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Linear Systems' Current Regulating Diodes

Abstract: Many analog circuit designs have the need for current regulation. Examples include circuits that process signals from sensors, circuits that amplify, and voltage reference or regulators. Current regulation can be referred to as a current source or a Norton device/equivalent circuit (cf. Thevenin equivalent circuit).

Common circuits to produce a constant current through a load of varying resistance are shown in Figure 1. In Figure 1a, R3 represents the load resistance that has a constant current passing through it from the +15V supply rail. The magnitude of that current is set by resistor R2 and by the control voltage presented to the positive input of the op-amp from R1. Note that the control voltage could be from an external source and could be a varying (AC) control signal. Also note that this configuration is sometimes called a current sink since the current is flowing down into the collector of the NPN transistor.

This circuit can be thought of as a simple amplifier with an emitter follower output stage (i.e., a unity voltage gain amplifier). Thus, the control voltage is replicated across R2. Ignoring the base current in the transistor and using Ohm's Law, the control voltage produces an emitter current that is replicated as the transistor's collector current. It will be constant across a range of resistance and is limited by the supply voltage for the circuit. This limitation is referred to as the circuit's voltage compliance – if the resistance is too large, the current source "runs out" of enough voltage to get the desired current.

To eliminate the small error caused by the previously neglected base current, the NPN transistor could be replaced by an N-channel MOSFET which effectively has no gate current for steady-state or slowly changing gate voltages.

An inversion of that circuit is shown in Figure 1b in which R6 is the varying load resistance, R5 and the control voltage from R4 set the current, and the load resistance connects to the circuit common or ground rather than the +15V source.

These types of current sources/sinks are fairly common, with slight variations to improve performance. As drawn, these are simplified schematics without supply bypass capacitors or frequency compensation components shown.

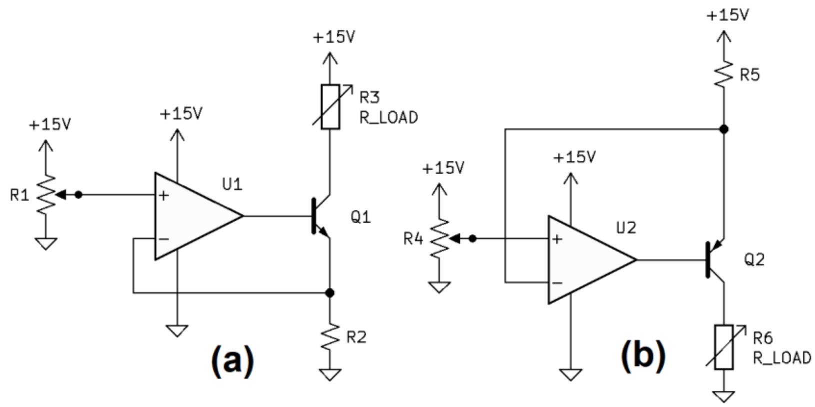

Figure 1

In some circuit configurations, a constant current device is needed that does not have the complexity of that which is shown in Figure 1. For example, in the simplified schematic of a discrete transistor amplifier shown in Figure 2 (using the **Linear Integrated Systems** matched pair NPN and PNP transistors LS312 and LS352), it would not be practical to add such complex circuitry for the current sources represented by I1, I2, and I3. These current sources are simple two-terminal devices that can be placed in various parts of the circuitry, even in locations that are not directly connected to ground or the power supply rail.

