Lab 2

AC Measurements

REFERENCE: Horowitz and Hill Sections 1.13, 1.18,1.19
Appendix A (Oscilloscope)

INTRODUCTION

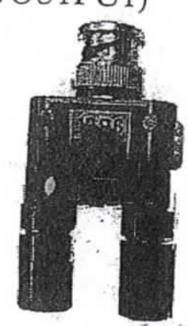
" The object of this lab is to learn measurement skills. You will become familiar with the oscilloscope, function generator, and pulse generator, in measuring time-varying electrical signals. You will measure:

- DC and AC voltages
- Frequency
- Phase
- Time constant of an RC circuit
- Amplitude and phase-shift responses of low-pass and high-pass RC filters.

EQUIPMENT

Analog Oscilloscope		(Tektronix 2235 or equivalent)
Function generator		(model with SYNC OUT as well as OUTPUT)
Pulse generator		(HP 8013B)
DC power supply		
multimeter		
~8 V transformer		
Resistors	5 k	
Capacitors	0.003 μF	
BNC cables		
BNC TEE		
BNC-banana adapter		
wooden board with binding posts		
use computer to plot graphs		
use graph paper at end of this manual to draw waveforms		

BNC - TEE



BNC – banana adapter

BNC cable

ABOUT ANALOG OSCILLOSCOPES

❝ The heart of an analog oscilloscope is its cathode ray tube (see Figure 2-1a). An electron gun produces a beam of electrons that strikes the screen, making a visible spot. The beam is deflected by two pairs of deflection plates. A sawtooth time-base voltage is supplied internally to the horizontal deflection plates to sweep the beam linearly with time across the screen horizontally. The voltage to be observed is supplied to the vertical deflection plates. The result is a picture of the signal voltage versus time.

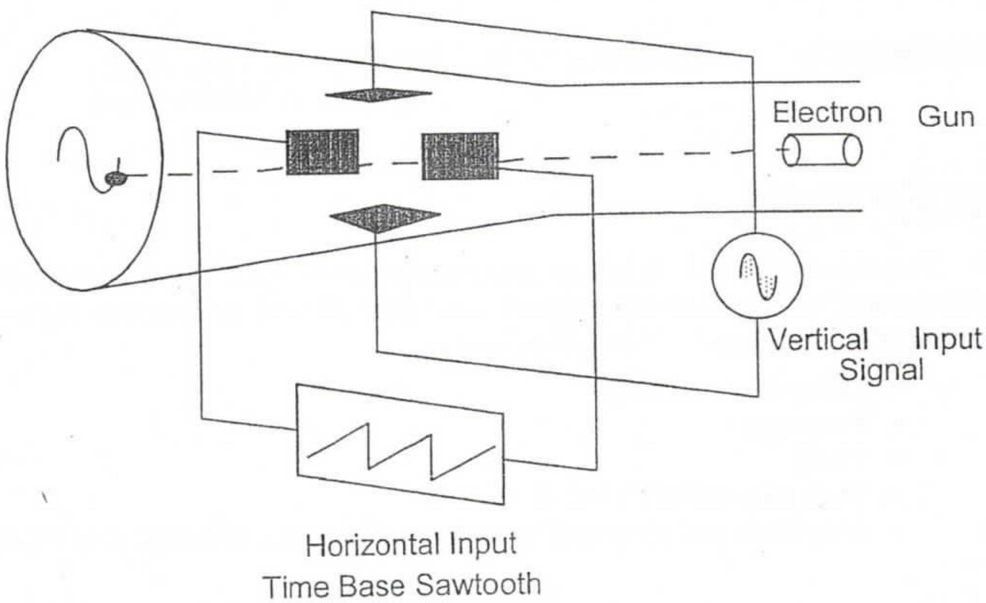


Figure 2-1

ABOUT TRIGGERING

Triggering of an oscilloscope is often confusing for beginners. A trigger is an event that starts the horizontal sweep or trace (see Figure 2-1b). This trigger event is defined by comparing two voltages: the moment when the "trigger source" voltage exceeds the "trigger level" voltage is the trigger event.

The "trigger source" can be:

- an external voltage EXT that you connect to the oscilloscope,
- or it can be one of the vertical inputs, CH1 or CH2.

Usually you must choose between AUTO and NORM triggering:

- NORM triggering will allow a trigger only if there is a trigger event.
- AUTO triggering will cause a trigger even if there is never a trigger event (the beginner will usually use this setting since it always yields a display).

