

Appendix A

Specifications and Quick Starts

We have gathered here for reference specifications and instructions for the use of the instruments referred to in this course. The important functionality of these instruments available via the front panel controls is described along with some of the remote control commands of interest to the programmer. You are strongly urged to work through the quickstarts for each instrument before attempting a lab in which the instrument is featured. For a listing of student drivers for the instruments (if they exist) see Chapter 5.

Index

| <i>Instrument</i> | <i>Drivers?</i> | <i>SCPI Compliant?</i> | <i>Page</i> |
|--|-----------------|------------------------|-------------|
| Ohaus Scout II Electronic Balance | Yes | No | AA-3 |
| Radio Shack Manual/Auto Range Digital Multimeter | Yes | No | AA-6 |
| Agilent Model 34401A Digital Multimeter | Yes | Yes | AA-9 |
| Instek Model GFG-8016G Signal Generator | - | - | AA-12 |
| Telulex Model Sg-100/A Signal Generator | Yes | No | AA-14 |
| Tektronix TDS210 Digital Oscilloscope | Yes | Yes | AA-16 |
| Agilent Model HPE3640 Programmable Power Supply | Yes | Yes | AA-21 |
| Vernier Software SBI Box | Yes | No | AA-24 |
| National Instruments PCI-1200 DAQ Card | Yes | - | AA-25 |

Introduction

Manuals

The size of manuals that accompany instruments can be large. We can reproduce here only a selection of the specifications for each instrument, and those that are considered to be of interest to the science student. Manuals produced by the manufacturers are available in the physics lab for shortterm borrowing. Some manuals can be accessed in PDF format via the course web page and via some of the web pages of the manufacturers.

Digital Instruments

The instruments used in this course are nearly all digital instruments. They possess in their circuitry an *analog-to-digital converter* or ADC (described in Chapter 3). To put the point simply here, an ADC samples an analog waveform at an instant of clock-time and converts the voltage to a number—and does

this repetitively at successive, equally-spaced clock-times. For the topics of conversion and instrument communication see Chapters 3 and 6. Here we focus on the instruments themselves, the kinds of measurements they make and their strengths and weaknesses. Four important considerations among others distinguish one instrument from another: acquisition speed, display capability, storage capability and control capability. Before launching into details of the first instrument, we shall spend a few moments elaborating these four points.

Acquisition Speed

For a discussion of the topic of *sampling* see Appendix E. Here we shall think of sampling as simply measurement. The rate at which instruments sample or measure varies greatly, and is for the most part determined by cost. The Radio Shack DMM costs \$99

and samples once each second (1 S/s). The Tek TDS210 digital storage oscilloscope (DSO) costs \$1500 and samples at the maximum rate of 1,000,000,000 per second (1 GS/s) at 8-bit resolution. The National Instruments data acquisition (DAQ) card costs \$700 and samples at a maximum rate of 10,000 per second (10 kS/s) at 12-bit resolution. The greater the sampling speed the finer the detail of a waveform that can be resolved. The greater the number of bits (word size) in the acquisition the greater the precision (number of meaningful digits) in the measurement. A tradeoff exists between sampling speed, cost, and word size.

Display and Storage Capability

Display capability is related to sample rate and storage capability. Most hand-held DMMs of the present generation have a minimum amount of RAM. A measurement they make they immediately display on a single-line LCD screen. A typical DSO on the other hand has a fair amount of memory and can store and display an entire acquisition (consisting of, perhaps, 2500 samples) on a multi-line LCD screen of as much as 320 pixels wide by 240 pixels high. The display and storage capabilities of instruments are steadily being increased.

Remote Control

Research-grade instruments are equipped with one or more communication port, most often an RS-232 or GPIB port and increasingly a USB port (discussed in Appendix 3).¹ But how controllable an instrument is does vary—depending on the instrument’s firmware. For example, the Radio Shack DMM will export a frame of data on its TxD line on command. But it supports no remote control of measurement type or range. The Agilent 34401A digital multimeter, the E3640A programmable power supply, and the Tek TDS210 DSO on the other hand support remote control over much of the functionality of the instrument that is accessible manually via its front panel controls.²

SCPI Compliance³

The degree and ease of control of an instrument depends to some extent on whether or not it is SCPI compliant. There was, until fairly recently, a number of proprietary ways of controlling an instrument—determined by the firmware shipped with the instrument.⁴ At the lowest level of “intelligence”, a hand-

held DMM typically reacts to a voltage transition on its RxD line by sending a standard string of data. At the middle level, instruments like the Telulex signal generator respond to an arbitrary set of ASCII strings to set modes and to import waveforms. At the highest level, instruments like the Tek oscilloscope and others produced by leading-edge companies like Hewlett-Packard, LeCroy, Keithley, Fluke and others respond to a set of commands and queries that have a definite logic and structure to them. Just as various consortia have come together to agree on standards of hardware interfacing (for RS-232, GPIB, and recently USB and Firewire) similar efforts have resulted in a degree of software standardization.

Software standardization began in 1990 when Hewlett-Packard and other companies defined what is now called the Standard Commands for Programmable Instruments (or SCPI for short, pronounced “skippy”). The idea behind SCPI is that a system controller sends commands or *program messages* to one or more instruments over a bus, and instruments send reply messages back to the controller. The reply may be a measurement result, an instrument setting, an error message and so forth. When a program message directly generates a reply, it is called a *query*. To give the flavor of SCPI commands a few typical ones are listed in Table AA-1. Such commands are referred to as *device-specific commands* to distinguish them from *interface-specific commands* (specific to RS-232 or GPIB) already described in Appendix B. More SCPI commands are listed in the following sections dealing with specific instruments.

Table AA-1. A few typical SCPI Commands and Queries. Queries terminate with a question mark.

| Command | Function |
|-----------------------------|---|
| ACQuire:MODE? | Queries oscilloscope acquisition mode |
| CH<x>:BANDwidth? | Queries the bandwidth setting of channel <x> |
| DISPlay:STYle DOTs MATH? | Set display style to dots Return definition of math waveform |

SCPI commands are based on a hierarchical or tree structure. Associated commands are grouped under a common node or root, thus forming sub-systems. A portion of the SOURce subsystem taken from the

E3640A power supply command set is listed in Table AA-2. **SOURce** is the root keyword of the command, **CURRent** and **VOLTage** are second level keywords and **TRIGgered** is a third level keyword. (Essential letters are printed in **UPPERcase**, optional letters in lowercase.) A colon (:) separates a command keyword from a lower level keyword.

Table AA-2. *The tree structure of the SOURce command taken from the Agilent E3640A programmable power supply command set. The tree of this command has three levels; lower branches of the tree are indented for easy identification.*

```
[SOURce:]
  CURRent {<current> | MIN | MAX | UP | DOWN}
  CURRent? [MIN | MAX]
  CURRent:
    TRIGgered {<current> | MIN | MAX}
    TRIGgered? {MIN | MAX}
```

```
VOLTage {<voltage> | MIN | MAX | UP | DOWN}
VOLTage? {MIN | MAX}
VOLTage:
  TRIGgered {<voltage> | MIN | MAX}
  TRIGgered? {MIN | MAX}
```

Legend: Square brackets [] indicate optional arguments, curly brackets {} indicate values or keywords. Arrow brackets <> indicate an optional numerical value. Vertical lines | mean “or”. These brackets are not part of the command.

About the Quick Starts

The Quick Starts in the following sections were designed to provide a quick introduction to the instrument. It was intended that some of them would be covered in labs or tutorials. For maximum effectiveness you are strongly urged to work your way through them before beginning a lab where the instrument is featured.

The Ohaus Scout II Electronic Balance

General Description

In many labs today the mechanical balance has been replaced with an electronic or digital balance. The Ohaus Scout II series of electronic balances (Figure AA-1) are good examples. They feature front panel controls, simplified menu, automatic shut off, multiple weighing units, parts counting and a weigh below hook. The model described here is number SR6010. It has a 600g capacity and an RS-232 port.



Figure AA-1. *The Ohaus series of electronic balance.*

There are two buttons on the front panel: “Zero On” (right) and “Mode Off” (left). The “Zero On” button is for turning the instrument on and for zeroing the unit before a weighing operation. The “Mode Off” button is for turning the instrument off and for stepping through menu selections.

Accuracy

Claimed accuracies are: readability 0.1g, repeatability 0.1 g (standard deviation), linearity ± 0.1 g.

Quick Start

To get a measurement from the balance do the following:

- Assuming the instrument is OFF, press the “Zero On” button momentarily to turn the instrument ON. All segments will appear briefly on the LCD display followed by a software revision number (“2.0”) and then “00”.
- Note the current weight unit printed at the right hand edge of the display. If a different weight unit is desired then press the “Mode Off” button

Specifications and Quick Starts

continuously until the desired weight unit appears.

- Before performing a manual weighing, the unit must first be zeroed. To do this press the “Zero On” button momentarily.
- Immediately after zeroing, place the object to be weighed on the pan. The balance will initiate a measurement cycle, at the end of which a stable reading will appear in the display.
- For each subsequent object to be weighed, press the “Zero On” button and repeat.

For the Programmer

Communication

The Scout II series of balances have a bidirectional RS-232 interface. The instrument is able to send measurements out the serial port and to respond to a small set of commands from a controlling computer. The unit is a DCE device; it is equipped with a standard DB-9 connector and requires a “straight-through” cable.

RS-232 Parameters (defaults)

The factory default RS-232 values are:

Baud Rate: **2400**
Coding: **7 bit ASCII**
Parity: **None**
Stop Bits: **2**
Handshaking: **None**

Other values are possible, but the defaults give the most reliable behavior (more on this below). The beginner is strongly urged to keep to the defaults.

RS-232 Commands

All commands must be in standard ASCII form and terminate with a carriage return <CR> (\r) or the carriage return-line feed combination <CR><LF> (\r\n). All strings returned by the balance are terminated with a carriage return-line feed. Commands supported are listed in Table AA-3.

Table AA-3. RS-232 Command Table for Ohaus Scout II Series of Electronic Balances. Some of these functions, e.g., certain units must first be turned on manually via the front panel.

| Command | Meaning |
|---------|--|
| ? | Print current mode |
| nnnnA | Set Auto Print Feature to “nnnn” nnnn=0 turns feature OFF nnnn=S output on stability nnnn=C output is continuous nnnn= 1-3600 sets auto print interval |
| C | Begin span calibration |
| L | Begin linearity calibration |
| xM | Place balance in unit “x” x=0 gram, x=1 ounces, x=2 troy ounces, x=3 pennyweights, x=4 parts counting, x=5 pounds |
| T | Same effect as pressing Zero On |
| V | Print software version |
| EscR | Resets setup and print menus to factory default. Resets RS-232 configuration |
| P | Print display data |
| LE | Shows last error code. Response: Err: Error Number |
| xS | Print stable data only. Where x=0 for OFF, x=1 for ON |

Data Format

The balance outputs a frame of 22 bytes (inclusive of the <CR><LF> at the end). The structure is explained in Figure AA-2.

The response string consists of two parts, a numeric part and a unit part. The numeric part begins in the 7th

character space and takes up a maximum of 6 character spaces. One space separates the numeric part from the unit part. The unit part occupies at most 3 character spaces.

Preparation for Remote Control

The balance is ready for student use and for remote control via LabVIEW. No special preparation is necessary if the student drivers listed in Chapter 5 are used. The balance has been left with the factory defaults. For exploratory reasons, the balance has been run at a baud rate of 9600, but higher than the default baud rate has been found to result in unreliable operation (more on this below). Data can be sent from the balance in either of two ways: continuously or in response to the “P” command (Table AA-3). If the highest speed is required then the balance should be run in continuous mode.

read buffer

```
\s\s\s\s\s\s300.2\sg\s\s\s\s\s\s\r\n
```

read buffer

```
\s\s\s\s\s\s10.590\soz\s\s\s\s\s\s\r\n
```

read buffer

```
\s\s\s\s\s\s9.650\sozt\s\s\s\s\s\s\r\n
```

Figure AA-2. Three example responses from the Ohaus Scout II balance for the calibration mass of 300 gram supplied with the instrument, grams (top), ounces (middle) and troy ounces (bottom).

