Experiment 3
IC Resistors

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1.0 Objective

This lab introduces the MicroLinear Lab Chips, with measurements of IC resistors and a distributed delay line. From the layout of the resistors, you will interpret the measured resistance as a sheet resistance of the layer from which the resistor is fabricated. The Micro Linear chips are "tile arrays" that consist of standard devices in fixed locations. The polysilicon resistors on Lab Chip 1 consist of 15 and 36 series-connected resistors, with aluminum (metal 1) being used as an interconnect layer. A long metal runner is measured from which you can measure the sheet resistance of the metal 1 layer. Using this value, you can make an improvement in your estimate of the polysilicon sheet resistance and attempt to estimate the metal-polysilicon contact resistance. A diffused "base resistor" is included that will enable you to measure the effect of depletion width on resistance.

The HP-4155 Parameter Analyzers will be used and the results compared to those obtained from the digital multimeter. The key concepts introduced in this lab are:

- Calculation of the sheet resistance given the layout of a resistor and the measured resistance
- The non-ideal behavior of IC resistors
- Measurement errors and the resulting uncertainty in calculated parameters
- The variation of resistance in junction-isolated diffusion resistors as a function of the reverse bias on the isolation diode.

2.0 Prelab

- Reading: H&S Chapter 2 (especially section 2.6) for sheet resistance
  Chapter 3.5 (see Example 3.6 for a similar structure to the base diffusion resistor).

- From the layout (1.5 μm between grid points) in Fig. 1, find the number of squares for the polysilicon resistor M3520 on Lab Chip 1. Assume that the contact regions at the ends of the resistor count as one square and use the effective number of square for right-angle bends from Appendix A at the end of this lab. You will note that in some cases, you will have to use "engineering judgement" in your estimates. In any case, state your assumptions and justify your choice for the value you use for the "effective" number of squares.

- Review Appendix A and B.

3.0 Procedure

3.1 Calculating the Polysilicon Sheet Resistance

1. Using the digital multimeter, measure the resistance of the polysilicon resistor RP1-RP2 (PINS #21-22) on Lab Chip 1. This resistor consists of 15 M3520 polysilicon resistors in series, as shown in Fig. 2.

2. The M3520 resistor is nominally 3450 Ω. Assuming your measurement is 15 times the resistance of one M3520, how close are your resistors to the nominal value.

3. Neglecting the contribution of the aluminum metal 1 interconnects and the polysilicon-aluminum ohmic contacts (we will consider these later), calculate the sheet resistance R_o of the polysilicon film.

4. If we assume that the polysilicon thickness is $t_{POLY} = 0.35$ μm (a typical value) and that the doping concentration is $N_d = 10^{19}$ cm^{-3}, estimate the mobility of electrons in the polysilicon film. Note that the grain boundaries in polysilicon greatly affect the mobility.