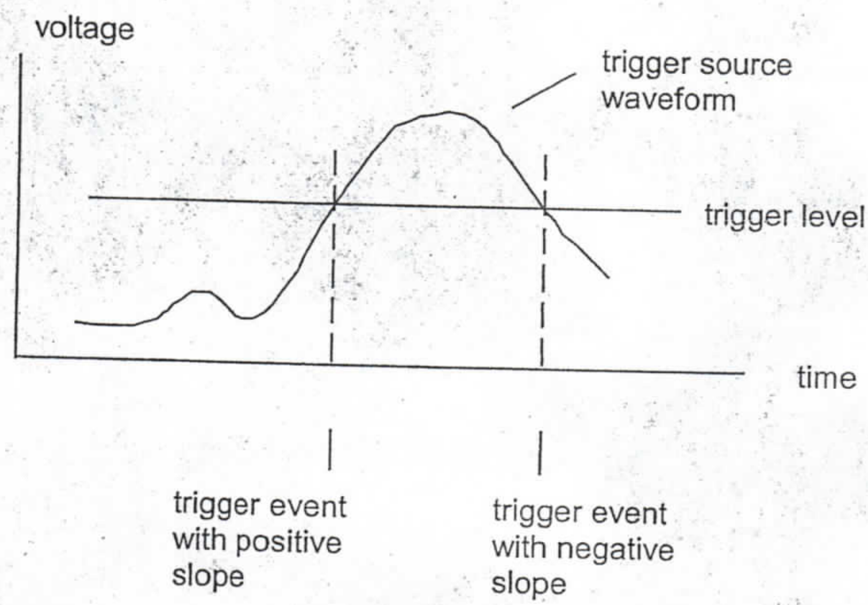
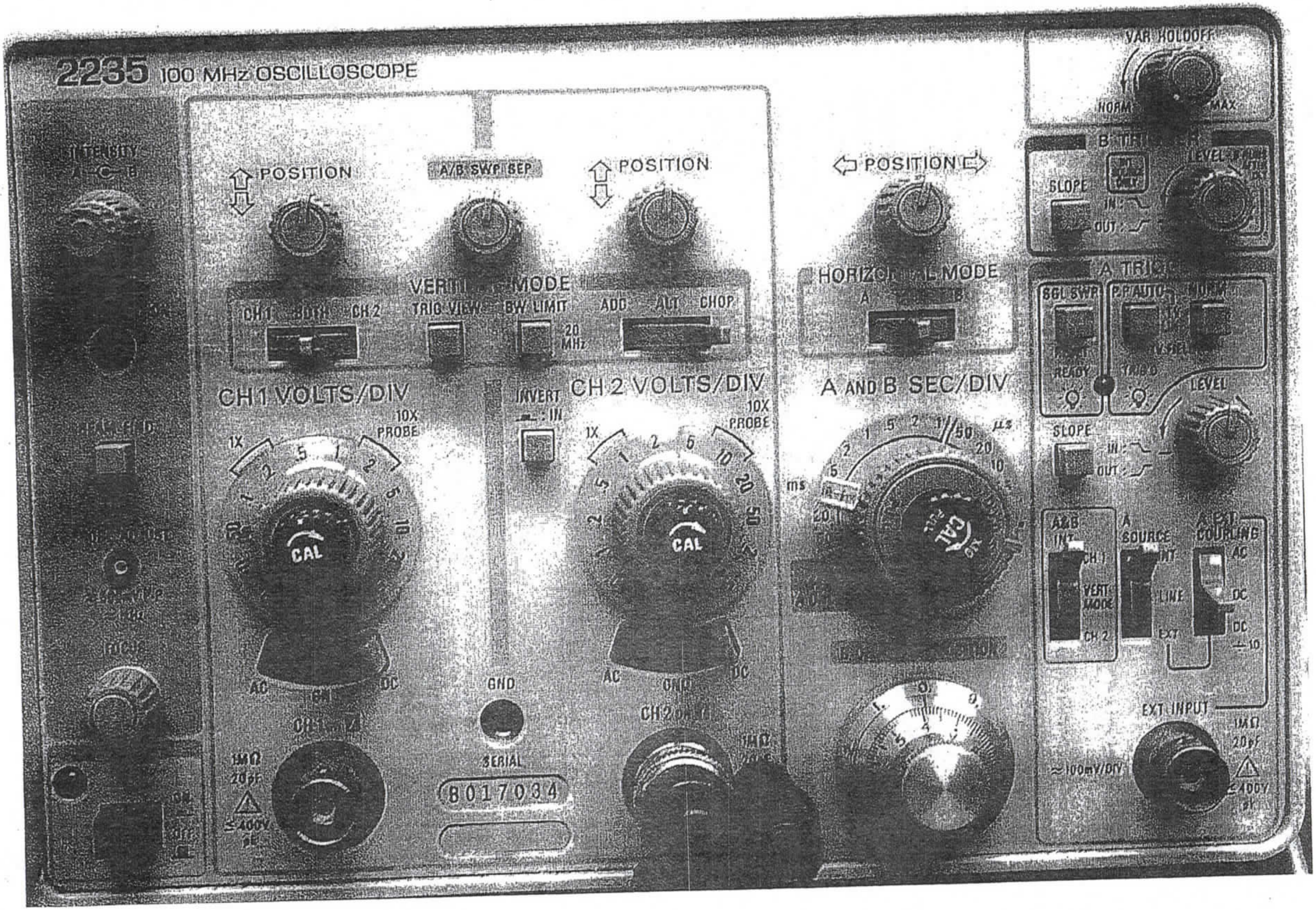


Figure 2-1 b   Oscilloscope triggering


2235 100 MHz OSCILLOSCOPE
POSITION
A/B SWP SEP
POSITION
POSITION
VAR HOLDOFF
NORM
MAX
SLOPE
IN
OUT
VERTICAL MODE
CH 1
BOTH
CH 2
TRIG VIEW
BW LIMIT
20 MHz
ADD
ALT
CHOP
HORIZONTAL MODE
SGL SWP
READY
P-P AUTO
NORM
LEVEL
CH 1 VOLTS/DIV
INVERT
CH 2 VOLTS/DIV
A AND B SEC/DIV
1X
10X PROBE
CAL
ms
μs
A&B INT
CH 1
VERT MODE
CH 2
A SOURCE
LINE
EXT
AC
DC
GND
SERIAL
8017034
EXT INPUT
1MΩ
20pF
≤400V pk
≈100mV/DIV

“ One use of the oscilloscope is to measure relative phases between two waveforms. This is done by adjusting both waveforms so that they are symmetric about the horizontal line in the middle of the screen. Then note the time delay Δt between the zero crossings, as shown in Figure 2-2. This corresponds to the phase shift, which is $\phi = 360° \, \Delta t / T$.

