CHAPTER 9. MEASUREMENT TECHNIQUES

Rather than attempt to describe how to make every possible measurement, this chapter describes common measurement techniques you can use in many applications.

The Foundations: Amplitude and Time Measurements
The two most basic measurements you can make are amplitude and time; almost every other measurement you'll make is based on one of these two fundamental techniques.

Since the oscilloscope is a voltage-measuring device, voltage is shown as amplitude on your scope screen. Of course, voltage, current, resistance, and power are related:

$$\text{current} = \frac{\text{voltage}}{\text{resistance}}$$

$$\text{resistance} = \frac{\text{voltage}}{\text{current}}$$

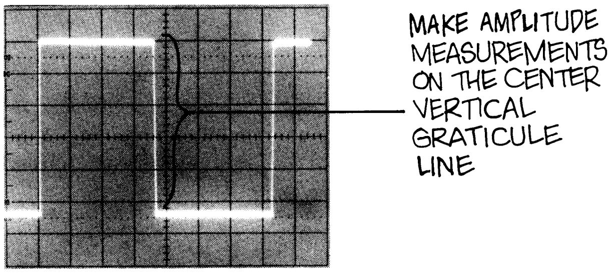
$$\text{power} = \text{current} \times \text{voltage}$$

Amplitude measurements are best made with a signal that covers most of the screen vertically. Use Exercise 6 to practice making amplitude measurements.

Time measurements are also more accurate when the signal covers a large area of the screen. Continue with the set-up you had for the amplitude measurement, but now use Exercise 7 to make a period measurement.

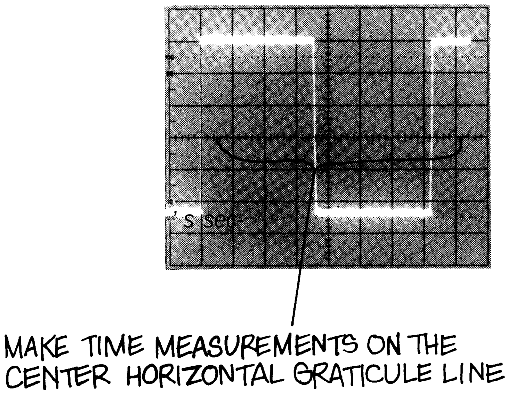
Exercise 6. AMPLITUDE MEASUREMENTS

1. Connect your probe to the channe 7/BNC connector and to the probe adjustment jack. Attach the probe ground strap to the collar of the channel 2 BNC. Make sure your probe is compensated and that all the variable controls are set in their detent positions.
2. The trigger MODE switch should be set to NORM for normal triggering. The HORIZONTAL MODE should be NO DLY (A on the 2275). Make sure the channel 7 coupling switch is set to AC and that the trigger SOURCE switch is on internal and the INT switch on CH 7. Set the VERTICAL MODE switch to CH 7 as well.
3. Use the trigger LEVEL control to obtain a stable trace and move the volts /division switch until the probe adjust square wave is about five divisions high. Now turn the seconds/division switch until two cycles of the waveform are on your screen. (The settings should be 0.7 V on the VOLTS/D/V and 0.2 ms on the SEC/DIV switches.)
4. Now use the CH 7 vertical POSITION control to move the square wave so that its top is on the second horizontal graticule line from the top edge of the screen. Use the horizontal position control to move the signal so that the bottom of one cycle intersects the center vertical graticule line.
5. Now you can count major and minor divisions down the center vertical graticule line and multiply by the VOLTS/DIV setting to make the measurement. For example, 5.0 divisions times 0.7 volts equals 0.5 volts. (If the voltage of the probe adjustment square wave in your scope is different from this example, that's because this signal is not a critical part of your scope and tight tolerances and exact calibration are not required.)



