Electronic Instruments

Purpose

This experiment introduces the four basic electronic instruments you will use in the course: the oscilloscope, the function generator, the counter/timer and the digital multimeter. Spend enough time in the lab this week to get familiar with the instruments. You do not have to write a report on this experiment.

Introduction

Any time you develop a new circuit, repair an electronic instrument, or measure the performance of an electronic component or system, you will need to use one or more items of test equipment. Almost every task requires an oscilloscope, the basic instrument for visualizing the time dependence of electronic signals. A signal or function generator is used to produce periodic signals of the frequency, amplitude, and waveform needed for input to the device under test. The counter/timer can measure time intervals and frequencies very accurately, and the digital multimeter measures voltages, currents, resistance, and it can test silicon diodes and transistors. Everything you do in an electronics laboratory depends upon your familiarity with these instruments.

The instructions for this experiment are designed help you start seeing patterns on the oscilloscope screen as soon as possible, and to familiarize you with the basic controls of each instrument. They do not cover all of the capabilities of the instruments. For greater detail, consult the manufacturer's manuals kept on the book shelf in the lab.

Readings

1. D&H 6.1, 6.3-6.7. Skim 1.1-1.8
2. You also may look at Sections 1.01-1.12 of Horowitz and Hill as well as the first three appendices: The Oscilloscope, Math Review, and The 5% Resistor Color Code.

Outline of the Experiment

1. Operation of the Tektronix 2246 oscilloscope, the FG504 function generator, the DC504A counter/timer, and the Fluke 77 digital multimeter.
2. Digital measurement of voltage, time, and frequency with the oscilloscope.
3. Set up test waveforms on the oscilloscope.

Problems (You need not turn these in this week):

1. Learn the color code for resistors (See D&H section 1-7). The sequence of colors

black **b**rown **r**ed **o**range **y**ellow **g**reen **b**lue **v**iolet **g**ray **w**hite

can be remembered by memorizing the backpacker's lament:

Black **b**ears **r**esting **o**n **y**our **g**ear **b**ring **v**ery **g**ray **w**eather.

What are the values and uncertainties of the resistors in Figure 1.1? Write the resistance using the most appropriate units of Ω, kΩ or MΩ, and include the % tolerance. (For example, 1.8 kΩ ± 5%.)

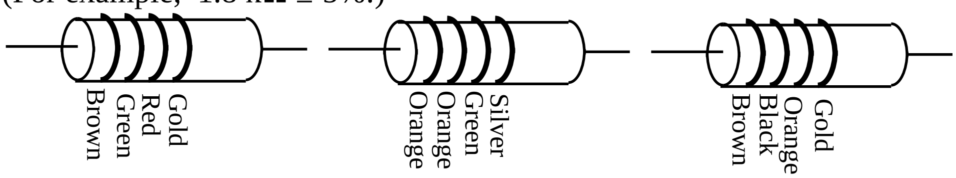


Figure 1.2 Color Coded Resistors

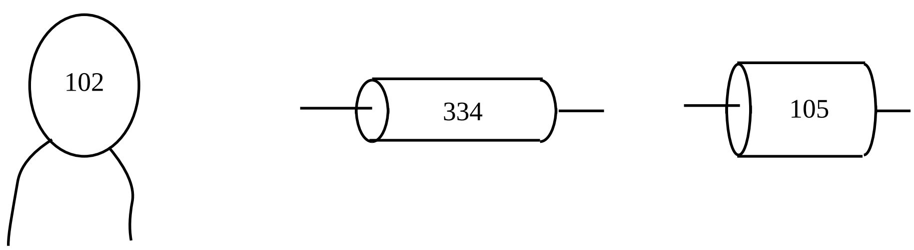


Figure 1.3 Number Coded Capacitors

2. There is a three-digit number code for labeling capacitors. The label 224 means 22 with 4 zeros, interpreted as a capacitance value in picofarads. (224 = 220,000 pF = 220 nF.) You also will see labels like 22 μF, 22 uF, 22 MF, and 22 MFD, all of which mean 22 microfarads. Another notation is 220 uuF, which means 220 picofarads (uu = micro micro). Write down the values of the capacitors shown in Figure 1.3. Use the most appropriate unit: pF, nF, or μF.

