

Physics 401 Classical Physics Laboratory

**Experiment 1**

**Introduction to the Oscilloscope, the Signal Generator and the Digital Multimeter**

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## I. Introduction

The aim of this first lab is to introduce the basic operations of several laboratory instruments by examining the response of various electrical circuit elements to steady (DC) and alternating (AC) applied voltages. These laboratory instruments are the dual-trace digital oscilloscope, the function generator, and the digital multimeter. The first step is to become familiar with the operation of a very versatile source of DC and AC voltages – the function generator. Later on in the course the function generator and oscilloscope will be used to examine the behavior of various electrical components, and the characteristics of AC and DC circuits. As a review some relationships are summarized below for a pure sine wave and a complex waveform.

(1) For a pure sine wave,  $V(t) = V_o \sin(2\pi t/T)$ , with amplitude in volts  $V_o$  ( $2V_o$  is the peak-to-peak amplitude in volts), and period in seconds  $T$ :

Quantity	Formula	Unit
frequency	$f = \frac{1}{T}$	Hertz (Hz)
angular frequency	$\omega = \frac{2\pi}{T} = 2\pi f$	radians per second (rad/s)
root mean square voltage	$V_{rms} = \sqrt{\frac{1}{T} \int_0^T [V(t)]^2 dt} = 0.707 V_o$	Volts (V)
half-wave average voltage	$V_{half-wave average} = \frac{1}{T/2} \int_0^{T/2} V(t) dt = 0.637 V_o$	Volts (V)
full-wave average voltage	$V_{full-wave average} = \frac{1}{T} \int_0^T V(t) dt = 0$	Volts (V)

Note that  $1.414 V_{rms} = 1.570 V_{half-wave average} = V_o$ .

(2) For a complex periodic waveform with period  $T = 2\pi/\omega_o$ , and with Fourier expansion

$$V(t) = a_o + \sum_{n=1}^{\infty} a_n \cos(n\omega_o t) + \sum_{n=1}^{\infty} b_n \sin(n\omega_o t),$$

where  $n$  is an integer,  $a_o$ ,  $a_n$  and  $b_n$  are constants with units of volts, the root mean square voltage is

$$V_{rms} = \sqrt{\frac{1}{T} \int_0^T [V(t)]^2 dt} = \sqrt{(a_0)^2 + \frac{1}{2} \sum_{n=1}^{\infty} (a_n)^2 + \frac{1}{2} \sum_{n=1}^{\infty} (b_n)^2}.$$

Note that the integration is over one period. Here is a physical interpretation of the rms voltage. Let the voltage source,  $V(t)$ , drive a current through a resistor,  $R$ . Also let a battery (a DC source) with voltage  $V_{rms}$  power a resistor of the same resistance,  $R$ . The power dissipated in the resistor is the same in the two circuits.

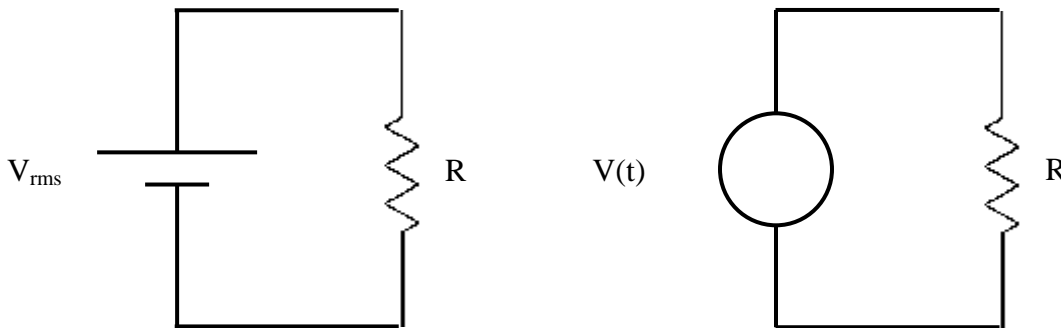


Figure 1. Two equivalent circuits which illustrate the meaning of an rms voltage.

## II. The oscilloscope

An oscilloscope is used to provide a visual display of a time dependent voltage, i.e. a graph of voltage versus time. The oscilloscope is arguably the most important laboratory instrument.

There are basically two different kinds of oscilloscopes: analog and digital. The analog oscilloscope has been the workhorse instrument in scientific laboratories for a long time. Newer digital oscilloscopes are increasingly used in these laboratories, thanks to the advanced integrated circuit technology. In this laboratory we will use the Tektronix model TDS3012B digital oscilloscope.

The basic specifications of the Tektronix 3012B dual trace oscilloscope are summarized in part V (Appendix) along with other instruments.

## A. Inputs

The primary function of the oscilloscope is discussed below. This oscilloscope has the ability to display two different waveforms simultaneously, for example, the input and the output of an amplifier. The signals are fed into the oscilloscope inputs, Channel 1 and Channel 2, through BNC connectors. The chassis of the oscilloscope represents ground potential. The two signals may be amplified differently using the **Volts/Div** knobs to achieve the desired display. These two sensitivity knobs adjust the amplification of the input waveform before it is applied to the vertical deflection plates of the CRT display. The two input signals may also be summed or subtracted ( $\pm$ ).

