II. Equipment Description

Supplies and Equipment

At the present time, students are not expected purchase any supplies for this lab other than their own paper and disks. However, because it is so difficult to keep track of hand tools, it will be more convenient to bring your own wire strippers and long-nose pliers. If a student wishes to keep a circuit wired between scheduled lab sessions, he/she may bring their own Protoboard and the components will be loaned by the lab. The electronics laboratory, located in NE-1018, is equipped as shown in Table 1:

Table 1.
Electronics Lab NE-1018 Equipment List

Item	Description
HP 54600B Digital Storage Oscilloscope (DSO) with HP 54657A Measurement/Storage Module	100 MHz repetitive BW, 2 MHz single shot BW, IEEE-488 interface to PC, DFT capability, waveform measurements and waveform storage
HP 33120A Function/Arbitrary Waveform Generator	sine, square, triangle, etc. plus arbitrary (programmable) functions, IEEE-488 interface to PC
HP 34401A Multimeter	4.5, 5.5, or 6.5 digit, dc/ac true rms, ohms, IEEE-488 interface to PC
HP E3631A Power Supply	±20 V, +6 V, IEEE-488 interface to PC
Rack of Tek TM-500 modules	PS 503A power supply (±20 V, +5 V), FG 501A function generator, DC 504 frequency counter, DM 502 digital volt-ohmmeter
Personal Computer interfaced to DSO, Function Generator, and Multimeter	hardware includes network connection, IEEE-488 interface, Cyrix 686 software includes Benchlink (scope waveform transfer) and HP VEE (graphical programming language to operate the DSO and function generator in an automated experiment)
Protoboard	prototyping system
Miscellaneous components and cables	

Equipment Description

Digital Storage Oscilloscope

The oscilloscope is the central piece of test equipment in most laboratories. Therefore, it is important to learn to use it effectively. To do this, the student is expected to develop a working concept of what goes on inside the "scope." This is best done by considering first a standard analog scope, and then second the digital storage oscilloscope (DSO), which closely emulates the look and feel of the analog scope. The student should carefully read the oscilloscope chapter of a laboratory-oriented instrumentation text.[1][2]

The HP 54600B DSO provided in the Electronics Lab is interfaced to a standard instrument interface bus known as "IEEE 488" (or also HPIB or GPIB) and can be completely controlled from the computer at the bench. This capability will be described separately. The following description applies to strictly manual operation of the scope from its front panel. The computer does not even need to be turned on.

The HP 54600B DSO has two input channels labeled "1X" and "2Y", each with a block of controls in the front panel section labeled "VERTICAL." Pushing the button labeled 1 or 2 will bring the menu on the screen for that input channel. The choices include turning the channel off or on, ac or dc input coupling, bandwidth limiting (to 20 MHz), inverting the waveform and programming the probe attenuation factor. Setting the correct probe attenuation factor is very important. This DSO cannot auto-identify the probes being used: for the 10X probes used in the Electronics Lab, the probe factor must be set to "10" or the readout will be incorrectly labeled. The button labeled "±" opens a menu that creates one or two additional traces which are mathematical combinations of the signals on channels 1 and 2, including a discrete Fourier transform (DFT). If you do not know what a DFT is, stay out of this menu! Each channel has sensitivity and position controls. The channel sensitivities read out in the upper left corner of the display. The zero-volt level (the baseline) is indicated by an arrow which appears on the right side of the display. Note that the input coupling choices include one indicated by a ground symbol: this applies a short-circuit to the input terminals of the amplifier, thus verifying the location of the zero-volt level for the user.

Under usual circumstances, both channels 1 and 2 create vertical (Y) deflections. The horizontal (X) deflection is then made directly proportional to time. This is controlled by the block of controls labeled "HORIZONTAL." Pushing the button marked "Main/Delayed" brings up the menu for the horizontal sweep. The selection "Main" gives the standard sweep which plots voltage (on channels 1 and/or 2) *vs.* time. The selection "Roll" is useful for very slow sweep rates: it emulates a pen-on-moving-paper chart recorder for low-speed signals. The selection "XY" turns off the horizontal sweep, and makes channel 1 the X deflection and channel 2 the Y deflection.

