CHAPTER 5. ALL ABOUT PROBES

Connecting all the measurement test points you'll need to the inputs of your oscilloscope is best done with a probe like the one illustrated in Figure 14. Though you could connect the scope and circuit-under-test with just a wire, this simplest of all possible connections would not let you realize the full capacities of your scope. The connection would probably load the circuit and the wire would act as an antenna and pick up stray signals — 60 Hz power, CBers, radio and tv stations — and these would be displayed on the screen along with the signal of interest.

Circuit Loading

Using a probe instead of a bare wire minimizes stray signals, but there's still an effect from putting a probe in a circuit called circuit loading. Circuit loading modifies the environment of the signals in the circuit you want to measure; it changes the signals in the circuit-under-test, either a little or lot, depending on how great the loading is.

Circuit loading is resistive, capacitive, and inductive. For signal frequencies under 5 kHz, the most important component of loading is resistance. To avoid significant circuit loading here, all you need is a probe with a resistance at least two orders of magnitude greater than the circuit impedance (100 MΩ probes for 1 MΩ sources; 1 MΩ probes for IO kΩ sources, and so on).

When you are making measurements on a circuit that contains high frequency signals, inductance and capacitance become important. You can't avoid adding capacitance when you make connections, but you can avoid adding more capacitance than necessary.

One way to do that is to use an attenuator probe; its design greatly reduces loading. Instead of loading the circuit with capacitance from the probe tip plus the cable plus the scope's own input, the 10X attenuator probe introduces about ten times less capacitance, as little as IO-14 picofarads (pF). The penalty is the reduction in signal amplitude from the 10:1 attenuation.

These probes are adjustable to compensate for variations in oscilloscope input capacitance and your scope has a reference signal available at the front panel. Making this adjustment is calledprobe *compensation* and you did it as the first step in Exercise 3 of Chapter 2.

Remember when you are measuring high frequencies, that the probe's impedance (resistance and reactance) changes with frequency. The probe's specification sheet or manual will contain a chart like that in Figure 15 that shows this change. Another point to remember when making high frequency measurements is to be sure to securely ground your probe with as short a ground clip as possible. As a matter of fact, in some very high frequency applications a special socket is provided in the circuit and the probe is plugged into that.

Measurement System Bandwidth

Then there is one more probe characteristic to consider: bandwidth. Like scopes, probes have bandwidth limitations; each has a specified range within which it does not attenuate the signal's amplitude more than -3 dB (0.707 of the original value). But don't assume that a 60 MHz probe and a 60 MHz scope give you a 60 MHz measurement capability. The combination will approximately equal the square root of the sum of the squares of the rise times (also see Chapter 10).

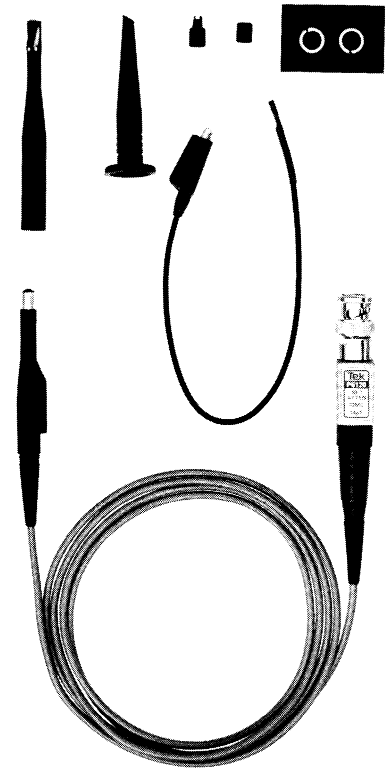

Figure 14.
PROBES CONNECTTHE SCOPE AND THE CIRCUIT-UNDER-TEST. Tektronix probes consist of a patented resistive cable and a grounded shield. Two P6120 probes and the accessories pictured above are supplied with every 2200 Series scope. The probe is a high impedance, minimum loading 10 X passive probe. The accessories for each probe (from left to right) are: a grabber tip for ICs and small diameter leads; a retractable hook tip; and IC tester tip cover; an insulating ground cover; marker bands; and (in the center) the ground lead.

