

# 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

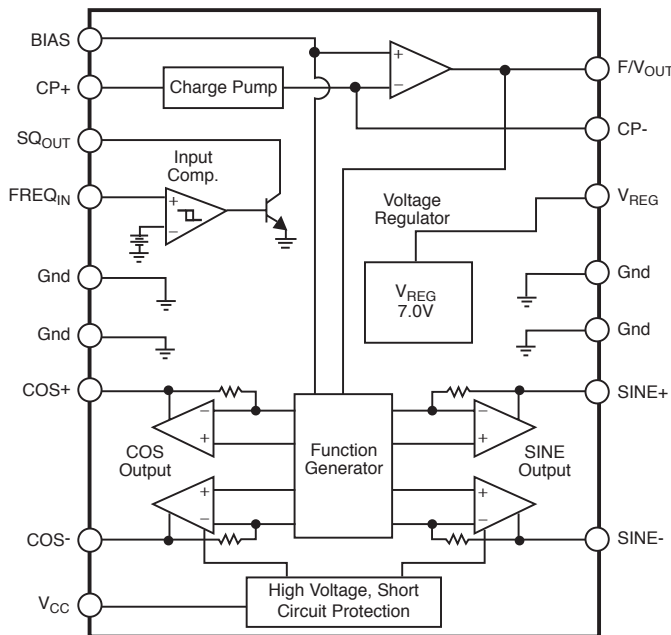
amplifiers that differentially drive the motor coils.

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

## Block Diagram

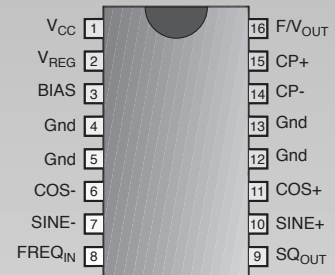


## Features

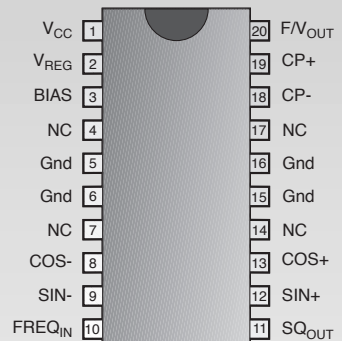
- Direct Sensor Input
- High Output Torque
- Wide Output Voltage Range
- High Impedance Inputs
- Accurate down to 10V  $V_{CC}$
- Fault Protection
  - Overvoltage
  - Short Circuit
- Low Voltage Operation

## Package Options

16 Lead PDIP (internally fused leads)



20 Lead SOIC (internally fused leads)



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PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>■ Supply Voltage Section</b>					
$I_{CC}$ Supply Current	$V_{CC} = 16\text{V}$ , $-40^{\circ}\text{C}$ , No Load		70	125	mA
$V_{CC}$ Normal Operation Range		8.0	13.1	16.0	V
<b>■ Input Comparator Section</b>					
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 *	$0\text{V} \leq V_{IN} \leq 8\text{V}$		-2	$\pm 10$	$\mu\text{A}$
Input Frequency Range		0		20	kHz
Input Voltage Range	in series with $1\text{k}\Omega$	-1		$V_{CC}$	V
Output $V_{SAT}$	$I_{CC} = 10\text{mA}$		0.15	0.40	V
Output Leakage	$V_{CC} = 7\text{V}$			10	$\mu\text{A}$
Logic 0 Input Voltage		2.0			V

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

<b>■ Voltage Regulator Section</b>					
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	$8.0\text{V} \leq V_{CC} \leq 16\text{V}$		20	150	mV
Power Supply Rejection	$V_{CC} = 13.1\text{V}$ , $1V_P/P$ 1kHz	34	46		dB

<b>■ Charge Pump Section</b>					
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	$I_{IN} = 1\text{mA}$		0.7	1.1	V
Linearity*	@ 0, 87.5, 175, 262.5, + 350Hz	-0.10	0.28	+0.70	%
F/ $V_{OUT}$ Gain	@ 350Hz, $C_T = 0.0033\mu\text{F}$ , $R_T = 243\text{k}\Omega$	7	10	13	mV/Hz
Norton Gain, Positive	$I_{IN} = 15\mu\text{A}$	0.9	1.0	1.1	I/I
Norton Gain, Negative	$I_{IN} = -15\mu\text{A}$	0.9	1.0	1.1	I/I

