Fully Integrated, Hall Effect-Based Linear Current Sensor IC with 2.4kVRMS Isolation and a Low-Resistance Current Conductor

## Description

The HTCSEMI HT8712 provides economical and precise solutions for AC or DC current sensing in industrial, commercial, and communications systems. The device package allows for easy implementation by the customer. Typical applications include motor control, load detection and management, switch-mode power supplies, and overcurrent fault protection. The device is not intended for automotive applications.

The device consists of a precise, low-offset, linear Hall circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which the Hall IC converts into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for accuracy after packaging.

Features and Benefits

- Low-noise analog signal path
- Device bandwidth is set via the new FILTER pin
- 5 µs output rise time in response to step input current
- 80 kHz bandwidth
- Total output error 1.5% at $T_A = 25\,°C$
- Small footprint, low-profile SOIC8 package
- 1.2 mΩ internal conductor resistance
- 2.4 kVRMS minimum isolation voltage from pins 1-4 to pins 5-8
- 5.0 V, single supply operation
- 66 to 185 mV/A output sensitivity
- Output voltage proportional to AC or DC currents
- Factory-trimmed for accuracy
- Extremely stable output offset voltage
- Nearly zero magnetic hysteresis
- Ratiometric output from supply voltage

SOP−8 R SUFFIX
HT8712R-xxA
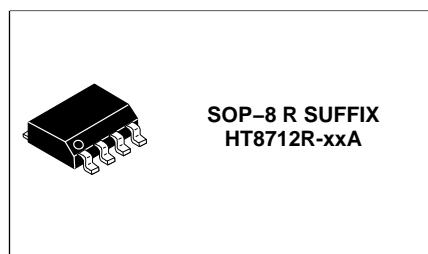
Typical Application
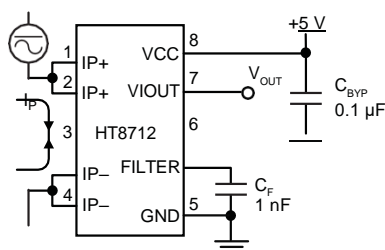
Application 1. The HT8712 outputs an analog signal, V_{OUT}. that varies linearly with the uni- or bi-directional AC or DC primary sampled current, I_P, within the range specified. C_F is recommended for noise management, with values that depend on the application.

Description (continued)

the device at up to 5×overcurrent conditions. The terminals of the conductive path are electrically isolated from the signal leads (pins 5 through 8). This allows the HT8712 to be used in applications requiring electrical isolation without the use of opto-isolators or other costly isolation techniques.

The HT8712 is provided in a small, surface mount SOIC8 package. The leadframe is plated with 100% matte tin, which is compatible with standard lead (Pb) free printed circuit board assembly processes. Internally, the device is Pb-free, except for flip-chip high-temperature Pb-based solder balls, currently exempt from RoHS. The device is fully calibrated prior to shipment from the factory.

Selection Guide

Part Number	Packing*	T_A (°C)	Optimized Range, I_P (A)	Sensitivity, Sens (Typ) (mV/A)
HT8712R-05A	Tape and reel, 2500 pieces/reel	−40 to 125	±5	185
HT8712R-20A	Tape and reel, 2500 pieces/reel	−40 to 125	±20	100
HT8712R-30A	Tape and reel, 2500 pieces/reel	−40 to 125	±30	66

*Contact HTCSEMI for additional packing options.

Absolute Maximum Ratings

Characteristic	Symbol	Notes	Rating	Units
Supply Voltage	V_{CC}		8	V
Reverse Supply Voltage	V_{RCC}		−0.1	V
Output Voltage	V_{IOUT}		8	V
Reverse Output Voltage	V_{RIOUT}		−0.1	V
Output Current Source	$I_{IOUT(Source)}$		3	mA
Output Current Sink	$I_{IOUT(Sink)}$		10	mA
Overcurrent Transient Tolerance	I_P	1 pulse, 100 ms	100	A
Nominal Operating Ambient Temperature	T_A	Range E	−40 to 125	ºC
Maximum Junction Temperature	$T_J(max)$		165	ºC
Storage Temperature	T_{stg}		−65 to 170	ºC

Isolation Characteristics

Characteristic	Symbol	Notes	Rating	Unit
Dielectric Strength Test Voltage*	V_{ISO}	Agency type-tested for 60 seconds per UL standard 60950-1, 1st Edition	2400	VAC
Working Voltage for Basic Isolation	V_{WFSI}	For basic (single) isolation per UL standard 60950-1, 1st Edition	354	VDC or V_{pk}
Working Voltage for Reinforced Isolation	V_{WFRI}	For reinforced (double) isolation per UL standard 60950-1, 1st Edition	184	VDC or V_{pk}

* HTCSEMI does not conduct 60-second testing. It is done only during the UL certification process.

