

PURPOSE: To be sure that each student begins the course with at least the minimum required knowledge of two instruments which we will be using continually this semester.

Refer to the appendix on the last page for preliminary details concerning the equipment to be used in this lab.

I. The *Linear-Sweep Mode* of Operation of a Dual-Trace Oscilloscope

A. In general there are two distinct modes of operation of an oscilloscope: the **linear-sweep mode** (called the "YT" mode on the Tektronix TDS210 oscilloscopes that we will use) and the **XY mode**.

The linear-sweep mode is the one you will use most often as you investigate voltage waveforms. The XY mode is essential for certain specialized displays. We will work with the linear-sweep mode first.

B. VERTICAL DEFLECTIONS AND SWEEP SPEED OF THE TWO TRACES

There is a bewildering array of knobs and switches on the front panel of any good oscilloscope. These knobs and switches are partitioned into operational groups or areas on the front panel. Soon you will learn which of the controls are used most often and then you can establish a kind of hierarchy of controls.

Now is a good time to begin to take a look at the *User Manual* for your oscilloscope.

Near the beginning of your manipulation of the controls, notice that you can insert a coaxial cable into the panel connector labelled "CH 1" and also a separate coaxial cable to "CH 2." These two **BNC bulkhead connectors** are the inputs to the two separate linear-sweep channels, usually called **CHANNEL ONE** and **CHANNEL TWO**, respectively. These two inputs allow you to display two different waveforms simultaneously. The **vertical deflections** of the oscilloscope traces that correspond to CH 1 and CH 2 are completely independent as far as the oscilloscope is concerned. (They may, of course, be related in some special and informative way in a circuit in which you are probing two different ports.) For a given input voltage the vertical deflection on a given channel is controlled by the VOLTS/DIV rotary switch. This is often called the **vertical gain control** for the channel.

However, the **linear sweep speeds** of the two traces, controlled by the SEC/DIV rotary switch, are always identical. You can choose a wide range of sweep speeds but the two traces move always at the sweep speed you have chosen.

C. With the help of an instructor, try to get both traces of the 'scope to appear on the 'scope screen. The two traces should show up as horizontal lines on the face of the 'scope if the sweep speed control is set so that the sweep is "fast." The sweep speed is controlled by adjustment of the "SEC/DIV" rotary switch.

If the SEC/DIV knob is turned counter-clockwise sufficiently far, you will observe "tracer-bullet" streaks moving at a constant speed horizontally and repeatedly from left to right.

You will notice that the "click-in" positions of the sweep speed control are calibrated in seconds per graticule division. (The **graticule** is the coordinate system superimposed on the 'scope screen.) So the shorter the interval in time, the faster the sweep speed. The fact that the calibration of the sweep speed control is indicated in seconds/division (and fractions of seconds/division) implies correctly that the two traces move across the screen at a *constant speed* for any given setting of the sweep speed control (SEC/DIV).

Record Your Observations Of The Following:

1. For what sweep speed settings are you able to actually detect the progress of the two traces as they move across the oscilloscope screen?
2. Do you ever see the traces moving from *right to left* on the screen?
4. At what sweep speed do you begin to see two very nearly continuous horizontal lines on the screen?
5. Now change the vertical position of at least one of the two traces on the screen. Can you move the CH 1 trace to positions that are alternately above and below the CH 2 trace? Ask your instructors if this is not clear.
7. Using a **BNC-to-BNC cable**, connect CH 1 to one of your **Stanford Research Systems (SRS) Model DS345** function generators. Put the SRS in the sine-wave mode and select a frequency of 350 Hz and an amplitude of about 1.0 V_{p-p} (i.e., 1.0 volts peak-to-peak). (Ask one of your instructors to explain what **peak-to-peak** means if this is unclear to you.) Your display will be affected now by the VOLTS/DIV knob for CH1 and by the SEC/DIV knob. In the space below, discuss briefly your observations of the consequences of changing these settings.

Now connect your other SRS function generator in the sine-wave mode to CH2 and adjust its frequency to 351 Hz at about the same amplitude as the signal you have on CH1. Now is a good time to learn how to **trigger** on the input to a chosen channel. (You are probably already triggering on one of the inputs.) With the help of your instructors, trigger the sweep on the input to CH1. When you are adjusted to this setting, the display on CH1 should be *stationary*. The display on CH2 is probably either blurred or in motion to the right or left. Describe below what you are observing in this situation.

Notice now that if you trigger on CH2 the waveform exhibited on CH2's trace is *stationary*. What is happening to the waveform on CH1 in this situation?

