AUTOMOTIVE GRADE

# CS8191

# Precision Air-Core Tach/Speedo Driver with Short Circuit Protection

## Description

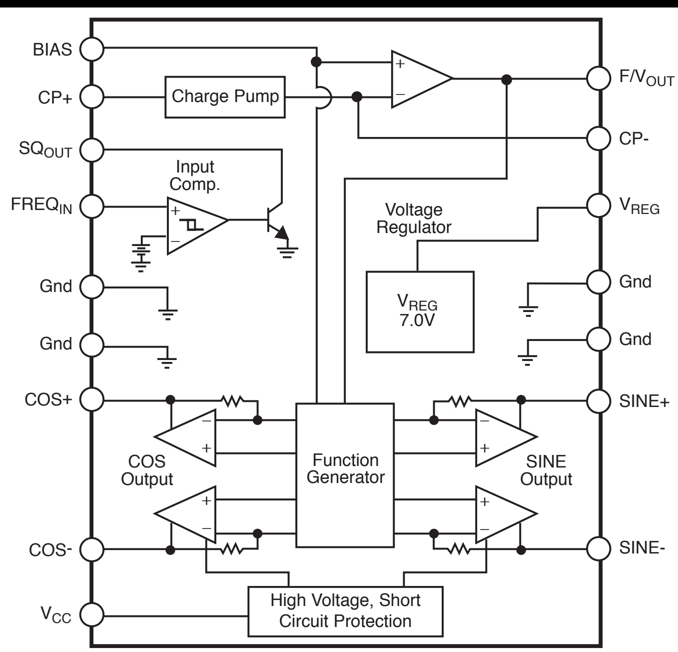
The CS8191 is specifically designed for use with 4 quadrant air-core meter movements. The IC includes an input comparator for sensing input frequency such as vehicle speed or engine RPM, a charge pump for frequency to voltage conversion, a bandgap reference for stable operation and a function generator with sine and cosine amplifiers that differentially drive the motor coils.

The CS8191 has a higher torque output and better output signal symmetry than other competitive parts (CS289, and LM1819). It is protected against short circuit and overvoltage (60V) fault conditions. Enhanced circuitry permits functional operation down to 8V.

### Absolute Maximum Ratings

| | | |
|---|---|---|
| Supply Voltage | ( ≤ 100ms pulse transient) | $V_{CC}$ = 60V |
| | (continuous) | $V_{CC}$ = 24V |
| Operating Temperature Range | | -40°C to +105°C |
| Junction Temperature Range | | -40°C to +150°C |
| Storage Temperature Range | | -55°C to +165°C |
| Electrostatic Discharge (Human Body Model) | | 4kV |
| Lead Temperature Soldering | | |
| Wave Solder (through hole styles only) | | 10 sec. max, 260°C peak |
| Reflow (SMD styles only) | | 60 sec. max above 183°C, 230°C peak |

### Block Diagram

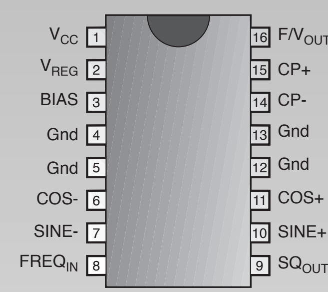



## Features

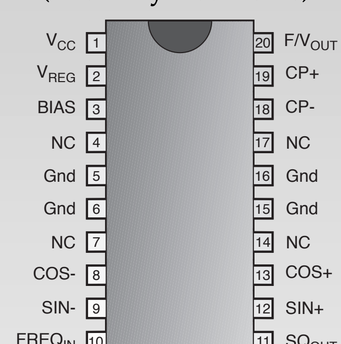
- Direct Sensor Input
- High Output Torque
- Wide Output Voltage Range
- High Impedance Inputs
- Accurate down to 10V $V_{CC}$
- Fault Protection
  - Overvoltage
  - Short Circuit
- Low Voltage Operation

## Package Options

**16 Lead PDIP (internally fused leads)**




**20 Lead SOIC (internally fused leads)**

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**Electrical Characteristics: -40°C ≤ $T_A$ ≤ 105°C, 8V ≤ $V_{CC}$ ≤ 16V unless otherwise specified.**

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|
| **■ Supply Voltage Section** | | | | | |
| $I_{CC}$ Supply Current | $V_{CC}$ = 16V, -40°C, No Load | | 70 | 125 | mA |
| $V_{CC}$ Normal Operation Range | | 8.0 | 13.1 | 16.0 | V |
| **■ Input Comparator Section** | | | | | |
| Positive Input Threshold | | 2.4 | 2.7 | 3.0 | V |
| Negative Input Threshold | | 2.0 | 2.3 | | V |
| Input Hysteresis | | 200 | 400 | 1000 | mV |
| Input Bias Current * | 0V ≤ $V_{IN}$ ≤ 8V | | -2 | ±10 | μA |
| Input Frequency Range | | 0 | | 20 | kHz |
| Input Voltage Range | in series with 1kΩ | -1 | | $V_{CC}$ | V |
| Output $V_{SAT}$ | $I_{CC}$ = 10mA | | 0.15 | 0.40 | V |
| Output Leakage | $V_{CC}$ = 7V | | | 10 | μA |
| Logic 0 Input Voltage | | 2.0 | | | V |

*Note: Input is clamped by an internal 12V Zener.