For example, if both probe and scope have rise times of 5.83 nanoseconds:

$$T_{r\,(system)} = \sqrt{T_{r\,(scope)}^2 + T_{r\,(probe)}^2}$$

$$T_r = \sqrt{34 + 34}$$

That works out to 8.25 nanoseconds, the equivalent to a bandwidth of 42.43 MHz because:

$$BW_{(megahertz)} = \frac{350}{T_{r\ (nanoseconds)}}$$

To get the full bandwidth from your scope, you need more bandwidth from the probe. Or you use the particular probe designed for that instrument. For example, in the case of the 2200 Series scopes and the P6120 10X Passive Probe, the probe and the scope have been designed to function together and you have the full 60 MHz bandwidth at the probe tip..

Probe Types

Generally you can divide probes by function, into voltage-sensing and current-sensing types. Then voltage probes can be further divided into passive and active types. One of these should meet your measurement requirements.

PROBE TYPES	CHARACTERISTICS
1 X passive, voltage-sensing	No signal reduction, which allows the maximum sensitivity at the probe tip; limited bandwidths: 4-34 MHz; high capacitance: 32-l 12 pF; signal handling to 500 V
10X/100X/1000X passive, voltage-sensing, attenuator	Attenuates signals; bandwidths to 300 MHz; adjustable capacitance; signal handling to 500 V (10X), 1.5 kV (100X), or 20 kV (1000X)
active, voltage-sensing, FET	Switchable attenuation; capacitance as low as 1.5 pF; more expensive, less rugged than other types; limited dynamic range; but bandwidths to 900 MHz; minimum circuit loading
current-sensing	Measure currents from 1 mA to 1000 A; DC to 50 MHz; very low loading
high voltaae	Signal handling to 40 kV

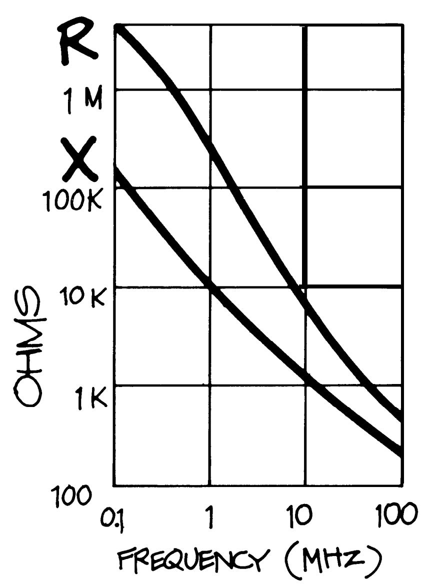

Figure 15.
PROBE IMPEDANCE IS RELATEDTO FREQUENCY as shown in the table above. The curves plot both resistance (R) and reactance (X) in ohms against frequency in megahertz. The plot shown is for the Tektronix P6120 probe on a l-meter cable.

Picking A Probe

For most applications, the probes that were supplied with your scope are the ones you should use. These will usually be attenuator probes. Then, to make sure that the probe can faithfully reproduce the signal for your scope, the compensation of the probe should be adjustable. If you're not going to use the probes that came with your scope, pick your probe based on the voltage you intend to measure. For example, if you're going to be looking at a 50 volt signal and your largest vertical sensitivity is 5 volts, that signal will take up ten major divisions of the screen. This is a situation where you need attenuation; a 10X probe would reduce the amplitude of your signal to reasonable proportions.

Proper termination is important to avoid unwanted reflections of the signal you want to measure within the cable. Probe/cable combinations designed to drive 1 megohm (1 MΩ) inputs are engineered to suppress these reflections. But for 50 Ω scopes, 50 Ω probes should be used. The proper termination is also necessary when you use a coaxial cable instead of a probe. If you use a 50 Ω cable and a 1 MΩ scope, be sure you also use a 50 Ω terminator at the scope input.