A digital oscilloscope measures a waveform by taking a sample of the waveform during a period called sampling time. By displaying the samples after signal processing, the accurate waveform can be viewed on the screen. The digital oscilloscope also stores the samples in its memory. This feature enables us to save the waveform and measure other characteristics of the waveform later. See Appendix for how to access various functions of the oscilloscope. Note that the basic voltage measurements and time measurements are displayed numerically on the screen along with the graph.

## B. Horizontal Time Base

Both input waveforms are always displayed with the same time base, which of course may be adjusted over a wide range by the **Time/Div** knob. The horizontal sweep rate depends upon an internal oscillator (actually, a ramp generator of variable frequency) and the internal horizontal deflection amplifiers. The time base calibration may be checked by connecting a BNC cable with leads or an oscilloscope probe from the 1.0 kHz output (PROBE COMP  $\approx$  5V) on the front of the oscilloscope to an input; this output provides a stable square wave (5 Volt) with 1.00 ms period.

The BNC connectors have cylindrical couplings on the end which twist and lock into position on the oscilloscope. Note that the coaxial cables have inner and an outer conductor. The outer conductor of the cable is grounded to the oscilloscope chassis.

For most experiments the **DELAY** should be turned off. Pressing AUTOSSET will set the controls for a default usable display. It is a time saver when you lost your display or you are not getting a stable display.

A useful feature in comparing the phase of two waveforms is XY mode (DISPLAY > XY Display > Triggered XY). When set at the XY mode, the internal time base is disconnected.

### C. Triggering

In order for waveforms displayed on the scope to appear stationary, it is necessary to synchronize the horizontal sweep with the input wave. This may be accomplished by setting the trigger source to Channel 1 (if Channel 1 is being used). Set the *Trigger Menu* >> *Normal & Source* >> *Ch 1*. The stability of the triggering is controlled by the *Trigger Level* knob. Adjusting this knob will change the trigger voltage required to start the sweep and therefore affects the phase of the waveform you see:

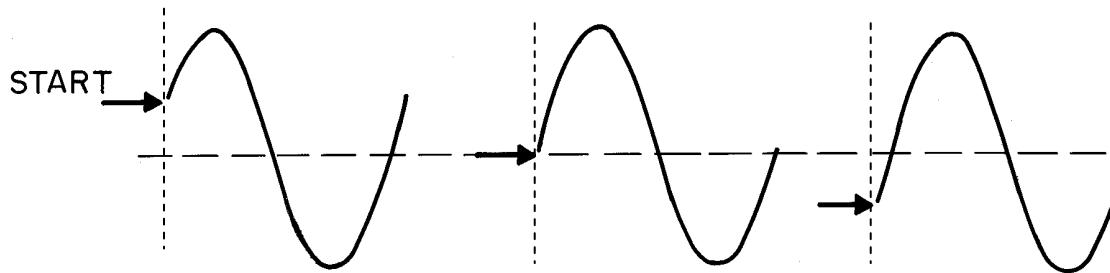


Figure 2. Sinusoidal wave form displayed at various trigger levels

If you move the trigger level greater than the peak or trough level, you will see the running waveform. It is similar to setting *Auto* mode in an analog scope. Digital scopes has special control to capture the signal if the signal is lost or unstable. When you press the AUTOSET button, the scope sets vertical, horizontal and trigger controls automatically. You can then manually adjust any of these controls if you need to optimize the display.

### III. Experiments

By carrying out the exercises below you will become familiar with the Wavetek Model 81 Function Generator (Wavetek for short), the Hewlett Packard 34401A Digital multimeter (DMM), and the Tektronix TDS3012B Digital Oscilloscope (Scope).

The DMM we use in the lab is a true RMS (root mean square) responding meter, which means it calculates the square root of the time-averaged voltage squared (see the expressions on pages 2 and 3). This is slightly different from an average responding meter, which is calibrated

to read the same as a true RMS meter for sine wave only. For other waveforms, an average responding meter will exhibit substantial differences from an RMS meter.

The **AC V** mode of the DMM measures the AC-coupled true RMS value. This mode is useful in situations where small AC signals are present in large DC offsets. An example of this situation is measuring AC ripple voltage present on DC power supplies.

#### A. Calibration of AC Mode of the DMM

To check the calibration of the **AC V** mode of the DMM the Scope can be used as a standard. To get started a detailed description of the set-up of all three instruments is provided. It would be a good idea to check off each step described below as you carry it out. Make certain all three instruments are plugged in, then turn them on.

##### 1. Scope

Turn on the oscilloscope. If it is already on, we suggest you turn it off and then back on again. The Scope goes through a set-up procedure when turned on. Wait until all tests have passed. The status report of the set-up procedure will stay on for a few seconds before it disappears itself. To remove it prematurely, you may press the MENU OFF key located at the right side of the screen display. The scope can be generally divided into 2 areas: display and the front panel control.