You are witnessing an experimental demonstration of the concept of **coherence** of two signals. Two sine waves are **coherent** if and only if their frequencies are absolutely equal. Two *independent* signal generators can never be *absolutely* coherent, but the SRSs you are using are such very precise, research-grade function generators that it is very difficult to observe any drift in the frequency of one SRS relative to the other, independent one.

II. Investigation Of The XY Mode Of Operation Of The Oscilloscope

1. Ask your instructors how to get into the **XY mode** on your 'scope. Once you are in the XY mode, the CH 1 signal causes deflection of the 'scope trace in the (horizontal) X-direction and the signal applied to CH 2 causes the Y-deflection.
2. Adjust the two frequencies on X and Y to be as nearly identical as you can with the precision you have on the SRS. (Notice that the precision with which you can set the frequency of the SRS is quite good!)

You should see the simplest of all **Lissajous figures**. (This is an ellipse with all of its possible forms, from purely linear to the completely open ellipse. This latter will be *circular* if the two amplitudes on X and Y are identical and the signals differ in phase by 90 degrees.) Try three different relative phase settings of the SRS function generators (with X and Y amplitudes identical) in the **phase-locked condition** at 1.000 kHz: 0°, 45°, and 90°. Describe your observations below for each of these three relative phases. (A simple picture for each will help.) Note that the amplitude settings on the SRS function generators should be the same and the voltage gains on X and Y channels should be the same for this part in order to see "the circle" in the 90-degree relative phase setting.

3. Describe below the effects of changing the X channel VOLTS/DIV knob and the Y channel VOLTS/DIV knob.

4. (A) Observe other Lissajous figures as you keep one function generator at a fixed frequency of 1.000 kHz and change the other one to 2.000 kHz and then to 3.000 kHz. Describe in the space below what you observe. (Notice whether the displays are very nearly *stationary* for these choices of frequencies.)

(B) Now with one SRS at 1.000 kHz pick some “arbitrary” frequency for the other SRS such as 2.3947 kHz and observe the display on the ‘scope. Is it stationary?

5. You can obtain a visual measure of the number of cycles occurring at the higher frequency per cycle of the lower frequency by observing how many times the signals at the two frequencies are TANGENT to the sides of the rectangle that encloses the display on the ‘scope screen. This is easy to do with sine waves only when the number of cycles per cycle is small.

To enhance your ability to get this measure of *cycles/cycle* it is sometimes convenient to put the SRS in the **triangle-wave mode**. In this mode the number of “tangent points” is easier to count.

Try this mode to get a measure of the cycles/cycle when the ratios are, for example, 4/5, and 3/2.5. We will adopt the convention that a ratio such as 4/5 means the ratio of frequencies at the X/Y inputs. In the space below give your results for the measure of X/Y cycles per cycle for 4/5 and 3/2.5.

8. The implication (an extrapolation) of the observations you have just made is that stationary patterns will be produced any time the two frequencies are in the ratio of two integers. Such frequencies are said to be **commensurable**.

This kind of operation in which the ratio of two frequencies can be measured to high accuracy is extremely useful in certain signal processing techniques, usually involving fairly high frequencies, such as several MHz on up to tens and hundreds of MHz.

IV. Exploring Some Other Functions and Uses of the Dual-Trace Oscilloscope

A. USING THE ADD FUNCTION OF THE 'SCOPE

1. Adjust the amplitudes of the two inputs on the display until they are equal. Now use the **ADD** function and observe the **linear superposition** of two waveforms of very nearly equal amplitude but slightly different frequencies, such as 21 kHz and 20 kHz. Make a reasonably clear drawing in the space below of what you observe in this addition process. (When you get to this point in the experiment, check with one of your instructors and let him see what you are observing before you draw it.)

2. Experiment with widely varying relative amplitudes of the sine waves into the two channels (and change the VOLTS/DIV gain knobs). Notice that the sum of two sine waves of different frequencies and different amplitudes can give unusual displays. Notice also that to make the most vivid display of superposition you need to keep the ratio of the two frequencies close to 1.0.

B. PHASE SHIFTING AND ADDITION OF TWO SINUSOIDS OF A GIVEN FREQUENCY

1. With a **phase shifter** provided by your instructors (explained by them at your work station) and using **JUST ONE SRS FUNCTION GENERATOR**, use a **BNC "TEE"** to split the signal from the SRS so that one coaxial connector goes to CH1 directly from the SRS and one coaxial connector goes to the input plug on the phase shifter. Then connect the output of the phase shifter to CH2 on the 'scope. (The frequency can be somewhere near 400 Hz in this part of the experiment.)

