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MCP3903

Six Channel Delta Sigma A/D Converter

Features

- Six Synchronous Sampling 16/24-bit Resolution Delta-Sigma A/D Converters with Proprietary Multi-Bit Architecture
- 91 dB SINAD, -100 dBc Total Harmonic Distortion (THD) (up to 35th harmonic), 102 dB Spurious-free Dynamic Range (SFDR) for Each Channel
- Programmable Data Rate up to 64 ksps
- Ultra Low-Power Shutdown Mode with <2 µA
- -115 dB Crosstalk Between any Two Channels
- Low Drift Internal Voltage Reference: 5 ppm/°C
- Differential Voltage Reference Input Pins
- High Gain PGA on Each Channel (up to 32 V/V)
- Phase Delay Compensation Between Each Pair of Channels with 1 µs Time Resolution
- High-Speed Addressable 10 MHz SPI Interface with Mode 0,0 and 1,1 Compatibility
- Independent Analog and Digital Power Supplies 4.5V - 5.5V AV_{DD}, 2.7V - 3.6V DV_{DD}
- Available in Small 28-lead SSOP Package
- Extended Temperature Range: -40°C to +125°C

Applications

- Energy Metering and Power Measurement
- Portable Instrumentation
- Medical and Power Monitoring

Description

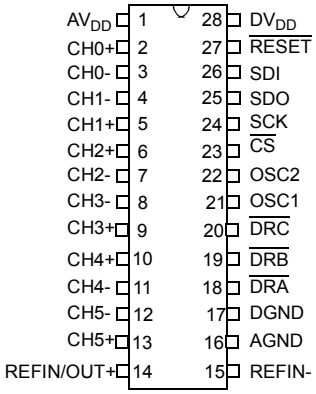
The MCP3903 is a six-channel Analog Front End (AFE) containing three pairs made out of two synchronous sampling Delta-Sigma Analog-to-Digital Converters (ADC) with PGA, a phase delay compensation block, internal voltage reference, and high-speed 10 MHz SPI compatible serial interface. The converters contain a proprietary dithering algorithm for reduced idle tones and improved THD.

The internal register map contains 24-bit wide ADC data words, a modulator output register as well as six 24-bit writable control registers to program gain, over-sampling ratio, phase, resolution, dithering, shut-down, reset and several communication features.

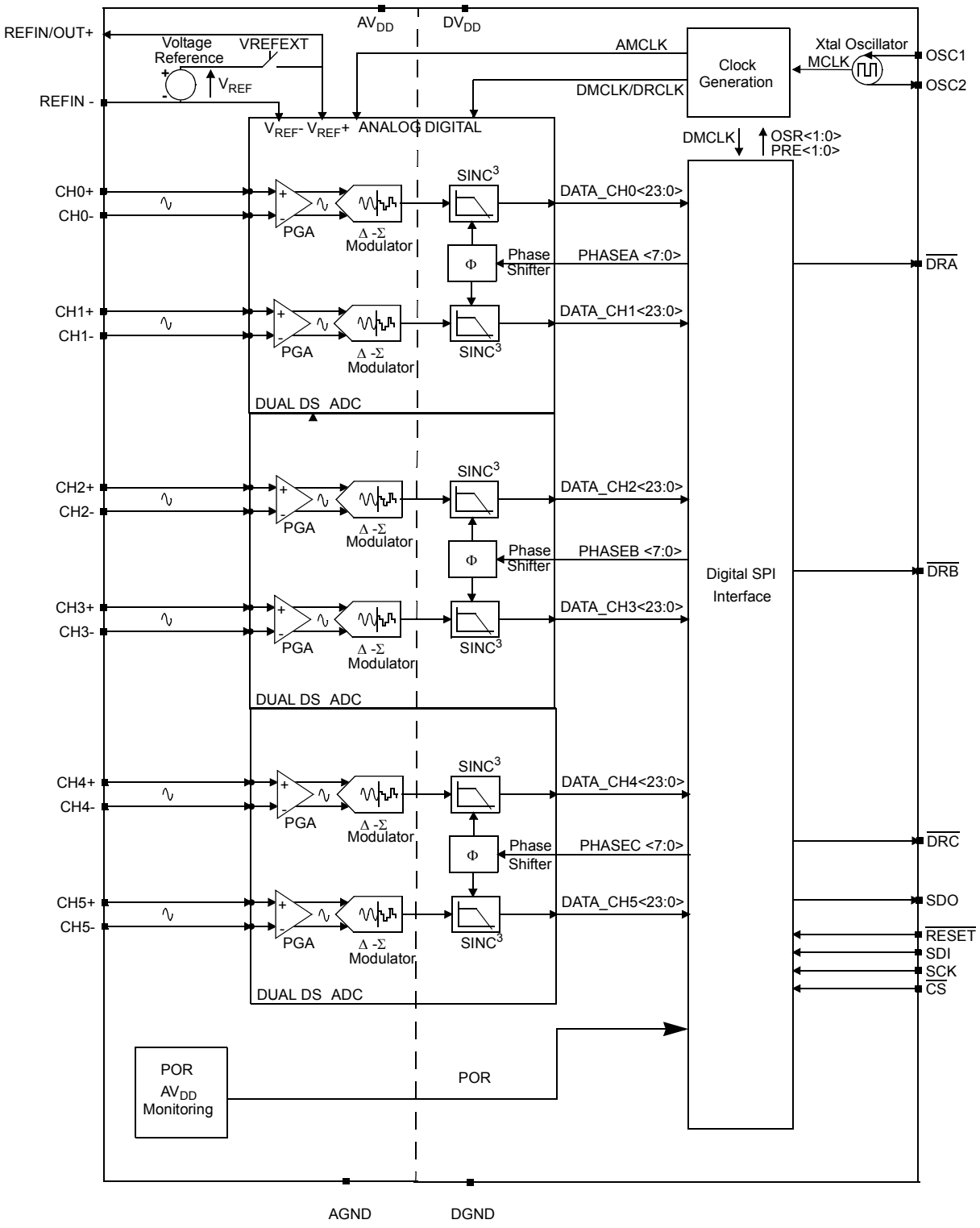
The communication is largely simplified with various Continuous Read modes that can be accessed by the Direct Memory Access (DMA) of an MCU and with separate Data Ready pins that can directly be connected to the Interrupt Request (IRQ) input of an MCU. The MCP3903 is capable of interfacing to a large variety of voltage and current sensors including shunts, current transformers, Rogowski coils, and Hall-effect sensors.

Package Type

28-Lead SSOP



Functional Block Diagram



1.0 ELECTRICAL CHARACTERISTICS

The Reliability Targets section includes the absolute maximum ratings for the device, defining the values that will cause no long term damage regardless of duration.

These tables also represent the testing requirements per the Max. and Min. columns.

1.1 RELIABILITY TARGETS

ABSOLUTE MAXIMUM RATINGS †

V_{DD} 7.0V
Digital inputs and outputs w.r.t. A_{GND} .....-0.6V to V_{DD} +0.6V
Analog input w.r.t. A_{GND} ....-6V to +6V
V_{REF} input w.r.t. A_{GND}.....-0.6V to V_{DD} +0.6V
Storage temperature ..... -65°C to +150°C
Ambient temp. with power applied..... -65°C to +125°C
Soldering temperature of leads (10 seconds)..... +300°C
ESD on the analog inputs (HBM,MM)..... 5.0 kV, 500V
ESD on all other pins (HBM,MM)..... 5.0 kV, 500V

TABLE 1-1: ANALOG SPECIFICATIONS TARGET TABLE

Electrical Specifications: Unless otherwise indicated, all parameters apply at AV_{DD} = 4.5 to 5.5V, DV_{DD} = 2.7 to 3.6V, Internal V_{REF}, MCLK = 4 MHz;PRESCALE = 1; OSR = 64; f_S = 1 MHz; f_D = 15.625 ksps; T_A = -40°C to +125°C, GAIN = 1, V_{IN} = $1V_{PP}$ = $353mV_{RMS}$ @ 50/60 Hz.

Param. Num.	Symbol	Characteristic	Min.	Typ.	Max.	Units	Test Conditions
Internal Voltage Reference							
A001	V_{REF}	Voltage	-2%	2.35	+2%	V	VREFEXT = 0
A002	TC_{REF}	Tempco	—	5	—	ppm/°C	VREFEXT = 0
A003	$ZOUT_{REF}$	Output Impedance		7	—	kΩ	AV_{DD}=5V, VREFEXT = 0
Voltage Reference Input							
A004		Input Capacitance	—	—	10	pF	
A005	V_{REF}	Differential Input Voltage Range (V_{REF+} - V_{REF-})	2.2	—	2.6	V	V_{REF} = (V_{REF+} - V_{REF-}), VREFEXT = 1
A006	V_{REF+}	Absolute Voltage on REFIN+ pin	1.9	—	2.9	V	VREFEXT = 1
A007	V_{REF-}	Absolute Voltage on REFIN- pin	-0.3	—	+0.3	V	V_{REF-} should be connected to AGND when VREFEXT=0
ADC Performance							
A008		Resolution (No Missing Codes)		24		bits	OSR = 256 (see Table 5-2)
A009	f_S	Sampling Frequency	See Table 4-2			kHz	f_S = DMCLK = MCLK / (4 x PRESCALE)
A010	f_D	Output Data Rate	See Table 4-2			ksps	f_D = DRCLK= DMCLK / OSR = MCLK / (4 x PRESCALE x OSR)

Note 1: This specification implies that the ADC output is valid over this entire differential range, i.e. there is no distortion or instability across this input range. Dynamic Performance is specified at -0.5 dB below the maximum signal range, V_{IN} = -0.5 dBFS @ 50/60 Hz = 333 mV_{RMS}, V_{REF} = 2.4V.

2: See terminology section for definition.

3: This parameter is established by characterization and not 100% tested.

4: For these operating currents, the following configuration bit settings apply: Config Register Settings: SHUTDOWN<5:0> = 000000, RESET<5:0> = 000000; VREFEXT = 0, CLKEXT = 0.

5: For these operating currents, the following configuration bit settings apply: Config Register Settings: SHUTDOWN<5:0> = 111111, VREFEXT = 1, CLKEXT = 1.

6: Applies to all gains. Offset error is dependant on PGA gain setting.

7: Outside of this range, ADC accuracy is not specified. An extended input range of +/- 6V can be applied continuously to the part with no risk for damage.

8: For proper operation and to keep ADC accuracy, AMCLK should always be in the range of 1 to 5 MHz with BOOST bits off. With BOOST bits on, AMCLK should be in the range of 1 to 8.192 MHz. AMCLK = MCLK/PRESCALE. When using a crystal, CLKEXT bit should be equal to '0'.

TABLE 1-1: ANALOG SPECIFICATIONS TARGET TABLE (CONTINUED)

Electrical Specifications: Unless otherwise indicated, all parameters apply at AV_{DD} = 4.5 to 5.5V, DV_{DD} = 2.7 to 3.6V, Internal V_{REF}, MCLK = 4 MHz;PRESCALE = 1; OSR = 64; f_S = 1 MHz; f_D = 15.625 ksps; T_A = -40°C to +125°C, GAIN = 1, V_{IN} = $1V_{PP}$ = $353mV_{RMS}$ @ 50/60 Hz.

