PhysLAB Current Source

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A current source is a key electronic circuit that provides a constant current independent of the voltage across it [1]. It is commonly used to bias a transistor and act as an active load in an amplifier circuit. Some key electronic applications such as integrators and sawtooth/ramp generators cannot be built without a current source. These types of sources give us control over the current in the circuit. This capability can be extremely useful in current sensitive electronics where increase in current can damage the components for e.g. a laser diode.

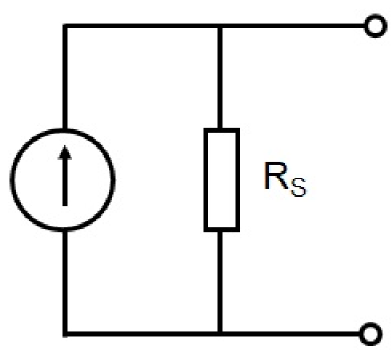


Figure 1: A current source representation.

A practical current source is represented by an ideal current source in parallel with a shunt resistance known as the Norton equivalent circuit (Figure 1). An ideal current source is a circuit that supplies constant current irrespective of the load voltage requirement. However, in practice, the output voltage range over which the current source can maintain its current level is known as the output compliance [2].

A basic current source design consists of a voltage source in series with a resistance. The major drawback of such a design is large power dissipation in the resistors as the voltage source used must be large to keep the current constant. This design is hardly used. A more robust current source is built using a transistor. Advanced techniques such as cascoding are implemented to make current sources designs more robust [3].

