LAB 1: INTRODUCTION TO LAB INSTRUMENTS

Objective

To become familiar with the instruments and software that will be used in the Mechatronics Lab.

Prelab Assignment

1. Go to the ME588 web site (under the heading labeled "Lab Resources") and review the lab instrument manuals.

Introduction

There are eight stations in the Mechatronics Laboratory. Each station is equipped with the following instruments:

- DELL PC running Windows 7 Professional
- HP/AGILENT/KEYSIGHT E3631A Triple Output DC Power Supply
- HP/AGILENT/KEYSIGHT 33120A 15 MHz Function Generator
- HP/AGILENT/KEYSIGHT 34401A Digital Multimeter
- AGILENT/KEYSIGHT DSO1012A 100 MHz Oscilloscope
- BITSCOPE DSO Logic Analyzer

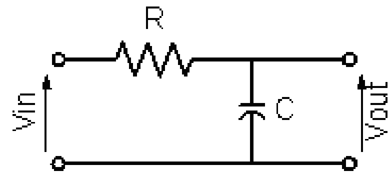
The HP/AGILENT/KEYSIGHT instruments provide powerful tools for the testing and measurement of analog and digital circuits. All the instruments are equipped with a GPIB interface, which is used for communication between the computer and the instruments (using the IntuiLink, BenchLink software or LabView with proper drivers). Proficient use of these instruments will be extremely beneficial during the later part of the course and your entire engineering career. Although this lab may not be as glamorous as some of the other labs, you are strongly advised to be patient and go through the procedures. You are also advised to make good use of the user manuals (see the course website). Refer to them as often as needed.

Procedure

1. Learn about the hardware available in the lab
   (a) Familiarize yourself with the HP/AGILENT/KEYSIGHT E3631A Triple Output DC Power Supply using Appendix A
   (b) Familiarize yourself with the HP/AGILENT/KEYSIGHT 33120A 15 MHz Function Generator using Appendix B
   (c) Familiarize yourself with the HP/AGILENT/KEYSIGHT 34401A Digital Multimeter using Appendix C
   (d) Familiarize yourself with the AGILENT/KEYSIGHT DSO1012A 100 MHz Oscilloscope using Appendix D
   (e) Familiarize yourself with the BITSCOPE DSO Logic Analyzer using Appendix E
   (f) Familiarize yourself with available software packages using Appendix F
2. Measuring the Characteristics of a Passive Low-Pass Filter

   In this part of the Lab, you are asked to build a simple RC low-pass circuit on the prototyping board and measure the characteristics of the filter using the instruments and software packages described above. The description of the procedures is intentionally brief. You are asked to think through what you are trying to measure (monitor) and design the proper excitation input signals to the circuit so that you can measure the output and obtain the information that you are seeking.

(a) On the prototyping board build the following RC circuit:



(b) Select a resistor with a resistance value, R, between 10 kΩ and 100 kΩ. Also select a capacitor with a capacitance value, C, between 1 μF and 10 μF.

(c) Measure the resistance value, R, using the multimeter and Intuilink software. Take ten or more measurements and obtain some statistical characteristics of the precision and accuracy of your measurement.

(d) Write down the first order differential equation that relates the input voltage, V_{in}, and the output voltage, V_{out}. Identify the time constant, τ, for this first order ODE and write down its value based on the resistance and capacitance that you used (don't forget about the units). Write down the bandwidth (cut-off) frequency, based on the -3 dB definition, of the low-pass filter that you built.

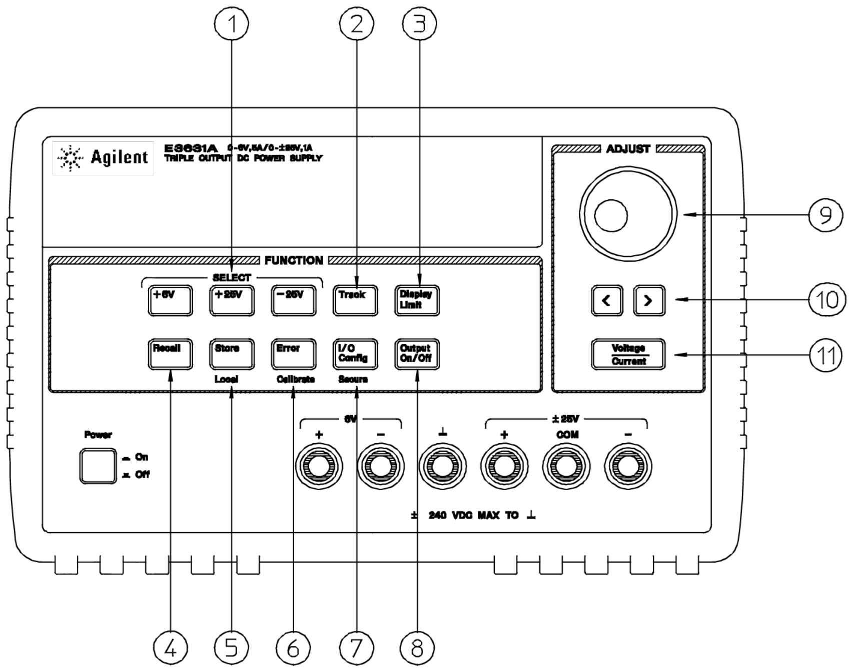
(e) Measure the rise-time and the 5% settling time of the step response of the RC circuit. What input signal(s) did you use? Compare the theoretical time constant value with the measured time constant value. Do they match? If not, how would you account for the discrepancy? Use the oscilloscope and associated software to find and record all values. Be sure to include a plot of input and output signals.

(f) At the bandwidth (cut-off) frequency, measure the relative phase difference and magnitude ratio between the input and output sinusoidal signals at that frequency. What input signal(s) did you use? Compare the theoretical cut-off frequency, magnitude ratio, and phase difference with the measured values. Do they match? If not, how would you account for the discrepancy? Use the oscilloscope and associated software to find and record all values. Be sure to include a plot of input and output signals.

(g) Use the FFT option on your oscilloscope to examine the frequency spectrum of both the input and output signals from part (f).