The probe's ruggedness, its flexibility, and the length of the cable can also be important (but remember, the more cable length, the more capacitance at the probe tip). And check the specifications to see if the bandwidth of the probe is sufficient, and make sure you have the adapters and tips you'll need. Most modern probes feature interchangeable tips and adaptors for many applications. Retractable hook tips let you attach the probe to most circuit components. Other adaptors connect probe leads to coaxial connectors or slip over square pins. Alligator clips for contacting large diameter test points are another possibility.

But for the reasons already mentioned (probe bandwidth, loading, termination), the best way to ensure that your scope and probe measurement system has the least effect on your measurements is to use the probe recommended for your scope. And always make sure it's compensated.

PART II. MAKING MEASUREMENTS

The first five chapters described how to select the exact oscilloscope functions you need to make the measurements you want. Now you can put what you've learned into practice with this section of the primer.

It begins with a review of waveform shapes and characteristics in Chapter 6. Then the discussions in Chapter 7 start with safety because you should always observe safety precautions when working on electrical equipment.

The first step in ensuring accurate measurements is making sure your scope is set up properly, and this subject is discussed in Chapter 8.

Chapter 9 discusses measurement techniques, beginning with fundamental time and amplitude measurements and ending with delayed sweep measurements.

The last chapter in the primer describes oscilloscope performance and how it affects your measurements.

CHAPTER 6. WAVEFORMS

The definition of a wave is "a disturbance traveling through a medium" while the definition of a *waveform* is "a graphic representation of a wave."

Like a wave, a waveform is dependent on two things: movement and time. The ripple on the surface of a pond exists as a movement of water in time. The waveform on your scope's screen is the movement of an electron beam during time.

The changes in the waveform with time form the waveshape, the most readily identifiable characteristic of a waveform. Figure 16 illustrates some common waveshapes.

