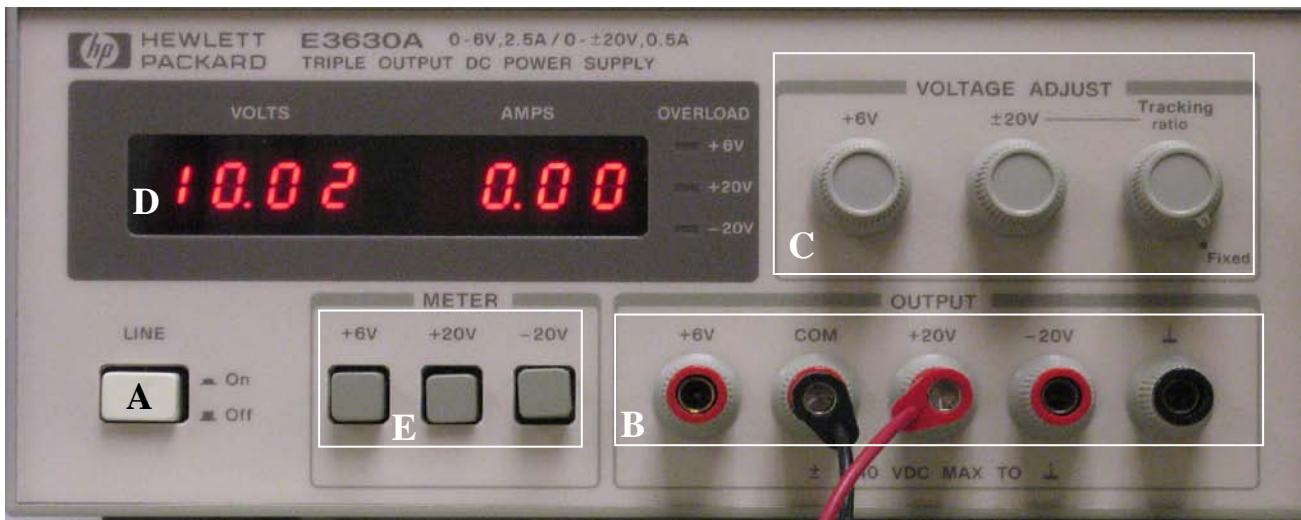


## Appendix A: Laboratory Equipment Manual

- 1. Introduction:** This appendix is a manual for equipment used in experiments 1-8. As a part of this series of laboratory exercises, students must acquire a minimum proficiency in operating the bench instruments that will be used in most of the exercises. Appendix A provides operating instructions for the most commonly used equipment features. Note that this manual is not comprehensive. Only the functions of the bench instruments commonly utilized in this course are covered. For more detailed information on a specific bench instrument, refer to the manual for that particular piece of equipment. Equipment manuals for all instruments are available either in the lab or in the EE lab support parts room.
- 2. Covered Equipment:** The laboratory instruments covered in this manual are as follows:
  - Power Supply, Hewlett-Packard (HP) Model # E3630A (Section 4).
  - Multimeter, HP Model # 34401A (Section 5).
  - Signal Generator HP Model 33220A (Section 6).
  - Oscilloscope, Agilent Model # 54622D (Section 7).
  - Electrical circuit prototyping board (Section 8).
  - Electrical connecting leads (Section 9).
  - RCL Meter, Fluke Model PM6303A (Section 10).
  - Circuit Prototyping Unit, Model IDL-800 (Section 11).
- 3. Note on Operational Instructions:** A general overview of operation for the instruments shown above and the associated support equipment is given in the sections below. However, additional operational information, where essential, may also be included in the laboratory exercises as a part of the experimental instructions.

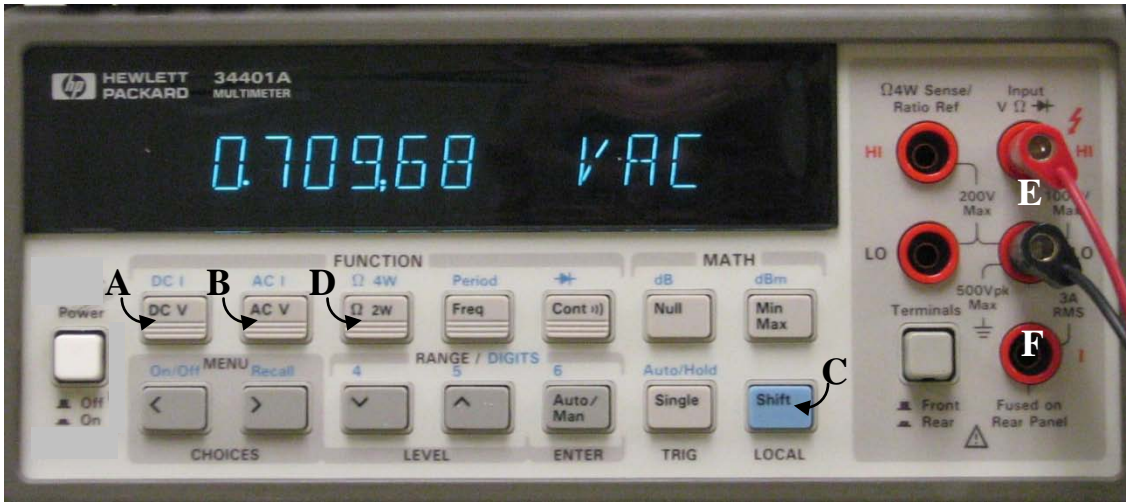
#### 4. Power Supply, Hewlett-Packard Model # E3630A: Refer to Fig. 1.