Appendix A HP/AGILENT/KEYSIGHT 3631A Triple Output Power Supply

The HP/AGILENT/KEYSIGHT 3631A has three power supplies: a +6 V supply capable of delivering 5 A, and a +25 V supplies capable of delivering 1 A and a -25 V supply capable of delivering 1 A. The (ground) output is the reference ground and is connected to the ground of the building. This is why it is important to connect the COM (common) terminal of the +25 V supplies, and the (-) terminal of the +6 V supply to the (ground) reference. Figure 1 shows the front panel of the 3631A power supply.



1 Meter and adjust selection keys
2 Tracking enable/disable key
3 Display limit key
4 Recall operating state key
5 Store operating state/Local key
6 Error/Calibrate key
7 I/O Configuration / Secure key
8 Output On/Off key
9 Control knob
10 Resolution selection keys
11 Voltage/current adjust selection key

Figure 1: Front Panel of the HP/AGILENT/KEYSIGHT 3631A Power Supply

To operate the power supply:

1. The OUTPUT ON/OFF key turns the output ON or OFF.
2. To Set the Output Voltage:
   (a) Press the +6 V, +25 V, -25 V keys to select the power supply to be set.
   (b) Press the VOLTAGE/CURRENT key so that the Volt Display is active.
   (c) Use the circular control knob to set the output voltage. Use the arrow keys for selecting the resolution.
3. To Set the Maximum Output Current:
   (a) The DISPLAY LIMIT key lets you select the maximum current that the power supply can deliver (up to 5 A for the 6 V and 1 A for the ±25 V supplies). This is a current protection feature.

   (b) Press the VOLTAGE/CURRENT key so that the Current Display is active.
   (c) Use the circular control knob and the resolution keys to set this limit (if needed).

4. To Read the Output Voltage or Output Current:
   (a) The VOLTAGE/CURRENT key also shows the output voltage and the output current of the power supply.
   (b) To measure the output current of the supply, make sure that the DISPLAY LIMIT key is not active

Appendix B HP/AGILENT/KEYSIGHT 33120A Function Generator

The HP/AGILENT/KEYSIGHT 33120A generates a whole range of waveforms with precise control on the frequency amplitude, waveform shape, offset voltage, etc. Figure 2 shows the front panel of the HP/AGILENT/KEYSIGHT 33120A function generator.