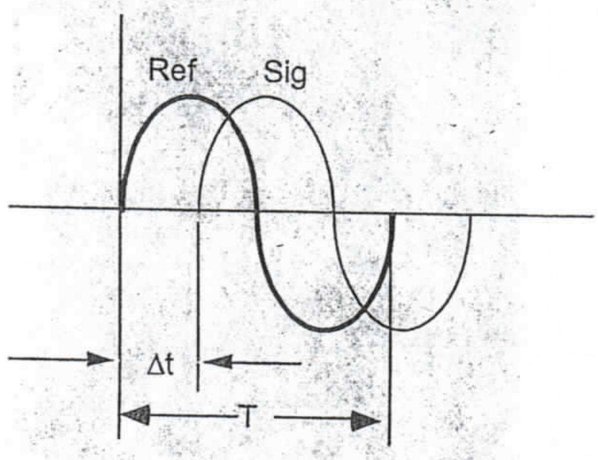
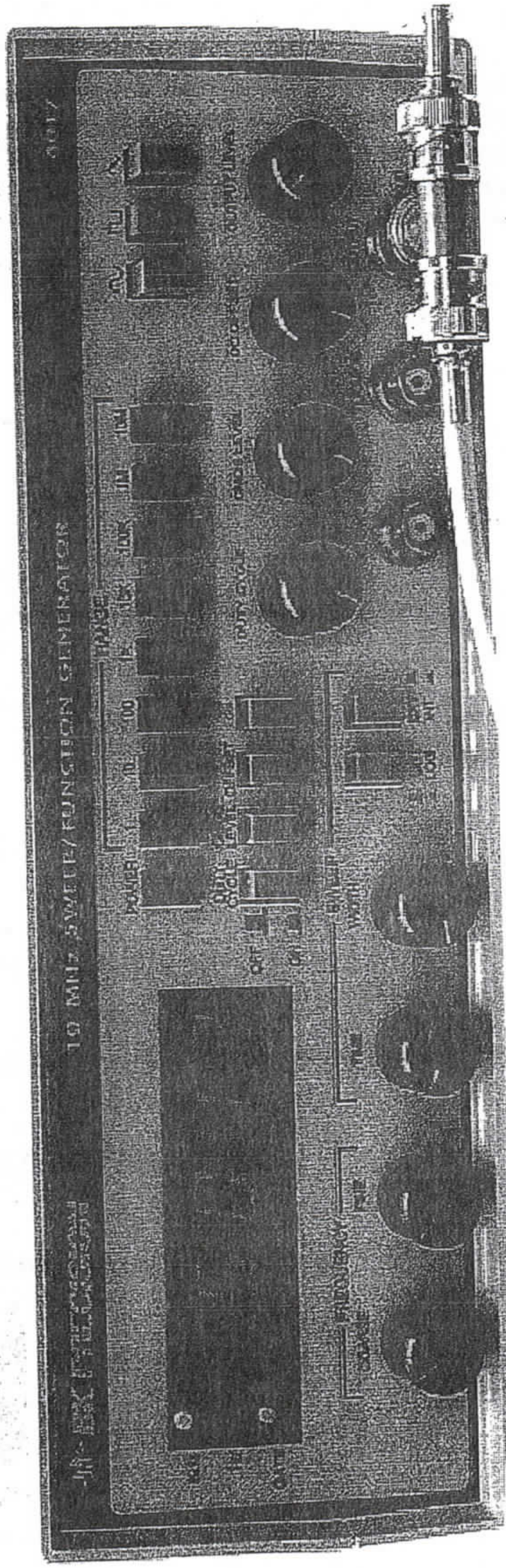


Figure 2-2

Tip: Sometimes it is hard to get *anything* to show on the scope. In that case, follow this procedure:

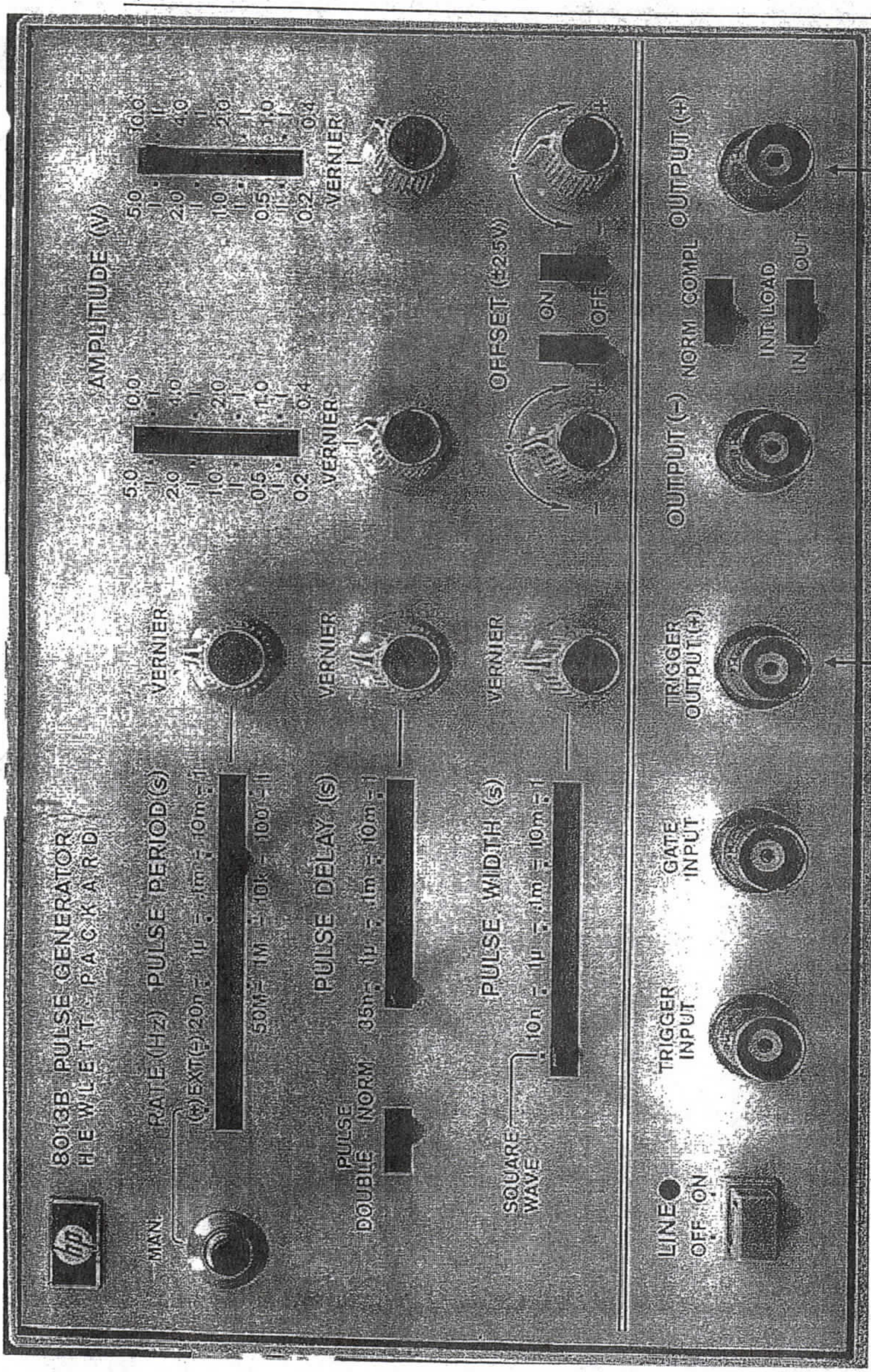
- set trigger to: AUTO, DC COUPLING,CH1
- set horizontal mode to: A
- set vertical mode to: BOTH
- set sweep speed to: 1 ms/div, CAL, MAGNIFIER OFF
- set vertical coupling to: ground
- turn up intensity
- wiggle vertical position until a horizontal line appears
- set vertical coupling to: AC or DC



Signal output

SYNC output
(labeled TTL/CMOS)

Function Generator.



Signal output

SYNC output
(labeled TTL/CMOS)

Pulse
Generator.

PROCEDURE

☛ Read Appendix A in the **text**. You will need to know oscilloscope terminology before you begin.

☛ In this lab you will record a lot of data. It is recommended that you record it in columns in your lab notebook, with separate columns for:

the reading (e.g. in mV)
the scale on the oscilloscope (e.g. 100 mV per division)
the estimated error for each measurement.

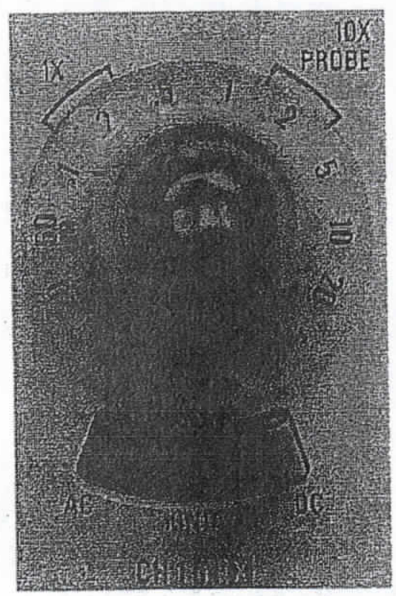
1. Measurement of Voltages

(a) DC Voltages

☛ To start, adjust the oscilloscope settings to the following:‡‡

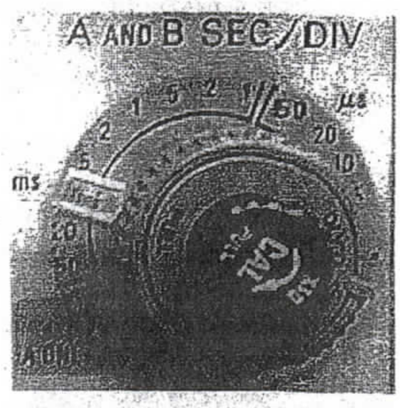
<u>vertical mode</u> CH1

CH1	Volts/Div	1 Volt (use 1x indicator on dial)
	input coupling	GND
	CAL knob	fully clockwise to click
CH2	same as CH1	
	set INVERT switch to the out position	



‡‡ These instructions are for Tektronix 2235; other analog oscilloscopes are similar.

<u>horizontal mode</u>	A	
time base	A sec/div	1 ms
	CAL knob	fully clockwise to click
var holdoff	NORM	
A trigger	P-P AUTO	
level	turn to approximately middle of knob's range	
slope	out	
A & B INT	CH1	
A source	INT	
A ext coupling	DC	



☞ Once you have found a trace that looks like a horizontal line, use the vertical position knob on CH1 to position the trace in the center of the display. Then change the CH1 coupling to DC.

