Appendix F
Onboard Octal 12 Bit A/D Data Sheet

The following data sheet describes the operation of Linear Technology's LTC1290 8 channel analog to digital converter with 12 bit resolution. For an explanation of how to use the A/D, consult Chapter 6 in this manual.

LINEAR TECHNOLOGY

LTC1290

Single Chip 12-Bit Data Acquisition System

FEATURES

- Software Programmable Features
  - -Unipolar/Bipolar Conversion
  - -4 Differential/8 Single Ended Inputs
  - -MSB or LSB First Data Sequence
  - -Variable Data Word Length
  - -Power Shutdown
- Built-In Sample and Hold
- Single Supply 5V or ±5V Operation
- Direct 4 Wire Interface to Most MPU Serial Ports and all MPU Parallel Ports
- 50kHz Maximum Throughput Rate

KEY SPECIFICATIONS

■ Resolution	12 Bits
■ Fast Conversion Time	13μs Max. Over Temp.
■ Low Supply Current	6.0mA

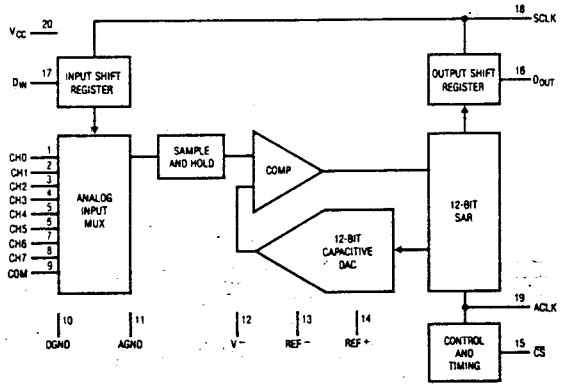
DESCRIPTION

The LTC1290 is a data acquisition component which contains a serial I/O successive approximation A/D converter. It uses LTCMOS™ switched capacitor technology to perform either 12-bit unipolar, or 11-bit plus sign bipolar A/D conversions. The 8-channel input multiplexer can be configured for either single ended or differential inputs (or combinations thereof). An on-chip sample and hold is included for all single ended input channels. When the LTC1290 is idle it can be powered down in applications where low power consumption is desired.

The serial I/O is designed to be compatible with industry standard full duplex serial interfaces. It allows either MSB or LSB first data and automatically provides 2's complement output coding in the bipolar mode. The output data word can be programmed for a length of 8, 12 or 16-bits. This allows easy interface to shift registers and a variety of processors.

LTCMOS is a trademark of Linear Technology Corporation.

BLOCK DIAGRAM



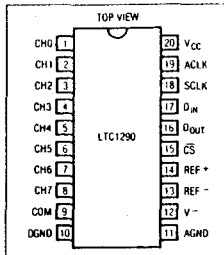
LINEAR TECHNOLOGY

ABSOLUTE MAXIMUM RATINGS

(Notes 1 and 2)

Supply Voltage (V_{CC}) to GND or V^- 12V
Negative Supply Voltage (V^-) ..... – 6V to GND
Voltage
  Analog and Reference Inputs .. (V^-) – 0.3V to V_{CC} + 0.3V
  Digital Inputs ..... – 0.3V to 12V
  Digital Outputs ..... – 0.3V to V_{CC} + 0.3V
Power Dissipation 500mW
Operating Temperature Range
  LTC1290BC, LTC1290CC, LTC1290DC ..... 0°C to 70°C
  LTC1290BI, LTC1290CI, LTC1290DI ..... – 40°C to 85°C
  LTC1290BM, LTC1290CM, LTC1290DM . – 55°C to 125°C
Storage Temperature Range ..... – 65°C to 150°C
Lead Temperature (Soldering, 10 sec.) ..... 300°C

PACKAGE/ORDER INFORMATION



J PACKAGE
20-LEAD CERAMIC DIP

ORDER PART NUMBER
LTC1290BMJ
LTC1290CMJ
LTC1290DMJ
LTC1290BIJ
LTC1290CIJ
LTC1290DIJ
LTC1290BCJ
LTC1290CCJ
LTC1290DCJ

CONVERTER AND MULTIPLEXER CHARACTERISTICS (Note 3)

PARAMETER	CONDITIONS		LTC1290B MIN	LTC1290B TYP	LTC1290B MAX	LTC1290C MIN	LTC1290C TYP	LTC1290C MAX	LTC1290D MIN	LTC1290D TYP	LTC1290D MAX	UNITS
Offset Error	(Note 4)	●			±1.5			±1.5			±1.5	LSB
Linearity Error (INL)	(Notes 4 and 5)	●			±0.5			±0.5			±0.75	LSB
Gain Error	(Note 4)	●			±0.5			±1.0			±4.0	LSB
Minimum Resolution for Which No Missing Codes are Guaranteed		●			12			12			12	Bits
Analog and REF Input Range	(Note 7)		(V^-) – 0.05V		V_{CC} + 0.05V	(V^-) – 0.05V		V_{CC} + 0.05V	(V^-) – 0.05V		V_{CC} + 0.05V	V
On Channel Leakage Current (Note 8)	On Channel = 5V, Off Channel = 0V	●			±1			±1			±1	μA
	On Channel = 0V, Off Channel = 5V	●			±1			±1			±1	μA
Off Channel Leakage Current (Note 8)	On Channel = 5V, Off Channel = 0V	●			±1			±1			±1	μA
	On Channel = 0V, Off Channel = 5V	●			±1			±1			±1	μA

AC CHARACTERISTICS (Note 3)

