Voltage divider

In electronics, a **voltage divider** (also known as a **potential divider**) is a linear circuit that produces an output voltage (V_{out}) that is a fraction of its input voltage (V_{in}). **Voltage division** refers to the partitioning of a voltage among the components of the divider.

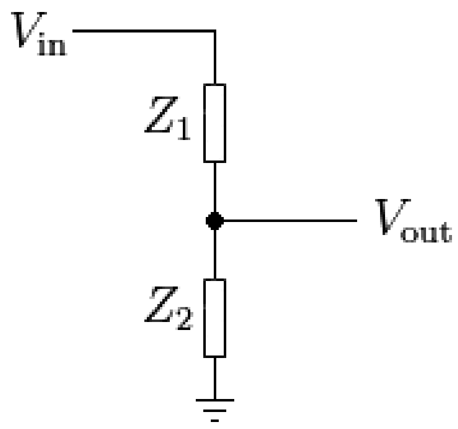

Figure 1: Voltage divider

An example of a voltage divider consists of two resistors in series or a potentiometer. It is commonly used to create a reference voltage, or to get a low voltage signal proportional to the voltage to be measured, and may also be used as a signal attenuator at low frequencies. For direct current and relatively low frequencies, a voltage divider may be sufficiently accurate if made only of resistors; where frequency response over a wide range is required, (such as in an oscilloscope probe), the voltage divider may have capacitive elements added to allow compensation for load capacitance. In electric power transmission, a capacitive voltage divider is used for measurement of high voltage.

General case

A voltage divider referenced to ground is created by connecting two electrical impedances in series, as shown in Figure 1. The input voltage is applied across the series impedances Z_1 and Z_2 and the output is the voltage across Z_2. Z_1 and Z_2 may be composed of any combination of elements such as resistors, inductors and capacitors.

Applying Ohm's Law, the relationship between the input voltage, V_{in}, and the output voltage, V_{out}, can be found:

$$V_{\mathrm{out}} = \frac{Z_2}{Z_1 + Z_2} \cdot V_{\mathrm{in}}$$

Proof:

$$V_{\mathrm{in}} = I \cdot (Z_1 + Z_2)$$

$$V_{\mathrm{out}} = I \cdot Z_2$$

$$I = \frac{V_{\mathrm{in}}}{Z_1 + Z_2}$$

$$V_{\mathrm{out}} = V_{\mathrm{in}} \cdot \frac{Z_2}{Z_1 + Z_2}$$

The transfer function (also known as the divider's **voltage ratio**) of this circuit is simply:

$$H = \frac{V_{out}}{V_{in}} = \frac{Z_2}{Z_1 + Z_2}$$

In general this transfer function is a complex, rational function of frequency.

Resistive divider

A resistive divider is a special case where both impedances, Z_1 and Z_2, are purely resistive (Figure 2).

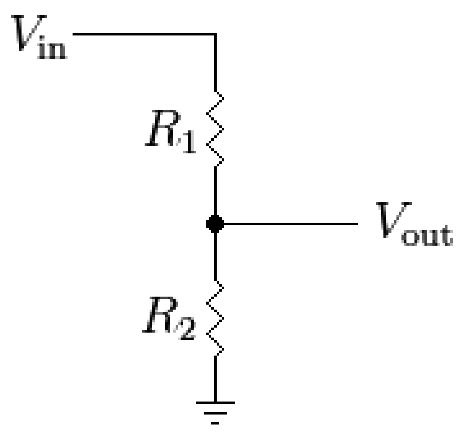

Figure 2: Simple resistive voltage divider

Substituting $Z_1 = R_1$ and $Z_2 = R_2$ into the previous expression gives:

$$V_{\mathrm{out}} = \frac{R_2}{R_1 + R_2} \cdot V_{\mathrm{in}}$$

As in the general case, R_1 and R_2 may be any combination of series/parallel resistors.

Examples

Resistive divider

As a simple example, if $R_1 = R_2$ then

$$V_{\mathrm{out}} = \frac{1}{2} \cdot V_{\mathrm{in}}$$

As a more specific and/or practical example, if V_{out}=6V and V_{in}=9V (both commonly used voltages), then:

$$\frac{V_{\mathrm{out}}}{V_{\mathrm{in}}} = \frac{R_2}{R_1 + R_2} = \frac{6}{9} = \frac{2}{3}$$

and by solving using algebra, R_2 must be twice the value of R_1.

