Transistor current sources

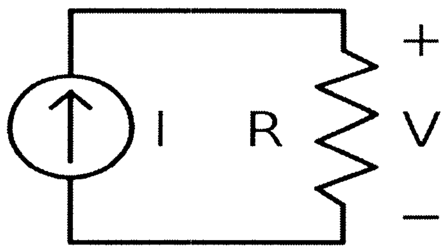


Figure 1: An Ideal current source, **I**, driving a resistor, **R**, and creating a voltage **V**

Constant Current Source:

A **Current source** is an electrical or electronic device that delivers or absorbs electric current. A current source is the dual of a voltage source. The term constant-current **sink** is sometimes used for sources fed from a negative voltage supply. Figure 1 shows a schematic for an ideal current source driving a resistor load.

Ideal current sources

In circuit theory, an **ideal current source** is a circuit element where the current through it is independent of the voltage across it. It is a mathematical model, which real devices can only approach in performance. If the current through an ideal current source can be specified independently of any other variable in a circuit, it is called an *independent* current source. Conversely, if the current through an ideal current source is determined by some other voltage or current in a circuit, it is called a **dependent** or **controlled current source**. Symbols for these sources are shown in **Figure 2**.

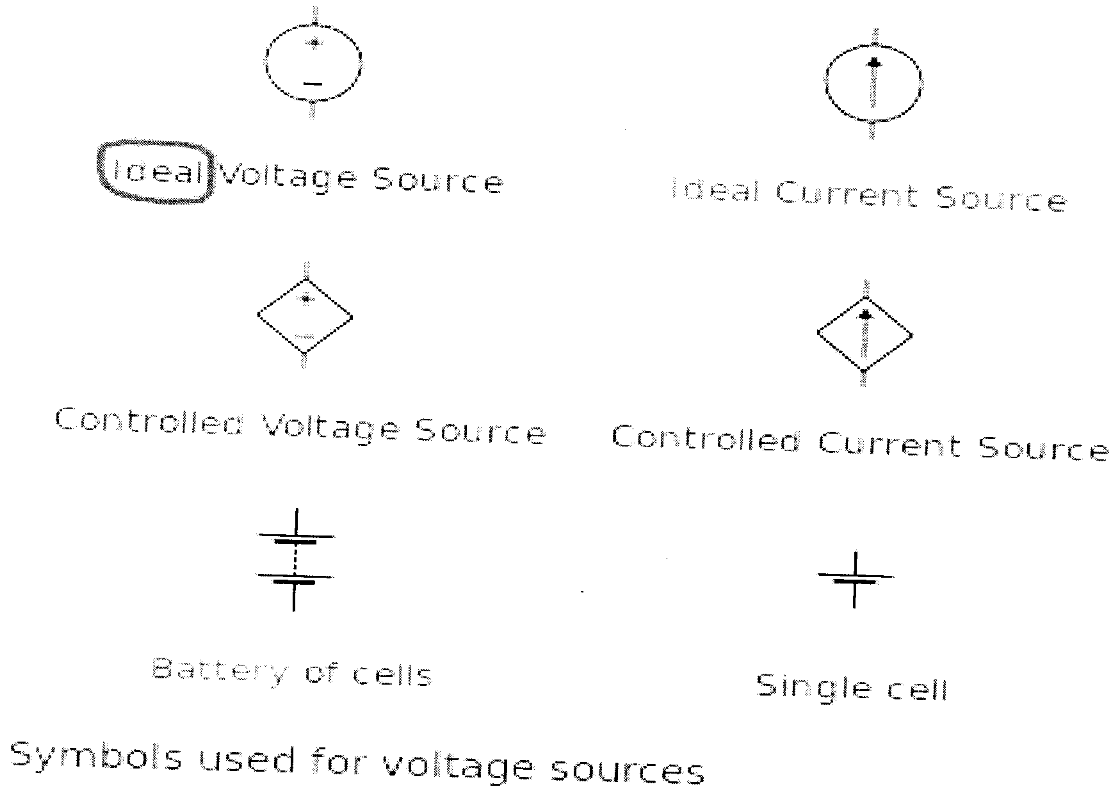


Figure2: Source symbols

An independent current source with zero current is identical to an ideal open circuit. For this reason, the internal resistance of an ideal current source is infinite. The voltage across an ideal current source is completely determined by the circuit it is connected to. When connected to a short circuit, there is zero voltage and thus zero power delivered. When connected to a load resistance, the voltage across the source approaches infinity as the load resistance approaches infinity (an open circuit). Thus, an ideal current source could supply unlimited power forever and so would represent an unlimited source of energy. Connecting an ideal open circuit to an ideal non- zero current source is not valid in circuit analysis as the circuit equation would be paradoxical, e.g., 5=0.

