Lab 1: Circuit Review

Goal

A voltage divider is a circuit that, given a certain voltage input, produces a predictable fraction of the input voltage as the output voltage. It is one of the most widespread electronic circuit fragments. Therefore, we will introduce basic instruments that will be used during the course and build and test a simple voltage divider during the Lab 1. The goal is to understand equivalent source resistance and circuit loading.

Objectives

1. Become familiar with CIRCUITLAB (`https://www.circuitlab.com/workbench/`) as tool to verify circuits before building it.
2. Become familiar with basic operations of the oscilloscope and the signal generator
3. Introduce different types of signals : Sinusoidal, triangle, square wave, pulses, and noise
4. Practice circuit building using a voltage divider
5. Collect and plot data
6. Compare observations from the voltage divider you build with the estimations made using calculations.
7. Discuss discrepancies in observations and calculations.

Expectations

1. You are expected to take detailed notes during each step outlined in the procedure that can be used during the lab report write-up.
2. You are expected to provide a neat table of the data that you measured where you clearly label what each data set is and include units for all measured quantities.
3. You are expected to clearly record the measured values of any components that you use.
4. You are expected to clearly record the detail related to images captured by the oscilloscope.
5. You are expected to make your final plots in a program such as Excel. Make sure that your data points appear clearly on the plots, that all axes are clearly labeled and have units.
6. If it is possible to compare your measurements with an expectation or a prediction, you are expected to do so in your lab report
7. You are expected to answer the questions encountered in this manual as well as discuss exercises given during the lectures in your lab write up.

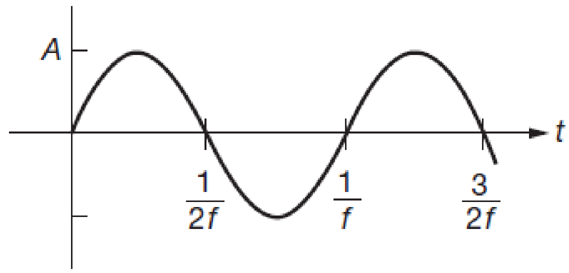

Figure 1: Sine wave of amplitude A and frequency f [1]

Introduction to Concepts

Signals are voltages that change in time in a unique way. They are the inputs and outputs of the circuits. Therefore it is useful to learn about certain common types of signals. You will learn about sinusoidal, triangle, square wave, pulses, and noise signals during the Lab 1.

Sinusoidal signals

Mathematically, what you have is a voltage described by

$$V = A\sin(2\pi ft \ + \phi)$$

where A is called the amplitude, f is the frequency in hertz (cycles per second), and ϕ is the phase offset of the wave. The angular frequency, $\omega \ = 2\pi f$ is measured in measured in radians per second (Figure 1).

In addition to its amplitude, peak-to-peak amplitude (pp-amplitude) is twice the amplitude, and root-mean-square amplitude (rms amplitude) $V_{rms} = (1/\sqrt{2}) \cdot A = 0.707 \cdot A$ are several other ways to characterize the magnitude of a any signal.

Ramp and its Variant Signals

A ramp a voltage rising (or falling) at a constant rate (Figure 2). A ramp can't go on forever and can be approximated by a finite ramp (Figure 2) or by a periodic ramp (known as a sawtooth, Figure 2). The triangle wave is a a symmetrical ramp (Figure 4)

Noise

Noise signals describe random noises of thermal origin. Noise voltages are characterized by their frequency spectrum (power per hertz) or by their amplitude distribution. One of the most common kind of noise signal is known as band-limited white Gaussian noise, which means a signal with equal power per hertz in some band of frequencies. When repeated measurements of its instantaneous amplitude are made, the distribution of amplitudes is a Gaussian (bell-shaped) distribution. These noise signals are originated by a resistor (Johnson noise or Nyquist noise), and it introduces uncertainty in sensitive measurements. Sample noise signal as it appears on an oscilloscope is shown in Figure.