Peculiarities of the Balance

The programmer should be alert to the following peculiarities of the balance:

- Whenever a VISA Open is executed with the balance connected to the serial port, the balance performs a zero automatically. There is no need to zero the instrument as part of an initialization sequence.
- If the balance is set to output continuously or is set to output in response to the “P” command, and if the printing of unstable data is enabled, then the balance will insert a question mark in place of the last space character in the return string of unstable data, as for example:

```
\s\s\s\s\s\s-269.9\sg\s\s\s\s\s?s?\r\n
```

This question mark can be used to flag data of questionable accuracy.

- At the baud rate of 9600 there are times when the instrument returns the string
ES\r\n

This occurrence is not documented in the manual. It apparently refers to “empty string” or a failure of the balance to provide a measurement. Such returns should be trapped and removed from the data array. To avoid this from happening set the baud rate to the 2400 default.

Sample Rate

The sample rate depends on the baud rate. At the default rate of 2400 with the instrument prepared to send in response to the “P” command, the sample rate is about 3 per second. At the baud rate of 9600 the sample rate is 4-5 per second. In continuous mode the sample rate is increased slightly.

Settings for a Sample Rate of 3 (non continuous)

- Baud rate **2400** (for most reliable results)
- Auto Print **OFF**
- Stable Data Output Only **OFF**
- Use “P” command

Settings for a Sample Rate of 3+ (continuous)

- Baud rate **2400** (for most reliable results)
- Auto Print **Cont**
- Stable Data Output Only **OFF**
- Collect data in a tight loop
- Since collection may begin in the middle of a data string, the first data string should be discarded.

NOTE: The balance does not always respond as expected when outputting data continuously. When in this state, the command to turn Auto Print OFF often has to be sent more than once to take effect. Attempting to switch from Auto Print Continuous to Auto Print OFF may cause the balance to freeze (see caution below regarding freezing).

Cautions at High Baud Rates

If a higher than default baud rate is used the numeric part of the display screen sometimes blanks (freezes). When this happens the instrument often ceases to respond to the Mode/Off button; it has to be restarted by unplugging and replugging the external power adapter. In addition, sampling may actual stop briefly in the course of a run. It often starts up again after a short time.

The Radio Shack Manual/Auto Range Digital Multimeter

General Description

The Radio Shack (RS) Manual/Auto Range DMM (Figure AA-3) is one of the least expensive DMMs on the market that has reasonable accuracy (1-2%) and a serial port.

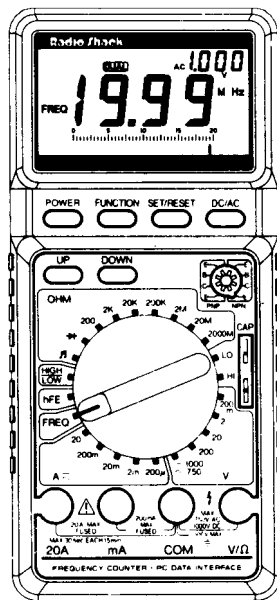


Figure AA-3. The RS multimeter (Cat. No. 22-168A)

Controls

The two most important buttons are the POWER button (colored red) and the DC/AC button. These buttons are located on the upper left and upper right hand corners of the DMM's control panel just below the display area.

The rotary switch in the center of the DMM's control panel is the FUNCTION and RANGE selector. With this switch you select the FUNCTION or kind of measurement you wish to make and the RANGE of the measurement. There are positions for at least seven types of function: resistance (OHM area), capacitance (LO, HI), voltage (V), current (A) and so on. There are 7 ranges of resistance (200 Ω , 2 k Ω , 20 k Ω , 200 k Ω , 2 M Ω , 20 M Ω and 2000 M Ω). On the 200 Ω range the DMM will display a maximum of 200 Ω ; if the resistance exceeds this value the DMM will print an "OL" in the display, meaning *overrange*. There are 5 ranges of voltage and current.

Sockets

Four sockets designed to accept a standard banana plug are arrayed along the bottom sector of the panel. These are labelled "20A", "mA", "COM" and "V/ Ω ". You will not be using the "20A" socket in this course. On the other hand, you will always use the "COM" socket, otherwise known as the COMMON or GROUND connection, in all measurements you make (excepting capacitance). To measure current use the "COM" and "mA" sockets; to measure resistance or voltage use the "COM" and "V/ Ω " sockets. There are also two sockets for measuring capacitance.

Specifications

Radio Shack claims the DMM has good voltage- and current-measuring characteristics, meaning that when operated as a voltmeter, it has a very large internal resistance (10 M Ω) and when operated as an ammeter it has a very small internal resistance (10 Ω - 1000 Ω depending on the range). Specifications are listed in Table AA-4. All measurements have an uncertainty associated with them. How to calculate this uncertainty is explained in *Example Problem AA-1*.

Quick Start

To turn the instrument on push the POWER button. The display should come alive. If the battery is weak a LOW BAT sign will appear in the display. If the LOW BAT sign does appear call your instructor—the battery will need replacing.

The instrument has a number of *modes* which are selected by the Function button. To see what these modes are do the following:

- Push the Function button slowly about 10 times and observe the mode names as they appear each time on the LCD screen. The modes are "A-H", "D-H", "MIN", "MAX", "REL", "MEM", "RCL", "DUAL", "COM", "CMP". After "CMP" the meter will revert back to the "A-H" mode.
- Put the DMM into any mode you like and then turn the DMM OFF and ON. Observe that the DMM will always revert to the "A-H" mode on boot up. Most of these modes will not concern us here, and so we restrict our description to the two most important:

A-H: A-H stands for Auto-Hold. In this mode the DMM shows in its secondary display the reading taken 4 seconds earlier. This is the power on mode and therefore the mode you will use most often in this course.
 COM: In this mode the DMM sends data contin-

uously out the RS-232 port when the DTR line is set high. This mode should be used only in special circumstances (for example, as part of a project).
 • REMEMBER: To quickly reset your DMM to the “A-H” default just turn it OFF and back ON.

Table AA-4. Selected specifications of the RS DMM. Input Impedance is 10 M on all DC and AC voltage ranges.

| Function | Range | Accuracy |
|-------------|---|---|
| DC Voltage | 200 mV, 2 V, 20 V, 200 V, 1000 V | ± 0.8% of display + 1 ls digits |
| DC Current | 200 µA, 2 mA 20 mA, 200 mA, 2 A 20 A | ± 1.0% of display + 1 ls digit ± 1.5% of display + 1 ls digit ± 2.5% of display + 5 ls digits |
| Resistance | 200 2 k , 20 k , 200 k , 2 M 20 M 2000 M | ± 1.0% of display + 3 ls digits ± 1.0% of display + 1 ls digit ± 1.5% of display + 2 ls digits ± 5.5% of display + 5 ls digits |
| AC Voltage | 200 mV, 2, 20, 200, 1000 V 750 V | ± 1.2% of display + 3 ls digits ± 1.5% of display + 3 ls digits |
| AC Current | 200 µA-2 mA 20 mA-200 mA 20 A | ± 1.5% of display + 3 ls digits ± 2.3% of display + 5 ls digits ± 3.5% of display + 7 ls digits |
| Frequency | 2 kHz – 20 kHz | ± 2.5% of display + 3 ls digits |
| Capacitance | 200 pF – 200 nF 20 µF – 200 µF | ± 2.5% of display + 3 ls digits ± 4.5% of display + 5 ls digits |

Example Problem AA-1
Calculating Uncertainty in a Measurement with an RS DMM

An RS DMM on its 2V range displays 0.123 volt. Write this measurement in standard form.

Solution:
 The accuracy (Table AA-4) is specified as 0.8% of the display reading + “1 ls digit”. This translates to

$$0.123 \times 0.008 = 0.000984$$

$$+ 0.001 \text{ (1 ls digit in the display)}$$

$$= 0.001984 \text{ (before rounding)}$$

$$= 0.002 \text{ volt}$$

rounded to 1 significant digit. Thus the measurement written in standard form is:

$$(0.123 \pm 0.002) \text{ volt.}$$

The precision of the measurement and the precision of the uncertainty must both extend to the same decimal place—in this case the third.

NOTE: For other measurements on other ranges the precision may extend to a decimal place other than the third.

For the Programmer

Communication

The instrument supports a uni-directional RS-232 interface. The port is accessed via five small holes on the right hand side of the instrument. It takes a non-standard connector (Figure AA-4). A standard DB-9 connector is fitted to the opposite end of the cable (which mates with a Mac cable if used). In the figure five lines are shown. The numbers correspond to the same numbered pins on the DB-9 (i.e., 2, 4, 7, 3, 5).⁵

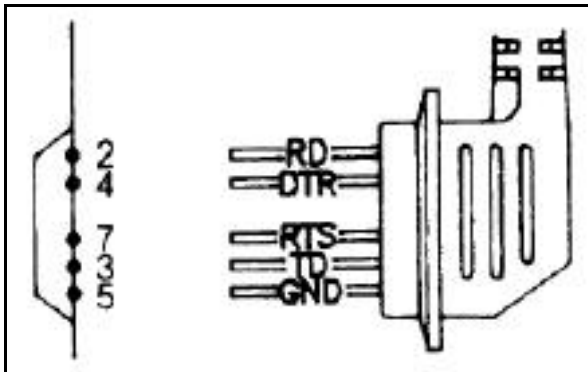


Figure AA-4. Wiring of the serial port on the Radio Shack DMM.

On bootup the lines may or may not be active, depending on the computer since the states of the lines are determined by the computer. On a standard Windows PC the TxD, RTS and DTR lines are all LOW (indicated by red LEDs on an RS-232 indicator box). On a tower Mac the TxD and DTR lines are LOW. On a Mac or Windows PC laptop no lines are active.

RS-232 Parameters (fixed)

The following RS-232 values are fixed and cannot be changed:

Baud Rate: **1200**
 Coding: **7 bit ASCII**
 Parity: **None**
 Stop Bits: **2**

Handshaking: None

The instrument does not support handshaking, but the RTS line must be unasserted or else the DMM will not send.⁶ The instrument supports no external control beyond a voltage transition on its RxD line—meaning “send data”. When in COM mode the DMM sends data continuously as soon as the DTR line is set HIGH (i.e., as soon as G performs a VISA Open—see Chapter 5).⁷ In this mode, the DMM sends data at the rate of 2 S/s approximately.

Data Format

The DMM outputs a frame of data of 14 bytes (inclusive of an ASCII <CR> byte at the end). The structure is explained by the following two examples:

| BYTES | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E |
|----------|---|---|---|---|---|---|---|---|---|---|---|---|---|----|
| Example1 | D | C | - | 1 | . | 9 | 9 | 9 | V | | | | | CR |
| Example2 | | | | | 1 | . | 9 | 9 | 9 | M | o | h | m | CR |

Unlike the Ohaus electronic balance described in the previous section that uses only a portion of its 22 byte frame, the RS DMM uses its full frame (here 14 bytes). What could be called a *Mode* string occupies bytes 1-3, a *numeric* string bytes 4-9, and a *unit* string bytes A-D.

Sample Rate

Maximum recommended sample rate (rate of producing a voltage transition on its RxD line) is 1 S/s. This does not apply to COM mode in which the sample output is set by the DMM itself at about 2 S/s approximately.