**Fig. 1. Lab Power Supply**

- 4.1. Description:** The Hewlett-Packard Power Supply (Model E3630A) is a triple-output power supply. The switch (A) in the lower left-hand corner of the front panel turns the power supply on. The power supply has three separate outputs. The output on the far left (square B, above, first output on left) is settable, 0 to +6 Volts DC, with a maximum current capability of 2.75 Amperes. The second output is the common low side, used for all voltages (like the – terminal on a battery). The third and fourth outputs from the left are the +20 V and –20 V outputs, and the black output at the right is the “ground” terminal. You could think of it as “zero volts” (0 V) or “earth ground.” The labeled +20V and –20 V outputs are both continuously adjustable from 0 to the maximum DC voltage (+ or – 20 V), with a maximum current output of 0.5 A.
- 4.2. Controls:** The output voltages are controlled by the upper controls (C) in the picture, marked “+6V” and “±20V.” When current overload occurs, the output circuits are protected so that current is clamped (restricted) at 110% of rated capacity, or about 0.55 A for the 20 ±V outputs. The “±20V” knob controls both the +20 V and –20 V outputs. When the “tracking ratio” knob is in the fixed position (max CCW), the two 20-volt outputs will always be equal and opposite, between 0 and 20 volts. Thus if the +20 V output is set at 10 V, the –20 V output is at –10 V. When the “tracking ratio” control is turned on (CW), the –20 V output can be set lower for a corresponding output of the +20 supply. For example, the control could be set to the mid-point, so that a +10 V reading would result in the other reading being –5 V. The tracking control allows a lower-magnitude negative voltage that is a constant fraction of the positive output. The “±20V” control knob still controls both outputs, however.
- 4.3. Display:** The display unit (D) is on the upper left. The three square buttons (E) (“+6V,” “+20V,” and “–20V”) switch the outputs to the display. Note that “overload” indicators for the three voltages light up when the maximum currents noted above are exceeded. For the output connected to the display, the voltage is shown on the left and the corresponding output current on the right.

5. Digital Multimeter (DMM), Hewlett-Packard (HP) Model # 34401A: Refer to Fig. 2, below:



**Fig. 2: Lab. Multimeter**

- 5.1. The Hewlett-Packard DMM (Model 34401A) has a more complex control panel, much of which will not be used in our exercises. Power is turned on with the square white button on the far left. The primary uses are DC voltage measurement (controlled by front panel button A), DC current measurement (blue front panel button C [“shift”] plus front panel switch A), AC voltage measurement (switch B), AC current measurement (blue front panel button C [“shift”] plus front panel switch B), and resistance measurement (button D). Many of the options on this instrument have to do with controlling the meter from a personal computer, which will not be used. The HP DMM uses the “banana plug” cables (Fig. 13, Section 9.), which are connected to the two left-hand upper red inputs (E) for voltage and resistance measurements, as shown.
- 5.2. The single input receptacle (F) is for current measurements. When it is desired to switch the meter into current-measurement mode (AC or DC), the red (+) lead is removed from the top left red banana receptacle (E) and plugged into receptacle F. Note that the DMM automatically switches measurement ranges, so that no adjustments have to be made relative to the size of the parameter measured.
- 5.3. The HP DMM also performs many other measurement functions, such as AC signal frequency, period, and so forth, which will not be used in this course.

6. **Signal Generator, Agilent Model # 33220A:** Figure 3 shows the front panel of the HP 33220A. This unit can produce a variety of AC signal types, which can be used as inputs to an electrical circuit so that the voltage and current characteristics of the circuit can be examined.



**Fig. 3. Signal Generator Front**

- 6.1. The signal generator is turned on by depressing the button A shown in the picture above. The display (B) can depict the frequency of the signal output, as shown above, the signal amplitude (in volts, normally peak-to-peak), or the DC offset that is added to an AC signal. The large knob or wheel (C) in box E is used to adjust the frequency or amplitude of the signal to the desired value (more on items in box E below). The “Output” button (G), disconnects the signal output without turning off the function generator. The actual shape of the signal being generated is adjusted by the buttons in box D above. Refer to Fig. 4, below, for more detail. The two coaxial output connectors (F above) output the signal generator waveform and a “sync signal” which can be used by an oscilloscope, for example, to assure that the generated signal can be displayed properly.



**Fig. 4. Signal Generator Function Keys**

Buttons 1-4 are “soft” buttons that can serve various functions printed on the display (see Fig. 3). Buttons 5-8 control the shape of the AC signal. Depressing key 5 generates a sinusoidal wave. Depressing key 6 results in a “square wave,” a signal that alternates between a + and – value, but is constant over each ½-cycle. Key 7 causes a “triangular wave,” which alternates between two levels, rising and falling linearly with time. Key 8 has the special function of allowing a pulse (single signal) to be generated, but it will not be used here. The other keys shown but not discussed will also not be used in our exercises.

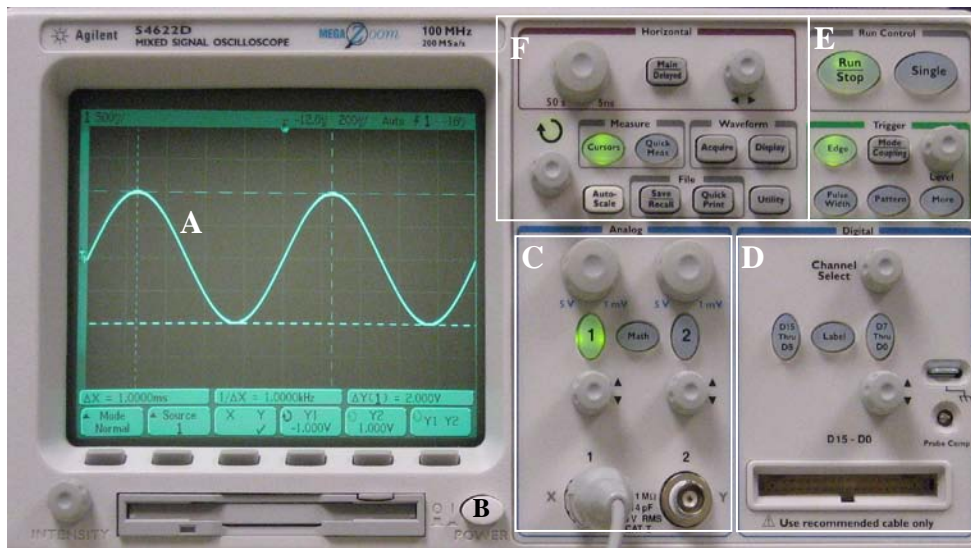
In Fig. 5, the controls shown adjust the frequency and amplitude of the waveform being generated. The large adjustment wheel has been mentioned. The keypad can be used to set a specific signal, including sign. The two small arrow buttons allow the user to shift back and forth between the digits of the amplitude or frequency being set, enabling extreme accuracy for setting these values. The large wheel provides continuous adjustment of the digit being changed.