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|
| **■ Voltage Regulator Section** | | | | | |
| Output Voltage | | 6.50 | 7.00 | 7.50 | V |
| Output Load Current | | | | 10 | mA |
| Output Load Regulation | 0 to 10 mA | | 10 | 50 | mV |
| Output Line Regulation | 8.0V ≤ $V_{CC}$ ≤ 16V | | 20 | 150 | mV |
| Power Supply Rejection | $V_{CC}$ = 13.1V, $1V_{P/P}$ 1kHz | 34 | 46 | | dB |
| **■ Charge Pump Section** | | | | | |
| Inverting Input Voltage | | 1.5 | 2.0 | 2.5 | V |
| Input Bias Current | | | 40 | 150 | nA |
| $V_{BIAS}$ Input Voltage | | 1.5 | 2.0 | 2.5 | V |
| Non Invert. Input Voltage | $I_{IN}$ = 1mA | | 0.7 | 1.1 | V |
| Linearity* | @ 0, 87.5, 175, 262.5, + 350Hz | -0.10 | 0.28 | +0.70 | % |
| F/$V_{OUT}$ Gain | @ 350Hz, $C_T$ = 0.0033μF, $R_T$ = 243kΩ | 7 | 10 | 13 | mV/Hz |
| Norton Gain, Positive | $I_{IN}$ = 15μA | 0.9 | 1.0 | 1.1 | I/I |
| Norton Gain, Negative | $I_{IN}$ = -15μA | 0.9 | 1.0 | 1.1 | I/I |

*Note: Applies to % of full scale (270°).

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|
| **■ Function Generator Section: -40° ≤ $T_A$ ≤ 85°C, $V_{CC}$ = 13.1V unless otherwise noted.** | | | | | |
| Differential Drive Voltage ($V_{COS}$+ - $V_{COS}$-) | 10V ≤ $V_{CC}$ ≤ 16V<br>Θ = 0° | 7.5 | 8.0 | 8.5 | V |
| Differential Drive Voltage ($V_{SIN}$+ - $V_{SIN}$-) | 10V ≤ $V_{CC}$ ≤ 16V<br>Θ = 90° | 7.5 | 8.0 | 8.5 | V |
| Differential Drive Voltage ($V_{COS}$+ - $V_{COS}$-) | 10V ≤ $V_{CC}$ ≤ 16V<br>Θ = 180° | -8.5 | -8.0 | -7.5 | V |
| Differential Drive Voltage ($V_{SIN}$+ - $V_{SIN}$-) | 10V ≤ $V_{CC}$ ≤ 16V<br>Θ = 270° | -8.5 | -8.0 | -7.5 | V |
| Differential Drive Load | 10V ≤ $V_{CC}$ ≤ 16V, -40°C<br>25°C<br>105°C | 178<br>239<br>314 | | | Ω<br>Ω<br>Ω |
| Zero Hertz Output Voltage | | -0.08 | 0.0 | +0.08 | V |

## Electrical Characteristics: continued

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|
| **■ Function Generator Section: continued** | | | | | |
| Function Generator Error * | $\Theta$ = 0° to 225° | -2 | 0 | +2 | deg |
| Reference Figures 1 - 4 | $\Theta$ = 226° to 305° | -3 | 0 | +3 | deg |
| Function Generator Error | 13.1V ≤ $V_{CC}$ ≤ 16V | -1 | 0 | +1 | deg |
| Function Generator Error | 13.1V ≤ $V_{CC}$ ≤ 10V | -1 | 0 | +1 | deg |
| Function Generator Error | 13.1V ≤ $V_{CC}$ ≤ 8.0V | -7 | 0 | +7 | deg |
| Function Generator Error | 25°C ≤ $T_A$ ≤ 80°C | -2 | 0 | +2 | deg |
| Function Generator Error | 25°C ≤ $T_A$ ≤ 105°C | -4 | 0 | +4 | deg |
| Function Generator Error | –40°C ≤ $T_A$ ≤ 25°C | -2 | 0 | +2 | deg |
| Function Generator Gain | $T_A$ = 25°C, $\Theta$ vs $F/V_{OUT}$ | 60 | 77 | 95 | °/V |

*Note: Deviation from nominal per Table 1 after calibration at 0° and 270°.

## Package Lead Description

| PACKAGE LEAD # | | LEAD SYMBOL | FUNCTION |
|---|---|---|---|
| **16L PDIP** | **20L SO** | | |
| 1 | 1 | $V_{CC}$ | Ignition or battery supply voltage. |
| 2 | 2 | $V_{REG}$ | Voltage regulator output. |
| 3 | 3 | BIAS | Test point or zero adjustment. |
| 4, 5, 12, 13 | 5, 6, 15, 16 | Gnd | Ground Connections. |
| 6 | 8 | COS- | Negative cosine output signal. |
| 7 | 9 | SIN- | Negative sine output signal. |
| 8 | 10 | $FREQ_{IN}$ | Speed or rpm input signal. |
| 9 | 11 | $SQ_{OUT}$ | Buffered square wave output signal. |
| 10 | 12 | SIN+ | Positive sine output signal. |
| 11 | 13 | COS+ | Positive cosine output signal. |
| 14 | 18 | CP- | Negative input to charge pump. |
| 15 | 19 | CP+ | Positive input to charge pump. |
| 16 | 20 | $F/V_{OUT}$ | Output voltage proportional to input signal frequency. |
| | 4, 7, 14, 17 | NC | No connection. |