When displaying a periodic voltage waveform *vs.* time, it is important that the X sweep be started at the same point in the waveform each time. This is the function of the controls in the block labeled "TRIGGER." The button labeled "Source" brings up a menu which gives the user

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[1] Robert A. Witte, "Electronic Test Instruments: Theory and Applications," PTR Prentice Hall, NJ, 1993. See Chapter 4.

[2] Stanley Wolf and Richard F. M. Smith, "Student Reference Manual for Electronic Instrumentation Laboratories," Prentice Hall, NJ, 1990. See Chapter 6.

control over which signal will be the trigger to the X sweep: the choices include channel 1, channel 2, an external input (Ext), or a signal derived from the ac line (Line). The button labeled "Mode" brings up a menu which includes auto-level triggering (Auto Lv), auto triggering (Auto), normal triggering (Normal) and single triggering (Single). Normal triggering means that an X sweep is initiated every time the selected signal crosses a triggering level defined by the knob labeled "Level." The trigger level is indicated on the screen when adjusting this knob. If the signal fails to cross the trigger level, the scope stops triggering and the display goes blank. Auto trigger overcomes this problem. Auto trigger works the same as normal as long as there is a valid trigger signal, but if a trigger event does not happen within a reasonable time, it initiates a sweep anyway. The resulting display helps the user see what has gone wrong. Auto-level triggering works the same as auto triggering with the addition that the scope attempts to automatically adjust the trigger level to a "good" value. This is the default setting at power-on. If the user is not happy with the default, then auto or normal settings can be tried. The single sweep setting makes only one sweep after its trigger level is satisfied; after this, the scope must be re-armed by pushing a trigger reset button to allow the next (single) sweep.

The button labeled "Slope/Coupling" conditions the signal which is being applied to the trigger circuitry. "Slope" determines whether a positive-going or negative-going crossing of the trigger level will initiate the X sweep. "Coupling" determines whether the path to the trigger circuit is dc-coupled (dc) or dc-blocked (ac). DC-blocking means that only the ac components of the signal can reach the trigger circuitry. The filters marked LF Reject, HF Reject and Noise Reject operate only on the signal being applied to the trigger circuitry, and can be tried to obtain a more-stable display. These filters do not affect the signal being displayed, but do affect the stability of the triggering process.

The knob labeled "Holdoff" conditions the triggering process by requiring a minimum time delay between the end of a sweep and successful trigger of the subsequent sweep. The minimum value feasible is 200 ns, and is normally the best value. On certain complex waveforms, adding the correct amount of trigger holdoff will be needed to stabilize the display. The correct amount is found by trial and error.

The block of controls marked "Measure" enable readouts of peak-to-peak, rms, and average values of the waveforms on channels 1 and 2. Note that a valid calculation of the average (dc) and rms values of a waveform can only be done if the scope is able to determine its period (this is done automatically, but sometimes fails on a noisy waveform). The "Cursors" can be turned on to enable readouts of the X and Y coordinates of selected points on a displayed waveform.

The "Save/Recall" buttons allow saving waveforms and control settings in internal nonvolatile memory. Up to 100 traces may be saved. These memories can be individually saved to, restored from, or cleared. "Save setup" saves the settings of every control on the scope, allowing later restoration of a complicated setup.

The button labeled "Display" provides the choices of normal, peak or averaged displays. "Normal" is the default setting: this constantly updates the screen for data which changes over repeated sweeps. "Peak" captures and accentuates very narrow pulses called "glitches" which may appear on a waveform. "Average" gives a display which is the event-average of many repeated sweeps (this is not time averaging). Event averaging is used to remove random noise from a displayed waveform.

The unlabeled knob near the "Save/Recall" buttons functions as an input device to be used as needed. When a menu item having many numerical choices is highlighted, turning this knob gives rapid scrolling through the available choices.

Probe compensation is an important process on all scopes. The probes used in this lab attenuate the input signals by a factor of 10:1 (this is the most widely used standard; however, some high-voltage probes have an attenuation factor of 100:1). It is important that this attenuation be precisely frequency-independent. To check the probe frequency compensation, connect the probe to the calibrator terminal on the scope front panel, which outputs an accurate square wave. If the displayed waveform is not a good square wave, but shows either a poor rise time or overshoot, the probe compensation must be adjusted. Ask your lab instructor to provide the correct adjusting tool. Also, do not forget to program the scope with the expected probe attenuation factor of 10:1 so that it will correctly label your readout.

