LM1014 Motor Speed Regulator

General Description
The LM1014 is a monolithic integrated circuit specifically designed to provide a low cost motor speed regulator for low voltage DC motors.

Features
- 5V to 20V operating voltage range
- Short circuit protection
- Remote pause control
- Saturation voltage 0.1V
- Motor connected to ground for ease of RF suppression
- Motor torque compensation
- Low current consumption

Functional Block Diagram and Typical Connection

Connection Diagram

Dual-In-Line Package

Order Number LM1014N-2
See NS Package N08E

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Absolute Maximum Ratings

Supply Voltage 24V
Operating Temperature Range -20 to +70°C
Storage Temperature Range -65 to +150°C
Lead Temp. (Soldering, 10 seconds) 300°C

Electrical Characteristics (Note 1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage Range</td>
<td></td>
<td>5.0</td>
<td>20.0</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Supply Current</td>
<td>Current into Pin 5</td>
<td></td>
<td>6.0</td>
<td>8.0</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>Reference Voltage</td>
<td></td>
<td></td>
<td>1.33</td>
<td></td>
<td>V</td>
<td>0.3 mV/°C</td>
</tr>
<tr>
<td>Line Regulation of</td>
<td>VS = 5V to VS = 20V</td>
<td></td>
<td></td>
<td>2.0</td>
<td>% VREF</td>
<td></td>
</tr>
<tr>
<td>Reference Voltage</td>
<td>Pin 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remote Stop Current</td>
<td>Current into Pin 3 when Grounded</td>
<td>125</td>
<td>200</td>
<td></td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>Output Current A1</td>
<td>VS = 5V</td>
<td>15</td>
<td>40</td>
<td></td>
<td>mA</td>
<td>Current into Pin 2</td>
</tr>
<tr>
<td></td>
<td>Pin 2 Gnd</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short Circuit Current Limit</td>
<td>R1 = 1Ω</td>
<td>1.4</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Motor Sense</td>
<td>R1 = 1Ω, R2 = 200Ω</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Deviation</td>
<td>Current into Pin 2: I2</td>
<td></td>
<td>± 3.0</td>
<td>%</td>
<td></td>
<td>(I2/Im – 1) Exclusive of External Components Tolerances</td>
</tr>
</tbody>
</table>

Note 1: Unless otherwise specified, VS = 5V to 20V and −15°C ≤ TA ≤ 55°C.
Note 2: The remote stop is activated by grounding pin 3. The motor restarts after disconnection of the ground connection.
Note 3: The current limit is set by resistor R1, i.e., I = 1.4V/R1. When the output current exceeds this limit, the drive to the output transistor is switched off by a latch circuit. The motor can only be restarted after interruption of the supply voltage.

Typical Performance Characteristics/Application

1. The output voltage VM is given by:

   \[ V_M = V_{REF} \left( 1 + \frac{R_3}{R_4} + \frac{I_M}{R_1 R_3} \right) / R_2 \]

2. R1, R3, R52 must be equal to dynamic motor winding resistance Rm in order to keep the speed constant during load torque variations.

3. Parameter of the motor used for the test results shown below:

   \[ R_M = 16.3 \Omega \] and back e.m.f. = 3.25V @2000 r.p.m.; torque constant 5.9 mA/mNm; External components: R1 = 1Ω

   Cu, R2 = 200Ω and R3 = 16 kΩ; VREF = 1.33V

   CBE = 2.2 µF and C3 = 0.47 µF.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Speed Deviation</td>
<td>VS = 5V to 10V</td>
<td>± 0.5%</td>
</tr>
<tr>
<td>(Voltage)</td>
<td>VS = 5V to 20V</td>
<td>± 1.0%</td>
</tr>
<tr>
<td>Motor Speed Deviation</td>
<td>IM = 25 mA to 125 mA</td>
<td>± 1.0%</td>
</tr>
<tr>
<td>(Load)</td>
<td>T = +5°C to +35°C</td>
<td>1.0%</td>
</tr>
<tr>
<td>Motor Speed Deviation</td>
<td>T = −15°C to +55°C</td>
<td>3.0%</td>
</tr>
<tr>
<td>(Temperature)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Application Hints**

This circuit has been primarily designed for cassette tape recorders, but is suitable for all low voltage DC motors, and performs the functions of motor speed control, remote stop (pause) and output short circuit protection. The circuit achieves good speed regulation under conditions of supply voltage, torque and temperature variations. Five components, a PNP pass transistor and four resistors, are required to match the circuit to the motor. As these are external to the IC a very wide range of motor characteristics can be accommodated.