Exercise 7. TIME MEASUREMENTS

Time measurements are best made with the center horizontal graticule line. Use the instrument settings from Exercise 6 and center the square wave vertically with the vertical POSITION control. Then line up one rising edge of the square wave with the graticule line that ond from the lefthand side of the screen with the HORIZONTAL position control. Make sure the next rising edge intersects the center horizontal graticule. Count major and minor divisions across the center horizontal graticule line from left to right as shown in the photo above. Multiply by the SEC/DIV setting; for example, 5.7 divisions times 0.2 milliseconds equals 7.74 milliseconds. (If the period of the probe adjustment square wave in your scope is different from this example, remember that this signal is not a critical part of the calibration of your scope.)



Frequency and Other Derived Measurements

The voltage and time measurements you just made are two examples of direct measurements. Once you've made a direct measurement, there are derived measurements you can calculate. Frequency is one example; it's derived from period measurements. While period is the length of time required to complete one cycle of a periodic waveform, frequency is the number of cycles that take place in a second. The measurement unit is a hertz (1 cycle/second) and it's the reciprocal of the period. So a period of 0.00114 second (or 1.14 milliseconds) means a frequency of 877 Hz.

More examples of derived measurements are the alternating current measurements illustrated by Figure 24.

Pulse Measurements

Pulse measurements are important when you work with digital equipment and data communications devices. Some of the signal parameters of a pulse were shown in Figure 20, but that was an illustration of an ideal pulse, not one that exists in the real world. The most important parameters of a real pulse are shown in Figure 25.

Use Exercise 8 to make derived measurements with the probe adjustment square wave.

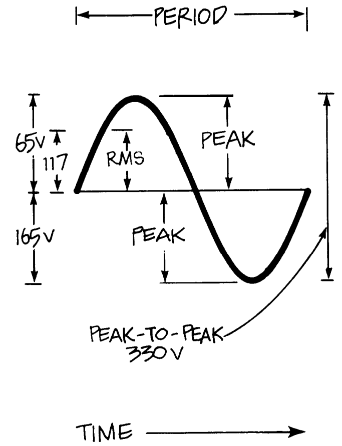


Figure 24.
DERIVED MEASUREMENTS are the result of calculations made after direct measurements. For example, alternating current measurements require an amplitude measurement first. The easiest place to start is with a peak-to-peak amplitude measurement of the voltage — in this case, 330 volts because peak-to-peak measurements ignore positive and negative signs. The peak voltage is one-half that (when there is no DC offset), and is also called a *maximum value;* it's 165 V in this case. Theaverage *value* is the total area under the voltage curves divided by the period in radians; in the case of a sine wave, the average value is 0 because the positive and negative values are equal. The RMS (root mean square) voltage for this sine wave — which represents the line voltage in the United States- is equal to the maximum value divided by the square root of 2: 165 ÷ 1.414 = 117 volts. You get from peak-to-peak to RMS voltage with: peak-to-peak ÷ 2 x the square root of 2.