Functional Block Diagram
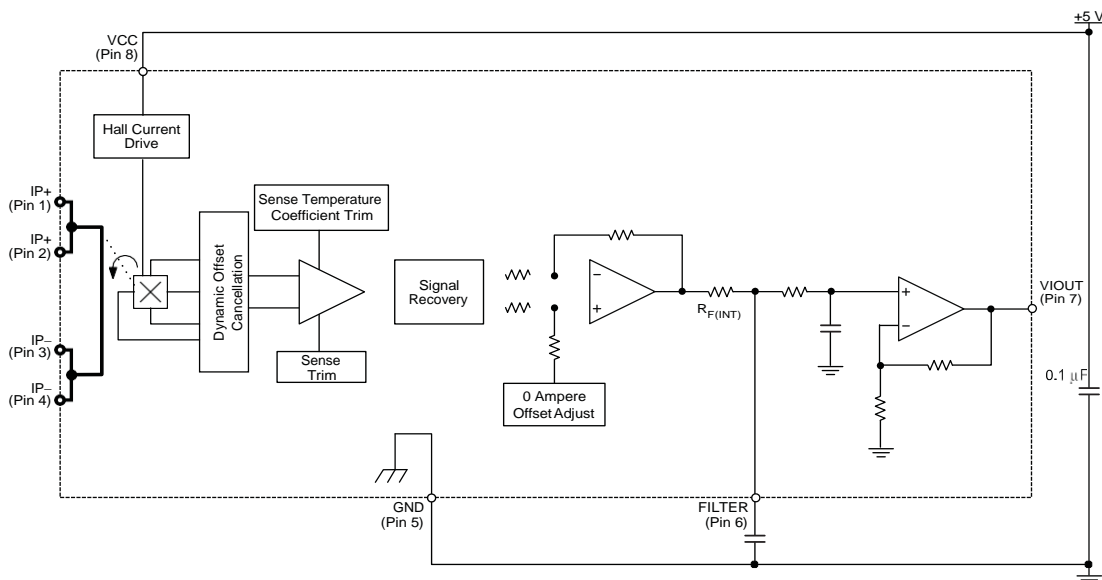
Pin-out Diagram
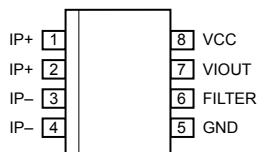
Terminal List Table

Number	Name	Description
1 and 2	IP+	Terminals for current being sampled; fused internally
3 and 4	IP–	Terminals for current being sampled; fused internally
5	GND	Signal ground terminal
6	FILTER	Terminal for external capacitor that sets bandwidth
7	VIOUT	Analog output signal
8	VCC	Device power supply terminal

COMMON OPERATING CHARACTERISTICS[1] over full range of T_A, C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
ELECTRICAL CHARACTERISTICS						
Supply Voltage	V_{CC}		4.5	5.0	5.5	V
Supply Current	I_{CC}	V_{CC} = 5.0 V, output open	–	10	13	mA
Output Capacitance Load	C_{LOAD}	VIOUT to GND	–	–	10	nF
Output Resistive Load	R_{LOAD}	VIOUT to GND	4.7	–	–	kΩ
Primary Conductor Resistance	$R_{PRIMARY}$	T_A = 25°C	–	1.2	–	mΩ
Rise Time	t_r	I_P = I_P(max), T_A = 25°C, C_{OUT} = open	–	3.5	–	µs
Frequency Bandwidth	f	–3 dB, T_A = 25°C; I_P is 10 A peak-to-peak	–	80	–	kHz
Nonlinearity	E_{LIN}	Over full range of I_P	–	1.5	–	%
Symmetry	E_{SYM}	Over full range of I_P	98	100	102	%
Zero Current Output Voltage	$V_{IOUT(Q)}$	Bidirectional; I_P = 0 A, T_A = 25°C	–	V_{CC} × 0.5	–	V
Power-On Time	t_{PO}	Output reaches 90% of steady-state level, T_J = 25°C, 20 A present on leadframe	–	35	–	µs
Magnetic Coupling[2]			–	12	–	G/A
Internal Filter Resistance[3]	$R_{F(INT)}$			1.7		kΩ

[1]Device may be operated at higher primary current levels, I_P, and ambient, T_A, and internal leadframe temperatures, T_A, provided that the Maximum Junction Temperature, T_J(max), is not exceeded.

[2]1G = 0.1 mT.

[3]$R_{F(INT)}$ forms an RC circuit via the FILTER pin.

COMMON THERMAL CHARACTERISTICS[1]

			Min.	Typ.	Max.	Units
Operating Internal Leadframe Temperature	T_A	E range	–40	–	125	°C

[1]Additional thermal information is available on the HTCSEMI website.

[2]The HTCSEMI evaluation board has 1500 mm[2] of 2 oz. copper on each side, connected to pins 1 and 2, and to pins 3 and 4, with thermal vias connect- ing the layers. Performance values include the power consumed by the PCB. Further details on the board are available from the Frequently Asked Questions document on our website. Further information about board design and thermal performance also can be found in the Applications Informa- tion section of this datasheet.

05A PERFORMANCE CHARACTERISTICS[1] T_A = –40°C to 125°C, C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–5	–	5	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	180	185	190	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 185 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	21	–	mV
Zero Current Output Slope	$\Delta V_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.26	–	mV/°C
		T_A = 25°C to 150°C	–	–0.08	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.054	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.008	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P =±5 A, T_A = 25°C	–	±1.5	–	%

[1]Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, $T_{J(max)}$, is not exceeded.
[2]Percentage of I_P, with I_P = 5 A. Output filtered.

20A PERFORMANCE CHARACTERISTICS[1] T_A = –40°C to 125°C, C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

| Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–20	–	20	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	96	100	104	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 100 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	11	–	mV
Zero Current Output Slope	$\Delta V_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.34	–	mV/°C
		T_A = 25°C to 150°C	–	–0.07	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.017	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.004	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P =±20 A, T_A = 25°C	–	±1.5	–	%

[1]Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, T_J(max), is not exceeded.
[2]Percentage of I_P, with I_P = 20 A. Output filtered.