No real current source is ideal (no unlimited energy sources exist) and all have a finite internal resistance (none can supply unlimited voltage). However, the internal resistance of a physical current source is effectively modeled in circuit analysis by combining a non-zero resistance in parallel with an ideal current source (the Norton equivalent circuit).

Physical current sources

Resistor current source

The simplest current source consists of a voltage source series with a resistor. The current available from such a source is given by the ratio of the voltage across the voltage source to the resistance of the resistor. For a nearly ideal current source, the value of this resistor should be very large but this implies that, for a specified current, the voltage source must be very large. Thus, efficiency is low (due to power loss in the resistor)and it is usually impractical to construct a 'good' current source this way. Nonetheless, it is often the case that such a circuit will provide adequate performance when the specified current and load resistance are small. For example, a 5V voltage source in series with a 4.7k ohms resistor will provide an *approximately* constant current of 1 mA (±5%) to a load resistance in the range of 50 to 450 ohms.

Active current sources

Active current sources have many important applications in electronic circuits. Current sources (current-stable resistors) are often used in place of ohmic resistors in analog integrated circuits to generate a current without causing attenuation at a point in the signal path to which the current source is attached. The collector of a bipolar transistor, the drain of a field effect transistor, or the plate of a vacuum tube naturally behave as current sources (or sinks) when properly connected to an external source of energy (such as a power supply) because the output impedance of these devices is naturally high when used in the current source configuration.

Transistor current sources

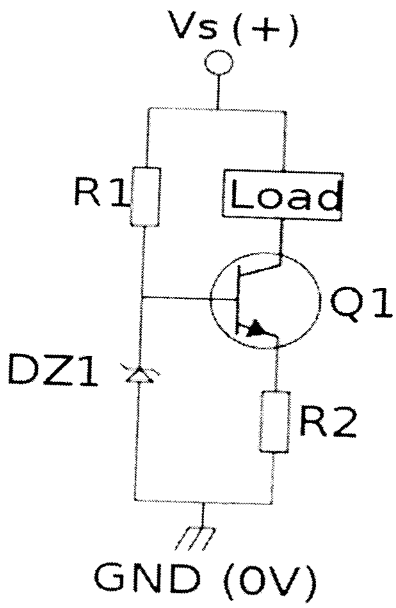


Figure 3: Typical constant current source (CCS)

Figure 3 shows a typical constant current source (CCS). DZI is a zener diode which, when reverse biased (as shown in the circuit) has a constant voltage drop across it irrespective of the current flowing through it. Thus, as long as the zener current (I_Z) is above a certain level (called holding current), the voltage across the zener diode (V_Z) will be constant. Resistor R1 supplies the zener current and the base current (I_B) of NPN transistor (Q1). The constant zener voltage is applied across the base of Q1 and emitter resistor R2. The operation of the circuit is as follows: Voltage across R2 (V_{R2}) is given by $V_Z - V_{BE}$, where V_{BE} is the base-emitter drop of Q1. The emitter current of Q1 which is also the current through R2 is given by

$$I_{R2}(=I_E)=\frac{V_{R2}}{R2}=\frac{V_Z-V_{BE}}{R}$$

Since V_Z is constant and V_{BE} is also (approximately) constant for a given temperature, it follows that V_{R2} is constant and hence I_E is also constant. Due to transistor action, emitter current I_E is very nearly equal to the collector current I_C of the transistor (which in turn, is the current through the load). Thus, the load current is constant (neglecting the output resistance of the transistor due to the Early effect) and the circuit operates as a constant current source. As long as the temperature remains constant (or doesn't vary much), the load current will be independent of the supply voltage, R1 and the transistor's gain. R2 allows the load current to be set at any desirable value and is calculated by

$$R2=\frac{V_Z-V_{BE}}{I_{R2}} \quad \text{or} \quad R2=\frac{V_Z-0.65}{I_{R2}},$$ since V_{BE} is typically 0.65 V for a silicon device. (I_{R2} is also the emitter current and is assumed to be the same as the collector or required load current, provided h_{FE} is sufficiently large). Resistance R_1 at resistor R1 is calculated as

$$R_1=\frac{V_S-V_Z}{I_Z+K.\ I_B}$$ where, K= 1.2 to 2 (so that R_1 is low enough to ensure adequate I_B),

$I_B = \frac{I_C\ (=I_E=I_{R2}\ )}{h_{FE(min)}}$ and $h_{FE(min)}$ is the lowest acceptable current gain for the particular transistor type being used.