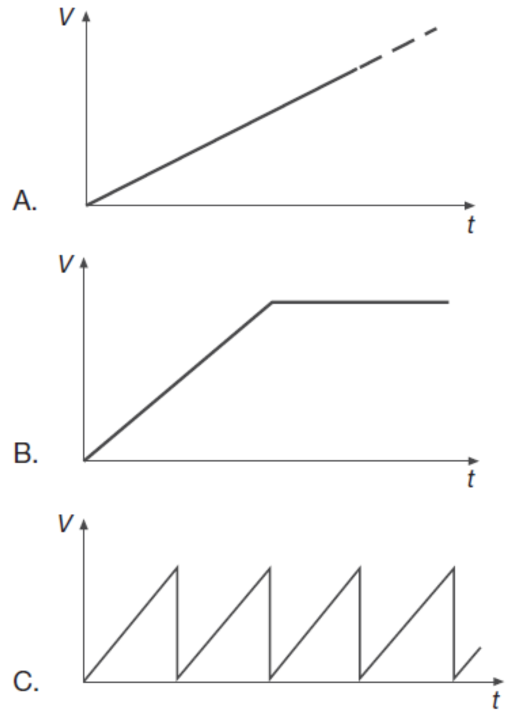

Figure 2: A: Voltage-ramp waveform. B: Ramp with limit. C: Sawtooth wave. [1]

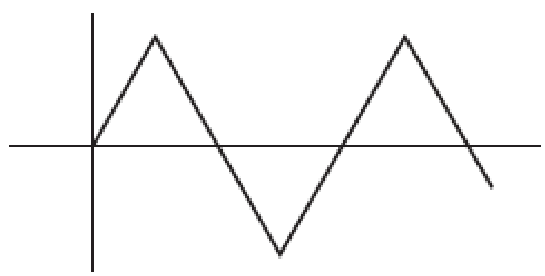

Figure 3: Triangle wave [1]

Figure 4: Noise signal [1]

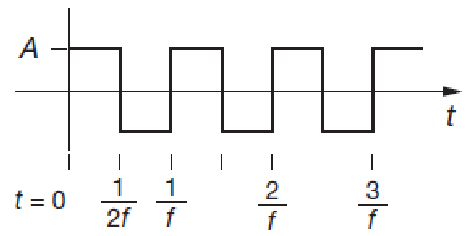

Figure 5: Square wave [1]

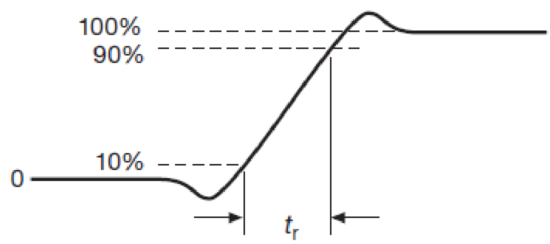

Figure 6: Square wave [1]

Square wave and Pulses

A square wave (Figure 5) is characterized by amplitude and frequency. The square wave varies in time as shown in Figure. The peak amplitude and the rms amplitude are the same for a square wave. The edges of a square wave are not perfectly square. A typical rise time t_r ranges from a few nanoseconds to a few microseconds as shown in Figure 6. The rise time is defined as the time required for the signal to go from 10% to 90% of its peak amplitude.

A pulse is defined by amplitude and pulse width. A train of periodic (equally spaced) pulses can also be generated that can be characterized by the frequency of pulses or pulse repetition rate. The duty cycle is the ratio of pulse width to repetition period (duty cycle ranges from zero to 100%). A single pulse signal is shown in Figure 7. Pulses can have positive or negative polarity. A pulse can be positive-going or negative-going as shown in Figure 7.

Steps and Spikes

A Step and spike signals are shown in Figure 8.

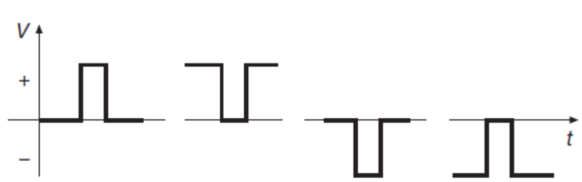

Figure 7: Positive- and negative-going pulses of both polarities. [1]

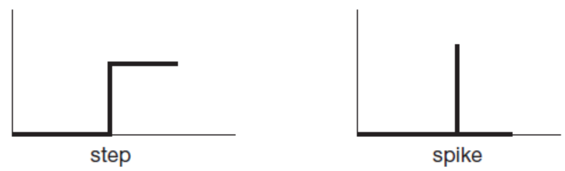

Figure 8: Steps and spikes. [1]

