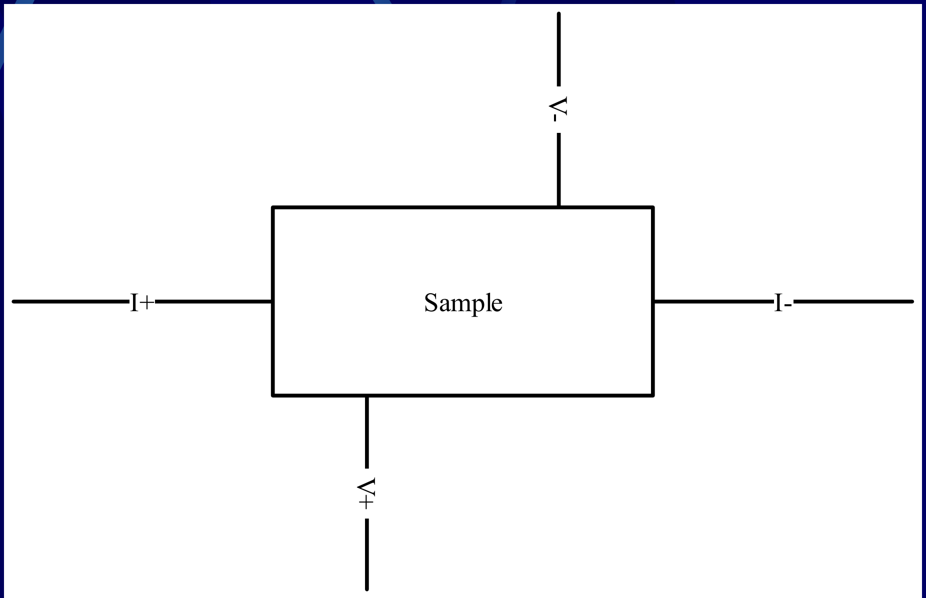
- No current in voltage leads*
- Therefore voltage drop is only that due to sample resistance
- Necessary when contact and lead resistances are not << sample resistance
- Used for resistivity, IV curves, critical current, and hall effect



*Well, OK, there is a little bit. It only matters for high resistance samples. For 1, 10, and 100 gains the input impedance for ACT is 1 MΩ. For gain 1000 its 10 k Ω. (Nominal values.)

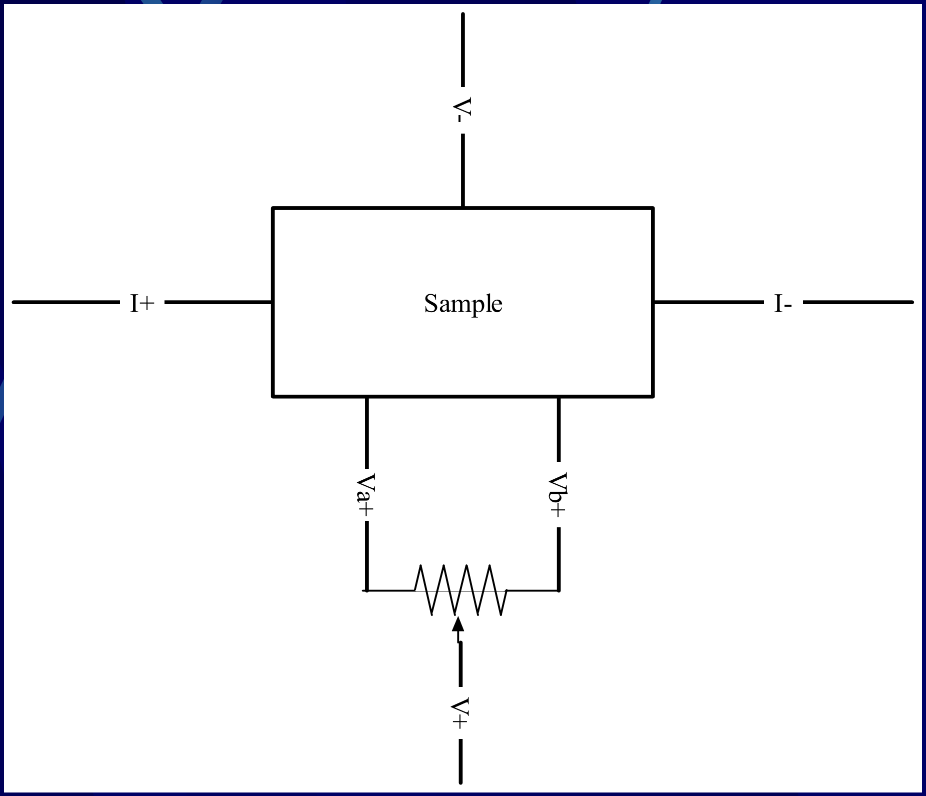
Longitudinal voltage in Hall effect

- Imperfect alignment of leads causes resistive voltage and hall voltage to add
- This makes it difficult to measure hall effect
- Difficult to distinguish magnetoresistance and hall effect Solution: 5 probe