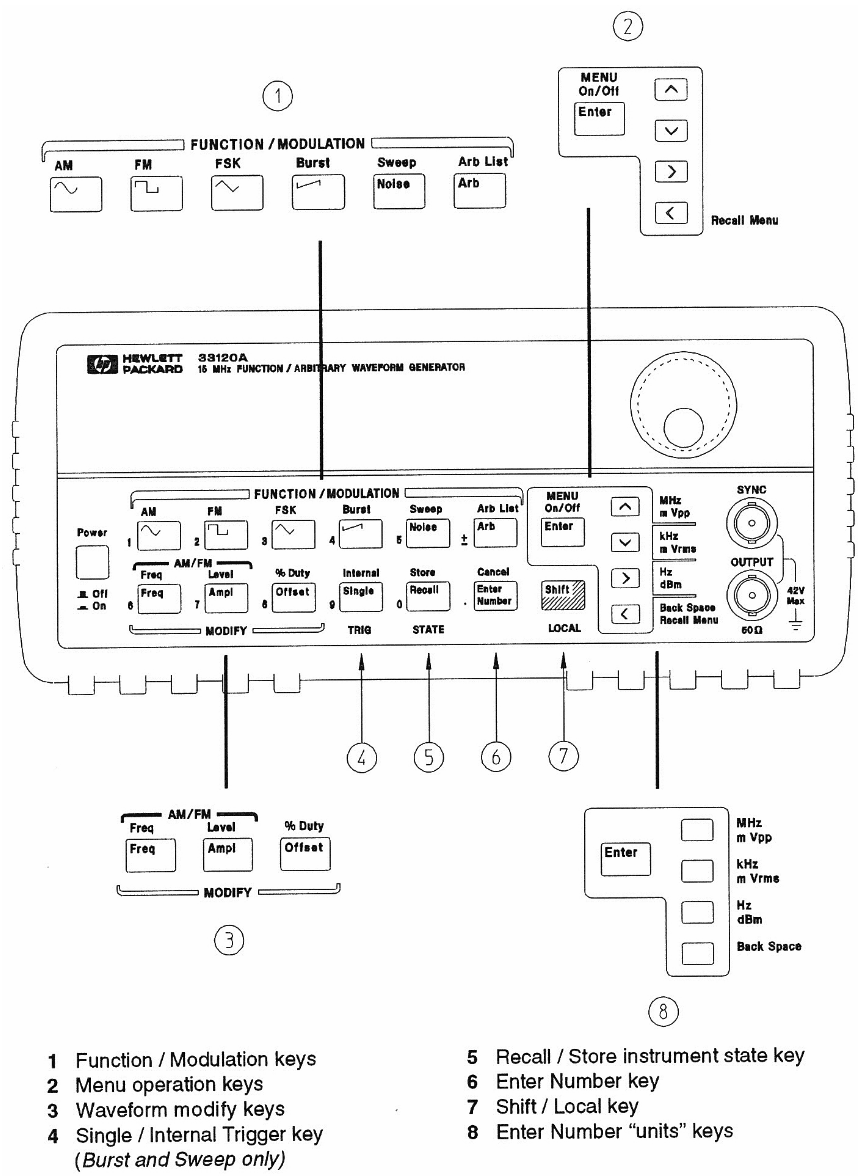


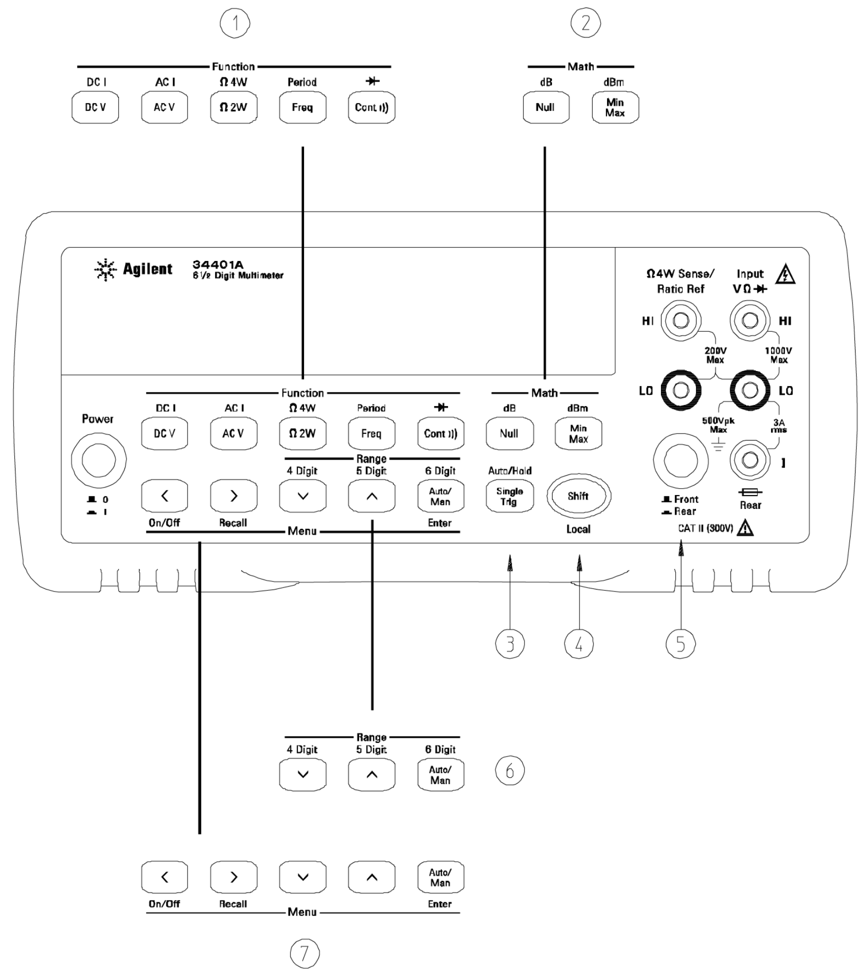
Figure 2: Front Panel of the HP/AGILENT/KEYSIGHT 33120A Function Generator

> *IMPORTANT*: The firmware inside the HP/AGILENT/KEYSIGHT 33120A assumes that you have placed a 50 Ω load across its output, in accordance with good RF engineering practice. It then calculates the output voltage by dividing its internal open- circuit voltage by two, and displays the answer. If the circuit that you connect to the output of the HP/AGILENT/KEYSIGHT 33120A does NOT have an equivalent Thevenin impedance of 50 Ω, then the voltage displayed will be inaccurate. For a high impedance load, you can set the display to "HI-Z", and the function generator will display the correct number. Do this by hitting:
> (Blue shift + MENU)
> right arrow to SYS MENU
> down arrow to OUT TERM
> The right/left arrows or the knob now toggle you between "50 Ω" and "HIGH Z". Set it to "HIGH Z" and hit enter. The display will now indicate the front panel voltage for a high impedance load.

1. The AC waveform keys select the type of function: sine wave, square wave, triangular wave or saw tooth wave,
2. The [Freq] key sets the frequency of the function.
   - The sine and square waves can be set from 0.1 mHz to 15 MHz.
   - The triangular and saw tooth waves can be set from 0.1 mHz to 100 kHz.
3. The [Ampl] key sets the amplitude of the function.
   - The amplitude can be set from 100 mVppk to 20 Vppk into an open circuit (50 mVppk to 10 Vppk into a 50 Ω load).
4. The [OFFSET] key allows you to add a DC offset voltage to the function.
   - Normally, the offset is set to zero volts and the AC waveform has an average value of zero. However, in some cases, it is good to offset the AC waveform to simulate DC and AC inputs to a circuit.
   - You can also choose a positive or negative offset using the green [±] key in the numerical entry.
5. The [Shift] [% Duty] key allows you to set the duty cycle of a square waveform only.

Appendix C HP/AGILENT/KEYSIGHT 34401A Digital Multimeter

The HP/AGILENT/KEYSIGHT 34401A is a high precision, $6\frac{1}{2}$ digit multimeter, capable of measuring voltage, current, resistance, frequency, time, etc. for DC and AC signals. Throughout the lab experiments, we will only use a small portion of its capabilities, but you are encouraged to learn all that you can about it. Figure 3 shows the front panel of an HP/AGILENT/KEYSIGHT 34401A multimeter.



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

Figure 3: Front Panel of the HP/AGILENT/KEYSIGHT 34401A Multimeter

1. Measuring Voltages:

   Voltages are measured in parallel with a circuit. The DC V (or the AC V) key should be selected. Figure 4 shows an example of how to measure the voltage at a point VB (VB is positive). Figure 5 shows how to measure the voltage across a component, VBC (VBC is positive).

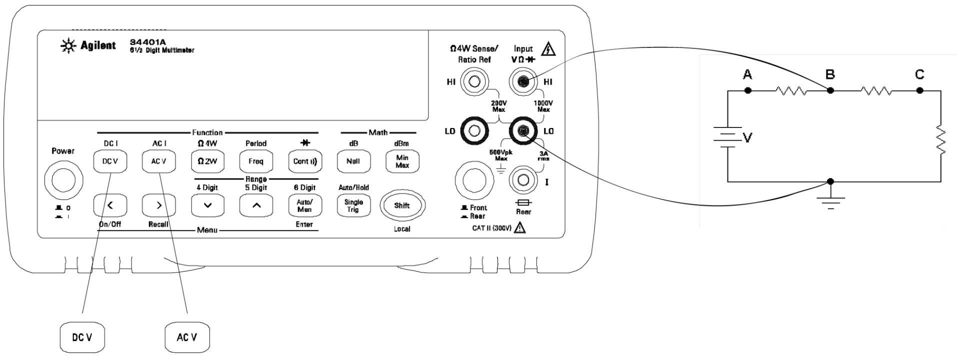


Figure 4: Measurement of Voltage VB

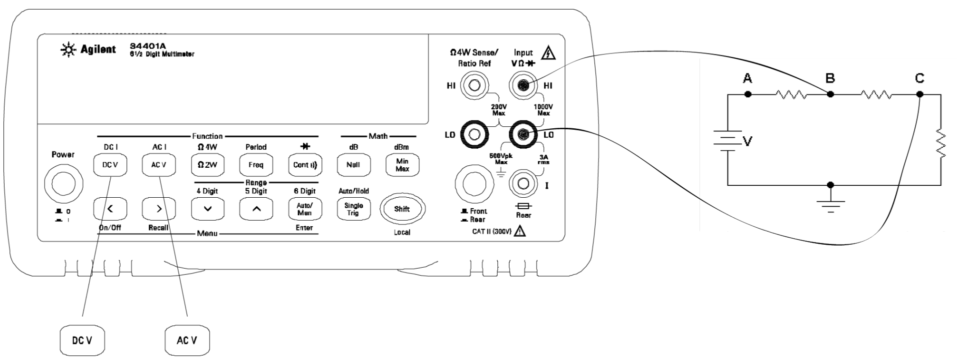


Figure 5: Measurement of Voltage VBC

The input resistance of the voltmeter is 10 MΩ. This means that it will not load the circuit and result in a large measurement error if the resistance is 300 kΩ or smaller.