30A PERFORMANCE CHARACTERISTICS[1] T_A = –40°C to 125°C, C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–30	–	30	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	63	66	69	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 66 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	7	–	mV
Zero Current Output Slope	$\Delta V_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.35	–	mV/°C
		T_A = 25°C to 150°C	–	–0.08	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.007	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.002	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P = ±30 A, T_A = 25°C	–	±1.5	–	%

[1]Device may be operated at higher primary current levels, I_P, and ambient temperatures, T_A, provided that the Maximum Junction Temperature, T_J(max), is not exceeded.
[2]Percentage of I_P, with I_P = 30 A. Output filtered.
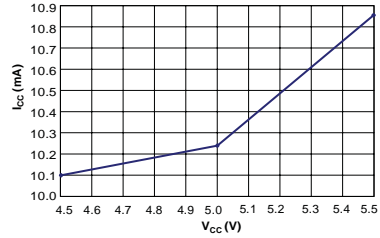
Characteristic Performance

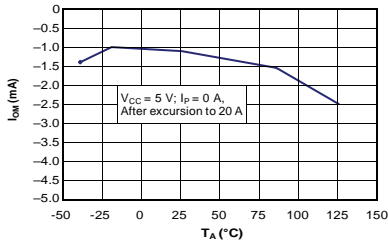I_P = 5 A, unless otherwise specified
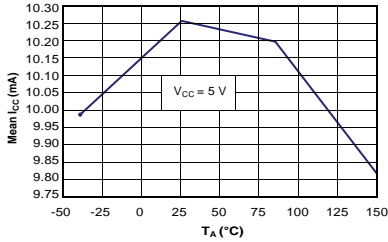
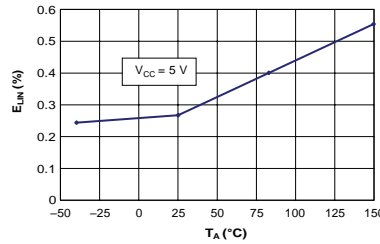Mean Supply Current versus Ambient Temperature

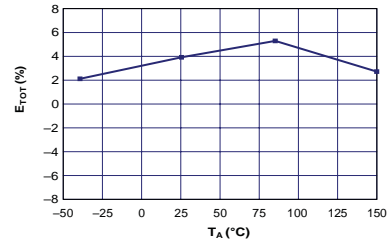Supply Current versus Supply Voltage
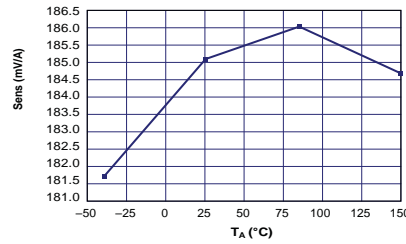

Magnetic Offset versus Ambient Temperature

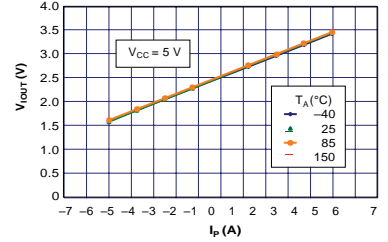Nonlinearity versus Ambient Temperature

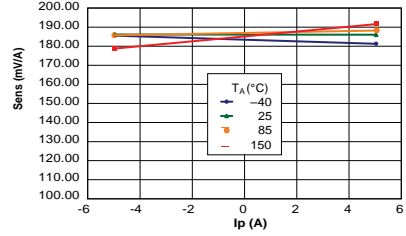Mean Total Output Error versus Ambient Temperature

Sensitivity versus Ambient Temperature

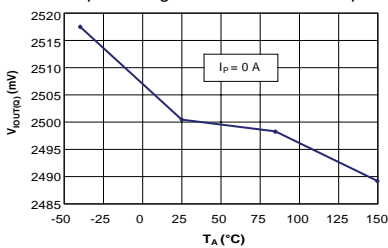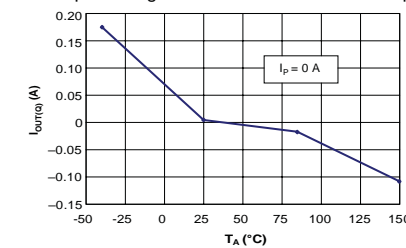Output Voltage versus Sensed Current