Procedure

TEKTRONIX 2246 OSCILLOSCOPE

The Tektronix 2246 oscilloscope is very similar to the generic 'scope described in D&H or H&H. (Be sure to read D&H 6.6 or H&H Appendix A before starting this section.) Our 'scopes have all of the controls described in these books, along with some additional features. The 2246 has four independent vertical channels instead of just two, so that four separate signals can be displayed at once. We also have two separate horizontal sweeps (called A and B) which allow traces with two different sweep speeds to be displayed at the same time. (The main use for this is to zoom in and magnify a small part of a trace while still displaying the full trace.) Finally we have a built-in digital measurement and cursor capability which is very useful for making measurements on the screen.

There are a few precautions to observe when operating the oscilloscope:

- Avoid burning out the screen. Turn down the intensity for a stationary bright spot, or a very bright line.
- Avoid overheating the instrument. Do not block ventilation of the interior by laying books or clothes on the case. This precaution applies to any instrument.
- Do not apply more than 400 V to any input terminal.
- Avoid serious or fatal injury from electrical shock. Voltages up to 14 kV occur inside the unit. Do not remove the cover or insert anything metallic through the vent holes.

Otherwise, the instrument is robust and cannot be damaged by wrong settings. Don't worry—turn it on and have fun.

We will begin by setting up the 'scope for basic one-channel operation. First, remove all cables left by previous users, and turn the 'scope on by depressing the ON/OFF button. Now set the panel controls as follows (you may want to use this standard setup in the future if you have trouble):

Beam Controls	A INTEN	Midrange	Intensity of the A sweep.
	B INTEN	Fully ccw	Turn off B sweep.

Digital Controls CLEAR

DISPLAY Press button

Inactivates the digital

measurement system.

Vertical Controls	POSITION (CH 1)	Midrange	Vertical position for Channel 1.
	MODE	CH 1 on	Select channel 1 to display.
	VOLTS/DIV	0.2 V	Sensitivity. Note value is displayed on screen.
	VAR	Fully cw	Variable sensitivity.
	COUPLING (CH 1)	GND	Gives 0 V input for setting baseline.
Horizontal Controls	POSITION	Midrange	Horizontal position. (At top near trigger controls.)
	10x MAG	Off	Expands horizontal trace.
	MODE	A	Selects A sweep only. (Just above TRACE SEP.)
	A SEC/DIV	1 ms	Sweep speed. Note value is displayed on screen.
	VAR	Fully cw	Variable sweep speed.
Trigger Controls	SOURCE	CH 1	Use CH 1 signal for triggering.
	A/B SELECT	A	Adjust A trigger settings.
	MODE	AUTO	Sweep even when no signal present.
	COUPLING	DC	Send CH 1 directly to trigger with no filtering.

The baseline beam trace should appear as a horizontal straight line. Readjust A INTEN for desired brightness, move the trace vertically until it coincides with the X-axis using POSITION (CH 1). Position the start of the trace so that it is visible at the left hand side of the screen using the horizontal POSITION control which is located at the top of the panel near the trigger controls.

If no trace is visible, check that the trigger MODE is on AUTO. If that fails, depress BEAM FIND to obtain a shrunken picture. See if the trace has been displaced off the screen and center it with the position controls if necessary. If you still don't see a trace, get help from an instructor.

Next we will try to display the signal from the scope CALIBRATOR output on the screen. Connect the CALIBRATOR output to the CH 1 input with a short coaxial cable and the alligator clip x1 probes. Note that the outside of the coax is always ground, and the inner conductor carries the signal. The inner conductor is connected to the red clip, so connect the red clip to the CALIBRATOR output. Now set the CH 1 vertical COUPLING to DC. A signal should appear on screen. Adjust the TRIGGER LEVEL (upper right corner of panel) to give a stable and stationary waveform. Get some help if you can't see the waveform.

Explore the effect of the following controls one at a time. Return each control to the original setting before you change the next. When using the variable scale controls (VAR), be sure to find the position of VAR that gives a calibrated display.

- CH 1 VOLTS/DIV, both the calibrated control and VAR (variable).
- SWEEP A SEC/DIV, both the calibrated control and VAR.
- CH 1 COUPLING: AC/DC/GND. Observe and understand the change in level.
- TRIGGER LEVEL and SLOPE.