☞ Connect the output of an adjustable power supply to the oscilloscope input CH1. You should see a trace at a non-zero voltage. Change the CH1 coupling back and forth, from GND to DC, to see the difference.

☞ Set your power supply to three different DC voltages and measure each voltage with both the oscilloscope and the digital multimeter.

✍ Compare the DC voltage measurements of the oscilloscope and the digital multimeter. Report the measurement uncertainty (error) values, based on the specifications for the multimeter and the oscilloscope, and your impression of how precisely you can read the oscilloscope display. Which is more precise, the meter or the oscilloscope?

(b) <u>AC Voltages</u>

☞ Connect the function generator to signal input CH1 of the oscilloscope.

☞ Set the function generator to produce a sine wave of about 1 Volt amplitude, a frequency of about 100 Hz, and no DC offset.

☛ Set a multimeter to the AC voltage function. Connect it to the function generator.

☛ ✍ Measure the peak-to-peak <u>AC voltage</u> using the oscilloscope. Calculate the RMS value of the voltage.

✍ Compare the AC voltage oscilloscope measurements to those on the digital multimeter. Report the measurement uncertainty (error) values. Which is more precise, the meter or the oscilloscope?

(c) <u>AC and DC coupling</u>

☛ Make sure the oscilloscope coupling is set to DC.

☛ Set the function generator frequency to about 10 kHz.

☛ Turn on the offset voltage on the function generator, and twiddle the offset up and down. You should see a vertical deflection of the trace.

☛ Now change the oscilloscope coupling to AC and twiddle the offset voltage <u>slowly</u>. You should see no change.

✍ Explain the difference between AC and DC coupling. Through what additional component inside the oscilloscope does the signal pass when using AC coupling?

2. <u>Measurement of Frequency</u>

☛ Use the same set-up as above. Use a digital multimeter to measure the frequency. Determine the frequency from the measured time per cycle. Repeat for five frequencies in total, over the entire range of the function generator.

✍ Make a table to compare the frequency measurements made with the oscilloscope to those with the digital multimeter. Include columns for the measurement uncertainty (error) values. Which is more accurate, the meter or the oscilloscope?

❝ As a practice, never trust the frequency and voltage readings shown on a function generator. Always make external measurements of the frequency and voltage.

3. Time Constant of an R-C Circuit

❝ The output voltage of an RC filter is

$V(t) = V_{max}\,[1 - \exp(-t/RC)]$ for charging

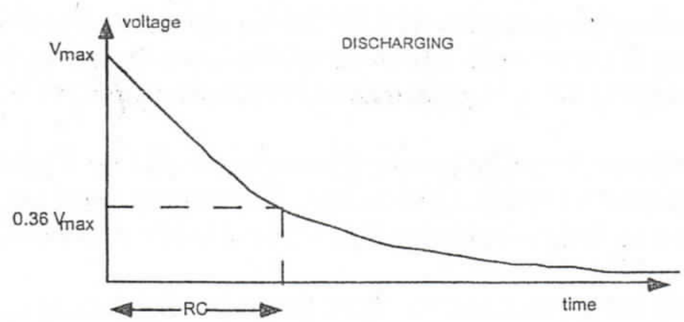
$V(t) = V_{max}\,\exp(-t/RC)$ for discharging

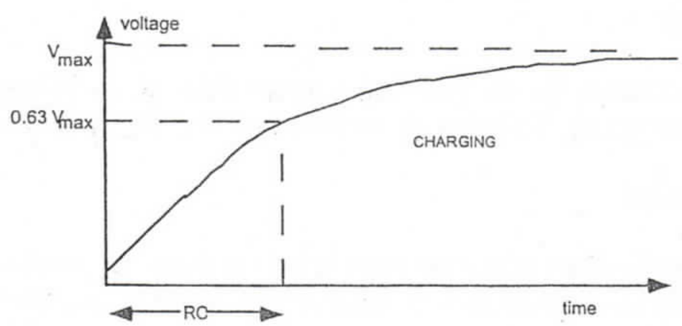
Rules of thumb:

RC The product RC is called the "RC time constant" or simply the "RC time".

When the input voltage of an R-C circuit changes from one level to another, the output voltage will approach its final value asymptotically. RC is the time required for the output to swing by 63% toward its final value. [Because $1 - \exp(-1) = 0.63$.]

5RC is the time required to swing within 1 % of the final value. [Because $\exp(-5) = 0.007 \pm 1\%$]





☛ ✍ Measure the actual values of a 5 k resistor and an 0.003 μF capacitor.

☞ Connect the series R-C circuit to a function generator and an oscilloscope, as shown in Figure2-3 a and 2-3 b. (This circuit is shown two ways to help you figure out how to wire it up.) Use a wooden board with binding posts.

☞ Set the multimeter to measure frequency, and connect it to the function generator.

☞ Set the oscilloscope for external triggering (EXT), and connect the trigger input to the SYNC output of the function generator (BNC connector labeled TTL/CMOS, see photo).

Sync output of function generator

☞ Set the function generator to produce <u>square</u> waves with a peak-to-peak amplitude of about 5 Volts. Set the frequency so that it is appropriate for measuring the time response of the R-C circuit -- the period $\tau = f^{-1}$ should be $\geq$ 10 RC.

☞ Set the oscilloscope vertical voltage scales to be the same, choosing a scale so that the trace fills a large portion of the screen. (If it fills only a small portion of the screen, your measurements will not be very precise.) Use GND input coupling to find where zero volts is, and use the vertical position to locate this on a gridline.

☞ If your function generator has a DC offset, adjust it so that the bottom of the waveform is at zero volts. Draw the oscilloscope display for the square wave, and indicate the voltage at both the bottom and top of the waveform.

