Voltage source

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A **voltage source** is any device or system that *produces* an electromotive force between its terminals OR *derives* a secondary voltage from a primary source of the electromotive force. A primary voltage source can supply (or absorb) energy to a circuit while a secondary voltage source dissipates energy from a circuit. An example of a primary source is a common battery while an example of a secondary source is a voltage regulator. In electric circuit theory, a voltage source is the dual of a current source. Figure 1 shows a schematic diagram of an ideal voltage source driving a resistor load.

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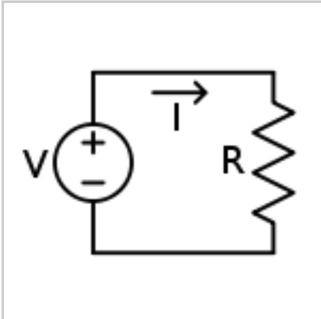
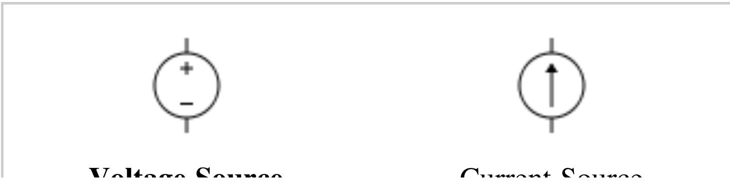


Figure 1: An ideal voltage source, *V*, driving a resistor, *R*, and creating a current *I*

Ideal voltage sources

In circuit theory, an **ideal voltage source** is a circuit element where the voltage across it is independent of the current through it. It only exists in mathematical models of circuits. If the voltage across an ideal voltage source can be specified independently of any other variable in a circuit, it is called an **independent** voltage source. Conversely, if the voltage across an ideal voltage source is determined by some other voltage or current in a circuit, it is called a **dependent** or **controlled voltage source**. Figure 2 shows symbols commonly used to denote voltage sources in circuit schematics.

The internal resistance of an ideal voltage source is zero; it is able to supply or absorb any amount of current. The current through an ideal voltage source is completely determined by the external circuit. When connected to an open circuit, there



is zero current and thus zero power. When connected to a load resistance, the current through the source approaches infinity as the load resistance approaches zero (a short circuit). Thus, an ideal voltage source can supply unlimited power.

No real voltage source is ideal; all have a non-zero effective internal resistance, and none can supply unlimited current. However, the internal resistance of a real voltage source is effectively modeled in linear circuit analysis by combining a non-zero resistance in series with an ideal voltage source (a Thévenin equivalent circuit).

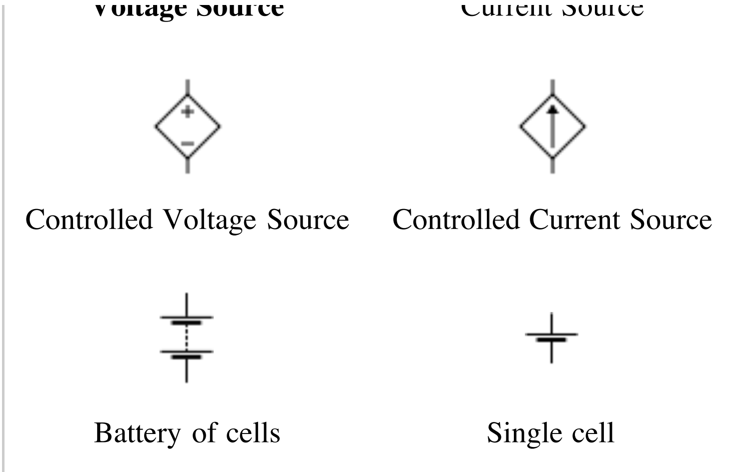


Figure 2: Symbols used for voltage sources

Physical voltage sources

Mains electricity (secondary voltage)

Main article: Mains electricity

This is probably the most familiar form of AC voltage source known. Generally its output impedance is very low (for example, IEC 725:1981 uses 0.4 ohms as a typical value).

Cell (primary voltage)

The simplest form of practical DC voltage source is the common cell, which is available in numerous voltages and current ratings. More than one cell can be combined in series, parallel or a combination of both the topologies to achieve greater voltage/current ratings. Such combinations are known as batteries.

