19 Pulse Measurements

OBJECTIVES:

After performing this experiment, you will be able to:

1. Measure rise time, fall time, pulse repetition time, pulse width, and duty cycle for a pulse waveform.
2. Explain the limitations of instrumentation in making pulse measurements.
3. Compute the oscilloscope bandwidth necessary to make a rise time measurement with an accuracy of 3%.

READING:

Floyd and Buchla, *Principles of Electric Circuits,* Sections 11–9, 11–10 and Application Activity
Oscilloscope Guide pp. 7-14

MATERIALS NEEDED:

One 1000 pF capacitor
Application Problem: One 2N3904 transistor, one 10 μF capacitor, resistors: 1.0 kΩ, 10 kΩ, 4.7 MΩ

SUMMARY OF THEORY:

A pulse is a signal that rises from one level to another, remains at the second level for some time, then returns to the original level. Definitions for pulses are illustrated in Figure 19–1. The time from one pulse to the next is the period, *T.* The reciprocal of the period is called the *pulse repetition frequency,* PRF. The time required for a pulse to rise from 10% to 90% of its maximum level is called the *rise time* and the time to return from 90% to 10% of the maximum level is called the *fall time.* Pulse width, abbreviated t_w, is measured at the 50% level, as illustrated. The duty cycle is the ratio of the pulse width to the period, usually expressed as a percentage:

$$\text{Percent duty cycle} = \left(\frac{t_w}{T}\right) 100\%$$

Actual pulses differ from the idealized model shown in Figure 19–1(a). They may have *sag, overshoot,* or *undershoot* as illustrated in Figure 19–1(b). In addition, if cables are mismatched in the system, *ringing* may be observed. Ringing is the appearance of a short oscillatory transient that appears at the top and bottom of a pulse, as illustrated in Figure 19–1(c).

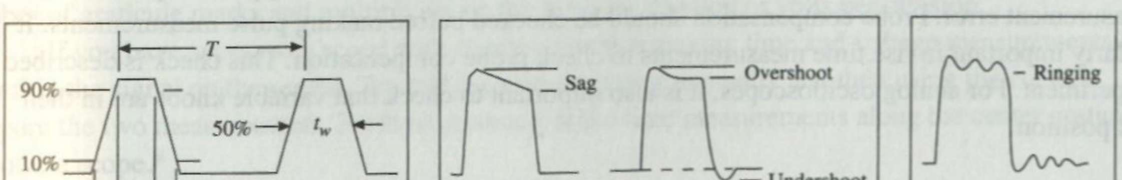

Figure 19–1

All measurements involve some error due to the limitations of the measurement instrument. In this experiment, you will be concerned with rise time measurements. The rise time of the oscilloscope's vertical amplifier (or digitizer's amplifier on a DSO) can distort the measured rise time of a signal. The oscilloscope's rise time is determined by the range of frequencies that can be passed through the vertical amplifier (or digitizing amplifier). This range of frequencies is called the bandwidth, an important specification generally found on the front panel of the scope. Both analog and digital oscilloscopes have internal amplifiers that affect rise time.

If the oscilloscope's internal amplifiers are too slow, rise time distortion may occur, leading to erroneous results. The oscilloscope rise time should be at least four times faster than the signal's rise time if the observed rise time is to have less than 3% error. If the oscilloscope rise time is only twice as fast as the measured rise time, the measurement error rises to over 12%! To find the rise time of an oscilloscope when the bandwidth is known, the following approximate relationship is useful:

$$t_{(r)\text{scope}} = \frac{0.35}{BW}$$

where $t_{(r)\text{scope}}$ is the rise time of the oscilloscope in microseconds and BW is the bandwidth in megahertz. For example, an oscilloscope with a 60 MHz bandwidth has a rise time of approximately 6 ns. Measurements of pulses with rise times faster than about 24 ns on this oscilloscope will have measurable error. A correction to the measured value can be applied to obtain the actual rise time of a pulse. The correction formula is

$$t_{(r)\text{true}} = \sqrt{t^2_{(r)\text{displayed}} + t^2_{(r)\text{scope}}}$$

where $t_{(r)\text{true}}$ is the actual rise time of the pulse, $t_{(r)\text{displayed}}$ is the observed rise time, and $t_{(r)\text{scope}}$ is the rise time of the oscilloscope. This formula can be applied to correct observed rise times by 10% or less.