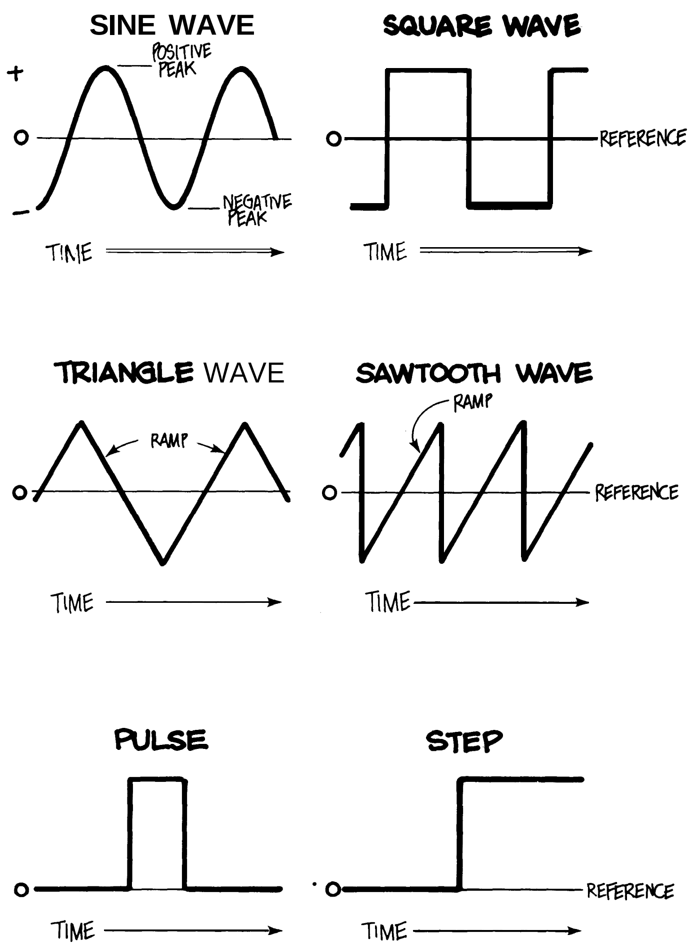

Figure 16.
BASIC WAVESHAPES include sine waves, and various non-sinusoidal waves such as *triangle waves, square waves,* and *sawtooth waves.* A square wave has equal amounts of time for its two states. Triangle and sawtooth waves are usually the result of circuits designed to control voltage with respect to time, like the sweep of an oscilloscope and some television circuits. In these waveforms, one (or both) transitions from state to state are made with a steady variation at a constant rate, a *ramp.* (Changes from one state to another on all waveforms except sine waves are called *transitions.)* The last two drawings represent aperiodic, single-shot waveforms. The first is a *pulse;* all pulses are marked by a rise, a finite duration, and a decay. The second one is a *step,* which is actually a single transition.

Waveshapes tell you a great deal about the signal. Anytime you see a change in the vertical dimension of a signal, you know that this amplitude change represents a change in voltage. Anytime there's a flat horizontal line, there was no change for that length of time. Straight diagonal lines mean a linear change, equal rise (or fall) of voltage for equal amounts of time. Sharp angles on a waveform mean a sudden change. But waveshapes alone are not the whole story. When you want to completely describe a waveform, you'll want to find the parameters of that particular waveform. Depending on the signal, these parameters might be amplitude, period, frequency, width, rise time, or phase. You can review these signal parameters with Figures 17 through 22.

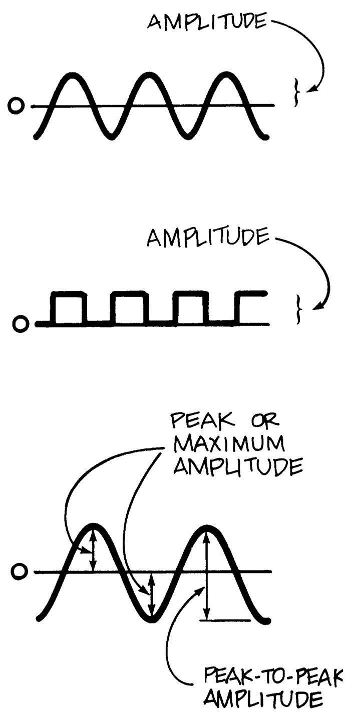

Figure 17.
AMPLITUDE IS A CHARACTERISTIC OF ALL WAVEFORMS. It is the amount of displacement from equilibrium at a particular point in time. Note that without a modifier, the word means the maximum change from a reference without regard to the direction of the change. In the first two drawings above (sine wave and square wave), the amplitude is the same even though the sine wave is larger from peak to peak. In the third drawing, an alternating current waveform is shown with peak (or maximum) amplitude and peak-to-peak amplitude parameters annotated. In oscilloscope measurements, amplitude usually means peak-to-peak amplitude.