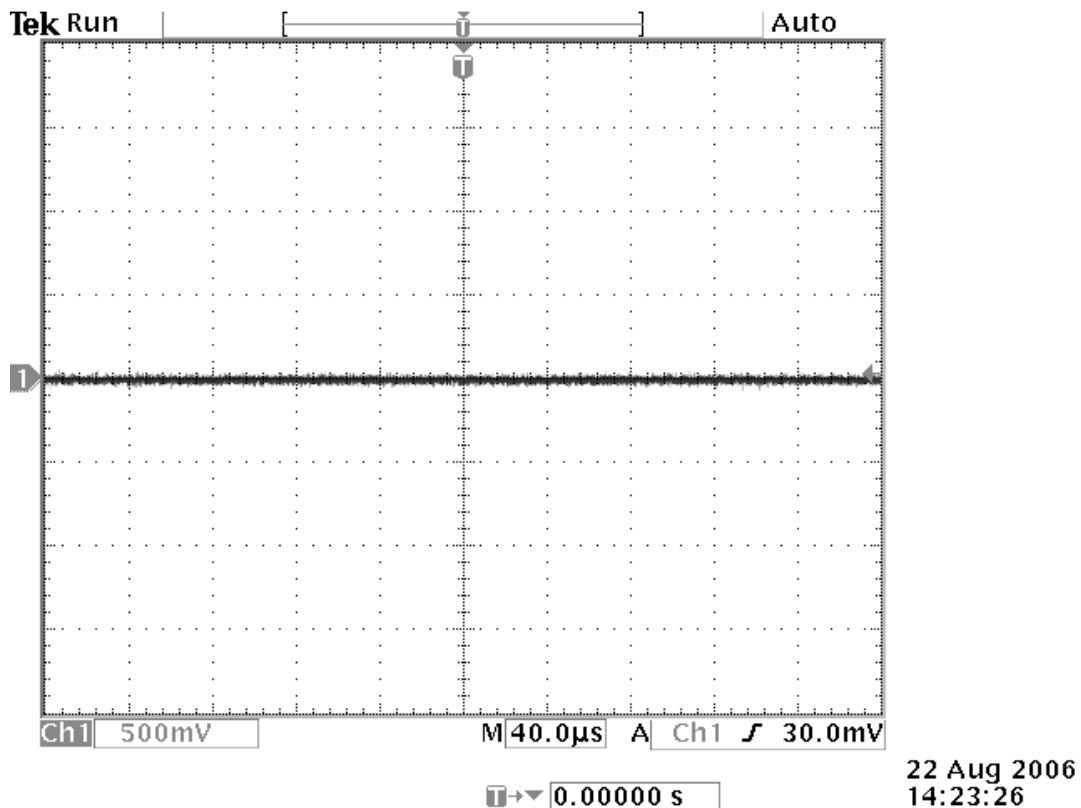
Note the locations of the grey keys at the bottom and the right side of the display. They are also called screen buttons. The grey keys allow you to choose the soft key selections on the display. If a pop-up menu appears, continue pushing the key to select an item from the menu.

Note also the knobs and buttons on the Scope front panel. Knobs are used to change the screen displays. The dark buttons bring up soft key menus on the display that allow you to access other features using the grey keys at the screen area. The regular buttons are instant action keys and changes generally appear on the screen instantly. There are 4 colored buttons which are self explanatory and are associated with the *Vertical* OFF button. Specifications and other documentations of the scope may be found in the Appendix.

- a) Turn the WAVEFORM INTENSITY) to viewable intensity level. Note that when you turns this knob, display shows the intensity level in percent on the screen. Set it about 15–20%.

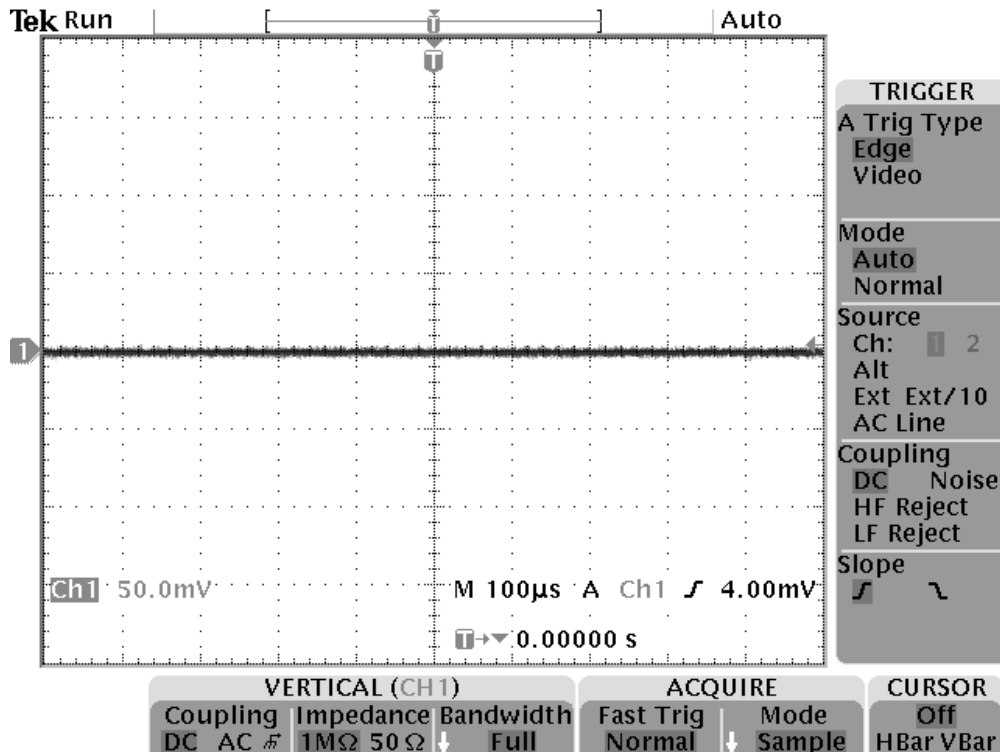
b) Press the DISPLAY button located at the top of the front panel. Note the various waveform display properties which are usually default. Pressing a bottom key would change the side softkey selections. Spend a few minutes to note how various parameters affect the display. Before you proceed, press AUTOSET button to go back to the default setting.