1 Operating instructions

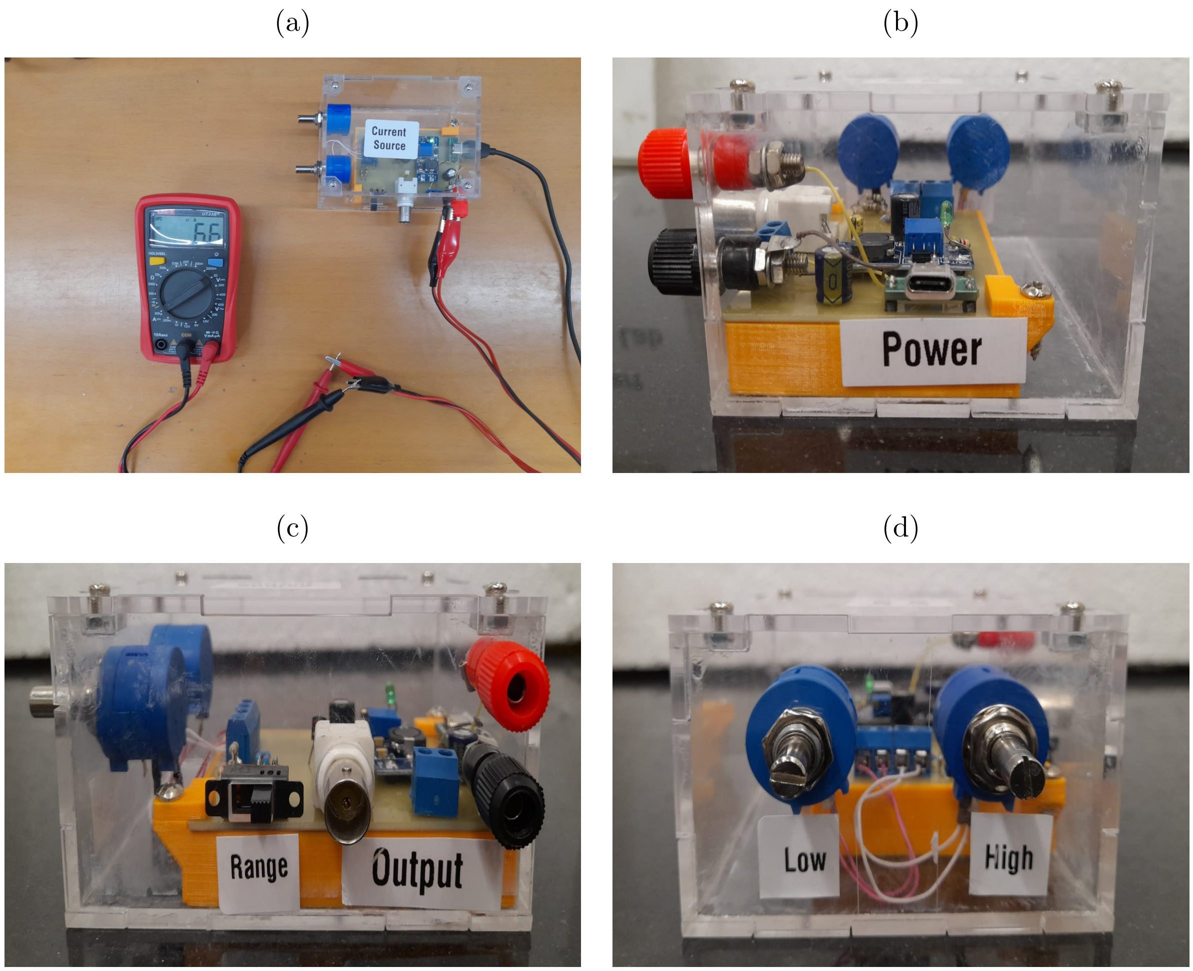


Figure 2: Various views of the home-built current source.

To use this current source (Figure 2a) you need to be aware of the following issues:

1. First, provide power to the current source by connecting to a computer via USB Type-C to USB-A 2.0 Male Charger Cable (Figure 2b).

2. The device has two types of output ports, (1) BNC port and (2) banana jacks. Current output can be taken by making connections to either of these ports (Figure 2c).

3. These current sources can output current from the microampere (μA) to the milliampere (mA) range. For using the μA range, the range labeled button should be pushed to the left, and for the mA range, it should be pushed to the right. The low labeled knob should be turned to vary the current in the μA range and the right labeled knob should be turned to change the current in the mA range (Figure 2d).

1.1 Internal circuitry

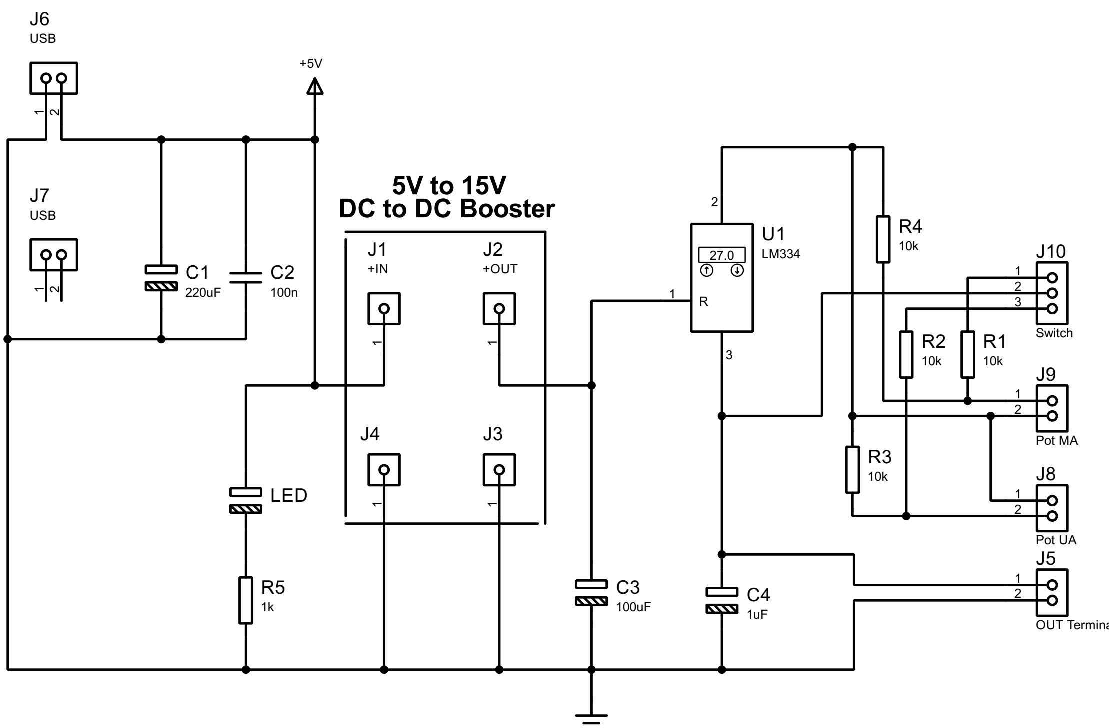
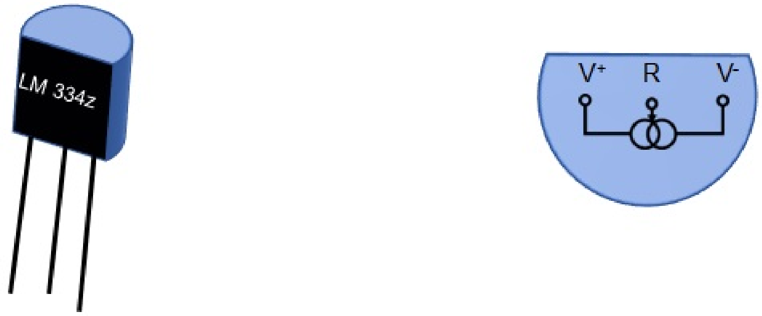