Peculiarities

As already stated, the RS DMM will not send unless the DTR line is unasserted in software. This requires the programmer to pay attention to the platform used. LabVIEW has a VI to enable the platform to be identified. The student driver RS Open makes this issue transparent to the student. For more information see Chapter 5, and in particular Figure 5-21.

Agilent Model 34401A Digital Multimeter

At the time of writing only two of these instruments were available in the Physical Sciences lab for student use. You will likely be using this instrument, if at all, for purposes of calibrating other instruments or for your project.

General Description

The Agilent Model 34401A DMM (Figure AA-5) is a research-grade 6-1/2 digit instrument with an accuracy in the 0.003% range.⁸ It is claimed to employ “a continuously integrating, multislope III ADC”. It provides measurements of DC and AC voltage, DC

and AC current, resistance, continuity, Diode Test, DC:DC Ratio measurements, period and frequency. It will perform a number of MATH operations and can store up to 512 readings in internal memory. This is one of the best instruments of its kind on the market that is within the budget of a teaching laboratory.

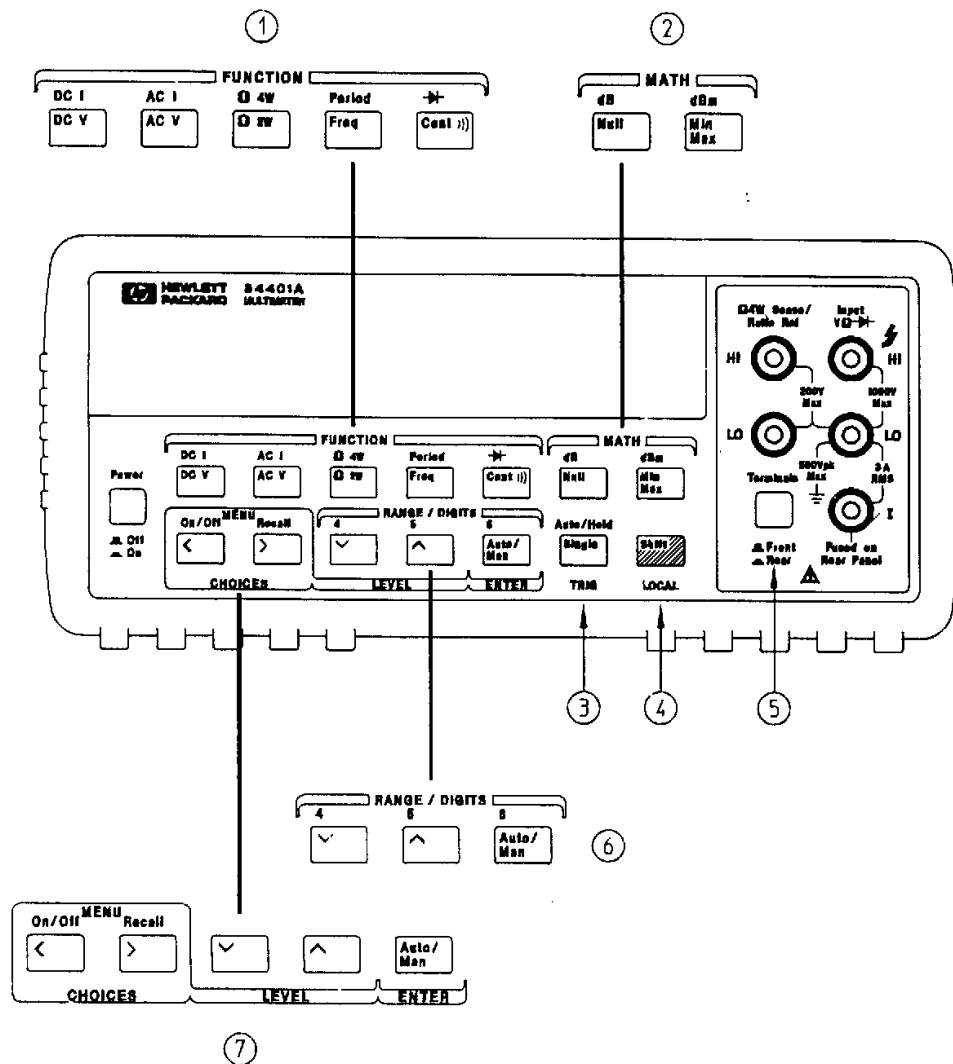


Figure AA-5. The front panel of the Agilent Model 34401A digital multimeter at a glance. This shows ① Measurement function keys, ② Math operation keys, ③ Single Trigger/AutoTrigger/Reading Hold key, ④ Shift/Local key, ⑤ Front/Rear Input Terminal Switch, ⑥ Range/Number of Digits Displayed keys, ⑦ Menu Operation keys.

Specifications

The instrument can be operated at three precision levels: 4-1/2 digits, 5-1/2 digits and 6-1/2 digits. The precision selected determines the *measurement speed*, the more precision the slower the speed. Measurement speed depends on the function as well as the resolution. A selection of measurement speeds is listed in Table AA-5. The instrument is also rated as to *transfer speed*, the speed at which it can transfer data in bulk to a controlling computer. Transfer speed is faster than measurement speed. A selection of transfer speeds is given in Table AA-6. As would be expected, transfer speed via GPIB is greater than for RS-232.

Table AA-5. A Selection of Measurement Speeds.

| Function | Digits | Readings/s |
|------------|--------|------------|
| DCV, DCI, | 6 1/2 | 0.6 (0.5) |
| Resistance | 6 1/2 | 6 (5) |
| | 5 1/2 | 60 (50) |
| | 5 1/2 | 300 |
| | 4 1/2 | 1000 |

Table AA-6. A selection of Transfer Speeds. This refers to the transfer of data from internal memory.

| Mode | ASCII Readings to... | Rate (#/sec) |
|---------------|----------------------|--------------|
| DC | RS-232 | 55 |
| | HP-IB | 1000 |
| AC | RS-232 | 50 |
| | HP-IB | 50 |
| Freq & Period | RS-232 | 55 |
| | HP-IB | 80 |

Quick Start

The front panel controls are grouped by function (Figure AA-5). When the instrument is turned ON it enters DC Voltage mode automatically. You are advised to ensure that the Front/Rear Input Terminal switch ⑤ is set for “Front”.

A command is entered in response to a menu via push buttons on the front panel. The menu is organized in a top down tree structure with three levels (Figure AA-6). Once into the menu you can move one item horizontally right or left by pressing the “>” or “<” buttons, one item down or up by pressing the “ ”

or “^” buttons, respectively.

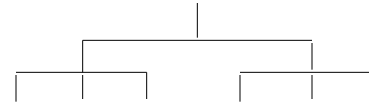


Figure AA-6. Tree structure of the menus.

To give the flavor of what is involved in examining and changing a mode we shall have you confirm the GPIB and RS-232 values in preparation for Lab #3. Do the following:

- ① With the instrument ON, turn the menu ON by pressing the “Shift” button then the “>” button.
- ② Keep pressing the “>” button until you reach “E I/O MENU”.
- ③ Press the “ ” button once to move down one level of the menu to “1:GPIB ADDR”.
- ④ Press the “ ” button again to move down one level to “# ADDR”. # is the current GPIB address of the instrument.
- ⑤ Press “ ” to go back to “1:GPIB ADDR”.
- ⑥ Press “>” to go to “2:Interface”.
- ⑦ Press “ ” to go to “RS-232” then press “>” to go to “GPIB”.
- ⑧ When you have finished press the “Auto/Man ENTER” button. The instrument should beep and show “SAVED” in the display to indicate that the change has been saved.

For the Programmer

Communication

The instrument supports RS-232 and GPIB communication, though only one interface may be used at a time and that interface must be selected from the front panel. The connectors are located on the rear panel. GPIB is the default interface. Parameter values are:

GPIB

Address: **22** (default)

RS-232

Baud Rate: **9600** (default)
 Coding: **7 bit ASCII** (default)
 Parity: **Even**
 Stop Bits: **2**
 Handshaking: **DTR/DSR**

The instrument provides error checking of remote control commands and prints error messages to the display. This greatly assists in debugging.

Serial Port Wiring

This instrument is a DTE; the serial port connector is a standard male DB-9. It is shipped with a null modem cable.

Device Specific Commands

This instrument responds to a host of device specific commands. A selection of the more useful is listed in Table AA-7.

Table AA-7. A Selection of Device-Specific Commands.

| Command | Action |
|------------------------|-------------------------------------|
| MEAS:VOLT:DC? 10,0.003 | |
| MEASure:Diode | Preset and make a diode measurement |
| | |

Storing/Outputting Data

The programmer has the choice of having the meter record data at high speed and save the data to internal memory or of streaming the data continuously in

response to the “Read?” command out the RS-232 or GPIB ports. With the former choice the programmer is limited to 512 measurements, whereas with the latter there is no such limitation.

For many projects in physics it is found to be desirable to limit the resolution to 4 1/2 digits for the highest speed and to stream the data over the RS-232 or GPIB port and collect it by means of a tight loop. The user may collect as many readings as needed and may stop the acquisition at any time. Some sample rates actually obtained are listed in Table AA-8. These were obtained using a single copper-constantan thermocouple as the voltage source. The sample rate at 4 1/2 and 5 1/2 digits of resolution typically differ by no more than 10%.

Table AA-8. Practical sample rates achieved with the example program *HPMVoltageLogger.vi* (Chapter 5)

| Range | Resolution | Sample Rate |
|-------|------------|-------------|
| 0.1 | 4 1/2 | 30 |
| 0.1 | 5 1/2 | 26 |
| 0.1 | 6 1/2 | 5 |

| | | | | | |
|-------------|-------------|-------------|------------|------------|------------|
| A:MEAS MENU | B:MATH MENU | C:TRIG MENU | D:SYS MENU | E:I/O MENU | F:CAL MENU |
|-------------|-------------|-------------|------------|------------|------------|

Figure AA-7. The top level menu items.

Use chemical cell

Instek Signal Generators Models GFG-8016G and GFG-8216A

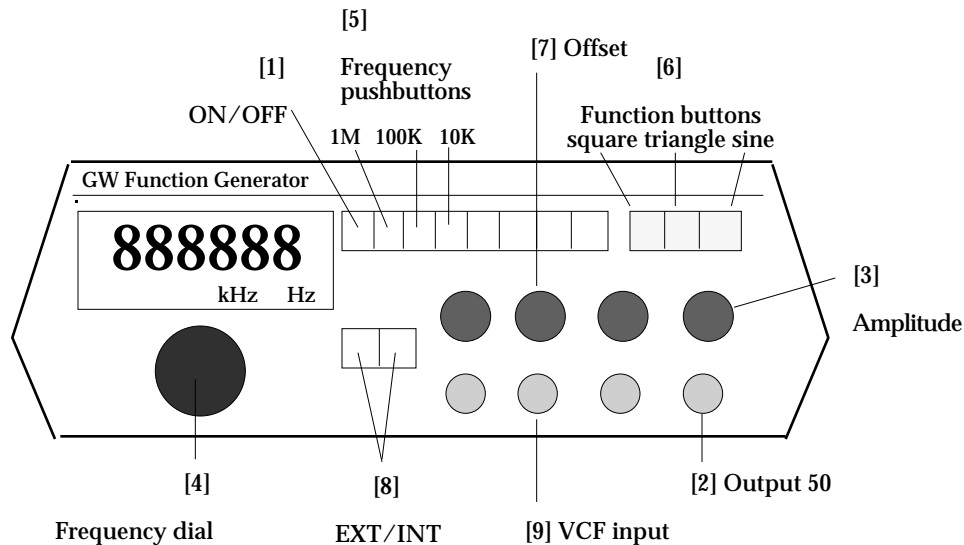
Three models of signal generator are available for use in this course, the Good Will Instek Model GFG-8016G or Model GFG-8216A for general use, and the Telulex Model SG-100/A for special projects. We describe here the GFG-8016G; the Model GFG-8216A is very similar.