Sensitivity versus Sensed Current
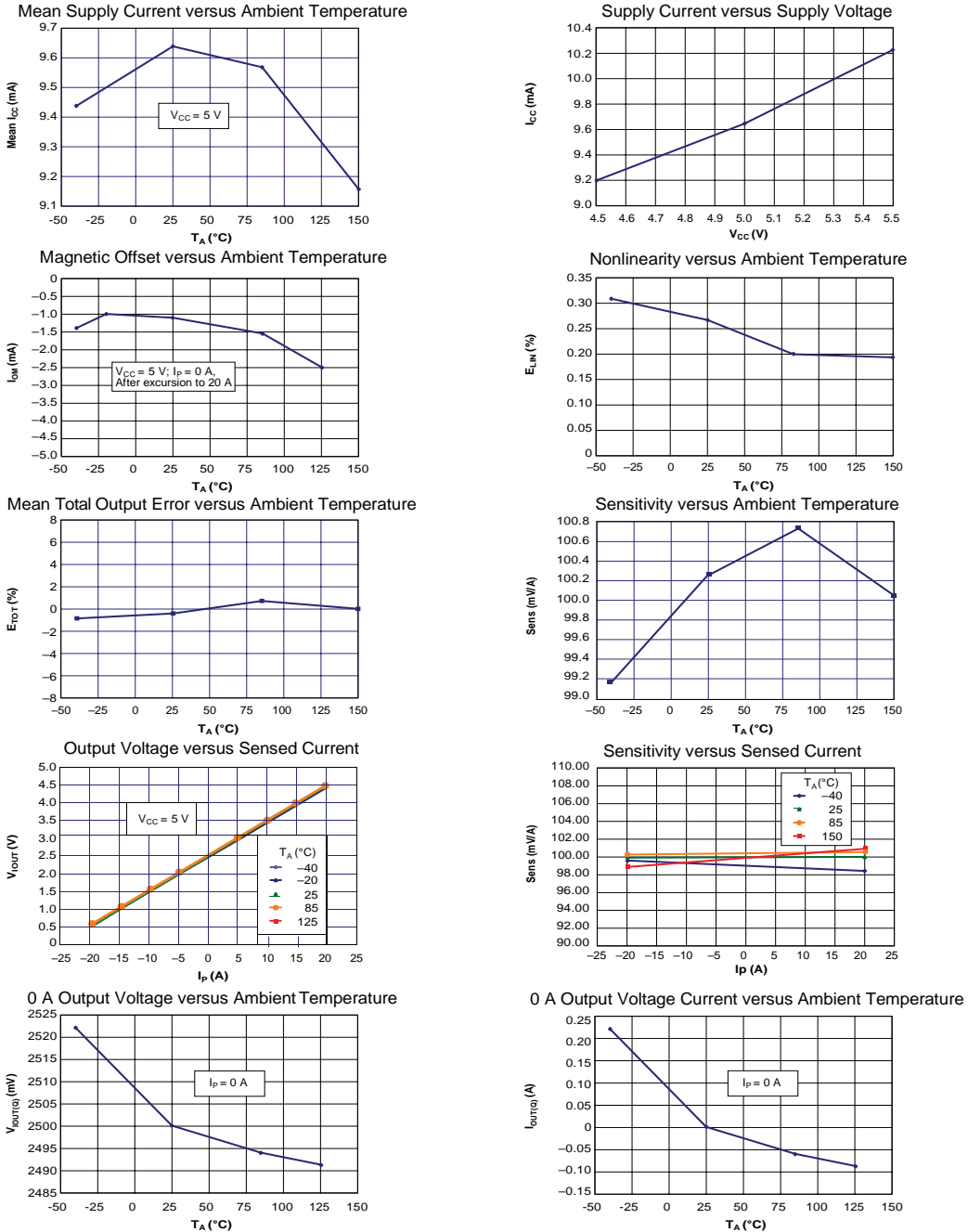

0 A Output Voltage versus Ambient Temperature

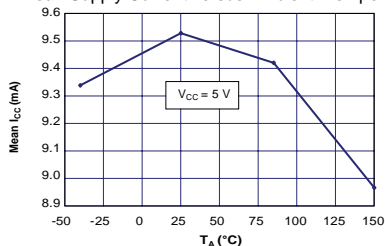0 A Output Voltage Current versus Ambient Temperature

## Characteristic Performance

I_P = 20 A, unless otherwise specified

Mean Supply Current versus Ambient Temperature

V_{CC} = 5 V

Supply Current versus Supply Voltage

Magnetic Offset versus Ambient Temperature

V_{CC} = 5 V; I_P = 0 A,
After excursion to 20 A

Nonlinearity versus Ambient Temperature

Mean Total Output Error versus Ambient Temperature

Sensitivity versus Ambient Temperature

Output Voltage versus Sensed Current

V_{CC} = 5 V

T_A (°C)
—40
—20
25
85
125

Sensitivity versus Sensed Current

T_A (°C)
—40
25
85
150

0 A Output Voltage versus Ambient Temperature

I_P = 0 A

0 A Output Voltage Current versus Ambient Temperature

I_P = 0 A

Characteristic Performance
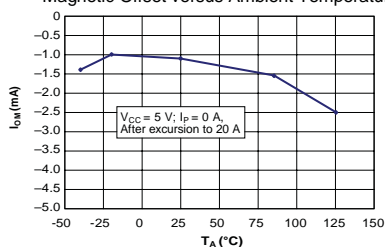
$I_P = 30$ A, unless otherwise specified

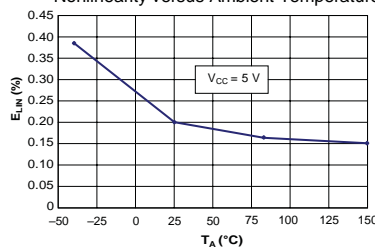Mean Supply Current versus Ambient Temperature
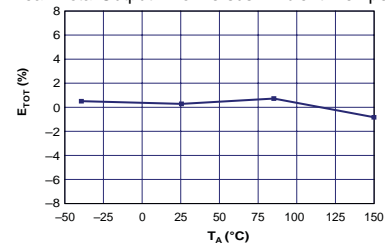

Supply Current versus Supply Voltage
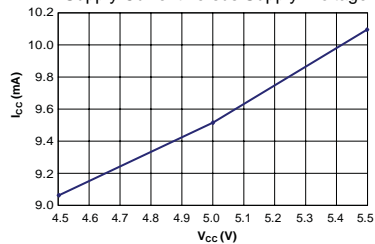
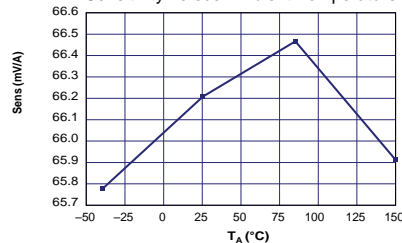Magnetic Offset versus Ambient Temperature
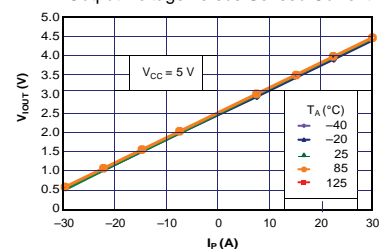