A more common current source in integrated circuits is the current mirror.

Simple transistor current source with diode compensation

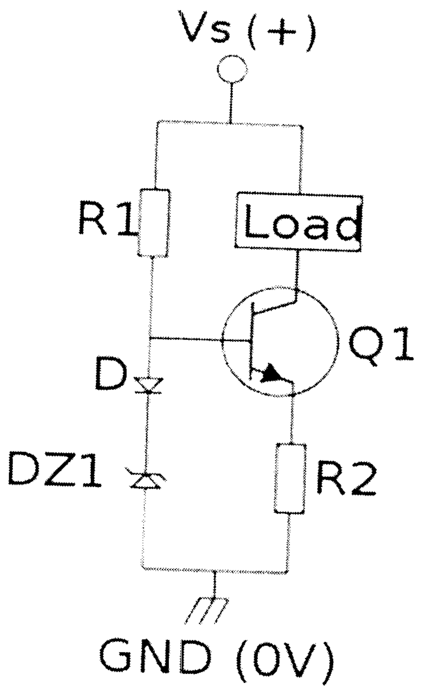


Figure 4: Typical constant current source (CCS) with diode compensation

Temperature changes will change the output current delivered by the circuit of Figure 3 because V_{BE} is sensitive to temperature. Temperature dependence can be compensated using the circuit of Figure 4 that includes a standard diode D (of the same semiconductor material as the transistor) in series with Zener diode as shown in the image on the left. The diode drop (V_D) tracks the V_{BE} changes due to temperature and thus significantly counteracts temperature dependence of the CCS.

Resistance R_2 is now calculated as

$$R_2 = \frac{V_Z + V_D - V_{BE}}{I_{R2}}$$

Since $V_D = V_{BE} = 0.65$ V,

$$R_2 = \frac{V_Z}{I_{R2}}$$

Therefore, (In practical V_D is never exactly equal to V_{BE} and hence it only suppresses the change in V_{BE} rather than nulling it out.)
And R_1 is calculated as

$$R_1 = \frac{V_S - V_Z - V_D}{I_Z + K . I_B}$$ (the compensating diode's forward voltage drop

V_D appears in the equation and is typically 0.65 V for silicon devices.)
This method is most effective for Zener diodes rated at 5.6 V or more. For breakdown diodes of less than 5.6 V , the compensating diode is usually not required because the breakdown mechanism is not as temperature dependent as it is in breakdown diodes above this voltage.

Simple transistor current source with LED

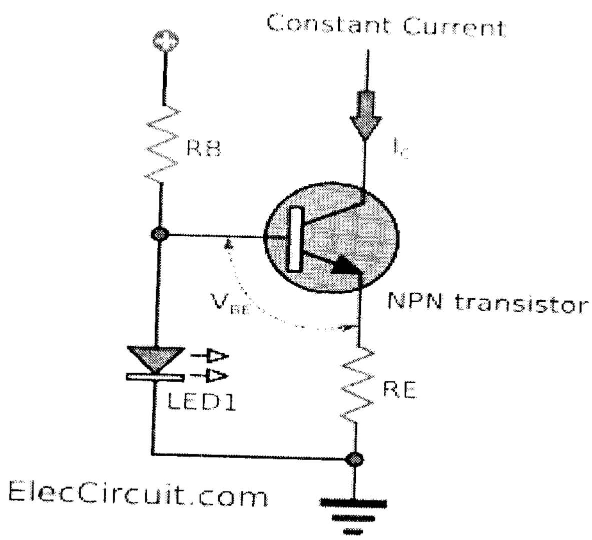


Figure 5: Typical constant current source (CCS) using LED instead of zener

Another method is to replace the Zener diode with light -emitting diode LED as shown in Figure 5. The LED voltage drop (V_D) is now used to drive the constant voltage and also has the additional advantage of tracking (compensating) V_{BE} changes due to temperature. R_2 is calculated as

$$R_2 = \frac{V_D - V_{BE}}{I_{R2}}$$

And R_1 as

$$R_1 = \frac{V_S - V_D}{I_D + K.I_B}$$, where I_D is the LED current.

In view of this it is a simple matter to design the circuit for a given current.