SYMBOL	PARAMETER	CONDITIONS		LTC1290B LTC1290C LTC1290D MIN	TYP	MAX	UNITS
f_{SCLK}	Shift Clock Frequency	V_{CC} = 5V (Note 6)		0		2.0	MHz
f_{ACLK}	A/D Clock Frequency	V_{CC} = 5V (Note 6)		(Note 10)		4.0	MHz
t_{ACC}	Delay Time from $\overline{CS}$ ↓ to D_{OUT} Data Valid	(Note 9)			2		ACLK Cycles
t_{SMPL}	Analog Input Sample Time	See Operating Sequence			7		SCLK Cycles
t_{CONV}	Conversion Time	See Operating Sequence			52		ACLK Cycles
t_{CYC}	Total Cycle Time	See Operating Sequence (Note 6)		12 SCLK + 56 ACLK			Cycles
t_{dDO}	Delay Time, SCLK ↓ to D_{OUT} Data Valid	See Test Circuits	LTC1290BC, LTC1290CC, LTC1290DC, LTC1290BI, LTC1290CI, LTC1290DI ●		130	220	ns
			LTC1290BM, LTC1290CM, LTC1290DM ●		180	270	ns
t_{dis}	Delay Time, $\overline{CS}$ ↑ to D_{OUT} Hi-Z	See Test Circuits	●		70	100	ns
t_{en}	Delay Time, 2nd ACLK ↓ to D_{OUT} Enabled	See Test Circuits	●		130	200	ns
t_{hCS}	Hold Time, $\overline{CS}$ After Last SCLK ↓	V_{CC} = 5V (Note 6)		0			ns
t_{hDI}	Hold Time, D_{IN} After SCLK ↓	V_{CC} = 5V (Note 6)		50			ns
t_{hDO}	Time Output Data Remains Valid After SCLK ↓				50		ns
t_f	D_{OUT} Fall Time	See Test Circuits	●		65	130	ns
t_r	D_{OUT} Rise Time	See Test Circuits	●		25	50	ns
t_{suDI}	Setup Time, D_{IN} Stable Before SCLK ↓	V_{CC} = 5V (Note 6)		50			ns
$t_{su\overline{CS}}$	Setup Time, $\overline{CS}$ ↓ Before Clocking in First Address Bit	(Note 6 and 9)		2 ACLK Cycles + 100ns			
$t_{WHC\overline{S}}$	$\overline{CS}$ High Time During Conversion	V_{CC} = 5V (Note 6)		52			ACLK Cycles
C_{IN}	Input Capacitance	Analog Inputs On Channel			100		pF
		Off Channel			5		pF
		Digital Inputs			5		pF

Note 1: Absolute maximum ratings are those values beyond which the life of a device may be impaired.

Note 2: All voltage values are with respect to ground with DGND, AGND, and REF⁻ wired together (unless otherwise noted).

Note 3: V_{CC} = 5V, V_{REF+} = 5V, V_{REF-} = 0V, V^- = 0V for unipolar mode and –5V for bipolar mode, ACLK = 4.0MHz unless otherwise specified. The ● indicates specs which apply over the full operating temperature range; all other limits and typicals T_A = 25°C.

Note 4: These specs apply for both unipolar and bipolar modes. In bipolar mode, one LSB is equal to the bipolar input span ($2V_{REF}$) divided by 4096. For example, when V_{REF} = 5V, 1LSB (bipolar) = 2(5V)/4096 = 2.44mV.

Note 5: Integral non-linearity is defined as the deviation of a code from a straight line passing through the actual endpoints of the transfer curve. The deviation is measured from the center of the quantization band.

Note 6: Recommended operating conditions.

Note 7: Two on-chip diodes are tied to each reference and analog input which will conduct for reference or analog input voltages one diode drop below V^- or one diode drop above V_{CC}. Be careful during testing at low V_{CC} levels (4.5V), as high level reference or analog inputs (5V) can cause this input diode to conduct, especially at elevated temperatures, and cause errors for inputs near full scale. This spec allows 50mV forward bias of either diode. This means that as long as the reference or analog input does not exceed the supply voltage by more than 50mV, the output code will be correct. To achieve an absolute 0V to 5V input voltage range will therefore require a minimum supply voltage of 4.950V over initial tolerance, temperature variations and loading.

Note 8: Channel leakage current is measured after the channel selection.

Note 9: To minimize errors caused by noise at the chip select input, the internal circuitry waits for two ACLK falling edge after a chip select falling edge is detected before responding to control input signals. Therefore, no attempt should be made to clock an address in or data out until the minimum chip select setup time has elapsed.

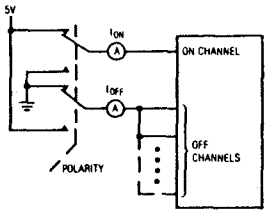
Note 10: Increased leakage currents at elevated temperatures cause the S/H to droop, therefore it's recommended that $f_{ACLK} \geq 500kHz$ at 125°C, $f_{ACLK} \geq 125kHz$ at 85°C, and $f_{ACLK} \geq 15kHz$ at 25°C.

DIGITAL AND DC ELECTRICAL CHARACTERISTICS (Note 3)

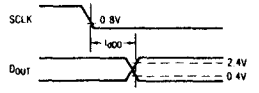
SYMBOL	PARAMETER	CONDITIONS		LTC1290B LTC1290C LTC1290D MIN	TYP	MAX	UNITS
V_{IH}	High Level Input Voltage	V_{CC} = 5.25V	•	2.0			V
V_{IL}	Low Level Input Voltage	V_{CC} = 4.75V	•			0.8	V
I_{IH}	High Level Input Current	$V_{IN} = V_{CC}$	•			2.5	µA
I_{IL}	Low Level Input Current	V_{IN} = 0V	•			–2.5	µA
V_{OH}	High Level Output Voltage	V_{CC} = 4.75V, I_O = 10µA			4.7		V
		I_O = 360µA	•	2.4	4.0		V
V_{OL}	Low Level Output Voltage	V_{CC} = 4.75V, I_O = 1.6mA	•			0.4	V
I_{OZ}	Hi-Z Output Leakage	$V_{OUT} = V_{CC}$, $\overline{CS}$ High	•			3	µA
		V_{OUT} = 0V, $\overline{CS}$ High	•			–3	µA
I_{SOURCE}	Output Source Current	V_{OUT} = 0V			–20		mA
I_{SINK}	Output Sink Current	$V_{OUT} = V_{CC}$			20		mA
I_{CC}	Positive Supply Current	$\overline{CS}$ High	•		6	10	mA
		$\overline{CS}$ High, Power Shutdown	•		5	10	µA
I_{REF}	Reference Current	V_{REF} = 5V	•		10	50	µA
I^-	Negative Supply Current	$\overline{CS}$ High	•		1	50	µA