Nonlinearity versus Ambient Temperature

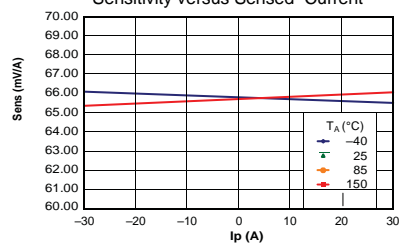Mean Total Output Error versus Ambient Temperature

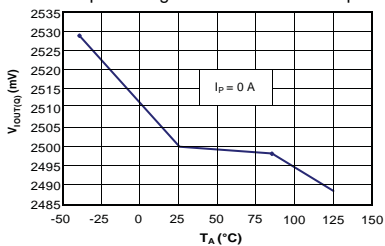Sensitivity versus Ambient Temperature
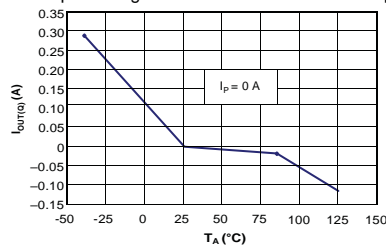

Output Voltage versus Sensed Current

Sensitivity versus Sensed Current

0 A Output Voltage versus Ambient Temperature

0 A Output Voltage Current versus Ambient Temperature

Definitions of Accuracy Characteristics

Sensitivity (Sens). The change in device output in response to a 1 A change through the primary conductor. The sensitivity is the product of the magnetic circuit sensitivity (G/A) and the linear IC amplifier gain (mV/G). The linear IC amplifier gain is programmed at the factory to optimize the sensitivity (mV/A) for the full-scale current of the device.

Noise (V$_{NOISE}$). The product of the linear IC amplifier gain (mV/G) and the noise floor for the HTCSEMI Hall effect linear IC (≈1 G). The noise floor is derived from the thermal and shot noise observed in Hall elements. Dividing the noise (mV) by the sensitivity (mV/A) provides the smallest current that the device is able to resolve.

Linearity (E$_{LIN}$). The degree to which the voltage output from the IC varies in direct proportion to the primary current through its full-scale amplitude. Nonlinearity in the output can be attributed to the saturation of the flux concentrator approaching the full-scale current. The following equation is used to derive the linearity:

$$100 \left\{ 1 - \left[\frac{\Delta \text{ gain} \times \% \text{ sat} \left(V_{\text{IOUT\_full-scale amperes}} - V_{\text{IOUT(Q)}} \right)}{2 \left(V_{\text{IOUT\_half-scale amperes}} - V_{\text{IOUT(Q)}} \right)} \right] \right\}$$

where $V_{\text{IOUT\_full-scale amperes}}$ = the output voltage (V) when the sampled current approximates full-scale $\pm I_P$.

Symmetry (E$_{SYM}$). The degree to which the absolute voltage output from the IC varies in proportion to either a positive or negative full-scale primary current. The following formula is used to derive symmetry:

$$100 \left(\frac{V_{\text{IOUT\_+ full-scale amperes}} - V_{\text{IOUT(Q)}}}{V_{\text{IOUT(Q)}} - V_{\text{IOUT\_-full-scale amperes}}} \right)$$

Quiescent output voltage (V$_{IOUT(Q)}$). The output of the device when the primary current is zero. For a unipolar supply voltage, it nominally remains at V$_{CC}$/2. Thus, V$_{CC}$ = 5 V translates into V$_{IOUT(Q)}$ = 2.5 V. Variation in V$_{IOUT(Q)}$ can be attributed to the resolution of the HTCSEMI linear IC quiescent voltage trim and thermal drift.

Electrical offset voltage (V$_{OE}$). The deviation of the device output from its ideal quiescent value of V$_{CC}$/ 2 due to nonmagnetic causes. To convert this voltage to amperes, divide by the device sensitivity, Sens.

Accuracy (E$_{TOT}$). The accuracy represents the maximum deviation of the actual output from its ideal value. This is also known as the total output error. The accuracy is illustrated graphically in the output voltage versus current chart at right.

Accuracy is divided into four areas:

- **0 A at 25°C.** Accuracy at the zero current flow at 25°C, without the effects of temperature.
- **0 A over Δ temperature.** Accuracy at the zero current flow including temperature effects.
- **Full-scale current at 25°C.** Accuracy at the the full-scale current at 25°C, without the effects of temperature.
- **Full-scale current over Δ temperature.** Accuracy at the full-scale current flow including temperature effects.

Ratiometry. The ratiometric feature means that its 0 A output, V$_{IOUT(Q)}$, (nominally equal to V$_{CC}$/2) and sensitivity, Sens, are proportional to its supply voltage, V$_{CC}$. The following formula is used to derive the ratiometric change in 0 A output voltage, ΔV$_{IOUT(Q)RAT}$ (%).

$$100 \left(\frac{V_{\text{IOUT(Q)VCC}} / V_{\text{IOUT(Q)5V}}}{V_{CC} / 5 \text{ V}} \right)$$