FIGURE 1.   Layout of M3520 resistor -- the left-hand contact region is indicated (see Prelab),
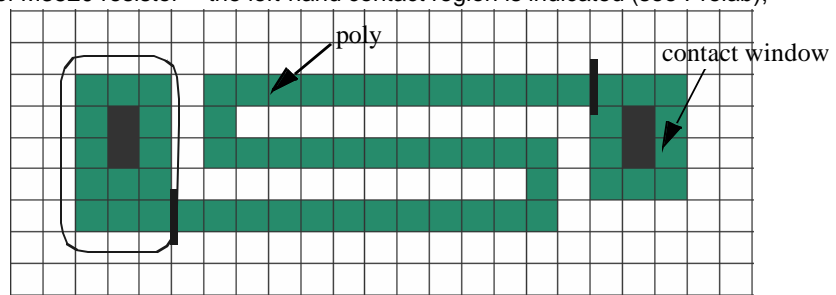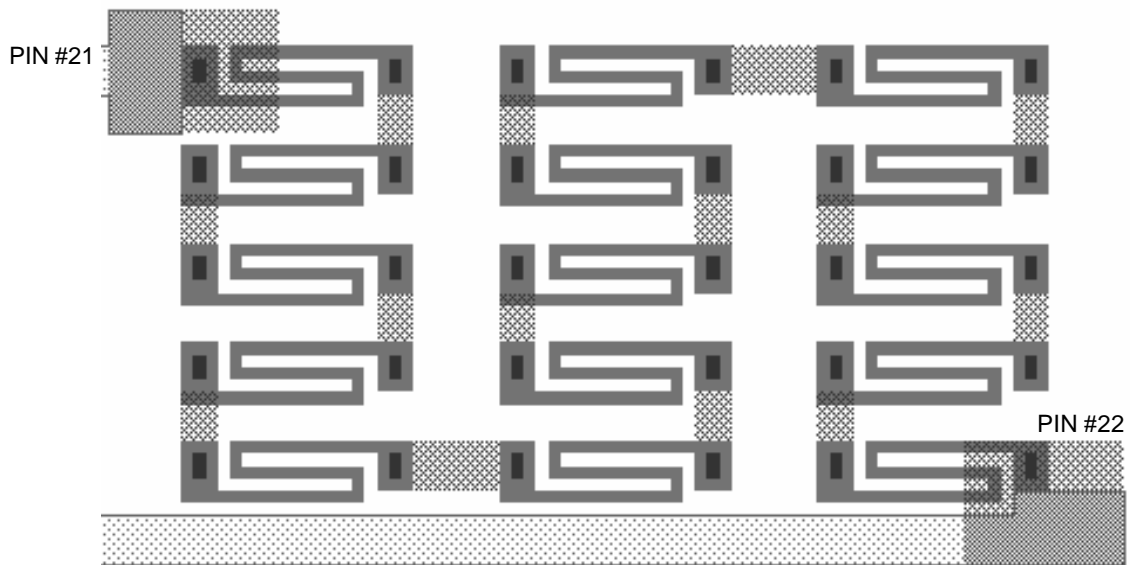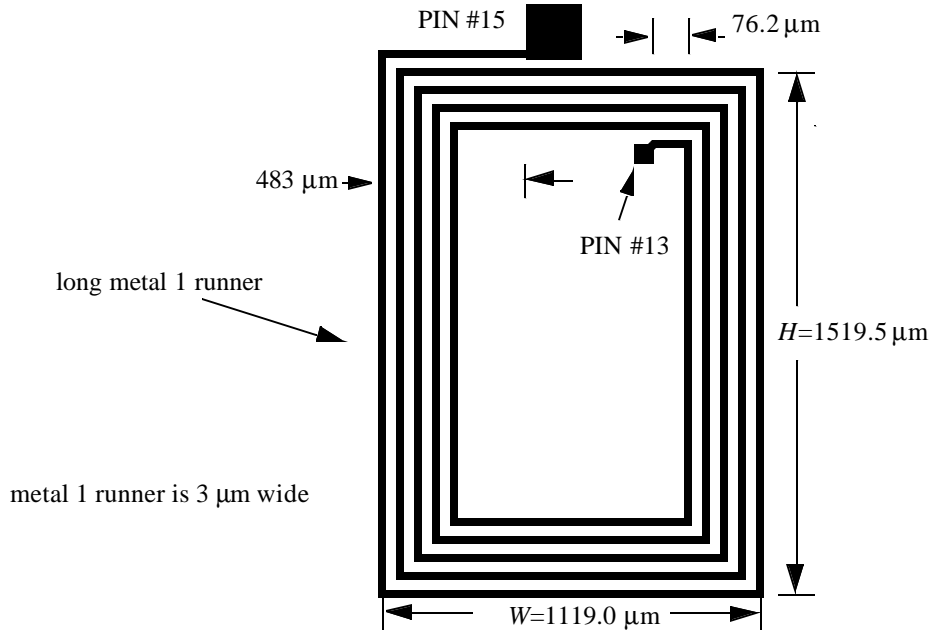
FIGURE 2.   Layout of RP1-RP2 resistor as 15 M3520 poly resistors in series (Lab Chip 1).