The trigger level controls the voltage at which the trace starts. Stability is lost when the trigger level lies outside range of the displayed voltage. Change TRIGGER MODE to NORMAL. Note that the trace now disappears when the trigger level is misadjusted.

Measure the peak-to-peak (p-p) voltage and the period of the waveform. The peak-to-peak voltage is the difference between the high and low extremes of the waveform. First adjust the scale factors to give a large trace—between 50% and 95% of the screen in height and about two periods horizontally. Check that the VAR controls are fully cw. Finally measure the dc voltages of the lowest and highest part of the waveform, and measure the time for a complete cycle. What is the frequency of the waveform? Do the peak-to-peak amplitude and the frequency agree with the markings on the 'scope panel?

Now try to get the same trace showing the CALIBRATOR signal, but use the CH 2 vertical input.

TEXTRONIX FG 504 FUNCTION GENERATOR

The FG 504 provides sine, square, triangle, pulse and ramp waveforms over the frequencies from 0.001 Hz to 40 MHz in ten decades. The output amplitude is 10 mV to 30 V peak-to-peak from an impedance of 50 Ω. The frequency may be controlled manually or swept automatically between START and STOP frequency dial settings with a linear or logarithmic sweep. The symmetry of the waveform may be varied, enabling square waves to be turned into pulses and triangle waves into ramps. The output may be modulated either by amplitude modulation or frequency modulation.

Power is supplied to the function generator by the TM504 power module into which the function generator and counter/timer are plugged. The ON/OFF switch is located at the right hand edge of the power module.

Again there are a few precautions to keep in mind:

- Turn the TM504 power module off before removing or inserting the FG 504 or any other plug in unit. Insertion or removal with power on can destroy the circuitry due to arcing at the rear terminals.

- Do not cover the perforated outer case—the instrument will overheat.
- Do not connect any output of the FG 504 directly to dc power or to the <u>output</u> of any other instrument. Doing so will burn out the output amplifier.

Except for these precautions the instrument cannot be damaged by incorrect settings.

We will set up the FG 504 as a free running oscillator with manual control of frequency. This is almost always the way we will use it. Remove any cables left by previous users, and turn the function generator on using the switch on the power module. Then set the panel controls as follows to generate a 1 V p-p sine wave at 1 kHz with no dc offset (you may want to use this standard setup in the future if you have trouble):

<u>Frequency Sweep</u>	SWEEP DURATION	OFF	Turn off frequency sweep.
<u>Trigger</u>	TRIGGER	FREE RUN	Free running oscillator, not triggered by ext. signal.
<u>Frequency</u>	RUN/HOLD	RUN	Do not freeze output signal.
	START FREQUENCY	10 Hz	Sets operating frequency.
	STOP FREQUENCY	anywhere	Not active.
	MULTIPLIER	10^2	$10\ \text{Hz} \cdot 10^2 = 1\ \text{kHz}$
	VAR	Fully cw	Calibrated position.
<u>Shape</u>	∼	Button in	Select sine waveform.
	RISE & FALL TIME	Fixed	Only effects square wave.
	SYMMETRY	Push in	No symmetry distortion.
<u>Amplitude</u>	ATTENUATOR	1 V = -30 dB	Set p-p amplitude.
	VAR	Fully cw	Calibrated position.
<u>DC Level</u>	OFFSET	Push in	No output dc offset.

Use a BNC coaxial cable to connect the function generator OUTPUT (lower right corner of panel) to the CH 1 input of the oscilloscope. Set up the 'scope to view the signal on channel 1 with dc coupling. Adjust the 'scope trigger level to obtain a stable waveform. Observe the sine wave and verify that the amplitude and frequency are as expected from the function generator controls.

Explore the effect on the waveform of the following controls. Vary only one control at a time and return it to its original value before changing to the next.

- Depress the ⊓⊔ (square), ∧∨ (triangle), and ∿ (sine) buttons and observe the waveforms.
- Rotate ATTENUATOR and VAR controls. Observe the amplitude changes.
- Pull out OFFSET knob and rotate it. Note the change in dc level.
- Set to ⊓⊔ (square) and vary the RISE & FALL TIME throughout its range.
- Set to ⊓⊔ (square), pull out SYMMETRY knob, and rotate through full range.
- Return to ∿ (sine) and change the FREQUENCY and MULTIPLIER.