5 probe Hall measurement

- Use potentiometer to zero measured voltage at B=0



AC Measurements

- Problem: DC measurements have high noise susceptibility
- Solution: apply AC current and measure resulting AC voltage
- Narrow banding and frequency choice allows quiet measurements
- Used for resistivity and hall effect measurements

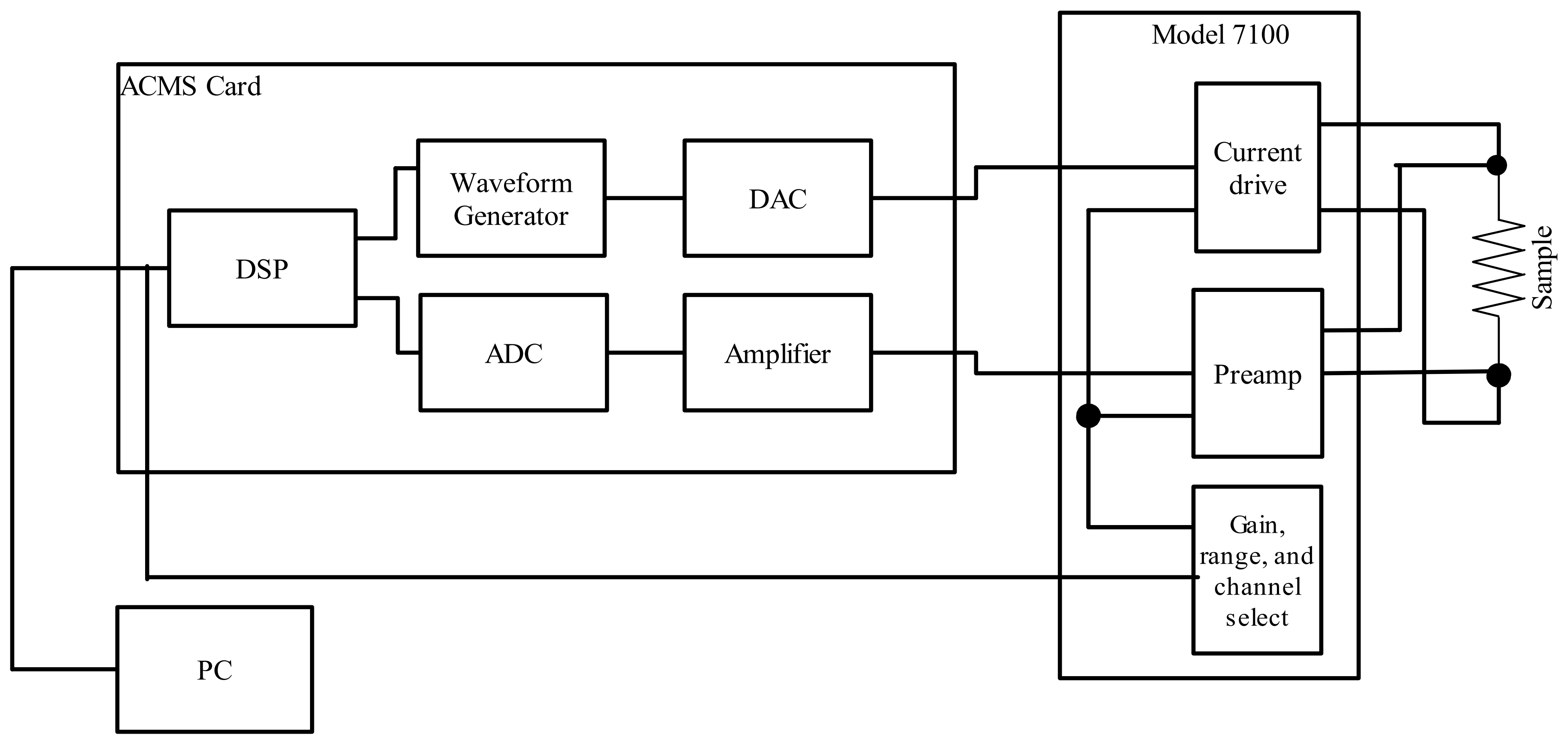
QD ACT Option

- High quality current source: 10 μA to 2 A
- Low noise voltage read back: <1 nV/sqrt(Hz) on gain 1000
- AC range: 1 Hz to 1 kHz used for resistivity and Hall effect
- Digital lock-in detection in software
- DC measurements for IV curves, critical current, and Seebeck (TTO)
- Optimized for relatively low resistances
  - Best accuracy for R<100 Ω
- Relays to multiplex for 2 channels