Figure 3: Schematic of the home-built current source.

Figure 3 shows the internal circuitry of the current source we have built in the lab. In this schematic the terminal labeled as the `Switch` (J10) is our range selector (Figure 2c), `Pot MA` (J9) is the potentiometer that controls the high current range (Figure 2d), `Pot UA` (J8) varies the low current range (Figure 2d), and the `OUT Terminal` (J5) is the banana-type output terminal (Figure 2c). Connected parallel to it is the BNC terminator (not shown in this schematic). `USB` (J6) terminal shown is the USB power terminal used to turn on the device (Figure 2b). The chief component in this circuit is the **IC LM334** (U1). It's a three-terminal floating current source (Figure 4a).



(a) (b)

Figure 4: (a) Circuit schematic and (b) pin configuration of LM 334 (bottom view).

This IC has the capability of adjusting current from 1 μA–10 mA. This range is obtained by designing the external resistance (R_{SET}) between the **R** terminal and **V**$^-$ terminal (Figure 4b). Set current (I_{SET}) flowing into the V$^+$ pin (the current through the device) is obtained from the formula (see the details in the Appendix A):

$$I_{SET} = 67.7 \text{ mV}/R_{SET} \tag{1}$$

1.2 Current output range

Figure 2a shows our basic setup to determine the output range of our current source. We used **UT50B** multimeter to measure the output current. The output range measured was as follows:

1. Low current range: 6.6 μA–900 μA
2. High current range: 460 μA–10 mA

1.3 Compliance voltage test

It is vital to know the compliance voltage of the current source. This is the maximum voltage that the current source can output while producing the rated current. To find out the limit for our home-built device, we used the following equipment:

1. Variable resistors (22 kΩ, 100 kΩ)
2. Digital multimeters (02)

3. Current source

To find the compliance voltage, we connected the current source, variable resistor, and a digital multimeter (acting as an ammeter) in series. We varied the value of the variable resistor until the current output of the source dropped by 5% of its set value. At this point, we measured the voltage across the source. Table 1 gives the summary of the results.

Table 1: Compliance voltage testing.

Output Current (mA)	Compliance Voltage (V)	Resistor (kΩ)
0.2	14.14	74.70
0.5	14.11	29.70
1.0	14.07	14.90
5.0	13.85	2.88
11.1	13.24	1.24

References

[1] D. Irwin, R. M. Nelms, Basic Engineering Circuit Analysis, 8th ed. (Wiley , 2008).

[2] P. Horowitz, W. Hill, The Art of Electronics, 2nd ed. (Cambridge University Press, 1989).

[3] A. S. Sedra, K. C. Smith, Microelectronic Circuits, 6th ed. (Oxford University Press, 2009).