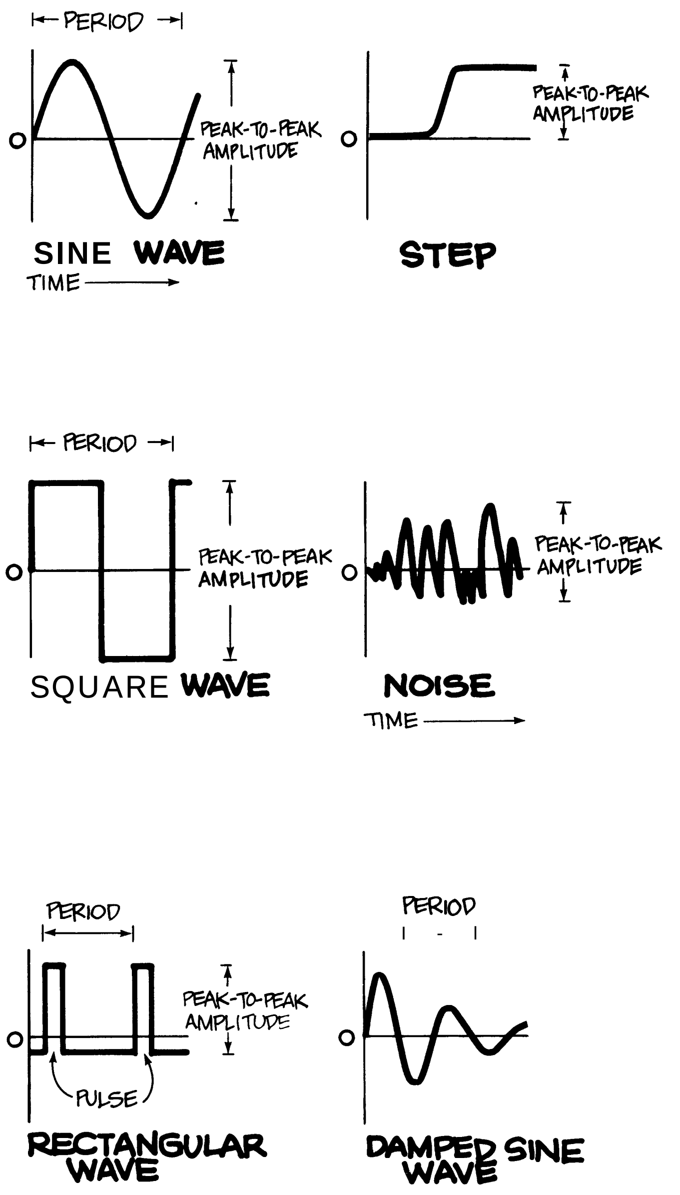

Figure 18.
PERIOD IS THE TIME REQUIRED FOR ONE CYCLE OF A SIGNAL if the signal repeats itself. Period is a parameter whether the signal is symmetrically shaped like the sine and square waves above, or whether it has a more complex and asymmetrical shape like the rectangular wave and damped sine wave. Period is always expressed in units of time. Naturally, one-time signals like the step or uncorrelated signals (without a time relation) like noise have no period.

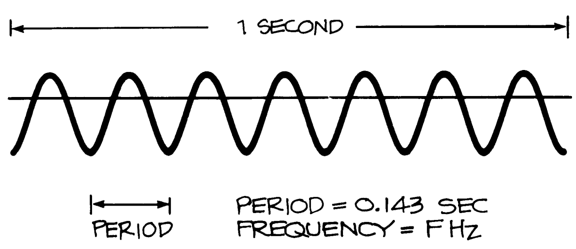

Figure 19.
IF A SIGNAL IS PERIODIC, IT HAS A FREQUENCY. Frequency is the number of times a signal repeats itself in a second; frequency is measured in Hertz: 1 Hz = 1 cycle per second; 1 kHz (kilohertz) = 1000 cycles/second; and 1 MHz (megahertz) = 1 ,000,000 cycles/second. Period and frequency are reciprocal: l/period = frequency, and l/frequency = period. For example, a 7 Hz signal has a period of 0.143 seconds: 1/7 Hz = 0.143 s, and 1/0.143 s = 7 Hz.

