Training Exercise 2: Capacitance Compensation and Bridge Balance

Goal:
   To consolidate your understanding of (IGOR and DataPro), and understand the purpose and operation of electrode capacitance compensation and bridge balance adjustment.

**Theory: Capacitance Compensation and Bridge Balance Correction**

1. What is capacitance compensation?
   There is artifactual capacitance associated with all glass microelectrodes, because there is a thin, nonconductive glass wall that separates two conductive solutions. It might make sense that most of the capacitance of microelectrodes is associated with the very (thin) tip, since you learned earlier that capacitance becomes larger as the distance of separation of charges decreases. Capacitance from your electrode can artificially slow the speed at which your amplifier can inject current, thus slowing the responses as well.

2. Capacitance compensation on your amplifier
   The capacitance compensation knob on your amplifier allows you to offset the effects of electrode capacitance. As you inject current into your preparation while turning the "cap comp" knob, the amplifier injects a scaled portion of your current pulse only at the start of the pulse. This is positive feedback! When properly set, this extra transient current can add back the current that is drawn by the electrode capacitance. Watch out, however. If cap comp is increased beyond that ideal value, the whole circuit can become unstable and undergo uncontrolled, large-amplitude oscillations. This usually results in the end of your recording and death to your recorded cell.

1. What is "bridge balance"?
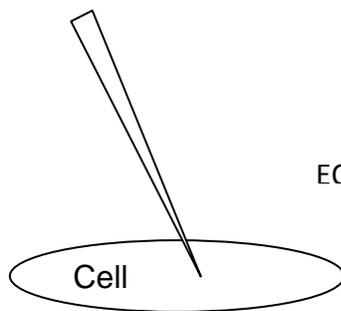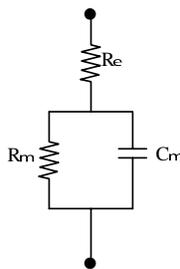
An electrode sticking inside a cell is functionally equivalent to the electrical circuit at the left. The electrode is equivalent to a single resistor (R_e), because the narrow electrode opening (about 1 µm) limits current flow through it, just like the opening of a narrow water hose limits the flow of water.
Current flowing through the electrode can only get to ground (and complete the circuit)

by flowing across the cell membrane. It has resistance (R_m) because of ion channels, and it also has capacitance (C_m) in parallel (the small amount of electrode capacitance is not pictured here).

The recording problem: We measure the potential difference between two points: the first is prior to the electrode resistance and the second is after the cell membrane (the two filled circles on the circuit diagram). As a result, the voltage drop includes both the electrode resistance and the membrane resistance. We need a way to subtract out the electrode resistance, leaving us only the membrane resistance.

In terms of our water hose analogy, imagine if you attached two hoses together, and measured the difference between the pressure entering the first hose and the pressure leaving the second. The drop in pressure would reflect the summed resistance of both hoses together.

The solution: A "bridge circuit". The fact that the cell membrane has capacitance allows us to distinguish the voltage drop across the electrode from the voltage drop across the cell membrane. Why? Remember the membrane capacitance stores charge. It initially draws the majority of the current that is injected, leaving a lesser amount to drive voltage changes across the membrane resistance. As the membrane approaches the limit of how much charge it can store, a relatively larger proportion of current flows across the cell resistance. The overall effect of capacitance is that it slows membrane voltage changes. In this way, capacitance acts as a "shock absorber" for voltage changes.