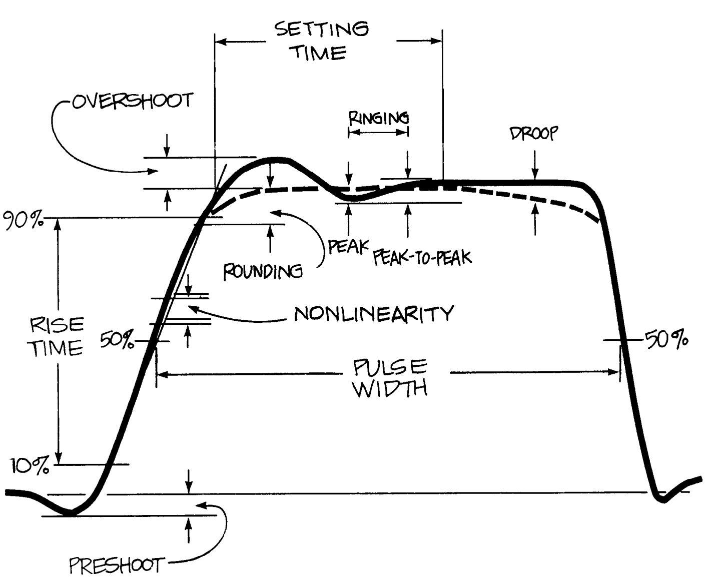


Figure 25.
REAL PULSE MEASUREMENTS include a few more parameters than those for an ideal pulse. In the diagram above, several are shown. Preshooting is a change of amplitude in the opposite direction that precedes the pulse. Overshooting and rounding are changes that occur after the initial transition. Ringing is a set of amplitude changes — usually a damped sinusoid -that follows overshooting. All are expressed as percentages of amplitude. Settling time expresses how long it takes the pulse to reach it maximum amplitude. Droop is a decrease in the maximum amplitude with time. And nonlinearity is any variation from a straight line drawn through the 10 and 90% points of a transition.

Exercise 8. DERIVED MEASUREMENTS

With the period measurement you just made in Exercise 7, calculate the frequency of the probe adjustment square wave. For example, if the period is 7 millisecond, then the frequency is the reciprocal, 7 IO.007 or 7000 Hz. Other derived measurements you can make are duty cycle, duty factor, and repetition rate. Duty cycle is the ratio of pulse width to signal period expressed as a percentage: 0.5 ms ÷ 7 ms, or 50%. But you knew that because for square waves, it's always 50%. Duty factor is 0.5. And the repetition rate (describing how often a pulse train occurs) is 7 /second in this case because repetition rate and frequency are equal for square waves. Your probe adjustment signal might differ slightly from this example; calculate the derived measurements for it. You can also calculate the peak, peak-to-peak, and average values of the probe adjustment square wave in your scope, Don't forget that you need both the alternating and direct components of the signal to make these measurements, so be sure to use direct coupling (DC) on the vertical channel you're using.

Use the directions in Exercise 9 to make a pulse measurement on the probe adjustment square wave.

Exercise 9.
PULSE WIDTH MEASUREMENTS

To measure the pulse width of the probe adjustment square wave quickly and easily, set your scope to trigger on and display channel 7. Your probe should still be connected to the channel 7 BNC connector and the probe adjustment jack from the previous exercises. Use 0.7 ms / division and the no delay horizontal mode (A sweep if you're using a 2275). Use AUTO triggering on the positive slope and adjust the trigger LEVEL control to get as much of the leading edge as possible on your screen. Switch the coupling on channel 7 to ground and center the baseline on the center horizontal graticule. Now use AC coupling because that will center the signal on the screen and you make pulse width measurements at the 50 % point of the waveform. Use your horizontal POSITION control to line up the 50 % point with the first major graticule from the left side of the screen. Now you can count divisions and subdivisions across the center horizontal and multiply by the SEC/D/V switch setting to find the pulse width.

Phase Measurements

You know that a waveform has phase, the amount of time that has passed since the cycle began, measured in degrees. There is also a phase relationship between two or more waveforms: the phase shift (if any). There are two ways to measure the phase shift between two waveforms. One is by putting one waveform on each channel of a dual-channel scope and viewing them directly in the chop or alternate vertical mode; trigger on either channel. Adjust the trigger LEVEL control for a stable display and measure the period of the waveforms. Then increase the sweep speed so that you have a display something like the second drawing back in Figure 22. Then measure the horizontal distance between the same points on the two waveforms. The phase shift is the difference in time divided by the period and multiplied by 360 to give you degrees.

Displaying the two waveforms and measuring when one starts with respect to another is possible with any dual trace scope, but that isn't the only way to make a phase measurement. Look at the front panel and you'll see that the vertical channel BNC connectors are labeled X and Y. The last position on the SEC/DIV switch is XY, and when you use it, the scope's time base is bypassed. The channel 1 input signal is still the horizontal axis of the scope's display, but now the signal on channel 2 becomes the vertical axis. In the X-Y mode, you can input one sinusoidal on each channel and your screen will display a Lissajous pattern. (They are named for Jules Antoine Lissajous, a French physicist; say "LEE-za-shu"). The shape of the pattern will indicate the phase difference between the two signal. Some examples of Lissajous patterns are shown in Figure 26.

