

# Six-Channel Delta-Sigma Analog-to-Digital Converter

## Features

- Synchronous Sampling
- On-chip 1.2V Reference (25ppm/°C typ)
- Power Supply Configurations:
  - VA+ = +3 V; VA- = -2 V; VD+ = +3 V
  - Supply tolerances ±10%
- Power Consumption
  - 20 mW Typical at VD+ = +3 V
- Simple Four-wire Serial Interface
- Charge Pump Driver output generates negative power supply.
- Ground-Referenced Bipolar Inputs

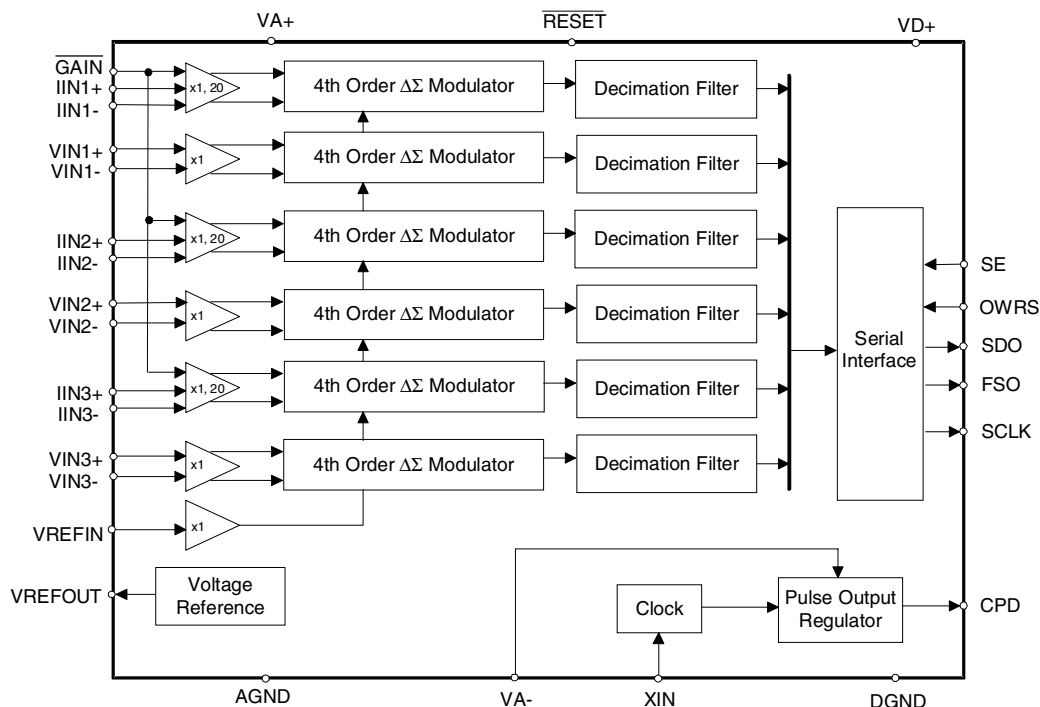
## Description

The CS5451A is a highly integrated Delta-Sigma ( $\Delta\Sigma$ ) Analog-to-Digital Converter (ADC) developed for the Power Measurement Industry. The CS5451A combines six  $\Delta\Sigma$  ADCs, decimation filters, and a serial interface on a single chip. The CS5451A interfaces directly to a current transformer or shunt to measure current, and resistive divider or transformer to measure voltage. The product features a serial interface for communication with a micro-controller or DSP. The product is initialized and fully functional upon reset, and includes a Voltage Reference.