2. Measuring Currents:

   Currents are measured in series with a circuit. Basically, the current passes by the multimeter so that it can be measured. The DC V or AC V keys should be selected using the blue Shift key. Figure 6 shows an example shows how of to measure I (I is positive).

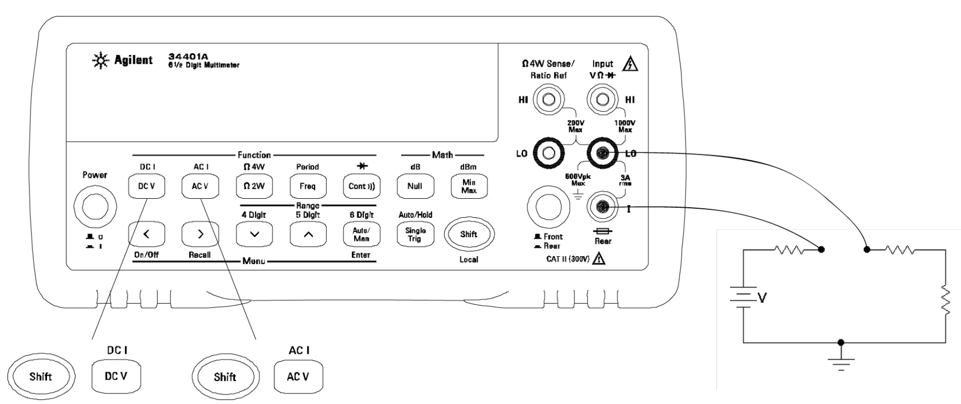


Figure 6: Measurement of Current

The input resistance of the ammeter is 0.1 Ω for the 1 A and 3 A ranges, and 5 Ω for the 10 mA and 100 mA ranges. This means that it will not load the circuit and result in a large measurement even for most resistance values (100 kΩ to 2 Ω). In order to measure a current, you need to break the circuit and re-route it through the multimeter. This is not possible in finished I.C. boards and is the main reason why technicians/engineers mostly measure voltages and calculate I using $V = IR$.

3. Measuring Resistances:

   In order to measure a resistance, the multimeter imposes a small voltage (mV level) on the resistor and measures the resulting current. The resistance is then $R = V/I$. Two wire (2W) resistance measurements are easy: Connect the resistor as shown below and press the Ω 2W key.

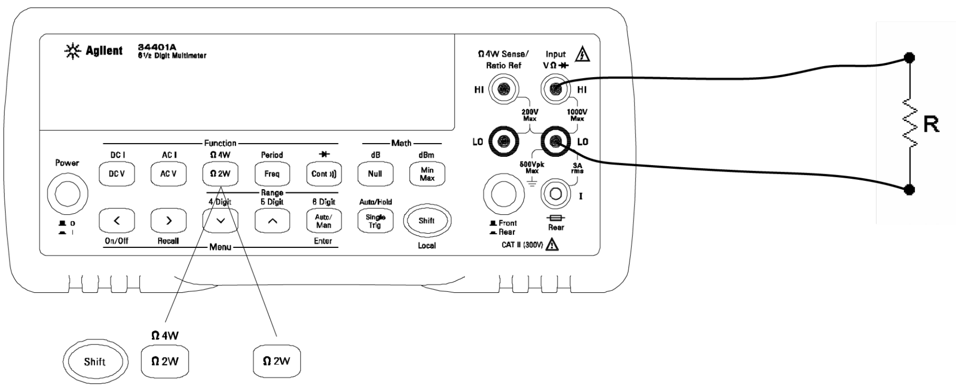


Figure 7: Measurement of Resistance

4. Measuring AC Signals:

   The multimeter can also measure the RMS values of AC waveforms (voltage or current, depending on the connection). The AC waveform can be a sine-wave, square-wave, triangular, or anything, since the multimeter only measures its RMS value (root mean square). The multimeter will also determine its frequency (Freq) and its period (Shift, Freq). The RMS voltages measurement is accurate up to 300 kHz, and the RMS current measurement is accurate to 5 kHz. The frequency and period are accurate up to 300 kHz but can go to 1 MHz with ¿600 mVppk.

5. Measuring Continuity (Cont):

   Many times, it is necessary to check if a node is connected to another node (via a short-circuit). For example, you may want to follow a ground node in a complicated circuit. You can connect the two nodes to the (V, Ω) and (LO) inputs (just like voltage or resistance measurements) and the multimeter will beep if there is a short circuit.

6. Setting the Resolution:
   The resolution keys are set using the Range/Digit area. You can select 4, 5, 6 resolution digits, or simply Auto (for automatic selection).

7. Single/Auto/Hold Measurements:
   In noisy or time-varying measurements, the display is constantly changing and it may be helpful to take a single measurement or hold a measurement until it is deleted. This key does the job. Use the Auto setting to set the multimeter back into its normal operation.

Appendix D AGILENT/KEYSIGHT DSO1012A Oscilloscope

The AGILENT/KEYSIGHT DSO1012A Oscilloscope is useful. Figure 8 shows the front panel of the oscilloscope.