TEST CIRCUITS

On and Off Channel Leakage Current

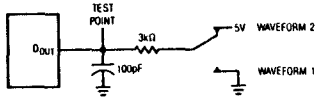


Voltage Waveforms for D_{OUT} Delay Time, t_{dDO}

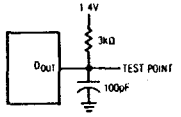


Voltage Waveform for D_{OUT} Rise and Fall Times, t_r, t_f

Load Circuit for t_{dis} and t_{en}

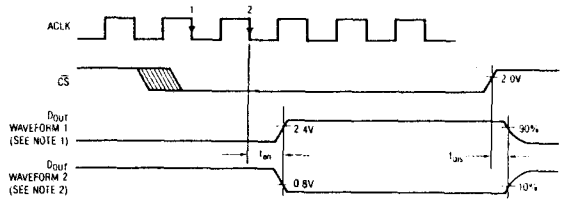


Load Circuit for t_{dDO}, t_r, and t_f



TEST CIRCUITS

Voltage Waveforms for t_{en} and t_{dis}



NOTE 1: WAVEFORM 1 IS FOR AN OUTPUT WITH INTERNAL CONDITIONS SUCH THAT THE OUTPUT IS HIGH UNLESS DISABLED BY THE OUTPUT CONTROL

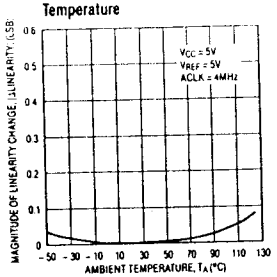
NOTE 2: WAVEFORM 2 IS FOR AN OUTPUT WITH INTERNAL CONDITIONS SUCH THAT THE OUTPUT IS LOW UNLESS DISABLED BY THE OUTPUT CONTROL

PIN FUNCTIONS

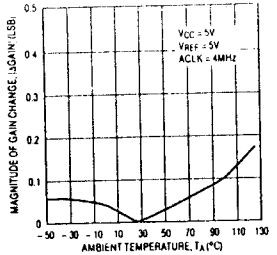
#	PIN	FUNCTION	DESCRIPTION
1-8	CH0-CH7	Analog Inputs	The analog inputs must be free of noise with respect to AGND.
9	COM	Common	The common pin defines the zero reference point for all single ended inputs. It must be free of noise and is usually tied to the analog ground plane.
10	DGND	Digital Ground	This is the ground for the internal logic. Tie to the ground plane.
11	AGND	Analog Ground	AGND should be tied directly to the analog ground plane.
12	V^-	Negative Supply	Tie V^- to most negative potential in the circuit. (Ground in single supply applications.)
13, 14	REF^-, REF^+	Reference Inputs	The reference inputs must be kept free of noise with respect to AGND.
15	$\overline{CS}$	Chip Select Input	A logic low on this input enables data transfer.
16	D_{OUT}	Digital Data Output	The A/D conversion result is shifted out of this output.
17	D_{IN}	Data Input	The A/D configuration word is shifted into this input.
18	SCLK	Shift Clock	This clock synchronizes the serial data transfer.
19	ACLK	A/D Conversion Clock	This clock controls the A/D conversion process.
20	V_{CC}	Positive Supply	This supply must be kept free of noise and ripple by bypassing directly to the analog ground plane.

TYPICAL PERFORMANCE CHARACTERISTICS

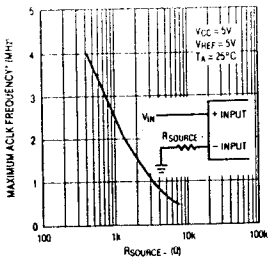
Change in Linearity Error vs Temperature



Change in Gain Error vs Temperature



Maximum ACLK Frequency vs Source Resistance



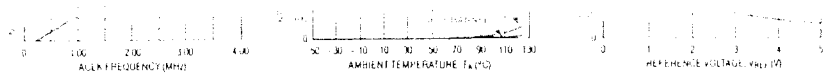
*MAXIMUM ACLK FREQUENCY REPRESENTS THE ACLK FREQUENCY AT WHICH A 0.1LSB SHIFT IN THE ERROR AT ANY CODE TRANSITION FROM ITS 4MHz VALUE IS FIRST DETECTED

TYPICAL PERFORMANCE CHARACTERISTICS

Maximum Filter Resistor vs Cycle Time

Sample and Hold Acquisition Time vs Source Resistance

Supply Current (Power Shutdown) vs Temperature



APPLICATIONS INFORMATION

The LTC1290 is a data acquisition component which contains the following functional blocks:

1. 12-bit successive approximation capacitive A/D converter
2. Analog multiplexer (MUX)
3. Sample and hold (S/H)
4. Synchronous, full duplex serial interface
5. Control and timing logic

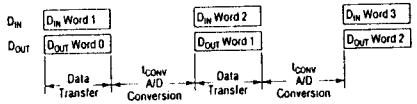
DIGITAL CONSIDERATIONS

Serial Interface

The LTC1290 communicates with microprocessors and other external circuitry via a synchronous, full duplex, four wire serial interface (see Operating Sequence). The shift clock (SCLK) synchronizes the data transfer with each bit being transmitted on the falling SCLK edge and captured on the rising SCLK edge in both transmitting and receiving systems. The data is transmitted and received simultaneously (full duplex).