3.2 Calculating the Metal 1 Sheet Resistance

1. Figure 3 shows a *very* long metal 1 aluminum runner connecting to two bonding pads (Metal Runner I and Metal Runner II, PINS 13-15) on Lab Chip 1. Note that Fig. 3 is not to scale. The metal runner has a small but non-zero resistance. Use the HP-4155 to find the resistance of this metal runner. Since metal is very conductive, the 4155 will reach its current compliance limit. This is not a problem; for small voltages, it will still give accurate results.

2. From the layout in Fig. 3, determine R_o of metal 1. The width of the runner is $3\,\mu$m. Assume that the large "chunks" at the pad of PIN #15 and the small one at the pad of PIN #13 together contribute about one square and that the five turns have approximately the same length for simplicity.

FIGURE 3.   Layout of long and narrow metal runner (Lab Chip 1)

PIN #15

76.2 μm

483 μm

PIN #13

long metal 1 runner

H=1519.5 μm

metal 1 runner is 3 μm wide

W=1119.0 μm

3.3   Estimation of Contact Resistance

1. Using the digital multimeter, measure the resistances of the 36 series-connected wide poly resistors (M3524) shown in Fig. 4. The layout and cross section of M3524 is given in Fig. 5.

2. Using the effective number of squares for the contact regions at the ends of each M3524 resistor from the Appendix and neglecting the contributions of the metal connections, estimate the sheet resistance of polysilicon and compare your result with what you found in 3.1. Which calculation would you place more confidence in? Why?

3. A more accurate value for the sheet resistance of polysilicon and potentially, an esti- mate of the resistance of the many polysilicon-aluminum ohmic contacts can be made using the measurements on *both* resistors (RP1-RP2 and RP3-RP4). The resis- tance of either resistor can be expressed as the sum of three contributions:

$$R = N_{poly}N_{sq}R_{sq} + (N_{hor}R_{hor} + N_{vert}R_{vert}) + N_{poly-Al}R_{poly-Al} \qquad \textbf{(EQ 1)}$$

where N_{poly} is the number of poly resistor segments (15 or 36), $N_{sq}R_{sq}$ is the resistance of each segment (found from the product of the polysilicon sheet resistance and the number of squares), the second term (in parentheses) is the total resistance of the metal 1 interconnections (both horizontal and vertical straps), and the final term is the total resistance due to the ohmic contacts between the polysilicon and the aluminum ($N_{poly-Al}$ is the number of contacts and $R_{poly-Al}$ is the *contact resistance* in Ω.)

By solving the two equations simultaneously, find the sheet resistance R_o of polysilicon and the contact resistance $R_{poly-Al}$ by using the results from 3.3 for the sheet resistance of metal 1. Given the uncertainty in your measurements, estimate the uncertainly in your values for R_o and $R_{poly-Al}$.

The metal "straps" between the poly segments have about 2 squares. Therefore, the RP3-RP4 resistor in Fig. 4 has a resistance given by

$$R_{3-4} = 36\, N_{sq}R_{sq} + \{30(2)R_{pm} + 5(2)R_{pm}\} + 72\, R_{poly-Al} \qquad \textbf{(EQ 2)}$$

A similar equation can be written for the RP1-RP2 resistor in Fig. 2. You can then solve the two equations in two unknowns (R_{sq} and $R_{poly-Al}$).

Note: due to the small value for $R_{poly-Al}$ and uncertainties in the measurements, the calculation may lead to a negative answer, which is obviously not physically reasonable. Note that we have assumed that the polysilicon has a uniform sheet resistance for the two areas of Lab Chip 1 where the two resistors are fabricated, which may not be correct. There are other contributions to the total measured resistance that haven't been accounted for; can you identify any of these? Would they affect your results?