Last, but most important, is the button labeled "Autoscale." Pushing this button gives the scope free rein to decide which input channels have important signals, and which do not, to pick the most favorable Y sensitivity factors and X sweep rates, and to automatically set the trigger conditions. In short, if you cannot get a good display on the scope, try pushing this button and see what comes up. There is no guarantee that the result will be satisfactory.

Function Generator

It is not necessary to learn how this standard laboratory instrument functions internally, but it is important to learn the names of a variety of standard test signals generated by the function generator. Most function generators can output sine, triangle, square and pulse waveforms. These waveforms are characterized by their frequency, and their peak-to-peak voltage, and average voltage, and possibly rms voltage. Normal sine, triangle and square waveforms have zero average value. The function generator can add a non-zero dc (average) value which is called "offset." This is handy for many applications. The pulse waveform steps between an upper and lower voltage: duty cycle (duty factor) is the percentage of time spent at the upper voltage. Additional output waveforms include ramp (often called sawtooth) and random noise. Sample waveforms are shown in Fig. 1.

The Electronics Lab has two function generators per bench: the Tek FG 501A, which is a basic unit located in an TM 500 equipment rack, and the HP 33120A, which is much more elaborate and is a stand-alone instrument.

The HP 33120A also has modulation and arbitrary waveform capabilities. It is interfaced to the bench computer through the IEEE 488 bus, and can be completely controlled by the computer, or through manual commands. Manual control is described here.

The primary function of each button is embossed on it in black. These include waveshape selection (sine, square, triangle, etc.), and display selection (to display frequency, amplitude, or offset). Pushing the buttons for any two waveshapes simultaneously (*e.g.*, sine *and* square) will produce an adjustable dc source. The waveform attribute which appears on the front panel display can be changed by any of three ways: (1) by turning the large knob, (2) by pushing the four arrow buttons (∧ ∨ > <) or (3) by direct numerical entry. The digit on the display which is flashing is the one affected by turning the knob, or is the one incremented or decremented by pushing either ∧ or ∨. The buttons marked > or < are used to select a different digit on the display. Direct numerical entry is done by first pushing the green "Enter Number" button, and then entering the desired number. The numerical value of each button during this operation is marked alongside it in green. This numerical entry sequence is terminated by pushing the button (one of the arrow keys) which has the correct frequency or voltage units marked alongside it in green.