## ORDERING INFORMATION:

CS5451A-IS -40°C to +85°C

28-pin SSOP



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## 1. PIN DESCRIPTION

Serial Clock Output	<b>SCLK</b>	□ 1	□ 28	<b>VD+</b>	Digital Supply
Serial Data Output	<b>SDO</b>	□ 2	□ 27	<b>DGND</b>	Digital Ground
Frame Sync	<b>FSO</b>	□ 3	□ 26	<b>CPD</b>	Charge Pump Drive
Serial Port Enable	<b>SE</b>	□ 4	□ 25	<b>XIN</b>	Master Clock
Current Input Gain	<b>GAIN</b>	□ 5	□ 24	<b>RESET</b>	Reset
Analog Ground	<b>AGND</b>	□ 6	□ 23	<b>OWRS</b>	Output Word Rate Select
Reference Input	<b>VREFIN</b>	□ 7	□ 22	<b>VIN1+</b>	Differential Voltage Input 1
Reference Output	<b>VREFOUT</b>	□ 8	□ 21	<b>VIN1-</b>	Differential Voltage Input 1
Positive Analog Supply	<b>VA+</b>	□ 9	□ 20	<b>IIN1+</b>	Differential Current Input 1
Negative Analog Supply	<b>VA-</b>	□ 10	□ 19	<b>IIN1-</b>	Differential Current Input 1
Differential Voltage Input 3	<b>VIN3+</b>	□ 11	□ 18	<b>VIN2+</b>	Differential Voltage Input 2
Differential Voltage Input 3	<b>VIN3-</b>	□ 12	□ 17	<b>VIN2-</b>	Differential Voltage Input 2
Differential Current Input 3	<b>IIN3+</b>	□ 13	□ 16	<b>IIN2+</b>	Differential Current Input 2
Differential Current Input 3	<b>IIN3-</b>	□ 14	□ 15	<b>IIN2-</b>	Differential Current Input 2

### Clock Generator

#### **XIN - Master Clock Input**

### Control Pins and Serial Data I/O

#### **SE - Serial Port Enable**

When SE is low, the output pins of the serial port are 3-stated.

#### **SDO - Serial Port Output**

Data will be at a rate determined by SCLK.

#### **FSO - Frame Signal Output**

Framing signal output for data transfer from SDO pin.

#### **SCLK - Serial Clock Output**

A clock signal on this pin determines the output rate of data for SDO pin. Rate of SCLK is determined by XIN frequency and state of OWRS input pin.

#### **RESET - Reset**

When reset is taken low, all internal registers are set to their default states.

#### **GAIN - Input Gain Control**

Sets input gain for current channels. A logic high sets internal gain to 1, a logic low level sets the gain to 20. If no connection is made to this pin, it will default to logic low level (through internal 200 kΩ resistor to DGND).

#### **OWRS - Output Word Rate Select**

When OWRS is set to logic low, the output word rate (OWR) at SDO pin is XIN/2048 (Hz). When set to logic high, the OWR at SDO pin is XIN/1024 (Hz). If no connection is made to this pin, then OWRS will default to logic low level (through internal 200 kΩ resistor to DGND).

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Measurement and Reference Input

**IIN(1-3)+, IIN(1-3)- - Differential Current Inputs**

Differential analog input pins for current channels.

**VIN(1-3)+, VIN(1-3)- - Differential Voltage Inputs**

Differential analog input pins for voltage channels.

**VREFOUT - Voltage Reference Output**

The on-chip voltage reference is output from this pin. The voltage reference has a nominal magnitude of 1.2 V and is referenced to the AGND pin on the converter.

**VREFIN - Voltage Reference Input**

The voltage input to this pin establishes the voltage reference for the on-chip modulator.

Power Supply Connections

**VA+ - Positive Analog Supply**

The positive analog supply is nominally  $+3V \pm 10\%$  relative to AGND.

**VA- - Negative Analog Supply**

The negative analog supply is nominally  $-2V \pm 10\%$  relative to AGND.

**AGND - Analog Ground**

The analog ground pin for input signals.

**VD+ - Positive Digital Supply**

The positive digital supply is nominally  $+3V \pm 10\%$  relative to DGND.

**DGND - Digital Ground**

The digital ground is typically at the same level as AGND.

**CPD - Charge Pump Drive**

This output pin drives the external charge pump circuitry to create a negative supply voltage.

## 2. CHARACTERISTICS AND SPECIFICATIONS

- Min / Max characteristics and specifications are guaranteed over all Operating Conditions
- Typical characteristics and specifications are measured at nominal supply voltages and  $T_A = 25\text{ }^\circ\text{C}$ .
- DGND = 0 V. All Voltages with respect to 0V.