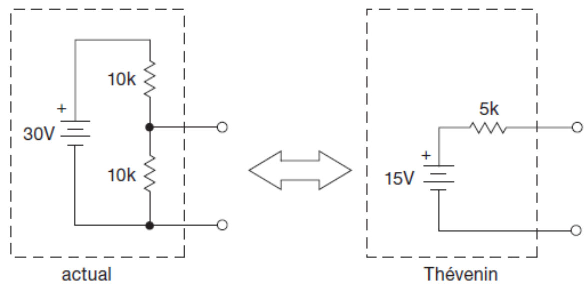

Figure 9: Voltage divider example.. [1]

Equivalent Source Resistance and Circuit Loading

As we have discussed in the Lecture 1, a voltage divider powered from some fixed voltage is equivalent to some smaller voltage source in series with a resistor (see Figure 9) called **Thevenin equivalent resistance or internal resistance**. The Thevenin equivalent resistance of the voltage divider output act as a source resistance. When a load resistor is attached to the output, the voltage divider's output voltage drop due to this internal resistance. This is a major draw back of the voltage divider as a voltage source or power supply. One solution is to construct the voltage divider with smaller resistors to make output voltage less sensitive to attaching a load resistor. Smaller resistors will result in large currents and large power dissipation in the voltage divider making it undesirable. The best approach for voltage source is to use active components (transistors and operational amplifiers) but will not be discussed further here.

One goal of the Lab 1 is to understand Thevenin equivalent or internal resistance is applied any signal source, not just batteries and voltage dividers. Signal sources (oscillators, amplifiers, and sensing devices) have an equivalent internal resistance and therefore can be assumed to be a voltage divider. **You will observe that attaching a load whose resistance is less than or even comparable to the internal resistance will reduce the output voltage considerably**. This reduction of the open-circuit voltage by the load is called **circuit loading**. Therefore, it is important to make $R_{load} \gg R_{internal}$ to reduce the effect of load resistance on source output voltage. The effect of load resistance on the output voltage is shown in Figure 10.

$$V_{out} = \frac{R_{load}}{R_{load} + R_{internal}} \cdot V_{open} \quad (1)$$

Where V_{out} is the output voltage across the load, V_{open} is the Thevenin equivalent voltage of the voltage divider, R_{load} is the resistance of the load and $R_{internal}$ is the Thevenin equivalent

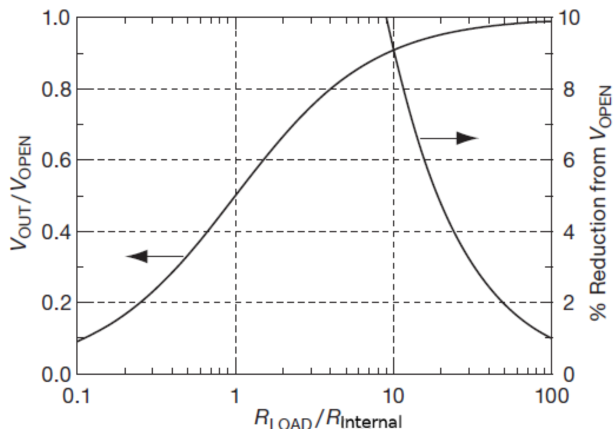

Figure 10: To minimize the attenuation of a signal source below its open-circuit voltage, keep the load resistance large compared with the output resistance. [1]

or internal resistance of the voltage/signal source. $R_{internal}$ **is equal to the Thevenin equivalent resistance**. $\frac{V_{out}}{V_{open}}$ is plotted for load resistance variation in units of $R_{internal}$ in Figure 10.

The high resistance condition $R_{load} \gg R_{internal}$ **is very important when when using power/signal sources as inputs to our circuits.**

Preliminary Lab Questions

1. Derive the equation 1 following the Lecture 1 exercise.
2. Plot the $\frac{V_{out}}{V_{open}}$ vs. $\frac{R_{load}}{R_{internal}}$ to reproduce the Figure 10.
3. Predict any limitation in the voltage divider model that would deviate from the experimental observation

Equipment and Parts

1. Power supply (EXTEC 18 V DC)
2. Signal generator (Instek GFG-8216G)
3. Oscilloscope (RIGOL DS11002E) and a probe
4. Proto-board

You will also need the following components in order to carry out this lab. It makes more sense to get them as you need them, rather than all at once before the start of the lab.