In addition to the rise time of the amplifier or digitizer, digital scopes have another specification that can affect the usable bandwidth. This specification is the maximum sampling rate. The required sampling rate for a given function depends on a number of variables, but an approximate formula for rise time measurements is

$$\text{Usable bandwidth} = \frac{\text{Maximum sampling rate}}{4.6}$$

From this formula, a 1 GHz sampling rate (1 GSa/s) will have a maximum usable bandwidth of 217 MHz. If the digitizer amplifier's bandwidth is less than this, then it should be used to determine the equivalent rise time of the scope.

Measurement of pulses normally should be done with the input signal coupled to the scope using dc coupling. This directly couples the signal to the oscilloscope and avoids causing pulse sag which can cause measurement error. Probe compensation should be checked before making pulse measurements. It is particularly important in rise time measurements to check probe compensation. This check is described in this experiment. For analog oscilloscopes, it is also important to check that variable knobs are in their calibrated position.

PROCEDURE:

1. From the manufacturer's specifications, find the bandwidth of the oscilloscope you are using. Normally the bandwidth is specified with a 10X probe connected to the input. You should make oscilloscope measurements with the 10X probe connected to avoid bandwidth reduction. Use the

specified bandwidth to compute the rise time of the oscilloscope as explained in the Summary of Theory. This will give you an idea of the limitations of the oscilloscope you are using to make accurate rise time measurements. Enter the bandwidth and rise time of the scope in Table 19–1.

2. Look on your oscilloscope for a probe compensation output. This output provides an internally generated square wave, usually at a frequency of 1.0 kHz. It is a good idea to check this signal when starting with an instrument to be sure that the probe is properly compensated. To compensate the probe, set the VOLTS/DIV control to view the square wave over several divisions of the display. An adjustment screw on the probe is used to obtain a good square wave with a flat top. An improperly compensated oscilloscope will produce inaccurate measurements. If directed by your instructor, adjust the probe compensation.

3. Set the function generator for a square wave at a frequency of 100 kHz and an amplitude of 4.0 V. A square wave cannot be measured accurately with your meter—you will need to measure the voltage with the oscilloscope. Check the 0 V level on the oscilloscope and adjust the generator to go from 0 V to 4.0 V. Most function generators have a separate control to adjust the dc level of the signal.

4. Measure the parameters listed in Table 19–2 for the square wave from the function generator. If you are using an oscilloscope that has percent markers etched on the front graticule, you may want to adjust the VOLTS/DIV to set the signal from 0% to 100% when making rise and fall time measurements. Then measure the time between the 10% and 90% markers.

5. To obtain practice measuring rise time, place a 1000 pF capacitor across the generator output. Measure the new rise and fall times. Record your results in Table 19–3.

6. If you have a separate pulse output from your function generator, measure the pulse characteristics listed in Table 19–4. To obtain good results with fast signals, the generator should be terminated in its characteristic impedance (typically 50 Ω). You will need to use the fastest sweep time available on your oscilloscope. Record your results in Table 19–4.

FOR FURTHER INVESTIGATION:

Most modern oscilloscopes have cursors that let you make time or voltage measurements by moving the cursors to the measurement points and reading the time or voltage difference of the cursors on a readout directly. A cursor is a vertical or horizontal line that you can position manually. Cursors allow you measurements automatically, without having to count graticule marks. Vertical cursors are used for time measurements and horizontal cursors are used for voltage measurements. Although cursors simplify the measurement and help avoid errors, it is useful to practice making manual measurements by counting the number of graticule marks and multiplying by the time per division or volts per division.