## Typical Performance Characteristics

**Figure 1: Function Generator Output Voltage vs Degrees of Deflection**

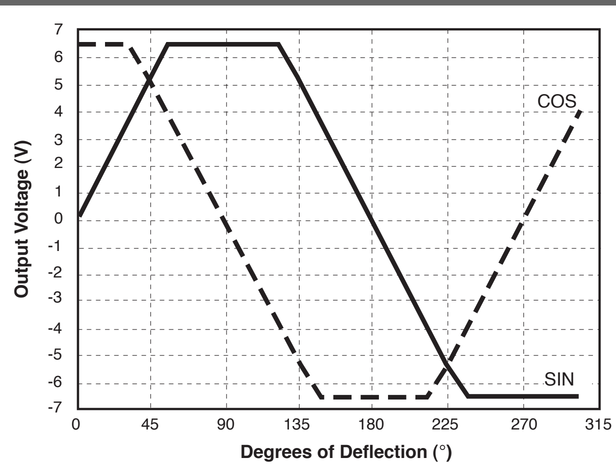
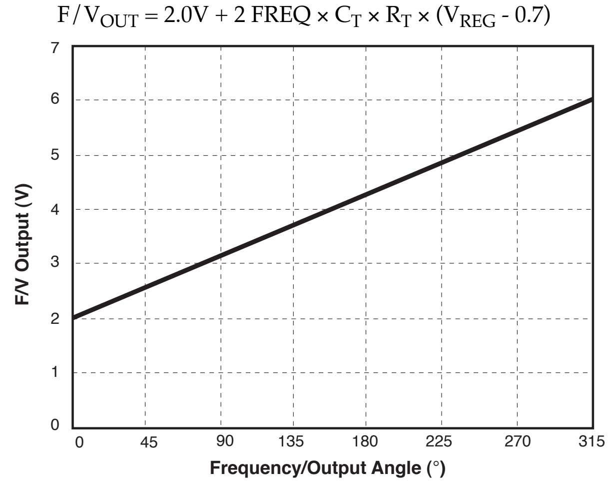


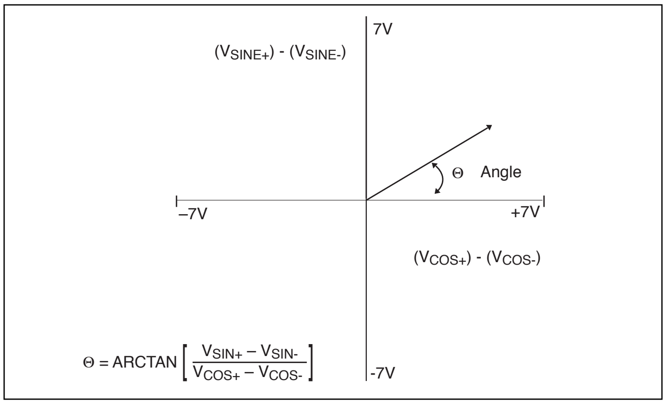

**Figure 2: Charge Pump Output Voltage vs Output Angle**

$F/V_{OUT}$ = 2.0V + 2 FREQ × $C_T$ × $R_T$ × ($V_{REG}$ - 0.7)