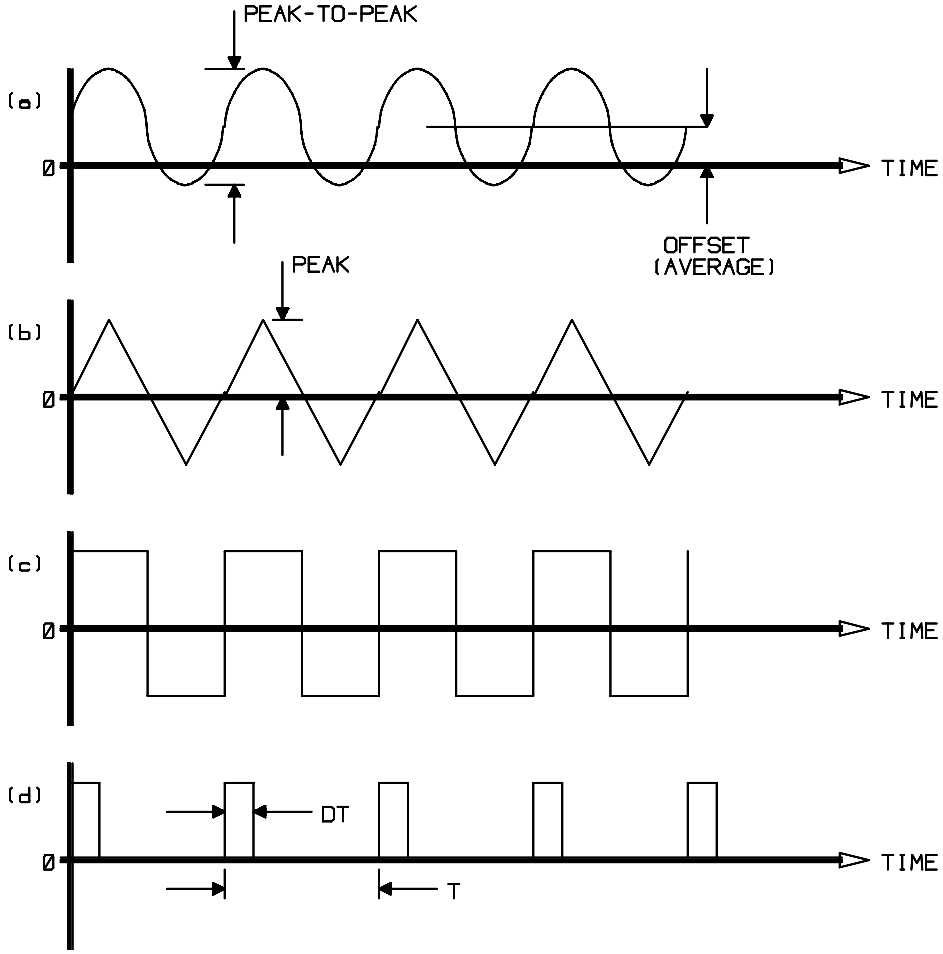

Fig. 1. (a) Sine wave with offset. (b) Triangle wave. (c) Square wave. (d) Pulse waveform with duty cycle "D."

Advanced functions such as turning on AM or FM modulation of an output waveform, or setting the duty factor of a pulse waveform, are activated by pushing the blue "Shift" button first, and then using the alternative meanings of each panel button, which are marked alongside in blue.

The equivalent circuit of the function generator is an ideal voltage source of the correct waveform, frequency and amplitude in series with 50 Ω. This raises the question of whether the amplitude display should be the internal value of voltage, or the actual value of voltage at the output terminals with whatever load the user has connected. The default behavior at power-on is that <u>the function generator assumes that the user has connected a 50-Ω load.</u> The display shows what the output voltage would be if this were truly the case. If the output terminals are actually open-circuited, the output voltage is double that on the readout. This is the more usual case for the Electronics Lab experiments. If you want the readout to indicate the internal (open-circuit) voltage, enter the following key strokes after every power-up:

1. shift-enter to activate the menu,
2. > or < until you have selected "D:SYStem MENU",
3. ∨ to get "1:OUT TERM",
4. ∨ to get one of the choices "50 OHM" and "INFINITY",
5. Use > or < to set the termination which best describes what <u>you</u> are doing.

Changing the termination setting changes the display reading: it does not change the actual output from the generator. Your setting goes into volatile memory, so you may have to reset it after a power outage. Another alternative available from the same "SYStem MENU" is to make the power-on default equal to the state in which the last user turned off the function generator. This option will be activated by the lab instructor at the beginning of the semester, but it is still wise to check the output termination setting as given above.

Digital Multimeter

The digital multimeter (DMM) is based on a low-speed, but highly accurate, analog-to-digital converter. It is designed to measure several attributes of an input signal, which may be a voltage, a current or a resistance. For voltage measurements, the input impedance of the DMM is ideally infinite, and in practice it is generally above 10 MΩ. For current measurements, the test leads must be moved to a different set of terminals (on most meters) to route the measured current through a current shunt. The input resistance for a current measurement is ideally zero, and in practice it is generally small enough to produce a voltage drop no greater than 2 V. Resistance measurements are made by exciting the test leads from a current source internal to the meter, and measuring the resulting voltage drop. The resistance read out on the meter is the ratio of the measured voltage to the exciting current.