**Fig. 5. Signal Generator Amplitude and Frequency Adjustment Controls**

- 6.2. The keypad shown in Fig. 5 will not be used in our experiments. Referring to Fig. 3, note that the digit of the amplitude or frequency being adjusted by the control wheel is highlighted. When the arrow buttons are used to shift the digit being adjusted, this highlight will follow the digit under adjustment. Very precise adjustments of the output signal are possible with this set of controls. For example, a frequency of 10.378654 kHz could be set on the display (although this level of accuracy is clearly not needed very frequently).
- 6.3. The signal output connectors (Fig. 3 [F]) referred to above are BNC connectors that are used to output signals to either the oscilloscope directly or to a circuit. When outputting to a circuit, the BNC-to-hook connector cable is used (Fig. 14 in Section 9). Note that there are variations to the BNC-to-hook and banana plug-to-hook connectors; see figures 14a and 14b. When outputting a “sync signal” directly to the oscilloscope, the coaxial RG-58 cable with dual coaxial connectors (Fig. 15, Section 9) is used.
- 6.4. Additional instructions for the signal generator will be given in the pertinent experiments, as required. Refer to the Agilent manual if necessary or to your teaching assistant or the instructor.

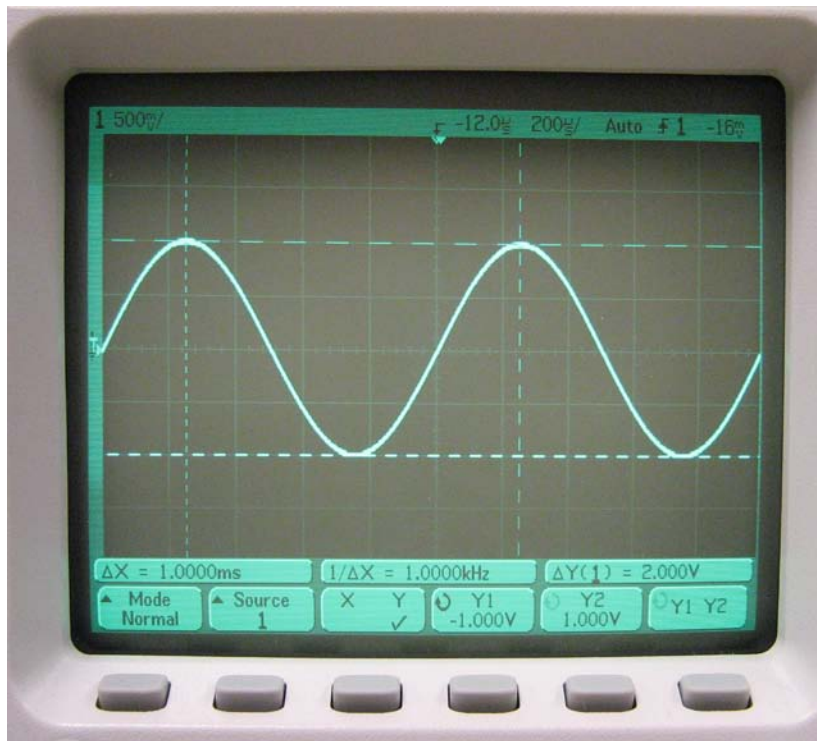
7. **Oscilloscope, Agilent Model # 54622D:** The oscilloscope front panel is shown in Fig. 7:



**Fig. 7.**  
**Oscilloscope**  
**Front Panel**

**7.1. Description:** The oscilloscope is an electronic instrument that draws a picture of a time-varying electrical signal on its display face (A). The display is a cathode-ray-tube (CRT) which is a very accurate display device. It is arranged so that the vertical variable is volts (or millivolts), and the sensitivity of this axis can be varied. The horizontal variable is time, which can also be adjusted so that the duration of a signal which is displayed may be only thousandths or even in millionths of a second. In this way, a very high-speed AC signal can be viewed on the oscilloscope, even though it is so brief an event that it is beyond human perception. The adjustment and use of the various controls shown in the picture above are discussed below.

**7.2. General Operation and Display:** The on-off switch for the oscilloscope is the oval white button at the bottom of the display (B). The display (A in Fig. 7) is shown in Fig. 8 and discussed below. Likewise, the two analog inputs and their controls (C) are shown in Fig. 9. The controls shown in box D, above, are for digital signal inputs. The Agilent 54622D oscilloscope is capable of displaying 16 digital signals (input via the large connector at the bottom of box D) in addition to the two analog signals input via the connectors in Box C. These digital inputs will not be used here, although they are utilized in later courses. The time adjustment and trigger controls (E) are shown in Fig. 10, and the menu, cursor, and additional controls at the top of the unit (F) in Fig. 11.



**Fig. 8.  
Oscilloscope  
Display  
Showing  
Cursors**

In Fig. 8, the oscilloscope display is shown with a sinusoidally-time-varying signal. In the upper left hand corner of the display is the notation “500mV/.” This means that each small vertical increment on the screen represents 500 mV, or 0.5 volts. Since the signal shown rises exactly four squares from its minimum, the signal must be 2 volts, peak-to-peak (also written as 2 V p-p). Near the middle of the screen top is a notation “200 $\mu$ s/.” This means that each horizontal increment represents 200 micro-seconds, or 0.0002 seconds. Although the signal is not exactly lined up with the squares, a quick count shows that it is exactly 1000  $\mu$ sec between peaks. This is noted in the bottom of the display.