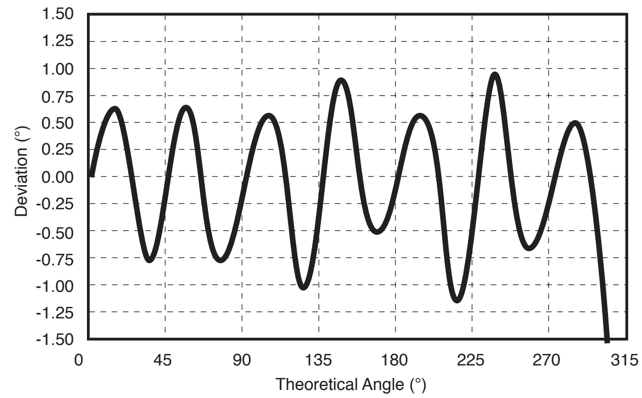


## Typical Performance Characteristics: continued

### Figure 3: Output Angle in Polar Form




### Figure 4: Nominal Output Deviation




## Nominal Angle vs. Ideal Angle (After calibrating at 180°)

**Note:** Temperature, voltage and nonlinearity not included.

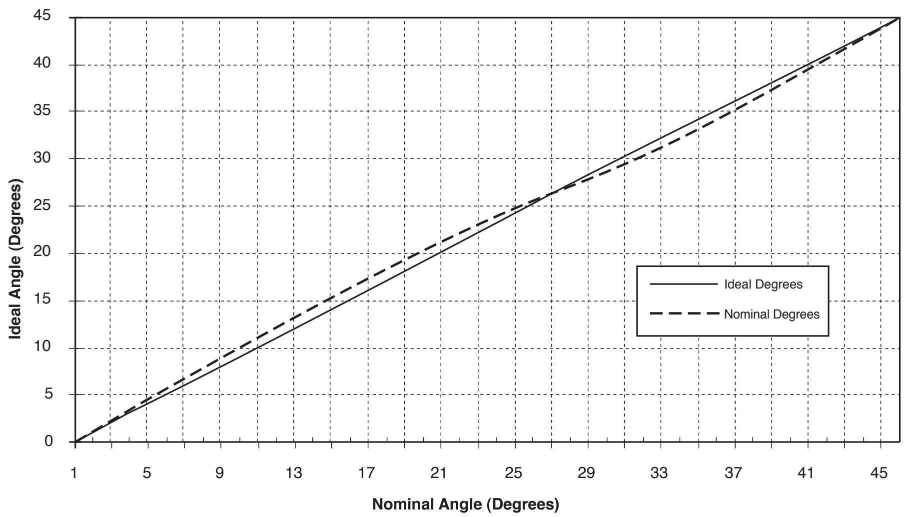



**Table 1:** Function Generator Output Nominal Angle vs. Ideal Angle (After calibrating at 270°)

| Ideal Θ Degrees | Nominal Θ Degrees | Ideal Θ Degrees | Nominal Θ Degrees | Ideal Θ Degrees | Nominal Θ Degrees | Ideal Θ Degrees | Nominal Θ Degrees | Ideal Θ Degrees | Nominal Θ Degrees | Ideal Θ Degrees | Nominal Θ Degrees |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 17 | 17.98 | 34 | 33.04 | 75 | 74.00 | 160 | 159.14 | 245 | 244.63 |
| 1 | 1.09 | 18 | 18.96 | 35 | 34.00 | 80 | 79.16 | 165 | 164.00 | 250 | 249.14 |
| 2 | 2.19 | 19 | 19.92 | 36 | 35.00 | 85 | 84.53 | 170 | 169.16 | 255 | 254.00 |
| 3 | 3.29 | 20 | 20.86 | 37 | 36.04 | 90 | 90.00 | 175 | 174.33 | 260 | 259.16 |
| 4 | 4.38 | 21 | 21.79 | 38 | 37.11 | 95 | 95.47 | 180 | 180.00 | 265 | 264.53 |
| 5 | 5.47 | 22 | 22.71 | 39 | 38.21 | 100 | 100.84 | 185 | 185.47 | 270 | 270.00 |
| 6 | 6.56 | 23 | 23.61 | 40 | 39.32 | 105 | 106.00 | 190 | 190.84 | 275 | 275.47 |
| 7 | 7.64 | 24 | 24.50 | 41 | 40.45 | 110 | 110.86 | 195 | 196.00 | 280 | 280.84 |
| 8 | 8.72 | 25 | 25.37 | 42 | 41.59 | 115 | 115.37 | 200 | 200.86 | 285 | 286.00 |
| 9 | 9.78 | 26 | 26.23 | 43 | 42.73 | 120 | 119.56 | 205 | 205.37 | 290 | 290.86 |
| 10 | 10.84 | 27 | 27.07 | 44 | 43.88 | 125 | 124.00 | 210 | 209.56 | 295 | 295.37 |
| 11 | 11.90 | 28 | 27.79 | 45 | 45.00 | 130 | 129.32 | 215 | 214.00 | 300 | 299.21 |
| 12 | 12.94 | 29 | 28.73 | 50 | 50.68 | 135 | 135.00 | 220 | 219.32 | 305 | 303.02 |
| 13 | 13.97 | 30 | 29.56 | 55 | 56.00 | 140 | 140.68 | 225 | 225.00 | | |
| 14 | 14.99 | 31 | 30.39 | 60 | 60.44 | 145 | 146.00 | 230 | 230.58 | | |
| 15 | 16.00 | 32 | 31.24 | 65 | 64.63 | 150 | 150.44 | 235 | 236.00 | | |
| 16 | 17.00 | 33 | 32.12 | 70 | 69.14 | 155 | 154.63 | 240 | 240.44 | | |

**Note:** Temperature, voltage and nonlinearity not included.

The CS8191 is specifically designed for use with air-core meter movements. It includes an input comparator for sensing an input signal from an ignition pulse or speed sensor, a charge pump for frequency to voltage conversion, a bandgap voltage regulator for stable operation, and a function generator with sine and cosine amplifiers to differentially drive the motor coils.