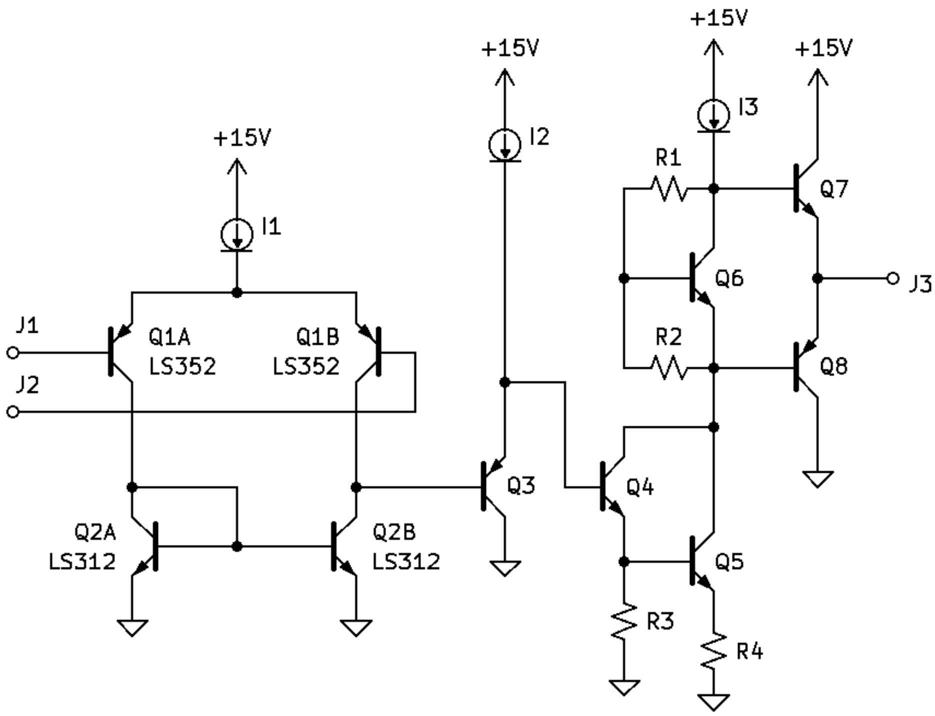

Figure 2

What is a two-terminal constant current device? Like the constant current circuits in Figure 1, it causes a constant current to flow through it regardless of the applied voltage or load resistance (+V and R1, respectively, in Figure 3). As before, the voltage compliance considerations must be observed (and the voltage must not exceed the breakdown voltage of the constant current device).

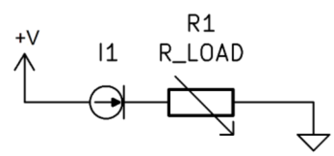

Figure 3

Two terminal constant current devices are commercially available, such as the **LIS** J500 series of devices. These devices are marketed as diodes (since outwardly they have two terminals) but are actually depletion mode N-channel junction FETs (N-JFET) plus a resistor to set the constant current level.

A depletion mode FET is made from a bar of silicon with electrical contacts near each end of the bar, forming a conduction channel. These metallic contacts are referred to as ohmic contacts as they are simple connections as opposed to silicon junction contacts (contacts made of P or N layers of doped silicon). The gate contact however *is* a doped silicon contact (represented as a diode in the FET symbol). See Figure 4.

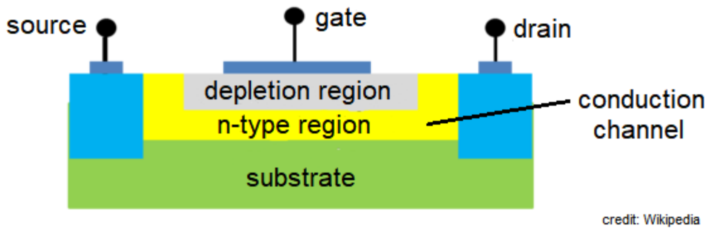

Figure 4

When used as an amplifying device, the gate voltage is more negative than the potential of the silicon bar near the diode area. No current flows through the diode (ignoring leakage currents) since it's reverse biased. However, the potential of the voltage on the gate causes the conductance through the silicon bar to vary due to the gate voltage's electrical field. The channel is depleted of charge carriers. The higher the negative voltage on the gate, the greater the electrical field and the narrower the conduction channel through the silicon bar.

This phenomenon of *field effect* varies the conductance of the channel. With no gate voltage, the channel acts as a low value resistance; with a sufficiently high negative voltage, the channel is completely depleted of charge carriers (i.e., is pinched off) and acts as a very high resistance. The ratio of the current flow through the JFET (measured at a particular drain-to-source voltage) and the gate voltage is the transconductance or transadmittance, measured in mhos (the reciprocal of resistance or impedance, measured in ohms). Transconductance is a DC characteristic related to resistance; transadmittance is an AC characteristic related to impedance.

If an N-JFET is connected as shown in Figure 5 with a positive voltage applied to terminal 1 and some load resistance to terminal 2 (which is then connected to ground), some current will flow downward. That current causes a voltage drop in the R-set resistor which puts the gate voltage at a somewhat more negative voltage than the source. This increases the channel resistance and reduces the magnitude of the current. An equilibrium point is reached based on the value of the R-set resistance and the transconductance of the JFET. Within the voltage compliance considerations as previously described, the device will provide a constant current to varying loads.

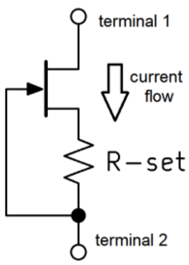

Figure 5

Because the constant current diode is a two-terminal device, the load could be placed above the diode with terminal 2 connecting to ground – or the diode could be placed in the midst of circuitry with no direct connection to power or ground.

To the extent that the current regulator diode is accurate, variations in the resistance of the load won't cause any variation in the current, implying good load regulation characteristics. Similarly, variations in the applied voltage won't cause the current through the load resistance to vary, implying good line regulation characteristics.

Specific Uses

1. Zener diodes and voltage reference diodes. These are commonly used to provide a reference voltage for various sensor circuits or for ADCs and DACs. The Zener or reference diode could receive its excitation voltage from the power supply via a resistor as shown in Figure 6a. One might assume that the nature of such voltage references would imply good line and load regulation. Sometimes the regulation is good enough, but for precision applications, the line regulation characteristics of a Zener diode leave much to be desired. An improvement can be realized by using a constant current diode like one of the J500 series devices (D2 in Figure 6b).