Experimental Setup

1. In the equipment rack, turn on the Dagan amplifier, letting it warm up.
2. Make sure the yellow capacitance compensation knob and bridge balance dial on panel are turned completely to their full counterclockwise extent (which is OFF).
3. Start DataPro by double clicking the "startup" icon on the desktop.
4. Immediately save the experiment as an "unpacked experiment", giving it a unique and informative name, such as "lab1" or Jan24_07ki.
5. Insert the model cell into the headstage of the amplifier.
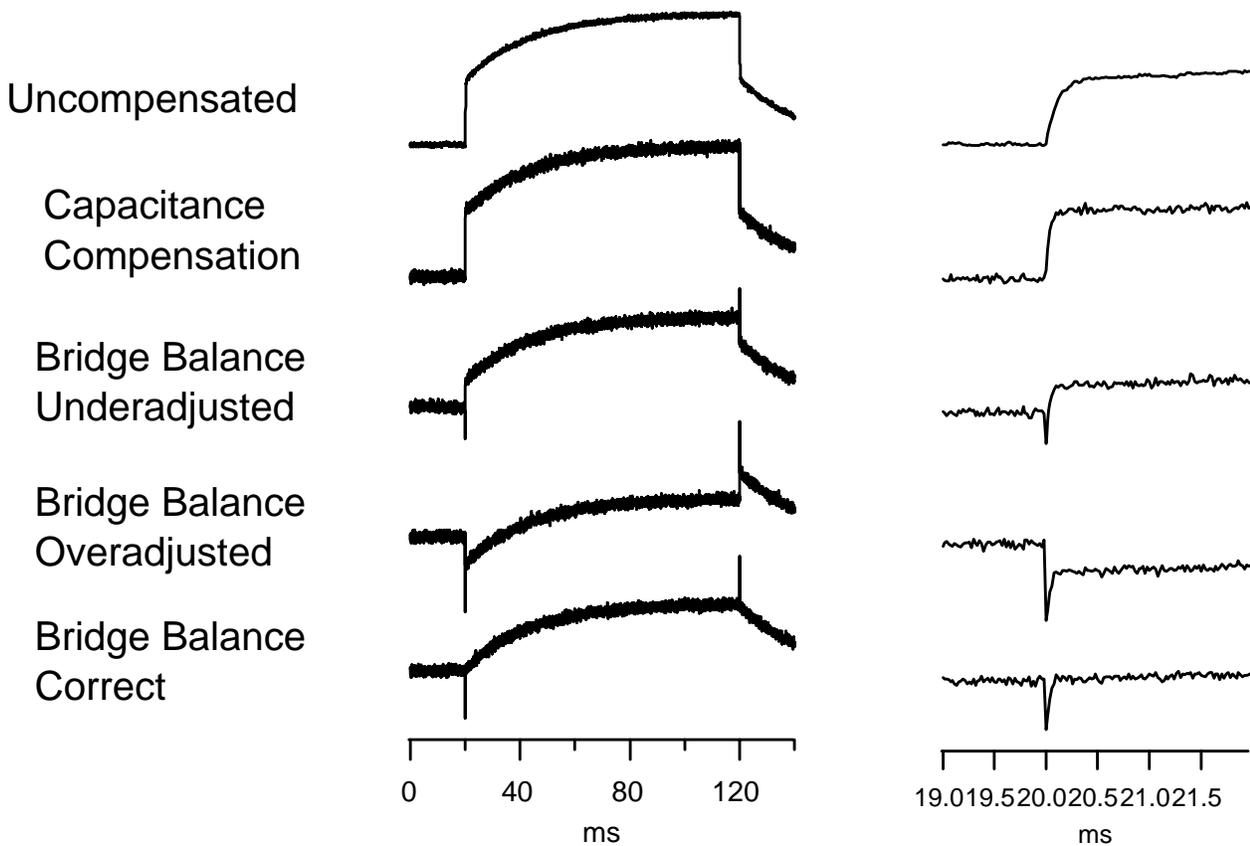
Performing capacitance compensation and bridge balance correction

1. In DataPro, send a 25 ms, 200 pA test pulse to the model cell. Note the response should have both a fast-rising and slow-rising component. Note also that these components are also visible on the offset of the response.

2. Now look only at the initial rise of the fast component in the test pulse display by setting the pulse duration to 5 ms.

3. While the pulse is running, begin turning the capacitance compensation dial clockwise. The rise time of the initial response should become even shorter, and you should see the background noise of the trace get larger. Keep turning the capacitance until you start to see

oscillations on your response. Decrease the cap comp just until these oscillations disappear. The noise on the trace will still be larger than when you began…this is normal.

4. Set your test pulse duration back to 25 ms. Now turn your bridge balance dial until the fast component of your response disappears, and your slower component appears to rise directly from the baseline (See figure below). Your have just canceled out the voltage drop across your model electrode, leaving you with the slower rising response of your model cell. To find out what the resistance of your electrode was, you can multiply the reading on your bridge balance dial and multiply it by 10. What is it? The test pulse display should also give you the resistance of your model cell membrane. What is it? You can even get a rough idea of the membrane time constant by eye (how long does it take for the response to reach about 2/3 of the final voltage excursion?).

See examples of capacitance compensation and bridge balance compensation below.

Figure 1. Electrode capacitance compensation and bridge balance adjustment using a model cell