Interaction with other options

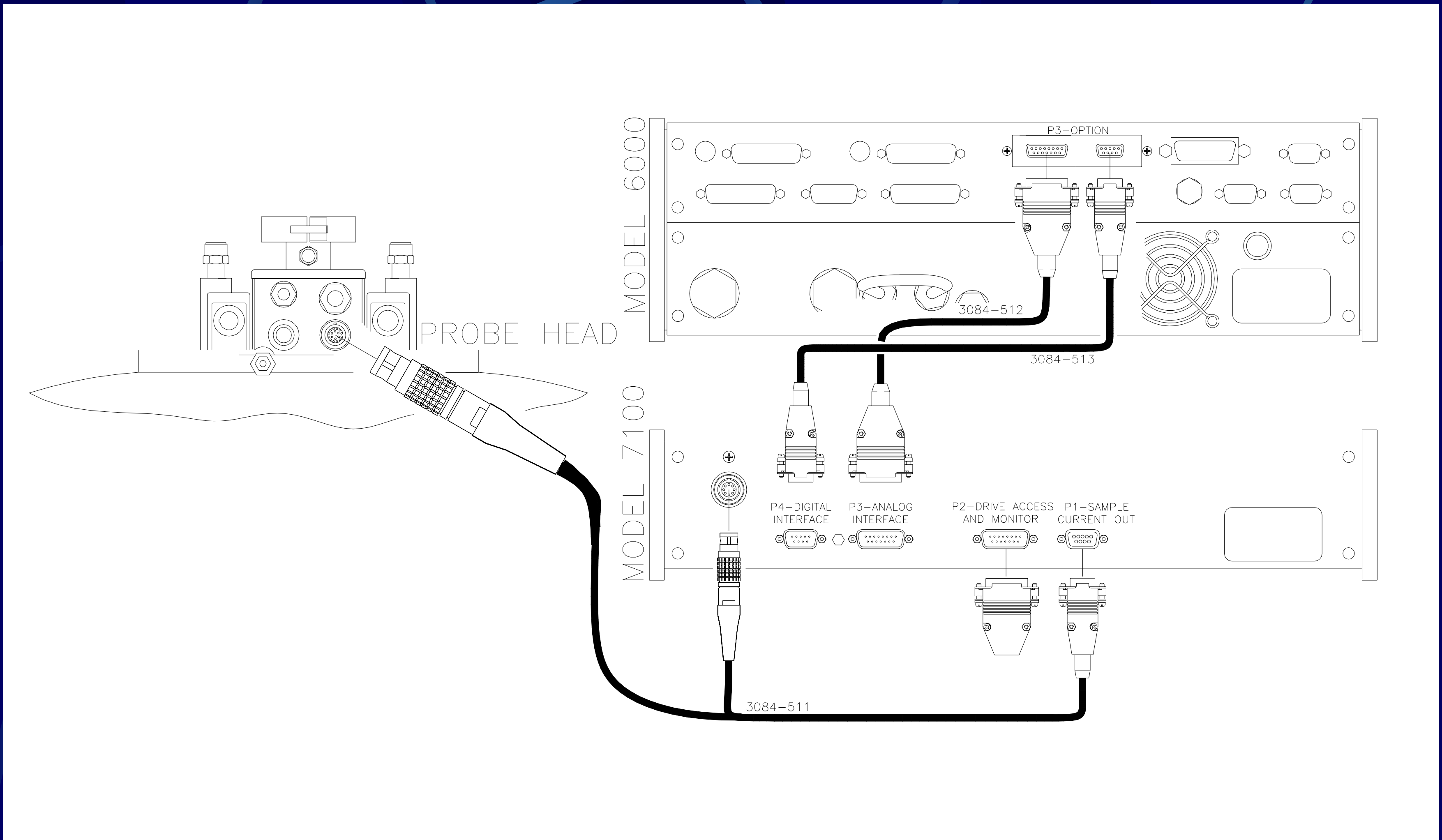
- ACT measurements may be performed with the following options:
  - Base system only (on a puck with normal PPMS cooling)
  - Horizontal rotator: to provide Hall vs. angle or magnetoresistance vs. angle
  - He3: to provide lower temperature
- Options that use the same hardware as ACT:
  - TTO uses ACT for Seebeck and resistivity measurements
  - ACMS uses the same option card. (It’s called the ACMS card.)