Param. Num.	Symbol	Characteristic	Min.	Typ.	Max.	Units	Test Conditions
A011	CHn+-	Analog Input Absolute Voltage	-1		+1	V	All analog input channels, measured to AGND **(Note 7)**
A012	A_{IN}	Analog Input Leakage Current		1		nA	**(Note 4)**
A013	(CH_{n+}-CH_{n-})	Differential Input Voltage Range			500 / GAIN	mV_P	**(Note 1)**
A014	V_{OS}	Offset Error	-3		3	mV	**(Note 6)(Note 2)**
A015		Offset Error Drift		1		µV/C	From -40°C to 125°C
A016	GE	Gain Error	-3		3	%	**All Gains**
A017		Gain Error Drift	—	2	—	ppm/°C	From -40°C to 125°C
A018	INL	Integral Non-Linearity		15		ppm	GAIN = 1, DITHER = ON
A019	Z_{IN}	Input Impedance	350	—	—	kΩ	Proportional to 1/AMCLK
A020	SINAD	Signal-to-Noise and Distortion Ratio	89	91	—	dB	T = 25°C
			80	81.5		dB	
A021	THD	Total Harmonic Distortion		-100	-97	dB	OSR = 256, DITHER = ON; **(Note 2)(Note 3)**
				-90	-87	dB	
A022	SNR	Signal To Noise Ratio	90	91.5		dB	T = 25°C
			80	81.5		dB	
A023	SFDR	Spurious Free Dynamic Range		102		dB	OSR = 256, DITHER = ON; **(Note 2) (Note 3)**
				91		dB	
A024	CTALK	Crosstalk (50 / 60 Hz)	—	-115	—	dB	OSR = 256, DITHER = ON; **(Note 2)(Note 3)**
A025	AC PSRR	AC Power Supply Rejection	—	-68	—	dB	AV_{DD} = 5V + 1Vpp @ 50 Hz
A026	DC PSRR	DC Power Supply Rejection	—	-68	—	dB	AV_{DD} = 4.5 to 5.5V, DV_{DD} = 3.3V
A027	CMRR	DC Common Mode Rejection Ratio	—	-75	—	dB	V_{CM} varies from -1V to +1V; **(Note 2)**
Oscillator Input							

Note 1: This specification implies that the ADC output is valid over this entire differential range, i.e. there is no distortion or instability across this input range. Dynamic Performance is specified at -0.5 dB below the maximum signal range, V_{IN} = -0.5 dBFS @ 50/60 Hz = 333 mV_{RMS}, V_{REF} = 2.4V.

2: See terminology section for definition.

3: This parameter is established by characterization and not 100% tested.

4: For these operating currents, the following configuration bit settings apply: Config Register Settings: SHUTDOWN<5:0> = 000000, RESET<5:0> = 000000; VREFEXT = 0, CLKEXT = 0.

5: For these operating currents, the following configuration bit settings apply: Config Register Settings: SHUTDOWN<5:0> = 111111, VREFEXT = 1, CLKEXT = 1.

6: Applies to all gains. Offset error is dependant on PGA gain setting.

7: Outside of this range, ADC accuracy is not specified. An extended input range of +/- 6V can be applied continuously to the part with no risk for damage.

8: For proper operation and to keep ADC accuracy, AMCLK should always be in the range of 1 to 5 MHz with BOOST bits off. With BOOST bits on, AMCLK should be in the range of 1 to 8.192 MHz. AMCLK = MCLK/PRESCALE. When using a crystal, CLKEXT bit should be equal to '0'.

TABLE 1-1: ANALOG SPECIFICATIONS TARGET TABLE (CONTINUED)

Electrical Specifications: Unless otherwise indicated, all parameters apply at AV_{DD} = 4.5 to 5.5V, DV_{DD} = 2.7 to 3.6V, Internal V_{REF}, MCLK = 4 MHz;PRESCALE = 1; OSR = 64; f_S = 1 MHz; f_D = 15.625 ksps; T_A = -40°C to +125°C, GAIN = 1, V_{IN} = $1V_{PP}$ = $353mV_{RMS}$ @ 50/60 Hz.

Param. Num.	Symbol	Characteristic	Min.	Typ.	Max.	Units	Test Conditions
A028	MCLK	Master Clock Frequency Range	1	—	16.384	MHz	**(Note 8)**
Power Specifications							
P001	AV_{DD}	Operating Voltage, Analog	4.5	—	5.5	V	
P002	DV_{DD}	Operating Voltage, Digital	2.7	—	3.6	V	
P003	AI_{DD}	Operating Current, Analog **(Note 4)**		7.1	9	mA	BOOST bits low on all channels
				12.3	16.8	mA	BOOST bits high on all channels
P004	DI_{DD}	Operating Current, Digital	—	1.2	1.7	mA	DV_{DD} = 3.6V, MCLK = 4 MHz
			—	2.4	3.4	mA	DV_{DD} = 3.6V, MCLK = 8.192 MHz
P005	$I_{DDS,A}$	Shutdown Current, Analog	—	—	1	µA	-40°C to 85°C, AV_{DD} pin only, **(Note 5)**
			—	—	3	µA	-40°C to 125°C, AV_{DD} pin only, **(Note 5)**
P006	$I_{DDS,D}$	Shutdown Current, Digital	—	—	1	µA	-40°C to 85°C, DV_{DD} pin only, **(Note 5)**
			—	—	5	µA	-40°C to 125°C, DV_{DD} pin only, **(Note 5)**

Note 1: This specification implies that the ADC output is valid over this entire differential range, i.e. there is no distortion or instability across this input range. Dynamic Performance is specified at -0.5 dB below the maximum signal range, V_{IN} = -0.5 dBFS @ 50/60 Hz = 333 mV_{RMS}, V_{REF} = 2.4V.

2: See terminology section for definition.

3: This parameter is established by characterization and not 100% tested.

4: For these operating currents, the following configuration bit settings apply: Config Register Settings: SHUTDOWN<5:0> = 000000, RESET<5:0> = 000000; VREFEXT = 0, CLKEXT = 0.

5: For these operating currents, the following configuration bit settings apply: Config Register Settings: SHUTDOWN<5:0> = 111111, VREFEXT = 1, CLKEXT = 1.

6: Applies to all gains. Offset error is dependant on PGA gain setting.

7: Outside of this range, ADC accuracy is not specified. An extended input range of +/- 6V can be applied continuously to the part with no risk for damage.

8: For proper operation and to keep ADC accuracy, AMCLK should always be in the range of 1 to 5 MHz with BOOST bits off. With BOOST bits on, AMCLK should be in the range of 1 to 8.192 MHz. AMCLK = MCLK/PRESCALE. When using a crystal, CLKEXT bit should be equal to '0'.

1.2 SERIAL INTERFACE CHARACTERISTICS

SERIAL INTERFACE SPECIFICATIONS

Electrical Specifications: Unless otherwise indicated, all parameters apply at AV_{DD} = 4.5 to 5.5V, DV_{DD} = 2.7 to 3.6V, -40°C < T_A <+125°C, C_{LOAD} = 30 pF.

Parameters	Sym	Min	Typ	Max	Units	Conditions
Serial Clock frequency	f_{SCK}	—	—	10	MHz	$2.7 \le DV_{DD} < 3.6$
$\overline{CS}$ setup time	t_{CSS}	50	—	—	ns	$2.7 \le DV_{DD} < 3.6$
$\overline{CS}$ hold time	t_{CSH}	100	—	—	ns	$2.7 \le DV_{DD} < 3.6$
$\overline{CS}$ disable time	t_{CSD}	50	—	—	ns	—
Data setup time	t_{SU}	10	—	—	ns	$2.7 \le DV_{DD} < 3.6$
Data hold time	t_{HD}	20	—	—	ns	$2.7 \le DV_{DD} < 3.6$
Serial Clock high time	t_{HI}	40	—	—	ns	$2.7 \le DV_{DD} < 3.6$
Serial Clock low time	t_{LO}	40	—	—	ns	$2.7 \le DV_{DD} < 3.6$
Serial Clock delay time	t_{CLD}	50	—	—	ns	—
Serial Clock enable time	t_{CLE}	50	—	—	ns	—
Output valid from SCK low	t_{DO}	—	—	50	ns	$2.7 \le DV_{DD} < 3.6$
Output hold time	t_{HO}	0	—	—	ns	
Output disable time	t_{DIS}	—	—	50	ns	$2.7 \le DV_{DD} < 3.6$
Reset Pulse Width ($\overline{RESET}$)	t_{MCLR}	100	—	—	ns	$2.7 \le DV_{DD} < 3.6$
Data Transfer Time to $\overline{DR}$ (Data Ready)	t_{DODR}		—	50	ns	$2.7 \le DV_{DD} < 3.6$
Data Ready Pulse Low Time	t_{DRP}		1/ DMCLK	—	µs	$2.7 \le DV_{DD} < 3.6$
Schmitt Trigger High-level Input voltage (All digital inputs)	V_{IH1}	.7 DV_{DD}	—	DV_{DD} +1	V	
Schmitt Trigger Low-level input voltage (All digital inputs)	V_{IL1}	-0.3	—	0.25 DV_{DD}	V	
Hysteresis of Schmitt Trigger Inputs (All digital inputs)	V_{HYS}	50	—		mV	
Low-level output voltage, SDO pin	V_{OL}	—	—	0.4	V	SDO pin only, I_{OL} = 2 mA, DV_{DD} = 3.3V
Low-level output voltage, $\overline{DRn}$ pins	V_{OL}			0.4	V	$\overline{DRn}$ pins only, I_{OL} = +1.5 mA, DV_{DD} =3.3V
High-level output voltage, SDO pin	V_{OH}	DV_{DD} - 0.5	—	—	V	SDO pin only, I_{OH} = -2 mA, DV_{DD} = 3.3V
High-level output voltage, $\overline{DRn}$ pins only	V_{OH}	DV_{DD} - 0.5	—	—	V	$\overline{DRn}$ pins only, I_{OH} = -1.5 mA, DV_{DD}=3.3V
Input leakage current	I_{LI}	—	—	±1	µA	$\overline{CS}$ = DV_{DD}, Inputs tied to DV_{DD} OR DGND
Output leakage current	I_{LO}	—	—	±1	µA	$\overline{CS}$ = DV_{DD}, Inputs tied to DV_{DD} OR DGND
Internal capacitance (all inputs and outputs)	C_{INT}	—	—	7	pF	T_A = 25°C, SCK = 1.0 MHz DV_{DD} = 3.3V **(Note 1)**

Note 1: This parameter is periodically sampled and not 100% tested.

TEMPERATURE CHARACTERISTICS

Electrical Specifications: Unless otherwise indicated, all parameters apply at AV_{DD} = 4.5 to 5.5V, DV_{DD} = 2.7 to 3.3 V.

Parameters	Sym	Min	Typ	Max	Units	Conditions
Temperature Ranges						
Operating Temperature Range	T_A	-40	—	+125	°C	**(Note 1)**
Storage Temperature Range	T_A	-65	—	+150	°C	
Thermal Package Resistances						
Thermal Resistance, 28-lead SSOP	θ_{JA}	—	71	—	°C/W	

Note 1: The internal junction temperature (T_J) must not exceed the absolute maximum specification of +150°C.