FIGURE 4.　　　　　　　　　　Layout of RP3-RP4 (PINS 23-24): 36 M3524 poly resistors in series, Lab Chip 1.
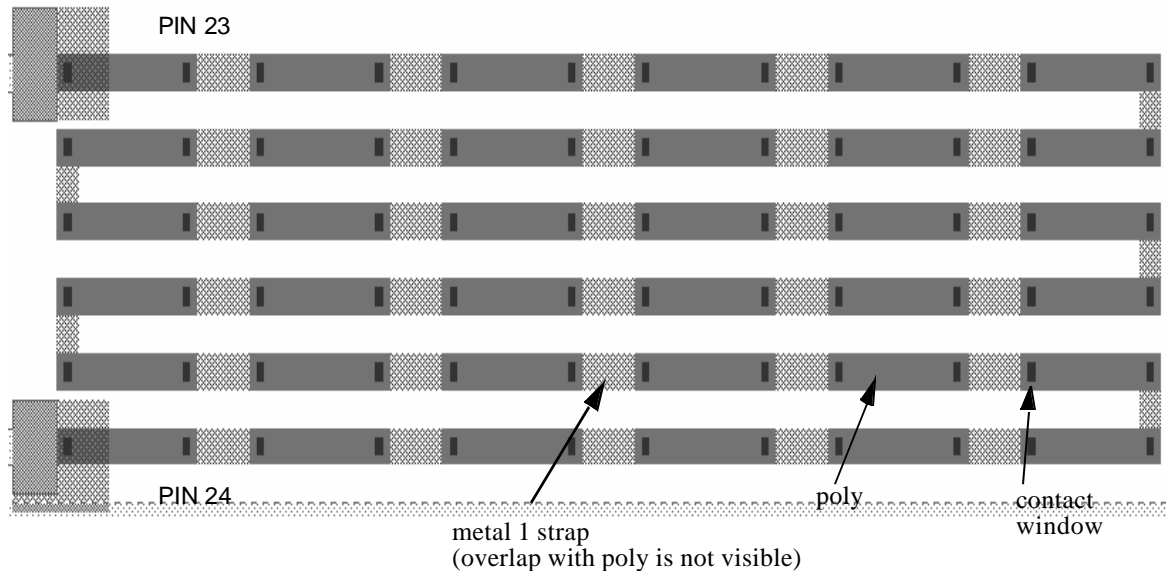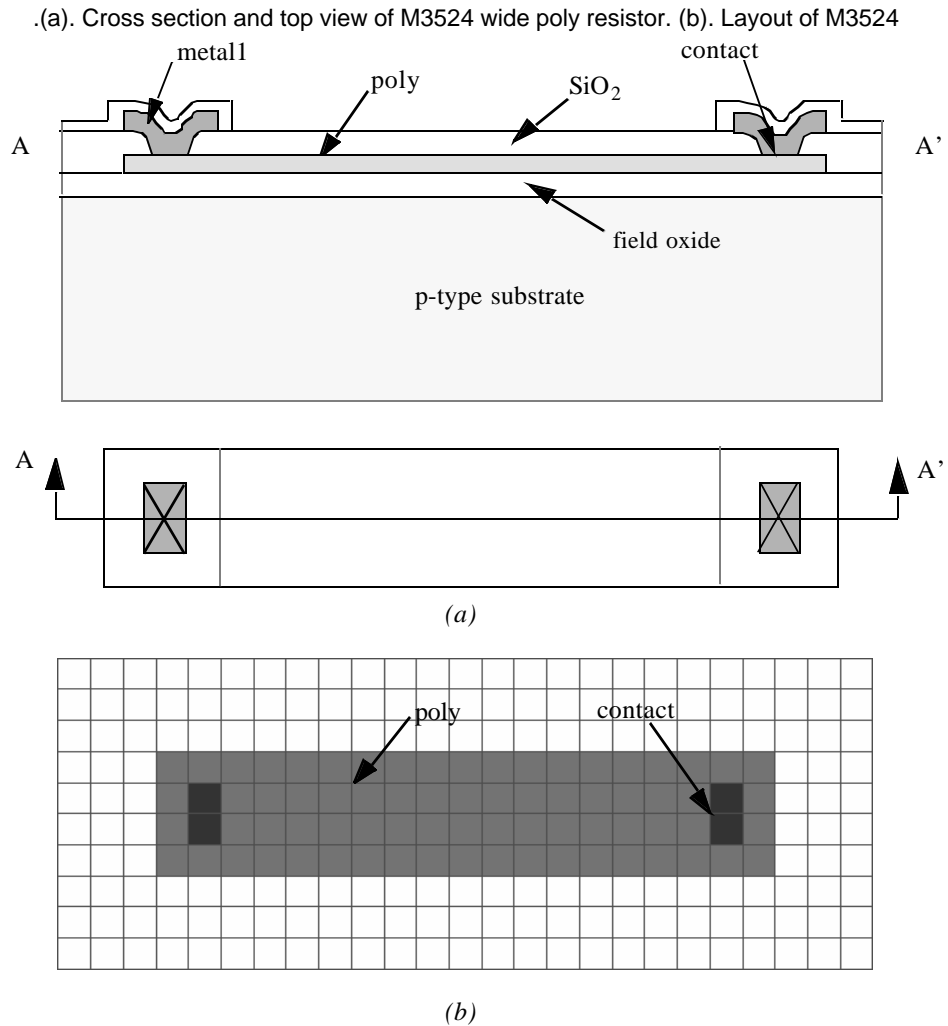