The attributes of the input signal which can be measured are its dc and ac values. Some multimeters include a function to measure the period or frequency as well. The dc value of a signal is by definition its time-averaged value. The ac value of a signal is not so clear. Different meters respond to different attributes of the signal to report the "ac" value, although the readout is almost always labeled "rms." Many DMMs actually perform the ac measurement by full-wave rectifying the signal (an absolute value operation), and then time-averaging the result. The converted value is reported as an rms equivalent value, *assuming that the signal had been a sine wave*. Obviously, if the signal is not a sine wave, the reading on the meter may not be the actual rms value. So-called true-rms meters perform the following processes: the signal is first squared point-by-point in time (that is, the meter has a nonlinear processor which converts v(t) into $v^2(t)$); then the squared signal is time averaged; this result is measured by the dc measuring circuitry; and finally the square root of this measured value is read out on the display as the "rms" value of the signal. This is the correct implementation of the rms definition.

Another point of uncertainty is the effect a dc component of signal will have on an ac measurement. Depending upon the meter, the dc component may or may not be removed prior to measuring the ac value. When using an unknown meter to measure an ac signal other than a zero-offset sine wave, it is important to consult the user's manual to find out exactly what is being measured.

The HP 34401A DMM measures the true rms value of an ac signal *after its dc content is removed.* The relationship between an rms reading taken from the dc-coupled scope, which responds to the complete signal, and the ac and dc readings taken from the DMM is:

$$X_{scope} = \sqrt{X^2_{meter,ac} + X^2_{meter,dc}} = X_{rms,total} \qquad (1)$$

The readout can be programmed for 4.5, 5.5, or 6.5 digits. ("One-half" of a digit is a reference to a digit on the display which can only be a zero or a one.) The measurement time varies inversely with the accuracy, and can be as long as 1.67 s for the full 6.5 digits. The number of displayed digits can be set using the button group labeled "Range/Digits," together with the shift key. For most lab experiments, 4.5 digits is plenty. Remember that the components used in this lab are normally only within 5% of their marked value, and that the parameters of the transistors and diodes are not known even that precisely. In most cases, therefore, experimental results within 10% of the theoretical results are considered accurate.

The functions which can be selected on the HP 34401A are the following: voltage, 2-wire resistance, frequency, continuity, current, 4-wire resistance, period, and diode checking. The first four items on this list are selected through the main labels on their corresponding front panel buttons. The last four items on the list are selected using the shift key. For each of these functions there may be a number of ranges available (a range is the maximum full-scale reading possible). For example, dc volts has full-scale ranges of 100 mV, 1 V, 10 V, 100 V, and 1000 V available. The meter can be set for autoranging, in which case it will choose the range for you. In general, it will pick the lowest range which does not result in an out-of-range error. The meter can also be set for manual ranging, which prevents annoying range changes as you move the probes from point to point in a circuit. The button group labeled "Range/Digits," when used without the shift key, toggles the meter between automatic and manual ranging, or can be used to force the meter to range up or down.

The two test probes are connected to the two upper right-hand jacks for voltage, 2-wire resistance, frequency and period, and continuity and diode checking. That is to say, for most of your experimental measurements, connect the leads to the jacks labeled "Input HI" and "Input

LO" on the far right-hand side of the meter. When making a current measurement, the test leads are moved to the lower right-hand pair of terminals labeled "Input LO" and "I." Make current measurements cautiously, because these two input terminals have a very low input resistance, as they should. If the current-input terminals were connected across a voltage source capable of high current, a large short-circuit current would result. The meter has an internal fuse which might blow in time to prevent its destruction. However, this mistake has been a common cause of damage to the lab meters in the past.

Resistance measurements in the Electronics Lab will be taken using the 2-wire method. To do this, select 2-wire ohms on the HP 34401A and connect the test leads to the two upper right-hand terminals. Use the test leads to probe a component or circuit which has been de-energized. The meter is sufficiently accurate when set for 6.5 digits that the resistance of the test leads can cause a notable error in its measurements. This is overcome by using 4-wire ohms, a technique in which the meter stimulates the component under test using leads connected on the two right-hand terminals, but senses the voltage drop across the component by using two additional test leads connected to the two left-hand terminals. This second set of leads is connected to the component-under-test *separately* from the first set, and eliminates lead-resistance error from the measurement. The 4-wire technique will not normally be needed in the lab experiments.

The HP 34401A has a hierarchical menu tree much like that of the HP 33120A function generator previously discussed. It is entered by using "Shift" plus "Menu On/Off." You should not normally enter the menu tree. Users who have become familiar with the operation of the meter could conceivably enter the menu tree for one purpose: there is a math menu which can be used to enable an automatic dB conversion of measurements, after the dB reference value is entered in this menu. The other math items are related to the statistics of a series of measurements.