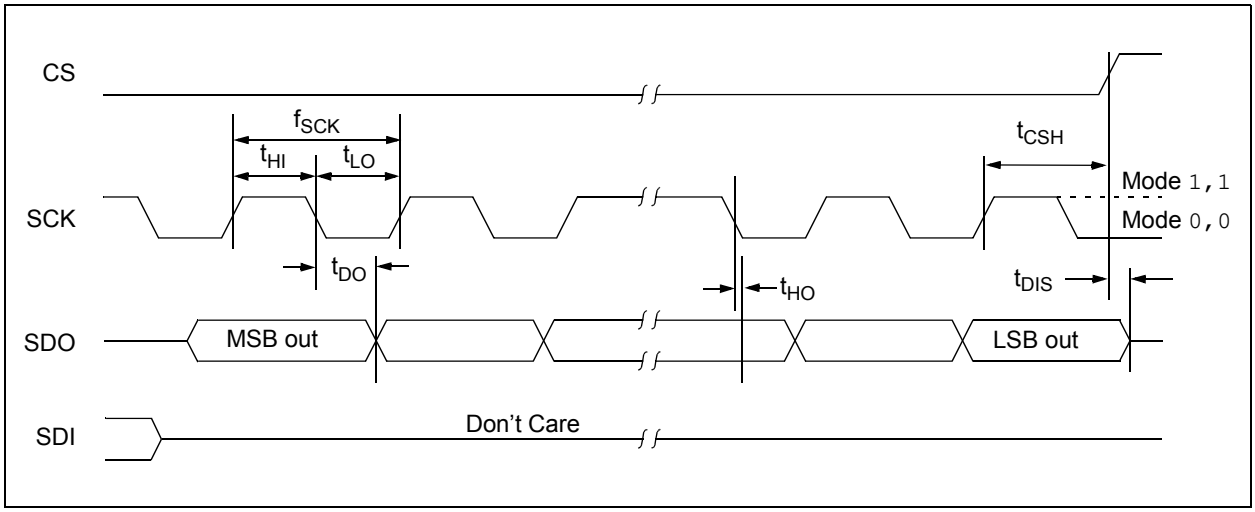


FIGURE 1-1: *Serial Output Timing Diagram.*

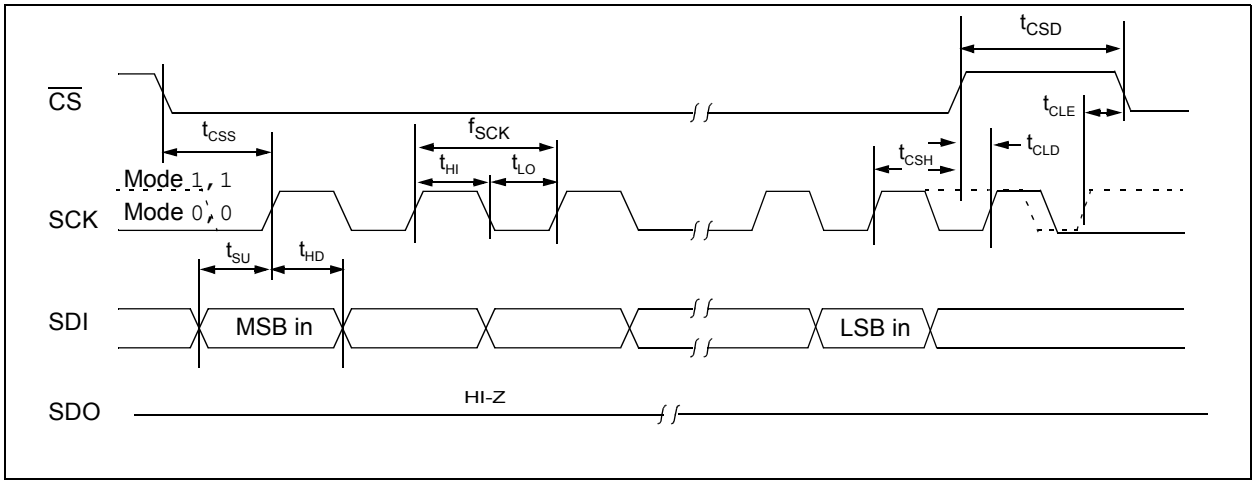


FIGURE 1-2: *Serial Input Timing Diagram.*

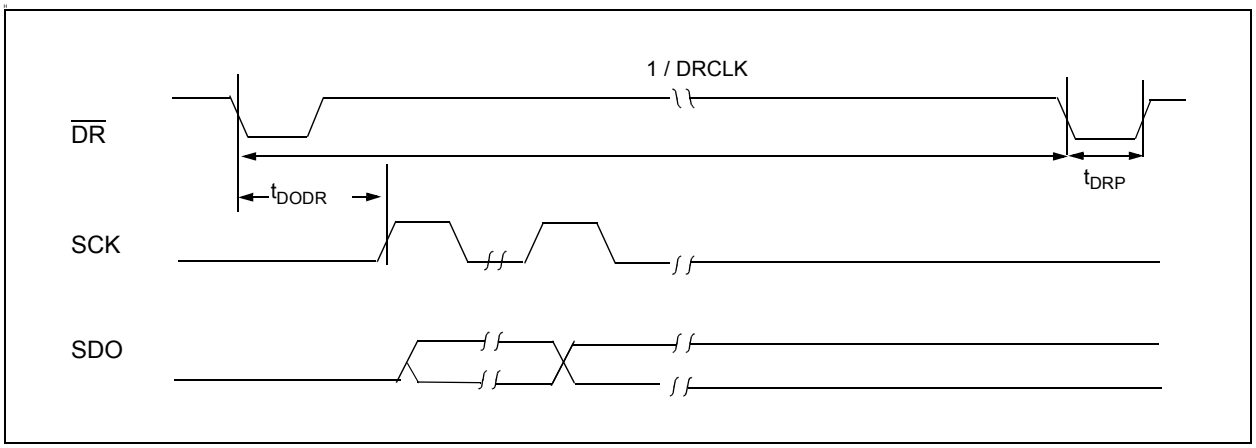


FIGURE 1-3: *Data Ready Pulse Timing Diagram.*

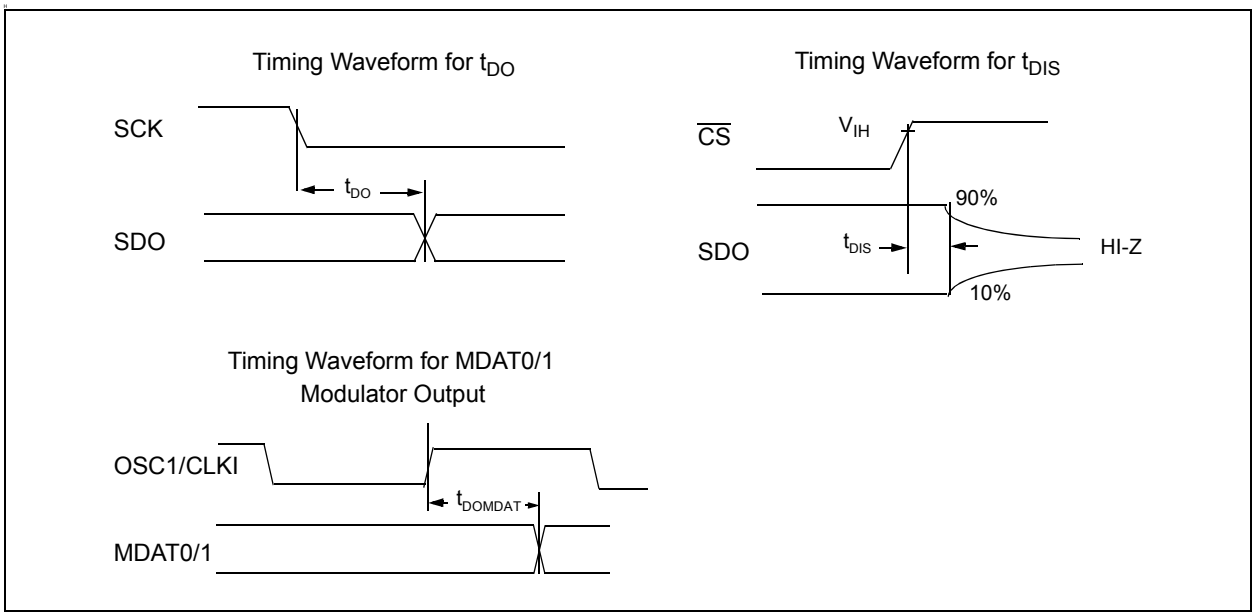


FIGURE 1-4: *Specific Timing Diagrams.*

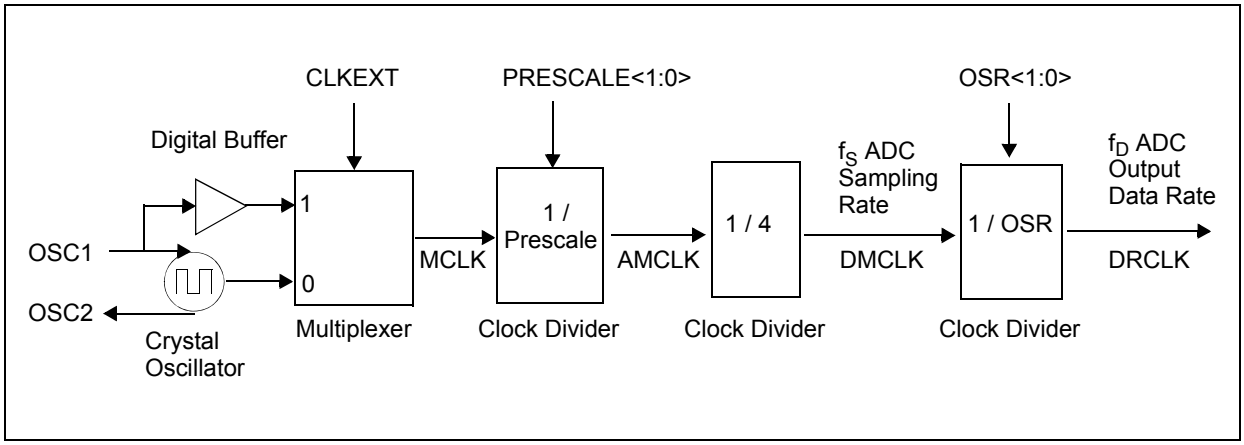


FIGURE 1-5: *MCP3903 Clock Detail.*

2.0 TYPICAL PERFORMANCE CURVES

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore outside the warranted range.

Note: Unless otherwise indicated, AV_{DD} = 5.0V, DV_{DD} = 3.3 V; Internal V_{REF}; T_A = +25°C, MCLK = 4 MHz; PRESCALE = 1; OSR = 64; GAIN = 1; Dithering OFF; V_{IN} = -0.5 dBFS @ 60 Hz.