Block Diagram



ACMS card also used for ACMS option

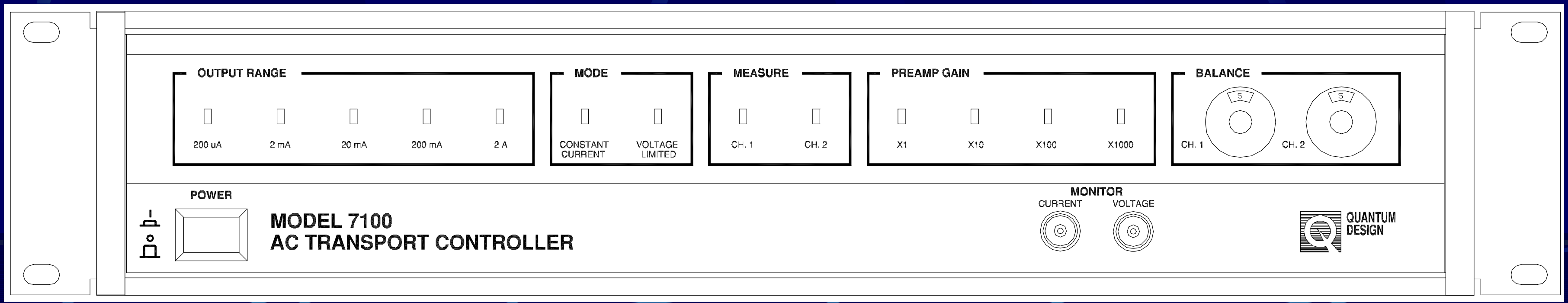
Cabling (std puck)



See connection diagrams for cabling with rotator and He3

Model 7100

- LEDs to show state of gain, range and channel
- Balance pots for Hall effect
  - Should be turned to 0 for other measurements (use Va+ lead)
- Output monitors
  - Imon: 2 V for full scale current (depends on current range)
  - Vmon: input voltage X gain. (Here gain is only the gain in the 7100, not ACMS card)



Ranges/Gains

BE CAREFUL!!!

- Current drive has 5 ranges:

200 μA	2 mA	20 mA	200 mA	2A

- ACMS has 4 gains:

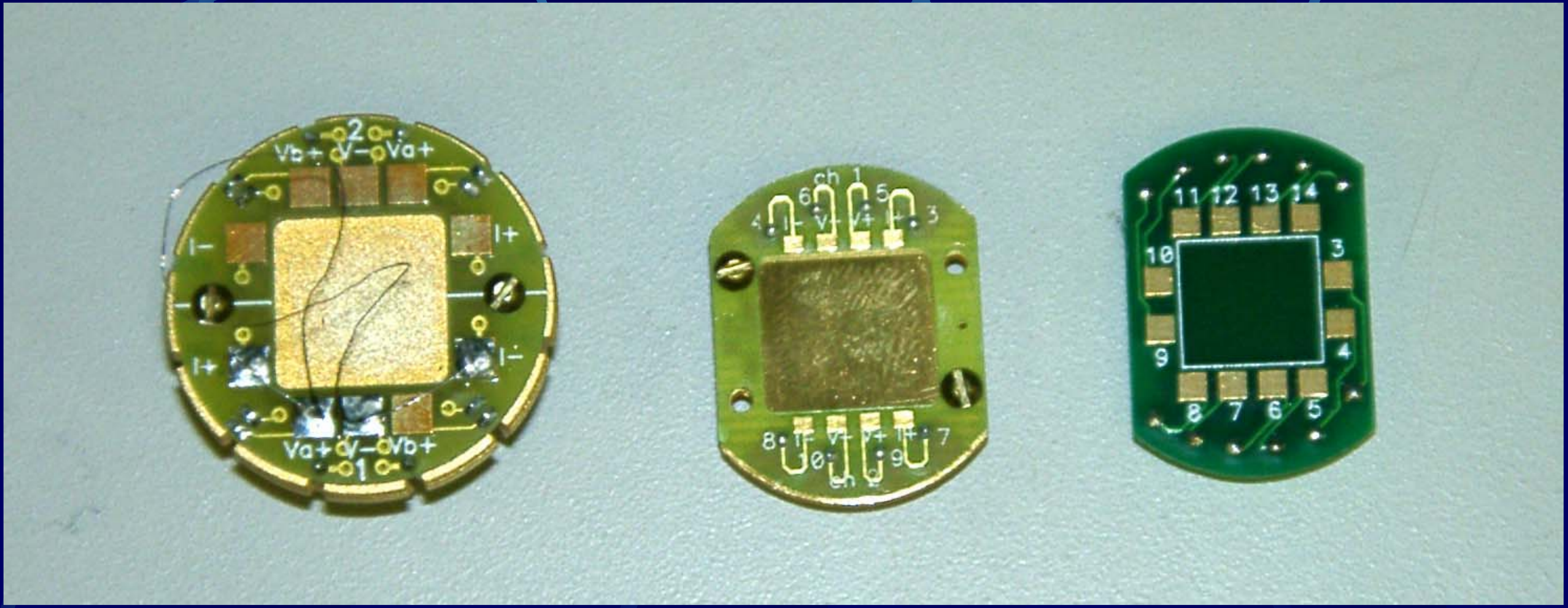
1	5	25	125

- Preamp has 4 gains:

1	10	100	1000

- ACMS gain X preamp gain -> 16 voltage ranges: 5 V (gain 1) to 40 μV (gain 125000)

Sample interfaces



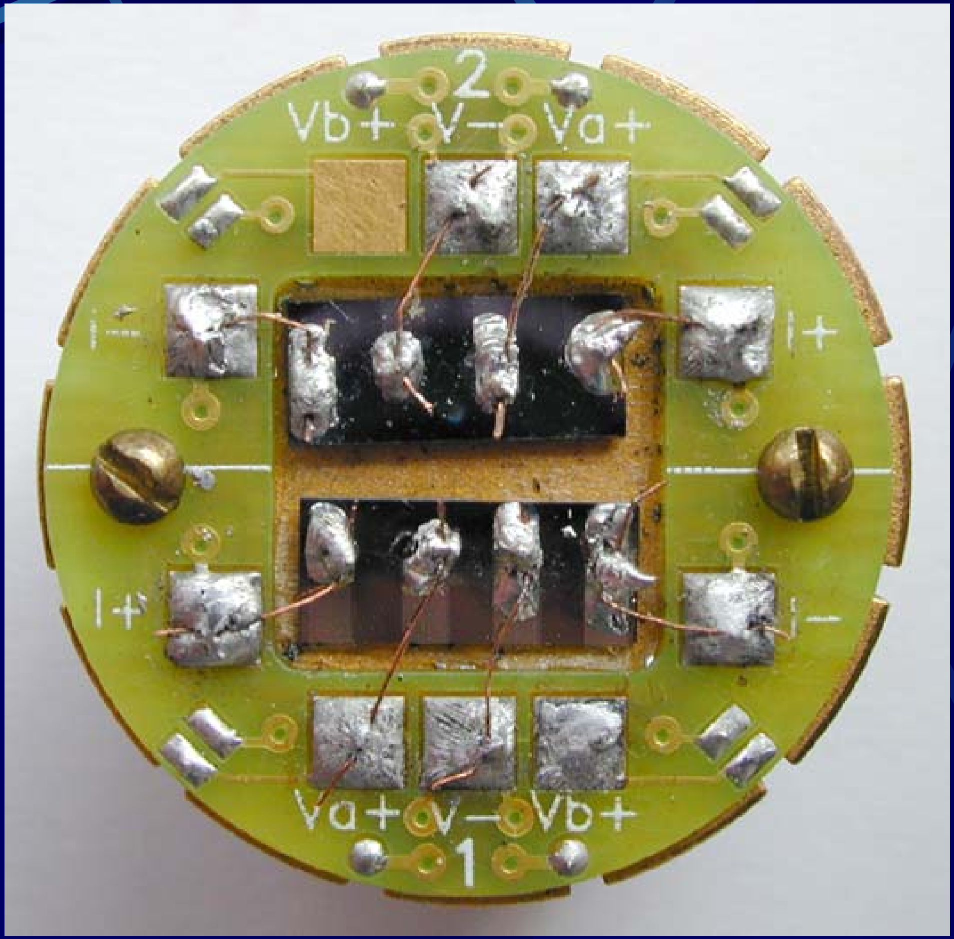
Performing an ACT measurement

- Mount sample
- Install sample
- Perform check at room temperature
  - Check resistivity or IV curve
  - Balance pots for Hall effect
- Start sequence