From the simplified block diagram of Figure 5A, the input signal is applied to the $FREQ_{IN}$ lead, this is the input to a high impedance comparator with a typical positive input threshold of 2.7V and typical hysteresis of 0.4V. The output of the comparator, $SQ_{OUT}$, is applied to the charge pump input CP+ through an external capacitor $C_T$. When the input signal changes state, $C_T$ is charged or discharged through R3 and R4. The charge accumulated on $C_T$ is mirrored to C4 by the Norton Amplifier circuit comprising of Q1, Q2 and Q3. The charge pump output voltage, $F/V_{OUT}$, ranges from 2V to 6.3V depending on the input signal frequency and the gain of the charge pump according to the formula:

$$F/V_{OUT} = 2.0V + 2 \times FREQ \times C_T \times R_T \times (V_{REG} - 0.7V)$$

$R_T$ is a potentiometer used to adjust the gain of the F/V output stage and give the correct meter deflection. The F/V output voltage is applied to the function generator which generates the sine and cosine output voltages. The output voltage of the sine and cosine amplifiers are derived from the on-chip amplifier and function generator circuitry. The various trip points for the circuit (i.e., 0°, 90°, 180°, 270°) are determined by an internal resistor divider and the bandgap voltage reference. The coils are differentially driven, allowing bidirectional current flow in the outputs, thus providing up to 305° range of meter deflection. Driving the coils differentially offers faster response time, higher current capability, higher output voltage swings, and reduced external component count. The key advantage is a higher torque output for the pointer.

The output angle, Θ, is equal to the F/V gain multiplied by the function generator gain:

$$\Theta = A_{F/V} \times A_{FG},$$

where:

$$A_{FG} = 77°/V \text{ (typ)}$$

The relationship between input frequency and output angle is:

$$\Theta = A_{FG} \times 2 \times FREQ \times C_T \times R_T \times (V_{REG} - 0.7V)$$

or, $$\Theta = 970 \times FREQ \times C_T \times R_T$$

The ripple voltage at the F/V converter's output is determined by the ratio of $C_T$ and C4 in the formula:

$$\Delta V = \frac{C_T(V_{REG} - 0.7V)}{C4}$$

Ripple voltage on the F/V output causes pointer or needle flutter especially at low input frequencies.

The response time of the F/V is determined by the time constant formed by $R_T$ and C4. Increasing the value of C4 will reduce the ripple on the F/V output but will also increase the response time. An increase in response time causes a very slow meter movement and may be unacceptable for many applications.

## Design Example

Maximum meter Deflection = 270°

Maximum Input Frequency = 350Hz

### 1. Select $R_T$ and $C_T$

$$\Theta = A_{GEN} \times \Delta_{F/V}$$

$$\Delta_{F/V} = 2 \times FREQ \times C_T \times R_T \times (V_{REG} - 0.7V)$$

$$\Theta = 970 \times FREQ \times C_T \times R_T$$

Let $C_T = 0.0033\mu F$, Find $R_T$

$$R_T = \frac{270°}{970 \times 350Hz \times 0.0033\mu F}$$

$$R_T = 243k\Omega$$

$R_T$ should be a 250kΩ potentiometer to trim out any inaccuracies due to IC tolerances or meter movement pointer placement.

### 2. Select R3 and R4

Resistor R3 sets the output current from the voltage regulator. The maximum output current from the voltage regulator is 10mA, R3 must ensure that the current does not exceed this limit.

Choose R3 = 3.3kΩ

The charge current for $C_T$ is:

$$\frac{V_{REG} - 0.7V}{3.3k\Omega} = 1.90mA$$

C1 must charge and discharge fully during each cycle of the input signal. Time for one cycle at maximum frequency is 2.85ms. To ensure that $C_T$ is discharged, assume that the (R3 + R4) $C_T$ time constant is less than 10% of the minimum input frequency pulse width.

$$T = 285\mu s$$

Choose R4 = 1kΩ.

Charge time: $T = R3 \times C_T = 3.3k\Omega \times 0.0033\mu F = 10.9\mu s$

Discharge time: $T = (R3 + R4)C_T = 4.3k\Omega \times 0.0033\mu F = 14.2\mu s$

### 3. Determine C4

C4 is selected to satisfy both the maximum allowable ripple voltage and response time of the meter movement.

$$C4 = \frac{C_T(V_{REG} - 0.7V)}{V_{RIPPLE(MAX)}}$$

With C4 = 0.47μF, the F/V ripple voltage is 44mV.

Figure 7 shows how the CS8191 and the CS8441 are used to produce a Speedometer and Odometer circuit.