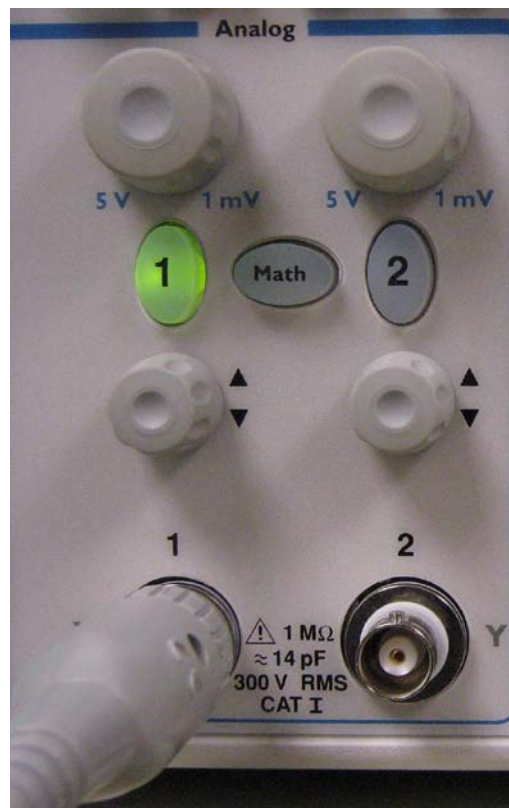
The two vertical lines on the display are called “cursors,” and they are positionable so that the time between them can be read. Thus the upper notation at the bottom left says “ $\Delta x = 1.0000$  msec.” This means that the period of the signal (the distance between the two vertical cursors) is 1 milli-second, or 1000  $\mu$ sec, as mentioned above. Since the frequency of a signal is the inverse of the period, the signal is exactly 1000 Hz, which is just what the second notation (bottom upper middle) says. The horizontal lines are also cursors which are positioned at the bottom and top of the signal. Note that the upper right notation on the bottom gives the difference in the two cursors, 2 volts, which is just what was noted above. The buttons at the bottom of the display are “soft buttons” – their function is changed, depending on what oscilloscope options are selected. In the case shown above, they control the cursor functions. These functions are discussed more completely below, in the section on cursor controls.

**7.3. Inputs and Input Controls:** Fig. 9 depicts the controls for the two oscilloscope analog inputs (shown in section C of Fig. 7).

The “1” and “2” oval buttons activate the menu at the bottom of the display (discussed above). The adjustment knobs at the top control the sensitivity of the respective channel. Thus, the 5V.....1mV” knob at top right controls the sensitivity of the Channel 1 input in volts/division, from 5V down to 1 mV. The smaller round knobs adjust the vertical position of the Channel 1 signal on the display. The signal is input via an oscilloscope probe (as discussed in Section 9; see Fig. 16) to the CH 1 input, a BNC-type receptacle, as shown.

The oscilloscope is a “dual-trace unit,” meaning that it can simultaneously display and analyze two separate signals at once. Thus the channel 2 input can receive a second signal, which can be displayed simultaneously with Channel 1. The Channel 2 controls are identical to the Channel 1 controls. The “Math” button activates a menu which allows two input signals to be added to and subtracted from each other in various combinations. Other functions such as Fourier analysis may also be performed. This feature will not be used in this course. Note that the “1,” “2,” and “Math” buttons light when activated.

**Fig. 9. Analog Input Controls**



**7.4. Run Mode and Trigger Controls:**

The close-up of the run mode and trigger controls (Fig. 7[E]) is shown in Fig. 10. The top “Run/Stop” determines if a single trace is displayed, or if a continuing real-time trace is shown. In the “Run” mode (button lighted green), the oscilloscope runs in real-time. Depressing the button causes a single sweep to be captured and held (button glows red). Depressing a second time returns the oscilloscope to “Run” mode. Exercises in this course that use the oscilloscope will normally require it to be in “Run” mode.

The trigger control section determines how the display is triggered, that is, how the horizontal sweep of the displays are started. The oval “Edge’ button sets triggering so that the display will begin to sweep when the signal reaches a certain level (or voltage). The round “Level” knob is adjustable to set the “trigger level” – how high the voltage must be before the signal sweep is started and the signal displayed. There are many ways the oscilloscope can be triggered to start the display which use the three lower oval buttons, but these will not be used here. The

**Fig. 10. Run Mode and Trigger Controls**





“Mode/Coupling” button may be used to select DC or AC coupling of the trigger (using soft button 2 shown in Fig. 8). Normally, edge triggering is used to synchronize most signals.

### 7.5. Menu, Cursor and Other Controls:

The controls in Fig. 11 include horizontal sweep and position, cursors, and data-related menus. The upper section (labeled “Horizontal”) has two main functions. The left circular knob sets the sweep rate for the display, from 50 seconds per small display square (see Figure 8 above) to 5 nanoseconds per square. The left round knob in this same section simply positions the display sweeps left and right if they are not centered for some reason. We will not use the “Main /Delayed” button. For the sections below, the “Horizontal” area, buttons in the boxes labeled “Waveform” and “File,” as well as the “Utility” button, will also not be used. The round knob at the lower left labeled with the circular arrow is used for setting values associated with the soft buttons under the display (Figure 8), and is used mainly in conjunction with the cursors. The “Autoscale” button is very useful when a signal has just been connected to one of the analog inputs. In this case, pressing the “Autoscale” button will activate a function that determines the correct horizontal sweep speed and also the correct vertical (voltage) sensitivity for the signal, so that the signal is automatically displayed properly. Whenever a new signal is introduced into one of the inputs, the “Autoscale” button is normally the first function that is activated.