### ANALOG CHARACTERISTICS

Parameter	Symbol	Min	Typ	Max	Unit	
<b>Accuracy (All Channels)</b>						
Total Harmonic Distortion	THD	74	-	-	dB	
Common Mode Rejection (DC, 50, 60 Hz)	CMRR	80	-	-	dB	
Common Mode + Signal on Input		VA-	-	VA+	V	
Input Sampling Rate		-	XIN/4	-	Hz	
<b>Analog Inputs</b> (Note 1)						
Differential Input Voltage Range [[ $I_{IN+}$ ] - ( $I_{IN-}$ )] or [[ $V_{IN+}$ ] - ( $V_{IN-}$ )]	Gain=20	VIN	-	80	-	mV <sub>P-P</sub>
	Gain=1	VIN	-	1.6	-	V <sub>P-P</sub>
Bipolar Offset	Gain=20	VOS	-	0.500	1	mV
	Gain=1	VOS	-	10	20	mV
Crosstalk (Channel-to-Channel) (50, 60 Hz)		-	-	-120	dB	
Input Capacitance	Gain = 20	IC	-	-	20	pF
	Gain = 1	IC	-	-	1	pF
Effective Input Impedance (Note 2)	Gain=20	EII	50	-	-	k $\Omega$
	Gain=1	EII	-	500	600	k $\Omega$
Noise (Referred to Input) 0-60 Hz	Gain=20		-	-	1	$\mu\text{V}_{\text{rms}}$
	Gain=1		-	-	20	$\mu\text{V}_{\text{rms}}$
0-1 kHz	Gain=20		-	-	2.5	$\mu\text{V}_{\text{rms}}$
	Gain=1		-	-	50	$\mu\text{V}_{\text{rms}}$
0-2 kHz	Gain=20		-	-	3.75	$\mu\text{V}_{\text{rms}}$
	Gain=1		-	-	75	$\mu\text{V}_{\text{rms}}$
<b>Dynamic Characteristics</b>						
High Rate Filter Output Word Rate	OWRS = "0"	OWR	-	XIN/2048	-	Hz
	OWRS = "1"	OWR	-	XIN/1024	-	Hz

- Notes: 1. All "Gain = 20" specifications apply only to the Current Channels. Voltage Channels are set to Gain=1.
2. Effective Input Impedance (EII) varies with clock frequency (XIN) and Input Capacitance (IC)  
 $EII = 1/(IC \cdot XIN/4)$

**ANALOG CHARACTERISTICS** (continued)

Parameter	Symbol	Min	Typ	Max	Unit	
<b>Reference Output</b>						
Output Voltage	REFOUT	1.15	-	1.25	V	
Temperature Coefficient		-	25	50	ppm/°C	
Load Regulation (Output Current 1 µA Source or Sink)	$\Delta V_R$	-	6	10	mV	
Power Supply Rejection	PSRR	60	-	-	dB	
<b>Reference Input</b>						
Input Voltage Range	VREF+	1.15	1.2	1.25	V	
Input Capacitance		-	-	10	pF	
Input CVF Current		-	-	1	µA	
<b>Power Supplies</b>						
Power Supply Currents	$I_{A+}$	PSCA	-	-	3	mA
	$I_{D+}$	PSCD	-	-	4	mA
Power Consumption (Note 3)	PC	-	-	27	mW	
Power Supply Rejection (see Note 4)	(DC)	PSRR	50	-	-	dB
	(50, 60 Hz)	PSRR	60	-	-	dB

- Notes: 3. All outputs unloaded. All inputs CMOS level.
4. Definition for PSRR: VREFIN tied to VREFOUT, VA+ = VD+ = 3V, AGND = DGND = 0V, VA- = -2V (using charge-pump circuit with CPD). In addition, a 106.07 mV rms (60 Hz) sinewave is imposed onto the VA+ and VD+ pins. The “+” and “-” input pins of both input channels are shorted to VA-. 2048 instantaneous digital output data words are collected for the channel under test. The rms value of the digital sinusoidal output signal is calculated, and this rms value is converted into the rms value of the sinusoidal voltage (measured in mV) that would need to be applied at the channel’s inputs, in order to cause the same digital sinusoidal output. This voltage is then defined as  $V_{eq}$ . PSRR is then (in dB):

$$PSRR = 20 \cdot \log \left\{ \frac{106.07}{V_{eq}} \right\}$$

**DIGITAL CHARACTERISTICS** (See Note 5)

Parameter	Symbol	Min	Typ	Max	Unit
High-Level Input Voltage	$V_{IH}$	0.6 VD+	-	VD+	V
Low-Level Input Voltage	$V_{IL}$	0.0	-	0.8	V
High-Level Output Voltage $I_{out} = -5.0$ mA	$V_{OH}$	(VD+) - 1.0	-	-	V
Low-Level Output Voltage $I_{out} = 5.0$ mA	$V_{OL}$	-	-	0.4	V
Input Leakage Current (Note 6)	$I_{in}$	-	±1	±10	µA
3-State Leakage Current	$I_{OZ}$	-	-	±10	µA
Digital Output Pin Capacitance	$C_{out}$	-	9	-	pF

- Notes: 5. All measurements performed under static conditions.
6. For OWRS and  $\overline{GAIN}$  pins, input leakage current is 30 µA (Max).