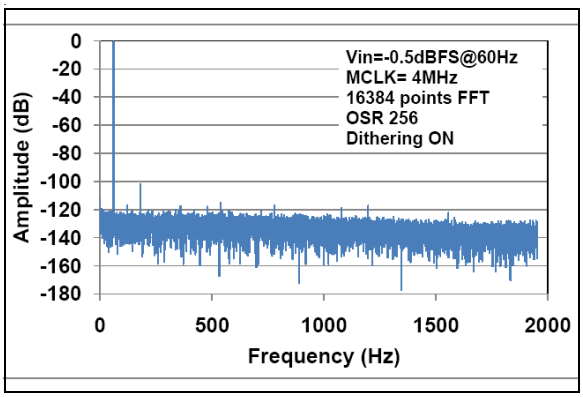


FIGURE 2-1: *Spectral Response.*

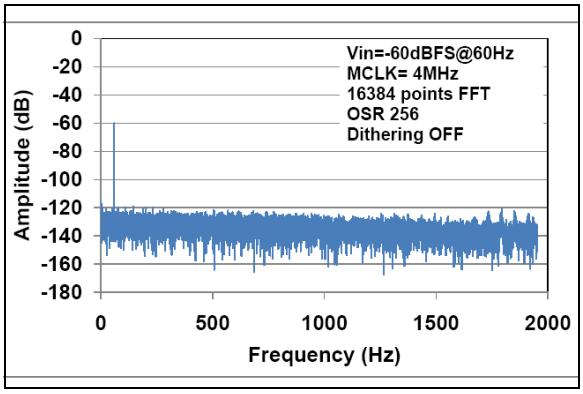


FIGURE 2-4: *Spectral Response.*

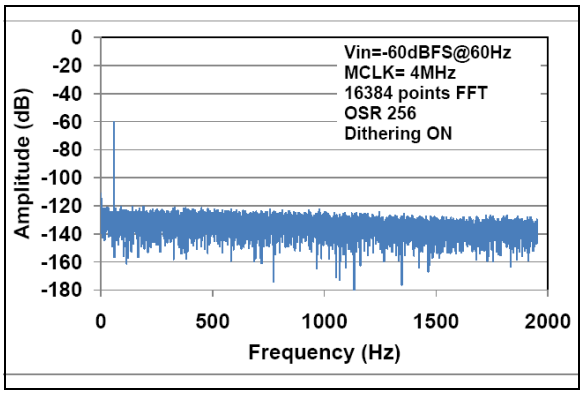


FIGURE 2-2: *Spectral Response.*

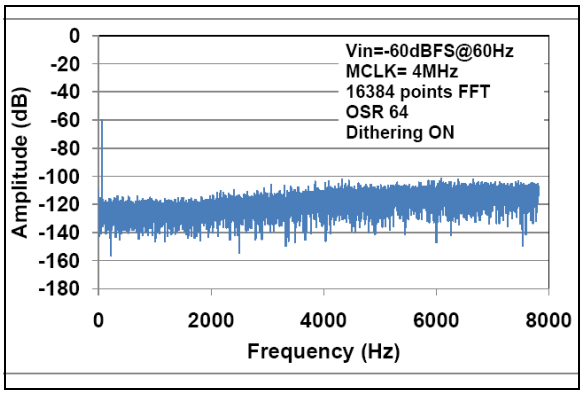


FIGURE 2-5: *Spectral Response.*

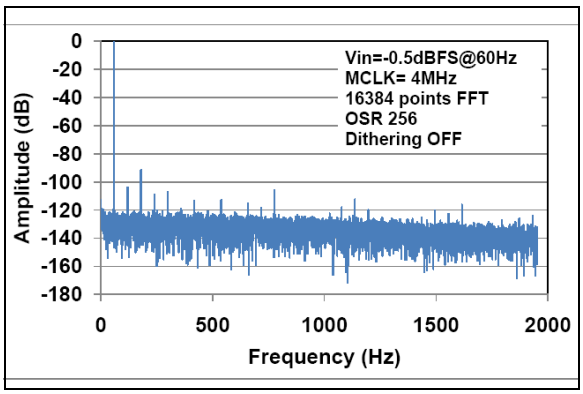


FIGURE 2-3: *Spectral Response.*

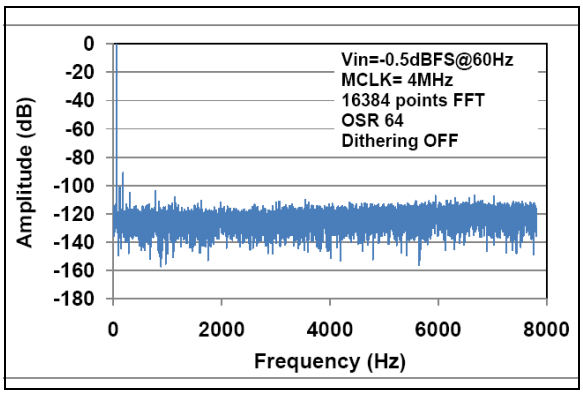


FIGURE 2-6: *Spectral Response.*

Note: Unless otherwise indicated, AV_{DD} = 5.0V, DV_{DD} = 3.3 V; T_A = +25°C, MCLK = 4 MHz; PRESCALE = 1; OSR = 64; GAIN = 1; Dithering OFF; V_{IN} = -0.5 dBFS @ 60 Hz.

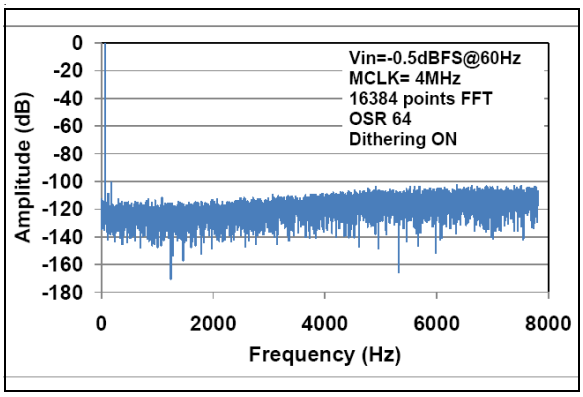


FIGURE 2-7: *Spectral Response.*

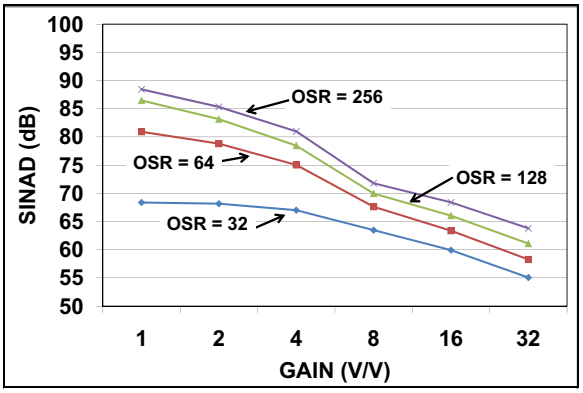


FIGURE 2-10: *Signal-to-Noise and Distortion vs. Gain (Dithering OFF).*

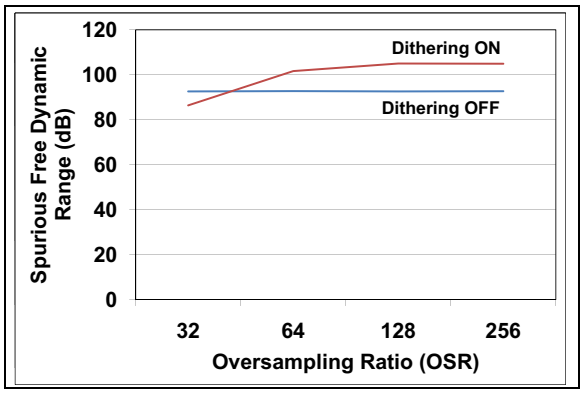


FIGURE 2-8: *Spurious Free Dynamic Range vs Oversampling Ratio.*

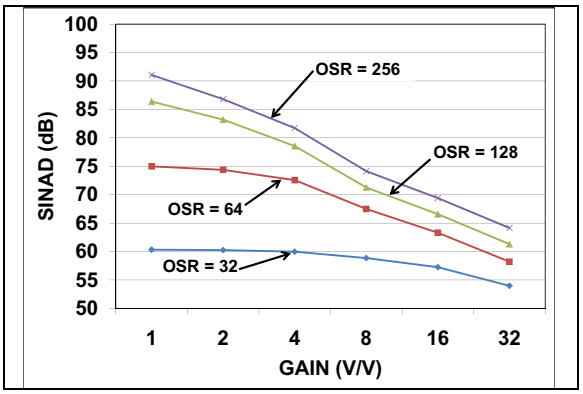


FIGURE 2-11: *Signal-to-Noise and Distortion vs. Gain (Dithering ON).*

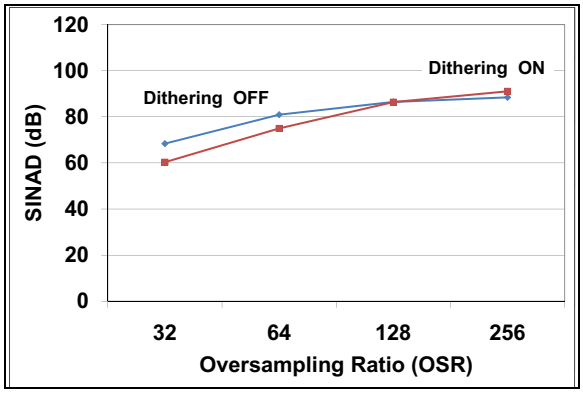


FIGURE 2-9: *Signal-to-Noise and Distortion vs. Oversampling Ratio.*

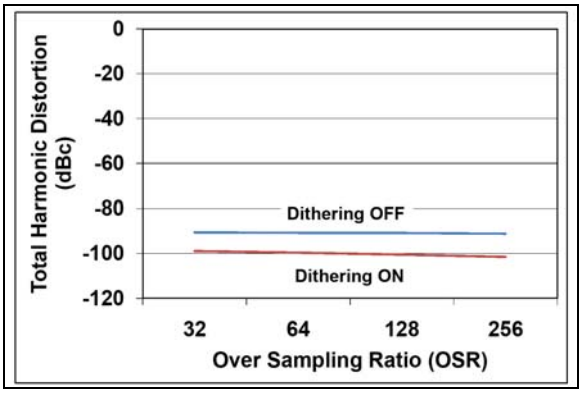


FIGURE 2-12: *Total Harmonic Distortion vs. Oversampling Ratio.*

Note: Unless otherwise indicated, AV_{DD} = 5.0V, DV_{DD} = 3.3 V; T_A = +25°C, MCLK = 4 MHz; PRESCALE = 1; OSR = 64; GAIN = 1; Dithering OFF; V_{IN} = -0.5 dBFS @ 60 Hz.