PIN 23

PIN 24

metal 1 strap
(overlap with poly is not visible)

poly

contact
window

FIGURE 5. .(a). Cross section and top view of M3524 wide poly resistor. (b). Layout of M3524

(a)

(b)

3.3.1 Contact measurement using the HP-4155

We will repeat the above experiment using the HP-4155. In Exp. 1, you found the resistance of a carbon resistor by taking the slope of the resistor's I-V characteristics. You will again use the same method to find the resistance of an IC resistor.

1. Use the canned diode program.

2. Place the Lab Chip 1 into the test fixture.

3. Connect **SMU1** to the connection dedicated to pin 23 and **SMU3** to pin 24.

4. Use the cursor and marker to find the resistances of the resistors. (refer to Appendices A and B).

5. Compare the results with the results obtained from the digital multimeter. Which do you think is more accurate?

### 3.4 Base Diffusion Resistor

Figure 6 shows the cross section and layout of the base diffusion resistor on Lab Chip 1. Note from the cross section that the well contact (PIN 20, RBW) is connected to the n type epitaxial (epi) layer that underlies the p-type base diffusion. If the reverse bias on the pn junction between the epi and the base diffusion is changed, then the depletion width will change, as calculated in Example 3.6 of H&S. As a result, the effective unde-pleted thickness of the base diffusion will change and the resistance between RB2 and RB1 (PINS 16 and 17) will increase. This effect is not as pronounced since the epi layer is more lightly doped than the base diffusion. Finally, note that even with RB2 and RBW shorted together and grounded, a large voltage on RB1 will cause an increase in the depletion width at that end of the resistor, which will cause deviations from a linear resistor.

Connect PINS 17 and 20 to GND and measure the *I-V* characteristic by changing the voltage of PIN 16 from 0 V to - 5 V. Note that a *negative* voltage is required to avoid forward-biasing the p-base-to-n-epi junction. Find the value of the resistor as the inverse of the slope of the *I-V* plot over the range 0 V to -1 V.

Now connect the power supply in series with a 100 kΩ resistor to RBW, PIN 20. Repeat the resistor *I-V* measurements over the range 0 to -1 V for voltages of 1 and 3 V applied to RBW. Defining the resistance R_B to be the inverse of the straight-line fit to *I-V* over the range 0 -> -1 V, plot R_B as a function of V_{RBW}.