The ratiometric change in sensitivity, ΔSens$_{RAT}$ (%), is defined as:

$$100 \left(\frac{Sens_{VCC} / Sens_{5V}}{V_{CC} / 5 \text{ V}} \right)$$

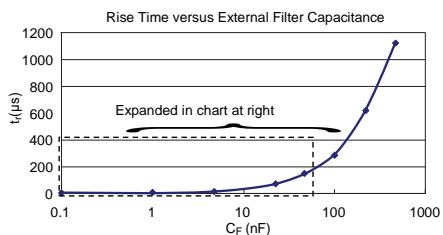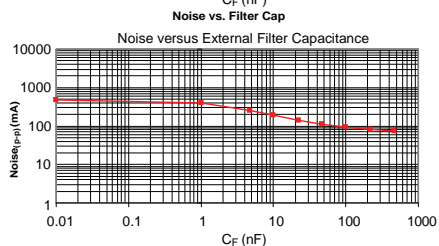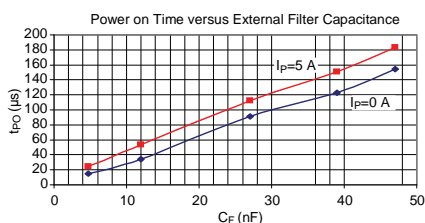**Output Voltage versus Sampled Current**
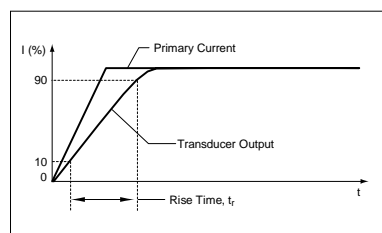Accuracy at 0 A and at Full-Scale Current
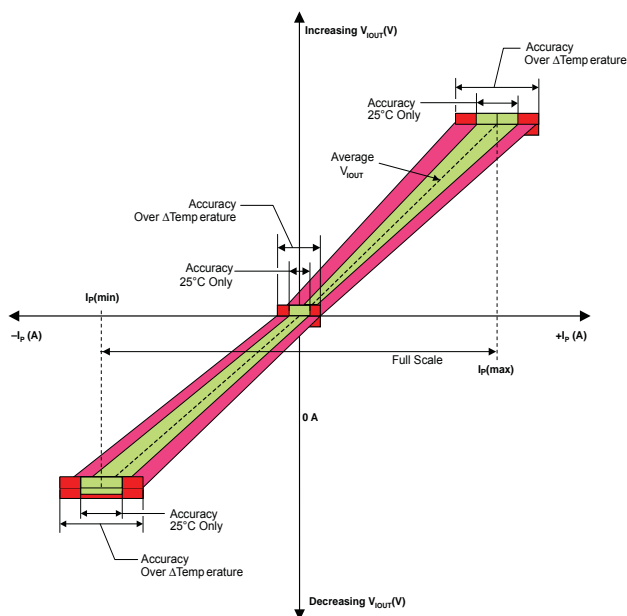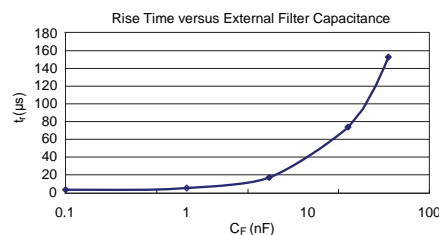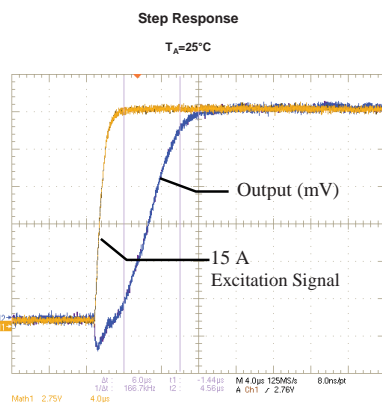
Definitions of Dynamic Response Characteristics

Power-On Time (t$_{PO}$). When the supply is ramped to its operating voltage, the device requires a finite time to power its internal components before responding to an input magnetic field. Power-On Time, t$_{PO}$, is defined as the time it takes for the output voltage to settle within ±10% of its steady state value under an applied magnetic field, after the power supply has reached its minimum specified operating voltage, V$_{CC}$(min), as shown in the chart at right.

t$_1$= time at which power supply reaches minimum specified operating voltage

t$_2$= time at which output voltage settles within ±10% of its steady state value under an applied magnetic field
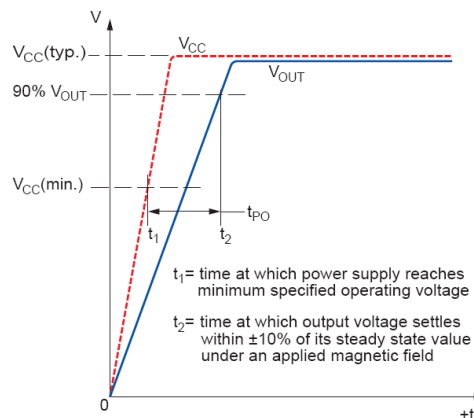
Rise time (t$_r$). The time interval between a) when the device reaches 10% of its full scale value, and b) when it reaches 90% of its full scale value. The rise time to a step response is used to derive the bandwidth of the device, in which f(–3 dB) = 0.35/t$_r$. Both t$_r$ and t$_{RESPONSE}$ are detrimentally affected by eddy current losses observed in the conductive IC ground plane.

Power on Time versus External Filter Capacitance

Noise vs. Filter Cap

Noise versus External Filter Capacitance

Rise Time versus External Filter Capacitance

Expanded in chart at right

C$_F$ (nF)	t$_r$ (μs)
Open	3.5
1	5.8
4.7	17.5
22	73.5
47	88.2
100	291.3
220	623
470	1120

Step Response

T$_A$=25°C

Output (mV)

15 A Excitation Signal

Rise Time versus External Filter Capacitance

Chopper Stabilization Technique

Chopper Stabilization is an innovative circuit technique that is used to minimize the offset voltage of a Hall element and an associated on-chip amplifier. HTCSEMI patented a Chopper Stabiliza- tion technique that nearly eliminates Hall IC output drift induced by temperature or package stress effects. This offset reduction technique is based on a signal modulation-demodulation process. Modulation is used to separate the undesired DC offset signal from the magnetically induced signal in the frequency domain.