## RECOMMENDED OPERATING CONDITIONS

Parameter		Symbol	Min	Typ	Max	Unit
DC Power Supplies	Positive Digital	VD+	2.7	3.0	3.5	V
	Positive Analog	VA+	2.7	3.0	3.5	V
	Negative Analog	VA-	-2.2	-2.0	-1.8	V
Voltage Reference Input		VREF+	-	1.2	-	V

## ABSOLUTE MAXIMUM RATINGS

Parameter		Symbol	Min	Typ	Max	Unit
DC Power Supplies	Positive Digital	VD+	-0.3	-	+3.5	V
	Positive Analog	VA+	-0.3	-	+3.5	V
	Negative Analog	VA-	-2.5	-	-0.3	V
Input Current, Any Pin Except Supplies	(Note 7 and 8)	I <sub>IN</sub>	-	-	±10	mA
Output Current		I <sub>OUT</sub>	-	-	±25	mA
Power Dissipation	(Note 9)	PDN	-	-	500	mW
Analog Input Voltage	All Analog Pins	V <sub>INA</sub>	(VA-) - 0.3	-	(VA+) + 0.3	V
Digital Input Voltage	All Digital Pins	V <sub>IND</sub>	-0.3	-	(VD+) + 0.3	V
Ambient Operating Temperature		T <sub>A</sub>	-40	-	85	°C
Storage Temperature		T <sub>stg</sub>	-65	-	150	°C

- Notes:
7. Applies to all pins including continuous over-voltage conditions at the analog input (AIN) pins.
  8. Transient current of up to 100 mA will not cause SCR latch-up. Maximum input current for a power supply pin is ±50 mA.
  9. Total power dissipation, including all input currents and output currents.

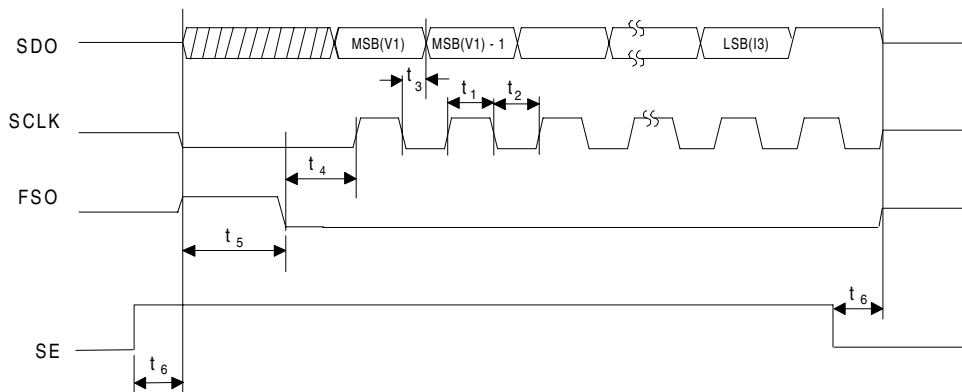
**WARNING:** Operation at or beyond these limits may result in permanent damage to the device. Normal operation is not guaranteed at these extremes.

**SWITCHING CHARACTERISTICS**

Parameter	Symbol	Min	Typ	Max	Unit
Master Clock Frequency (Note 10)	XIN	3	4.000	5	MHz
Master Clock Duty Cycle	-	40	-	60	%
Rise Times Any Digital Input (Note 11) Any Digital Output	$t_{rise}$	-	- 50	1.0 -	$\mu$ s ns
Fall Times Any Digital Input (Note 11) Any Digital Output	$t_{fall}$	-	- 50	1.0 -	$\mu$ s ns
<b>Serial Port Timing</b>					
Serial Clock Frequency (Note 10)	SCLK	-	500	-	kHz
	SCLK	-	1000	-	kHz
Serial Clock Pulse Width High (Note 10)	$t_1$	-	0.5	-	SCLK
Pulse Width Low (Note 10)	$t_2$	-	0.5	-	SCLK
SCLK falling to New Data Bit	$t_3$	-	-	50	ns
FSO Falling to SCLK Rising Delay (Note 10)	$t_4$	-	0.5	-	SCLK
FSO Pulse Width (Note 10)	$t_5$	-	1	-	SCLK
SE Rising to Output Enabled	$t_6$	-	-	50	ns
SE Falling to Output in Tri-state	$t_7$	-	-	50	ns

Notes: 10. Device parameters are specified with a 4.000MHz clock, OWRS = 1.