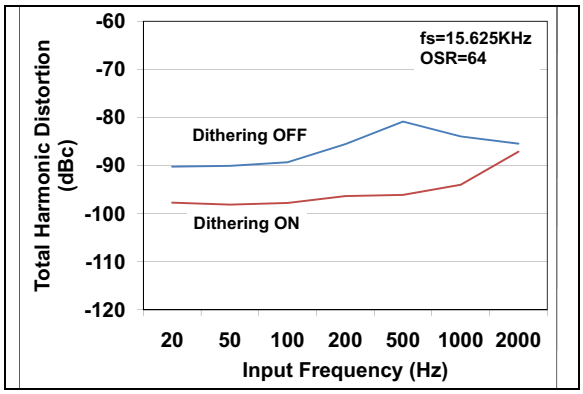


FIGURE 2-13: *Total Harmonic Distortion vs. Input Signal Frequency.*

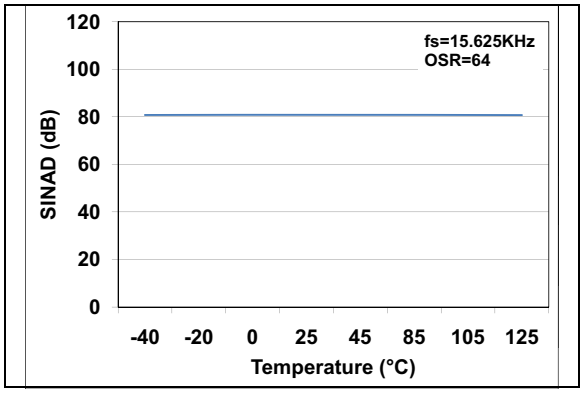


FIGURE 2-16: *Signal-to-Noise and Distortion vs. Temperature.*

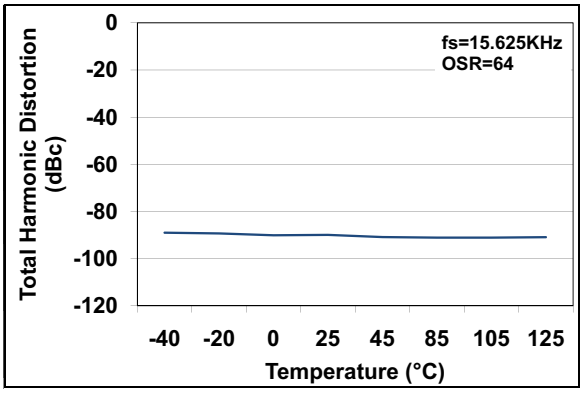


FIGURE 2-14: *Total Harmonic Distortion vs. Temperature.*

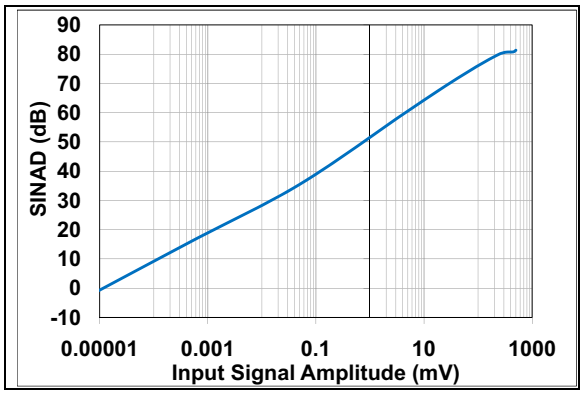


FIGURE 2-17: *Signal-to-Noise and Distortion vs. Input Signal Amplitude.*

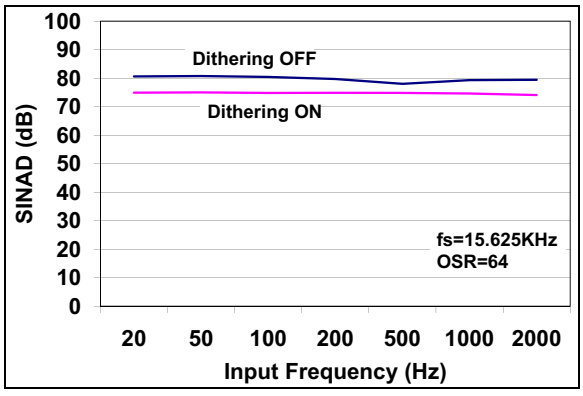


FIGURE 2-15: *Signal-to-Noise and Distortion vs. Input Signal Frequency.*

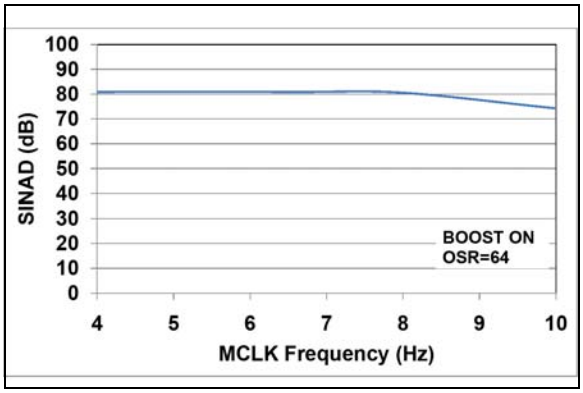


FIGURE 2-18: *Signal-to-Noise and Distortion vs. Master Clock.*

Note: Unless otherwise indicated, AV_{DD} = 5.0V, DV_{DD} = 3.3 V; T_A = +25°C, MCLK = 4 MHz; PRESCALE = 1; OSR = 64; GAIN = 1; Dithering OFF; V_{IN} = -0.5 dBFS @ 60 Hz.

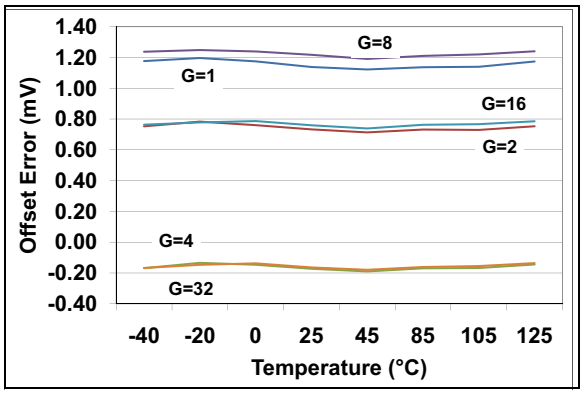


FIGURE 2-19: *Offset Error vs. Temperature (Channel 0).*

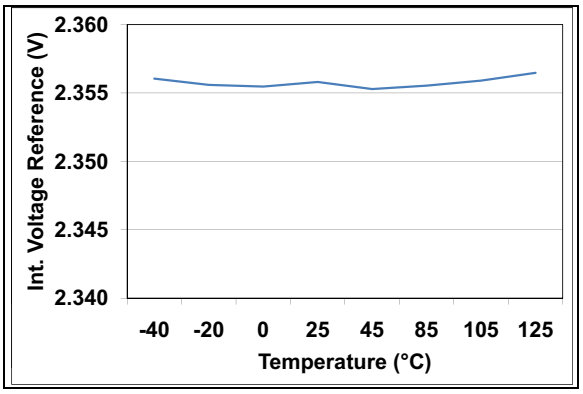


FIGURE 2-22: *Internal Voltage Reference vs. Temperature.*

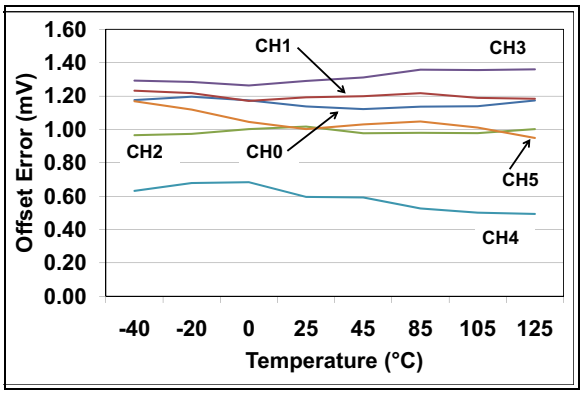


FIGURE 2-20: *Channel-to-Channel Offset Match vs. Temperature.*

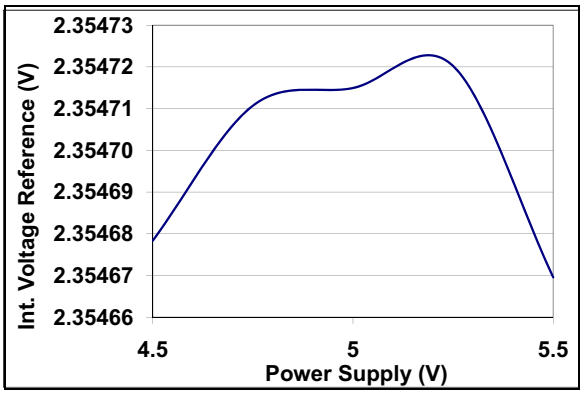


FIGURE 2-23: *Internal Voltage Reference vs. Supply Voltage.*

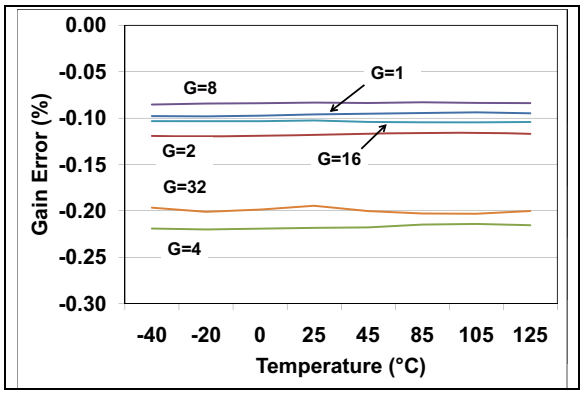


FIGURE 2-21: *Gain Error vs. Temperature.*

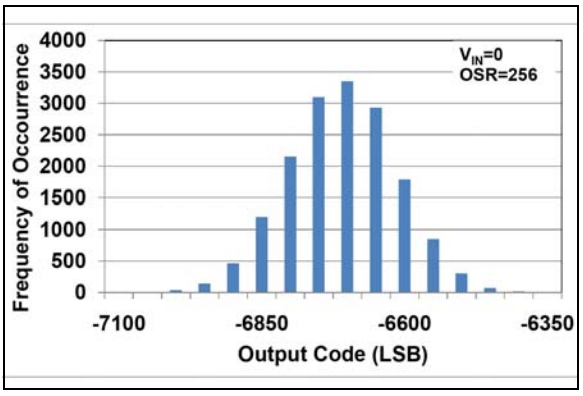


FIGURE 2-24: *Noise Histogram.*

Note: Unless otherwise indicated, AV_{DD} = 5.0V, DV_{DD} = 3.3 V; T_A = +25°C, MCLK = 4 MHz; PRESCALE = 1; OSR = 64; GAIN = 1; Dithering OFF; V_{IN} = -0.5 dBFS @ 60 Hz.

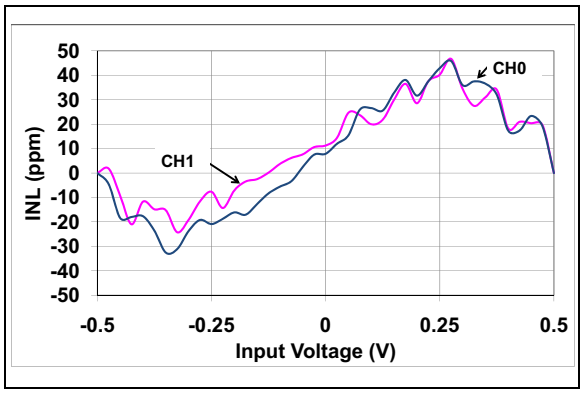


FIGURE 2-25: *Integral Non-Linearity (Dithering OFF).*

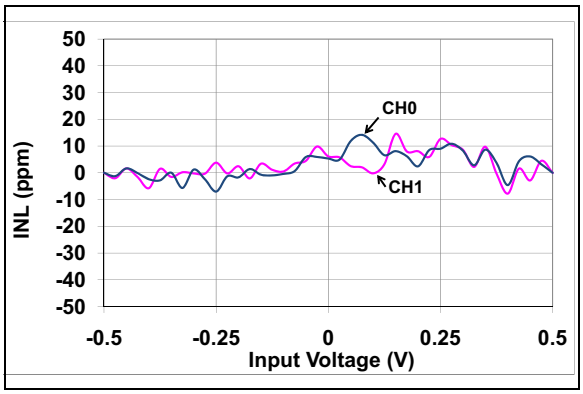


FIGURE 2-26: *Integral Non-Linearity (Dithering ON).*

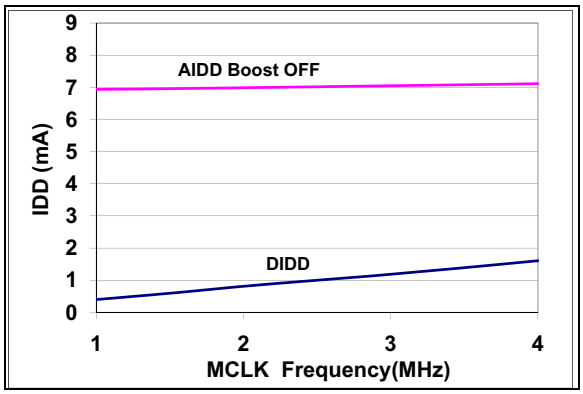


FIGURE 2-27: *Operating Current vs. Master Clock (MCLK).*

3.0 PIN DESCRIPTION

TABLE 3-1: PIN FUNCTION TABLE

Pin No.	Symbol	Function
1	AV_{DD}	Analog Power Supply Pin
2	CH0+	Non-Inverting Analog Input Pin for Channel 0
3	CH0-	Inverting Analog Input Pin for Channel 0
4	CH1-	Inverting Analog Input Pin for Channel 1
5	CH1+	Non-Inverting Analog Input Pin for Channel 1
6	CH2+	Non-Inverting Analog Input Pin for Channel 2
7	CH2-	Inverting Analog Input Pin for Channel 2
8	CH3-	Inverting Analog Input Pin for Channel 3
9	CH3+	Non-Inverting Analog Input Pin for Channel 3
10	CH4+	Non-Inverting Analog Input Pin for Channel 4
11	CH4-	Inverting Analog Input Pin for Channel 4
12	CH5-	Inverting Analog Input Pin for Channel 5
13	CH5+	Non-Inverting Analog Input Pin for Channel 5
14	REFIN+/OUT	Non-Inverting Voltage Reference Input and Internal Reference Output Pin
15	REFIN-	Inverting Voltage Reference Input Pin
16	A_{GND}	Analog Ground Pin, Return Path for internal analog circuitry
17	D_{GND}	Digital Ground Pin, Return Path for internal digital circuitry
18	$\overline{DRA}$	Data Ready Signal Output for channels pair A
19	$\overline{DRB}$	Data Ready Signal Output for channels pair B
20	$\overline{DRC}$	Data Ready Signal Output for channels pair C
21	OSC1	Oscillator Crystal Connection Pin or Clock Input Pin
22	OSC2	Oscillator Crystal Connection Pin
23	$\overline{CS}$	Chip Select for Serial Interface
24	SCK	Serial Interface Clock Pin
25	SDO	Serial Interface Data Output Pin
26	SDI	Serial Interface Data Input Pin
27	$\overline{RESET}$	Master Reset Logic Input Pin
28	DV_{DD}	Digital Power Supply Pin

3.1 $\overline{RESET}$

This pin is active low and places the entire chip in a reset state when active.