Laboratory Software

The software installed on the PC includes the following: Interactive HPIB, a manual command generator for the IEEE-488 interface card which supports the instrument bus connecting the computer to the scope, function generator, and digital multimeter; BenchLink, a simple windows-based program which allows passing of data from the scope to a word processor or spreadsheet; and HP-VEE, a graphical programming language which can include the scope and function generator instrument drivers among its program statements. The PCs also have network connections, and evaluation versions of PSpice, a widely used simulation package. The following discussion will be aided by the listing in Table 2 of the default file name extensions used by each of the relevant software packages.

Interactive HPIB should not normally be used by the student. It allows commands to be manually sent to the bus-controlled instruments for test purposes. The appropriate IEEE-488 bus commands are automatically generated by the software packages BenchLink and HP-VEE. Please do not change any address settings in any software package, or from the menus on the scope or function generator. If you desire to learn more about the IEEE 488 bus, there are a number of references available.[3][4]

Table 2
Default File Name Extensions

File Extension	File Description
.IBC	Interactive HPIB instrument configuration file.
.PCX or .TIF	BenchLink image file containing copy of DSO screen. Suitable for Windows Paintbrush, or import into most word processors.
.WFM	BenchLink waveform file containing a DSO trace captured as a list of time-voltage pairs. Suitable for recall by BenchLink.
.PRN	BenchLink output file containing a DSO trace captured as tab-separated time-voltage pairs. Suitable for Lotus 1-2-3.
.CSV	BenchLink output file containing a DSO trace captured as comma-separated time-voltage pairs. Suitable for Microsoft Excel.
.VEE	Program file written in HP-VEE.
.CIR	PSpice circuit description file.
.LIB	PSpice library of device models (entries in a ".MODEL" statement)
.NET	PSpice netlist - automatically generated file describing a schematic
.PLB	PSpice package library - used for the circuit board layout program
.SCH	PSpice schematic description file.
.SLB	PSpice symbol library - contains the symbols used to draw a schematic
.OUT	PSpice output file containing the results of a simulation.
.DAT	PSpice data file containing simulation results which will be displayed by "PROBE."
.PDF	Source file for Adobe Acrobat reader. The PSpice on-line manual and many device data sheets from the Web are in this format.

BenchLink is an effective aid to recording experimental data. The student must learn how to use this for the scope waveforms. A display appearing on the scope may be recorded using BenchLink in either of two forms: as an image file, or as a waveform file. The image file is a replica of what appears on the DSO screen in .PCX or .TIF format. This file type can be imported into the Window Paintbrush accessory, or into most word processors. The alternative waveform file saves the information in one selected trace appearing on the DSO as a list of time-voltage pairs. If the waveform file is saved for later use in BenchLink, it is in .WFM format. The waveform file can also be exported to a spreadsheet or data base program either in comma-separated format (.CSV) or in tab-separated format (.PRN).

Fig. 2 was recorded in the laboratory using BenchLink, and will serve to illustrate several of the points made so far. Although three waveforms appear in Fig. 2, only one scope channel was used. The triangle and square waves were viewed and then stored in the scope's trace

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[3] Stanley Wolf and Richard F. M. Smith, *op. cit.*

[4] Harold S. Stone, "Microcomputer Interfacing," Addison-Wesley Publishing Co., MA, 1982.