☞ Adjust the oscilloscope horizontal time base so that the discharge time takes a considerable portion of the display. Use the horizontal position to locate the waveform so that the triggering time is at a convenient gridline.

(Your display should look like the figure above, labeled "charging." Change the oscilloscope trigger slope between + and - to see the difference it makes.)

(a) <u>Charging</u>

☞ ✍ Determine the charging time constant from the oscilloscope display. Estimate your errors. Calculate the ratio of your charging time to RC.

(b) <u>Discharging</u>

☞ Change the scope triggering slope to see the discharge portion of the trace. (Your display should look like the figure above, labeled " discharging.")

✍ Determine the discharging time constant from the oscilloscope display. Estimate your errors. Calculate the ratio of your discharging time to RC.

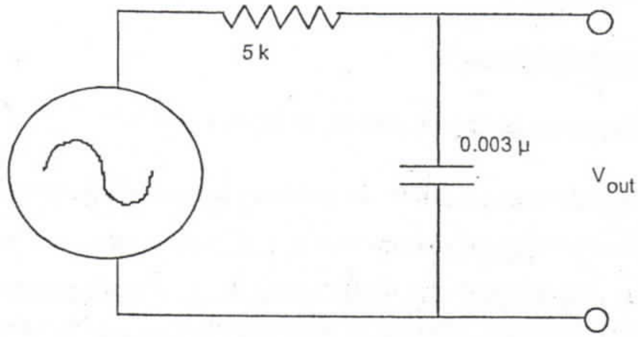


Figure 2-3 a

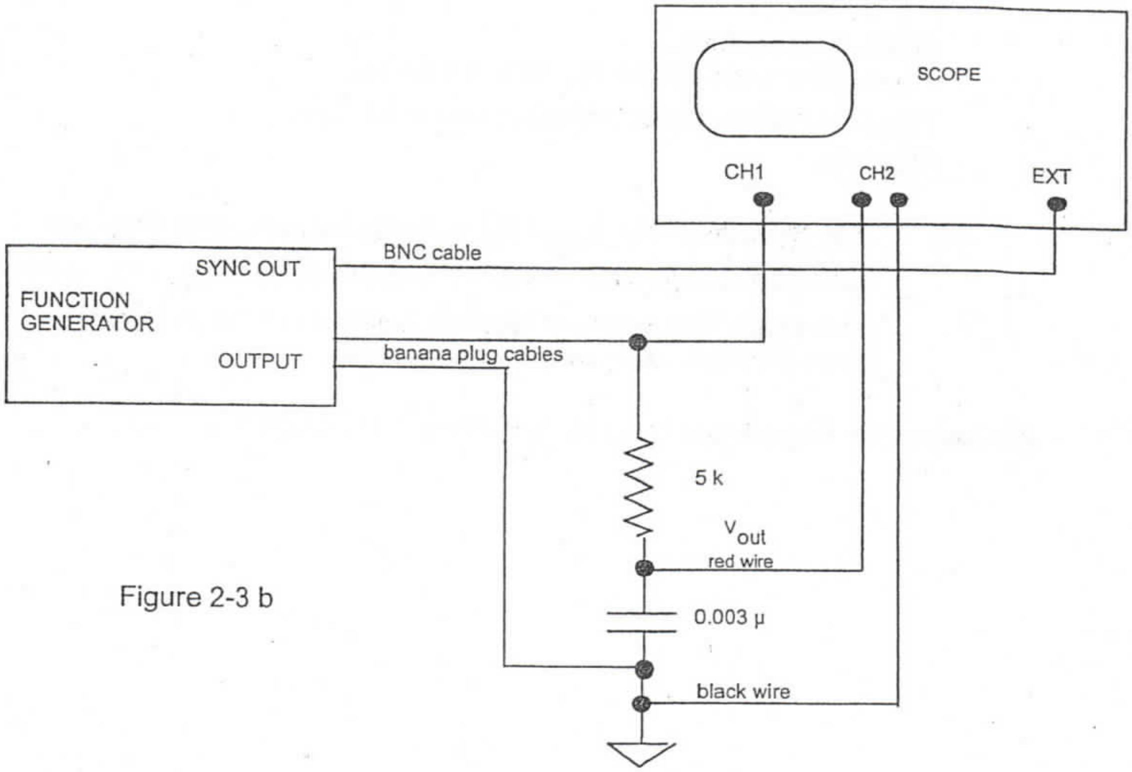


Figure 2-3 b

4. <u>R-C Low-Pass Filter</u>

(a) <u>Amplitude Response</u>

☞ Use the same circuit as above, in Figure 2-3 b.

☞ Set the function generator to produce a <u>sinusoidal</u> output with an amplitude of about 4 or 5 V peak-to-peak. Use a 1, 2, 5 frequency sequence from 10^1 to 10^5 Hz (i.e., 10, 20, 50, 100, 200, 500 Hz, ...). Also include a frequency of $f = 1 / (2\pi RC)$ in this sequence, as calculated from measured values of R and C.

✍ (i) Record a table of your data with columns for:

f (Hz), error bar for f
V_{in}, oscilloscope scale for V_{in}, error bar for V_{in}
V_{out}, oscilloscope scale for V_{out}, error bar for V_{out}.
V_{out} / V_{in}

(ii) Plot the voltage ratio V_{out} / V_{in} with log-log axes, with frequency on the horizontal scale. Make a theoretical plot of V_{out} / V_{in} on the same graph. You may use Graphical Analysis or other software to create the graph using the instructions below.