c) Press MENU OFF. Previous menu and other information inside the main display frame are now removed and you can see the display in full. This is useful to observe the waveform in detail. Standard information is shown at the bottom of the frame, as shown below. It shows the vertical amplitude/division of the active channel(s), horizontal timebase/division, trigger source and the trigger level. Occasionally you might see the cursor information at the right side. It can be turned on and off by using the CURSOR button.



d) Press QUICK MENU button. This shows frequently used menu functions. Observe the menu at the bottom. *DC Coupling* allows both DC and AC component of a waveform. *AC Coupling* allows only the AC component of the waveform. *Ground Coupling* disconnects the input signal. *Input Impedance* of the scope is 1 MΩ. *Full Bandwidth* will

allow frequency of the waveforms up to 100 MHz. Since the digital scope acquires a waveform point by point, *Normal* mode will select 10,000 points per frame while *Fast Trigger* will acquire only 500 points to capture fast waveforms. Set the Acquire to the default setting of *Normal* and *Sample*.



If you have more time at the end of the lab, familiarize with the rest of the functions. Scope manuals are available in the lab for classroom use. Consult the manual for an explanation of any unfamiliar terms on the Scope menus or panel.

e) Select the Trigger setting at the menu at the right side of the screen as follows:

- Trigger Type: Edge
- Mode: Normal
- Source: Ext (External)
- Coupling: DC
- Slope: Forward or Leading slope

f) During the later part of this lab, you may need to print the scope display or save data as a file. In order to access the scope through the Internet, there is a program called 'eScope' on the desktop. By double clicking the *eScope* icon, a browser page will appear. You will



need to enter the IP# of the scope and select the TDS3012B as the scope. The IP# is given on the top of each scope. You will need to use the browser *Print* command to print to the printer in the room. To save data, you may need to use the *Data* menu and select SPREADSHEET format to save the data.

## 2. Wavetek

The front panel of the Wavetek is divided into three sections: controls, connectors and displays/indicators. All front panel controls except the **Power** are momentary contact switches. Most controls have associated indicator lights. The menu structure of the Wavetek is shown in Appendix I.

a) Set **OUTPUT** to sine wave ( $\sim$ ).

b) Set **MAIN PARAMETERS** to **FREQ** by pressing the **FUNCTION** key. Adjust the frequency to display 10 Hz with the **MODIFIER** and **RANGE** keys.

c) Set **MAIN PARAMETERS** to **AMPL** (amplitude). Again by pressing the **MODIFIER** and **RANGE** keys, adjust the amplitude to the maximum (16 V). Note that this maximum is from zero level to the peak value. Therefore the actual peak to peak value should be calculated as 32 Volts.

d) Set **MAIN PARAMETERS** to **OFST** (Offset). Make sure it is set at 0 V. If not, use the **MODIFIER** and **RANGE** keys to change it.

## 3. DMM

The (complicated) menu structure of the DMM is shown in Appendix.

a) Push in the **AC V** button (AC volt measurement mode).

b) Press **Shift** key and then the > key. You will see a menu appear on the DMM display. The first Menu is the **A: MEAS** (measurement) menu. Press the  $\vee$  key. A new sub-menu **1: AC FILTER** will appear. Using the  $\vee$  key and the > keys, select **SLOW**. Press the **Enter** key to save the configuration.

c) At the **MEAS** menu, use the > key to select the **5: RESOLUTION** sub-menu and set the resolution to the **SLOW 6 DIGIT** option. Save the changes. This will optimize the DMM's features before measuring a signal

4. Connect the Wavetek to the Scope

a) Using a BNC cable, connect **SYNC OUT** on the Wavetek to the **EXT TRI** at the lower right of the Scope.

b) Using a BNC T fitting, connect **OUT** on the Wavetek to the channel **1** of the Scope and also connect the **OUT** to the right-most pair of inputs of the DMM with a banana plug connector. There are three banana-style inputs at the right-most front panel: V &  $\Omega$ ,  $\Omega$ W and I (current). Use the pair, V &  $\Omega$ . The middle input is the ground reference. The key on the banana plug indicates the grounded side. Note that the bottom input is for current measurements.