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

**■ Function Generator Section:  $-40^{\circ} \leq T_A \leq 85^{\circ}\text{C}$ ,  $V_{CC} = 13.1\text{V}$  unless otherwise noted.**

Differential Drive Voltage ( $V_{COS+} - V_{COS-}$ )	$10\text{V} \leq V_{CC} \leq 16\text{V}$ $\Theta = 0^{\circ}$	7.5	8.0	8.5	V
Differential Drive Voltage ( $V_{SIN+} - V_{SIN-}$ )	$10\text{V} \leq V_{CC} \leq 16\text{V}$ $\Theta = 90^{\circ}$	7.5	8.0	8.5	V
Differential Drive Voltage ( $V_{COS+} - V_{COS-}$ )	$10\text{V} \leq V_{CC} \leq 16\text{V}$ $\Theta = 180^{\circ}$	-8.5	-8.0	-7.5	V
Differential Drive Voltage ( $V_{SIN+} - V_{SIN-}$ )	$10\text{V} \leq V_{CC} \leq 16\text{V}$ $\Theta = 270^{\circ}$	-8.5	-8.0	-7.5	V
Differential Drive Load	$10\text{V} \leq V_{CC} \leq 16\text{V}$ , $-40^{\circ}\text{C}$	178			$\Omega$
	25 $^{\circ}\text{C}$	239			$\Omega$
	105 $^{\circ}\text{C}$	314			$\Omega$
Zero Hertz Output Voltage		-0.08	0.0	+0.08	V

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

\*Note: Deviation from nominal per Table 1 after calibration at  $0^\circ$  and  $270^\circ$ .

Package Lead Description

PACKAGE LEAD #		LEAD SYMBOL	FUNCTION
<b>16L PDIP</b>	<b>20L SO</b>		
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 <sub>IN</sub>	Speed or rpm input signal.
9	11	SQ <sub>OUT</sub>	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

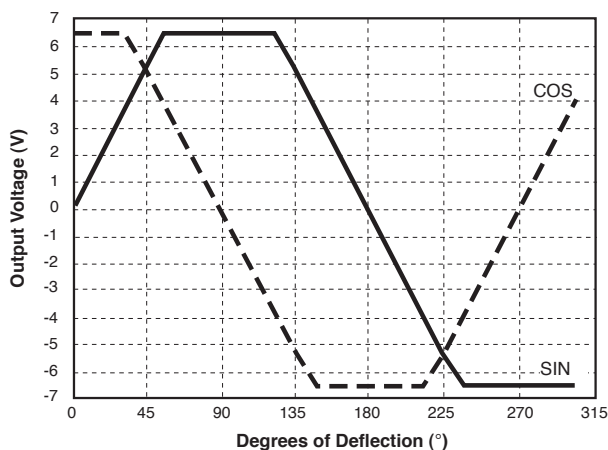
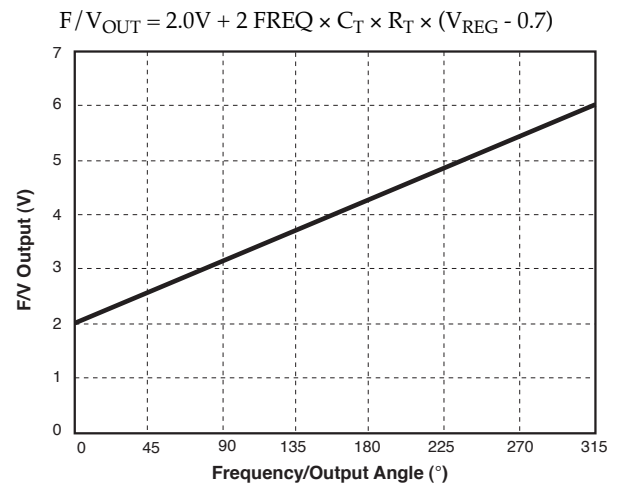