General Description

This instrument (Figure AA-8) is manufactured by Good Will Industries, Taiwan. It is a combination signal generator and frequency counter. It provides sine, triangle, square, TTL, pulse and CMOS waveforms over a frequency from 0.2 Hz to 2 MHz in 7 ranges. It has a standard 50 Ω output ($\pm 10\%$), a variable DC offset and a voltage-controlled frequency (VCF) input.

Frequency accuracy is 5% and sinewave distortion is claimed to be less than 1% from 0.2 Hz to 200 kHz.

The instrument has a built-in frequency counter (6-digit display) that can be used to read the internally-generated signal or a signal applied externally to a front panel BNC connector. The frequency range of the counter is 0.1 Hz to 10 MHz. Input sensitivity is 20 mV RMS.



Some Specifications:

| | |
|--------------------|---|
| Amplitude | > 20 Vp-p (open circuit), > 10 Vp-p (into 50 Ω) |
| Attenuation | -20 dB \pm 1.0 dB (at 1 kHz) |
| DC Offset | < -10V to +10V (< -5V to > +5V into 50 Ω load) |
| Frequency Response | < 0.1 dB 0.2 Hz - 100 kHz, < 0.5 dB 100 kHz - 2 MHz |

Figure AA-8. A drawing of the front panel of the Instek Model GFG-8016G function generator.

Quick Start

Operation of the instrument is straightforward. We shall guide you through selecting a 1 kHz sinewave and connecting the signal generator to the oscilloscope. Do the following:

- ① Push the ON/OFF button [1] to turn the instrument ON.
- ② Confirm that the EXT/INT buttons [8] are both OUT; this will ensure the display shows the frequency of the internally-generated signal and not the signal applied externally.
- ③ Depress the appropriate Function button [6] to select a sine wave.

- ④ Manipulate the Frequency pushbuttons [5] and the Frequency dial [4] to select a frequency of about 1.000 kHz.

NOTE the blinking GATE LED in the display. The frequency counter takes about 1 second to compute an average frequency. The gate time depends on the frequency. To continue...

- ⑤ Ensure the Amplitude control [3] is midrange (with the indicator straight up), and the attenuation OFF. If necessary, push the amplitude control IN to turn off the attenuation.
- ⑥ Ensure the DC OFFSET control [7] is midrange, or OFF. A DC offset refers to a DC voltage added to the AC output, which is not wanted here.
- ⑦ Connect the 50 Ω OUTPUT of the generator [2] to CH1 of your oscilloscope with a “BNC” coaxial cable. This cable’s construction is illustrated in Figure AA-9. The signal is carried on the cable’s central conductor. The braided shield is ground which connects to the outer casing of the cable end. BNC cable has twist lock connectors at both ends so take care when connecting the cable to the signal generator and oscilloscope.

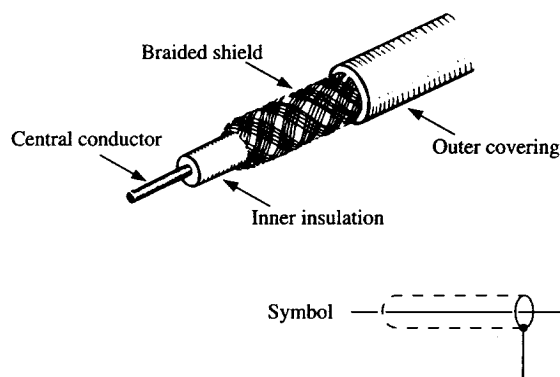


Figure AA-9. The composition and symbol of coaxial cable.

For the Programmer

This instrument has no RS-232 or GPIB port and therefore does not support the kind of communication

described for other instruments here. However, it does have a voltage controlled (VCF) input.

Voltage-Controlled Frequency

The frequency output of the generator can be controlled by a DC or AC voltage applied to the VCF input [9]. This voltage can be varied between 0 and 10 volts or -10 and 0 volts. The frequency is swept down, meaning the higher the voltage applied to this input the lower the frequency output.

The voltage applied to the VCF input can be held constant or swept. The speed of the sweep is determined by the settling time of the supply. Typical frequency ranges obtained with an Agilent programmable power supply on the 8V range providing the controlling voltage are listed in Table AA-8. Some gaps in frequency are the result of the fact that the VCF maximum was 8 volts (approximately) and not 10 V. Using a programmable power supply such as the Agilent, the controlling voltage can be swept down as well as up.

Table AA-8. High limit, low limit frequencies obtained with voltage VCF inputs of 0.02 V and 8.22 V (approximately). To obtain this data the frequency control of the signal generator was kept at maximum (fully clockwise) on the range indicated.

| Range | High Limit | Low Limit |
|-------|------------|-----------|
| 1 M | 2.1 MHz | 450 kHz |
| 100 k | 210 kHz | 45 kHz |
| 10 k | 21 kHz | 4.6 kHz |
| 1 k | 2.1 kHz | 460 Hz |
| 100 | 200 Hz | 46 Hz |

Some trial and error is required to find the best frequency range of the generator for the sweep range desired. Attention should be paid to the issue of linearity, i.e., how linearly does the frequency output depend on the voltage applied to the VCF input. A calibration curve should be prepared.

Telulex Model SG-100/A Signal Generator

This instrument will likely be used only for projects or practice programming.

General Description

The Telulex Model SG-100/A signal generator (Figure AA-10) is a fully digital instrument of late 1990s technology. Though developed by Telulex Corp., it is now marketed by Berkeley Nucleonics, Cal., under the model name BNC Model 625A signal generator.⁹



Figure AA-10. Telulex Model SG-100/A otherwise known as the BNC Model 625A signal generator.

The instrument provides a broad range of operating modes, such as arbitrary waveform, pulse, word data integration, function, dual tone, sweep, VCO, AM, FM, SSB, FSK, and burst. An arbitrary waveform can be downloaded to the instrument over the RS-232 interface from a host computer. The instrument is claimed to have an architecture based on the latest advances in digital signal processing (DSP) and direct digital synthesis (DDS) technology.

The instrument is claimed to deliver clean, fully synthesized, DC to 21.5 MHz modulated or unmodulated waveforms with 0.01 Hz frequency resolution and 1 mV and 0.1 dBm amplitude resolution. A large LCD display allows all modulation parameters to be seen simultaneously and to assist in the navigation of the various modes.

Front Panel

As can be seen in the figure, the front panel is equipped with a multiline LCD screen, a large rotary knob, a keypad for entering numbers and selecting

functions and two BNC connectors (lower right hand corner). Of the latter the SIG Out connector is the main signal output. The SYNC Out connector is a TTL/CMOS compatible square-wave output. It is a “hardwired” version of the main output and is available in all modes. The SYNC Out swings 0 V to +5 V and is useful for driving digital circuitry.

Quick Start

Modes of operation are changed, frequencies entered, etc. by pushing buttons on the keypad. To give you the flavor of what is involved we describe how to enter a waveform and how to set a frequency. Do the following:

- ① The ON button is located in the lower left hand corner of the panel. Push this button to turn the instrument ON. When the instrument boots it performs diagnostics and loads an initialization from non-volatile RAM. This information is printed to its LCD screen. Wait a few moments for this to complete. The unit defaults to generating a 1.000000 MHz sinewave at a level of +10.0 dBm (roughly 2.2 volts peak-to-peak into a 50 Ω load).
- ② To change the frequency, press the Next Cursor Field (N) button once. The cursor will move to the frequency field. The cursor position is indicated by a flashing digit.
- ③ You can change the frequency two different ways: 1) by entering a new value and 2) by modifying the current value. To enter a new value type in the frequency using the numeric keypad. Then press the MHz (Z), KHz (Y) or Hz (X) key to set the frequency units. The instrument will make a double-clicking sound to indicate that a new frequency value has been accepted. For practice, try entering a frequency of 2.000000 MHz.

For the Programmer

Communication

The instrument supports communication via RS-232 only. The values of the RS-232 parameters are:

| | |
|------------|---|
| Baud Rate: | 300, 1200, 2400, 4800, 9600 , 19200, 38400, 57600, 115200 (default 9600) |
| Coding: | 8 bit ASCII |

Parity: **None**
 Stop Bits: **1**
 Handshaking: **None**

The manufacturer recommends the instrument be operated with default settings. You are strongly urged to follow this advice.

Serial Port Wiring

The wiring of the serial port is a standard female DB9. The instrument is a DCE and connects to the com-

puter with a “straight-through” cable.

Instrument Specific Commands

The instrument is not SCPI compliant. The tradeoff is the instrument’s relatively low cost. The designers of the instrument’s firmware adopted the strategy that each key on the keypad has an associated ASCII character which when sent to the instrument over the RS-232 port, has the same effect as pressing that key on the keypad. The keypad and the associated ASCII characters can be seen more clearly in Figure AA-11.

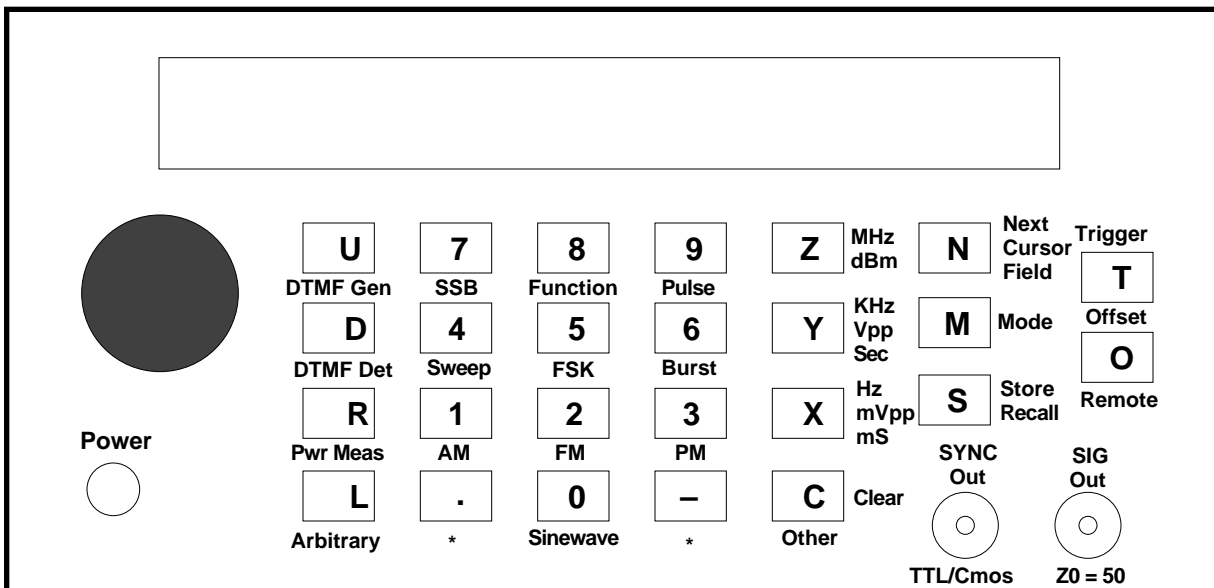


Figure AA-11. A line drawing of the front panel of the Telulex Model SG-100/A signal generator.

Programming Rules

1. All ASCII commands are case insensitive, meaning that upper and lower case letters are treated equally.
2. When the 625 has finished executing a command, it will return a command prompt, which is the DOS “>” character (109₁₀). If a long string of commands is sent to the 625, a separate “>” character will be returned for each command as it is executed (see the Peculiarities section below).
3. All whitespace characters (<CR>s, <LF>s, tabs, spaces and commas) between commands are ignored. Invalid commands (ASCII characters that are not listed in the command menu) are likewise ignored.
4. If the 625 is reporting data to the control program, it will place a colon (:) character before the data.
5. An ASCII “hello” string is sent to the RS-232 port on power up. It is therefore not recommended that the instrument be turned OFF and then ON again during a communication session, otherwise the “hello” string will enter the serial buffer and will have to be specially purged in software.