## Circuit Description and Application Notes: continued

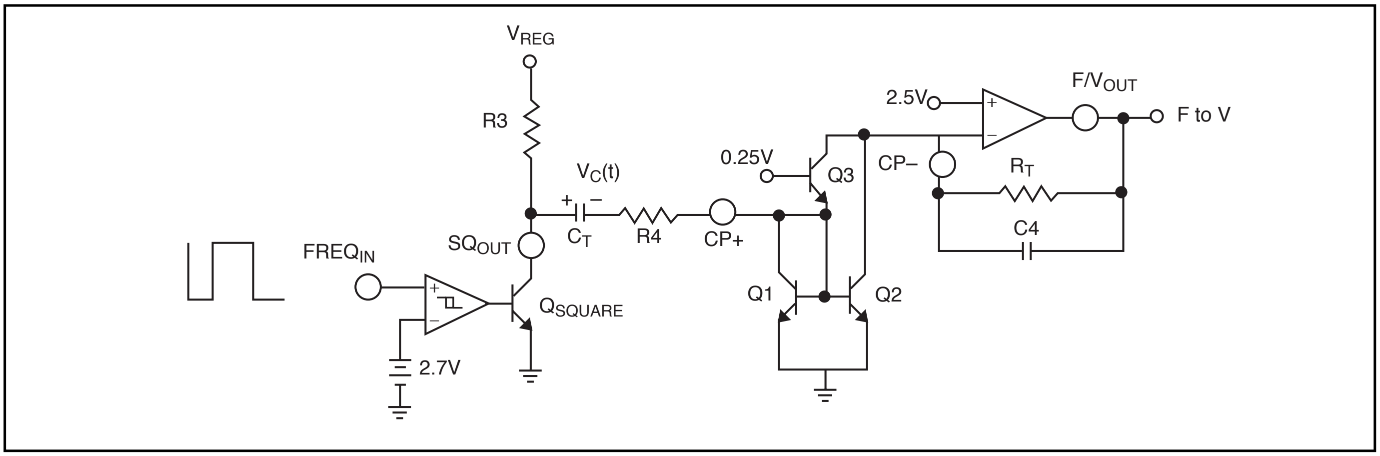



**Figure 5A: Partial Schematic of Input and Charge Pump**

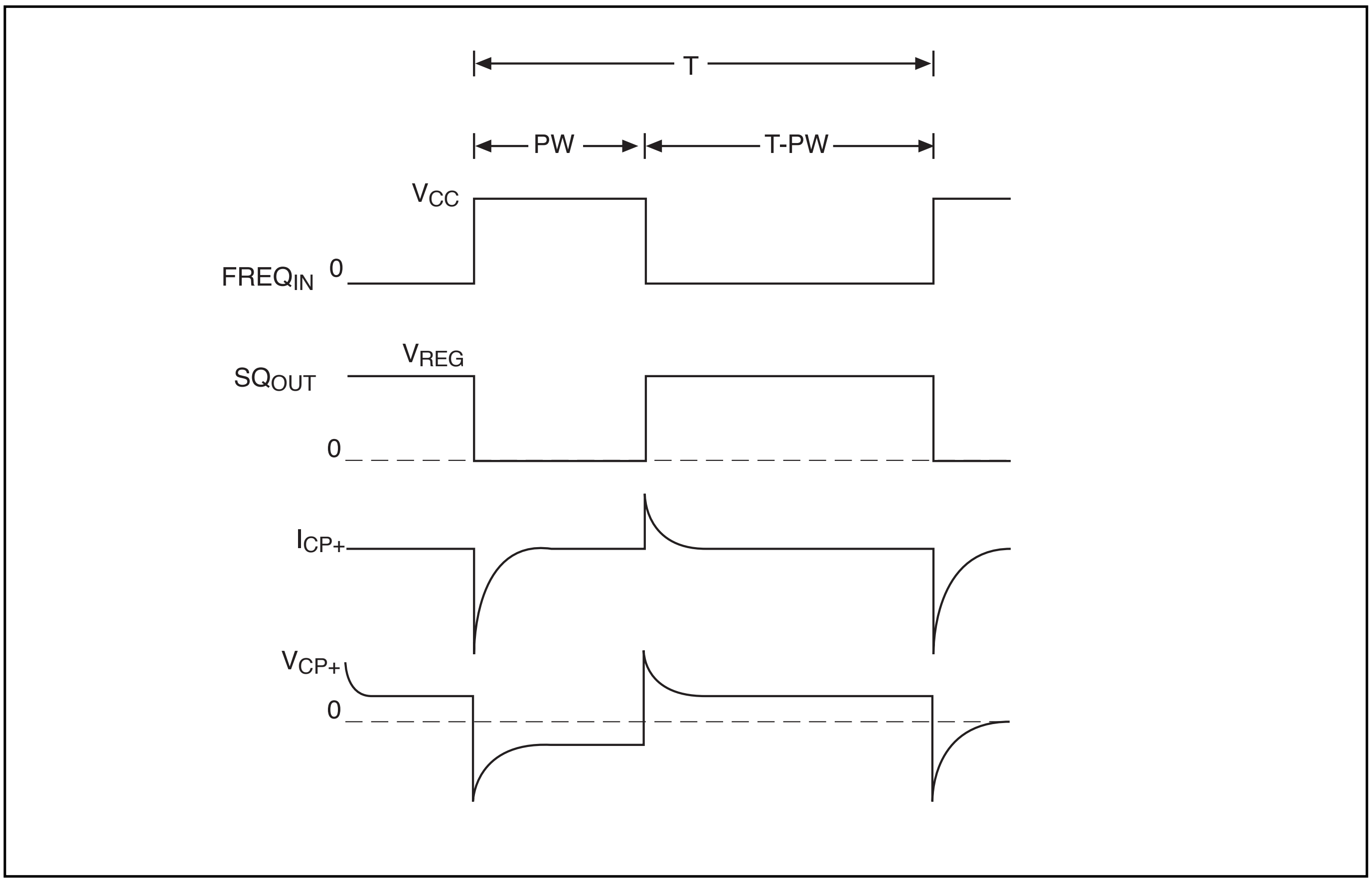



**Figure 5B: Timing Diagram of FREQ$_{IN}$ and I$_{CP}$**

## Speedometer/Odometer or Tachometer Application

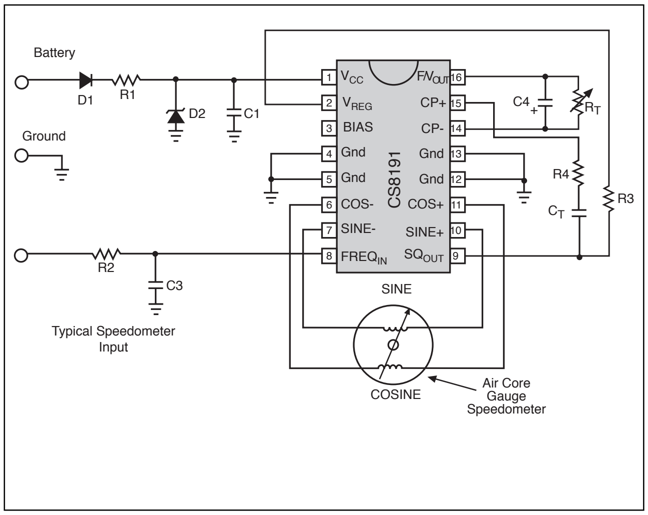



**Figure 6**

R1 - 3.9, 500mW

R2 - 10kΩ
R3 - 3kΩ
R4 - 1kΩ
$R_T$ - Trim Resistor +/- 20 PPM/DEG. C
C1 - 0.1μF
C2 - With CS-8441 application, 10μF
C3 - 0.1μF
C4 - 0.47μF
$C_T$ - 0.0033μF, +/- 30 PPM/°C
D1 - 1A, 600 PIV
D2 - 50V, 500mW Zener

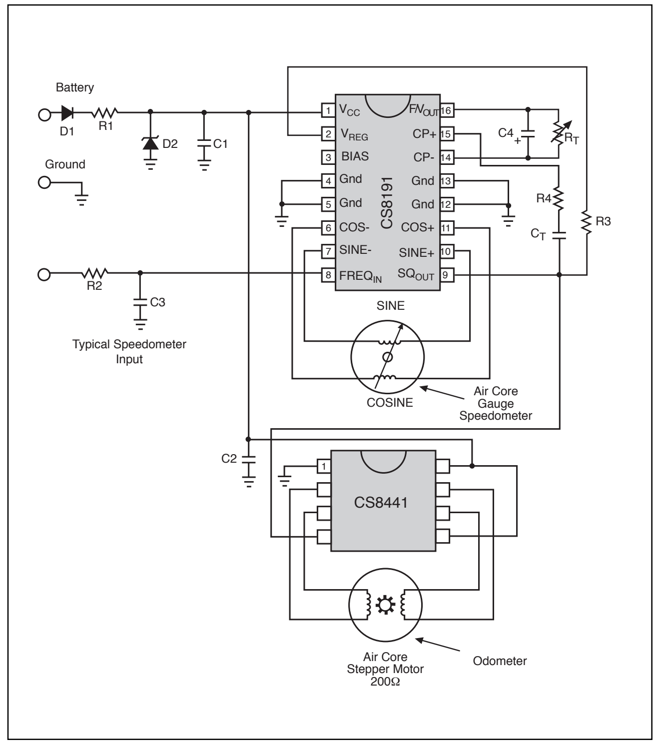



**Figure 7**

Note 1: The product of $C_T$ and $R_T$ have a direct effect on gain and therefore directly effect temperature compensation.
Note 2: C4 Range; 20pF to .2μF.
Note 3: R4 Range; 100kΩ to 500kΩ.