5. Set the parameters of the Scope

a) Set **Time/Div** of the Scope to 20 ms.

b) When you turn **TRIGGER LEVEL** knob, note the trigger level on the display. With external and normal trigger, we are assured of a stable display.

c) Press the **DELAY** button at the horizontal section. Adjust the horizontal **POSITION** knob so that the sweep starts at the left edge of the screen and passes through its center. If necessary adjust the vertical position control ( Channel 1 **POSITION** knob).

d) Admire the sine wave, or call the instructor if there are problems.

6. Make measurements with the Scope

a) Record readings from the Scope (peak to peak voltage,  $V_{p-p}$ , mean voltage,  $V_{avg}$ , and RMS voltage,  $V_{rms}$ , frequency, and period) using the **MEASURE** button. Also record the reading on the DMM. Do the measurements made by the Scope agree with the settings of the Wavetek? Explain the difference between the peak to peak voltage and the DMM reading. What should be the average voltage for a sine wave? Calculate the

peak to peak voltage from the DMM reading and compare it with the readings from the Scope. Do the values agree?

b) Switch the Wavetek to triangle, bipolar square wave, positive unipolar square wave and negative unipolar square wave. Record the same readings as in part a. Why are the DMM readings different for sine, triangular and bipolar rectangular waves?

7. Measure the response of the Scope to higher frequencies

With the Wavetek switched to sine wave, record  $V_{rms}$  and frequency on the Scope, and the DMM reading for the following frequencies: 100 Hz, 1 kHz, 10 kHz, 100 kHz, 1 MHz, and 10 MHz. Use **AUTOSET** to obtain a quick stable display. Enter the DMM readings into a Origin and make a semi-log plot. If you use the paper you may tape the semi log papers together to accommodate the range of data. Repeat the measurements for a sufficient number of frequencies to obtain a smooth set of data. What do these results indicate about the frequency response of the Scope and DMM?

At what frequency does the DMM reading fall to 70.7% of the Scope's reading? (This frequency is called the 3-dB roll off frequency).

B. Effect of a DC Offset

You can now study the effect of a combined AC and DC signal.

1. Use the same setup as in part A (making certain that the input coupling to the Scope is still set to DC). Set the Wavetek to a 100 Hz sine wave with an amplitude of 1.00 V, and a DC offset (**OFST**) of 0.00 V. Note the DMM reading and measure  $V_{p-p}$ ,  $V_{rms}$  and  $V_{avg}$  with the Scope. Now change the offset on Wavetek and observe how the waveform on scope display moves. Increase the offset to its maximum. Note the DMM reading and  $V_{pp}$ ,  $V_{rms}$  and  $V_{avg}$  with the Scope. Change the DC offset towards the negative DC voltage and note the same effect. Record the readings. Explain the difference in RMS readings between the DMM and the Scope. Print the image to document this step. Can you predict what would happen to the waveform if a larger DC offset were available from the Wavetek?

2. Switch the Scope input coupling (Vertical Ch1) to AC. Explain what happens to the ground level and why?

3. Switch the DMM to DC volts by pressing the **DC V** button. Note how the reading now scales with the DC offset control. Switch the Scope input to DC and compare the DMM reading with the Scope's  $V_{avg}$ . The DMM reading may be fluctuating due to input filter effect. The DMM uses integrating analog to digital converter (ADC) at the heart of its circuitry. One desirable characteristic of this type of ADC is its ability to reject spurious signals, especially the power line related noise present with the signals on the input. This is called Normal Mode Rejection (NMR). Normal mode noise rejection is achieved when DMM measures the average of the input by 'integrating' it over a fixed period. If the integration time is set to a whole number of power line cycles (PLCs) of the spurious input, these errors (and their harmonics) will average out approximately to zero. The DMM has 100 (highest) PLCs (or the longest integration time of 1.67 sec for 60 Hz) if its AC FILTER is set to SLOW 6 DIGIT. The lowest PLC is 0.02 (integration time of 400  $\mu$ sec) with FAST 4 DIGIT. The DMM's default integration time is 10 PLCs (167 ms) with SLOW 5 DIGIT resolution. Therefore it is recommended, for better resolution and increased noise rejection, select a longer integration time. Change the Wavetek frequency to 60 Hz and 120 Hz and note how the readings fluctuate. If you have time, change the **RESOLUTION** to various settings at a fixed frequency to see how the DMM works.

4. In this part we will explore "Min-Max" function of the DMM. This method will help us to find the minimum and maximum voltages of a time-varying signal. Typical examples are temperature fluctuations, switching signals and noise signals.

First set up the time-varying dc signal using the Wavetek function generator. Set the function generator to sine wave, 0.5 Hz (frequency), 1  $V_{pp}$  (peak to peak amplitude), 1.0 V dc offset. Next, set up the DMM to DCV, 6-1/2 digit mode. Finally, set the oscilloscope channel 1 to 500 mV/div (vertical scale), 1 sec/div (horizontal timebase) and DC Coupling.