Note that general purpose oscilloscope Lissajous pattern phase measurements are usually limited by the frequency response of the horizontal amplifier (typically designed with far less bandwidth than vertical channels). Specialized X-Y scopes or monitors will have almost identical vertical and horizontal systems.

X-Y **Measurements**

Finding the phase shift of two sinusoidal signals with a Lissajous pattern is one example of an X-Y measurement. The X-Y capability can be used for other measurements as well. The Lissajous patterns can also be used to determine the frequency of an unknown signal when you have a known signal on the other channel. This is a very accurate frequency measurement as long as your known signal is accurate and both signals are sine waves. The patterns you can see are illustrated in Figure 26, where the effects of both frequency and phase differences are shown.

Component checking in service or production situations is another X-Y application; it requires only a simple transistor checker like that shown in Figure 27

There are many other applications for X-Y measurements in television servicing, in engine analysis, and in 2-way radio servicing, for examples. In fact, any time you have physical phenomena that are interdependent and not time-dependent, X-Y measurements are the answer. Aerodynamic lift and drag, motor speed and torque, or

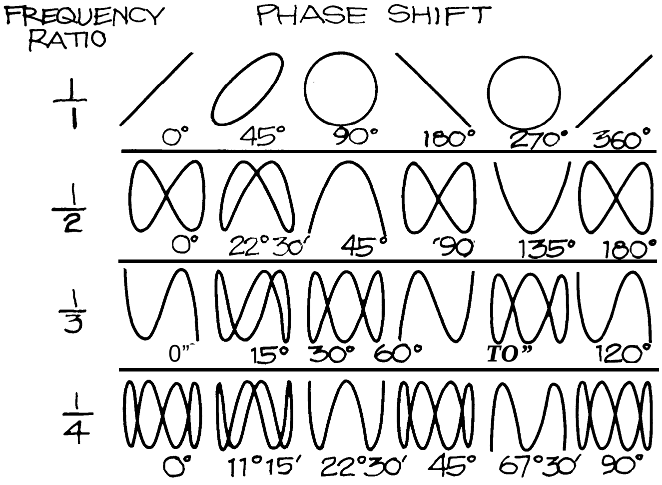


Figure 26.
FREQUENCY MEASUREMENTS WITH LISSAJOUS PATTERNS require a known sine wave on one channel. If there is no phase shift, the ratio between the known and unknown signals will correspond to the ratio of horizontal and vertical lobes of the pattern. When the frequencies are the same, only the shifts in phase will affect the pattern. In the drawings above, both phase and frequency differences are shown.