Sources using active electronic devices (secondary voltages)

Many techniques for producing sources of emf in electronic devices/circuits exist. The simplest circuits in their basic form involve placing a resistor in series with the load and then shunting a variable amount of "excess" current, bypassing the load, so that the resulting voltage level is not much higher at no load than at full load. Any device with a low dynamic resistance can be used as a voltage-regulating shunt. A more efficient but complex approach is the series-pass circuit, formed by adding an emitter follower to the output of the shunt regulator. It should be pointed out however that all forms of linear regulation waste power. Switching regulators can be used to increase the efficiency of the conversion, but have their own disadvantages, such as complexity, reliability, noise and cost.

LED Voltage source

An LED in series with a resistor can be used to make a voltage source with an output voltage of about 1.5 - 4.0 V depending on the current passing through the LED and its type (color). The load and line regulation is fair; this circuit is akin to the Zener diode stabilizer but does not regulate as well. If even lower regulated voltages or higher power levels are required, a common silicon diode (e.g. 1N4148) or rectifier (e.g.

1N4001) can be substituted for the LED. In this case voltages of around 0.6 - 0.7 V are produced providing reasonable load and line regulation but poor temperature stability (−2 mV/°C). Multiple diodes can also be used in series, for higher voltages.

Zener voltage source

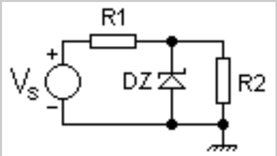


Figure 3: Constant voltage source using Zener diode.

Figure 3 shows a circuit that can be used to provide a source of lower voltage (or EMF) when only a higher voltage is available. This approach has the advantage of great simplicity, and Zeners are readily available up to 100V. However, at the higher voltages, power dissipation poses a major design challenge, unless only a small load current is needed. Its output impedance is generally much lower than that of the potential divider because of the wasted current passing through the Zener diode. The image shows a constant voltage source (CVS) using a Zener diode (DZ). This circuit acts as a voltage regulator in that it maintains a constant voltage across the load (R_2) irrespective of its value or variation in V_S. This circuit is usually used when the load current is very small (or R_2 is large) and does not vary. This CVS appears in constant current source circuits. Once the load current (I_{R2}) is known, resistor R_1 can be calculated as,

$$R1 = \frac{V_S - V_Z}{I_Z + I_{R2}} \ ,$$

where V_Z is the Zener voltage and I_Z is the Zener current. This circuit wastes power by dissipating $V_Z \cdot I_Z$ watts; to achieve good regulation, I_z must be large relative to I_{load}.

This CVS is used in applications where some variation in the output voltage is acceptable. A large filter capacitor placed in parallel with DZ (or R_2) can reduce output ripple. When R_2 is replaced with the base-emitter circuit of a transistor, the circuit acts as a voltage source (regulator) for the emitter resistor and as a current source for the collector resistor. See linear regulator and current source for applications of this voltage source.

V_{BE} multiplier voltage source

A V_{BE} multiplier voltage source is shown in Figure 4.[1] Its operation is based upon the transistor Q having a high enough current gain (h_{FE}) that the base current is negligible. Then the output voltage depends only on the transistor's V_{BE} and the ratio of the resistors R_1 and R_2. Analysis of the circuit is as follows:

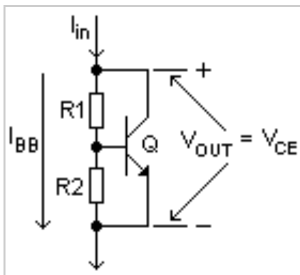


Figure 4: A V_{BE} multiplier constant voltage source.

$$V_{\text{out}} \, (= V_{\text{CE}}) = V_{R_1} + V_{R_2} \ .$$

Because base current of the transistor is negligible, it follows that $I_{R_1} = I_{R_2} = I_{BB}$, and so:

$$V_{\text{out}} = I_{\text{BB}}(R_1 + R_2) \ .$$

But,

$$I_{\mathrm{BB}} = \frac{V_{\mathrm{BE}}}{R_2} \ ,$$

so,

$$V_{\mathrm{out}} = \frac{V_{\mathrm{BE}}}{R_2}(R_1 + R_2) = V_{\mathrm{BE}}\left(1 + \frac{R_1}{R_2}\right) \ .$$