Sample mounting

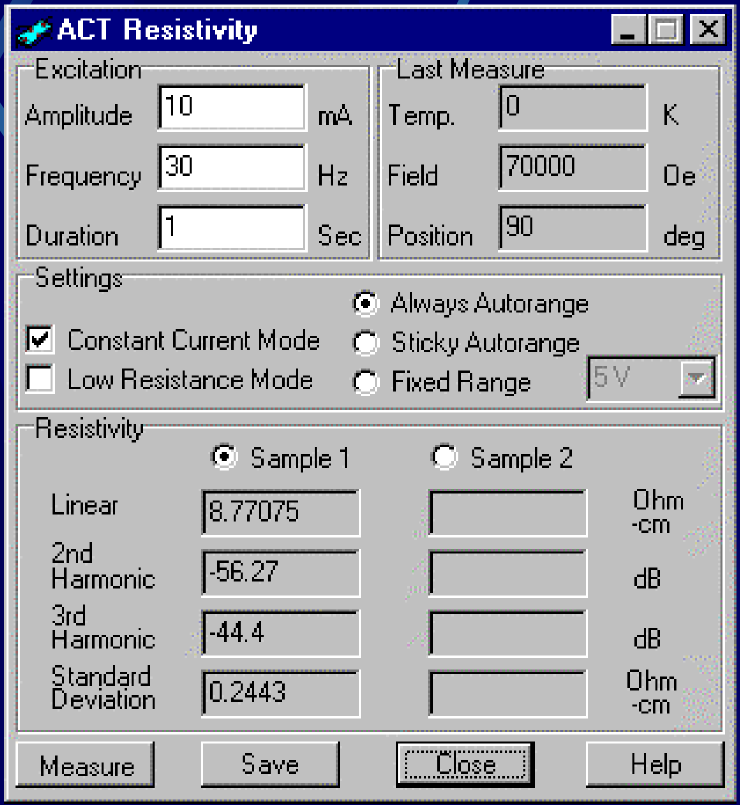
- Ways to attach leads
  - Solder
  - Silver paint
  - Silver epoxy
  - Indium cold welds
- Sample must be electrically isolated from ground (puck)
  - Bulk samples: cigarette paper soaked with 7031 varnish between sample and puck
  - Thin films isolated by substrate

Niobium thin film samples



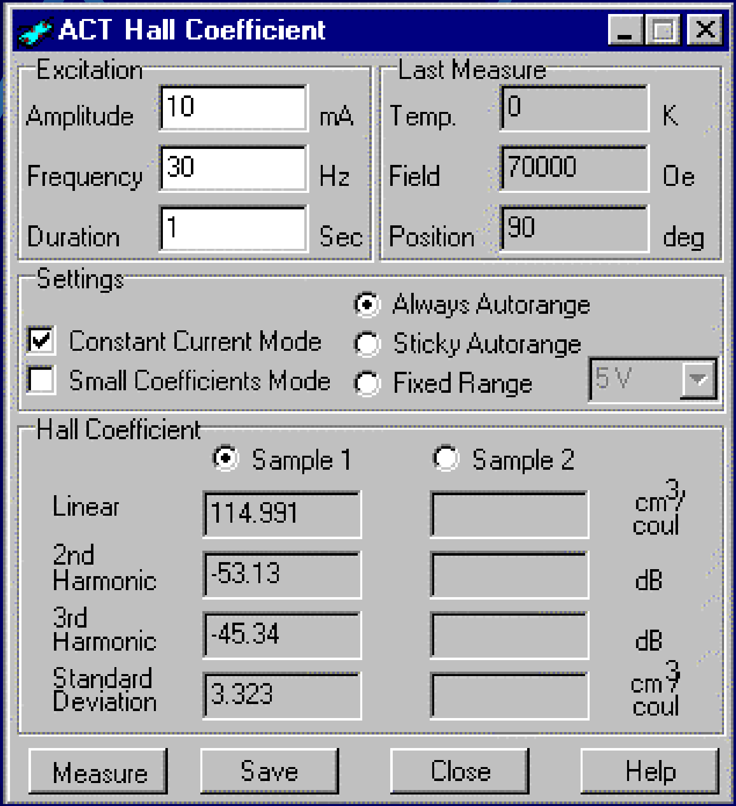
Resistivity Measurement

- Main parameters:
  - Frequency
  - Current amplitude
  - Duration
- Avoid frequencies commensurate to the line
  - Ex: 100 Hz is 5/3 of 60 Hz
- Choose current amplitude for good signal but low self heating
- Choose duration for good averaging but low self heating