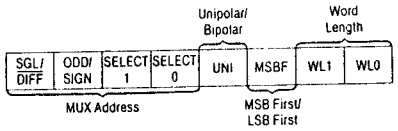
APPLICATIONS INFORMATION

Data transfer is initiated by a falling chip select ($\overline{CS}$) signal. After the falling $\overline{CS}$ is recognized, an 8-bit input word is shifted into the D_{IN} input which configures the LTC1290 for the next conversion. Simultaneously, the result of the previous conversion is output on the D_{OUT} line. At the end of the data exchange the requested conversion begins and $\overline{CS}$ should be brought high. After t_{CONV}, the conversion is complete and the results will be available on the next data transfer cycle. As shown below, the result of a conversion is delayed by one $\overline{CS}$ cycle from the input word requesting it.



Input Data Word

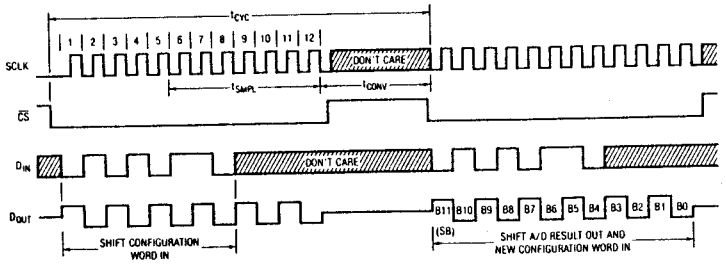
The LTC1290 eight bit data word is clocked into the D_{IN} input on the first eight rising SCLK edges after chip select is recognized. Further inputs on the D_{IN} pin are then ignored until the next $\overline{CS}$ cycle. The eight bits of the input word are defined as follows:



MUX Address

The first four bits of the input word assign the MUX configuration for the requested conversion. For a given channel selection, the converter will measure the voltage between the two channels indicated by the + and – signs in the selected row of the following table. Note that in differential mode (SGL/$\overline{DIFF}$ = 0) measurements are limited to four adjacent input pairs with either polarity. In single ended mode, all input channels are measured with respect to COM.

Operating Sequence
(Example: Differential Inputs (CH3-CH2), Bipolar, MSB First and 12-Bit Word Length)



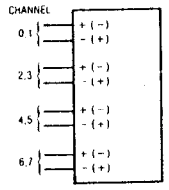
APPLICATIONS INFORMATION

Table 1. Multiplexer Channel Selection

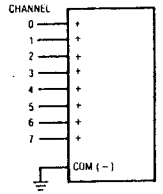
MUX ADDRESS				DIFFERENTIAL CHANNEL SELECTION							
SGL/ DIFF	ODD/ SIGN	SELECT 1	SELECT 0	0	1	2	3	4	5	6	7
0	0	0	0	+	–						
0	0	0	1			+	–				
0	0	1	0					+	–		
0	0	1	1							+	–
0	1	0	0	–	+						
0	1	0	1			–	+				
0	1	1	0					–	+		
0	1	1	1							–	+

MUX ADDRESS				SINGLE ENDED CHANNEL SELECTION								
SGL/ DIFF	ODD/ SIGN	SELECT 1	SELECT 0	0	1	2	3	4	5	6	7	COM
1	0	0	0	+								–
1	0	0	1			+						–
1	0	1	0					+				–
1	0	1	1							+		–
1	1	0	0		+							–
1	1	0	1				+					–
1	1	1	0						+			–
1	1	1	1								+	–

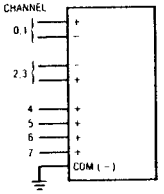
4 Differential



8 Single Ended



Combinations of Differential and Single Ended



Changing the MUX Assignment "On the Fly"

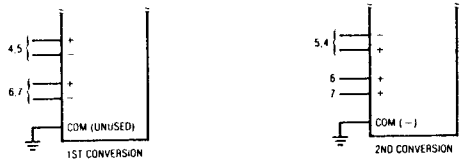


Figure 1. Examples of Multiplexer Options on the LTC1290

APPLICATIONS INFORMATION

Unipolar/Bipolar (UNI)

The fifth input bit (UNI) determines whether the conversion will be unipolar or bipolar. When UNI is a logical one, a unipolar conversion will be performed on the selected input voltage. When UNI is a logical zero, a bipolar conversion will result. The input span and code assignment for each conversion type are shown in the figures below.

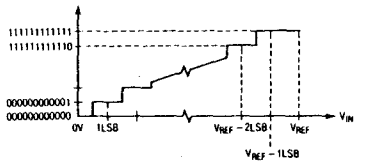
Unipolar Output Code (UNI = 1)

OUTPUT CODE	INPUT VOLTAGE	INPUT VOLTAGE (V_{REF} = 5V)
111111111111	V_{REF} – 1LSB	4.9988V
111111111110	V_{REF} – 2LSB	4.9976V
•	•	•
•	•	•
•	•	•
000000000001	1LSB	0.0012V
000000000000	0V	0V

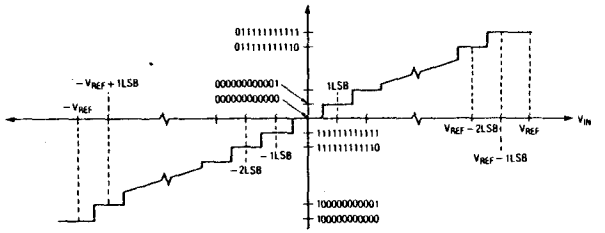
Bipolar Output Code (UNI = 0)