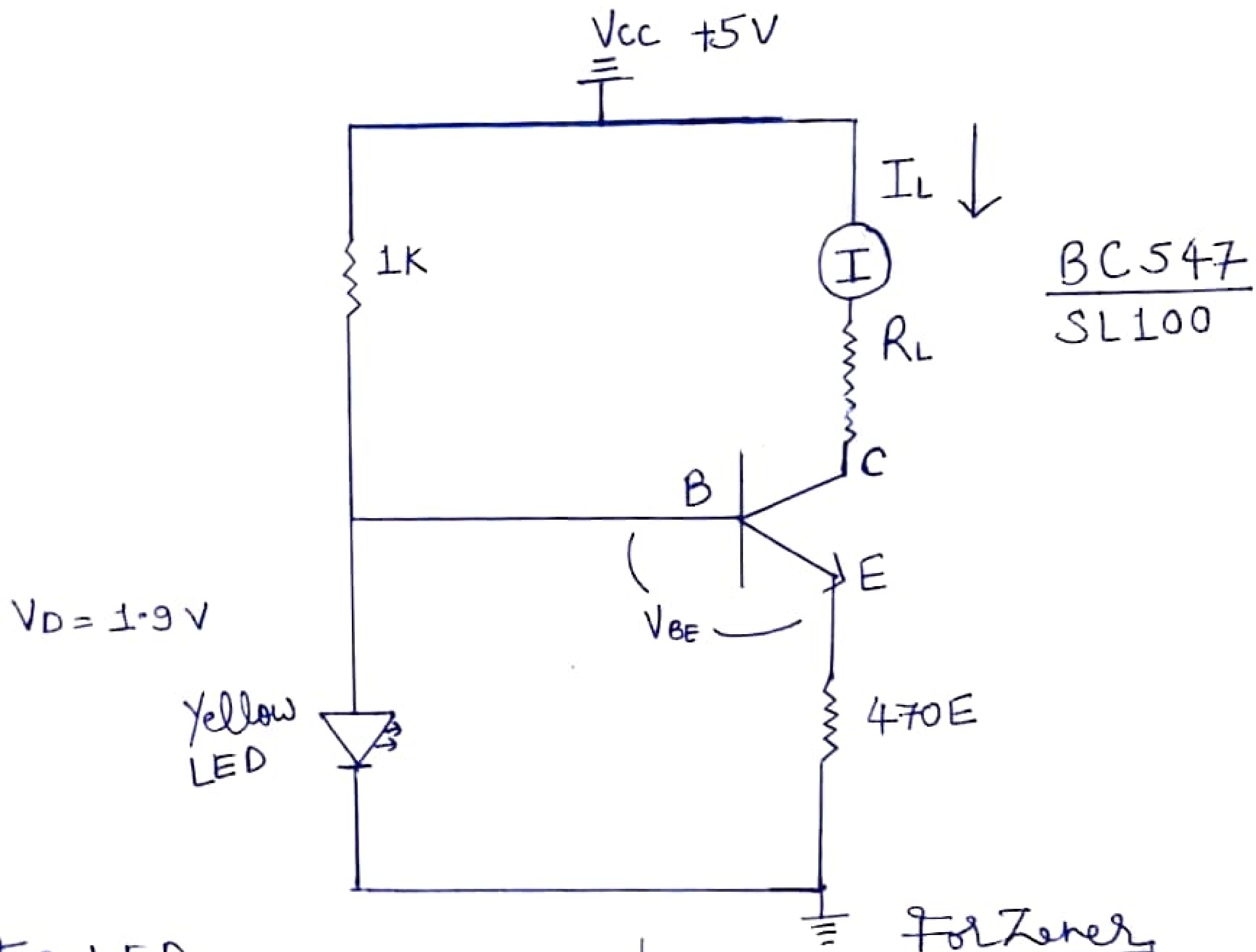
$Ie = (\beta + 1)\, Ib$

$I_{load} = Ic = \beta Ib$

$I_{load} = \beta\, Ve(\beta + 1)\, Re$

$I_{load} = Vb - 0.6Re$

NB: This assumes the use of a silicon transistor as the base emitter drop is given as 0.6V



For LED

Table 1 at Vcc = 5V constant

R_L	I_L
100 E	
220 E	
330 E	
470 E	
1 K	

Table 2 at R_L constant 470 E

V_S	I_L
5V	
6V	
7V	
8V	
9V	
10V	

For Zener

Table 1 at Vcc = 10V constant

R_L	I_L
100E	
220E	
330E	
470E	
560E	

Table 2 at R_L constant 470E

V_S	I_L
9V	
10V	
11V	
12V	
13V	
14V	