Figure 2: Charge Pump Output Voltage vs Output Angle



Typical Performance Characteristics: continued

Figure 3: Output Angle in Polar Form

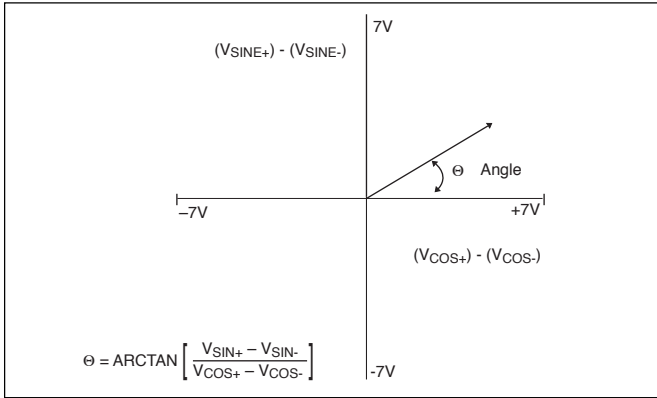
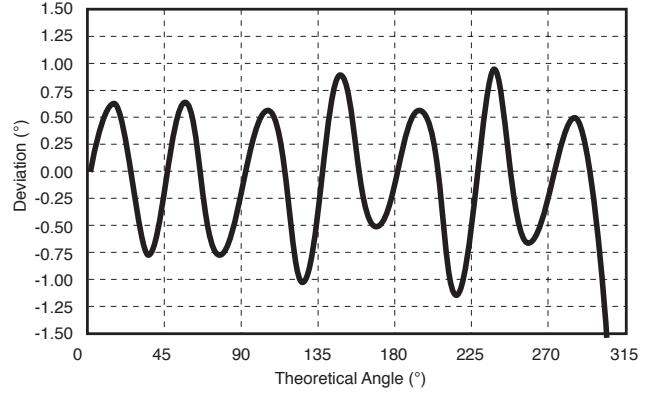


Figure 4: Nominal Output Deviation



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

Note: Temperature, voltage and nonlinearity not included.

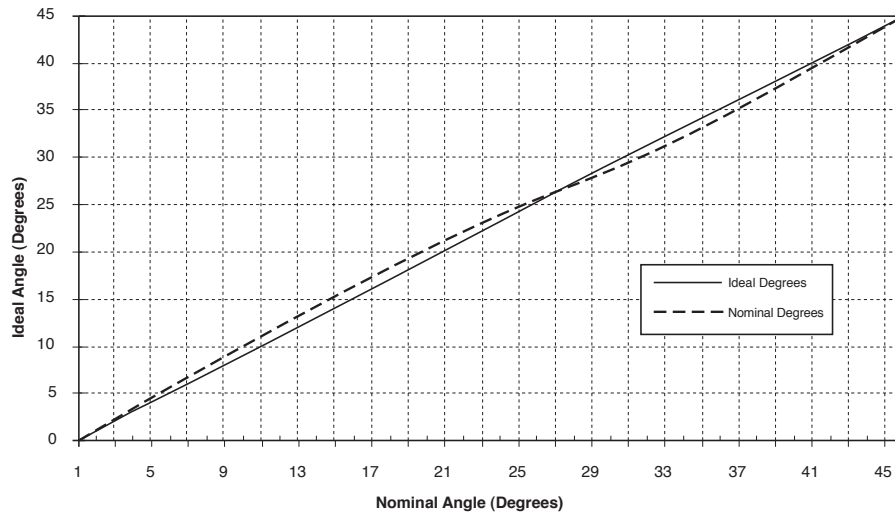


Table 1: Function Generator Output Nominal Angle vs. Ideal Angle (After calibrating at 270°)

Ideal $\theta$ Degrees	Nominal $\theta$ Degrees	Ideal $\theta$ Degrees	Nominal $\theta$ Degrees	Ideal $\theta$ Degrees	Nominal $\theta$ Degrees	Ideal $\theta$ Degrees	Nominal $\theta$ Degrees	Ideal $\theta$ Degrees	Nominal $\theta$ Degrees	Ideal $\theta$ Degrees	Nominal $\theta$ 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  $R_3$  and  $R_4$ . The charge accumulated on  $C_T$  is mirrored to  $C_4$  by the Norton Amplifier circuit comprising of  $Q_1$ ,  $Q_2$  and  $Q_3$ . 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.,  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$ ,  $270^\circ$ ) 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  $305^\circ$  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,  $\Theta$ , is equal to the  $F/V$  gain multiplied by the function generator gain:

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

where:

$$A_{FG} = 77^\circ/V \text{ (typ)}$$

The relationship between input frequency and output angle is:

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

$$\text{or, } \Theta = 970 \times FREQ \times C_T \times R_T$$

The ripple voltage at the  $F/V$  converter's output is determined by the ratio of  $C_T$  and  $C_4$  in the formula:

$$\Delta V = \frac{C_T(V_{REG} - 0.7V)}{C_4}$$

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  $C_4$ . Increasing the value of  $C_4$  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 =  $270^\circ$

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  $R_T$

$$R_T = \frac{270^\circ}{970 \times 350\text{Hz} \times 0.0033\mu F}$$

$$R_T = 243\text{k}\Omega$$

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

### 2. Select $R_3$ and $R_4$

Resistor  $R_3$  sets the output current from the voltage regulator. The maximum output current from the voltage regulator is 10mA,  $R_3$  must ensure that the current does not exceed this limit.