OUTPUT CODE	INPUT VOLTAGE	INPUT VOLTAGE (V_{REF} = 5V)
011111111111	V_{REF} – 1LSB	4.9976V
011111111110	V_{REF} – 2LSB	4.9851V
•	•	•
•	•	•
•	•	•
000000000001	1LSB	0.0024V
000000000000	0V	0V
111111111111	– 1LSB	– 0.0024V
111111111110	– 2LSB	– 0.0048V
•	•	•
•	•	•
•	•	•
100000000001	$-(V_{REF})$ + 1LSB	– 4.9976V
100000000000	$-(V_{REF})$	– 5.0000V

Unipolar Transfer Curve (UNI = 1)



Bipolar Transfer Curve (UNI = 0)



APPLICATIONS INFORMATION

MSB First/LSB First Format (MSBF)

The output data of the LTC1290 is programmed for MSB first or LSB first sequence using the MSBF bit. For MSBF first output data the input word clocked to the LTC1290 should always contain a logical one in the sixth bit location (MSBF bit). Likewise for LSB first output data the input word clocked to the LTC1290 should always contain a zero in the MSBF bit location. The MSBF bit affects only the order of the output data word. The order of the input word is unaffected by this bit.

MSBF	OUTPUT FORMAT
0	LSB First
1	MSB First

Word Length (WL1, WL0) and Power Shutdown

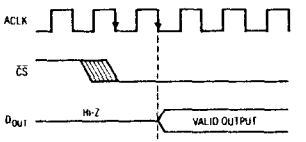
The last two bits of the input word (WL1 and WL0) program the output data word length and the power shutdown feature of the LTC1290. Word lengths of 8, 12 or 16-bits can be selected according to the following table. The WL1 and WL0 bits in a given D_{IN} word control the length of the present, not the next, D_{OUT} word. WL1 and WL0 are never "don't cares" and must be set for the correct D_{OUT} word length even when a "dummy" D_{IN} word is sent. On any transfer cycle, the word length should be made equal to the number of SCLK cycles sent by the MPU. Power down will occur when WL1 = 0 and WL0 = 1 is selected. The previous conversion result will be clocked out as a 10-bit word so a "dummy" conversion is required before powering down the LTC1290. Conversions are resumed once $\overline{CS}$ goes low or an SCLK is applied, if $\overline{CS}$ is already low.

WL1	WL0	OUTPUT WORD LENGTH
0	0	8-Bits
0	1	Power Shutdown
1	0	12-Bits
1	1	16-Bits

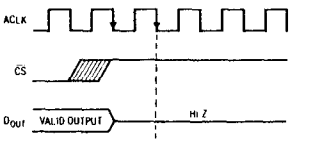
Deglitcher

A deglitching circuit has been added to the Chip Select input of the LTC1290 to minimize the effects of errors caused by noise on that input. This circuit ignores changes in state on the $\overline{CS}$ input that are shorter in duration than one ACLK cycle. After a change of state on the $\overline{CS}$ input, the LTC1290 waits for two falling edge of the ACLK before recognizing a valid chip select. One indication of $\overline{CS}$ recognition is the D_{OUT} line becoming active (leaving the Hi-Z state). Note that the deglitching applies to both the rising and falling $\overline{CS}$ edges.

Low $\overline{CS}$ Recognized Internally



High $\overline{CS}$ Recognized Internally



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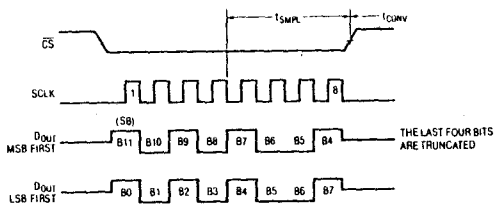
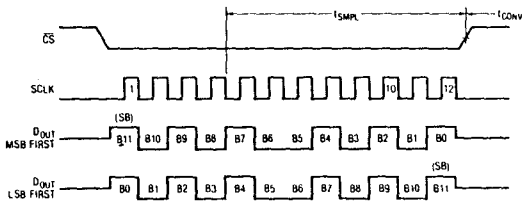
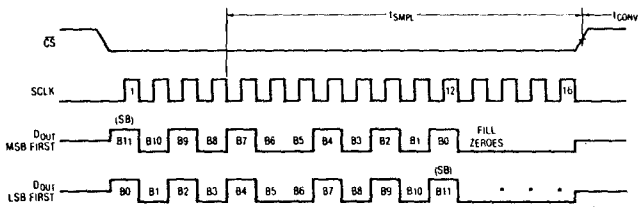
8-Bit Word Length



12-Bit Word Length



16-Bit Word Length



*IN UNIPOLAR MODE, THESE BITS ARE FILLED WITH ZEROES
IN BIPOLAR MODE, THE SIGN BIT IS EXTENDED INTO THESE LOCATIONS

Figure 2. Data Output (D_{OUT}) Timing with Different Word Lengths

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$\overline{CS}$ Low During Conversion

In the normal mode of operation, $\overline{CS}$ is brought high during the conversion time. The serial port ignores any SCLK activity while $\overline{CS}$ is high. The LTC1290 will also operate with $\overline{CS}$ low during the conversion. In this mode, SCLK must remain low during the conversion as shown in the following figure. After the conversion is complete, the D_{OUT} line will become active with the first output bit. Then the data transfer can begin as normal.