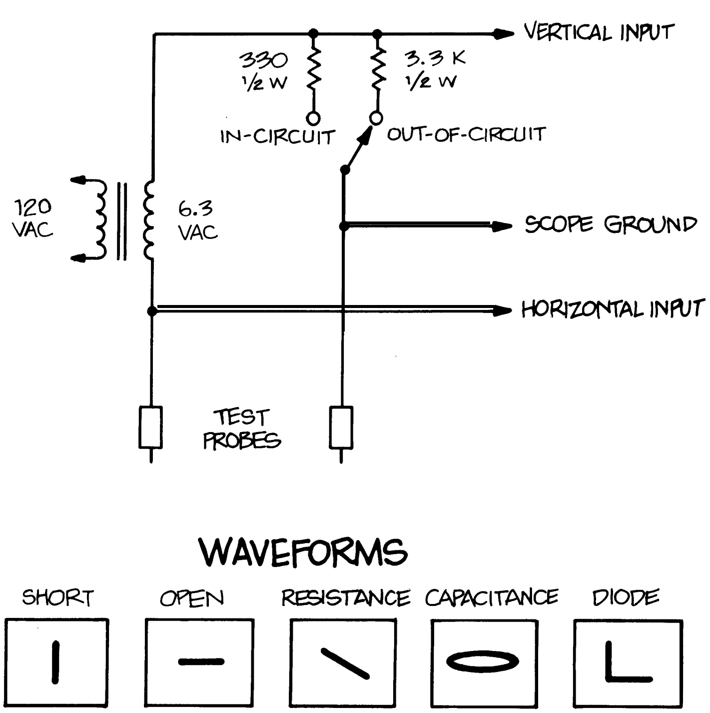


Figure 27.
X-Y COMPONENT CHECKING requires the transistor checker shown above. With it connected to your scope and the scope in the X-Y mode, patterns like those illustrated indicate the component's condition. The waveforms shown are found when the components are not in a circuit; in-circuit component patterns will differ because of resistors and capacitors associated with the component.

pressure and volume of liquids and gasses are more examples. With the proper transducer, you can use your scope to make any of these measurements.

Differential Measurements

The ADD vertical mode and the channel 2 INVERT button of your 2200 Series scope let you make differential measurements. Often differential measurements let you eliminate undesirable components from a signal that you're trying to measure. If you have a signal that's very similar to the unnecessary noise, the set up is simple. Put the signal with the spurious information on channel 1. Connect the signal that is like unwanted components to channel 2. Set both input coupling switches to DC (use AC if the DC components of the signal are too large), and select the alternate vertical mode by moving the VERTICAL MODE switches to BOTH and ALT

Now set your volts/division switches so that the two signals are about equal in amplitude. Then you can move the right-hand VERTICAL MODE switch to ADD and press the INVERT button so that the common mode signals have opposite polarities.

If you use the channel 2 VOLTS/DIV switch and VAR control for maximum cancellation of the common signal, the signal that remains on-screen will only contain the desired part of the channel 1input signal. The two common mode signals have cancelled out leaving only the difference between the two.

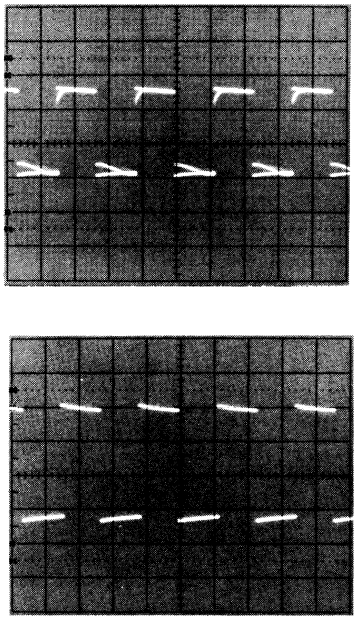


Figure 28.
DIFFERENTIAL MEASUREMENTS allow you to remove unwanted information from a signal anytime you have another signal that closely resembles the unwanted components. For example, the first photo shows a 1 kHz square contaminated by a 60 Hz sine wave. Once the common-mode component (the sine wave) is input to channel 2 and that channel is inverted, the signals can be added with the ADD vertical mode. The result is shown in the second photo.

Using the Z Axis

Remember from Part I that the CRT in your scope has three axes of information: X is the horizontal component of the graph, Y is the vertical, and Z is the brightness or darkness of the electron beam. The 2200 Series scopes all have an external Z-axis input BNC connector on the back of the instrument. This input lets you change the brightness (modulate the intensity) of the signal on the screen with an external signal. The Z-axis input will accept a signal of up to 30 V through a usable frequency range of DC to 5 MHz. Positive voltages decrease the brightness and negative voltages increase it; 5 volts will cause a noticeable change.

The Z-axis input is an advantage to users that have their instruments set up for a long series of tests. One example is the testing of high fidelity equipment illustrated by Figure 29.