(iii) Compare the frequency at $V_{out} / V_{in} = 0.707$ to $f = 1 / (2\pi RC)$

Software Instructions: making log-log plots using "Graphical Analysis for Windows"

- In the `Data Table Window`, change the name of the two columns from `X` and `Y` as shown in Figure 1-13 to something more meaningful, like `length` or `mass`.

- Enter the data in the two columns.

- Create a new column as shown in Figure 2-14, with the logarithm of the data in the first column. Give the column a meaningful name, `log(length)`.

- Click `OK`. A new column of data will appear in the `Data Table Window`.

- Repeat for the other column of data. In the end, you should have four columns of data, where the last two are logarithms of the first two, as shown in Figure 2-15.

- Select the desired log columns for plotting by clicking on the item in the `Graph Window` shown with two arrows, and then select the desired column of data from the menu.

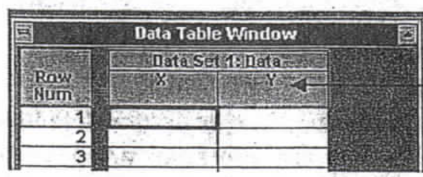


Figure 2-13. In "Graphical Analysis, double-click on a column heading to change its name to something meaningful, like `frequency`, or `amplitude`.

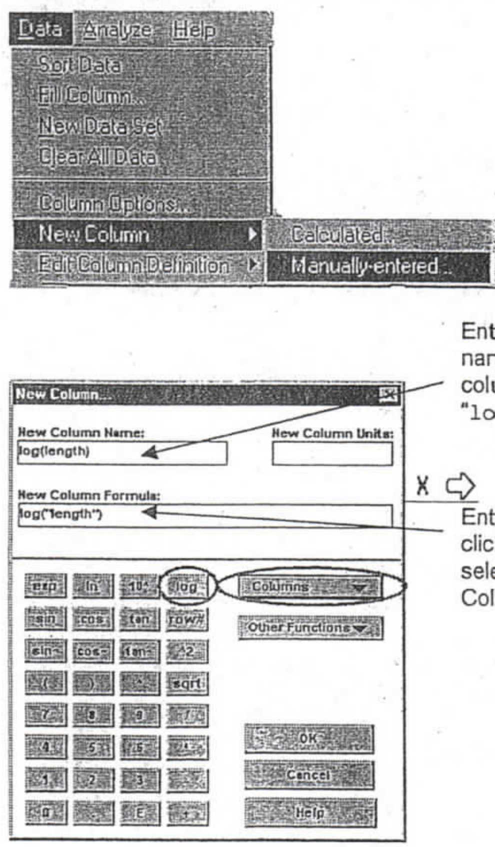


Figure 2-14. (a) Creating a new data column and (b) filling it with computed data.

(b) <u>Phase Response</u>

☛ Use the same circuit as above.

☛ Measure the phase shift of the voltage across the capacitor relative to the input voltage from the oscillator in a 1, 2, 5 frequency sequence from 10^1 to 10^5 Hz. (See Figure 2-3 a and 2.3 b. Also include a frequency of $f=1 / (2\pi RC)$ in this sequence.

✍ (i) Record your data with columns for:

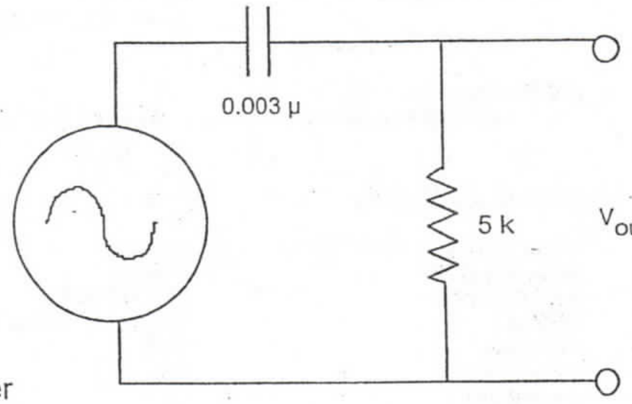
f (Hz),	error bar for f
delay in msec,	error bar for delay in msec
phase in degrees,	error bar for phase in degrees.

(ii) Plot the phase curve on a graph with a semi-log scale (θ linear, f log). Compare with a theoretical plot of the phase shift on the same graph.

(iii) What is the phase angle, measured and theoretical, at $f=1/(2\pi RC)$?

5. R-C High-Pass Filter

☛ Use the same 5 kΩ resistor and 0.003 μF capacitor as in the *R-C* low-pass filter, above, but swap them to make a high-pass filter.



High Pass Filter

☛ ✍ Make the same amplitude response measurements and plots as for the low-pass filter, above.

6. Measurement skills [no response necessary for lab report]

Use your remaining time in the lab session to familiarize yourself with the oscilloscope and pulse generator.

☛ Connect the function generator to the oscilloscope as shown in Figure 2-4.