Note 4: The IC must be protected from transients above 60V and reverse battery conditions.
Note 5: Additional filtering on the $FREQ_{IN}$ lead may be required.

In some cases a designer may wish to use the CS8191 only as a driver for an air-core meter having performed the F/V conversion elsewhere in the circuit.

Figure 8 shows how to drive the CS8191 with a DC voltage ranging from 2V to 6V. This is accomplished by forcing a voltage on the $F/V_{OUT}$ lead. The alternative scheme shown in figure 9 uses an external op amp as a buffer and operates over an input voltage range of 0V to 4V.

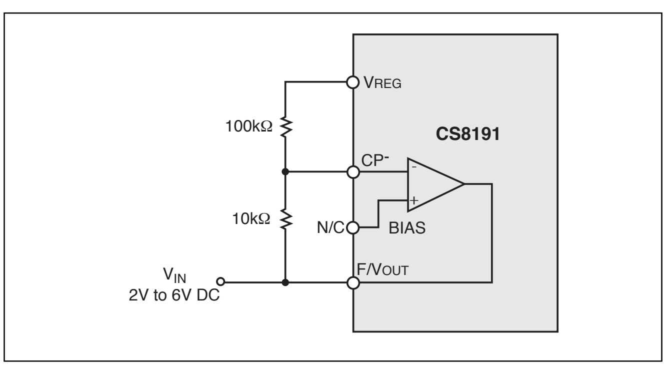



**Figure 8. Driving the CS8191 from an external DC voltage.**

An alternative solution is to use the CS4101 which has a separate function generator input lead and can be driven directly from a DC source. Figure 8 and 9 are not temperature compensated.