Motor speed control is by means of a negative output impedance voltage regulator. The negative output impedance is a function of the external resistors.

If the output current exceeds a preset limit, the base drive to the external PNP transistor is switched off and can only be restarted after reconnection of the supply voltage. The remote stop is activated by closing a DC switch.

**System Description**

The voltage across the terminals of a DC motor is given by:

\[ V_M = E_0 + R_M I_M \]

\[ E_0 = \text{back e.m.f. - proportional to speed} \]
\[ I_M = \text{motor current - proportional to load torque} \]
\[ R_M = \text{motor winding resistance} \]

The regulator must therefore be a source whose voltage can be controlled to maintain the desired back e.m.f., with a negative output resistance whose value equals the motor winding resistance in order to maintain the desired speed during torque variations. (See Figure 1)

A block diagram of the system is shown in Figure 2 with the external components connected. The circuit comprises of a stable voltage reference source, \( V_{ref} \), two high gain differential amplifiers, \( A_1 \) and \( A_2 \), short circuit detector + latch and remote stop circuit.

Amplifier \( A_2 \) is a high gain differential - input amplifier. (DC collector current; 125 \( \mu \)A). Feedback through \( T_1 \) maintains the potentials at the input terminals 9 and 10 equal, therefore the collector current of \( T_1 \) will be in the ratio of \( R_1/R_2 \) of the motor current \( I_M \). This current is mirrored (5 : 1) and will be supplied via \( R_9 \). Amplifier \( A_2 \) has been designed to work with its inputs at or near the supply voltage.

Amplifier \( A_1 \) is also a high gain differential amplifier, but with Darlington inputs. (DC collector current:280 \( \mu \)A). Feedback through \( T_2 \), \( R_1 \), \( R_3 \) and \( R_4 \) maintains the potential at pin 1 equal to \( V_{ref} \). The total current through resistor \( R_3 \) will be:

\[ \frac{V_{ref} + I_M R_1}{R_4} = \frac{I_M R_1}{5R_2} \]

The output voltage \( V_M \) is thus given by:

\[ V_M = V_{ref} \left( \frac{1 + \frac{R_3}{R_4}}{1 + \frac{R_1}{R_2}} \right) \]

Therefore by varying \( R_3/R_4 \) a no load voltage \( V_0 \) can be supplied which equals the back e.m.f. \( E_0 \) of the motor at the desired speed. The value of the negative resistance \( R_0 \) is given by:

\[ R_1 \left( \frac{R_3}{5R_2} \right) \]

The increase in output voltage \( V_M \) due to an increase in motor current is given by \( \Delta I_M R_0 \). The increase in the voltage drop across the motor winding resistor \( R_M \) is \( \Delta I_M R_M \) in order to keep the speed constant during load torque variations the resistance \( R_0 \) must be equal to \( R_M \).

The reference voltage source is based on the bandgap regulator principle(1) and comprises transistors \( T_1 \) to \( T_{10} \). The reference voltage is given by:

\[ V_{ref} = V_{be1} + V_T \left( 1 + \frac{R_3}{R_5} \right) \ln \left( \frac{R_6}{R_4} \right) \]

with \( R_9 = 10 \) with \( V_T = kT/q \).

The bandgap regulator is driven from an internally generated 3.8 V regulator. This regulator comprises of \( T_{11}/T_{16}, T_{23} \) and resistors \( R_7 \) and \( R_8 \).

Resistors \( R_{15} \) and \( R_{16} \), transistors \( T_{27} \) and \( T_{28} \) serve the sole purpose of starting this regulator. It only needs to supply enough base current to \( T_{11} \) to develop 600 mV across \( R_7 \) to ensure start-up. This start-up network is disabled by transistor \( T_{24} \) as soon as the output voltage exceeds 3V. Resistors \( R_{11} \) and \( R_{12} \) are used to sense the output voltage for this purpose.