If you have access to a scope with cursors, practice making time and voltage measurements by centering the signal on the screen. Try making measurements manually and then using the cursors; compare the two measurements. For best accuracy, make time measurements along the center graticule line of the scope.*

*For more information, download "XYZs of Oscilloscopes Primer" at https://www.tek.com

APPLICATION PROBLEM:

The bandwidth of a circuit is the range of frequencies it can pass as illustrated in Figure 19–2. If the lower frequency is very low or dc, the bandwidth is approximately equal to the upper frequency at which the output has dropped to 70.7% of the midband frequencies. The bandwidth of such an amplifier can be found by maintaining a sinusoidal signal at a constant level on the input and increasing the frequency until the output has dropped to 70.7% of the midband level. This frequency can then be measured with an oscilloscope.

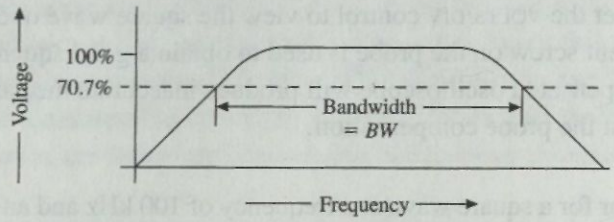

Figure 19–2

An alternative method for determining the bandwidth is to use a relatively fast rising square wave on the input and measure the rise time $t_{(r)}$ of the output signal. This method is good only for circuits with flat frequency responses, such as audio amplifiers. The bandwidth is given by

$$BW = \frac{0.35}{t_{(r)}}$$

Construct the transistor amplifier shown in Figure 19–3. Set the function generator for a 250 mV_{pp} sinusoidal wave at 100 kHz. It is a good idea to monitor both the input and output waveform to assure that the waveform into the circuit under test is undistorted. Measure the output voltage at the collector of the transistor. Then, while observing the output on an oscilloscope, raise the generator frequency until the output drops to 70.7%. You can use the 0% to 100% marks on the edge of the graticule for this. Measure this frequency and report it as the bandwidth of the circuit.

Change the input signal from a sine wave into a square wave at 100 kHz. Measure the rise time of the output square wave and use this measurement to determine the bandwidth. Compare the two methods in your report.