1. Three of the 10 K resistors
2. A 100 k potentiometer or the resistor box
3. Connecting wires

Procedure

Signal Sources

1. Configure the signal generator to generate 200 Hz sinusoidal signal
2. Connect the BNC cable from the signal generator to the channel 1 of the oscilloscope.
3. Observe the sinusoidal signal in the oscilloscope by utilizing the auto tune feature
4. Use the cursor feature to measure the amplitude
5. Set the peak amplitude to 2V
6. Now use the cursor feature to measure the period and calculate the frequency of the signal
7. Use the measurement feature to display period and frequency of the signal
8. Use the storage feature to save an image of the signal

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1. Configure the signal generator to generate 200 Hz square signal
2. Observe the square signal in the oscilloscope by utilizing the auto tune feature
3. Use the cursor feature to measure the amplitude
4. Set the peak amplitude to 2V
5. Now use the cursor feature to measure the period and calculate the frequency of the signal
6. Use the measurement feature to display period and frequency of the signal
7. Use the storage feature to save an image of the signal
8. Zoom in time axis to observe the rising edge of the square wave
9. Utilize the cursor feature to measure the rise time t_r of the square wave

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1. Configure the signal generator to generate 200 Hz triangle signal
2. Observe the triangle signal in the oscilloscope by utilizing the auto tune feature
3. Use the cursor feature to measure the amplitude
4. Set the peak amplitude to 2V
5. Now use the cursor feature to measure the period and calculate the frequency of the signal
6. Use the measurement feature to display period and frequency of the signal
7. Use the storage feature to save an image of the signal

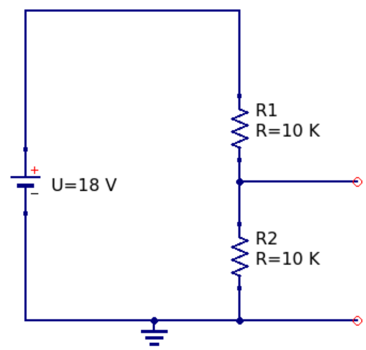

Figure 11: Voltage divider to be build

Equivalent Source Resistance and Circuit Loading

1. We will build the voltage divider shown in Figure 11.
2. Calculate Thevenin equivalent voltage, V_{open} for the circuit shown in Figure 11?
3. Calculate output voltage with no load resistor?
4. Calculate output voltage with 10 K load resistor?
5. Check the resistance of all the resistors using the multimeter to verify?
6. Use 18 V as input voltage from a power supply to the voltage divider.
7. Measure the input voltage of the power supply using the multimeter.
8. Build the voltage divider shown in Figure 11 with no load resistance connected.
9. Measure the output voltage with no load resistor, V_{open}
10. Verify your calculations for output voltage with no load resistor
11. Connect 10K load resistor and measure the output voltage
12. Compare your measurement with calculation for the voltage divider output voltage while 10 K load resistor is connected, V_{out}
13. Remove the 10K load resistor and measure the output voltage, V_{open}
14. Set the potentiometer or Resistor Box resistance to 5 K
15. Verify the resistance with the multimeter
16. Connect the potentiometer (or Resistor Box) as the load resistor
17. Measure the output voltage with the load attached
18. Compare with calculation for output voltage

Start taking data

1. Increase the potentiometer (or Resistor Box) resistance by approximately 5 K
2. Measure the resistance across the potentiometer (or Resistor Box) using multimeter by disconnecting from the voltage divider
3. Note down the resistance of the potentiometer (or Resistor Box)
4. Connect the potentiometer (or Resistor Box) back
5. measure the output voltage with the load connected, V_{out}
6. Repeat until maximum resistance of the potentiometer (or Resistor Box) has reached
7. Plot $\frac{V_{out}}{V_{open}}$ vs. $\frac{R_{load}}{R_{internal}}$ (Load resistor in units of internal (Thevenin) resistance)
8. Overlay data points with calculated curve for the same quantities.
9. Reproduce the plot shown in figure 10 using the data acquired.
10. Using the plot verify $R_{load} > 10 \times R_{internal}$ is a good rule to follow.
11. Discuss about how to minimize the circuit loading when using signal sources.
12. Discuss about disagreements observed between measurements and calculation of output voltage

References

[1] Horowitz and Hill. *Art of Electronics*. Cambridge University Press, 2015.