11. Specified using 10% and 90% points on wave-form of interest. Output loaded with 50pF.



**Figure 1. Serial Port Timing**



### 3. GENERAL DESCRIPTION

The CS5451A is designed for 3-phase power meter applications and interfaces to a current transformers or shunt to measure current, and a resistive divider or transformer to measure voltage.

The CS5451A combines six  $\Delta\Sigma$  modulators and decimation filters, three channels assigned for current input that have programmable input gain amplifiers, and three channels assigned for voltage input.

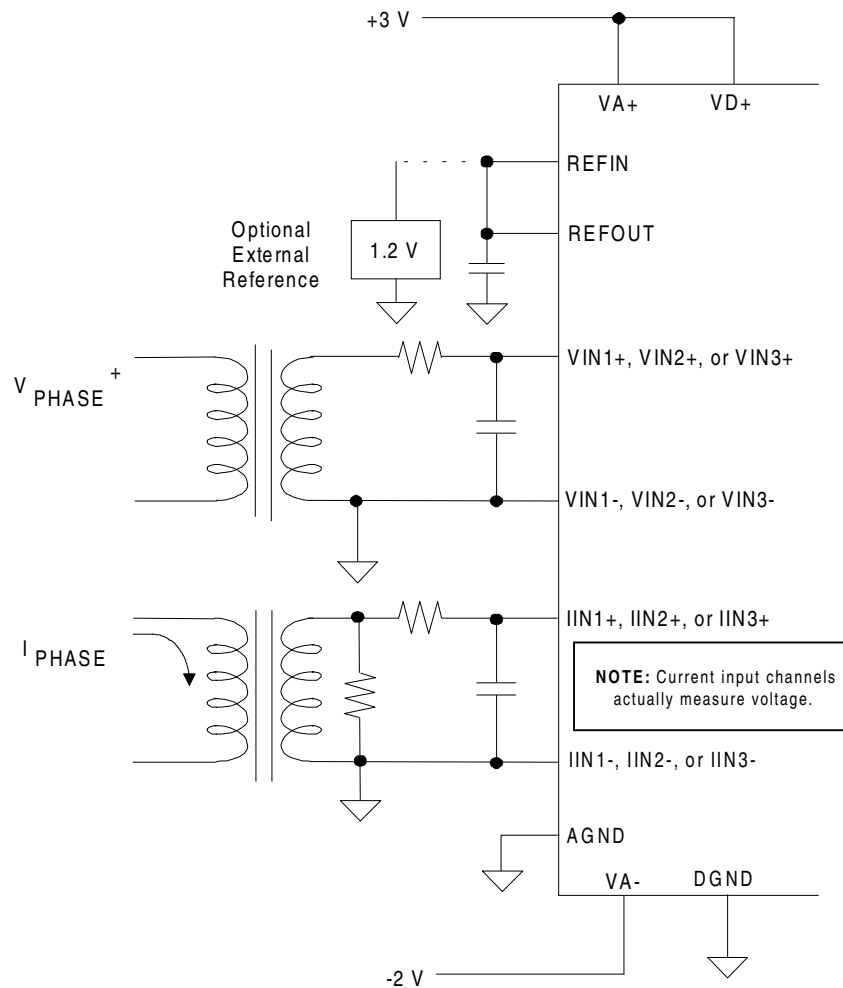
The CS5451A includes six decimation filters that output data at a 2000 Hz or 4000 Hz output word

rate (OWR) when the input frequency at XIN = 4.096 MHz.

The device outputs data on a serial output port.

### 3.1 Theory of Operation

The CS5451A is designed to operate from a single +3V supply and provides a  $80\text{mV}_{\text{P-P}}$  and  $1.6\text{V}_{\text{P-P}}$  input range for the current channels and  $1.6\text{V}_{\text{P-P}}$  range for the voltage channels. These voltages represent the maximum zero-to-peak voltage levels that can be presented to the inputs. The CS5451A is designed to accommodate common mode + signal levels from VA- to VA+. Figure 2 illustrates the



**Figure 2. Typical Connection Diagram**

CS5451A typical inputs and power supply connections.