If you have not done yet, using a T-connector at the 'OUT' terminal of the function generator, connect one BNC cable each to the oscilloscope and to the DMM. In real practice, it is frequently desirable to determine the minimum and maximum voltage for a pre-set time window. We can approximate this time window by using the trigger menu of the DMM. Let us assume that 40 samples would be sufficient to represent the fluctuations. Although the procedure to 'program' the DMM looks complicated, it will become easier with some practice.

- To set the DMM to trigger 40 samples, first press "Shift" and then "Recall" to see the menu.
- To get to the first level of the menu, use "^" button.
- Then use ">" or "<" buttons to get to the menu "C. TRIG MENU".

- Now press “V” once to get to the 2<sup>nd</sup> level of the sub-menu. You should see “1. READ HOLD”.
- Press “>” twice to see “3. N SAMPLES”.
- To change the parameters, press “V” once to see “00001 SMPLS”.
- Press “>” 4 times to get to the right-most zero.
- Press “^” 4 times to change the zero to ‘4’.
- Press “>” once to get to the right-most digit ‘1’.
- By pressing “V” once, change it to ‘0’.
- This procedure completes the process of entering the 40 samples to take during the measurement. To save and exit from the menu, press ‘ENTER’ button once.
- As long as the power is on, this value will be saved in the volatile memory of the DMM.

By pressing “Min Max” button once, you will notice “Math” annunciator will appear on the display. The “Min Max” data previously stored in the volatile memory will also be replaced by the new “Min Max” values. Since we are going to sample 40 readings, we will need to start the trigger to initiate the data acquisition sequence. First press the “Min Max” button once to initialize the values in the memory. Then immediately press “TRIG” button (also marked as ‘Single’) once. The DMM will beep and starts the data recording. In about 15 seconds, you will notice the “Trig” annunciator appears on the display. This signals that the DMM has completed taking 40 samples.

To read the minimum and maximum values, press “Shift” and then “Recall” to open the menu. At the first menu level, you should see “1. MIN-MAX”. If you did not see it right away, use the arrow buttons as described above to arrive at this menu. Press “V” once to read the minimum value. Note down this data in your notebook for reference. Press “>” one at a time to read the maximum (MAX), average (AVG) and the number of samples (RDG). Record them in your notebook. You may exit the menu by pressing the “ENTER” button once.

At the oscilloscope, press the **MEASURE** button to display the menu. Select *Max*, *Min* and *Mean* ( $V_{\max}$ ,  $V_{\min}$  and  $V_{\text{avg}}$ ). Note down the values in your notebook. Sketch a rough plot of the waveform and locate the values on your plot. Compare these values with what you had recorded earlier from the DMM. How much do minimum and maximum values differ from each other? How does the average value compare? Would you expect that the DMM would measure the same maximum and minimum as the oscilloscope if you increase the frequency 10 times to 5 Hz? Can you explain if they are different? How would you improve your measurement if they are different? [ *Hint: number of samples.* ]

### C. Input and Output Resistance

In this part you will measure input and output resistances (impedances).

1. Make sure the Scope input is switched back to DC. Disconnect the Wavetek from the Scope and the DMM. Connect the DMM to the Scope input. Push in the 2 wire ohms button ( **$\Omega 2W$** ) on the DMM. It will now read a resistance of  $1\text{ M}\Omega$  ( $1\text{ M}\Omega = 10^6$  ohms). You are now measuring the input resistance of the Scope. Remember this number for future experiments. This is what the Scope "looks like" to any circuit to which it is connected.
2. Connect the Wavetek to a 1.111 Kmax decade resistance box and the Scope as shown in the figure below. Temporarily disconnect the resistance box and measure the peak to peak amplitude of a sine wave (Wavetek set to 100 Hz with zero dc offset volt.). Adjust the Wavetek amplitude to give a peak to peak amplitude of 4.0 volts. Reconnect the resistance box and adjust the resistance until the peak to peak amplitude decreases by half to 2.0 volts. If there is some distortion of the sine wave decrease the amplitude and begin again. The value of the resistance when the signal is reduced by a factor of two is the output resistance of the Wavetek. This resistance represents what the Wavetek "looks like" to a circuit to which it is connected. Explain why this procedure works. ( Hint: assume that the Wavetek is a constant voltage source in series with its resistance. In principle, this method assumes that  $R_{out} \ll R_{in}$  where  $R_{in}$  is the input resistance of the Scope measured above. A correction could be made for the finite input resistance of the Scope.)