Remote Control Example

A programmer accustomed to SCPI compliant instruments will find the programming of this signal generator to be highly unusual, not to say archaic. An example of an ASCII character command sequence is the following:

Specifications and Quick Starts

M0 F1 3.141Z N 2.3Z F0

NOTE: Spaces are not actually needed between characters. They were added here only to make the commands more readable.

The command sequence breaks down as follows:

- M0 - Set 625 to Sinewave mode
- F1 - Move cursor to field 1 (frequency field)
- 3.141Z - Enter a frequency value of 3.141 MHz
- N - Move cursor to next cursor field (field 2,

level field)

- 2.3Z - Enter a level of -2.3 dBm
- F0 - Move cursor to field 0 (turn cursor off)

Peculiarities

The fact that the execution of each command string is signalled by the return of a ">" character means that these characters have to be meticulously removed from the serial buffer in software. This task is performed by the student drivers listed in Chapter 5.

Tektronix TDS210 Digital Oscilloscope

The Tektronix TDS210 digital oscilloscope was the least expensive of the TDS2xx series oscilloscopes that Tektronix marketed.¹⁰ This oscilloscope is therefore ideally suited for student use in a teaching laboratory. What you learn on this DSO, you can apply to any other more modern instrument of its type and from any number of manufacturers.

General Description

The Tek TDS210 digital oscilloscope (Figure AA-12) is marketed with three optional extension modules. The description here applies to the basic oscilloscope with the TDS2CM ("Communications") module installed. This is the configuration of all of the oscilloscopes in the physics lab.¹¹ This module provides hardcopy output and communication via the RS-232 and GPIB ports (more on this below).

The oscilloscope can perform 1 GS/s of 8-bit resolu-

tion on two signals simultaneously (applied to the CH1 and CH2 connectors). Maximum number of samples per channel is 2500. Maximum analog bandwidth is 60 MHz with bandwidth limiting (BWL) OFF, or 20 MHz with BWL ON. Its input impedance (DC coupled) is 1 M \pm 2% (in parallel with 20 pF \pm 3 pF). There are three acquisition modes: *sample*, *peakdetect*, and *average*. Accuracy is typically 3% in average acquisition mode.

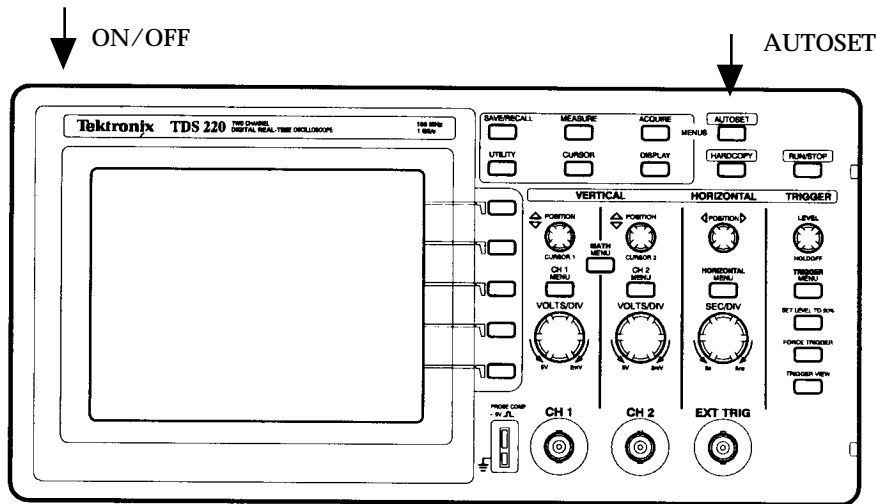


Figure AA-12. Line drawing of the Tektronix Model TDS210 digital real-time oscilloscope.

MATH

The instrument performs a limited number of math operations, for example “CH1-CH2”, “CH2-CH1”, “CH1+CH2”, “CH1 Inverted” and “CH2 Inverted”. These functions are selected via the MATH Menu button. When a function is selected, the instrument places the result in memory location “MATH”, enters MATH mode, displays the waveform, and turns both channels OFF. Measurements that would otherwise be possible on the CH1 and CH2 signals are disabled. You can exit MATH mode by turning CH1 or CH2 back on via the CH1 or CH2 menu buttons.

Storage

The waveforms applied to the CH1 and CH2 connectors that are sampled simultaneously are stored in memory locations “CH1” and “CH2”. These waveforms may be subsequently transferred to memory locations “REFA” and “REFB” for reference or comparison purposes. To transfer a CH1 signal, first press the SAVE/RECALL button. For Source select “CH1”, for REF select “A”, then press Save. If the REFA button is “On” the REFA signal will be displayed (in light pen) along with the CH1 signal (Figure AA-13 in dark pen). The REFA signal will continue to be displayed until you press the REFA button “Off”.

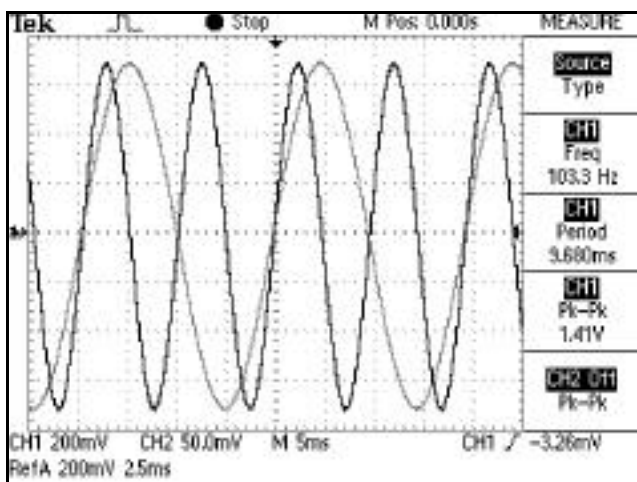


Figure AA-13. A hardcopy from the oscilloscope showing the current CH1 display (dark pen) and the previously saved waveform in Ref A (light pen). The RefA waveform scaling is shown in the lower left hand corner of the display.

Quick Start

Before attempting to measure anything with your oscilloscope it is useful to make your way through the following activities.

First Boot

Turn the oscilloscope ON NOW if you have not done so already. When the oscilloscope boots it performs diagnostics and prints the results to its LCD screen. If anything is amiss (if a message states something has FAILED a test) alert your instructor. After a second or two the screen should clear.

The LCD screen has two recognizable areas, a larger square area for displaying waveforms and a smaller rectangular area to the right of it with five measure (MEAS) boxes for displaying menu selections and numeric results. You select from menus by pressing the toggle buttons shown in Figure AA-15.

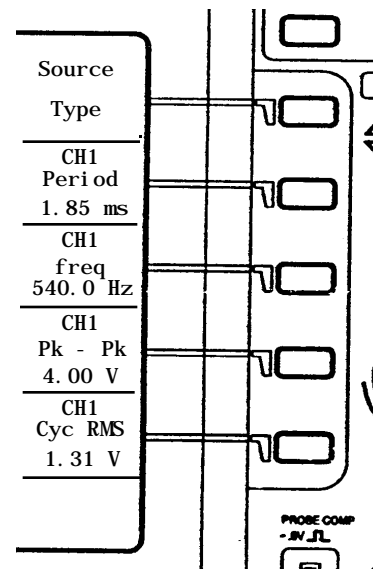


Figure AA-15. A closeup of the oscilloscope display showing the five menu/result boxes to the right of the waveform area and the toggle buttons.

Connecting the Signal Source

Assuming you have set up the signal generator as described in the signal generator Quick Start and have connected it to CH1 of the scope do the following:

- ① Turn the signal generator ON. You might immediately see a sinewave on the oscilloscope display. If you do, continue with step ③. If you do not

Specifications and Quick Starts

then do the following:

- ② Press the CH1 Menu button once or twice until you see the sinewave.
- ③ Press the MEASURE button
- ④ Press AUTOSET.

→ **The MEASURE state.** You can think of the MEASURE state as the *home* state of the oscilloscope, the state in which the oscilloscope displays numerical results in the result (MEAS) boxes, and the state in which the word MEASURE is printed above the topmost box on the right hand side of the display. To minimize confusion you should return your oscilloscope to the MEASURE state whenever you change an item in a menu. Going to the MEASURE state is easy—just press the MEASURE button.

Displaying/Removing a Trace

At this stage you should have only the CH1 signal showing since the CH2 signal is zero or just noise. If you do not see the CH2 trace continue with step ⑥. If you do see the CH2 trace do the following:

- ⑤ Press the CH2 Menu button once or twice to remove the CH2 trace from the display.
- ⑥ Press MEASURE (to go back to the MEASURE state), then press AUTOSET.

Attenuation

In order for the numerical results in display boxes to be correct you must remove any attenuation that may have been inadvertently set on the CH1 input by other users. To do this do the following:

- ⑦ While in MEASURE state press the CH1 Menu button.
- ⑧ Press the bottom toggle button as many times as it takes to bring up “X1” in the Probe box.
- ⑨ Press the MEASURE button, then press AUTOSET.

At this stage the sinewave should fill the waveform area of the screen as is shown in Figure AA-16.

Digital Jaggies

As a first time user of a digital oscilloscope you will no doubt notice the jagged appearance of the sine wave. This is normal and results from the process of digitization. In any run the input signal is sampled 2500 times making 2500 line segments in the display.

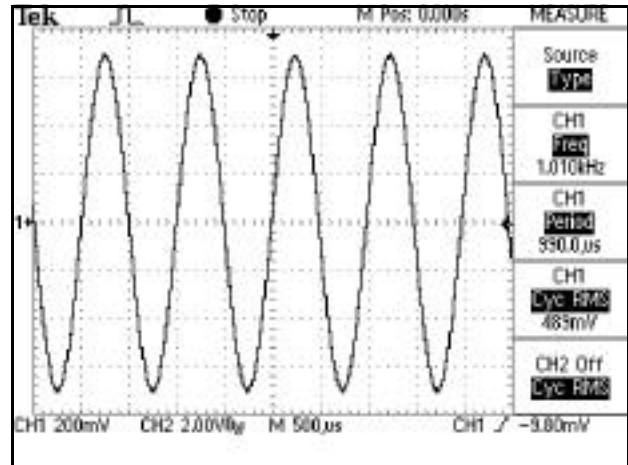





Figure AA-16. A typical display on the Tek TDS210 DSO. At this stage your oscilloscope need only resemble what is shown here.

The Display Screen

Identify the following aspects of your display screen:

The Icon Display

The icon in the upper left hand corner shows the present *acquisition mode*. Icons for the various modes are reproduced below. Sample Mode is the default mode and the current reading should be Sample Mode.

-  Sample mode
-  Peak detect mode
-  Average mode

Trigger Status

If your signal is “triggered” it is frozen in position and not moving to the right or left. Trigger status (upper middle top of the screen) shows if the trigger source is adequate or if acquisition is stopped. Current reading should be *Trig'd*, meaning the signal is triggered.

Horizontal Trigger Position

The downward arrow marker (upper middle of the screen) shows the horizontal trigger position. This is the position on the waveform at which the acquisition begins. This also shows the horizontal position since the horizontal position control (Figure AA-17) moves the trigger position horizontally. For your own interest, rotate the Horizontal Position control back and forth now to see its effect on the marker. Then reset the marker to its original, center, position.