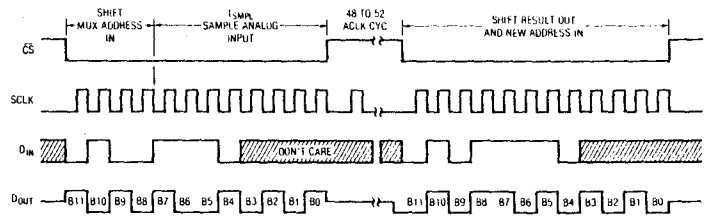

Figure 3. $\overline{CS}$ High During Conversion

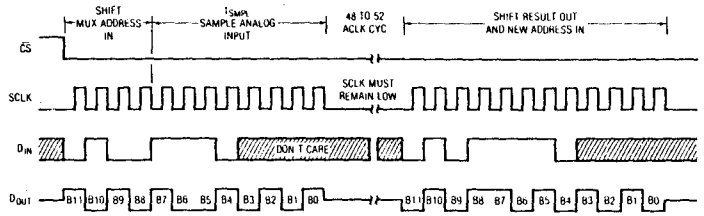

Figure 4. $\overline{CS}$ Low During Conversion

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supply should also be kept to a minimum and the V_{CC} supply should have a low output impedance such as that obtained from a voltage regulator (e.g. LT323A). Figures 7 and 8 show the effects of good and poor V_{CC} bypassing.

Figure 7. Poor V_{CC} Bypassing. Noise and Ripple Can Cause A/D Errors

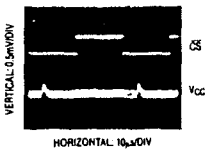

Figure 8. Good V_{CC} Bypassing Keeps Noise and Ripple on V_{CC} Below 1mV

3. Analog Inputs

Because of the capacitive redistribution A/D conversion techniques used, the analog inputs of the LTC1290 have capacitive switching input current spikes. These current spikes settle quickly and do not cause a problem. However, if large source resistances are used or if slow settling op amps drive the inputs, care must be taken to insure that the transients caused by the current spikes settle completely before the conversion begins.

Source Resistance

The analog inputs of the LTC1290 look like a 100pF capacitor (C_{IN}) is series with a 500Ω resistor (R_{ON}) as shown in Figure 9. C_{IN} gets switched between the selected "+" and "–" inputs once during each conversion cycle. Large external source resistors and capacitances will slow the settling of the inputs. It is important that the overall RC time constants be short enough to allow the analog inputs to completely settle within the allowed time.

"+" Input Settling

This input capacitor is switched onto the "+" input during the sample phase (t_{SMPL}, see Figure 10). The sample phase starts at the 4th SCLK cycle and lasts until the falling edge of the last SCLK (the 8th, 12th or 16th SCLK cycle depending on the selected word length). The voltage on the "+" input must settle completely within this sample time. Minimizing R_{SOURCE}^+ and C1 will improve the input settling time. If large "+" input source resistance must be used, the sample time can be increased by using a slower SCLK frequency or selecting a longer word length. With the minimum possible sample time of 2μs, **$R_{SOURCE}^+ < 1k$ and C1 < 20pF will provide adequate settling.**

"–" Input Settling

At the end of the sample phase the input capacitor switches to the "–" input and the conversion starts (see Figure 10). During the conversion, the "+" input voltage is effectively "held" by the sample and hold and will not affect the conversion result. However, it is critical that the "–" input voltage be free of noise and settle completely during the first four ACLK cycles of the conversion time. Minimizing R_{SOURCE}^- and C2 will improve settling time. If large "–" input source resistance must be used, the time allowed for settling can be extended by using a slower ACLK frequency. At the maximum ACLK rate of 4MHz, **$R_{SOURCE}^- < 250Ω$ and C2 < 20pF will provide adequate settling.**

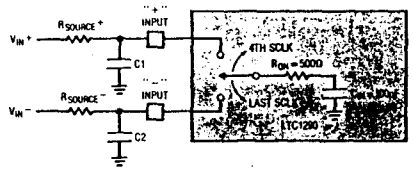

Figure 9. Analog Input Equivalent Circuit

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Input Op Amps

When driving the analog inputs with an op amp it is important that the op amp settle within the allowed time (see Figure 10). Again, the "+" and "–" input sampling times can be extended as described above to accommodate slower op amps. Most op amps including the LT1006 and LT1013 single supply op amps can be made to settle well even with the minimum settling windows of 2μs ("+" input) and 1μs ("–" input) which occur at the maximum clock rates (ACLK = 4MHz and SCLK = 2MHz). Figures 11 and 12 show examples of adequate and poor op amp settling.

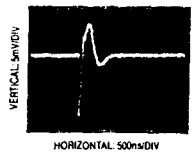

Figure 11. Adequate Settling of Op Amps Driving Analog Input

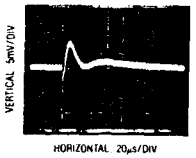

Figure 12. Poor Op Amp Settling Can Cause A/D Errors

RC Input Filtering

It is possible to filter the inputs with an RC network as shown in Figure 13. For large values of C_F (e.g., 1μF), the capacitive input switching currents are averaged into a net DC current. Therefore, a filter should be chosen with a small resistor and large capacitor to prevent DC drops across the resistor. The magnitude of the DC current is approximately $I_{DC} = 100pF \times V_{IN}/t_{CYC}$ and is roughly proportional to V_{IN}. When running at the minimum cycle time of 20μs, the input current equals 25μA at $V_{IN} = 5V$. In this case, a filter resistor of 5Ω will cause 0.1LSB of full-scale error. If a larger filter resistor must be used, errors can be eliminated by increasing the cycle time as shown in the typical curve of Maximum Filter Resistor vs Cycle Time.