### 3.2 Performing Measurements

The converter outputs are transferred in 16-bit signed (two's complement) data formats as a percentage of full scale. Table 1 below illustrates the ideal relationship between the differential voltage presented to any one of the input channels and the corresponding output code. Note that for the current channels, the state of the  $\overline{\text{GAIN}}$  input pin is assumed to driven low such that the PGA gain on the current channels is 1x. If the PGA gain of the current channels is set to 20x, a +40 mV differential voltage is presented across any pair of "IINk+" and "IINk-" pins (k = 1, 2, 3) would cause a (nominal) output code of 32767.

Differential Input Voltage (mV)	Output Code (hexadecimal)	Output Code (decimal)
+800	7FFF	32767
0.0122 to 0.0366	0001	1
-0.0122 to 0.0122	0000	0
-0.0122 to -0.0366	FFFF	-1
-800	8000	-32768

**Table 1. Nominal Relationship for Differential Input Voltage vs. Output Code, for all channels. (Assume PGA gain is set to 1x.)**

### 3.3 High Rate Digital Filters

If the OWRS pin is set to logic low, the high-rate filters are implemented as fixed sinc<sup>3</sup> filters with the following transfer function:

$$H(z) = \left( \frac{1 - z^{-256}}{1 - z^{-1}} \right)^3$$

This filter samples the modulator bit stream at XIN/8 Hz and decimates to XIN/2048 Hz.

If the OWRS pin is set to logic high, then the transfer function is

$$H(z) = \left( \frac{1 - z^{-128}}{1 - z^{-1}} \right)^3$$

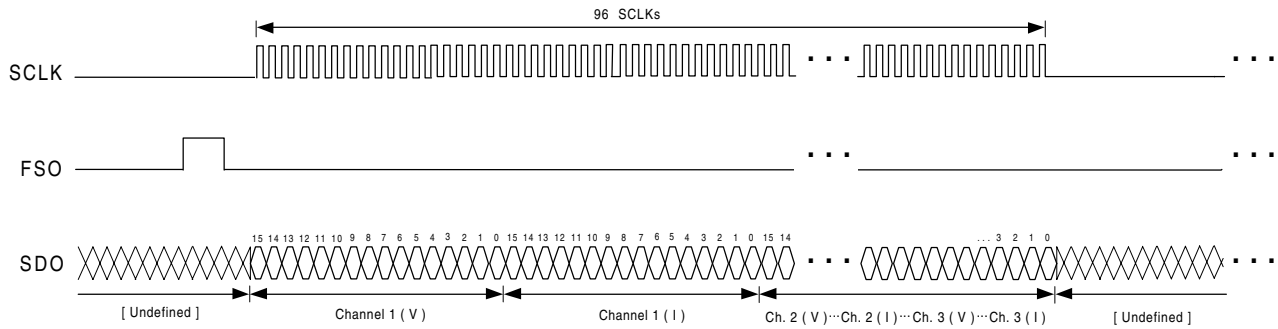
The above filter samples the modulator bit stream at XIN/8 Hz and decimates to XIN/1024 Hz.

### 3.4 Serial Interface

The CS5451A communicates with a target device via a master serial data output port. Output data is provided on the SDO output synchronous with the SCLK output. A third output, FSO, is a framing signal used to signal the start of output data. These three outputs will be driven as long as the SE (serial enable) input is held high. Otherwise, these outputs will be high impedance.

Data out (SDO) changes as a result of SCLK falling, and always outputs valid data with SCLK rising. When data is being transferred, the SCLK frequency is either 1/8 of the XIN input frequency (when OWRS is held low) or 1/4 of the XIN input frequency (when OWRS is held high). Any other time, SCLK is held low. (See Figures 3 and 4.)

The framing signal (FSO) output is normally low, but produces a high level pulse lasting one SCLK period when the instantaneous voltage/current data samples are about to be transmitted out of the serial



**Figure 4. Close-up of One Data Frame**

interface (after each A/D conversion cycle). Note: SCLK is not active during FSO high.

For 96 SCLK periods after FSO falls, SCLK is active and SDO produces valid output. Six channels of 16 bit data are output, MSB first. Voltage and current measurements are output (in that order) for three phases. SCLK will then be held low until the next sample period.

### 3.5 System Initialization

When power to the CS5451A is applied, the chip must be held in a reset condition using the  $\overline{\text{RESET}}$  input.