Appendix A Datasheet

LM134/LM234/LM334 3-Terminal Adjustable Current Sources

Check for Samples: LM134, LM234, LM334

FEATURES

- Operates From 1V to 40V
- 0.02%/V Current Regulation
- Programmable From 1µA to 10mA
- True 2-Terminal Operation
- Available as Fully Specified Temperature Sensor
- ±3% Initial Accuracy

DESCRIPTION

The LM134/LM234/LM334 are 3-terminal adjustable current sources featuring 10,000:1 range in operating current, excellent current regulation and a wide dynamic voltage range of 1V to 40V. Current is established with one external resistor and no other parts are required. Initial current accuracy is ±3%. The LM134/LM234/LM334 are true floating current sources with no separate power supply connections. In addition, reverse applied voltages of up to 20V will draw only a few dozen microamperes of current, allowing the devices to act as both a rectifier and current source in AC applications.

The sense voltage used to establish operating current in the LM134 is 64mV at 25°C and is directly proportional to absolute temperature (°K). The simplest one external resistor connection, then, generates a current with ≈+0.33%/°C temperature dependence. Zero drift operation can be obtained by adding one extra resistor and a diode.

Applications for the current sources include bias networks, surge protection, low power reference, ramp generation, LED driver, and temperature sensing. The LM234-3 and LM234-6 are specified as true temperature sensors with ensured initial accuracy of ±3°C and ±6°C, respectively. These devices are ideal in remote sense applications because series resistance in long wire runs does not affect accuracy. In addition, only 2 wires are required.

The LM134 is specified over a temperature range of −55°C to +125°C, the LM234 from −25°C to +100°C and the LM334 from 0°C to +70°C. These devices are available in TO hermetic, TO-92 and SOIC-8 plastic packages.

Connection Diagrams

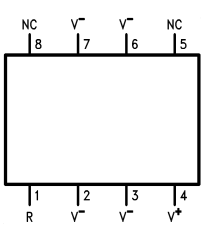


Figure 1. SOIC-8 Surface Mount Package (LM334M; LM334M/NOPB; LM334MX; LM334MX/NOPB) See Package Number D

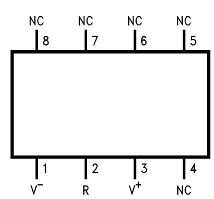


Figure 2. SOIC-8 Alternative Pinout Surface Mount Package (LM334SM; LM334SM/NOPB; LM334SMX; LM334SMX/NOPB) See Package Number D

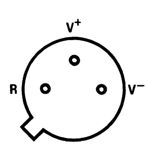


Figure 3. TO Metal Can Package (Bottom View) See Package Number NDV

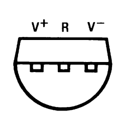


Figure 4. TO-92 Plastic Package (Bottom View) See Package Number LP

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Absolute Maximum Ratings[1][2]

V^+ to V^- Forward Voltage		LM134/LM234/LM334	40V
		LM234-3/LM234-6	30V
V^+ to V^- Reverse Voltage			20V
R Pin to V^- Voltage			5V
Set Current			10 mA
Power Dissipation			400 mW
ESD Susceptibility[3]			2000V
Operating Temperature Range[4]		LM134	−55°C to +125°C
		LM234/LM234-3/LM234-6	−25°C to +100°C
		LM334	0°C to +70°C
Soldering Information	TO-92 Package (10 sec.)		260°C
	TO Package (10 sec.)		300°C
	SOIC Package	Vapor Phase (60 sec.)	215°C
		Infrared (15 sec.)	220°C

(1) "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not ensure specific performance limits.
(2) If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/Distributors for availability and specifications.
(3) Human body model, 100pF discharged through a 1.5kΩ resistor.
(4) For elevated temperature operation, T_J max is:

LM134	150°C
LM234	125°C
LM334	100°C

See Thermal Characteristics.