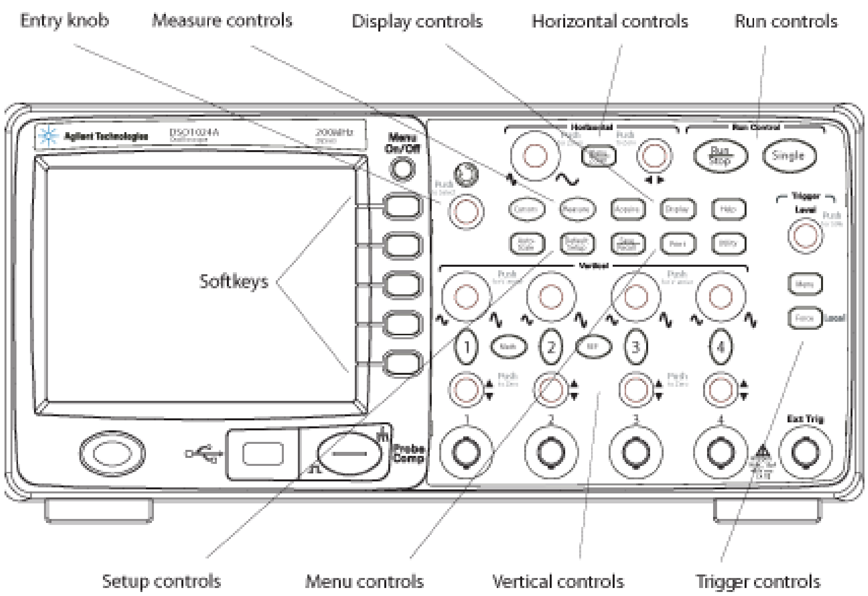


Figure 8: Front Panel of AGILENT/KEYSIGHT 54622D Mixed Signal Oscilloscope

D.1 Time Domain Measurements

1. The 1 and 2 keys turn on and off the display of the two analog channels.
2. The Auto-Scale key automatically scales the display to show the waveforms. Do not use this key too often. You can develop a very bad habit and never learn how to use a scope!
3. The Volts/Div knobs change the amplitude axis scaling for each channel.
   - You will find that you can easily “saturate” a scope and you should never do this.The waveform must always be within the display area.
   - The scale is shown at the upper left corner.
4. The Position knob moves the zero amplitude point of the waveform up and down.
5. The Time/Div knob changes the time axis scaling for both channels.
6. The Delay knob moves the zero time point of the waveform left and right.
7. Coupling and HF rejection can be configured on the channel menu by pressing 1 or 2.
8. The Coupling key selects the triggering coupling setting
   - AC coupling will not show the DC offset of the signal.
   - DC coupling will show the DC offset of the signal.
   - The LF Reject uses a 10 kHz cutoff.
9. The HF Reject key introduces low-pass filter with a cutoff frequency of 100 kHz to reject all noise above 100 kHz on the trigger path.

D.2 Triggering

The scope needs a signal to trigger its sampling circuitry. The triggering signal could be derived from the signal itself or from external or internal references.

1. The Menu key under the TRIGGER section opens the triggering options. The following will assume that the triggering options are shown on the right side of the screen.
2. The Mode button selects the triggering mode. We will use EDGE at all times.
3. The Source button selects the source of the triggering signal.
   - CH1 or CH2 will use the analog inputs for triggering.
   - EXT will use an external signal for triggering.
4. The Slope button selects the slope of the signal for triggering.
   - Rising edge triggers as the signal crosses the trigger value while increasing.
   - Falling edge triggers as the signal crosses the trigger value while decreasing.

D.3 Measurements

The Measure key can be used to measure various time and amplitude properties of the analog signals.

D.4 Cursors

The Cursors key can be used to place two amplitude and two time cursors on screen. These can be used to estimate measurements or compare the two analog signals.

D.5 FFT

The Math key can be used to perform math on the analog signals. The most frequently used of these options is FFT.

Appendix E BITSCOPE DSO Logic Analyzer

The DSO logic analyzer replaces mixed signal oscilloscopes with a cheap, compact unit. It is capable of analyzing up to 2 analog channels and 8 digital channels. The unit is entirely controlled by a desktop computer connected by LAN or cross-over cable.

E.1 Setup of the DSO Software

1. Open the 586 folder on the desktop. Run DSO.
2. Click SETUP on the right side.
3. Change the first connection to ETHERNET and enter the IP address from the top of the BitScope in the box to the right. Click Ok.
4. Click the POWER button to connect to the BitScope.
5. If the analog channels display a sawtooth wave, there is likely a configuration problem.

E.2 Analog Channels

1. The ALT key on the right side enables display of only analog channels.
2. The yellow CH A block and green CH B block contain options for the analog channels.
3. The ON keys enable and disable the analog channels.
4. The first number box above ON is the amplitude scaling.
   - Left Click the box to auto-scale.
   - Right click the box for a drop down menu of possible settings.
5. The second number box above ON is the input range.
   - Left Click the box to auto-scale.
   - Right click the box for a drop down menu of possible settings.
6. The number box reading 1:1 is for scope probes with gain settings.
   - Left Click the box to auto-scale.
   - Right click the box for a drop down menu of possible settings.

E.3 Digital Channels

1. The MIXED key on the right side to enables display of mixed analog and digital channels.

Appendix F IntuiLink Software Package

The power supply, function generator and digital multimeter are connected to the PC by an instrumentation bus called GPIB (General Purpose Instrumentation Bus). This connection between instruments is similar to the Ethernet connection found in computer networks. GPIB allows the instruments to exchange information between the GPIB controller and the test instruments. The bench instruments are connected to the PC through a GPIB controller card installed in the PC expansion slot.

The communication through GPIB is achieved through a set of GPIB commands that are available and documented in the user's guide of the instruments. The GPIB commands are standard and, like C or Pascal, completely independent of the type of computer. Use of GPIB also requires understanding of the commands and syntax. However, using software like Intuilink allows a PC user to control the instruments without understanding GPIB syntax. The Intuilink software communicates with the instruments using GPIB commands and almost all the functions of the instrument are available from the PC. Benchlink also allows the data transfer in spreadsheets or other image file formats. The acquired data can be plotted and charted as desired.