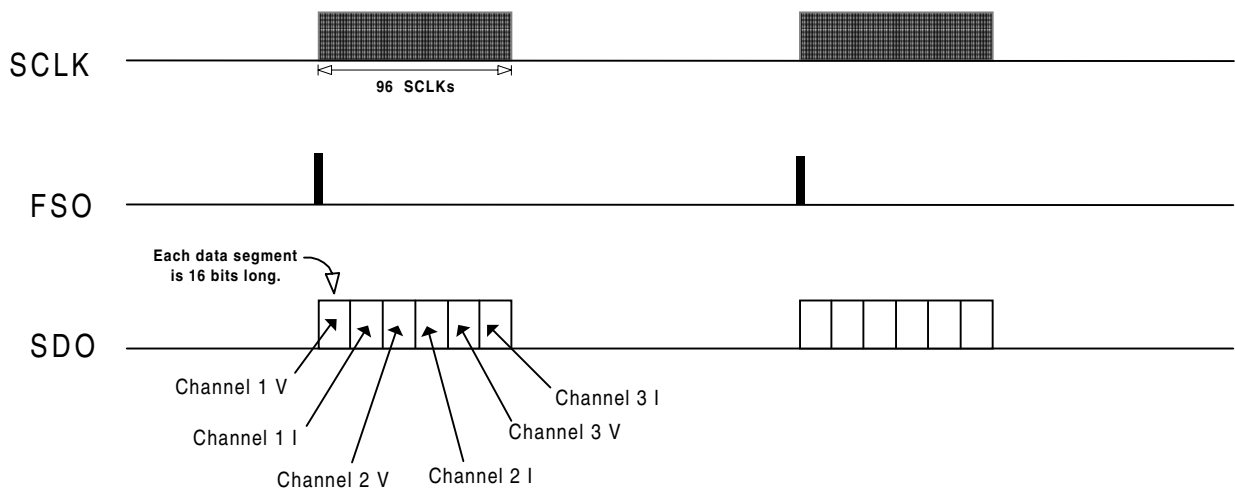
A hardware reset is initiated when the  $\overline{\text{RESET}}$  pin is forced low with a minimum pulse width of 50 ns.

### 3.6 Analog Inputs

The analog inputs of the CS5451A are bipolar voltage inputs: Three voltage channel inputs  $V_{IN}(1-3)$  and three current channel inputs  $I_{IN}(1-3)$ . The CS5451A accommodates a full scale range of  $80\text{ mV}_{P-P}$  or  $1.6\text{ V}_{P-P}$  on the Current Channels and  $1.6\text{ V}_{P-P}$  on the Voltage Channels.

### 3.7 Voltage Reference

The CS5451A is specified for operation with a +1.2 V reference between the  $V_{REFIN}$  and  $AGND$  pins. The converter includes an internal 1.2 V reference



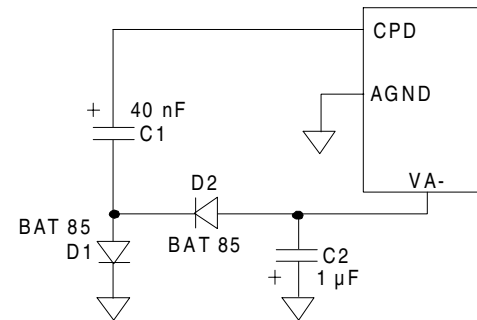
**Figure 3. Serial Port Data Transfer**

(50 ppm/°C drift) that can be used by connecting the VREFOUT pin to the VREFIN pin of the device. If higher accuracy/stability is required, an external reference can be used.

### 3.8 Power Supply

The low, stable analog power consumption and superior supply rejection of the CS5451A allow for the use of a simple charge-pump negative supply generator. The use of a negative supply alleviates the need for level shifting of the analog inputs. The CPD pin and capacitor C1 provide the necessary analog supply current as shown in Figure 5. The Schottky diodes D1 and D2 are chosen for their low forward voltages and high-speed capabilities. The capacitor C2 provides the required charge storage and bypassing of the negative supply. The CPD output signal provides the charge pump driver signal. The frequency of the charge pump driver signal is synchronous to XIN. The nominal average frequency is 1 MHz. The level on the VA- pin is fed back internally so that the CPD output will regulate the VA- level to -2/3 of VA+ level.