Choose  $R_3 = 3.3\text{k}\Omega$

The charge current for  $C_T$  is:

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

$C_1$  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  $(R_3 + R_4)$   $C_T$  time constant is less than 10% of the minimum input frequency pulse width.

$$T = 285\mu s$$

Choose  $R_4 = 1\text{k}\Omega$ .

Charge time:  $T = R_3 \times C_T = 3.3\text{k}\Omega \times 0.0033\mu F = 10.9\mu s$

Discharge time:  $T = (R_3 + R_4)C_T = 4.3\text{k}\Omega \times 0.0033\mu F = 14.2\mu s$

### 3. Determine $C_4$

$C_4$  is selected to satisfy both the maximum allowable ripple voltage and response time of the meter movement.

$$C_4 = \frac{C_T(V_{REG} - 0.7V)}{V_{RIPPLE(MAX)}}$$

With  $C_4 = 0.47\mu F$ , 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.

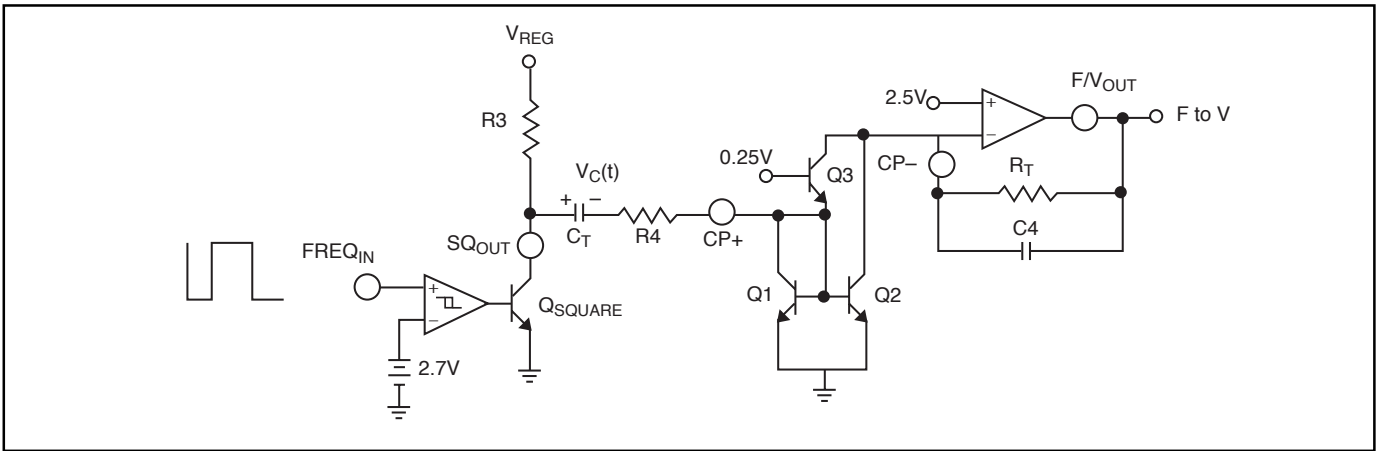


Figure 5A: Partial Schematic of Input and Charge Pump

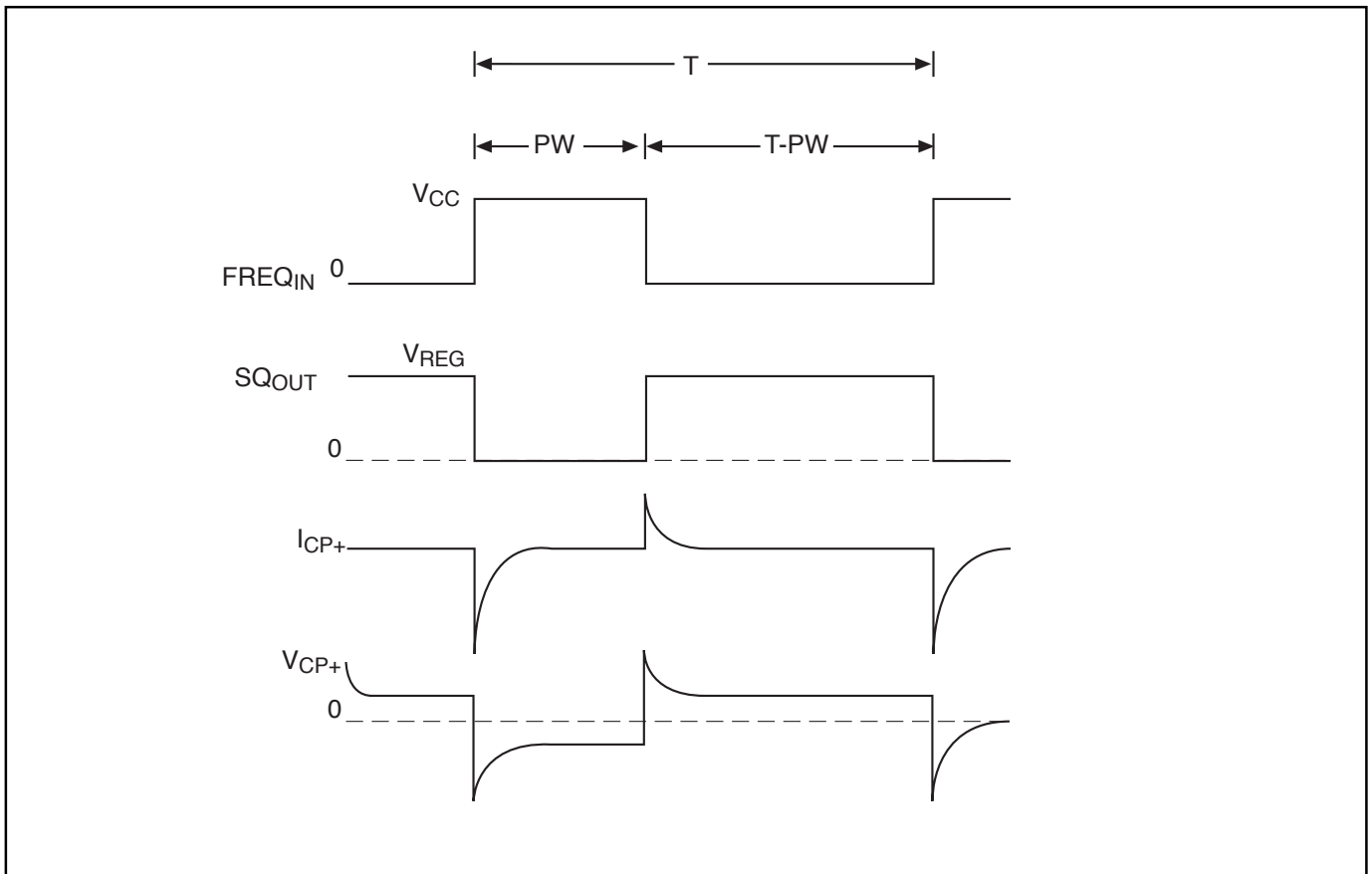


Figure 5B: Timing Diagram of FREQ\_IN and I\_CP

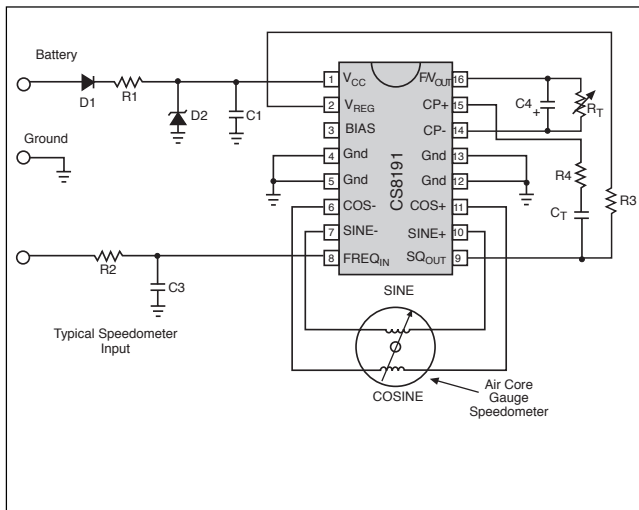


Figure 6

- R1 - 3.9, 500mW
- R2 - 10kΩ
- R3 - 3kΩ
- R4 - 1kΩ
- R<sub>T</sub> - Trim Resistor +/- 20 PPM/DEG. C
- C1 - 0.1μF
- C2 - With CS-8441 application, 10μF
- C3 - 0.1μF
- C4 - 0.47μF
- C<sub>T</sub> - 0.0033μF, +/- 30 PPM/°C
- D1 - 1A, 600 PIV
- D2 - 50V, 500mW Zener

- Note 1: The product of C<sub>T</sub> and R<sub>T</sub> have a direct effect on gain and therefore directly effect temperature compensation.