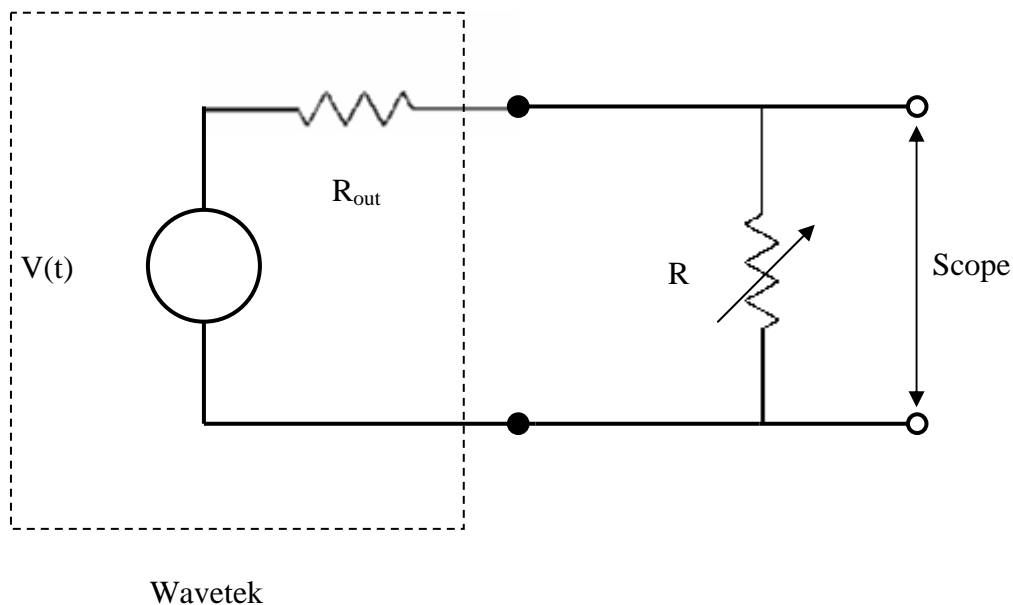


Figure 3. Connection of Wavetek, resistance box and Scope for input resistance measurements

3. The DMM has an input resistance which depends on how it is set. To check and reset the input resistance of the DMM, look at the submenu **3: INPUT R** of the **MEAS** menu. Reset it to  $>10\text{ G}\Omega$  ( $1\text{ G}\Omega = 10^9\Omega$ ), if it is not.

**IV. Appendix**

## 1. Specifications of Digital Oscilloscope

Item	Specification
Frequency response	DC to 100 MHz
Vertical sensitivity range	1 mV/division to 10 V/div
Horizontal sweep rate	4 ns/div to 10 sec/div
Input resistance	1 M $\Omega$
Maximum sample rates	$1.25 \times 10^9$ Samples/sec
Resolution	9 bits

## 2. Specifications of Wavetek

Item	Specification
Frequency range	10.000 mHz - 50.00 MHz
Frequency accuracy	$\pm 3\%$ of reading (10 mHz - 999.9 mHz) $\pm 0.1\%$ of reading (1.000 Hz - 50.00 MHz)
Output level	20.0 mV - 32.0 V <sub>ptp</sub> into open circuit 10.0 mV - 16.0 V <sub>pp</sub> into 50 $\Omega$
Output accuracy	$\pm 4\%$ of reading (10.0 mV - 16.0 V)
Offset range	$\pm 800$ mV - $\pm 8.00$
Offset accuracy	$\pm (1\% \text{ of setting} + 1\% \text{ of amplitude} + 0.2 \text{ mV})$ (Within $\pm 800$ mV) $\pm (1\% \text{ of setting} + 1\% \text{ of amplitude} + 2 \text{ mV})$ (Within $\pm 8$ V)
Output impedance	50 $\Omega \pm 1\%$



## 3. Specifications of DMM

DCV range	0 - 1000 V
DCV accuracy	$\pm$ (% of reading + % of range) (1 year accuracy)
Range: 100.0000 mV	0.005 + 0.0035
1.000000 V	0.0040 + 0.0007
10.00000 V	0.0035 + 0.0005
100.0000 V	0.0045 + 0.0006
1000.000 V	0.0045 + 0.0010

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DCI range	0 - 3 A
DCI accuracy	$\pm$ (% of reading + % of range) (1 year accuracy)
Range: 10.00000 mA	0.050 + 0.020
100.0000 mA	0.050 + 0.005
1.000000 A	0.100 + 0.010
3.000000 A	0.120 + 0.020

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Resistance range	0 - 120 M $\Omega$
Resistance accuracy	$\pm$ (% of reading + % of range) (1 year accuracy)
Range: 100.0000 $\Omega$	0.010 + 0.004
1.000000 k $\Omega$	0.010 + 0.001
10.00000 k $\Omega$	0.010 + 0.001
100.0000 k $\Omega$	0.010 + 0.001
1.000000 M $\Omega$	0.010 + 0.001
10.00000 M $\Omega$	0.040 + 0.001
100.0000 M $\Omega$	0.800 + 0.010

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ACV (True RMS) range	100 mV - 750 V	
ACV accuracy	$\pm$ (% of reading + % of range) (1 year accuracy)	
Range: 100.0000 mV	3 Hz - 5 Hz	1.00 + 0.04
	5 Hz - 10 Hz	0.35 + 0.04
	10 Hz - 20 kHz	0.06 + 0.04
	20 kHz - 50 kHz	0.12 + 0.05
	50 kHz - 100 kHz	0.60 + 0.08
	100 kHz - 300 kHz	4.00 + 0.50
1.000000 V	3 Hz - 5 Hz	1.00 + 0.03
to	5 Hz - 10 Hz	0.06 + 0.03
750.000 V	10 Hz - 20 kHz	0.12 + 0.05
	20 kHz - 50 kHz	0.12 + 0.05
	50 kHz - 100 kHz	0.60 + 0.08
	100 kHz - 300 kHz	4.00 + 0.50