Then, using a low-pass filter, the modulated DC offset is suppressed while the magnetically induced signal passes through

the filter. As a result of this chopper stabilization approach, the output voltage from the Hall IC is desensitized to the effects of temperature and mechanical stress. This technique produces devices that have an extremely stable Electrical Offset Voltage, are immune to thermal stress, and have precise recoverability after temperature cycling.
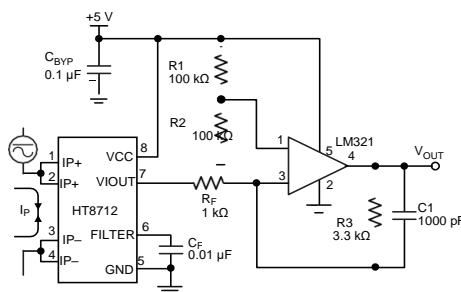
This technique is made possible through the use of a BiCMOS process that allows the use of low-offset and low-noise amplifiers in combination with high-density logic integration and sample and hold circuits.
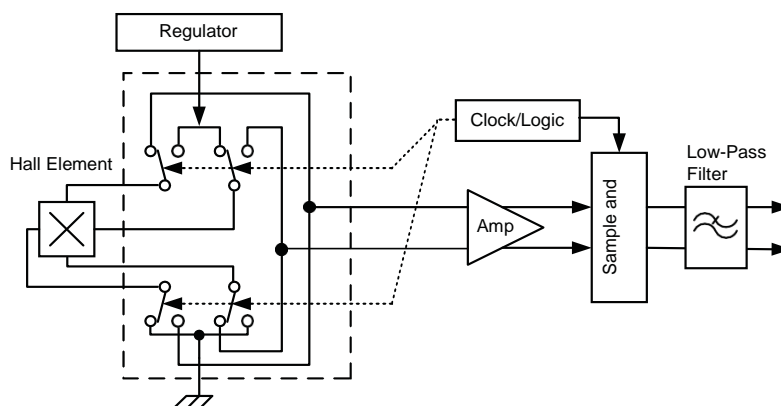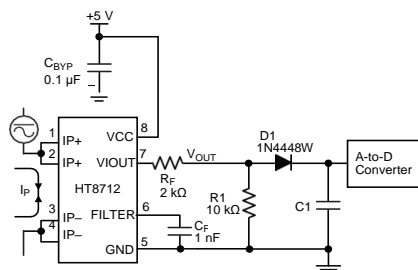
Concept of Chopper Stabilization Technique

Typical Applications
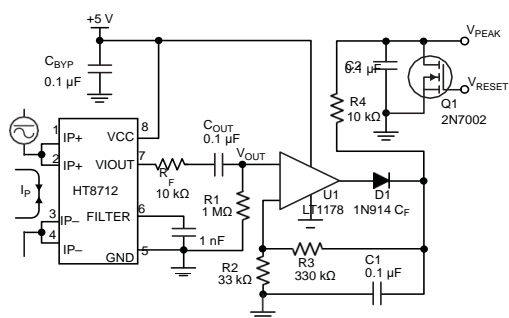
Application 2. Peak Detecting Circuit

Application 3. This configuration increases gain to 610 mV/A (tested using the HT8712R-05A).

Application 4. Rectified Output. 3.3 V scaling and rectification application for A-to-D converters. Replaces current transformer solutions with simpler ACS circuit. C1 is a function of the load resistance and filtering desired. R1 can be omitted if the full range is desired.
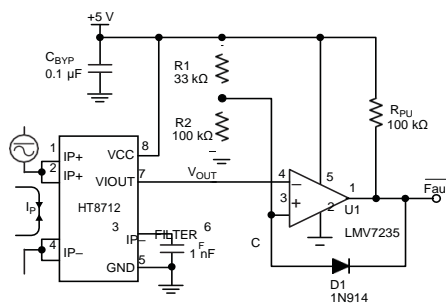
Application 5. 10 A Overcurrent Fault Latch. Fault threshold set by R1 and R2. This circuit latches an overcurrent fault and holds it until the 5 V rail is powered down.

Improving Sensing System Accuracy Using the FILTER Pin

In low-frequency sensing applications, it is often advantageous to add a simple RC filter to the output of the device. Such a low-pass filter improves the signal-to-noise ratio, and therefore the resolution, of the device output signal. However, the addition of an RC filter to the output of a sensor IC can result in undesirable device output attenuation — even for DC signals.

Signal attenuation, ΔV_{ATT}, is a result of the resistive divider effect between the resistance of the external filter, R_F (see Application 6), and the input impedance and resistance of the customer interface circuit, R_{INTFC}. The transfer function of this resistive divider is given by:

$$\Delta V_{ATT} = V_{IOUT}\left(\frac{R_{INTFC}}{R_F + R_{INTFC}}\right) \quad .$$

Even if R_F and R_{INTFC} are designed to match, the two individual resistance values will most likely drift by different amounts over

temperature. Therefore, signal attenuation will vary as a function of temperature. Note that, in many cases, the input impedance, R_{INTFC}, of a typical analog-to-digital converter (ADC) can be as low as 10 kΩ.