FIGURE 6.   Base Diffusion Resistor on Lab Chip 1. Pin 20 controls the resistor RB.
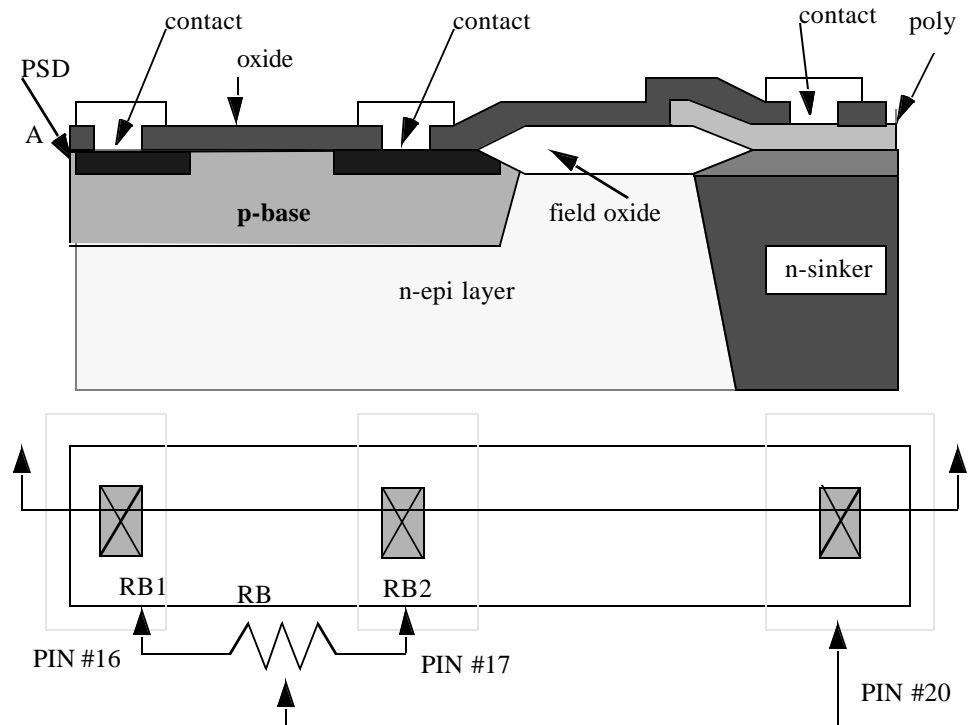
These measurements can also be obtained using the HP-4155, without the external power supply. For this measurement, you need to put pin 17 to ground, sweep the voltage and measure the current going through pin 16; you are also stepping the voltage on pin 20 (through the 100 kΩ resistor) between 1 volt and 3 volts. If this sounds familiar to you, you are right! The FET I_D -- V_{DS} program used in Exp. 1 performs exactly this function. SMU1 is ground (pin 17), SMU2 sweeps (pin 16), and SMU3 steps (pin 20).
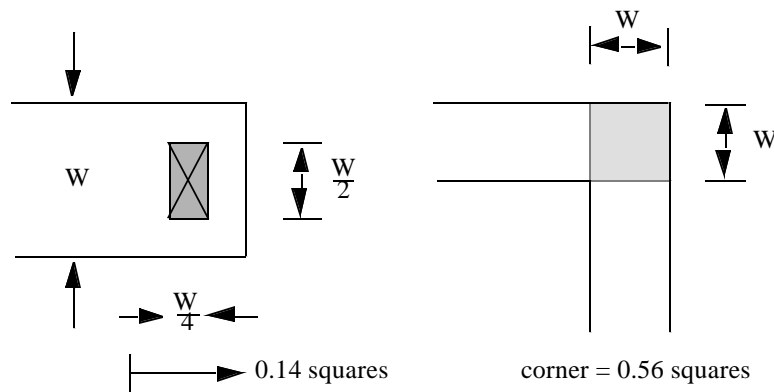
4.0 Appendix A

For IC layout, it is convenient to work with a parameter called sheet resistance R_{o} For a region of length L and width W the sheet resistance is found from

$$R = \left(\frac{1}{q\mu_n N_d}\right)\frac{L}{Wt} = \frac{L}{W}\left(\frac{1}{q\mu_n N_d t}\right) = \frac{L}{W}R_\square$$

where L/W is the number of squares. Non-rectangular regions can be accounted for by defining an effective number of squares, as shown in Fig. 7.