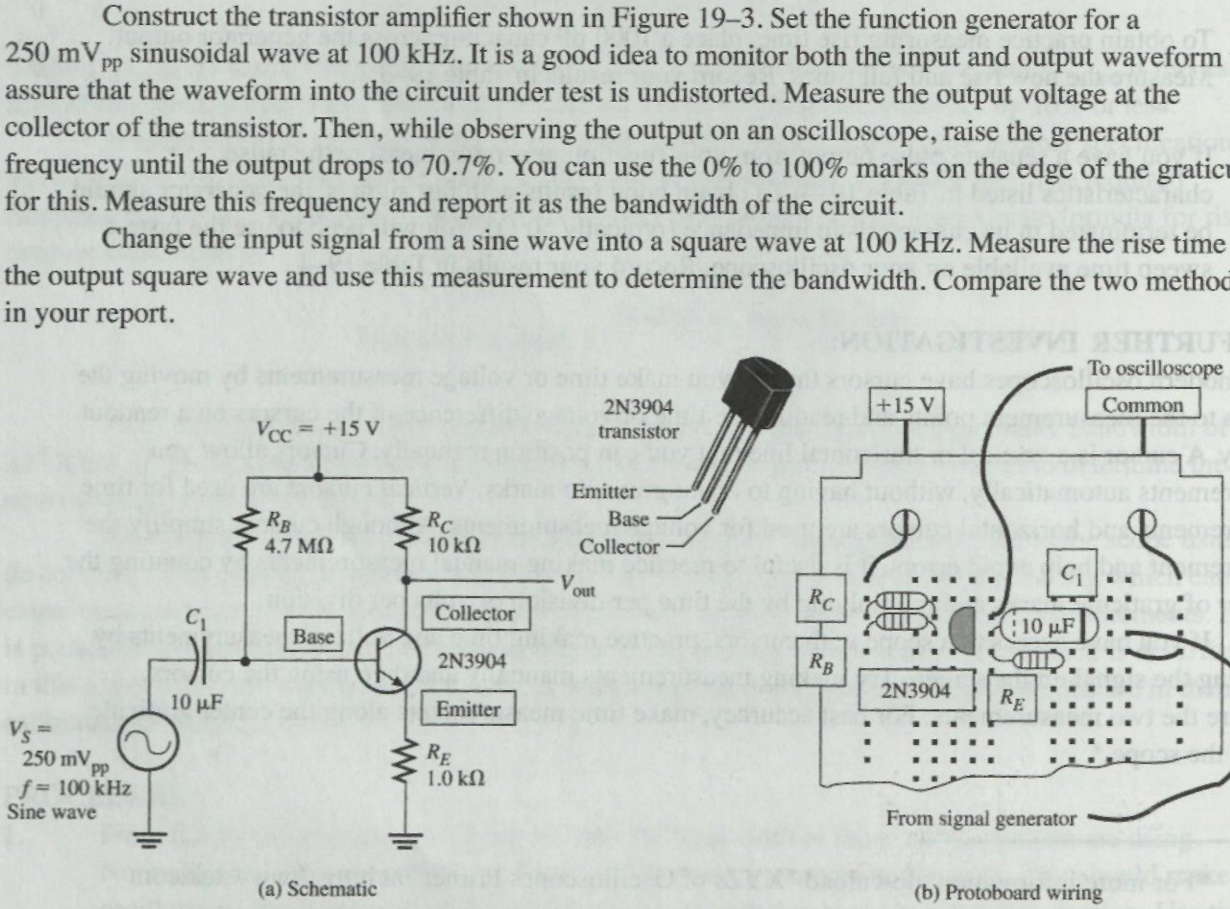

Figure 19–3

Report for Experiment 19

Name ____________
Date ____________
Class ____________

ABSTRACT:

DATA:

Table 19–1
Oscilloscope

$BW =$	
$t_{(r)} =$	

Table 19–2
Function Generator
(square wave output)

Rise time, $t_{(r)}$	
Fall time, $t_{(f)}$	
Period, T	
Pulse width, t_w	
% duty cycle	

Table 19–3
Function Generator
(with 1000 pF capacitor across output)

Rise time, $t_{(r)}$	
Fall time, $t_{(f)}$	

Table 19–4
Function Generator
(pulse output)

Rise time, $t_{(r)}$	
Fall time, $t_{(f)}$	
Period, T	
Pulse width, t_w	
% duty cycle	

RESULTS AND CONCLUSION:

FURTHER INVESTIGATION RESULTS:

APPLICATION PROBLEM RESULTS:

EVALUATION AND REVIEW QUESTIONS:

1. Were any of the measurements limited by the bandwidth of the oscilloscope? If so, which ones?

2. If you need to measure a pulse with a predicted rise time of 10 ns, what bandwidth should the oscilloscope have to measure the time within 3%? (Hint: the rise time of the scope should be 4X better than the pulse rise time.)

3. The SEC/DIV control on many analog oscilloscopes has a X10 magnifier. When the magnifier is ON, the time scale must be divided by 10. Explain.

4. An analog oscilloscope presentation has the SEC/DIV control set to 2.0 µs/div and the X10 magnifier is OFF. Determine the rise time of the pulse shown in Figure 19–4.

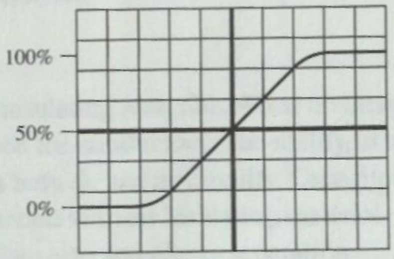

Figure 19–4

5. Repeat question 4 if the X10 magnifier had been ON.

6. Why are pulse measurements normally done using dc coupling for the signal?