The HT8712 contains an internal resistor, a FILTER pin connection to the printed circuit board, and an internal buffer amplifier. With this circuit architecture, users can implement a simple RC filter via the addition of a capacitor, C_F (see Application 7) from the FILTER pin to ground. The buffer amplifier inside of the HT8712 (located after the internal resistor and FILTER pin connection) eliminates the attenuation caused by the resistive divider effect described in the equation for ΔV_{ATT}. Therefore, the HT8712 device is ideal for use in high-accuracy applications that cannot afford the signal attenuation associated with the use of an external RC low-pass filter.

Application 6. When a low pass filter is constructed externally to a standard Hall effect device, a resistive divider may exist between the filter resistor, R_F, and the resistance of the customer interface circuit, R_{INTFC}. This resistive divider will cause excessive attenuation, as given by the transfer function for ΔV_{ATT}.
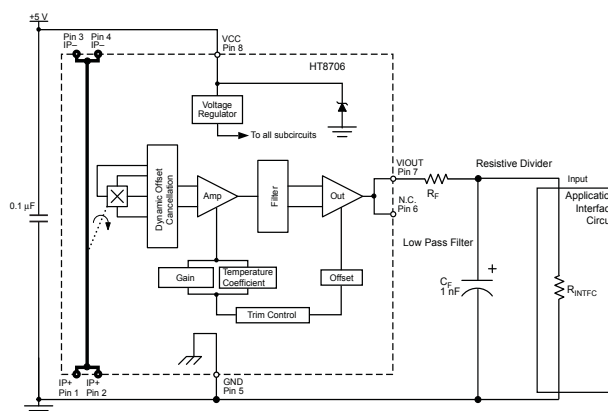

Application 7. Using the FILTER pin provided on the HT8712 eliminates the attenuation effects of the resistor divider between R_F and R_{INTFC}, shown in Application 6.
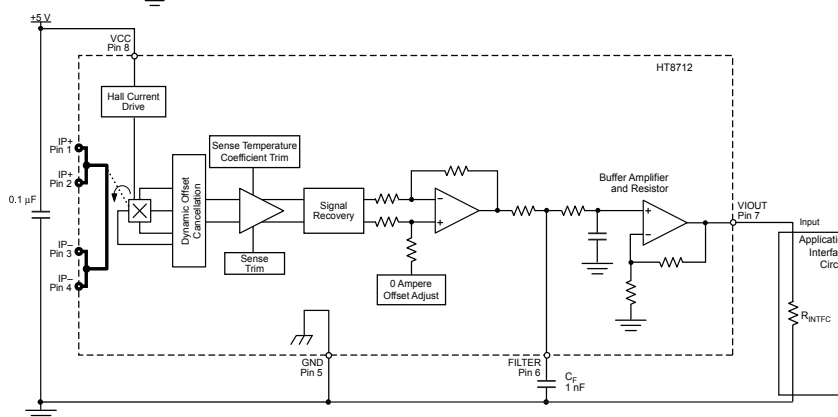
PACKAGE DIMENSIONS

SOIC−8 NB
CASE 751−07
ISSUE AK
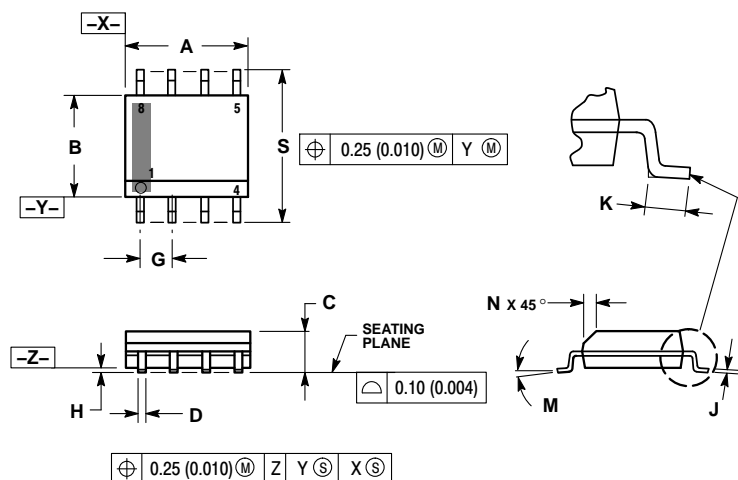
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: MILLIMETER.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.
5. DIMENSION D DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.127 (0.005) TOTAL IN EXCESS OF THE D DIMENSION AT MAXIMUM MATERIAL CONDITION.
6. 751−01 THRU 751−06 ARE OBSOLETE. NEW STANDARD IS 751−07.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	4.80	5.00	0.189	0.197
B	3.80	4.00	0.150	0.157
C	1.35	1.75	0.053	0.069
D	0.33	0.51	0.013	0.020
G	1.27 BSC		0.050 BSC	
H	0.10	0.25	0.004	0.010
J	0.19	0.25	0.007	0.010
K	0.40	1.27	0.016	0.050
M	0 °	8 °	0 °	8 °
N	0.25	0.50	0.010	0.020
S	5.80	6.20	0.228	0.244

⊕ 0.25 (0.010) Ⓜ Y Ⓜ

⊕ 0.25 (0.010) Ⓜ Z Y Ⓢ X Ⓢ

△ 0.10 (0.004)

SOLDERING FOOTPRINT*
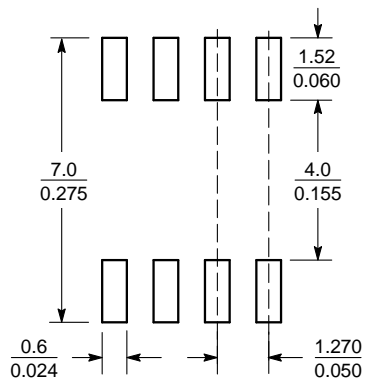
SCALE 6:1   (mm/inches)

*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.