Current limiting is provided by transistors \( T_{51}, T_{52} \) and \( T_{53} \). When the voltage across the external resistor \( R_1 \), connected between pin 8 and 10, becomes high enough to turn on \( T_{52} \) and \( T_{53} \) (approximately 1.4V), current source \( T_{51} \) turns on transistor \( T_{55} \) and the latch circuit changes state, i.e., \( T_{47} \) turns on. Hence transistor \( T_{50} \) is turned on by current source \( T_{42} \) and sinks all the base current supplied to \( T_{29} \), thereby switching off the external transistor. Transistor \( T_{25} \) holds off the start-up circuit. The latch can only be reset by interruption of the supply voltage. The latch circuit is supplied with equal currents from two collectors of \( T_{50} \). The purpose of the capacitor connected to the base of \( T_{47} \) is to ensure that the latch always starts in the "T_{47} off and T_{54} on" state.

The remote stop is activated by connecting pin 4 to ground. Transistor \( T_{45} \) (collector current 180 \( \mu \)A) activates current source \( T_{42} \). Transistor \( T_{50} \) is driven into saturation by \( T_{42} \), switching off the base drive to the external transistor. At the same time, the Darlington connected transistors \( T_{58} \) and \( T_{59} \) discharge the capacitors of the motorfilter and transistor \( T_{25} \) holds off the start-up circuit. After disconnecting pin 4, current source \( T_{42} \) turns off and transistor \( T_{29} \) will supply the maximum base drive to restart the motor.


\[ \text{FIGURE 1.} \]

\[ + \]

\[ \text{V}_{0} \]

\[ \text{V}_{M} \]

\[ \text{R}_{0} \]

\[ \text{TLH/6159-4} \]
System Description

1. To ensure stable operation of the system the feedback loop requires compensation capacitors between the base-emitter of the power pass transistor and across $R_3$ (to smooth current spikes caused by commutator brushes).

   Recommended values: $C_{be} = 2.2 - 10 \text{mF}$
   
   $C_3 = 0.47 - 1 \text{\mu F}$

2. To minimize the voltage drop between the supply line and the motor, resistor $R_1$ should be kept to a very low value.

   Recommended values: $R_1 = 1 - 5\Omega$
   
   $R_2 = 200\Omega$

3. The output current limit is set by $R_3$:

   $I_{\text{limit}} = \frac{1.4V}{R_1}$

4. An improved performance of the system for supply voltage variations can be achieved by connecting a resistor between pin 1 and the supply voltage line. ($V_{\text{ref 3}}$ and $V_{\text{ref 4}}$ only).

   Recommended values: $R (V_{\text{ref 3}}) = 6.8 \text{ M\Omega}$
   
   $R(V_{\text{ref 4}}) = 4 \text{ M\Omega}$

5. The overall temperature performance of the regulator system is primarily determined by the matching of the temperature coefficient of the motor voltage and the output voltage $V_M$. Ideally $dR_0/dT$ is made equal to $dR_M/dT$ and $dV_0/dT$ to $dE_0/dT$. The temperature coefficient of $V_0$ is a multiple of the temperature coefficient of the reference voltage $V_{\text{ref}}$. Four reference voltages are available, two with a negative – and two with a positive temperature coefficient.

Since $dR_M/dT$ is positive, a copper sensing resistor $R_1$ (assuming $R_2$ and $R_3$ are both of the same type) will then give optimum speed regulation over the full temperature range. Alternatively, a sensing resistor $R_1$ with a more negative coefficient than that of $R_M$ can be employed e.g. carbon but then a reference voltage with a positive temperature coefficient must be used. However, care must be taken that the resistance $R_1 R_3/5R_2$ never becomes more than $R_M$ otherwise the system will overcompensate for torque changes and can become unstable. Therefore, when employing a sensing resistor with a negative temperature coefficient, $R_0$ must be made smaller than $R_M$ (factor 0.9). This will degrade the torque regulation accordingly.