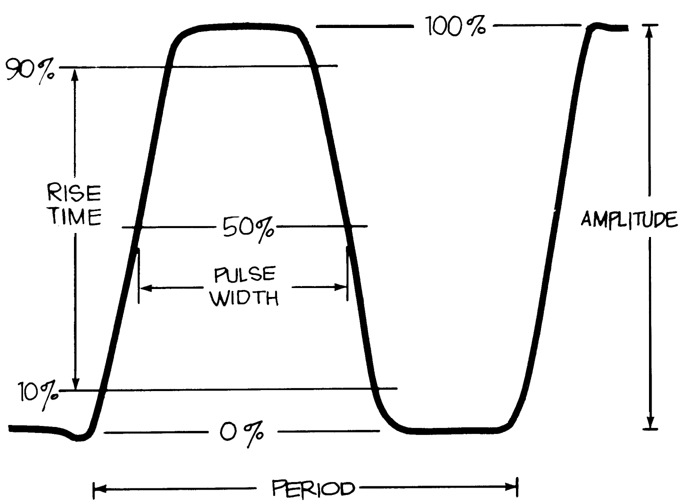

Figure 20.
THE PARAMETERS OF A PULSE can be important in a number of different applications. Digital circuitry, X-ray equipment, and data communications are examples. Pulse specifications include transition times measured on the leading edge of a positive-going transition; this is the rise *time. Fall time* is the transition time on a negative-going trailing edge. Pulse *width* is measured at the 50% points and amplitude from 0 to 100%. Any displacement from 0 volts for the base of the pulse is the baseline *offset.*

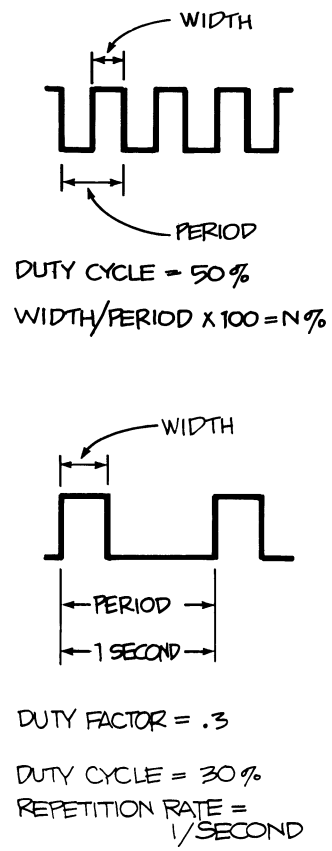

Figure 21.
DUTY CYCLE, DUTY FACTOR, AND REPETITION RATE are parameters of all rectangular waves. They are particularly important in digital circuitry. *Duty cycle* is the ratio of pulse width to signal period expressed as a percentage. For square waves, it's always 50% as you can see; for the pulse wave in the second drawing, it's 30%. *Duty factor* is the same thing as duty cycle except it is expressed as a decimal, not a percentage. A *repetition rate* describes how often a pulse train occurs and is used instead of frequency to describe waveforms like that in the second drawing.

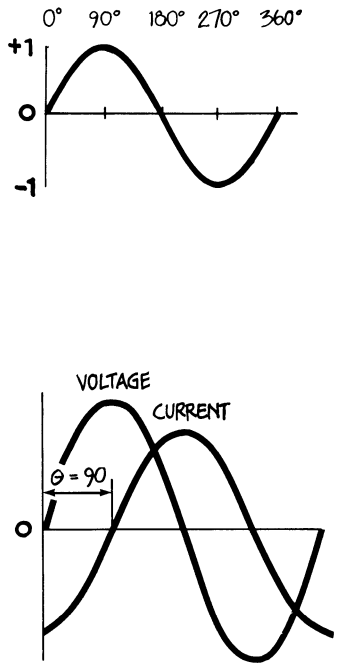

Figure 22.
PHASE is best explained with a sine wave. Remember that this waveform is based on the sine of all the angles from 0 through 360. The result is a plot that changes from 0 to 0°, 1 at 90°, 0 again at 180°, -1 at 270°, and finally 0 again at 360". Consequently, it is useful to refer to the phase angle (or simply phase, when there is no ambiquity) of a sine wave when you want to describe how much of the period has elapsed. Another use of phase is found when you want to describe a relationship between two signals. Picture two clocks with their second hands sweeping the dial every 60 seconds. If the second hands touch the twelve at the same time, the clocks are in phase; if they don't, then they're *out of phase.* To express how far out of phase they are, you use phase *shift* in degrees. To illustrate, the waveform labeled CURRENT in the drawing above is said to be 90° out of phase with the voltage waveform. Other ways of reporting the same information are "the current waveform has a 90 degree phase angle with respect to the voltage waveform" or "the current waveform lags the voltage waveform by 90°." Note that there is always a reference to another waveform; in this case, between the voltage and current waveforms of an inductor.