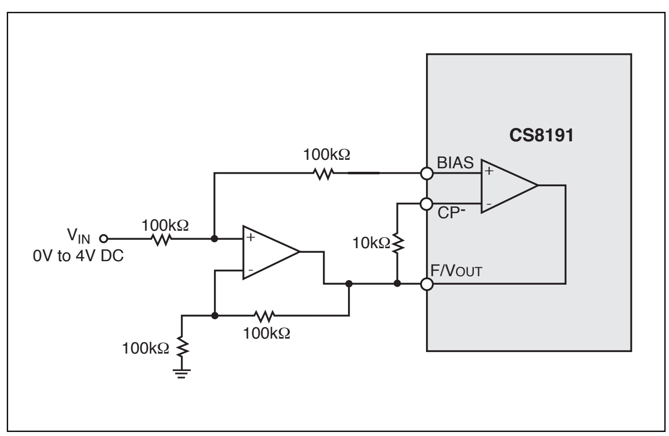



**Figure 9. Driving the CS8191 from an external DC voltage using an Op Amp Buffer.**

## Package Specification

### PACKAGE DIMENSIONS IN mm (INCHES)

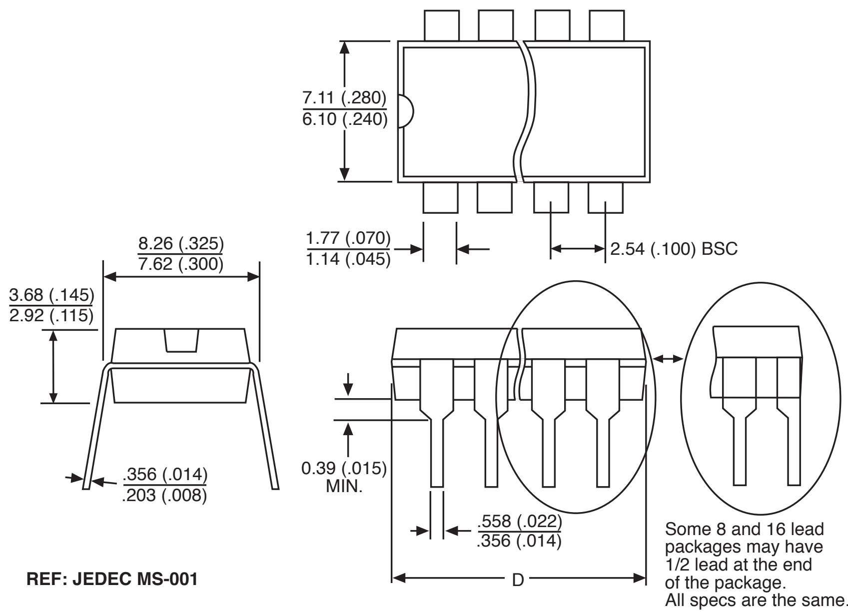
| Lead Count | D | | | |
|---|---|---|---|---|
| | Metric | | English | |
| | Max | Min | Max | Min |
| 16L PDIP *(internally fused leads)* | 19.69 | 18.67 | .775 | .735 |
| 20L SOIC *(internally fused leads)* | 13.00 | 12.60 | .512 | .496 |

### PACKAGE THERMAL DATA

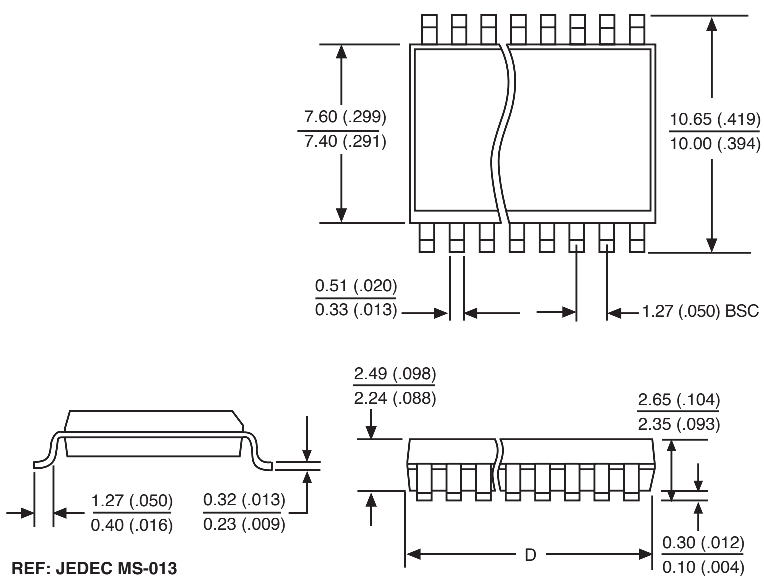
| Thermal Data | | 16L PDIP* | 20L SOIC* | |
|---|---|---|---|---|
| $R_{\Theta JC}$ | typ | 15 | 9 | °C/W |
| $R_{\Theta JA}$ | typ | 50 | 55 | °C/W |

*Internally Fused Leads

### Plastic DIP (N); 300 mil wide




### Surface Mount Wide Body (DW); 300 mil wide




### Ordering Information

| Part Number | Description |
|---|---|
| CS8191XNF16 | 16L PDIP *(internally fused leads)* |
| CS8191XDWF20 | 20L SOIC *(internally fused leads)* |
| CS8191XDWFR20 | 20L SOIC *(internally fused leads)* *(tape & reel)* |

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