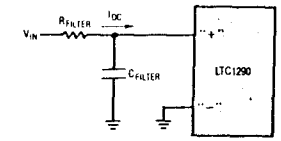

Figure 13. RC Input Filtering

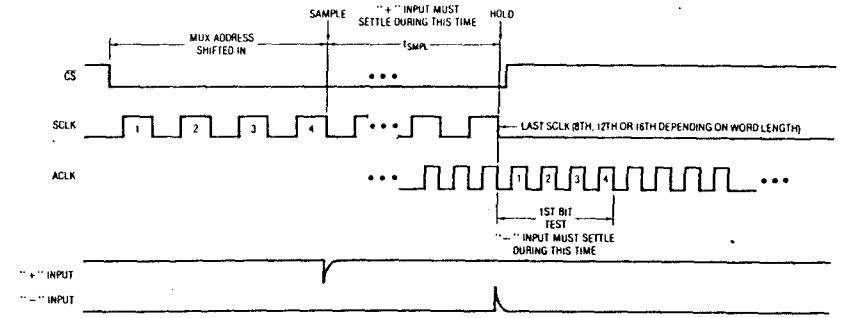

Figure 10. "+" and "–" Input Settling Windows

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Input Leakage Current

Input leakage currents can also create errors if the source resistance gets too large. For instance, the maximum input leakage specification of 1μA (at 125°C) flowing through a source resistance of 1kΩ will cause a voltage drop of 1mV or 0.8LSB. This error will be much reduced at lower temperatures because leakage drops rapidly (see typical curve of Input Channel Leakage Current vs Temperature).

Noise Coupling into Inputs

High source resistance input signals (>500Ω) are more sensitive to coupling from external sources. It is preferable to use channels near the center of the package (i.e., CH2-CH7) for signals which have the highest output resistance because they are essentially shielded by the pins on the package ends (DGND and CH0). Grounding any unused inputs (especially the end pin, CH0) will also reduce outside coupling into high source resistances.

4. Sample and Hold

Single Ended Inputs

The LTC1290 provides a built-in sample and hold (S&H) function for all signals acquired in the single ended mode (COM pin grounded). This sample and hold allows the LTC1290 to convert rapidly varying signals (see typical curve of S&H Acquisition Time vs Source Resistance). The input voltage is sampled during the t_{SMPL} time as shown in Figure 10. The sampling interval begins after the fourth MUX address bit is shifted in and continues during the remainder of the data transfer. On the falling edge of the final SCLK, the S&H goes into hold mode and the conversion begins. The voltage will be held on either the 8th, 12th or 16th falling edge of the SCLK depending on the word length selected.

Differential Inputs

With differential inputs or when the COM pin is not tied to ground, the A/D no longer converts just a single voltage but rather the difference between two voltages. In these cases, the voltage on the selected "+" input is still sampled and held and therefore may be rapidly time varying just as in single ended mode. However, the voltage on the selected "–" input must remain constant and be free of noise and ripple throughout the conversion time. Otherwise, the differencing operation may not be performed accurately. The conversion time is 52 ACLK cycles. Therefore, a change in the "–" input voltage during this interval can cause conversion errors. For a sinusoidal voltage on the "–" input this error would be:

$$V_{ERROR(MAX)} = V_{PEAK} \times 2 \times \pi \times f("-") \times 52/f_{ACLK}$$

Where f("–") is the frequency of the "–" input voltage, V_{PEAK} is its peak amplitude and f_{ACLK} is the frequency of the ACLK. In most cases V_{ERROR} will not be significant. For a 60Hz signal on the "–" input to generate a 1/4LSB error (300μV) with the converter running at ACLK = 4MHz, its peak value would have to be 61mV.

5. Reference Inputs

The voltage between the reference inputs of the LTC1290 defines the voltage span of the A/D converter. The reference inputs will have transient capacitive switching currents due to the switched capacitor conversion technique (see Figure 14). During each bit test of the conversion (every 4 ACLK cycles), a capacitive current spike will be generated on the reference pins by the A/D. These current spikes settle quickly and do not cause a problem. However, if slow settling circuitry is used to drive the reference inputs, care must be taken to insure that transients caused by these current spikes settle completely during each bit test of the conversion.

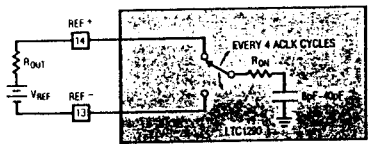

Figure 14. Reference Input Equivalent Circuit

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When driving the reference inputs, two things should be kept in mind:

1. Transients on the reference inputs caused by the capacitive switching currents must settle completely during each bit test (each 4 ACLK cycles). Figures 15 and 16 show examples of both adequate and poor settling. Using a slower ACLK will allow more time for the reference to settle. However, even at the maximum ACLK rate of 4MHz most references and op amps can be made to settle within the 1μs bit time. For example the LT1027 will settle adequately or with a 10μF bypass capacitor at REF^+ the LT1021 can also be used.
2. It is recommended that the REF^- input be tied directly to the analog ground plane. If REF^- is biased at a voltage other than ground, the voltage must not change during a conversion cycle. This voltage must also be free of noise and ripple with respect to analog ground.

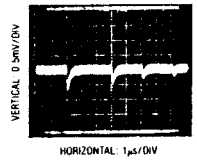

Figure 15. Adequate Reference Settling

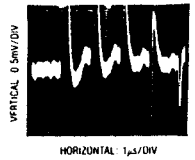

Figure 16. Poor Reference Settling Can Cause A/D Errors

6. Reduced Reference Operation

The effective resolution of the LTC1290 can be increased by reducing the input span of the converter. The LTC1290 exhibits good linearity and gain over a wide range of reference voltages (see typical curves of Linearity and Gain Error vs Reference Voltage). However, care must be taken when operating at low values of V_{REF} because of the reduced LSB step size and the resulting higher accuracy requirement placed on the converter. The following factors must be considered when operating at low V_{REF} values.

1. Offset
2. Noise

Offset with Reduced V_{REF}

The offset of the LTC1290 has a larger effect on the output code when the A/D is operated with reduced reference voltage. The offset (which is typically a fixed voltage) becomes a larger fraction of an LSB as the size of the LSB is reduced. The typical curve of Unadjusted Offset Error vs Reference Voltage shows how offset in LSBs is related to reference voltage for a typical value of V_{OS}. For example, a V_{OS} of 0.1mV which is 0.1LSB with a 5V reference becomes 0.4LSB with a 1.25V reference. If this offset is unacceptable, it can be corrected digitally by the receiving system or by offsetting the "–" input to the LTC1290.