To solve for R1:

$$R_1 = \frac{R_2 \cdot V_{\mathrm{in}}}{V_{\mathrm{out}}} - R_2$$

To solve for R2:

$$R_2 = \frac{R_1}{\left(\frac{V_{\mathrm{in}}}{V_{\mathrm{out}}} - 1\right)}$$

Any ratio between 0 and 1 is possible. That is, using resistors alone it is not possible to either invert the voltage or increase V_{out} above V_{in}.

Low-pass RC filter

Consider a divider consisting of a resistor and capacitor as shown in Figure 3.

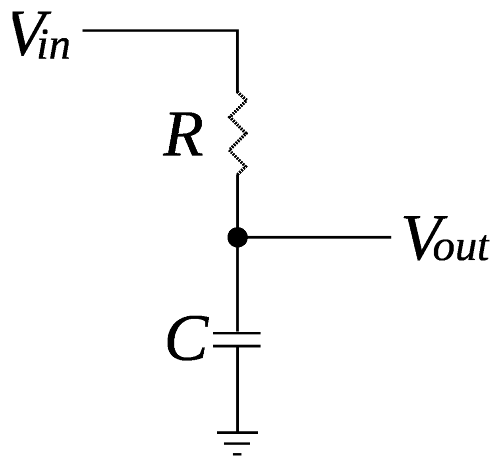

Figure 3: Resistor/capacitor voltage divider

Comparing with the general case, we see $Z_1 = R$ and Z_2 is the impedance of the capacitor, given by

$$Z_2 = -jX_{\mathrm{C}} = \frac{1}{j\omega C} \ ,$$

where X_C is the reactance of the capacitor, C is the capacitance of the capacitor, *j* is the imaginary unit, and *ω* (omega) is the radian frequency of the input voltage.

This divider will then have the voltage ratio:

$$\frac{V_{\mathrm{out}}}{V_{\mathrm{in}}} = \frac{Z_2}{Z_1 + Z_2} = \frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R} = \frac{1}{1 + j\omega\ RC} .$$

The product of *τ (tau) = RC* is called the *time constant* of the circuit.

The ratio then depends on frequency, in this case decreasing as frequency increases. This circuit is, in fact, a basic (first-order) lowpass filter. The ratio contains an imaginary number, and actually contains both the amplitude and phase shift information of the filter. To extract just the amplitude ratio, calculate the magnitude of the ratio, that is:

$$\left| \frac{V_{\mathrm{out}}}{V_{\mathrm{in}}} \right| = \frac{1}{\sqrt{1 + (\omega RC)^2}} \ .$$

Inductive divider

Inductive dividers split DC input according to resistive divider rules above.

Inductive dividers split AC input according to inductance:

$$V_{out} = V_{in} \cdot \frac{L_2}{L_1 + L_2}$$

The above equation is for ideal conditions. In the real world the amount of mutual inductance will alter the results.

Capacitive divider

Capacitive dividers do not pass DC input.

For an AC input a simple capacitive equation is:

$$V_{out} = V_{in} \cdot \frac{C_1}{C_1 + C_2}$$

Capacitive dividers are limited in current by the capacitance of the elements used.

This effect is opposite to resistive division and inductive division.

Loading effect

The voltage output of a voltage divider is not fixed but varies according to the load. To obtain a reasonably stable output voltage the output current should be a small fraction of the input current. The drawback of this is that most of the input current is wasted as heat in the resistors.

Applications

Voltage dividers are used for adjusting the level of a signal, for bias of active devices in amplifiers, and for measurement of voltages. A Wheatstone bridge and a multimeter both include voltage dividers. A potentiometer is used as a variable voltage divider in the volume control of a radio.

References

Further reading

- Horowitz, Paul; Hill, Winfield (1989). *The Art of Electronics*. Cambridge University Press.

External links

- Voltage divider or potentiometer calculations (http://www.sengpielaudio.com/calculator-voltagedivider.htm)
- Voltage divider tutorial video in HD (http://www.afrotechmods.com/groovy/voltage_divider/voltage_divider.htm)
- Online calculator to choose the values by series E24, E96 (http://www.magic-worlld.narod.ru)
- Online voltage divider calculator: chooses the best pair from a given series and also gives the color code (http://www.cl-projects.de/projects/tools/resmatch-en.phtml)
- Voltage divider theory (http://www.tedpavlic.com/teaching/osu/ece209/support/circuits_sys_review.pdf) - RC low-pass filter example and voltage divider using Thévenin's theorem

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