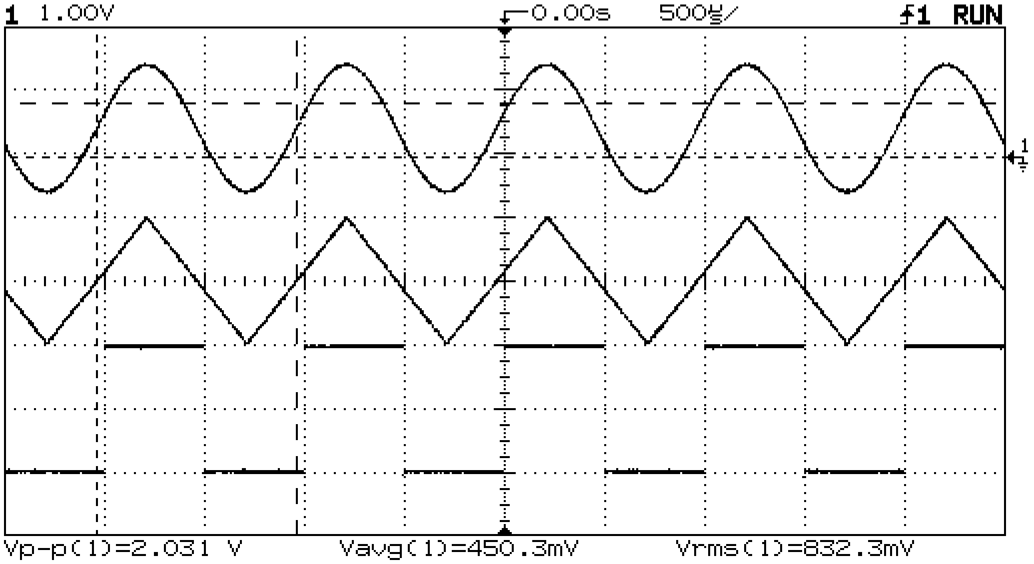

Fig. 2. Waveforms taken from HP 54600B DSO using BenchLink. (.PCX format)

memories. Only the sine wave was "live" when BenchLink was used to copy the scope's screen to a .PCX file, which was then imported into this word processor (AmiPro 3.0). Because the sine wave was recorded live, you can see its baseline indicator on the right side of the screen. The vertical and horizontal information appearing along the top of the screen applies solely to the sine wave. It can be seen that the vertical sensitivity was 1 V/div, and the horizontal timebase was set to 500 µs/div. Therefore, the amplitude of the sine wave is about 2 Vp-p, and its period is about 1 ms. The baseline indicator shows that the sine wave had about 0.5 V of offset. It is impossible to tell from this figure what scale factors apply to the triangle and square waves. This is a limitation of the storage facility on this scope.

The readouts along the bottom of the screen were created by turning on the scope's measurement utility. Because the sine wave was recorded live (on channel 1), these readouts all apply to it. The first gives its peak-to-peak value more accurately as 2.031 Vp-p, the second gives the average value (synonymous with dc value or offset value) as 0.4503 V, and the third gives its rms value as 0.8323 V. The absolute accuracy of these measurements is about 2 or 3 significant figures. Several cursors also appear in Fig. 2. These were generated automatically by the measurement utility. In order to find the average or rms value of a waveform, its period must be known. The vertical cursors indicate the period the measurement utility is using for its calculations.

The HP-VEE software package is a graphical programming language which incorporates instrument drivers for the DSO and function generator among its iconic programming "statements." This package is used for writing automatic laboratory testing routines which control equipment interfaced to the IEEE 488 bus, run the experiment and gather the data, analyze the data, and possibly export the data as automated reports. Writing such a program is not expected in this first electronics laboratory; however, the student may be given a pre-written program to automate a repetitious experiment. To learn more about this programming language, see an HP-VEE tutorial guide.[5]

PSpice is a specific commercial implementation of the well-known public domain program "SPICE." This package is used for circuit simulation. The evaluation version of PSpice supplied on the laboratory computers includes a schematic entry program. A circuit schematic is drawn using the symbols found in the symbol library, the component values and types are entered on the schematic, and a standard SPICE input file is generated from this if the model library has a model for every component type used. Files containing schematics carry .SCH extensions. The circuit description file generated by the schematic program carries a .CIR extension. Manually writing a .CIR file is usually the first step given in most SPICE references and tutorials written for older versions of SPICE. The simulation is run using the .CIR file as the input. The output is written to the .OUT file, which contains an echo of the file description, error statements, and all print/plot data points. Additionally, if the PSpice "Probe" facility is used, a file with the .DAT extension is generated. This is the input file to Probe. The complete manuals for PSpice are all stored on the hard drives in the lab in .PDF format (they must be viewed using Adobe Acrobat). The student is welcome to copy the PSpice evaluation version or any of these manuals and print them for his/her own use.