Note that when symmetry knob is out, the frequency is divided by ten. Short pulses can be generated in this mode.

The function generator has a trigger output which can be used to trigger the 'scope. Using the trigger output is more convenient than triggering the scope off of the waveform itself because you avoid having to readjust the 'scope trigger every time you change the waveform. To see how the trigger output works, first return the function generator to 1 V p-p sine waves at 1 kHz with zero dc offset. Then push in both the CH 1 and the CH 4 vertical MODE buttons on the 'scope so that both channels will be displayed. Set the 'scope trigger SOURCE to CH 4, and connect a coaxial cable from the function generator trigger output to the 'scope CH 4 input. (Your set-up should now look like Figure 1.4 except you will not yet have the counter/timer connected.) Observe both the sine wave and the trigger signal on the 'scope. Adjust the 'scope trigger level for a stable display. Now change the amplitude and frequency of the sine wave, and notice how the 'scope remains nicely triggered.

TEXTRONIX DC 504A COUNTER/TIMER

The DC 504A counter/timer can measure frequencies in the range from 0.01 Hz to 100 MHz. The frequency is measured by counting the number of cycles of the input waveform which pass through a gate that is opened for a definite time. The gating time can be set to values from 10 ms to 10 s with an accuracy of about 1 part in 10^6, which is achieved by using a 10 MHz quartz crystal clock. The frequency display on the instrument reads directly in kHz. The DC 504A can also be used to measure time intervals.

The DC 504A is simple enough that we can describe the function of all of its controls here. The FUNCTION knob controls the basic operating mode. There are two different ranges for frequency measurements, 0-10 MHz and 0-100 MHz. Use the 0-100 MHz range only for frequencies above 10 MHz. In the PERIOD mode the operation is the same as in the 0-10 MHz frequency mode except that the period rather than the frequency is displayed. The two WIDTH modes allow measurements of the duration of either positive or negative pulses, and the TOTALIZE mode simply counts pulses until the counter is reset. The TIME/AVGS knob selects the gate time for frequency measurements or the number of pulses to be averaged in time measurement modes. If you select a long time the measurements will be more accurate but the display will be updated less often. The input coupling controls are like those on a 'scope, and the trigger level adjusts the voltage threshold that the input waveform must cross to be counted. The input attenuator has two settings, X1 for signals up to 4 V p-p, and X5 for signals up to 20 V p-p. Finally, the reset button resets the counter (used with TOTALIZE), and the DISPLAY UPDATE button freezes the display.

We will use the counter/timer to precisely measure the frequency of signals from the function generator. First complete the test set-up shown in Figure 1.4 by connecting the function generator trigger output to the counter/timer input. Since the trigger output now goes to two places, you will have to use a BNC "tee" adapter. Set the function generator to produce 1 kHz sine waves.

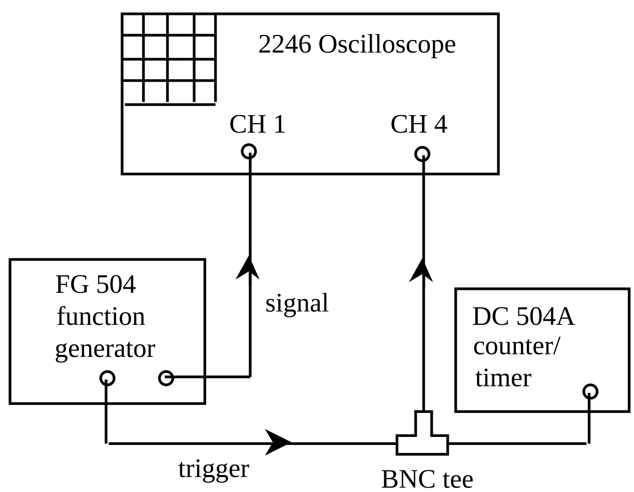


Figure 1.4 Measurement Set-up

To measure the frequency, set the counter/timer controls as follows:

FUNCTION	FREQ TO 10 MHz	Frequency measurement to 10 MHz.
TIME/AVG	0.1 SEC	Gate on for 0.1 s.
DISPLAY UPDATE	RUN	Do not freeze display.
COUPL	DC	Needed to measure low frequencies <10 Hz.
ATTEN	X5	Gives correct trigger range.
TRIGGER LEVEL		Adjust for stable reading

Adjust the trigger level for a stable reading. Check that the OVERFLOW light is not on. If it goes on, switch to a shorter gate time. Compare the frequency measured by the counter/timer with the frequency you expect from the function generator settings, and the frequency measured on the oscilloscope. Try changing the frequency, and explore the effect of the TIME/AVG setting.