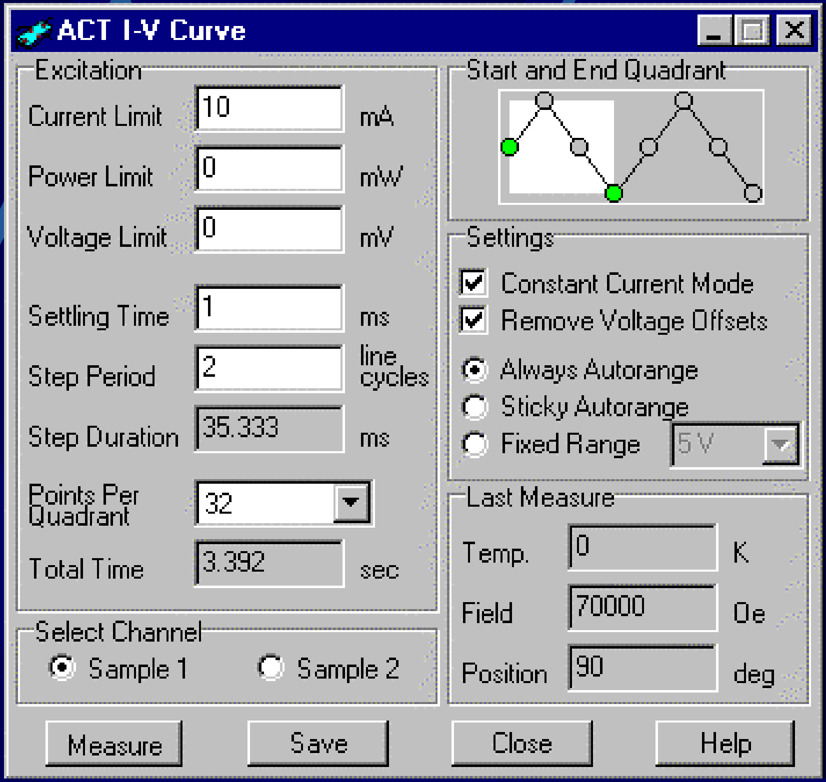
Hall Effect Measurement

- Looks identical to resistivity measurement for hardware
- Same constraints for parameter choices
- Often need to look at Hall resistance since Hall coefficient calculation assumes no longitudinal component



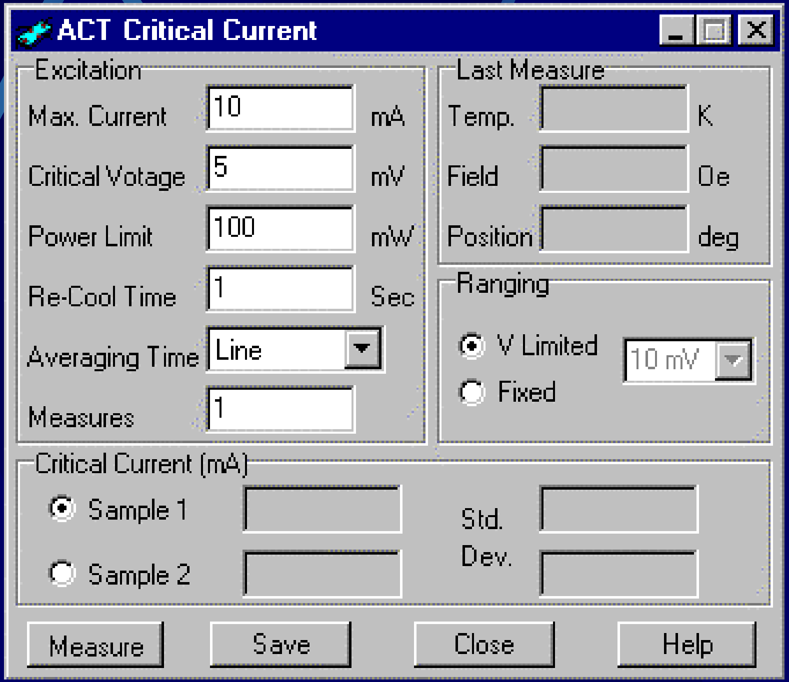
IV Curve

- Choose quadrants for measurement
- Choose maximum current
- Choose power and voltage limit to avoid sample damage



Critical Current Measurement

- Choose max current that you are willing to apply to sample
- Choose critical voltage
- Measurement stops when critical voltage or max current is reached
  - Crit. curr. reported if crit. volt. reached.
- Choose power limit to avoid sample damage