**Fig. 11. Menu, Cursor, and Other Controls**

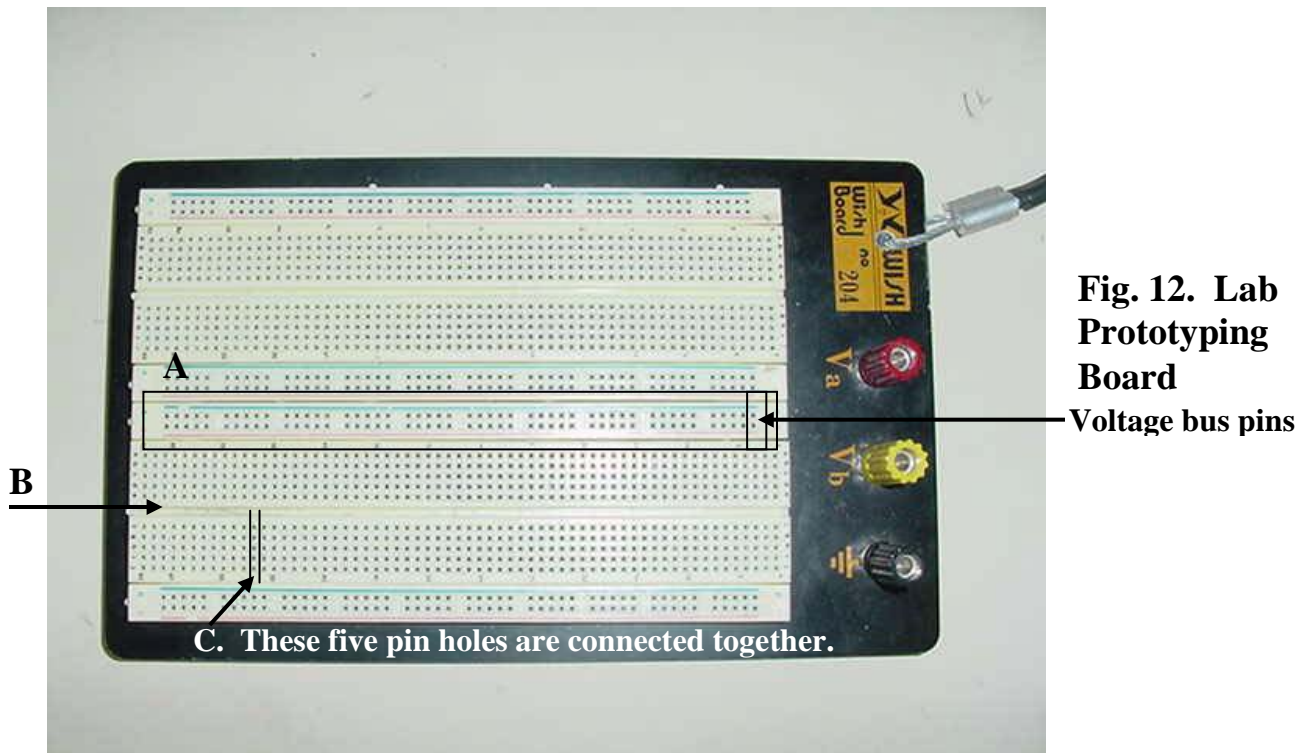


The CURSOR button in the box labeled “Quick Meas” is very useful. It activates the cursors on the screen, both horizontal and vertical (button lighted when cursors are on). When activated, a cursor menu appears at the bottom of the display, controlled by the six soft buttons (Fig. 8). The round knob at the bottom left in Figure 11 controls whichever of the cursors are selected. Two vertical and two horizontal cursors are available. Vertical cursors can measure time differences, and horizontal cursors are used to measure voltage differences. The two sets of cursors can be displayed simultaneously, so that, as in Figure 8, both the amplitude and frequency (or period) of a signal may be measured at the same time.

Refer to figure 8 for the following discussion. The notation at the bottom left of the display says “Normal Mode,” which simply means the signal that the cursor is measuring is being viewed normally in real-time. We have already discussed the screen parameters above. The second button on the lower left says “Source 1,” which means that the signal the cursors are being used to measure is the input to analog channel 1 (Figure 9). The next label simply shows X and Y. Note that the Y is checked. This means that the y cursors are now being adjusted. Once again, the adjustment (moving the cursors) is done using the round knob on the lower left in Figure 11. The next two bottom labels going to the right on the display are labeled “Y1” and “Y2.” The corresponding soft button beneath each label controls which cursor is chosen for adjustment. Note the small circular arrow on the label that is third from the right. This means that the corresponding soft button is activated and the Y1 cursor is being controlled. The label

also says “-1.000 V,” which means that the Y1 cursor is the lower horizontal cursor, since the center of the screen in this case is 0 volts. The Y2 cursor is at +1 volt, as indicated by its label, second from the right. The upper label at the bottom right shows the difference in the two cursors, which, as we have already seen, is 2 V. The right-most soft button selects the cursor pairs. Note that depressing the third-from-the-left button (“X....Y”) selects the other cursor pair, in this case, the X cursors. Then, depressing the two buttons to the right of that button allow each of the X cursors to be selected for adjustment. When X1 and X2 are selected, the difference shown (bottom upper right label) will be the period of the signal, in this case, 1000  $\mu$ sec, as noted above.

**8. Circuit Prototyping Board:** Refer to Fig. 12, below.



**Fig. 12. Lab Prototyping Board**  
Voltage bus pins

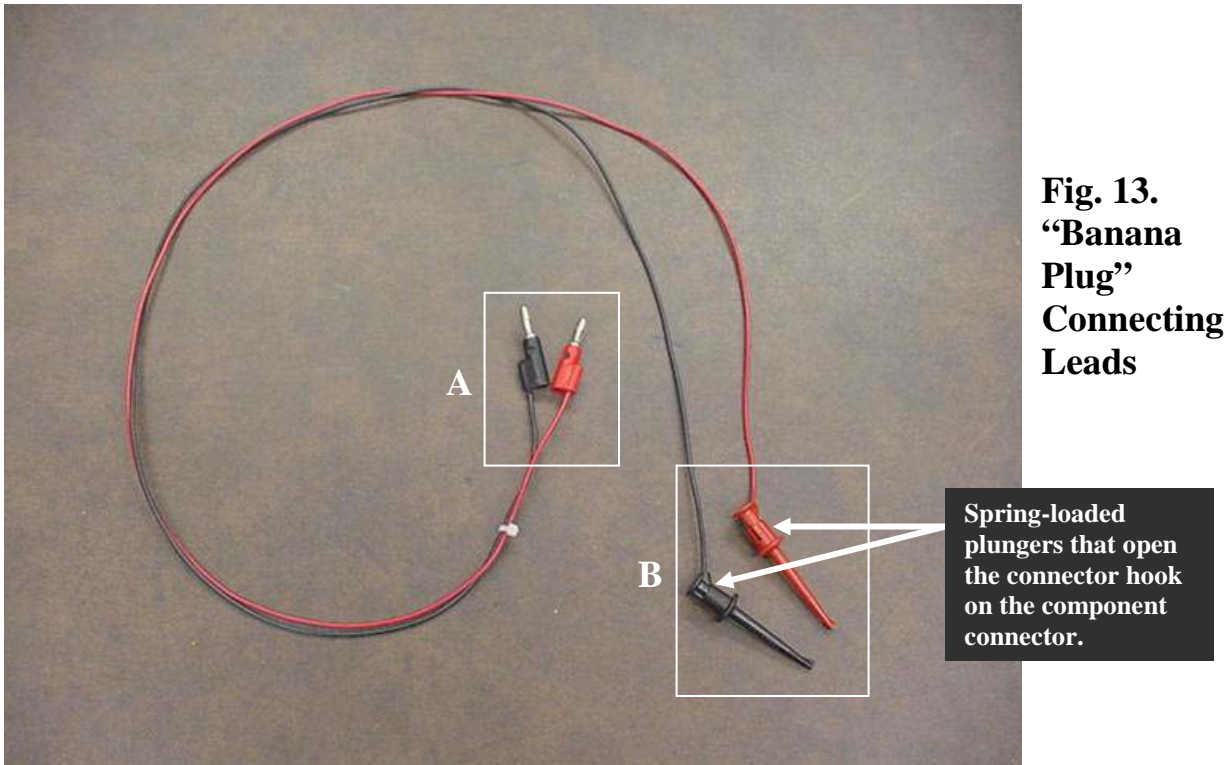
The prototyping board allows test circuits to be quickly wired together and modified. A common DC voltage may be brought in to the large terminals on the left side (we will not use these terminals in our exercises). The rows of pin holes between the red and blue lines may be conveniently used to make a sort of “voltage bus” by wiring the groups together. Note that there are two parts of the board with five pin holes on each side of a channel (channel marked “B” above). These pins are connected in such a way as to allow electrical components to be connected to each other simply by plugging them into the board. Each set of five pins in a row (on either side of the channel) is wired together, so that two wires or component leads plugged into any of the five adjacent holes (example marked “C” above) are automatically connected to each other.