- Note 2: C<sub>4</sub> Range; 20pF to .2μF.
- Note 3: R<sub>4</sub> Range; 100kΩ to 500kΩ.

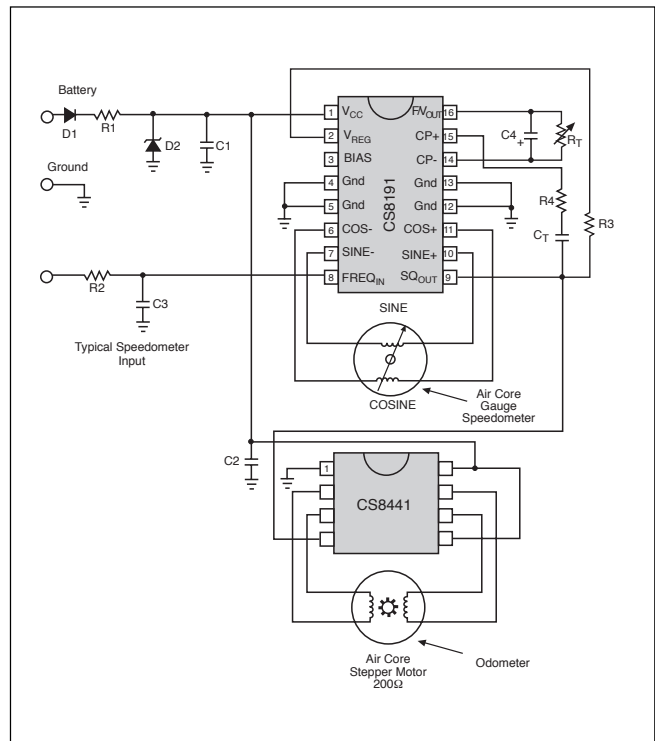


Figure 7

- Note 4: The IC must be protected from transients above 60V and reverse battery conditions.
- Note 5: Additional filtering on the FREQ<sub>IN</sub> 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<sub>OUT</sub> 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.

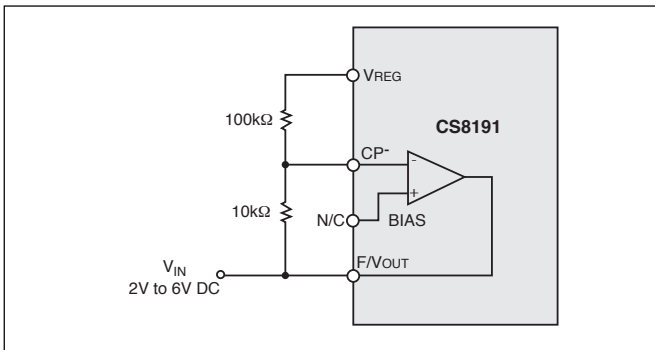


Figure 8. Driving the CS8191 from an external DC voltage.

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.

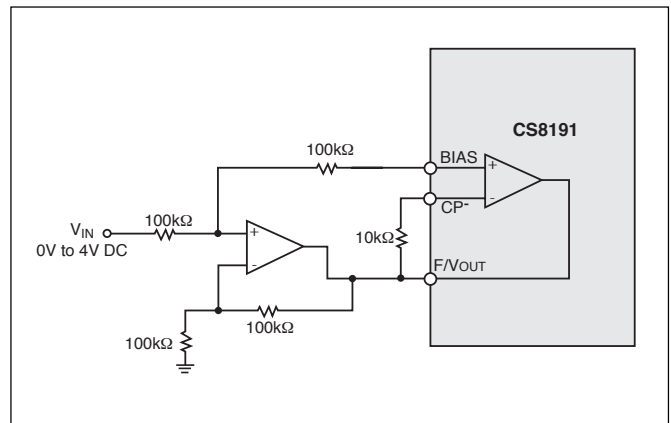


Figure 9. Driving the CS8191 from an external DC voltage using an Op Amp Buffer.