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ACI (True RMS) range	0 - 3 A	
ACI accuracy	$\pm$ (% of reading + % of range) (1 year accuracy)	
Range: 1.000000 A	3 Hz - 5 Hz	1.00 + 0.04
	5 Hz - 10 Hz	0.30 + 0.04
	10 Hz - 5 kHz	0.10 + 0.04
3.00000 A	3 Hz - 5 Hz	1.10 + 0.06
	5 Hz - 10 Hz	0.35 + 0.06
	10 Hz - 5 kHz	0.15 + 0.06

Additional Low Frequency Errors for ACV & ACI (% of reading)

Frequency	AC Filter*		
	Slow	Medium	Fast
10 Hz - 20 Hz	0	0.74	-
20 Hz - 40 Hz	0	0.22	-
40 Hz - 100 Hz	0	0.06	0.73
100 Hz - 200 Hz	0	0.01	0.22
200 Hz - 1 kHz	0	0	0.18
> 1 kHz	0	0	0

\* AC Filter enables you to either optimize low frequency accuracy or achieve faster ac settling time. It is recommended that slow AC Filter with 6 digit resolution should be used in this experiment.

#### Additional Crest Factor Errors (non-sine wave)

Crest Factor**	Error (% of reading)
1 - 2	0.05 %
2 - 3	0.15%
3 - 4	0.30%
4 - 5	0.40%

\*\* Crest Factor (CF) is the ratio of Peak Value and the RMS value of the waveform. Note that CF for sine wave is 1.414 and for the triangular wave is 1.732.

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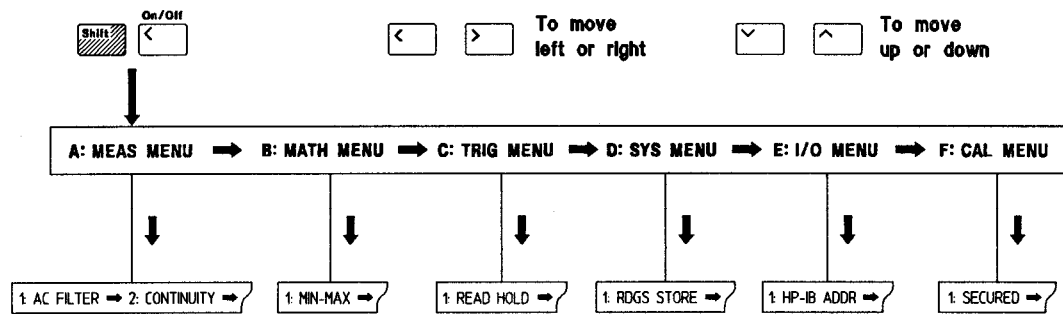
Frequency range	0 - 300 kHz	
Frequency & Period accuracy $\pm$ (% of reading ) (1 year accuracy)		
Range: 100 mV	3 Hz - 5 Hz	0.10
to	5 Hz - 10 Hz	0.05
750 v	10 Hz - 40 Hz	0.03
	40 Hz - 300 Hz	0.01

#### Additional Low Frequency Errors for Frequency & Period (% Of reading)

Frequency	Resolution		
	6 1/2	5 1/2	4 1/2
3 Hz - 5 Hz	0	0.12	0.12
5 Hz - 10 Hz	0	0.17	0.17
10 Hz - 40 Hz	0	0.2	0.2
40 Hz - 100 Hz	0	0.06	0.21
100 Hz - 300 Hz	0	0.03	0.21
300 Hz - 1 kHz	0	0.01	0.07
> 1 kHz	0	0	0.02

### HP34401A DMM menu structure

To turn on menu press:



To enter command press:



**A: MEASurement MENU**

1: AC FILTER → 2: CONTINUITY → 3: INPUT R → 4: RATIO FUNC → 5: RESOLUTION

**B: MATH MENU**

1: MIN-MAX → 2: NULL VALUE → 3: dB REL → 4: dBm REF R → 5: LIMIT TEST → 6: HIGH LIMIT → 7: LOW LIMIT

**C: TRIGger MENU**

1: READ HOLD → 2: TRIG DELAY → 3: N SAMPLES

**D: SYStem MENU**

1: RDGS STORE → 2: SAVED RDGS → 3: ERROR → 4: TEST → 5: DISPLAY → 6: BEEP → 7: COMMA → 8: REVISION

**E: Input / Output MENU**

1: HP-IB ADDR → 2: INTERFACE → 3: BAUD RATE → 4: PARITY → 5: LANGUAGE

**F: CALibration MENU**

1: SECURED → [ 1: UNSECURED ] → [ 2: CALIBRATE ] → 3: CAL COUNT → 4: MESSAGE

NOTE: The two commands enclosed in square brackets ( [ ] ) in the CAL MENU are "hidden" unless the multimeter is UNSECURED for calibration.