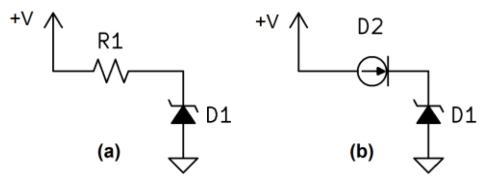

Figure 6

2. Discrete transistor amplifiers. See the circuitry in Figure 2, above, or in Figure 7, below. In Figure 7, the constant current source shared by the differential input FETs (LSK389) forces a total of 4 mA through the two FETs to keep them both in their linear operating range. This current is steered back and forth between the two FETs depending on the input voltage at J1 and the equal magnitude but opposite phase [angle] voltage the fed back from the output.

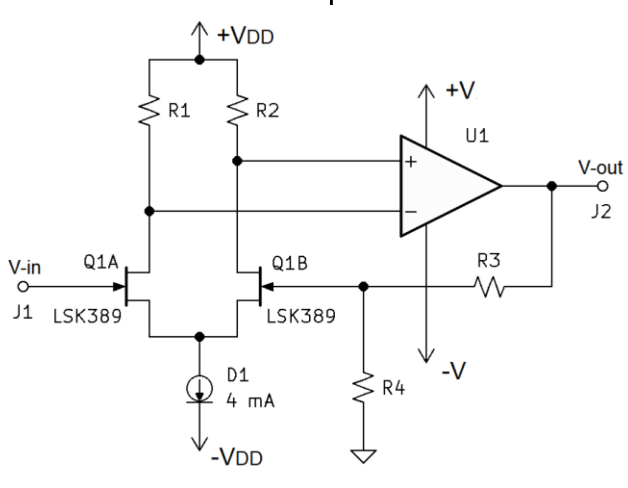

Figure 7

3. Current source plus current mirror. Figure 8 shows a circuit similar to that which appears in Figure 2 and represents a typical sub-circuit. This uses a constant current diode (D1) to force a reference current through the left half of a current mirror (Q1A). That current is matched as I_{LOAD} in the right half of the current mirror (Q1B) and through the Z_{LOAD}. Z_{LOAD} represents the following amplification or frequency shaping stages used in typical sensor circuitry. Note that Q1A and Q1B are fabricated on the same silicon chip and are therefore matched devices (matched V_{BE} and β). This is essential to ensure that the current mirror works as designed.

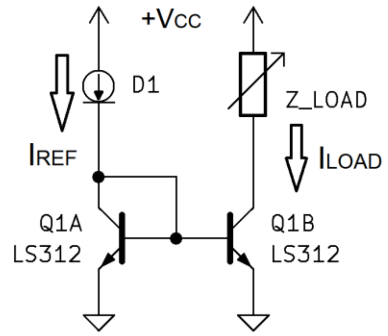

Figure 8

This configuration helps to isolate the constant current diode from the (perhaps) unpredictable resistance or impedance variations of the load.

In cases where the load current must be some multiple of the reference current, multiple matched transistors (fabricated on the same chip) are used. Figure 9a shows an example where I_{LOAD} is 5X I_{REF}. Figure 9b shows an example where I_{LOAD} is 1.5X I_{REF}.

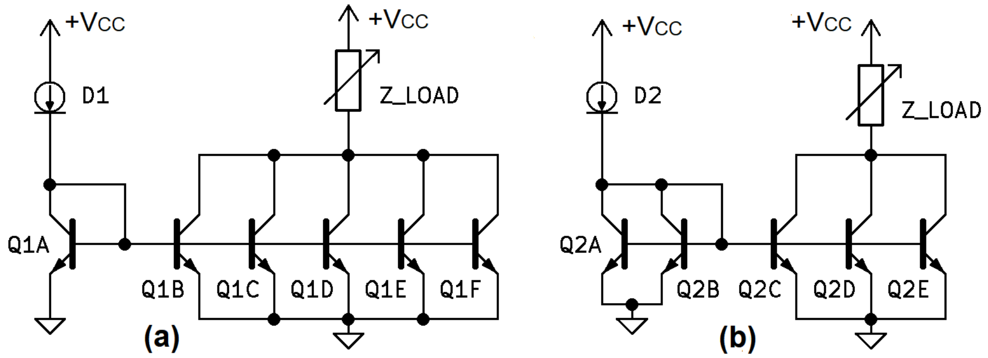

Figure 9

These circuits might see usage as part of the biasing circuitry for an amplifier; as an excitation source for LEDs or sensors; as a charging circuit for super capacitors or batteries; or as a current calibrator for photodiodes or other sensors (temperature, pressure, flow volume, etc.).

Conclusion: There are multiple uses for constant current diodes such as the Linear Integrated Systems J500 devices. Properly applied, they will simplify analog circuit designs for voltage reference circuits, amplifier circuits, and sensor signal processors.