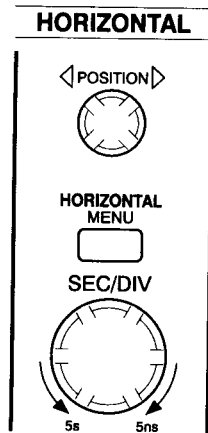


Figure AA-17. The horizontal controls on the oscilloscope.

Timebase

The timebase refers to the time equivalent of 1 horizontal (cm) division on the display. A numerical readout shows the main timebase setting. Current reading should be 1 ms.

Vertical Scale Factors

Numerical readouts (bottom left) show the vertical scale factors for CH1 and CH2. A *vertical scale factor* refers to the voltage equivalent of each vertical (cm) division on the display. Current readings should be whatever is shown in your version of Figure AA-16—here 2.00 V.

Ground Reference

An on-screen marker (middle right) shows the ground reference point of the waveform. No marker means the channel is not displayed. The current marker position should be mid-way up the right hand side.

The Results Area

To get your oscilloscope to interpret your waveform and to print the results in the MEAS boxes do the following:

- ① Press the MEASURE button.
- ② Press the topmost toggle button to display Source.
- ③ Press the lower four toggle buttons as required one after the other to display CH1 at the top of each box.
- ④ Press the topmost toggle button to display Type. Press the lower four toggle buttons as required

one after the other to display different waveform information—period, frequency etc. Typical results are shown in Figure AA-16, which figure your screen should now resemble closely except for the actual numbers.

Observations and Questions

You are now in a position to answer these questions about your waveform:

- ? Is the displayed Period value the inverse of the displayed Frequency value?
- ? Is the displayed “Cyc RMS” value (meaning rms value calculated over one cycle) equal to one-half the displayed “Pk-Pk” value divided by the square root of 2?
- ? Can you speculate on why the answer to the previous question might not be yes?

For the Programmer

Communication

The instrument supports communication and control via both RS-232 and GPIB ports.¹² Connectors are located on the rear panel. Maximum baud rate via the serial port is 9600.¹³ GPIB transfers are observed to be about 2x faster than serial transfers.

Whatever interface is used, communication takes place via *commands* and *queries* in the form of ASCII strings with SCPI syntax (described above). A selection of SCPI commands exclusive to this instrument is listed in Table AA-9. As explained above for other SCPI instruments, the syntax requires that commands and subcommands in the same branch of a command tree be separated by a colon (:), commands of an unrelated nature must be separated by a semicolon (;). An example of how to combine commands into a single string is explained in Example Problem AA-2.

Table AA-9. A Selection of Set Commands and Queries for use with the Tek TDS210 Digital Oscilloscope.¹⁴

| Command | Type | Description |
|-----------------|-------|--|
| CH<x>? | Query | Returns oscilloscope vertical parameters for channel x |
| DATa:ENCdg ASCi | Set | Sets waveform data encoding to ASCII |
| CURVe? | Query | Transfer oscilloscope waveform data |

Example Problem AA-2
Constructing a Command String for a Tek Oscilloscope

Construct as a single command string, the instruction to a TekTDS210 digital oscilloscope to transfer the data from channel 1 in ASCII form.

Solution:

Certain commands listed in Table AA-9 can be concatenated with a semicolon. Thus the command string required is:

Setting Values of Communication Parameters

Unlike the Agilent instruments described elsewhere in this appendix, the Tek oscilloscope has no provision to be set to GPIB or RS-232 mode exclusively. It can, in principle, be remotely controlled over both interfaces concurrently. This is not possible simultaneously.

RS-232

The values of the RS-232 parameters can be set from the front panel as follows:

- ① With the oscilloscope ON, press the Utility button, then press the Options button, and finally press the RS232 Setup button. Recommended parameters are:

Baud Rate: **9600**
 Flow Control: **None**
 EOL String: **<CR>** if you are using a Mac,
 <CR> <LF> if you are using a
 Windows PC, **<LF>** if a UNIX box
 Parity: **None**

- ② If necessary, make the changes required.

GPIB

The values of the GPIB parameters can be set as follows:

- ① With the oscilloscope ON, press the Utility button, then press the Options button, and finally press the GPIB Setup button. Values recommended are:

Address: **1**
 Bus Connection: **Talk-Listen**

- ② If necessary, make the changes required.

Waveform Transfer

Waveforms can be transferred from the oscilloscope to the controlling computer and vice versa as explained in Figure AA-14. To put this into words, you can transfer the contents of the five memory locations from the oscilloscope to your computer; but you can transfer a waveform from your computer to the oscilloscope's REFA and REFB locations only. This is a somewhat advanced topic. You will likely not be doing transfers in this course.

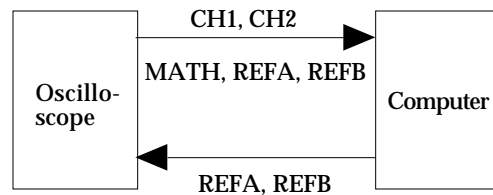


Figure AA-14. Transfers supported between oscilloscope and computer.

Data Format

Waveform data uses one 8-bit data byte (I8) to represent each data point regardless of the acquisition mode. The oscilloscope can transfer waveform data in either ASCII or binary format. Use the DATA:ENCdg command to specify one of the following formats:

- ASCII data is represented by signed integer (I8) values. The range of values depends on the byte width specified. One-byte-wide data ranges from -128 to 127. Two-byte-wide data ranges from -32768 to 32767. Two-byte-wide data capability is included for compatibility with legacy products. One-byte-wide data is recommended for maximum efficiency and transfer speed.

Each data value requires two to seven characters. This includes one character for the minus sign if the value is negative, one to five ASCII characters for the waveform value, and a comma to separate data points. An example of an ASCII waveform data string is the following:

CURVE<space>-110,-109,-110,-110,-109,-107,-109,-107...

This kind of file is often called a Comma-Separated Value (CSV) file. (For an example of a CSV file see Chapter 4.)

- Binary data can be represented by signed integer or positive integer values. The range of the values

depends on the byte-width specified. It is anticipated you will probably not use binary transfers in this course; in any case, for more information see the manual.

Though binary transfers are faster and more efficient in terms of memory usage than are ASCII transfers, they are trickier to program. Beginners are strongly urged to use ASCII format.

Agilent Model E3640A Programmable Power Supply

General Description

The Agilent Technologies Model E3640A programmable power supply (Figure AA-18) is of late 1990s technology. It is a single-output, dual range 30 watt supply. It has two ranges: LOW: 0 to +8V @ 0 to 3 A and HIGH: 0 to +20V @ 0 to 1.5 A. It can function as a constant voltage (CV) source or a constant current (CC) source, and will automatically switch from the one source type to the other depending on the load resistance. Voltage and current limits may be set

independently. It has over-voltage (OVP) protection and 5 memory locations for the storage of settings. A relatively short settling time makes the instrument ideally suited for studies of the electrical characteristics of devices over a range of voltage while minimizing device self-heating. A major feature of the instrument is that two or more supplies can be connected in series or in parallel to provide various voltages and currents.

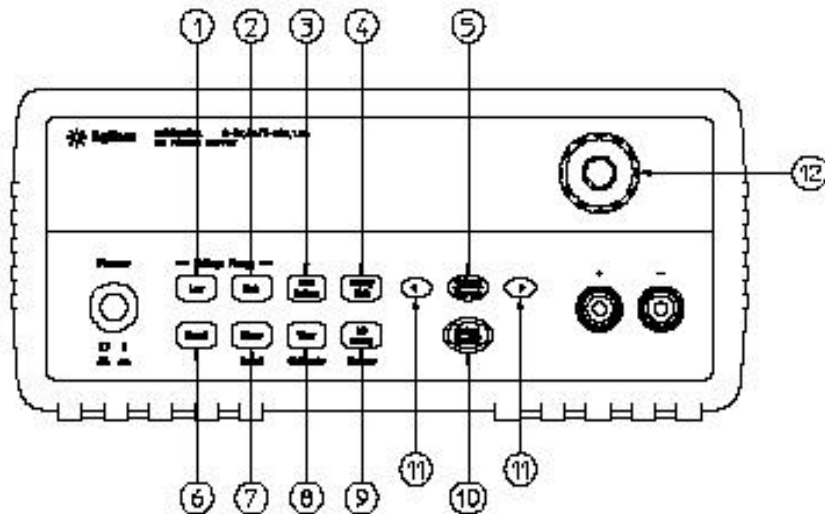


Figure AA-18. The Agilent Model HPE3640A programmable power supply.

- | | |
|--|-------------------------------------|
| 1 Low Voltage Range Selection key | 7 State Storage Menu/Local key |
| 2 High Voltage Range Selection key | 8 View Menu/Calibrate key |
| 3 Overvoltage Protection key | 9 I/O Configuration menu/Secure key |
| 4 Display Limit key | 10 Output On/Off key |
| 5 Voltage/Current Adjust Selection key | 11 Resolution Selection keys |
| 6 Stored State Recall/Reset Menu | 12 Knob |

Specifications

A selection of specifications is listed in Table AA-10. The supply can be controlled remotely as well as from the front panel. It is of interest that the resolution available remotely exceeds the resolution available via the front panel.

Table AA-10. *Some Specifications applying to the temperature range 0 to 40 °C with the instrument connected to a resistive load.*

| | |
|------------------------|---|
| Programming Accuracy | Voltage: < 0.05% + 10 mV Current: < 0.2% + 10 mA |
| Readback Accuracy | Voltage: < 0.05% + 5 mV Current: < 0.15% + 5 mA |
| Programming Resolution | Voltage: < 5 mV Current: < 1 mA |
| Front Panel Resolution | Voltage: 10 mV Current: 1 mA |
| Ripple and Noise | < 0.5 mV rms |
| Settling Time | < 90 msec for the output voltage to change from 1% to 99% following receipt of VOLTage or APPLY command via GPIB or RS-232. |

Quick Start

This Quick Start will take you through a test of the instrument's voltage and current outputs.

Voltage Output Checkout

You can confirm the power supply's voltage function by the following procedure:

- ① Ensure the power supply is OFF.
- ② Ensure that any load that may have been left connected to the output of the supply has been removed. Turn the power supply ON by pressing the Power button on the left side of the panel. The power supply will go into the *power-on/reset* state. In this state the output is disabled (the OFF annunciator turns on); its low voltage range is selected, and the OVP annunciator and low voltage range indication annunciator turn on (for example, the 8V annunciator turns on for the E3640A model); and the knob is selected for voltage control.
- ③ Push the "Output On/Off" button to enable the output. The OFF annunciator turns off and the CV annunciator turns on. The instrument is now in

meter mode. This means that the display shows the actual output voltage in volts and the output current in amperes.

- ④ Rotate the knob clockwise and then counterclockwise to confirm that the front panel voltmeter responds as you would expect. With no load connected the ammeter should indicate nearly zero. Push the "High" button to switch to high voltage (20V) range and repeat. When you are satisfied the supply is working correctly go back to the "Low" voltage range and a voltage of 0.00 V.

Current Output Checkout

You can confirm the power supply's current function by the following procedure:

- ① Start with the instrument OFF. Turn the instrument ON.
- ② Connect an insulated banana cable across the output (+) and (-) terminals.
- ③ Enable the output. The CV or CC annunciator will turn on depending on the resistance of the test lead. You will likely see something like "0.00V 0.000A" displayed. The display is in *meter* mode.
- ④ Set the display to the *limit* mode by pressing the "Display Limit" button; the Limit annunciator will flash. By means of the knob adjust the voltage limit to 1.0 volt to insure CC operation. The CC annunciator will turn on. To go back to meter mode when you have finished this task, press the "Display Limit" key again or let the display time out after several seconds.
- ⑤ With the display in meter mode (from step ④) turn the knob clockwise and then counterclockwise to confirm that the ammeter responds to knob control and that the voltmeter displays nearly zero (the voltmeter displays the voltage drop across the test lead). You should see the instrument switch from CV to CC and back again.