To connect circuit components to the board, wires are inserted into the holes on the prototype board. As described above, components plugged into the same set of five holes on either side of the two channels in the board are automatically connected together. Special wiring kits are also available with very stiff single-conductor wire

ends that can be pressed into the connecting holes for wiring between components, if necessary.

9. **Circuit Connection Cables:** The various pieces of equipment discussed above will normally be connected to each other and to the circuit under study by a series of connecting cables. These cables are shown below.

9.1. **“Banana plug” Connecting Leads with “Hook Connectors:”** Refer to Fig. 13.



**Fig. 13.**  
**“Banana Plug”**  
**Connecting Leads**

The connecting leads for the power supply and DMM are shown above. The larger-end “banana plugs” (A) plug into the instrument outlets on both the power supply and the DMM (see Figs. 1[B] and 2[E]). The smaller ends (B in Fig. 13, above) contain a hook which can be bared by pushing on the spring-loaded back of the connector. This end connects to the circuit component to be provided power or to be measured. Note that the red banana plug is plugged into the red socket on the DC power supply, the black plug to the black socket. Thus, when plugged into the DC power supply, the red spring-loaded connector is +, the black connector –.

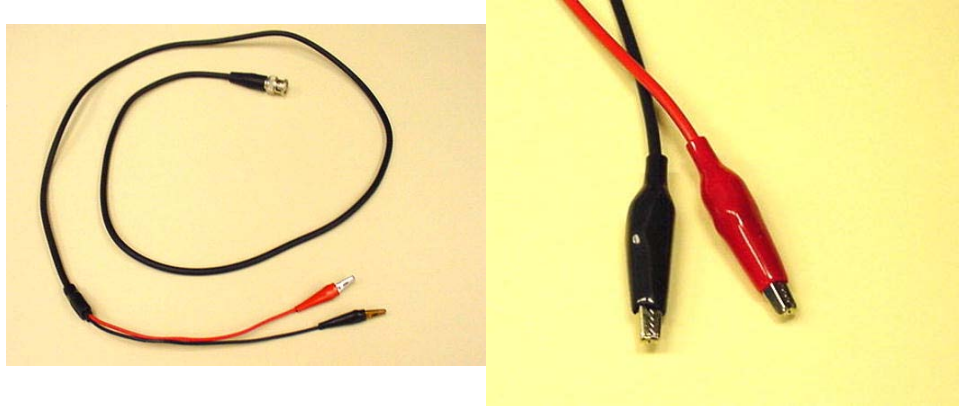
9.2. **BNC-to-Hook-End Connector Cable:** Refer to Fig. 14, below.



**Fig. 14. BNC-**  
**to-Hook End**  
**Connecting**  
**Lead**

This cable is customarily used with the signal generator. The BNC connector is attached to the output of the signal generator, and the hook-end connectors are used to connect the signal to components in the circuit under test. The hook-end connectors contain a spring-loaded plunger that allows the hook to be connected. They are identical to the hook-ends on the banana plug cables.

**9.3. Note on Banana Plug and BNC-to-Hook-End Connector Cables:** Sometimes these cables are available with “alligator clip” ends instead of the hook-type connectors. See 14a, b below:



**Fig. 14 a, b. BNC Cable with Alligator Clip Leads. Note: the alligator clips on the right may also be attached to banana plug cables.**

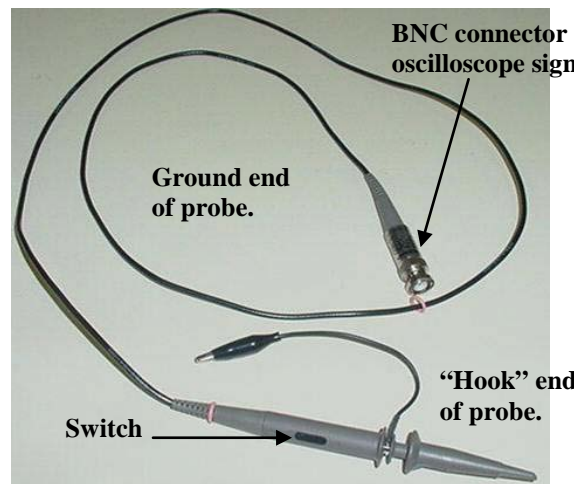
**9.4. Coaxial Cable:** Refer to Fig. 15.



**Fig. 15. BNC Cable**

The coaxial connector cable uses RG-58 coaxial wire (which has a center metal conductor with a second wire conductor woven around it, separated from the center conductor by an insulating plastic sleeve). Each end of the cable terminates in a BNC coaxial connector, as shown. The coaxial cable is used to connect a “sync signal” from the signal generator to the oscilloscope when necessary.