Thermal Characteristics

over operating free-air temperature range (unless otherwise noted)

Thermal Resistance	TO-92	TO	SOIC-8
θ_{ja} (Junction to Ambient)	180°C/W (0.4″ leads)	440°C/W	165°C/W
	160°C/W (0.125″ leads)		
θ_{jc} (Junction to Case)	N/A	32°C/W	80°C/W

Electrical Characteristics[1]

Parameter	Conditions		LM134/LM234			LM334			Units
			Min	Typ	Max	Min	Typ	Max	
Set Current Error, V^+=2.5V[2]	10μA ≤ I_{SET} ≤ 1mA				3			6	%
	1mA < I_{SET} ≤ 5mA				5			8	%
	2μA ≤ I_{SET} < 10μA				8			12	%
Ratio of Set Current to Bias Current	100μA ≤ I_{SET} ≤ 1mA		14	18	23	14	18	26	
	1mA ≤ I_{SET} ≤ 5mA			14			14		
	2 μA≤I_{SET}≤100 μA			18	23		18	26	
Minimum Operating Voltage	2μA ≤ I_{SET} ≤ 100μA			0.8			0.8		V
	100μA < I_{SET} ≤ 1mA			0.9			0.9		V
	1mA < I_{SET} ≤ 5mA			1.0			1.0		V
Average Change in Set Current with Input Voltage	2μA ≤ I_{SET} ≤ 1mA	1.5 ≤ V^+ ≤ 5V		0.02	0.05		0.02	0.1	%/V
		5V ≤ V^+ ≤ 40V		0.01	0.03		0.01	0.05	%/V
	1mA < I_{SET} ≤ 5mA	1.5V ≤ V ≤ 5V		0.03			0.03		%/V
		5V ≤ V ≤ 40V		0.02			0.02		%/V
Temperature Dependence of Set Current[3]	25μA ≤ I_{SET} ≤ 1mA		0.96T	T	1.04T	0.96T	T	1.04T	
Effective Shunt Capacitance				15			15		pF

(1) Unless otherwise specified, tests are performed at T_j = 25°C with pulse testing so that junction temperature does not change during test
(2) Set current is the current flowing into the V^+ pin. For the Basic 2-Terminal Current Source circuit shown in Figure 13. I_{SET} is determined by the following formula: I_{SET} = 67.7 mV/R_{SET} (@ 25°C). Set current error is expressed as a percent deviation from this amount. I_{SET} increases at 0.336%/°C @ T_j = 25°C (227 μV/°C).
(3) I_{SET} is directly proportional to absolute temperature (°K). I_{SET} at any temperature can be calculated from: $I_{SET} = I_o (T/T_o)$ where I_o is I_{SET} measured at T_o (°K).

Electrical Characteristics[1]

Parameter	Conditions		LM234-3			LM234-6			Units
			Min	Typ	Max	Min	Typ	Max	
Set Current Error, V^+=2.5V [2]	100μA ≤ I_{SET} ≤ 1mA				±1			±2	%
	T_J = 25°								
Equivalent Temperature Error					±3			±6	°C
Ratio of Set Current to Bias Current	100μA ≤ I_{SET} ≤ 1mA		14	18	26	14	18	26	
Minimum Operating Voltage	100μA I_{SET} ≤ 1mA			0.9			0.9		V
Average Change in Set Current with Input Voltage	100μA ≤ I_{SET} ≤ 1mA	1.5 ≤ V^+ ≤ 5V		0.02	0.05		0.02	0.01	%/V
		5V ≤ V^+ ≤ 30V		0.01	0.03		0.01	0.05	%/V
Temperature Dependence of Set Current[3]	100μA ≤ I_{SET} ≤ 1mA		0.98T	T	1.02T	0.97T	T	1.03T	
Equivalent Slope Error					±2			±3	%
Effective Shunt Capacitance				15			15		pF

(1) Unless otherwise specified, tests are performed at T_j = 25°C with pulse testing so that junction temperature does not change during test
(2) Set current is the current flowing into the V^+ pin. For the Basic 2-Terminal Current Source circuit shown in Figure 13. I_{SET} is determined by the following formula: I_{SET} = 67.7 mV/R_{SET} (@ 25°C). Set current error is expressed as a percent deviation from this amount. I_{SET} increases at 0.336%/°C @ T_j = 25°C (227 μV/°C).
(3) I_{SET} is directly proportional to absolute temperature (°K). I_{SET} at any temperature can be calculated from: $I_{SET} = I_o (T/T_o)$ where I_o is I_{SET} measured at T_o (°K).