From the above equation, it follows that the output voltage of this circuit depends only on V_{BE} and the ratio of R_1 and R_2. The circuit is known as a "V_{BE} multiplier", since the above equation shows that the V_{BE}, which is typically about 0.6 V, is multiplied by $(1 + R_1/R_2)$. This circuit provides a constant output voltage that is set by the ratio of R_1 and R_2, if V_{BE} is constant. Also, R_1 (or R_2) can be made variable to compensate for V_{BE} variations due to device tolerance. A V_{BE} multiplier is also known as a *rubber diode* or a *rubber zener*. [1] (http://www.st-andrews.ac.uk/~www_pa/Scots_Guide/audio/part2/page3.html)

Uses of V_{BE} multiplier

Because it does not require a ground connection (that is, it is a floating circuit) and gives a predictable and easily adjustable voltage drop, this circuit is frequently used in biasing the class-AB output stages of power amplifiers. R_1 (or R_2) is varied till the required voltage is achieved. Sometimes R_1 and R_2 are replaced by a potentiometer for easy adjustment, though this should be configured so that even with a dirty pot, the V_{out} can never rise so much that it destroys the amp. Since V_{BE} decreases with increasing temperature (thereby reducing the V_{BE} multiplier's output voltage) this circuit also acts to compensate for temperature induced changes of V_{BE} in the output devices. This tends to counteract the effect of reduction in V_{BE} of the output devices and helps prevent thermal runaway of the output stage. This is called bias temperature compensation in the electronics industry at large, but a "bias servo" in the field of audio amplifiers.

Other types of practical (real world) voltage sources

There are other naturally occurring voltage sources in the world. One example is the voltage produced by the contact of two dissimilar metals.

Potential divider (secondary volt.)

This is the simplest way of producing a source of lower EMF from a source of higher EMF, and is the basic operating mechanism of the 'potentiometer' (a measuring device for accurately measuring potential differences). However to gain a low output impedance the parallel combination of the two resistors must be low. This means that to achieve a stable output voltage over a variety of loads the power wasted in the potential divider must be significantly greater than the power delivered to the load. Also the potential divider can only produce a stable output voltage if it has a stable input voltage. Sometimes the potential divider is used as a simple, cheap method of providing a source of voltage where the output impedance is not too important (such as voltage references for high input impedance op-amps).

Capacitor (primary volt.)

A capacitor (especially a large one) can be considered a voltage source, provided a constant charge stored in the capacitor. If the capacitor is very large, current flowing out of the capacitor will not change the charge much, hence the voltage across the capacitor will remain approximately constant, similarly to a battery. High energy density supercapacitors have been developed to act as high energy voltage sources for power backup and other applications sometimes replacing conventional batteries or cells, and share properties with both.

Comparison between voltage and current sources

Most sources of electrical energy (the mains, a battery, ...) are best modelled as voltage sources.

An *ideal* voltage source provides no energy when it is loaded by an open circuit (i.e. an infinite impedance), but approaches infinite energy and current when the load resistance approaches zero (a short circuit). Such a theoretical device would have a zero ohm output impedance in series with the source. A real-world voltage source has a very low, but non-zero output impedance: often much less than 1 ohm.

Conversely, a current source provides a constant current, as long as the load connected to the source terminals has sufficiently low impedance. An ideal current source would provide no energy to a short circuit and approach infinite energy and voltage as the load resistance approaches infinity (an open circuit). An *ideal* current source has an infinite output impedance in parallel with the source. A *real-world* current source has a very high, but finite output impedance. In the case of transistor current sources, impedances of a few megohms (at low frequencies) are typical.

An *ideal* current source cannot be connected to an *ideal* open circuit. Nor an ideal voltage source to an ideal short circuit, since this would be equivalent to declaring that "5 is equal to 0". Since no ideal sources of either variety exist (all real-world examples have finite and non-zero source impedance), any current source can be considered as a voltage source with the *same* source impedance and vice versa. Voltage sources and current sources are sometimes said to be duals of each other and any non ideal source can be converted from one to the other by applying Norton's or Thevenin's theorems.

References and notes

1. ^ A. S. Sedra and K.C. Smith (2004). *Microelectronic Circuits* (http://worldcat.org/isbn/0-19-514251-9) (Fifth Edition ed.). New York: Oxford. pp. §14.5.2 pp.1246–1249. ISBN 0-19-514251-9. http://worldcat.org/isbn/0-19-514251-9.

See also

- Bandgap voltage reference
- Current source
- Voltage divider