**9.5. Oscilloscope Probe Cable:** The oscilloscope probe is shown in Fig. 16, below.



**Fig. 16.**  
**Oscilloscope**  
**Probe Cable**

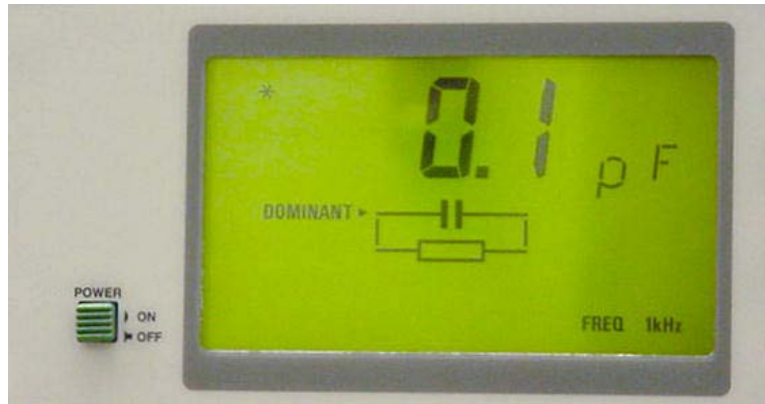
The oscilloscope probe cable (normally referred to as the “oscilloscope probe,” or simply the “probe”) is used to connect a signal in the circuit under analysis into one of the signal inputs on the oscilloscope (Figs. 7 & 9). As shown above, the BNC end of the cable is attached to one of the BNC signal inputs on the oscilloscope. The “hook” end contains a spring-loaded plunger which exposes the hook that is connected to the circuit element under examination (somewhat similar to the hook-end of the banana plug connector, but more elaborate), while the “ground” end goes to the low-voltage side of the circuit. Note the small switch on the side of the probe (bottom of picture). This switch can be used to attenuate a larger-magnitude signal by a factor of 10 when switched to the “10X” position. In the other position (“1X”), the probe offers no attenuation, but passes a signal through directly to the oscilloscope input. We will use only the 1X switch setting on the probes. Note that there are several variations of oscilloscope probes. In some, there is an adjustment mechanism on the BNC connector end (not shown above) that allows the frequency response of the probe to be adjusted.

**10. Fluke Automatic LCR Meter, Model # PM6303A:** The Fluke precision meter, shown in Fig. 17, is primarily intended for measurement of inductor and capacitor values, although it can measure resistors as well. Its value in measuring resistance will be primarily when determining the resistance of inductors, which normally are made of coils of wire, and thus have resistance as well as inductance properties. The front panel of the LC meter is shown below. Note that the meter has a liquid crystal display, an on-off switch to the left, control switches in the center area, and terminals to hold the device being measured to the right. Operational details are given below.



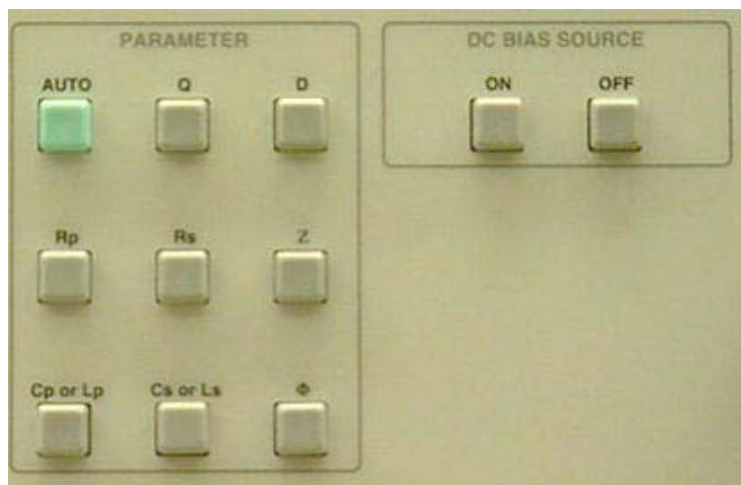
**Fig. 17. LC Meter Chassis**

**10.1. LCD Display:** The LC meter display is a liquid crystal display that shows the measurement being made (pictorially) and the value of the measurement, together with the appropriate units. For example, in Figure 18 below, the circuit selected is a parallel capacitor and resistor circuit. No capacitor is connected, so that the measurement shown is the minimum that can be displayed, 0.1 pico Farad [pF]). Note the power (off/on) switch to the left.



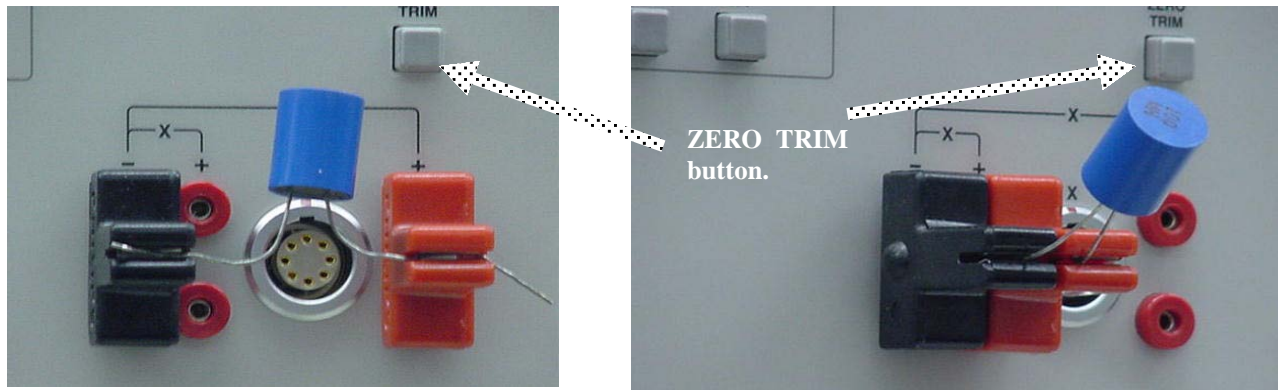
**Figure 18. LC Meter Display**

**10.2. LC Meter Controls:** Figure 19 shows the control section of the LC meter front panel. Note that the two buttons to the right control a bias (voltage) that can be applied in certain tests, but will not be used in our measurements. The switch group to the left controls the type of measurement. The green AUTO button, when pressed, causes the meter to automatically determine the type of impedance (R, L, or C) and measure appropriately. The Rp and Rs and Cp/Lp and Cs/Ls buttons cause the meter to measure R, L, or C, respectively, with the “p” signifying parallel components and the “s” being for serial components. When measuring L and C, since there is a small amount of AC resistance in the capacitor and a good deal of resistance in the inductor, use the “s” function, since the equivalent circuit of the capacitor or inductor is effectively like a resistor and capacitor or resistor and inductor in series. The Q, D, Z, and  $\Phi$  buttons will not be used.