Typical Performance Characteristics

Output Impedance

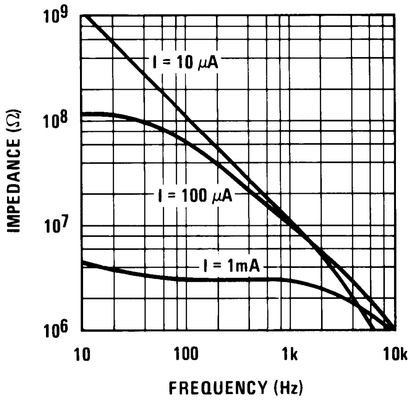


Figure 5.

Maximum Slew Rate
Linear Operation

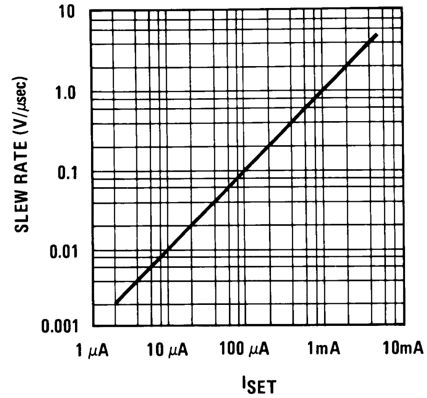


Figure 6.

Start-Up

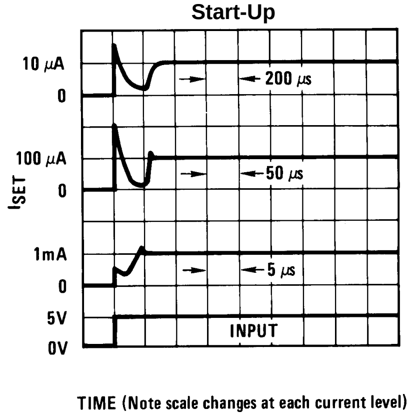


Figure 7.

Transient Response

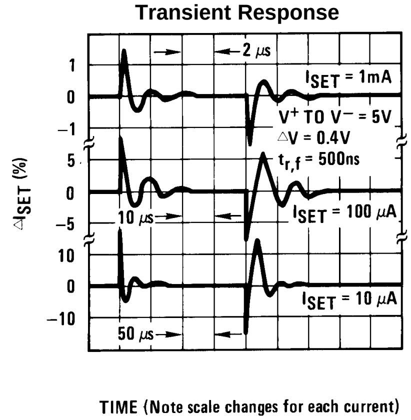


Figure 8.

Voltage Across R_{SET} (V_R)

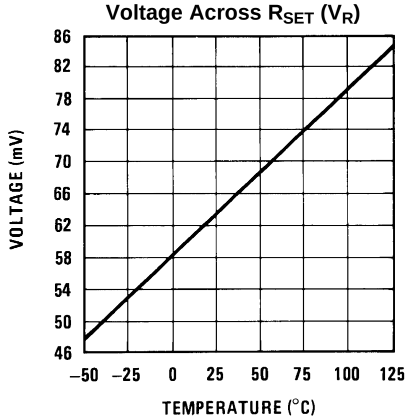


Figure 9.

Current Noise

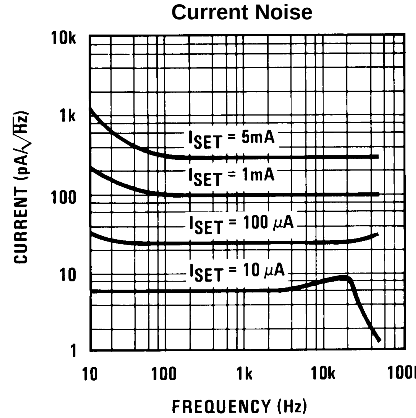


Figure 10.

Typical Performance Characteristics (continued)

Turn-On Voltage

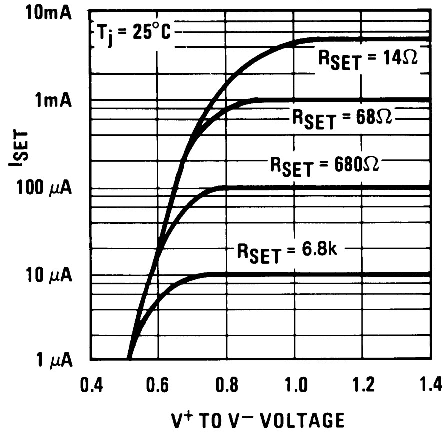


Figure 11.