Trigger the linear sweep on CH1 at an appropriate speed so that at least five or six cycles of the waveform are conveniently visible on the 'scope screen. The signal produced by the input to CH2 will very likely be **out of phase** with the signal on CH1. If, by pure chance, the two are **in phase**, adjust the knob on the phase shifter to put the two waveforms out of phase. (That is, their crests and troughs do not occur simultaneously on the two-channel display.)

Experiment with changing the phase of one waveform relative to the other by adjustment of the phase shifter. Also notice what happens when you trigger on CH2 instead of CH1 during this adjustment and comment below on what you see.

2. Now, with the two waveforms adjusted to be clearly out of phase and each with peak-to-peak amplitude between one or two graticule divisions, ADD the two waveforms and observe the period of the resulting waveform. How does the period of the added waveforms compare with the period of the two separate waveforms?

Remember: Any two sine waves with the same frequency are said to be **coherent**. They need not be in phase to qualify as coherent.

3. In the space below (and on added sheet if necessary), show analytically that if you add two sinusoidal waves of the same frequency with arbitrary relative phase and arbitrary relative amplitudes you get a single sine wave of precisely the same frequency.

Appendix: Oscilloscopes, Oscilloscope Probes, and Function Generators

A. OSCILLOSCOPES

Oscilloscopes are used for the display and measurement of the voltage between two junctions, or **nodes**, in a circuit. Recall that any two nodes in a circuit constitute a single **port**.

Oscilloscopes can display constant **DC voltages**, but their principal use is in the display of *time-varying* voltages, almost always called **AC voltages**.

Oscilloscopes are especially well suited for the display and measurement of DC and AC which are *combined*. In this circumstance, the AC is said to “ride on” the DC. It is common to call the DC component of such a signal the **DC offset voltage**.

B. OSCILLOSCOPE PROBES

An **oscilloscope probe** is a (nearly always) coaxial cable with two leads of wire on one end and a **BNC (“bee-n-see”) connector** on the other end. The two leads at the one end nearly always have two **alligator clips** or one alligator clip and one spring-loaded hook attached to them so that these two leads may be connected easily to the two points in a circuit across which you want to measure the voltage. (Note that it is customary to refer to a **voltage** (or **potential difference**) as being *across* two **nodes** or *at* a **port**.) The end of the probe with the BNC connector attached to it plugs into one of the **input channels** on the ‘scope. The ‘scope input channels have BNC sockets on them. To connect the ‘scope probe to the ‘scope, you push the BNC plug onto the BNC socket and then turn the plug one-quarter turn to lock it firmly in place.

It is also common to connect instruments such as function generators to an oscilloscope directly by means of a **BNC-to-BNC cable**—a cable which has one BNC plug on each end.

Coaxial cables that you will encounter almost invariably consist of a flexible braided **shield** which surrounds a flexible dielectric material with a single wire along the center. (The braided shield is protected by a rubber cover usually, so the braided shield is not routinely visible.) The coaxial cable has special characteristics which make it suitable for use as a **transmission line** at high frequencies (tens and hundreds of MHz). We will probably not need to take advantage of this feature of coaxial cables in Physics 326. However, you will see this kind of activity in Physics 426. For now, the coaxial cable is simply a convenient **shielded two-conductor pair**.

C. FUNCTION GENERATORS

A **function generator** is a device capable of producing time-varying voltage waveforms in several different *shapes* (such as **sine waves**, **triangle waves**, and **square waves**). Generators which produce only *sine waves* are nearly always referred to as **signal generators**.

All common function generators and signal generators have controls which allow the user to adjust the frequency and the amplitude of the signal produced. It is quite common to encounter function generators and signal generators which are capable of producing signals with amplitudes ranging from a few millivolts up to 20.0 volts peak-to-peak. (The phrase “volts **peak-to-peak**” means the amplitude of a time-varying signal as measured between the positive (highest) peak and the negative (lowest) peak. Note that, for sine waves, this is simply twice the conventional amplitude.) The range of frequencies that can be produced by function generators and signal generators varies greatly among different manufacturers and models of generators. To get a greater range of frequencies (particularly to get *high* frequencies such as tens of MHz or a few GHz), you have to pay more money. But it is quite common to work with signal generators that work in the range from a fraction of one hertz to a few megahertz. The **Stanford Research Systems Model DS345** function generators that we will use most of the time in this lab work from 1.0 millihertz up to 30.2 megahertz (in the sine-wave mode).