Change FUNCTION to PERIOD. Note that the units are now microseconds, and check again that the OVERFLOW LAMP is OFF. Is the period measurement consistent with the frequency measurement?

FLUKE 77 DIGITAL MULTIMETER

Most measurements that are done with the digital multimeter could also be made with the 'scope, but the multimeter is usually more accurate, and it is very convenient for continuously monitoring steady voltages or currents.

Check the accuracy of the ohms range by measuring precision resistors of 1 Ω, 1 kΩ, and 1 MΩ. Identify an ordinary 1 kΩ 1/4-watt resistor by its color code and measure it with the multimeter.

Determine the frequency range for which the multimeter can be used to measure ac voltage. Generate 500 Hz sine waves of 1 V p-p amplitude with the function generator, and arrange that the oscilloscope and multimeter both measure the same signal. Be sure that the 'scope input is dc coupled. Determine the amplitude from the oscilloscope trace and compare with the multimeter reading. Note that the multimeter measures rms amplitudes and recall that p-p = $2\sqrt{2}$ rms. Now vary the frequency from 10 Hz to 10 kHz. What is the frequency range over which the multimeter reading is constant to within 2%? Remember in the future that this is the usable frequency range for the ac setting of the multimeter.

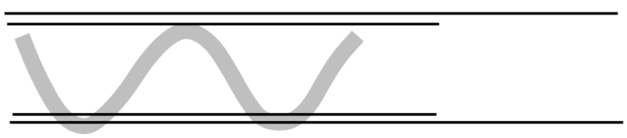
DIGITAL MEASUREMENTS WITH THE OSCILLOSCOPE

Digital measurements of voltage, time, and frequency can be made for signals in CH 1 and CH 2 of the oscilloscope. There are two modes of operation: a manual mode using CURSORS and an automatic mode called the CH 1/CH 2 VOLTMETER. The CURSORS are more accurate but the VOLTMETER is easier to use. A menu system is used to access the functions. The digital measurements will be most accurate when the displayed signal nearly fills the oscilloscope screen. Set the amplitude to cover about 5 divisions vertically and the sweep speed to give about 2 periods horizontally.

First try using the CURSORS to measure a 1 kHz sine wave from the function generator. Measure both the period and the frequency and compare with readings from the counter timer. Also measure the peak-to-peak amplitude. If you get lost in the menu system, you can always get back to the beginning by pressing the CLEAR DISPLAY button several times.

Next try out the CH 1/CH 2 VOLTMETER using the same 1 kHz sine wave. Measure the peak-to-peak amplitude and the dc level. Then introduce some dc offset from the function generator and note the changed readings.

Also, note that the automatic mode searches for the very top and bottom of the signals, which may not be what you want. For example, in the schematic of a noisy sine wave below, automatic mode will return the upper and lower most lines which will include the noise contribution. A careful manual measurement indicated by the inner (shorter) lines can remove the noise from the amplitude measurement.



SET UP TEST WAVEFORMS

This is an important check point to evaluate your understanding and skill. If you are having trouble, be sure to get help from an instructor.

Set the oscilloscope controls VOLTS/DIV and SEC/DIV such that the display covers about 5 vertical divisions and about 2 periods across the screen. Use the counter-timer and the digital measurements on the oscilloscope to verify that you have obtained the signal you are seeking.

1. 5 Hz triangle waves with a peak-to-peak amplitude of 3 V. (You will have to use NORMAL triggering, not AUTO. Why?)

2. 35 MHz sine waves with an amplitude of 500 mV.

3. 10 kHz square waves with low value at 0 V and high value at + 5.0 V.

4. Pulses at a frequency of 1 kHz, with an 800 μs low level at 0 V and a 200 μs high level at + 5.0 V. (This could be used as a TTL logic signal).