FIGURE 7.   Effective number of squares for resistor-end and corner

0.14 squares   corner = 0.56 squares

5.0 Appendix B: HP 4155 quick reference

5.1 Convention

The following convention will be used in regards to commands.

- References to a button will be enclosed with bold brackets. (e.g. **[EXE]** refers to the **execute** key.)
- References to keystrokes which need to be "typed in" will be in bold italics. (e.g. *VGS* means type in the keystrokes V-G-S.)

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- References to "softkeys" will be represented by bold braces. (e.g. **{CURSOR}** refers to the key that corresponds to the cursor key shown on the CRT.

5.2 The Softkey Menu

1. The **{EXTN}** softkey toggles through the hierarchy of menus of softkeys.
2. For a complete list of softkeys, consult the **OPERATIONS MANUAL** .

5.3 Using the Cursor and Marker to Obtain the Slope of a Line for 4155

1. Hit the **{MARKER}** key.
2. The marker can be moved using the circular knob. Notice that as the marker moves, its current x and y value is displayed on the top of the graph.
3. When the marker reaches the first point of your line, hit the **{SHORT CURSOR}** key. Notice that a small crosshairs has appeared in the center of the graph.
4. Hit the **{CURSOR > O}** key and now the crosshairs lies on the marker.
5. Hit the **{LINE ON}** key and now the first point of the line is set. Notice that a small box has appeared below the graph and contains information of the line such as its gradient and intercepts.
6. Move the marker using the knob to the second point of your line.
7. Hit **{CURSOR > O}** and now the line has been properly fitted.

5.4 How to Get the Slope of a Line on HP-4155

1. When you have the graph on the screen, press **{MARKER/CURSOR}** softkey on the bottom, then **{MARKER}** softkey on the right until it switches to **ON.** You should see the marker on the line, which looks like a small circle.
2. Then press **{LINE}** softkey on the bottom, the press **{LINE SELECT}** softkey on the right until it says **LINE SELECT 1** or **2.** Press **{LINE}** softkey on the right to switch it to **ON.** Now there should be some display on the screen about the intercept and the gradient (slope) of the line.
3. You can use the turning knob to move the marker to a point on the line, press **{CUR-SOR TO MARKER}** softkey on the right, which moves the cursor (a cross-hair) to where the marker is. Then press **{SELECT CURSOR 1}** to make that your cursor point 1. Repeat this step to choose another cursor point. And the slope should be displayed on the screen.

5.5 Getting a Hardcopy of Your Data

1. Hit the **[PLOT]** key
2. Enter the print parameters (size and orientation) or accept the default settings
3. Hit the **[EXE]** key

5.6 Warning

Not all the boxes (4155A and B) work exactly alike; consult your TA if you run into difficulties.

FIGURE 8.

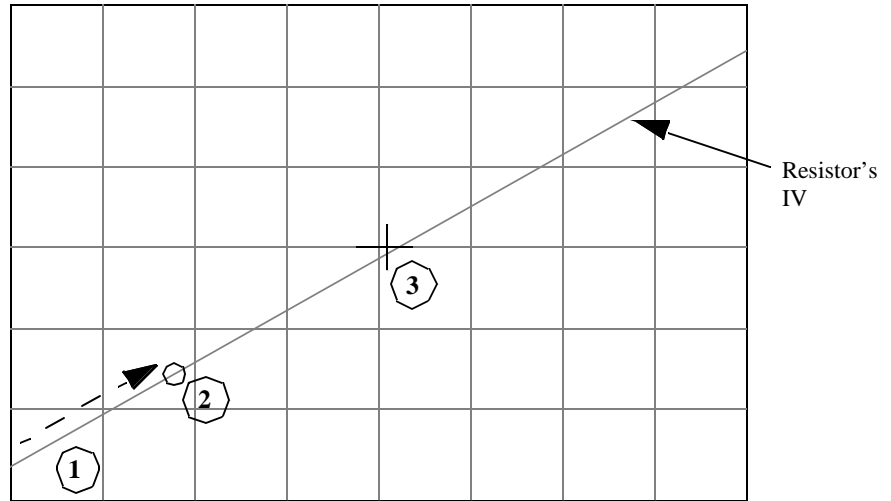Steps 1 - 3: Moving the cursor and bringing up the short cursor