## Package Specification

### PACKAGE DIMENSIONS IN mm (INCHES)

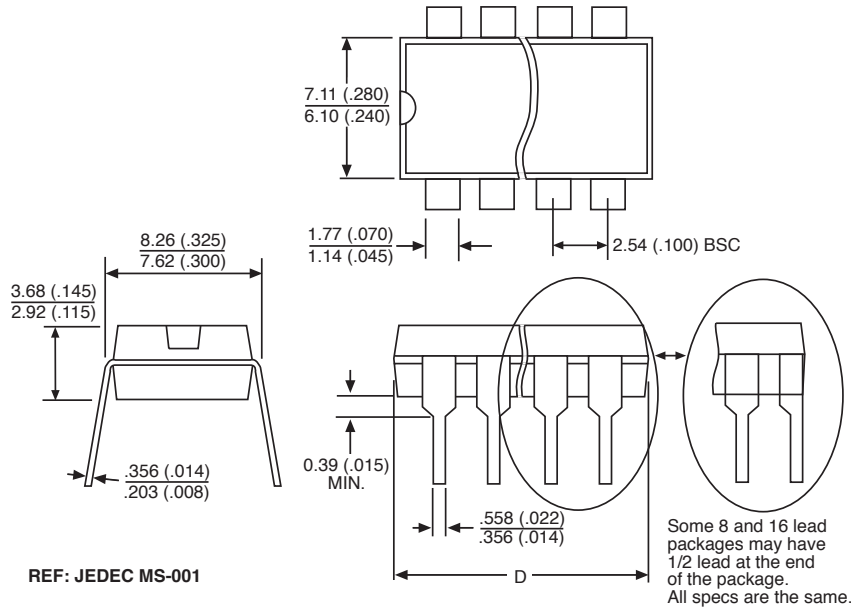
Lead Count	D			
	Metric		English	
	Max	Min	Max	Min
16L PDIP ( <i>internally fused leads</i> )	19.69	18.67	.775	.735
20L SOIC ( <i>internally fused leads</i> )	13.00	12.60	.512	.496

### PACKAGE THERMAL DATA

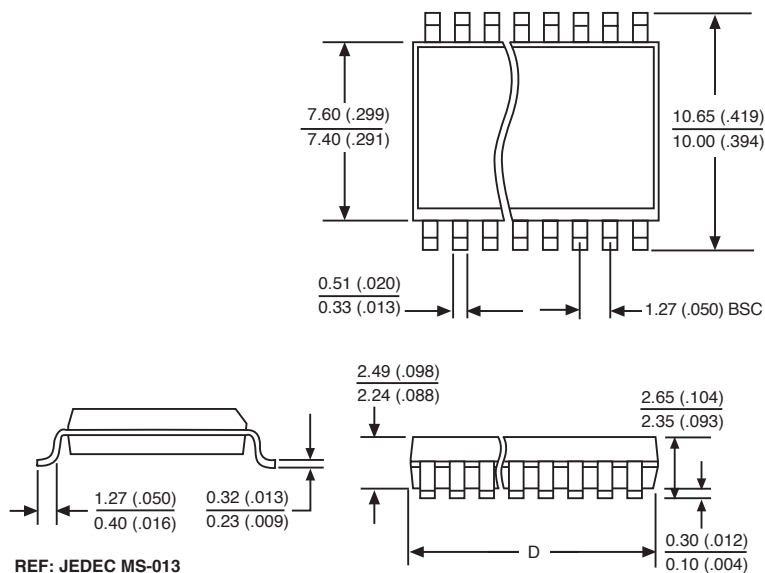
Thermal Data	16L PDIP*	20L SOIC*	
R <sub>θJC</sub> typ	15	9	°C/W
R <sub>θJA</sub> typ	50	55	°C/W

\*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 ( <i>internally fused leads</i> )
CS8191XDWF20	20L SOIC ( <i>internally fused leads</i> )
CS8191XDWFR20	20L SOIC ( <i>internally fused leads</i> ) ( <i>tape &amp; reel</i> )

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