Ratio of I_{SET} to I_{BIAS}

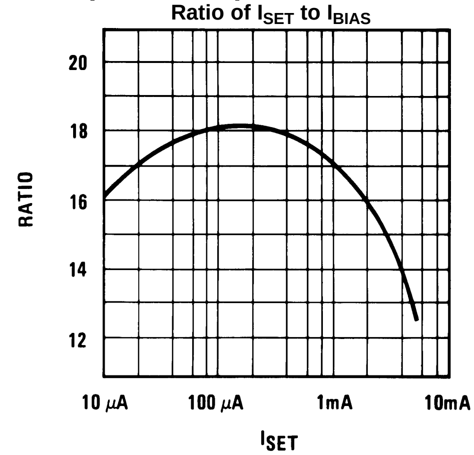


Figure 12.

APPLICATION HINTS

The LM134 has been designed for ease of application, but a general discussion of design features is presented here to familiarize the designer with device characteristics which may not be immediately obvious. These include the effects of slewing, power dissipation, capacitance, noise, and contact resistance.

Calculating R_{SET}

The total current through the LM134 (I_{SET}) is the sum of the current going through the SET resistor (I_R) and the LM134's bias current (I_{BIAS}), as shown in Figure 13.

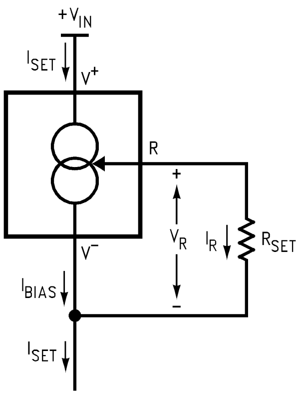


Figure 13. Basic Current Source

A graph showing the ratio of these two currents is supplied under **Ratio of I_{SET} to I_{BIAS}** in Typical Performance Characteristics. The current flowing through R_{SET} is determined by V_R, which is approximately 214μV/°K (64 mV/298°K ~ 214μV/°K).

$$I_{SET} = I_R + I_{BIAS} = \frac{V_R}{R_{SET}} + I_{BIAS} \quad (1)$$

Since (for a given set current) I_{BIAS} is simply a percentage of I_{SET}, the equation can be rewritten

$$I_{SET} = \left(\frac{V_R}{R_{SET}}\right)\left(\frac{n}{n-1}\right)$$

where

- n is the ratio of I_{SET} to I_{BIAS} as specified in Electrical Characteristics and shown in the graph (2)

Since n is typically 18 for 2μA ≤ I_{SET} ≤ 1mA, the equation can be further simplified to

$$I_{SET} = \left(\frac{V_R}{R_{SET}}\right)(1.059) = \frac{227\ \mu V/°K}{R_{SET}} \quad (3)$$

for most set currents.

Slew Rate

At slew rates above a given threshold (see curve), the LM134 may exhibit non-linear current shifts. The slewing rate at which this occurs is directly proportional to I_{SET}. At I_{SET} = 10μA, maximum dV/dt is 0.01V/μs; at I_{SET} = 1mA, the limit is 1V/μs. Slew rates above the limit do not harm the LM134, or cause large currents to flow.

Thermal Effects

Internal heating can have a significant effect on current regulation for I_{SET} greater than 100μA. For example, each 1V increase across the LM134 at I_{SET} = 1 mA will increase junction temperature by ≈0.4°C in still air. Output current (I_{SET}) has a temperature coefficient of ≈0.33%/°C, so the change in current due to temperature rise will be (0.4) (0.33) = 0.132%. This is a 10:1 degradation in regulation compared to true electrical effects. Thermal effects, therefore, must be taken into account when DC regulation is critical and I_{SET} exceeds 100μA. Heat sinking of the TO package or the TO-92 leads can reduce this effect by more than 3:1.