Noise with Reduced V_{REF}

The total input referred noise of the LTC1290 can be reduced to approximately 200μV peak-to-peak using a ground plane, good bypassing, good layout techniques and minimizing noise on the reference inputs. This noise is insignificant with a 5V reference but will become a larger fraction of an LSB as the size of the LSB is reduced. The typical curve of Noise Error vs Reference Voltage shows the LSB contribution of this 200μV of noise.

For operation with a 5V reference, the 200μV noise is only 0.16LSB peak-to-peak. In this case, the LTC1290 noise will contribute virtually no uncertainty to the output code. However, for reduced references, the noise may become a significant fraction of an LSB and cause undesirable jitter

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in the output code. For example, with a 1.25V reference, this same 200μV noise is 0.64LSB peak-to-peak. This will reduce the range of input voltages over which a stable output code can be achieved by 0.64LSB. In this case averaging readings may be necessary.

This noise data was taken in a very clean setup. Any setup induced noise (noise or ripple on V_{CC}, V_{REF}, V_{IN} or V^-) will add to the internal noise. The lower the reference voltage to be used, the more critical it becomes to have a clean, noise-free setup.

7. LTC1290 AC Characteristics

Two commonly used figures of merit for specifying the dynamic performance of the A/D's in digital signal processing applications are the Signal-to-Noise Ratio (SNR) and the "effective number of bits (ENOB)." SNR is defined as the ratio of the RMS magnitude of the fundamental to the RMS magnitude of all the nonfundamental signals up to the Nyquist frequency (half the sampling frequency). The theoretical minimum SNR for a sine wave input is given by

$$SNR = (6.02N + 1.76dB)$$

where N is the number of bits. Thus the SNR is a function of the resolution of the A/D. For an ideal 12-bit A/D the SNR is equal to 74dB. A Fast Fourier Transform (FFT) plot of the output spectrum of the LTC1290 is shown in Figures 17A and 17B. The input (F_{IN}) frequencies are 1kHz and 25kHz with the sampling frequency (F_S) at 50.6kHz. The SNR obtained from the plot are 73.25dB and 72.54dB.

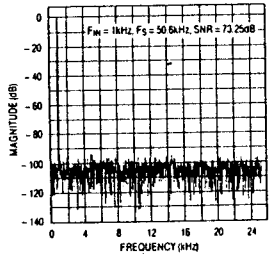

Figure 17A. LTC1290 FFT Plot

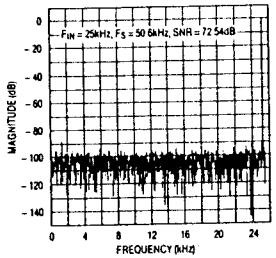

Figure 17B. LTC1290 FFT Plot

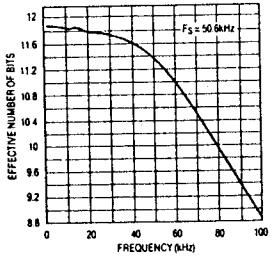

Figure 18. LTC1290 ENOB vs Input Frequency

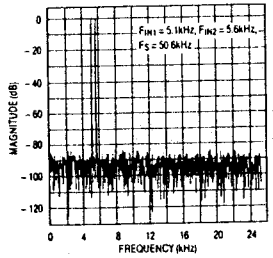

Figure 19. LTC1290 FFT Plot

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Rewriting the SNR expression it is possible to obtain the equivalent resolution based on the SNR measurement.

$$N = (SNR - 1.76dB)/6.02$$

This is the so-called effective number of bits (ENOB). For the example shown in Figures 17A and 17B, N = 11.9 bits and 11.8 bits, respectively. Figure 18 shows a plot of ENOB as a function of input frequency. The curve shows the A/D's ENOB remain in the range of 11.9 to 11.8 for input frequencies up to $F_S/2$.

Figure 19 shows an FFT plot of the output spectrum for two tones applied to the input of the A/D. Non-linearities in the A/D will cause distortion products at the sum and difference frequencies of the fundamentals and products of the fundamentals. This is classically referred to as intermodulation distortion (IMD).

8. Overvoltage Protection

Applying signals to the analog MUX that exceed the positive or negative supply of the device will degrade the accuracy of the A/D. Should the signal exceed a diode drop (0.6V) from either supply, permanent damage could be done to the device. These conditions should be prevented either with proper supply sequencing or by use of external circuitry to clamp the input signals. Such a circuit is shown in Figure 20.

Overvoltage conditions could occur when power is first applied to the device. For single supply operation (i.e. unipolar mode), V_{CC} should be turned on first, then REF+, if they are not tied together. If this condition cannot be met, connecting a Schottky diode from REF+ to V_{CC} is recommended (see Figure 21). For dual supplies (bipolar mode) V^- should be turned on first followed by V_{CC} and then REF+. A Schottky diode from V_{CC} to the ground plane is recommended to prevent the V_{CC} pin from going below ground during the time interval when V^- has first been applied and V_{CC} is floating (see Figure 22).

Because a unique input protection structure is used on the digital input pins, the signal levels on these pins can exceed the device V_{CC} without any damage occuring.

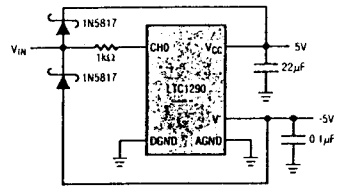

Figure 20. Overvoltage Protection for MUX

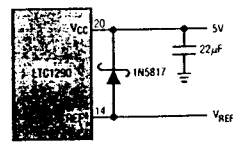

Figure 21.

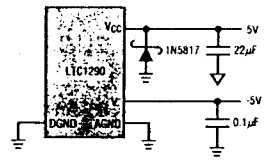

Figure 22.