IMPORTANT: If you wish you can change the digit that flashes by turning the knob. To change this press the resolution selection keys "<" or ">" appropriately.

- ⑥ Turn off the power supply and remove the short.

CAUTION

If used carelessly, this instrument has the capacity to quickly destroy a component connected to it. To

illustrate the caution you should exercise we consider an example.

Example Problem AA-3 *Setting the Power Supply's Current Limiting*

You are given a zener diode type 1N375 which is described as a 6.2V zener of 0.5W power rating. You are to use the power supply to plot the zener diode's current vs voltage characteristic in the reverse direction. Describe how you would set the current limiting on the power supply to do this.

Solution:

If the zener can dissipate no more than 0.5W at its breakdown voltage of 6.2V, then at 6.2 V it should pass a current of no greater than

$$I_{\max} = \frac{P_{\max}}{V} = \frac{0.5(W)}{6.2(V)} = 81mA.$$

Thus to ensure the zener does not self-destruct the current should be limited to about half of the maximum current, or about 50 mA. This value, though somewhat arbitrarily chosen, will achieve the desired result.

For the Programmer

Communication

The instrument possesses both RS-232 and GPIB interfaces, though only one interface may be used at a time, and that interface must be set via the front panel.

Default GPIB parameters:

Address: 5

Possible values of the RS-232 parameters:

Baud Rate: **9600** (factory setting)

Coding: **8** data bits

Parity: **None**

Start Bits: **1** (fixed)

Stop Bits: **2** (fixed)

Handshaking: **CTS/DTR** (fixed)

This instrument is unusual in that handshaking cannot be turned off.

Changing Settings

We shall assume you have worked your way through the QuickStart. To confirm the GPIB/RS-232 parameters (part of Lab #3), do the following:

- ① Turn the instrument ON.
- ② Press the "I/O Config" button. If "GPIB/488" is displayed rotate the knob until "RS-232" is displayed.
- ③ Hold down the "I/O Config" button and rotate the knob until "9600 Baud" appears in the display.

The Vernier Software SBI Box

The Vernier Software serial box interface (SBI) is an example of a *free-running serial digitizer*. A free-running digitizer is one of the simplest types of digitizing devices, in that it is a device over which there is no computer control. It is a device that is always operational and sending data so long as power is applied to it. It is commonly a device built from a very simple circuit, of low-speed and therefore inexpensive. A glance through the electronics hobbyist magazines (“Poptronics”, “Electronics World” and others) will reveal the existence of a number of these devices on the market. Many are designed for the parallel (printer) port on a Windows PC, while others have a serial port and work on any platform. We discuss here an example of this latter kind of device. This instrument has been used for data acquisition in the first year physics lab at UTSC for 15 years. Though very simple and inexpensive it provides an interesting and challenging problem in programming for the ardent student of computer science.

General Description

This device (Figure AA-19) is called the “Serial Box Interface” or SBI box for short. It is marketed by Vernier Software for use in education. The box is equipped with two ports (Port 1 and Port 2) each capable of supporting two analog (0-5V) input lines, thus making in principle for four input lines. One line of each port is called the “Input Voltage Line”, the other the “ID Input Line”. Which of the two lines gets read is controlled by the DTR serial line. Normally, with the DTR line high by default (unasserted), the Input Voltage line is read. To read the ID Input lines the DTR line must be set low in software (asserted).



Figure AA-19. The SBI box showing Port 1 and Port 2.

The signal on a line selected is digitized to 12-bits and output on the serial line in two 8-bit bytes. The operation is called *word formatting*. The lower six bits of each 8-bit byte is the data sent in low-byte, high-byte order. The higher two bits of each 8-bit byte identifies the origin of the bytes—the Input Voltage line or the ID Input Line. Thus each data frame consists of four 8-bit bytes. Frames are sent continuously with no special indicator of the beginning or ending of

a frame.

Technical Details

The ADC in the SBI box is a Linear Technology LTC1290DCN, 12-bit switched-capacitor, successive approximation type with 8 inputs and an on-chip multiplexer. Only 4 of the 8 inputs are actually used here.

PLD

The actual serial word formatting (as described above) is performed by an AMD PALCE16V8H-25PC/4. The firmware was programmed by Vernier Software engineers.

Wiring

Each port on the box is equipped with a DIN-5 connector for connecting the sensors (Figure AA-20). All Vernier sensors terminate in a DIN-5.

Figure AA-20. The pinout looking into the socket on the SBI box.

For the Programmer

Communication

The values of the RS-232 parameters are fixed:

Baud rate: **2400** (Actual rate = 2327 bps)

Word Length: **8 bits**

Parity: **none**

Stop Bits: **2**

Transmit Data: Must transmit all 1's to power SBI

The data consists of 4-byte groups of the form:

```
(0) (don't care) D5  D4  D3 D2 D1 D0
(0) (don't care) D11 D10 D9 D8 D7 D6
(1) (don't care) D5  D4  D3 D2 D1 D0
(1) (don't care) D11 D10 D9 D8 D7 D6
```

A high-order bit of “0” means the byte originates from Port 1, if “1” then Port 2. The bytes from any one port are always sent in the low-byte, high-byte order. Thus the bytes are in groups of 4, but the order of the bytes read by the controlling computer depends on where in the “cycle of 4” reading began. Thus the ordering may be 2 bytes from Port 1, 2 bytes from Port 2, which

is the “desired order”. An undesired order would be 1 high-byte from Port 1, 2 bytes from Port 2, followed by 1 low-byte from Port 1 and so forth. Thus the bytes need to be tested as to their port of origin. One strategy of programming would be to “shift” bytes not in the desired order. Of course, this problem would exist in reading from the ID input lines as well as from the Input Voltage lines.¹⁵

The Vernier Software SBI box is now regarded by the company as a “legacy” product. It has for some years been superceded by their ULI board and a new product called LabPro which is designed to be used with a USB interface. You will not likely be using this box in this course.

National Instruments PCI-1200 DAQ Card

A PCI-1200 digital acquisition (DAQ) card is installed in all of the computers in the Physical Sciences lab. This card is a PCI device and is useable with any computer with a PCI slot.¹⁶ The card is complex and so a Quick Start will be directed by the instructor in Lab #4.

Why a DAQ Card?

A DAQ card encapsulates into one system box much of the functionality and control capabilities of a host of stand-alone instruments. A DAQ card can be used to measure a voltage much like a DMM and to generate an AC signal much like a signal generator. A DAQ card can be used to provide control signals for external switches and to monitor the state of external switches. And finally, a DAQ card can perform these functions more-or-less simultaneously.

General Description

The PCI-1200 DAQ card (pinout shown in Figure AA-21) is manufactured by National Instruments (NI), the company that markets LabVIEW. The card is configured by the software that NI supplies called *DAQ Channel Wizard*. With this program all card resources can be allocated or just a subset of them. The cards in all the computers have been preconfigured for this course.

The Lines

There are 50 lines. Reading from the top down there are 8 analog input lines (ACH0-ACH7), 2 12-bit digital-to-analog (DAC) output lines (DAC0OUT, DAC1OUT), 24 lines of TTL-compatible digital I/O (PA0-PA7, PB0-PB7, PC0-PC7), and 3 16-bit

counter/timer lines for timing I/O. These lines are made to terminate in a breakout box to assist the user in connecting the lines to external signal sources and sensors. In Lab #4 you will begin your study of the card with the analog input channels, so we begin our description here with them.

Instrumentation Amplifier

Each analog input channel is connected through an *instrumentation amplifier* (Figure AA-22). An instrumentation amplifier is essentially an opamp (described in Chapter 2) with non-inverting (+) and inverting (-) inputs. The amplifier applies a selectable gain, common-mode voltage rejection, and high input impedance to the analog input signals. (A common mode voltage is an undesirable electrical noise that appears in equal measure at both inputs.) Signals are routed to the (+) and (-) inputs of the amplifier through input multiplexers. The amplifier converts the two input signals to a signal equal to the difference between the two input signals multiplied by the amplifier’s gain setting. The amplifier output voltage is referenced to the PCI-1200 ground. The PCI-1200 ADC measures the output voltage by performing an analogue-to-digital (A/D) conversion. How the inputs are wired is determined by the *mode* selected (more on this below).

| | | | |
|---------------|----|----|----------|
| ACH0 | 1 | 2 | ACH1 |
| ACH2 | 3 | 4 | ACH3 |
| ACH4 | 5 | 6 | ACH5 |
| ACH6 | 7 | 8 | ACH7 |
| AISENSE/AIGND | 9 | 10 | DAC0OUT |
| AGND | 11 | 12 | DAC1OUT |
| DGND | 13 | 14 | PA0 |
| PA1 | 15 | 16 | PA2 |
| PA3 | 17 | 18 | PA4 |
| PA5 | 19 | 20 | PA6 |
| PA7 | 21 | 22 | PB0 |
| PB1 | 23 | 24 | PB2 |
| PB3 | 25 | 26 | PB4 |
| PB5 | 27 | 28 | PB6 |
| PB7 | 29 | 30 | PC0 |
| PC1 | 31 | 32 | PC2 |
| PC3 | 33 | 34 | PC4 |
| PC5 | 35 | 36 | PC6 |
| PC7 | 37 | 38 | EXTTRIG |
| EXTUPDATE* | 39 | 40 | EXTCONV* |
| OUTB0 | 41 | 42 | GATB0 |
| OUTB1 | 43 | 44 | GATB1 |
| CLKB1 | 45 | 46 | OUTB2 |
| GATB2 | 47 | 48 | CLKB2 |
| +5 V | 49 | 50 | DGND |

Figure AA-21. Pinout of the PCI-1200 DAQ card connector.

Selected Specifications for Analog Input

Number of channels: 8 single-ended, 8 pseudodifferential or 4 differential, software selectable

Type of ADC: Successive approximation

Resolution: 12 bits, 1 in 4096

Max sampling rate: 100 kS/s

Input coupling: DC

Overtoltage protection: $\pm 35V$ power on
 $\pm 25V$ power off

Input Impedance

Normal power on: 100G in parallel with 50pF

Power off: 4.7 k min

Input bias current: ± 100 pA

Types of Signal Source

Signal sources are described as being of two types: *floating* and *ground-referenced*.

Floating Signal Source

A floating signal source is one that is not connected in any way to the building ground system but has an

isolated ground-reference point. Some examples of floating signal sources are chemical cells, the outputs of transformers and thermocouples. The ground reference of a floating signal source should be tied to AIGND to establish a local or onboard reference for the signal.

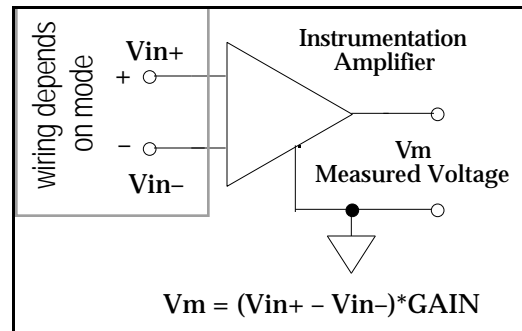


Figure AA-22. Each of the 8 signals appearing at the 8 analog input channels passes through a multiplexer and then into an opamp instrumentation amplifier.

Ground-Referenced Signal Source

A ground-referenced signal source is one that is connected in some way to the building system ground and is therefore already connected to a common ground point with respect to the PCI-1200, assuming that the computer is plugged into the same power system. Examples of this kind of source are nonisolated (single-ended) outputs of instruments and devices that plug into the building power system, i.e., outputs of simple power supplies and signal generators (literally any instrument with a BNC coaxial output connector).