Safety, Grounding Arrangements and Signals

Safety is often discussed in terms of voltage levels, although it is actually the current level internal to a person's body which determines the degree of hazard. The maximum voltage level used in this lab is about 20 V, which will not cause a dangerous current to flow through a person under normal circumstances. Except for equipment failure, electrical safety is assured in this lab through the exclusive use of low voltages in the experiments.

Because electrical equipment can fail, and because all of the lab equipment is powered from the 120-V power system, the equipment in this lab is equipped with a third pin on its power cord called "ground." This pin connects to a non-current-carrying wire, color-coded green, which runs throughout the building and is connected to a ground rod driven into the earth. It is also bonded to the plumbing and structural steel of the building. This ensures that even if there should be an internal failure in an oscilloscope, for example, its metal chassis could not attain a voltage level different from the plumbing or other grounded metal parts of the building. This third-wire grounding scheme is a requirement of the National Electric Code.

This safety grounding system poses problems for many lab experiments, however. In most pieces of laboratory equipment, the metal chassis, which is safety-grounded, is also used as one of the input or output connections. It is usually much more difficult to design the circuitry to work properly without connecting it to the chassis. Connecting a scope to a lab circuit will then automatically connect a node of that circuit to "ground" if the scope has a grounded input terminal, for example. The difficulty arises when several pieces of grounded test equipment are in use. This is the normal case, and it requires that the student be very aware of which terminals are grounded and where they are connected in the circuit, because multiple ground connections to the circuit can tie several nodes together (through the test equipment ground paths) in an

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[5] Robert Helsel, "Graphical Programming: A Tutorial for HP-VEE," Prentice Hall PTR, NJ, 1995.

unexpected way. The resulting short circuit can cause the circuit to misbehave, or cause large currents to flow through the test leads. In some experiments it is important to have a certain test instrument which has no ground connections to its terminals (even though its metal chassis will be safety-grounded). Such an instrument is said to be "floating." Table 3 is a list of the status of the major pieces of test equipment in the Electronics Lab.

Table 3
Grounding Status of Electronics Lab Test Equipment

Item	**Grounding Status of Inputs/Outputs**
HP 54600B Oscilloscope	Grounded inputs.
HP 33120A Function Generator	Floating output.
HP 34401A Digital Multimeter	Floating inputs.
HP E3631A Power Supp;y	Floating outputs.
TM 500 Rack: PS 503A Power Supply	Floating +/- 20 V outputs. Grounded +5 V output.
TM 500 Rack: FG 501A Function Generator	Grounded output.
TM 500 Rack: DM 502 Digital Volt-Ohmmeter	Floating input.
TM 500 Rack: DC 504 Frequency Counter	Grounded input.
Personal Computer	All interface connections are grounded.
Hand-held Battery-Powered Instruments	Floating.

The grounding status of the test equipment is the reason for the very specific instructions about the scope connections in some of the experiments in this manual. In addition to the problem of "shorting-out" a part of a circuit through multiple ground connections, there is the problem of a "ground loop." Ground loops are often created in lab setups by connecting test lead ground clips to several physically-distant points in a circuit. Even though these points may all be shown on the schematic diagram as the same node, the wire interconnecting them has a certain amount of resistance and inductance. In the normal operation of the circuit, signal currents may be expected to flow from one of these points to the other. If the test lead ground clips are connected at widely separated points, some of the signal current will leave the circuit and flow through the test leads to an instrument chassis, then through one instrument power cord and the building ground system to another instrument, and thence back to the circuit under test. This causes unexpected voltage drops on the instrument test leads which may induce interference into the measurement if the circulating current is large enough (it often is). This sort of ground loop problem occurs in circuits which have several signal-processing stages, one relatively high level and the other operating with smaller signal levels. Another hazard is that a ground loop allows any current that may be flowing in the building ground system access to your circuit. This is often the cause of interference from 60-Hz signals appearing in the circuit under test. (Even though there is not supposed to be any current in the ground system normally, there is usually at least a small current present.) The experiments in this manual are designed to be relatively insensitive to ground loop problems. However, it is a good habit to connect all test equipment ground clips to the circuit under test at a single point.

Equipment Description