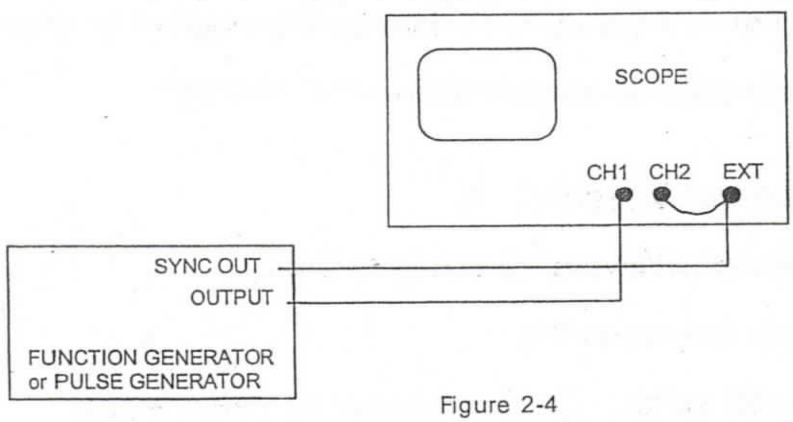


Figure 2-4

☞ Adjust the oscilloscope settings to the following settings (hereafter referred to as the *original settings)*.

Vertical mode		BOTH and ALT
CH1	Volts/Div	1 Volt (use 1X indicator on dial)
	input coupling	DC
CH2	same as CH1	
	INVERT switch	set to the out position
horizontal mode		A
time base A sec/div		0.2 s
VAR HOLDOFF		NORM
A TRIGGER		P-P AUTO
LEVEL		turn to about the middle
SLOPE		out
A & B INT		CH1
A SOURCE		EXT
A EXT COUPLING		DC

☞ Adjust the function generator settings to produce a sine wave with a frequency of about 100 Hz, with DC offset turned OFF.

☞ Learn the various vertical modes

Try various settings of the vertical mode switches and see the display.

Use the "BOTH" mode on the vertical mode. Compare ALT and CHOP. (You may need to adjust the beam intensity on the scope.)

Change time base to 5 μs, observing the display. Again compare ALT and CHOP. You may be able to see the chopping of the signals in the chop mode.

Do you understand the difference between ALT and CHOP?

☞ Learn how to use X-Y mode.

First return the oscilloscope to the original settings.

Then set the time base to X-Y.

Vary the CH1 and CH2 volts/div and see how the display changes.

Make a Lissajous figure. Connect a ~8 V transformer to CH1 and a sine wave from the function generator to CH2. Adjust the frequency to multiples of 60 Hz while watching the display.

☞ <u>Learn about trigger levels</u>

First return the oscilloscope to the original settings, and set the time scale to 0.2 ms.

Change the cables to the function generator as shown in Figure 2-5.
Adjust the function generator to produce a sine wave of about1 kHz.

Vary the <u>trigger level</u> and the <u>trigger slope</u>. Observe the results. Do you understand why the display depends as it does on these settings?

Change the trigger mode from AUTO to NORM. Adjust the trigger level and/or the function generator amplitude until you see that the oscilloscope no longer triggers. Then adjust them back so that they do trigger. Do you understand why the display depends on these parameters in the NORM trigger mode?

Return the oscilloscope triggering to AUTO before proceeding.

☞ <u>Learn how to use dual time bases</u>[§§]
Adjust the B Delay Time to zero (or as near as possible).

Set the HORIZONTAL MODE to ALT.

Turn B Trigger level all the way to +

You should see an additional set of traces, corresponding to A and B. If not, adjust A and B intensity or other settings until you do.

Turn A/B SWP SEP to separate the two sets of traces.

Vary B Delay Time and observe the result.

Pull the "DLY'D SWEEP" knob and
adjust delayed sweep time scale to 20 μs. Observe the effect on the display.

Note the de-intensified display of A; this shows the portion of the A trace that is represented by the B trace.

Change the function generator to produce a square wave at 1 MHz. Set the oscilloscope to A sec/div = .5 μs, B sec/div = .05 μs.

[§§] Some models, such as Tektronix 2235, have a "delayed sweep" feature required for this step, while others do not. If your scope doesn't have this feature, and if the lab is equipped with more than one type of scope, ask your TA.

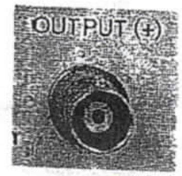
Adjust the B DELAY ten-turn knob until you find the trailing edge of the square-wave waveform. You may have to adjust the B intensity knob to see the trace; start off with the B intensity knob in a central position.

Measure the decay time of the trailing edge. Do you see ringing? Does the function generator produce this ringing at much lower frequencies as well?

Repeat with the leading edge.

☞ <u>Learn to use the pulse generator</u>

Repeat the steps above, using the the delayed sweep, but this time use the Pulse Generator instead of the Function Generator. The purpose of this exercise is to learn about pulse generators, and to further develop oscilloscope skills.



For the output, use the pulse generator's right-most BNC connector.

Adjust the HP pulse generator so that it has the following settings:

Sliding switches:

Pulse period:	20 n - 1 μ
Pulse delay:	adjust to minimum
Pulse width:	10 n - 1 μ
Amplitude:	adjust to maximum

Other switches:

Pulse:	Norm
Offset	Off
Output	Norm
Int Load	IN

Verniers:

Pulse period	3 O'Clock position
Pulse width	12 O'Clock position
Amplitude	12 O'Clock position

When examining the delayed traces, notice whether the pulse generator produces a more ideal square pulse than the square wave from the function generator. Look for "ringing".

After you've finished with the delayed trace:

- Set the scope to Horizontal Mode A, so that you are no longer viewing the delayed sweep.
- Pull the time base knob out so that the mark on the inner knob is aligned with the two black marks on the clear outer knob; now they will move together when you adjust them. Be sure that the vertical coupling of CH1 is set to be DC.
- On the pulse generator, vary the following, and observe how the waveform changes:
  - o Vary the venier. for pulse period.
  - o Vary the vernier for the pulse width (up to a maximum of 50% of the pulse period).
  - o Switch between NORM and COMPL output.