There are a number of software packages that can provide communication between a PC and HP/AGILENT/KEYSIGHT instruments when linked through either an GPIB or RS-232 interface. There are three packages installed on the workstation PC:

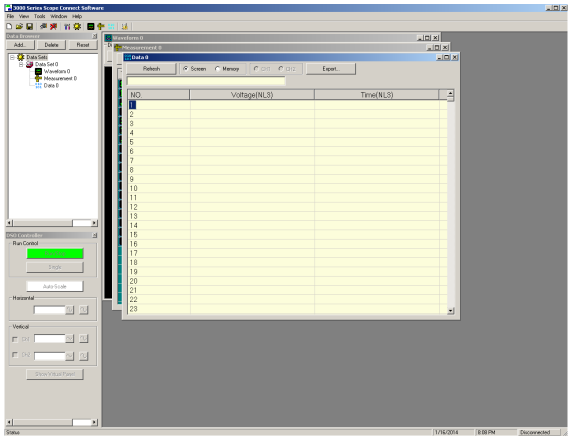
- 3000 Scope Series Connect Software - For communication between the PC and the DSO3102A scope
- AGILENT/KEYSIGHT DMM Connectivity Utility - For communication between the PC and the 34401A digital multi-meter
- Intuilink Waveform Editor - For communication between the PC and the 33120A function generator

F.1 3000 Scope Series Connect Software

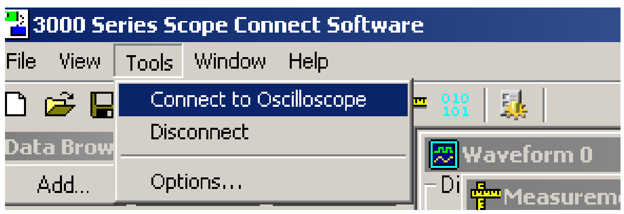
The 3000 Scope Series Connect Software can be used to load measured signal waveforms and data from the AGILENT/KEYSIGHT DSO3102A scope. Waveform data can be exported into an Excel document, or saved as a bitmap image file. This program will prove quite handy when you are trying to capture a scoped signal to put in your lab reports, or when you want to perform post-processing using either a spreadsheet or Matlab. Throughout the program, the data and image that is shown is based on what is currently on the scope display screen. Waveform data consists of time and amplitude information of a single channel on the oscilloscope.

The following procedure describes how to use the IntuiLink for Scope software to capture data from the scope screen and export it to an Excel document.

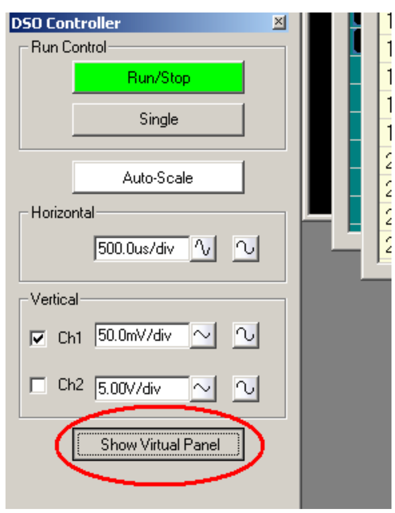
1. Turn on the function generator, scope and connect a coax cable from the output of the function generator to the scope.
2. To connect to the scope, first load the software. Find the DSO3000 icon on the desktop and double click it.
3. The software will now load with 3 windows; Data, Measurement, and Waveform (usually with Data on top):



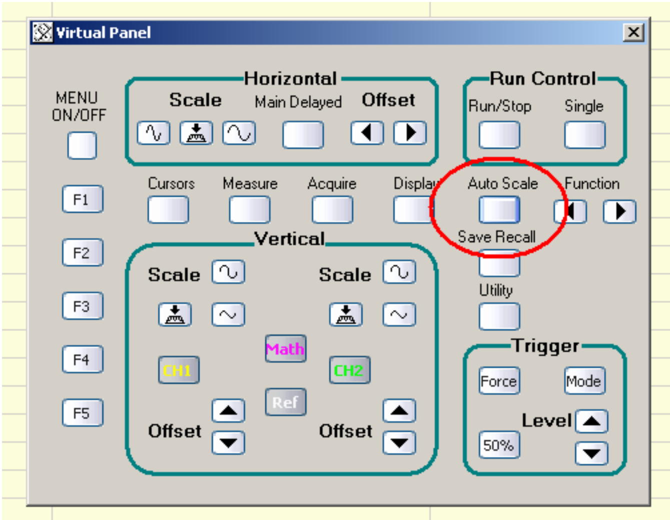
4. For now, let us connect to the scope by selecting Tools, and then Connect to Oscilloscope:



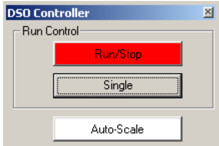
5. Your oscilloscope will now be connected to the application. **Important note**: Once connected, the oscilloscope locks all the physical buttons on the oscilloscope itself, and you will only be able to control the scope from the software! To regain access to the physical buttons, first disconnect the oscilloscope from the software, using Tools → Disconnect, and then press the Force (Local) button under Trigger on the oscilloscope itself.
6. You can now control all the features of your oscilloscope using the software.
7. Select the virtual panel by pressing the Show Virtual Panel Button:



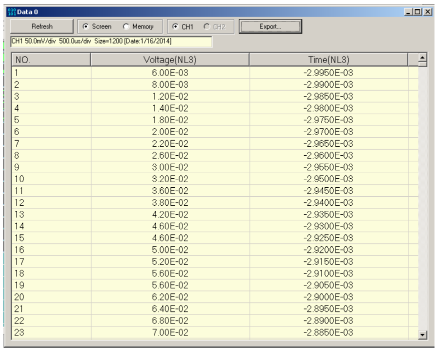
8. Press the Auto-Scale button to view the waveform. **Note**: The Auto-Scale function fails when recording slowly-changing waveforms, so one should familiarize oneself with manually adjusting the vertical and horizontal scales:

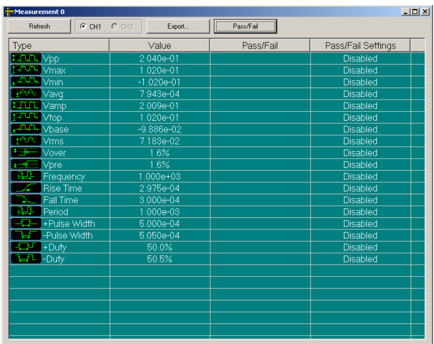


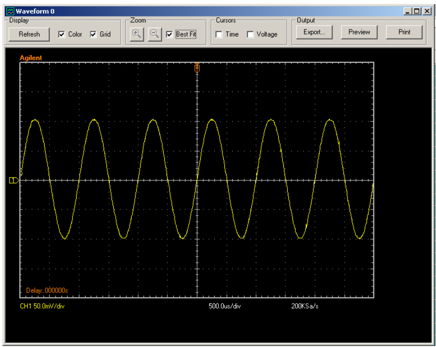
9. Take a single reading of the signal by pressing the Single Button:



10. Go through all the windows and hit Refresh to update the data. The windows should appear as such:







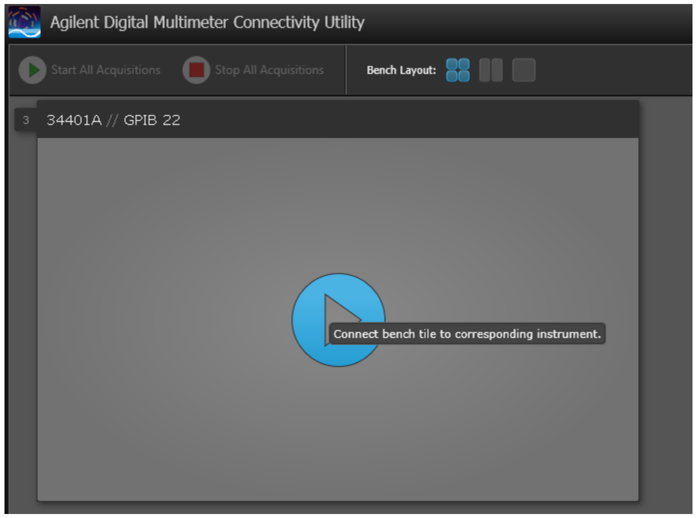
11. Each of these windows should have an export option, to either Excel or a bitmap file (BMP). Select the Data0 Window and press Export and save it to a desired location. **Note**: The Measurement and Data windows only display one channel at a time; a new window will need to be created for a second channel with the add new data or measurement button:

F.2 AGILENT/KEYSIGHT Digital Multimeter Connectivity Utility

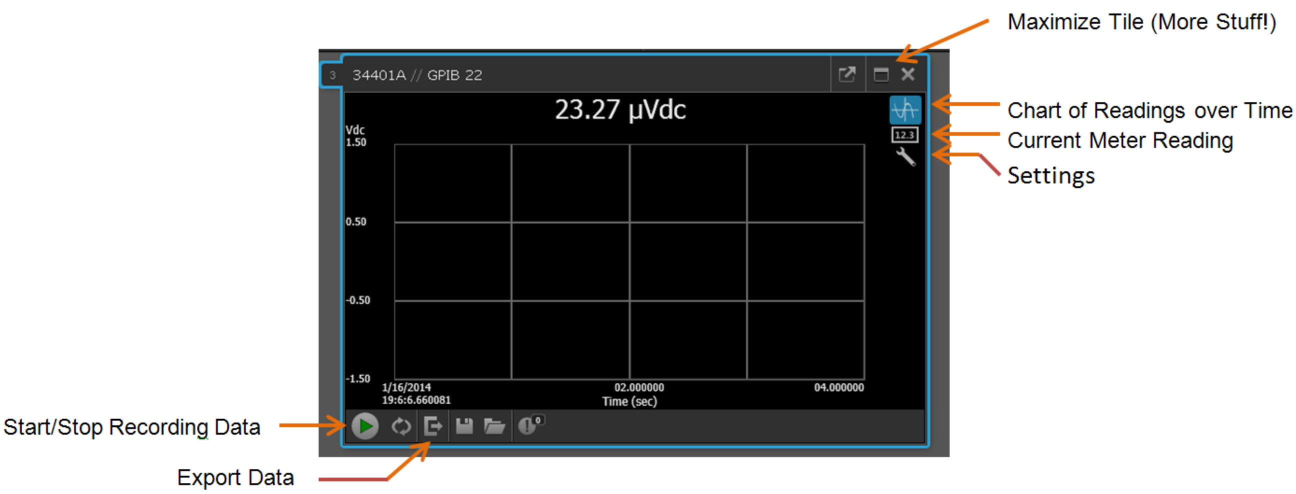
The Excel IntuiLink program combined with the 34401A DMM is a convenient data acquisition system with an adjustable sample rate. Using this software, one can record data and export it to Excel or Matlab. In the following example we will go through the steps of creating a simple test project using the DMM and Connectivity Utility.

1. To run the Connectivity Utility, find the Agilent DMM icon on the desktop and double click it.
2. The Utility will open and search through all the connected instruments for associated multimeters. When it has found the DMM, it will appropriately display the instrument in the bottom corner with a check mark next to it:

3. Connect to the instrument by clicking on the connect button from the main screen:



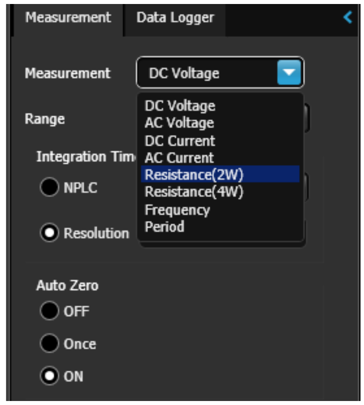
4. You will now be presented with a basic chart that–when recording–will display your multimeter reading over time:



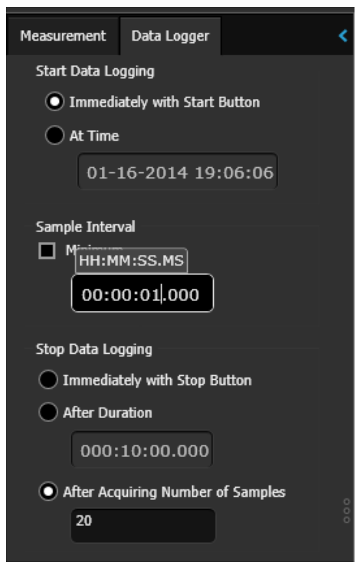
5. Scroll through all the different options and familiarize yourself with them.