Calibration file

- ACT-##########.cal contains detailed calibration information
- Calibration performed upstairs (by Quy)
- Calibration is on matched set of ACMS card and Model 7100 (not plug and play).
- ACT.ini contains serial numbers to point to calibration file
- When ACMS card is in Option Crate slot 2 (Evercool), add lines to end of cal file:

  Option Controller= 14

  Option Slot= 2

Artifacts

- Inductive cross-talk due to inconel sample chamber feedthrough
  - Causes bump in resistivity at 25 to 35 K
  - http://www.qdusa.com/resources/pdf/ppmsappnotes/AR04.pdf
- Common mode leak through
  - Can cause measurement errors for very low resistance samples
  - Can cause measurement errors when contact resistances are high and/or imbalanced
  - http://www.qdusa.com/resources/pdf/ppmsappnotes/com_mode.pdf

Troubleshooting

- Most common problem is cables
  - Use connection diagram
- Use hardware self check to check for gross hardware problems
- Check sample connections using desktop puck box and DMM
  - Delicate leads often fail

Troubleshooting Noise

- Try a different frequency
- Check for vibrating leads in magnetic field
- Check for noisy current range
  - Example: if measurements are noisy at 210 mA but not at 190 mA with the same gain settings, 2 A current range is noisy
  - Bad current range usually due to bad relay
- Check for noisy gain
  - Example: if measurements are noisy on gain 100 but not at gain 1000 for the same current, gain 100 is probably at fault

ACT Quiz (page 1/2)

(Answers in Red)

1. Which options require some or all of the ACT hardware? (Circle all that apply)

(a) AC Transport Option   (b) Horizontal Rotator (ACT can be used with HR, but is not required)

(c) ACMS   (d) Thermal Transport Option

2. Why is the ACT capable of damaging some samples? (Circle one answer)

(a) Because the ACT can supply high voltage (b) Because the ACT uses AC excitation

(c) Because the ACT can supply high current (d) Because of the monkeys inside

3. Why is it important to use the 4-probe measurement technique instead of 2-probe for low resistance samples? Under what conditions are accurate results obtained with 2-probe measurements?

In the 2-probe measurement, you measure the resistance of the sample plus the resistances of the leads and contacts to the sample. These resistances can cause a significant error since they are often comparable to or greater than the sample resistance.

If the lead and contact resistances are << than the sample resistance, then 2-probe measurements will yield accurate results.

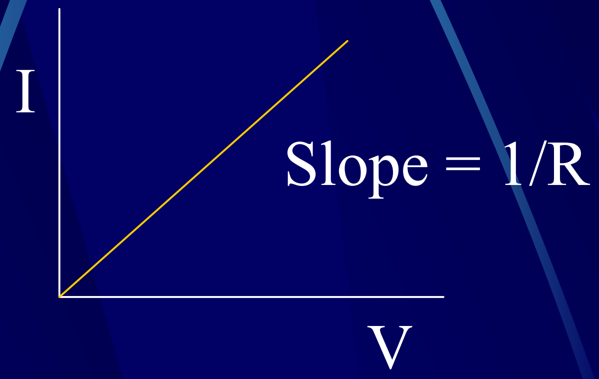
4. The ACMS card has failed on a customer system, so he can no longer perform ACT measurements. What steps must you take to get the customer up and running for accurate ACT measurements?

The ACMS card and the Model 7100 are calibrated as a set. Therefore, you cannot replace just the ACMS card. Instead, have the customer return the Model 7100 and the ACMS card. Repair or replace the ACMS card, then calibrate the card and Model 7100 as a set. Then send the set to the customer along with the new ACT calibration file. Remember to update the ACT.ini file so that the system uses the new calibration file.

ACT Quiz (page 2/2)

5. Draw the IV-curve for a resistor. What type of curve is it?

The curve is a straight line because I=V/R with R constant for a resistor.



6. (Extra credit-difficult) The ACT current drive has a maximum compliance of >10 V, but the voltage read back can only measure up to 5 V. Why is it useful for the maximum compliance voltage to be greater than the maximum read back voltage? (Hint: Think about 4-probe measurements.)

In a 4-probe measurement, the current source must drive current through the series combination of the sample, and leads, and the contacts. If the lead or contact resistances are comparable to the sample resistance, then the voltage output of the current source will be significantly higher than the voltage read back at the voltage leads. Therefore, in order to take advantage of the full dynamic range of the instrument (i.e., to use the full read back voltage range available), it is useful to have a voltage compliance on the current source that is higher than the maximum read back voltage.