Analog Input Channels

The 8 input lines (or channels) can be configured as 8 single-ended inputs or as 4 differential inputs according to the input *mode* selected. There are 3 analog input modes called *RSE Input*, *NRSE Input* and *Diff Input*. We spend a few moments describing each.

1 RSE Input (Eight Channels, Reset Conditions)

RSE stands for Referenced Single Ended. RSE input should be used if the source of your signal is floating with respect to ground. RSE means that all input signals are referenced to a common ground point that is tied to the analog input ground (AIGND). The differential amplifier (-) input is also tied to analog ground.

With this configuration, the PCI-1200 can monitor 8 different analog input channels via multiplexing. In this mode the signal return path is analog ground at the connector through the AISENSE/AIGND pin (Figure AA-23).

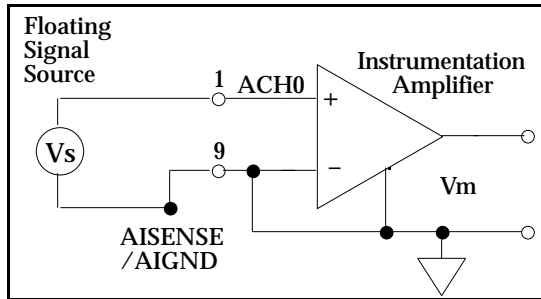


Figure AA-23. How to use the RSE input mode to measure the voltage of a source that is floating wrt ground.

2 NRSE Input (Eight Channels)

NRSE stands for Non-Referenced Single Ended. NRSE mode should be used when the source whose voltage is to be measured has one side grounded. NRSE means that all input signals are referenced to the same common mode voltage, which floats with respect to the PCI-1200 analog ground. This common mode voltage is subsequently subtracted by the input instrumentation amplifier. In this mode the signal return path is through the (-) terminal of the amplifier at the connector through the AISENSE/ AIGND pin (Figure AA-24).

3 Diff Input (Four Channels)

Diff input means that each input signal has its own reference. It is the difference between each signal and its reference that is measured. The signal and its reference are each assigned an input channel. In this mode, the PCI-1200 can monitor 4 differential analog input signals via multiplexing. The signal return path is through the amplifier's (-) terminal and through ACH1, ACH3, ACH5 or ACH7, depending on which channel pair is selected (Figure AA-25).

This mode is recommended when any of the following apply:

- Input signals are low level (less than 1 V)
- Leads connecting the signals to the PCI-1200 are greater than 10 ft in length

- Any of the input signals require a separate ground-reference point or return signal
- The signal leads travel through noisy environments

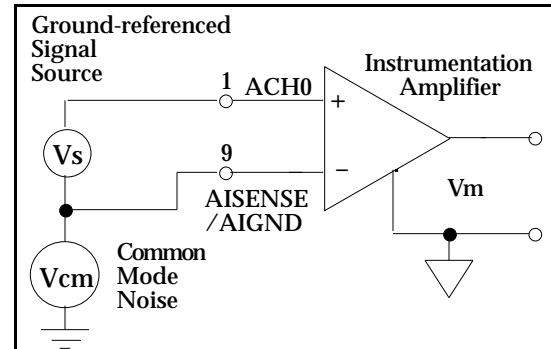


Figure AA-24. How to use the NRSE input mode to measure the voltage of a source that has one side grounded.

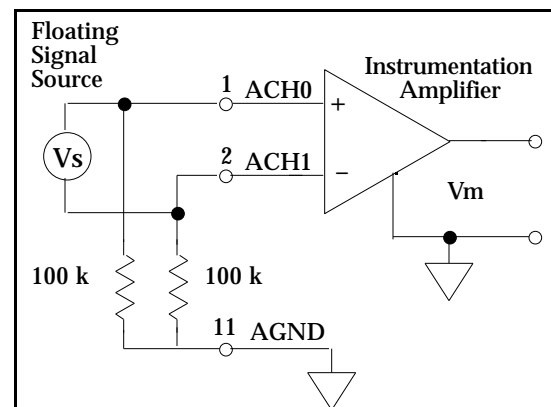


Figure AA-25. How to use the Diff input mode to measure the voltage of a source that is floating wrt ground.

Differential signal connections reduce picked up noise and increase common-mode signal and noise rejection. With these connections, input signals can float within the common-mode limits of the input instrumentation amplifier. We have chosen to have you use this mode in all analog input measurements you make in this course.

On the Issue of Gain

Even if a sensor has a signal conditioning circuit, the signal applied to an analog input line of a DAQ card can vary over the range of millivolts to volts. Though most of the time you will want a gain setting of only 1, there will be times when you want to amplify the

signal to take full advantage of the 12-bit resolution of the card. Gain settings for bipolar and unipolar operation are listed in Tables AA-11. Minimum and maximum values can be set with the control limits. Setting the control limits automatically selects the gain. There will be more on this subject in Lab #4.

Table AA-11a. Bipolar Analog Input Signal Range Versus Gain

| Gain Setting | Input Signal Range |
|--------------|--------------------|
| 1 | -5.0 to 4.99756 V |
| 2 | -2.5 to 2.49878 V |
| 5 | -1.0 to 0.99951 V |
| 10 | -500 to 499.756 mV |
| 20 | -250 to 249.877 mV |
| 50 | -100 to 99.951 mV |
| 100 | -50 to 49.975 mV |

Table AA-11b. Unipolar Analog Input Signal Range Versus Gain

| Gain Setting | Input Signal Range |
|--------------|--------------------|
| 1 | 0 to 9.99756 V |
| 2 | 0 to 4.99878 V |
| 5 | 0 to 1.99951 V |
| 10 | 0 to 999.756 mV |
| 20 | 0 to 499.877 mV |
| 50 | 0 to 199.951 mV |
| 100 | 0 to 99.975 mV |

Analog Output Signal Connections

The use of the analogue output lines of a DAQ card are arguably of less importance than the analogue input lines. To give some examples, analogue outputs might be used to provide the retarding voltage in a photoelectric effect experiment or an analogue waveform (such as a sine wave).

Pins 10 through 12 on the I/O connector are analog output signal pins. Pins 10 and 12 are the DAC0OUT and DAC1OUT signal pins. DAC0OUT is the voltage output signal for analog output channel 0. DAC1OUT is the voltage output signal for analog output channel 1. Pin 11, AGND, is the ground-reference point for both analog output channels and analog input channels.

The following output ranges are available:

| | |
|-----------------------|----------------------------|
| Bipolar output: | ±5 V |
| Unipolar output: | 0 to 10 V |
| Maximum load current: | ±2 mA for 12-bit linearity |
| Output coupling: | DC |
| Output impedance: | 0.2 typ |
| Current drive: | ±2 mA |
| Power on state: | 0V |

Digital I/O

The digital I/O of a DAQ card is used almost exclusively in aspects of control. A digital input line might be used to monitor the state of a switch, whether it is open or closed. A digital output line might be used to trigger the state of a switch (AC or DC) and thereby control a high-power device like a heater or motor.

Pins 13 through 37 of the I/O connector are digital I/O signal pins. Digital I/O on the PCI-1200 uses the 82C55A IC. The 82C55A is a general purpose peripheral interface containing 24 program-mable I/O pins. These pins represent the three 8-bit ports (PA, PB, and PC) of the 82C55A.

Pins 14 through 21 are connected to the digital lines PA<7..0> for digital I/O port A. Pins 22 through 29 are connected to the digital lines PB<7..0> for digital I/O port B. Pins 30 through 37 are connected to the digital lines PC<7..0> for digital I/O port C. Pin 13, DGND, is the digital ground pin for all three digital I/O ports.

Selected Specifications for Digital I/O

| | |
|-----------------------|--|
| Number of channels: | 24 I/O (three 8-bit ports, uses 82C55A PPI) |
| Compatibility: | TTL |
| Digital logic levels: | -0.3V Input Low < 0.8 V 2.2 V Input high < 5.3 V Output Low < 0.4 V ÷ 4 V < Output high |
| Protection: | -0.5 to 5.5 V power on ± 0.5 V power off |

Power Connections

Pin 49 of the I/O connector supplies +5V from the computer's power supply via a self-resetting fuse. The fuse will reset automatically within a few seconds after the overcurrent condition is removed. Pin 49 is referenced to DGND and the +5V can be used to

power external digital circuitry or low power sensors.

Power rating: 1A at +4.75 to +5.25 V

This concludes our description of the PCI-1200 DAQ card. The four major functions of the card, analogue I/O and digital I/O are explored in Lab #4.

Practice Problems

1. The Radio Shack DMM and Agilent 34401A DMM are both used to measure the voltage of the same chemical cell. The results are as follows:

Show by means of uncertainty calculations that the measurements of these two devices agree to within the experimental uncertainties—or they do not.

2. You are given the following instruments: an RS DMM, TekTDS210 DSO, DAQ board. Explain in one paragraph how you would use these instruments to measure the output from (i) a chemical cell, and (ii) a K-type thermocouple.

EndNotes for Appendix A

¹ The industry is changing rapidly in regard to the interfaces supported. It is anticipated that very soon the standard serial and GPIB interfaces will be replaced by universal serial bus (USB) and IEEE-1394 or “Fire Wire” interfaces. At present the parallel (printer) port on Windows PCs is often used with lower-end or “hobbyist” data collection devices. These printer port devices are long obsolete and will soon disappear.

² The Tek oscilloscope does not support external control over all values of the RS-232 parameters. These are most reliably set manually from the front panel of the instrument before an attempt is made to access the instrument remotely.

³ This material was adapted from the document “SCPI Technical Backgrounder” on the SCPI consortium website: <http://www.scpiconsortium.org/aboutscpi.htm>.

⁴ Some of these legacy languages are still supported, for example, “Agilent 3478A” and “Fluke 8840”. They are long obsolete and are expected to soon disappear.

⁵ If a Macintosh high speed modem cable is used, the RTS line (pin 4 on a DB-25) must be disconnected or else the DMM will not send. This has the electrical effect of “unasserting” the RTS line (See next note). All of the DB-25 Mac cables in the physics lab have been modified in this way.

⁶ Unaccountably, the LabVIEW 5.1 VISA VIs do not support control over the modem RTS and DTR lines on a Macintosh. If an attempt is made to control the lines via a VISA attribute node, an error message is generated.

⁷ This fact is not documented by Radio Shack or by Metex Corporation, the OEM of the instrument.

⁸ Agilent Technologies is a subsidiary of the Hewlett-Packard Company. For more information on Agilent and Hewlett-Packard products log onto the Hewlett-Packard website, www.hp.com.

⁹ Telulex was acquired by Berkeley Nucleonics Corp (BNC). You can obtain more information from the BNC website: www.berkeleynucleonics.com.

¹⁰ These oscilloscopes were purchased in 1997, the year they first came on the market.

¹¹ These extension modules are the TDS2HM Hard Copy Module, the TDS2CM Communications Module and the TDS2MM Measurement Module. The TDS2CM Module also provides the functionality of the TDS2HM Module.

¹² In fact both ports can in principle be used alternately by one or two computers (see Lab #3). Both ports cannot be accessed simultaneously. Attempts to do this have failed.

¹³ Tektronix claims a maximum baud rate of 19200. However, attempts by the author to communicate at this rate have failed (except for reception of instrument ID). In spite of Tek’s claim the maximum, reliable, baud rate appears to be 9600.

¹⁴ These commands and queries were selected from the Tektronix TDS2xx-series Two Channel Digital Oscilloscope Programmers Manual 070-9576-02.

¹⁵ Another problem exists in using LabVIEW VISA functions with the SBI box on the Macintosh. The VISA functions in LabVIEW 5.1 do not support manipulation of the handshake lines. An attempt to assert the DTR line returns an error (see note 7).

¹⁶ This description is drawn from the National Instruments PCI-1200 User Manual and the Data Acquisition Basics Manual. Both manuals are available in the physics lab for short-term borrowing.