When $\overline{RESET}$=0, all registers are reset to their default value, no communication can take place, no clock is distributed inside the part. This state is equivalent to a POR state.

Since the default state of the ADCs is on, the analog power consumption when $\overline{RESET}$ = 0 is equivalent to when $\overline{RESET}$ = 1. Only the digital power consumption is largely reduced because this current consumption is essentially dynamic and is reduced drastically when there is no clock running. All the analog biases are enabled during a reset so that the part is fully operational just after a $\overline{RESET}$ rising edge. This input is Schmitt triggered.

3.2 Digital V_{DD} (DV_{DD})

DV_{DD} is the power supply pin for the digital circuitry within the MCP3903. This pin requires appropriate bypass capacitors and should be maintained between 2.7V and 3.6V for specified operation.

3.3 Analog V_{DD} (AV_{DD})

AV_{DD} is the power supply pin for the analog circuitry within the MCP3903.

This pin requires appropriate bypass capacitors and should be maintained to 5V ±10% for specified operation.

3.4 ADC Differential Analog Inputs(CHn+/CHn-)

CHn- and CHn+, are the two fully-differential analog voltage inputs for the Delta-Sigma ADCs. There are six channels in total grouped in three channel pairs.

The linear and specified region of the channels are dependent on the PGA gain. This region corresponds to a differential voltage range of ±500 mV/GAIN with V_{REF} = 2.4V. The maximum absolute voltage, with respect to AGND, for each CHn+/- input pin is +/-1V with no distortion and ±6V with no breaking after continuous voltage.

3.5 Analog Ground (AGND)

AGND is the ground connection to internal analog circuitry (ADCs, PGA, voltage reference, POR). To ensure accuracy and noise cancellation, this pin must be connected to the same ground as DGND, preferably with a star connection. If an analog ground plane is available, it is recommended that this pin be tied to this plane of the PCB. This plane should also reference all other analog circuitry in the system.

3.6 Non-Inverting Reference Input, Internal Reference Output (REFIN+/OUT)

This pin is the non-inverting side of the differential voltage reference input for all ADCs or the internal voltage reference output. When VREFEXT = 1, and an external voltage reference source can be used, the internal voltage reference is disabled. When using an external differential voltage reference, it should be connected to its V_{REF+} pin.

When using an external single-ended reference, it should be connected to this pin.

When VREFEXT = 0, the internal voltage reference is enabled and connected to this pin through a switch. This voltage reference has minimal drive capability and thus needs proper buffering and bypass capacitances (10 µF tantalum in parallel with 0.1 µF ceramic) if used as a voltage source.

For optimal performance, bypass capacitances should be connected between this pin and AGND at all times even when the internal voltage reference is used.

3.7 Inverting Reference Input (REFIN-)

This pin is the inverting side of the differential voltage reference input for both ADCs. When using an external differential voltage reference, it should be connected to its V_{REF-} pin. When using an external single-ended voltage reference, or when VREFEXT = 0 (Default) and using the internal voltage reference, this pin should be directly connected to AGND.

3.8 Digital Ground Connection (DGND)

DGND is the ground connection to internal digital circuitry (SINC filters, oscillator, serial interface). To ensure accuracy and noise cancellation, DGND must be connected to the same ground as AGND, preferably with a star connection. If a digital ground plane is available, it is recommended that this pin be tied to this plane of the Printed Circuit Board (PCB). This plane should also reference all other digital circuitry in the system.

3.9 $\overline{DRn}$ (Data Ready Pins)

The Data Ready pins indicate if a new conversion result is ready to be read on each of the A, B and C pairs of ADCs. The default state of this pin is high when DR_HIZN=1 and is high impedance when DR_HIZN=0 (Default). After each conversion is finished, a low pulse will take place on the data ready pins to indicate the conversion result is ready as an interrupt. This pulse is synchronous with the master clock and has a defined and constant width.

The Data Ready pins are independent of the SPI interface and act like an interrupt output.The Data Ready pins state is not latched and the pulse width (and period) are both determined by the MCLK frequency, over-sampling rate, and internal clock pre-scale settings. The DR pulse width is equal to one DMCLK period and the frequency of the pulses is equal to DRCLK (see Figure 1-3).

Note:	These pins should not be left floating when $\overline{DR\_HIZ}$ bit is low; a 100kΩ pull-up resistor connected to DV_{DD} is recommended.

3.10 Oscillator And Master Clock Input Pins (OSC1/CLKI, OSC2)

OSC1/CLKI and OSC2 provide the master clock for the device. When CLKEXT = 0 (Default), a resonant crystal or clock source with a similar sinusoidal waveform must be placed across these pins to ensure proper operation. The typical clock frequency specified is 4 MHz. However, the clock frequency can be 1 MHz to 5 MHz without disturbing ADC accuracy. With the current boost circuit enabled, the master clock can be used up to 8.192 MHz without disturbing ADC accuracy. Appropriate load capacitance should be connected to these pins for proper operation.

Note:	When CLKEXT = 1, the crystal oscillator is disabled, as well as the OSC2 input. The OSC1 becomes the master clock input CLKI, direct path for an external clock source, for example a clock source generated by an MCU.

3.11 $\overline{CS}$ (Chip Select)

This pin is the SPI Chip Select that enables the serial communication. When this pin is high, no communication can take place. A chip select falling edge initiates the serial communication and a chip select rising edge terminates the communication. No communication can take place even when $\overline{CS}$ is low and when $\overline{RESET}$ is low.

This input is Schmitt-triggered.

3.12 SCK (Serial Data Clock)

This is the serial clock pin for SPI communication. Data is clocked into the device on the RISING edge of SCK. Data is clocked out of the device on the FALLING edge of SCK. The MCP3903 interface is compatible with both SPI 0,0 and 1,1 modes. The maximum clock speed specified is 10 MHz. This input is Schmitt triggered.

3.13 SDO (Serial Data Output)

This is the SPI data output pin. Data is clocked out of the device on the FALLING edge of SCK. This pin stays at high impedance during the control byte. It also stays at high impedance during the whole communication for write commands and when the CS pin is high or when the RESET pin is low. This pin is active only when a read command is processed. Each read is processed by a packet of 24 bits (size of each register), except on the ADC output registers when WIDTH=0.

3.14 SDI (Serial Data Input)

This is the SPI data input pin. Data is clocked into the device on the RISING edge of SCK. When CS is low, this pin is used to communicate with a series of 8-bit commands. The interface is half-duplex (inputs and outputs do not happen at the same time). Each communication starts with a chip select falling edge followed by an 8-bit control byte entered through the SDI pin. Each write is processed by packets of 24 bits (size of each register). Each command is either a Read or a Write command. Toggling SDI during a Read command has no effect. This input is Schmitt-triggered.

4.0 TERMINOLOGY AND FORMULAS

This section defines the terms and formulas used throughout this data sheet. The following terms are defined:

MCLK - Master Clock

AMCLK - Analog Master Clock

DMCLK - Digital Master Clock

DRCLK - Data Rate Clock

OSR - Oversampling Ratio

Offset Error

Gain Error

Integral Non-Linearity Error

Signal-To-Noise Ratio (SNR)

Signal-To-Noise Ratio And Distortion (SINAD)

Total Harmonic Distortion (THD)

Spurious-Free Dynamic Range (SFDR)

MCP3903 Delta-Sigma Architecture

Idle Tones

Dithering

Crosstalk

PSRR

CMRR

ADC Reset Mode

Hard Reset Mode (RESET = 0)

ADC Shutdown Mode

Full Shutdown Mode

4.1 MCLK - Master Clock

This is the fastest clock present in the device. This is the frequency of the crystal placed at the OSC1/OSC2 inputs when CLKEXT = 0 or the frequency of the clock input at the OSC1/CLKI when CLKEXT = 1.

4.2 AMCLK - Analog Master Clock

This is the clock frequency that is present on the analog portion of the device, after prescaling has occurred via the CONFIG PRESCALE<1:0> register bits. The analog portion includes the PGAs and the two sigma-delta modulators.

EQUATION 4-1:

$$AMCLK = \frac{MCLK}{PRESCALE}$$

TABLE 4-1: MCP3903 OVERSAMPLING RATIO SETTINGS

Config PRE<1:0>		Analog Master Clock Prescale
0	0	AMCLK = MCLK/ 1 (default)
0	1	AMCLK = MCLK/ 2
1	0	AMCLK = MCLK/ 4
1	1	AMCLK = MCLK/ 8

4.3 DMCLK - Digital Master Clock

This is the clock frequency that is present on the digital portion of the device, after prescaling and division by 4. This is also the sampling frequency, that is the rate at which the modulator outputs are refreshed. Each period of this clock corresponds to one sample and one modulator output.

EQUATION 4-2:

$$DMCLK = \frac{AMCLK}{4} = \frac{MCLK}{4 \times PRESCALE}$$

4.4 DRCLK - Data Rate Clock

This is the output data rate i.e. the rate at which the ADCs output new data. Each new data is signaled by a data ready pulse on the $\overline{DR}$ pin.

This data rate is depending on the OSR and the prescaler with the following formula:

EQUATION 4-3:

$$DRCLK = \frac{DMCLK}{OSR} = \frac{AMCLK}{4 \times OSR} = \frac{MCLK}{4 \times OSR \times PRESCALE}$$

Since this is the output data rate, and since the decimation filter is a SINC (or notch) filter, there is a notch in the filter transfer function at each integer multiple of this rate.

The following table describes the various combinations of OSR and PRESCALE and their associated AMCLK, DMCLK and DRCLK rates.

TABLE 4-2: DEVICE DATA RATES IN FUNCTION OF MCLK, OSR, AND PRESCALE

PRE <1:0>		OSR <1:0>		OSR	AMCLK	DMCLK	DRCLK	DRCLK (ksps)
1	1	1	1	256	MCLK/8	MCLK/32	MCLK/8192	0.4882
1	1	1	0	128	MCLK/8	MCLK/32	MCLK/4096	0.976
1	1	0	1	64	MCLK/8	MCLK/32	MCLK/2048	1.95
1	1	0	0	32	MCLK/8	MCLK/32	MCLK/1024	3.9
1	0	1	1	256	MCLK/4	MCLK/16	MCLK/4096	0.976
1	0	1	0	128	MCLK/4	MCLK/16	MCLK/2048	1.95
1	0	0	1	64	MCLK/4	MCLK/16	MCLK/1024	3.9
1	0	0	0	32	MCLK/4	MCLK/16	MCLK/512	7.8125
0	1	1	1	256	MCLK/2	MCLK/8	MCLK/2048	1.95
0	1	1	0	128	MCLK/2	MCLK/8	MCLK/1024	3.9
0	1	0	1	64	MCLK/2	MCLK/8	MCLK/512	7.8125
0	1	0	0	32	MCLK/2	MCLK/8	MCLK/256	15.625
0	0	1	1	256	MCLK	MCLK/4	MCLK/1024	3.9
0	0	1	0	128	MCLK	MCLK/4	MCLK/512	7.8125
0	**0**	**0**	**1**	**64**	**MCLK**	MCLK/4	MCLK/256	**15.625**
0	0	0	0	32	MCLK	MCLK/4	MCLK/128	31.25

Note: For OSR = 32 and 64, DITHER = 0. For OSR = 128 and 256, DITHER = 1.