**Fig. 19: LC Meter Controls**

**10.3. LC Meter Device Test Fixture:** Inductors and capacitors to be tested are connected to the tester via clip connectors (Fig. 20, below), so that no other test leads are required. Important: **Do not use any other test leads, since they can contribute additional circuit inductance and/or capacitance, and will lead to incorrect readings!** The clips have friction clamps that will hold each device in place. The red clip connector is plugged into the right-most sockets when the test leads of the device are spread apart (left illustration, Fig. 20), and into the left sockets when the leads are close together (right, below). Either connection is “correct” in terms of getting a good measurement; the two possibilities of connection are simply for convenience. The “zero trim” button above the test terminals is for calibration (see below).



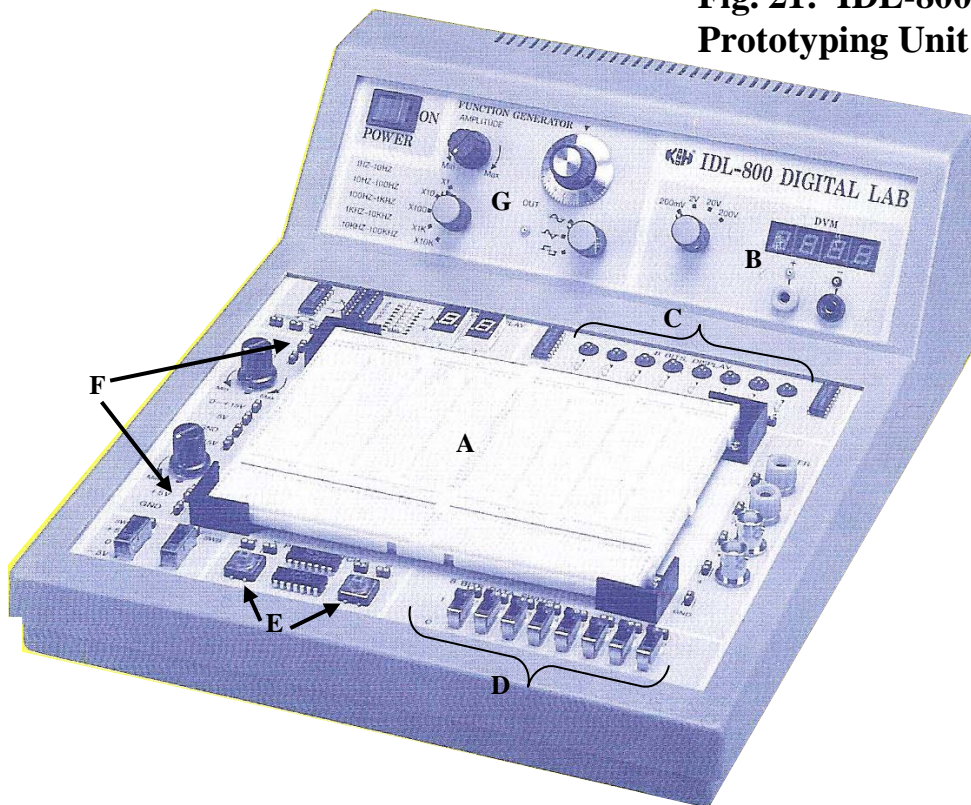
**Figure 20: LC Meter Test Fixture (Note positive [red] clip may be plugged into either of two sets of sockets, depending on configuration of device leads. Negative clip is always plugged into the left-most position.)**

- 10.4. Basic Measurement Procedure:** You will normally be measuring inductors and capacitors on this meter. Please observe the following procedure
- If the LC meter is off, turn it on using the on-off switch.
  - On startup, the meter goes through a self-test, and it will then enter the test mode it was in when turned off.
  - Perform a functional test by pressing the green AUTO key, then pressing the ZERO TRIM button.
  - After about 3-4 seconds (during which the display says “busy”), the calibration will complete and the display will say “pass.” If it does not, notify the lab teaching assistant.
  - Normally, unless told otherwise, press the Cs/Ls button and insert the component into the clips.
  - Let the meter stabilize a moment and then record the reading on the display.
  - We will not normally read resistance when measuring capacitors on this meter, since capacitors have very little AC resistance. However, when taking an inductor reading, after recording the inductance, press the Rs button and record the resistance. The resistance of an inductor is substantial (that is, a good deal more than 0), since inductors are normally made of coils of wire, which has significant resistance. We need to take this resistance into account in our circuit considerations.
- 10.5. Note:** The LC meter is relatively expensive, and thus there are only two in the laboratory instead of one at each station, as is the case for the other equipment. Since everyone will need to use the LC meter when the experiment calls for using an inductor or capacitor in a circuit, please quickly make your measurements, record the values, and vacate the meter, so that other teams can take their measurements.

**11. Circuit Prototyping Unit, Model IDL-800:** The IDL-800 circuit prototyping unit, shown in Fig. 21, supports circuit development using both analog and digital circuits. It will be used in this course for digital circuits only, in Laboratory Exercise #3. Relevant controls are discussed below.

**11.1. Layout of prototyping Unit:** In Fig. 21 below, the center section (A) is a circuit board where digital circuits may be inserted and connected to build various digital circuits. Circuits are plugged across the channels in the board (faintly visible in the photograph). Then, any wire plugged into one of the parallel holes in a row with one of the circuit pins is automatically connected to that pin. A numerical LED readout (B) is also provided, although not used in this course.

**Fig. 21: IDL-800 Prototyping Unit**



**11.2. Power for Digital Circuits:** Various voltages are provided by the IDL-800. Here, we will use only the  $\pm 5V$  power supplies (F), which can be connected to the circuit chip power inputs to provide the appropriate power.

**11.3. Inputs for Circuits:** Two-position switches (D) can provide logic 1 and 0 inputs to any digital circuit. The “up” position is logic 1, while the “down” position is logic 0. Two momentary switches (E) are also provided to simulate a brief logic input. Both switches provide the desired input only when depressed and held. The small outputs above the switches provide both momentary 1 and momentary 0 levels.

**11.4. Circuit Outputs:** The LED lights (C) may be connected to any digital circuit node. Logic 1 lights the LED; logic 0 corresponds to the LED off.

**11.5. Clock:** The IDL-800 also provides a digital clock for time-varying logic circuits (G), which will not be used in Experiment #3.