Resistor's IV

FIGURE 9.

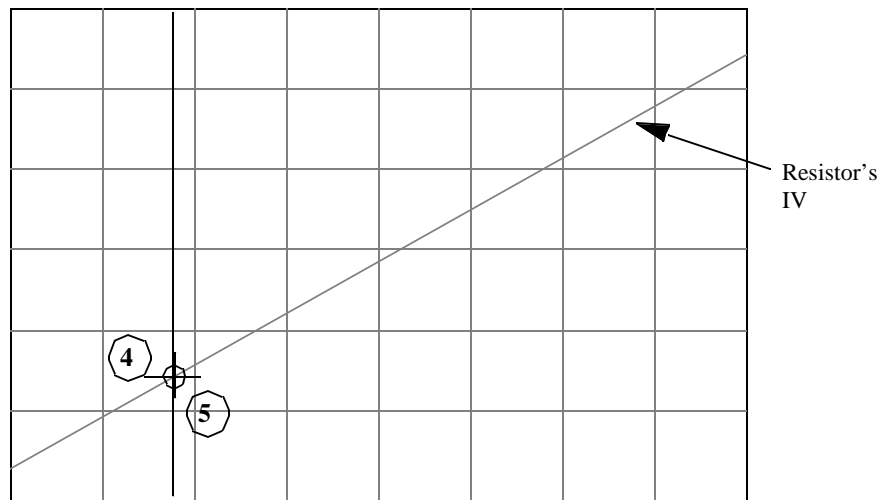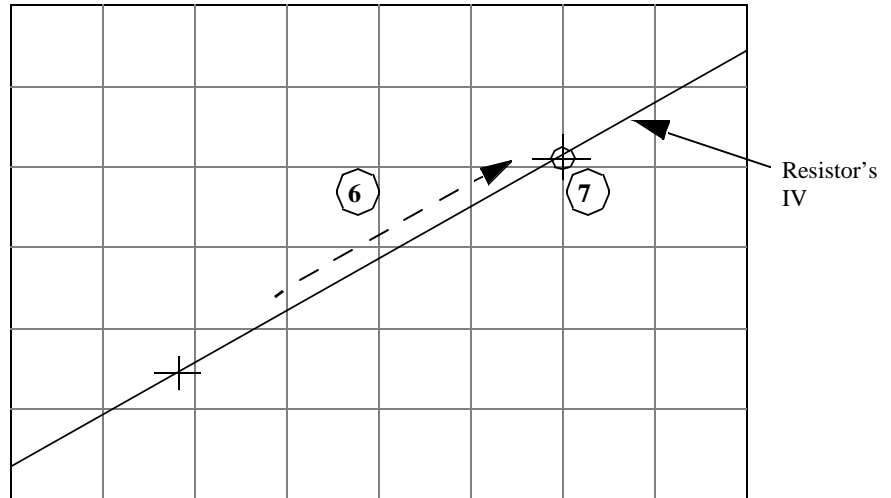Steps 4 and 5: Placing the Cursor on the Marker and Turning on the Line

Resistor's IV

FIGURE 10. Steps 6 and 7: Moving the Marker and Placing the Cursor on the 2nd Point of the Line

Resistor's IV

═══════ Lab Tip ═══════

Should you get lost at any of the screens, you can hit **[PREV]** to go to the previous screen and return to what you were doing by hitting **[NEXT]**. You can then start over.