4.5 OSR - Oversampling Ratio

The ratio of the sampling frequency to the output data rate is OSR = DMCLK/DRCLK. The default OSR is 64, or with MCLK = 4 MHz, PRESCALE = 1, AMCLK = 4 MHz, f_S = 1 MHz, f_D = 15.625 ksps. The following bits in the CONFIG1 register are used to change the oversampling ratio (OSR).

TABLE 4-3: MCP3903 OVERSAMPLING RATIO SETTINGS

CONFIG OSR<1:0>		OVER SAMPLING RATIO (OSR)
0	0	32
0	1	64 (DEFAULT)
1	0	128
1	1	256

4.6 Offset Error

This is the error induced by the ADC when the inputs are shorted together (V_{IN} = 0V). The specification incorporates both PGA and ADC offset contributions. This error varies with PGA and OSR settings. The offset is different on each channel and varies from chip to chip. This offset error can easily be calibrated out by a MCU with a subtraction. The offset is specified in mV.

The offset on the MCP3903 has a low temperature coefficient, see **Section 2.0 "Typical Performance Curves"**.

4.7 Gain Error

This is the error induced by the ADC on the slope of the transfer function. It is the deviation expressed in % compared to the ideal transfer function defined by Equation 5-3. The specification incorporates both PGA and ADC gain error contributions, but not the V_{REF} contribution (it is measured with an external V_{REF}).This error varies with PGA and OSR settings.

The gain error on the MCP3903 has a low temperature coefficient. See the typical performance curves for more information.

4.8 Integral Non-Linearity Error

Integral non-linearity error is the maximum deviation of an ADC transition point from the corresponding point of an ideal transfer function, with the offset and gain errors removed, or with the end points equal to zero.

It is the maximum remaining error after calibration of offset and gain errors for a DC input signal.

4.9 Signal-To-Noise Ratio (SNR)

For the MCP3903 ADC, the signal-to-noise ratio is a ratio of the output fundamental signal power to the noise power (not including the harmonics of the signal), when the input is a sinewave at a predetermined frequency. It is measured in dB. Usually, only the maximum signal to noise ratio is specified. The SNR figure depends mainly on the OSR and DITHER settings of the device.

EQUATION 4-4: SIGNAL-TO-NOISE RATIO

$$SNR(dB) = 10log\left(\frac{SignalPower}{NoisePower}\right)$$

4.10 Signal-To-Noise Ratio And Distortion (SINAD)

The most important figure of merit for the analog performance of the ADCs present on the MCP3903 is the Signal-to-Noise And Distortion (SINAD) specification.

Signal-to-noise and distortion ratio is similar to signal-to-noise ratio, with the exception that you must include the harmonics power in the noise power calculation. The SINAD specification depends mainly on the OSR and DITHER settings.

EQUATION 4-5: SINAD EQUATION

$$SINAD(dB) = 10\log\left(\frac{SignalPower}{Noise + HarmonicsPower}\right)$$

The calculated combination of SNR and THD per the following formula also yields SINAD:

EQUATION 4-6: SINAD, THD, AND SNR RELATIONSHIP

$$SINAD(dB) = 10log\left[10^{\left(\frac{SNR}{10}\right)} + 10^{\left(\frac{-THD}{10}\right)}\right]$$

4.11 Total Harmonic Distortion (THD)

The total harmonic distortion is the ratio of the output harmonics power to the fundamental signal power for a sinewave input and is defined by the following equation.

EQUATION 4-7:

$$THD(dB) = 10log\left(\frac{HarmonicsPower}{FundamentalPower}\right)$$

The THD calculation includes the first 35 harmonics for the MCP3903 specifications. The THD is usually only measured with respect to the 10 first harmonics. THD is sometimes expressed in %. For converting the THD in %, here is the formula:

EQUATION 4-8:

$$THD(\%) = 100 \times 10^{\frac{THD(dB)}{20}}$$

This specification depends mainly on the DITHER setting.

4.12 Spurious-Free Dynamic Range (SFDR)

SFDR is the ratio between the output power of the fundamental and the highest spur in the frequency spectrum. The spur frequency is not necessarily a harmonic of the fundamental even though it is usually the case. This figure represents the dynamic range of the ADC when a full-scale signal is used at the input. This specification depends mainly on the DITHER setting.

EQUATION 4-9:

$$SFDR(dB) = 10log\left(\frac{FundamentalPower}{HighestSpurPower}\right)$$

4.13 MCP3903 Delta-Sigma Architecture

The MCP3903 incorporates six Delta-Sigma ADCs with a multi-bit digital to analog converter as quantizer. A Delta-Sigma ADC is an oversampling converter that incorporates a built-in modulator which is digitizing the quantity of charge integrated by the modulator loop (see Figure 5-1). The quantizer is the block that is performing the analog-to-digital conversion. The quantizer is typically 1-bit, or a simple comparator which helps to maintain the linearity performance of the ADC (the DAC structure is inherently linear in this case).

Multi-bit quantizers help to lower the quantization error (the error fed back in the loop can be very large with 1-bit quantizers) without changing the order of the modulator or the OSR, which leads to better SNR figures. However, typically, the linearity of such architectures is more difficult to achieve since the DAC is no more simple to realize and its linearity limits the THD of such ADCs.

The MCP3903's 5-level quantizer is a flash ADC composed of 4 comparators arranged with equally spaced thresholds and a thermometer coding. The MCP3903 also includes proprietary 5-level DAC architecture that is inherently linear for improved THD figures.

4.14 Idle Tones

A Delta-Sigma converter is an integrating converter. It also has a finite quantization step (LSB) which can be detected by its quantizer. A DC input voltage that is below the quantization step should only provide an all zeros result since the input is not large enough to be detected. As an integrating device, any Delta-Sigma will show, in this case, idle tones. This means that the output will have spurs in the frequency content that are depending on the ratio between quantization step voltage and the input voltage. These spurs are the result of the integrated sub-quantization step inputs that will eventually cross the quantization steps after a long enough integration. This will induce an AC frequency at the output of the ADC and can be shown in the ADC output spectrum.

These idle tones are residues that are inherent to the quantization process and the fact that the converter is integrating at all times without being reset. They are residues of the finite resolution of the conversion process. They are very difficult to attenuate and they are heavily signal dependent. They can degrade both SFDR and THD of the converter, even for DC inputs. They can be localized in the baseband of the converter and thus difficult to filter from the actual input signal.

For power metering applications, idle tones can be very disturbing because energy can be detected even at the 50 or 60 Hz frequency, depending on the DC offset of the ADCs, while no power is really present at the inputs. The only practical way to suppress or attenuate idle tones phenomenon is to apply dithering to the ADC. The idle tones amplitudes are a function of the order of the modulator, the OSR and the number of levels in the quantizer of the modulator. A higher order, a higher OSR, or a higher number of levels for the quantizer will attenuate the idle tones amplitude.

4.15 Dithering

In order to suppress or attenuate the idle tones present in any Delta-Sigma ADCs, dithering can be applied to the ADC. Dithering is the process of adding an error to the ADC feedback loop in order to "decorrelate" the outputs and "break" the idle tone's behavior. Usually a random or pseudo-random generator adds an analog or digital error to the feedback loop of the delta-sigma ADC in order to ensure that no tonal behavior can happen at its outputs. This error is filter by the feedback loop and typically has a zero average value so that the converter static transfer function is not disturbed by the dithering process. However, the dithering process slightly increases the noise floor (it adds noise to the part) while reducing its tonal behavior and thus improving SFDR and THD. The dithering process scrambles the idle tones into baseband white noise and ensures that dynamic specs (SNR, SINAD, THD, SFDR) are less signal dependent. The MCP3903 incorporates a proprietary dithering algorithm on all ADCs in order to remove idle tones and improve THD, which is crucial for power metering applications.

4.16 Crosstalk

The crosstalk is defined as the perturbation caused by one ADC channel on the other ADC channel. It is a measurement of the isolation between the six ADCs present in the chip.

This measurement is a two-step procedure:

1. Measure one ADC input with no perturbation on any other ADC (ADC inputs shorted).
2. Measure the same ADC input with a perturbation sine wave signal on the other ADC at a certain predefined frequency.

The crosstalk is then the ratio between the output power of the ADC when the perturbation is present and when it is not divided by the power of the perturbation signal.

A lower crosstalk value implies more independence and isolation between the six channels.

The measurement of this signal is performed under the following conditions:

- GAIN = 1,
- PRESCALE = 1,
- OSR = 256,
- MCLK = 4 MHz

Step 1

- CH0+=CH0-=AGND
- CHn+=CHn-=AGND, n different than 0

Step 2

- CH0+=CH0-=AGND
- CHn+ - CHn-=1V_{P-P} @ 50/60 Hz (Full-scale sine wave)

The crosstalk is then calculated with the following formula:

EQUATION 4-10:

$$CTalk(dB) = 10log\left(\frac{\Delta CH0Power}{\Delta CHnPower}\right)$$

4.17 PSRR

This is the ratio between a change in the power supply voltage and the ADC output codes. It measures the influence of the power supply voltage on the ADC outputs.

The PSRR specification can be DC (the power supply is taking multiple DC values) or AC (the power supply is a sinewave at a certain frequency with a certain common mode). In AC, the amplitude of the sinewave is representing the change in the power supply.

It is defined as:

EQUATION 4-11:

$$PSRR(dB) = 20log\left(\frac{\Delta V_{OUT}}{\Delta AV_{DD}}\right)$$

Where V_{OUT} is the equivalent input voltage that the output code translates to with the ADC transfer function. In the MCP3903 specification, AV_{DD} varies from 4.5V to 5.5V, and for AC PSRR a 50/60 Hz sinewave is chosen, centered around 5V with a maximum 500 mV amplitude. The PSRR specification is measured with DV_{DD} = 3.3V.

4.18 CMRR

This is the ratio between a change in the Common-Mode input voltage and the ADC output codes. It measures the influence of the Common-Mode input voltage on the ADC outputs.

The CMRR specification can be DC (the common-mode input voltage is taking multiple DC values) or AC (the common-mode input voltage is a sinewave at a certain frequency with a certain common mode). In AC, the amplitude of the sinewave is representing the change in the power supply.

It is defined as:

EQUATION 4-12:

$$CMRR(dB) = 20log\left(\frac{\Delta V_{OUT}}{\Delta V_{CM}}\right)$$

Where V_{CM}= (CHn+ + CHn-)/2 is the Common-Mode input voltage and V_{OUT} is the equivalent input voltage that the output code translates to with the ADC transfer function. In the MCP3903 specification, VCM varies from -1V to +1V, and for AC specification a 50/60 Hz sinewave is chosen centered around 0V with a 500 mV amplitude.

4.19 ADC Reset Mode

ADC Reset mode (called also soft reset mode) can only be entered through setting high the RESET<5:0> bits in the configuration register. This mode is defined as the condition where the converters are active but their output is forced to 0.

The registers are not affected in this reset mode and retain their values.

The ADCs can immediately output meaningful codes after leaving reset mode (and after the sinc filter settling time of 3/DRCLK). This mode is both entered and exited through setting of bits in the configuration register.

Each converter can be placed in soft reset mode independently. The configuration registers are not modified by the soft reset mode.

A data ready pulse will not be generated by any ADC while in reset mode.