Note the value of C1 in Figure 5. The 40 nF value is recommended when the input frequency presented to the XIN pin is 4.00 MHz. If the user decides to use an XIN frequency that is significantly different than 4.00 MHz (if the XIN frequency is increased/decreased by more than 5% of 4.00 MHz, then it is recommended that the user should alter the value of C1. The percentage change in the value of C1 (with respect to a reference value of 40 nF) should be inversely proportional to the percentage change in the XIN frequency. For example, if the XIN frequency is increased from 4.00 MHz to



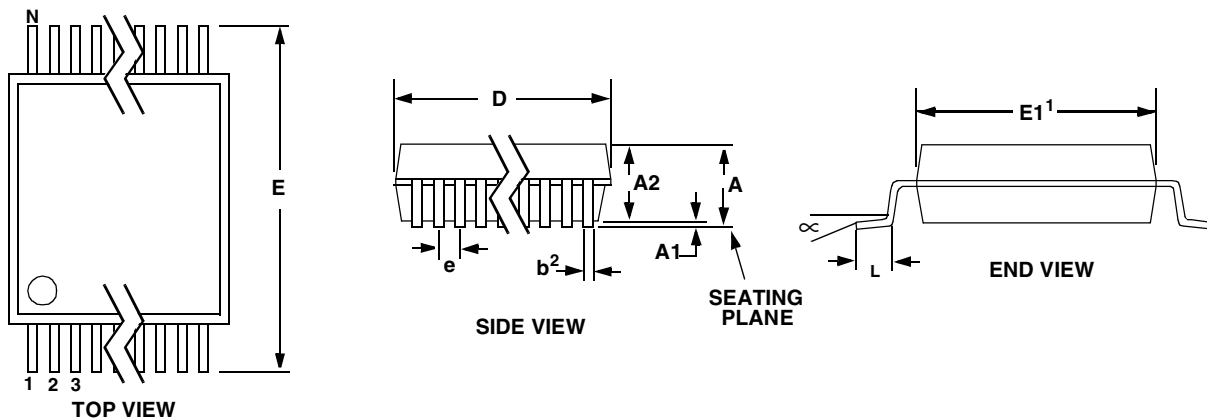
**Figure 5. Generating VA- with a Charge Pump**

4.5 MHz, this represents a percentage increase of 12.5%. Therefore, the value of C1 should be reduced by 12.5%, making the new value for C1 to be 35 nF. For more information about the operation of this type of charge pump circuit, the reader can refer to Cirrus Logic, Inc.'s application note *AN152: Using the CS5521/24/28, and CS5525/26 Charge Pump Drive for External Loads*.

### 3.9 PCB Layout

For optimal performance, the CS5451A should be placed entirely over an analog ground plane with both the VA- and DGND pins of the device connected to the analog plane. Place the analog-digital plane split immediately adjacent to the digital portion of the chip.

**Note:** Refer to the CDB5451 Evaluation Board for suggested layout details and Applications Note 18 for more detailed layout guidelines. Before layout, please call for our Free Schematic Review Service.

**4. PACKAGE DIMENSIONS**
**28L SSOP PACKAGE DRAWING**


DIM	INCHES			MILLIMETERS			NOTE
	MIN	NOM	MAX	MIN	NOM	MAX	
A	--	--	0.084	--	--	2.13	
A1	0.002	0.006	0.010	0.05	0.13	0.25	
A2	0.064	0.069	0.074	1.62	1.75	1.88	
b	0.009	--	0.015	0.22	--	0.38	2,3
D	0.390	0.4015	0.413	9.90	10.20	10.50	1
E	0.291	0.307	0.323	7.40	7.80	8.20	
E1	0.197	0.209	0.220	5.00	5.30	5.60	1
e	0.022	0.026	0.030	0.55	0.65	0.75	
L	0.025	0.0354	0.041	0.63	0.90	1.03	
∞	0°	4°	8°	0°	4°	8°	

**JEDEC #: MO-150**

- Notes:
1. "D" and "E1" are reference datums and do not include mold flash or protrusions, but do include mold mismatch and are measured at the parting line, mold flash or protrusions shall not exceed 0.20 mm per side.
  2. Dimension "b" does not include dambar protrusion/intrusion. Allowable dambar protrusion shall be 0.13 mm total in excess of "b" dimension at maximum material condition. Dambar intrusion shall not reduce dimension "b" by more than 0.07 mm at least material condition.
  3. These dimensions apply to the flat section of the lead between 0.10 and 0.25 mm from lead tips.

## 5. REVISIONS

Revision	Date	Changes
A1	July 2003	Initial Release
PP1	13 October 2003	Initial release for Preliminary Product Information

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### Contacting Cirrus Logic Support

For all product questions and inquiries contact a Cirrus Logic Sales Representative.

To find the one nearest to you go to [www.cirrus.com](http://www.cirrus.com)

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