6. If you maximize the tile, more options will be presented such as a Histogram and Table, while the settings will be moved from a different selection to the left half of the screen:

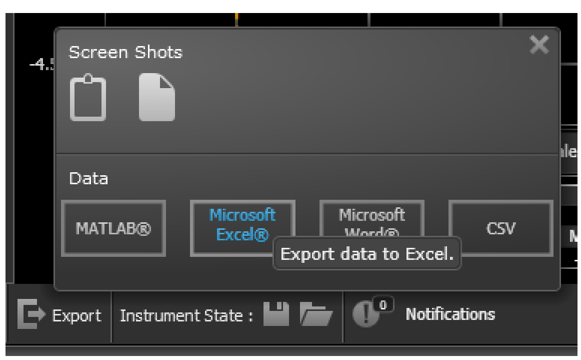
7. Under Measurement, select Resistance(2W):



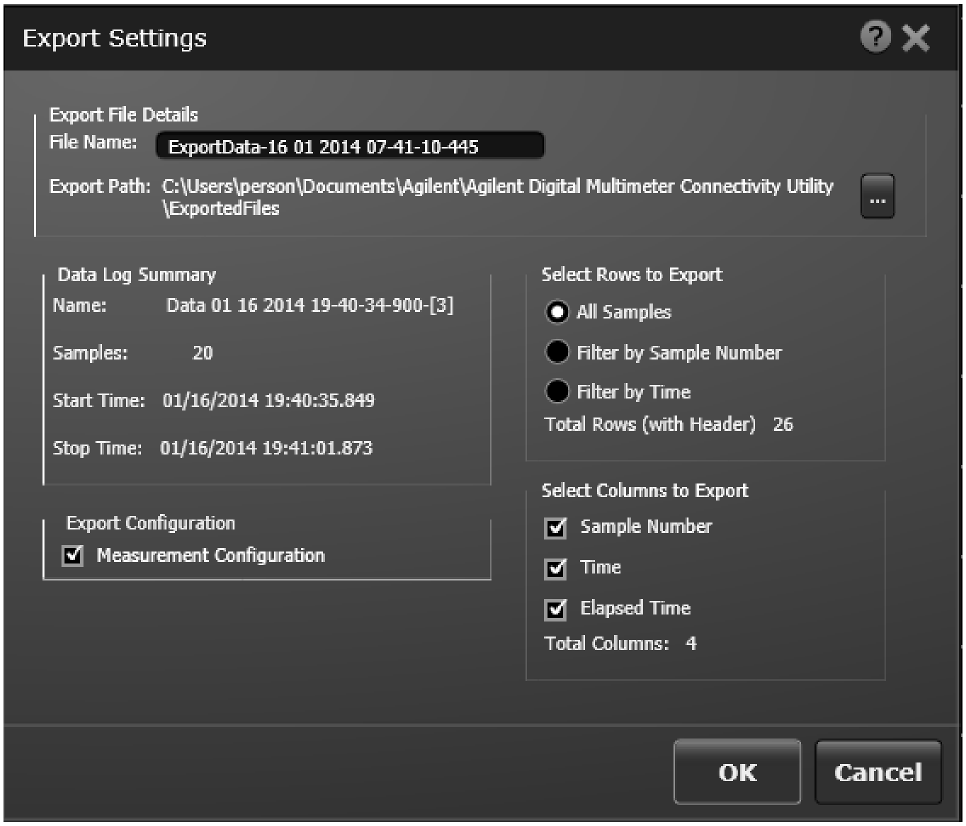
8. Select the Data Logger, uncheck Minimum under Sample Interval, select a sampling interval of 1 second, and then set the Utility to log 20 samples:



9. Hit the Start Button to begin recording your data.
10. Let us now export the data to Excel by clicking the export button and selecting Excel:



11. Select a file name and location, and hit OK to save the data:



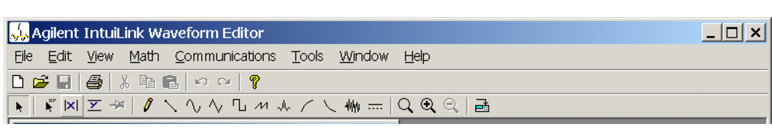
12. Your saved data file should automatically load and launch an Excel spreadsheet.

F.3 Intuilink Waveform Editor

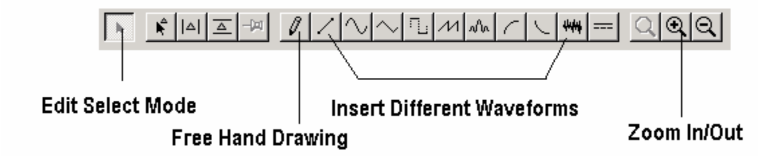
One of the most significant features of the Intuilink package is the ability to generate arbitrary waveform with the function generator. The User's Guide has more detailed description of the functionality of the software as well as trouble-shooting suggestions.

The following procedure will guide you to generate an arbitrary waveform of your choosing through the Benchlink and function generator combination:

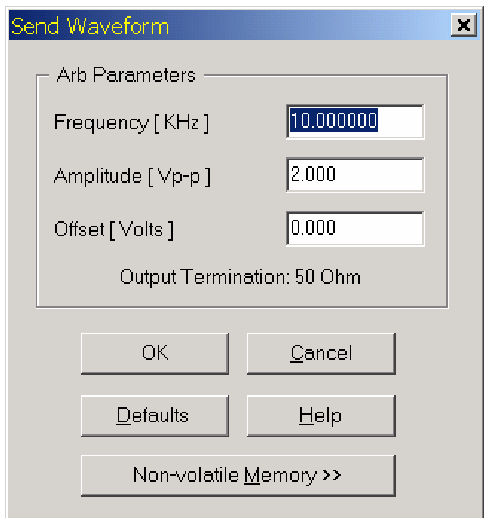
1. Turn on the function generator, scope and connect a coax cable from the output of the function generator to the scope.
2. Run the Waveform Editor program using one of the following two methods:
   - Choose Start — Programs — AGILENT Intuilink — Waveform Generator — Waveform Editor
   - Open 586 folder on desktop — Waveform Editor
3. As the program opens up it will search for the function generator and it will open with the drawing screen as shown below:



4. With the mouse, choose the drawing palette (pencil icon). This allows you to draw on the screen. Start drawing on the screen and feel free to use different icons.
5. Choosing the pointer icon and tracing it back allows you to erase the waveforms that are drawn on the screen. The drawing palette is briefly described below:



6. Once the waveform drawing is complete, it needs to be sent to the function generator. Click on the Communications menu — Send Waveform:
7. A dialog box will appear, enter the frequency and amplitude you desire.



8. Click on the Non-Volatile Memory and enter a name for the waveform that you want to store in the non-volatile memory of the function generator. Let's use the name "test". If the non-volatile memory causes an error, use the Volatile Memory radio button instead.
9. As soon as you click on OK, the waveform will be converted to data samples and depending on the complexity of the arbitrary waveform it will take 20-30 seconds before the function generator generates the waveform. It will show up on the scope.