When an ADC exists ADC reset mode, any phase delay present before reset was entered will still be present. If one ADC was not in reset, the ADC leaving reset mode will automatically resynchronize the phase delay relative to the other ADC channel, per the phase delay register block and give data ready pulses accordingly.

If an ADC is placed in Reset mode while the other is converting, it is not shutting down the internal clock. When going back out of reset, it will be resynchronized automatically with the clock that did not stop during reset.

If all ADCs are in soft reset or shutdown modes, the clock is no longer distributed to the digital core for low power operation. Once the ADC is back to normal operation, the clock is automatically distributed again.

4.20 Hard Reset Mode ($\overline{\text{RESET}}$ = 0)

This mode is only available during a POR or when the $\overline{\text{RESET}}$ pin is pulled low. The $\overline{\text{RESET}}$ pin low state places the device in a hard reset mode.

In this mode, all internal registers are reset to their default state.

The DC biases for the analog blocks are still active, i.e. the MCP3903 is ready to convert. However, this pin clears all conversion data in the ADCs. The comparator outputs of all ADCs are forced to their reset state (0011). The SINC filters are all reset, as well as their double output buffers. See serial timing for minimum pulse low time, in **Section 1.0 "Electrical Characteristics"**.

During a hard reset, no communication with the part is possible. The digital interface is maintained in a reset state.

4.21 ADC Shutdown Mode

ADC shutdown mode is defined as a state where the converters and their biases are off, consuming only leakage current. After this is removed, start-up delay time (SINC filter settling time) will occur before outputting meaningful codes. The start-up delay is needed to power-up all DC biases in the channel that was in shutdown. This delay is the same than t_{POR} and any $\overline{\text{DR}}$ pulse coming within this delay should be discarded.

Each converter can be placed in shutdown mode independently. The CONFIG registers are not modified by the shutdown mode. This mode is only available through programming of the SHUTDOWN<5:0> bits in the CONFIG register.

The output data is flushed to all zeros while in ADC shutdown. No data ready pulses are generated by any ADC while in ADC shutdown mode.

When an ADC exits ADC shutdown mode, any phase delay present before shutdown was entered will still be present. If one ADC was not in shutdown, the ADC leaving shutdown mode will automatically resynchronize the phase delay relative to the other ADC channel, per the phase delay register block and give data ready pulses accordingly.

If an ADC is placed in shutdown while others are converting, then the internal clock will not shut down. When going back out of shutdown, it will be automatically resynchronized with the clock that did not stop during reset.

If all ADCs are in ADC reset or ADC shutdown modes, the clock is not distributed to the digital core for low power operation. Once any of the ADC is back to normal operation, the clock is automatically distributed again.

4.22 Full Shutdown Mode

The lowest power consumption can be achieved when SHUTDOWN<5:0>=111111, VREFEXT=CLKEXT= 1. This mode is called "Full shutdown mode", and no analog circuitry is enabled. In this mode, the POR A_{VDD} monitoring circuit is also disabled. When the clock is idle (OSC1 = high or low continuously), no clock is propagated throughout the chip. All ADCs are in shutdown, the internal voltage reference is disabled and the internal oscillator is disabled.

The only circuit that remains active is the SPI interface but this circuit does not induce any static power consumption. If SCK is idle, the only current consumption comes from the leakage currents induced by the transistors and is less than 1 µA on each power supply, for temperatures lower than 85°C.

This mode can be used to power down the chip completely and avoid power consumption when there is no data to convert at the analog inputs. Any SCK or MCLK edge coming while in this mode will induce dynamic power consumption.

Once any of the SHUTDOWN, CLKEXT and VREFEXT bits returns to 0, the POR AV_{DD} monitoring block is back to operation and AV_{DD} monitoring can take place.

5.0 DEVICE OVERVIEW

5.1 Analog Inputs (CHn+/-)

The MCP3903 analog inputs can be connected directly to current and voltage transducers (such as shunts, current transformers, or Rogowski coils). Each input pin is protected by specialized ESD structures that are certified to pass 5 kV HBM and 500V MM contact charge. These structures allow bipolar ±6V continuous voltage with respect to AGND, to be present at their inputs without the risk of permanent damage.

All channels have fully differential voltage inputs for better noise performance. The absolute voltage at each pin relative to AGND should be maintained in the ±1V range during operation in order to ensure the specified ADC accuracy. The Common-Mode signals should be adapted to respect both the previous conditions and the differential input voltage range. For best performance, the Common-Mode signals should be maintained to AGND.

5.2 Programmable Gain Amplifiers (PGA)

The six Programmable Gain Amplifiers (PGAs) reside at the front-end of each Delta-Sigma ADC. They have two functions: translate the common-mode of the input from AGND to an internal level between AGND and A_{VDD}, and amplify the input differential signal. The translation of the common mode does not change the differential signal but recenters the common-mode so that the input signal can be properly amplified.

The PGA block can be used to amplify very low signals, but the differential input range of the delta-sigma modulator must not be exceeded. The PGA is controlled by the PGA_CHn<2:0> bits in the GAIN register. The following table represents the gain settings for the PGA:

TABLE 5-1: PGA CONFIGURATION SETTING

Gain PGA_CHn<2:0>			Gain (V/V)	Gain (dB)	V_{IN} Range (V)
0	0	0	1	0	±0.5
0	0	1	2	6	±0.25
0	1	0	4	12	±0.125
0	1	1	8	18	±0.0625
1	0	0	16	24	±0.03125
1	0	1	32	30	±0.015625

5.3 Delta-Sigma Modulator

5.3.1 ARCHITECTURE

All ADCs are identical in the MCP3903 and they include a second-order modulator with a multi-bit DAC architecture (see Figure 5-1). The quantizer is a flash ADC composed of 4 comparators with equally spaced thresholds and a thermometer output coding. The proprietary 5-level architecture ensures minimum quantization noise at the outputs of the modulators without disturbing linearity or inducing additional distortion. The sampling frequency is DMCLK (typically 1 MHz with MCLK=4 MHz) so the modulator outputs are refreshed at a DMCLK rate. The modulator outputs are available in the MOD register.

Each modulator also includes a dithering algorithm that can be enabled through the DITHER<5:0> bits in the configuration register. This dithering process improves THD and SFDR (for high OSR settings) while increasing slightly the noise floor of the ADCs. For power metering applications and applications that are distortion-sensitive, it is recommended to keep DITHER enabled for all ADCs. In the case of power metering applications, THD and SFDR are critical specifications to optimize SNR (noise floor). This is not really problematic due to large averaging factor at the output of the ADCs, therefore even for low OSR settings, the dithering algorithm will show a positive impact on the performance of the application.

Figure 5-1 represents a simplified block diagram of the Delta-Sigma ADC present on MCP3903.

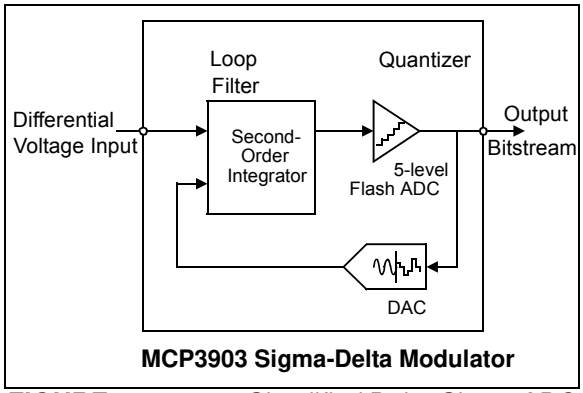


FIGURE 5-1: *Simplified Delta-Sigma ADC Block Diagram.*

5.3.2 MODULATOR INPUT RANGE AND SATURATION POINT

For a specified voltage reference value of 2.4V, the modulator specified differential input range is ±500 mV. The input range is proportional to V_{REF} and scales according to the V_{REF} voltage. This range ensures the stability of the modulator over amplitude and frequency. Outside of this range, the modulator is still functional, however its stability is no longer guaranteed and therefore it is not recommended to exceed this limit. The saturation point for the modulator is $V_{REF}/3$ since the transfer function of the ADC includes a gain of 3 by default (independent from the PGA setting. See **Section 5.5 "ADC OUTPUT CODING"**).

5.3.3 BOOST MODE

The Delta-Sigma modulators also include an independent BOOST mode for each channel. If the corresponding BOOST<1:0> bit is enabled, the power consumption of the modulator is multiplied by 2 and its bandwidth is increased to be able to sustain AMCLK clock frequencies up to 8.192 MHz while keeping the ADC accuracy. When disabled, the power consumption returns back to normal and the AMCLK clock frequencies can only reach up to 5 MHz without affecting ADC accuracy.

5.4 SINC^3 Filter

All ADCs present in the MCP3903 include a decimation filter that is a third-order sinc (or notch) filter. This filter processes the multi-bit bitstream into 16 or 24 bits words (depending on the WIDTH configuration bit). The settling time of the filter is 3 DMCLK periods. It is recommended to discard unsettled data to avoid data corruption which can be done easily by setting the DR_LTY bit high in the STATUS/COM register.

The resolution achievable at the output of the sinc filter (the output of the ADC) is dependant on the OSR and is summarized in the following table:

TABLE 5-2: ADC RESOLUTION VS. OSR

OSR<1:0>		OSR	ADC Resolution (bits) No Missing Codes
0	0	32	17
0	1	64	20
1	0	128	23
1	1	256	24

For 24 -bit output mode (WIDTH = 1), the output of the sinc filter is padded with least significant zeros for any resolution less than 24 bits.

For 16-bit output modes, the output of the sinc filter is rounded to the closest 16-bit number in order to conserve only 16-bit words and to minimize truncation error.

The gain of the transfer function of this filter is 1 at each multiple of DMCLK (typically 1 MHz) so a proper anti-aliasing filter must be placed at the inputs to attenuate the frequency content around DMCLK, and keep the desired accuracy over the baseband of the converter. This anti-aliasing filter can be a simple first-order RC network, with a sufficiently low time constant to generate high rejection at DMCLK frequency.

EQUATION 5-1: SINC FILTER TRANSFER FUNCTION H(Z)

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

Where:

$$z = \exp\left(\frac{2\pi fj}{DMCLK}\right)$$

The Normal-Mode Rejection Ratio (NMRR), or gain of the transfer function, is shown in the following equation:

EQUATION 5-2: MAGNITUDE OF FREQUENCY RESPONSE H(f)

$$NMRR(f) = \left|\frac{sinc\left(\pi \cdot \frac{f}{DRCLK}\right)}{sinc\left(\pi \cdot \frac{f}{DMCLK}\right)}\right|^3$$

or:

$$NMRR(f) = \left|\frac{\sin c\left(\pi \cdot \frac{f}{f_D}\right)}{\sin c\left(\pi \cdot \frac{f}{f_S}\right)}\right|^3$$

where:

$$\sin c(x) = \frac{\sin(x)}{x}$$

Figure 5-2 shows the sinc filter frequency response:

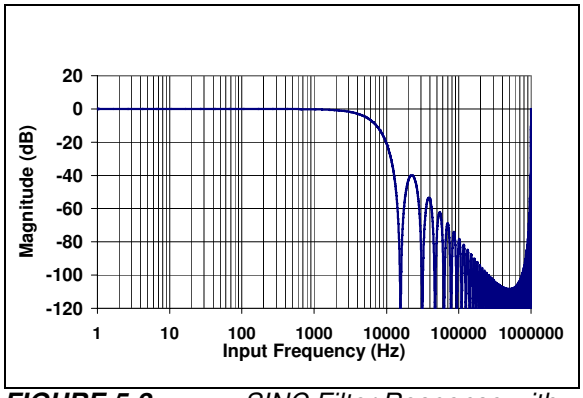


FIGURE 5-2: *SINC Filter Response with MCLK = 4 MHz, OSR = 64, PRESCALE = 1.*