

MODEL 141 20-BIT A/D CONVERTER

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TABLE OF CONTENTS

INTRODUCTION	Page 2
1. INSTALLATION	Page 3
2. PERFORMING CONVERSIONS	Page 5
3. CHANNEL SELECTION	Page 8
4. CONTROL OUTPUTS & DIGITAL INPUT	Page 9
5. OPERATING SUGGESTIONS	Page 10
6. TROUBLESHOOTING	Page 11
7. INTERNAL ADJUSTMENTS	Page 12
8. SPECIFICATIONS	Page 14
WARRANTY	Page 15

Introduction

The Lawson Labs Model 141 Analog-to-Digital card enables an IBM PC/XT/AT or compatible computer to translate continuously variable analog voltages into their digital equivalents of ones and zeros. It also provides a means for the computer to turn external equipment on and off. These functions are the basics of monitoring and control systems. Both the analog inputs and the digital outputs are protected against overvoltages.

The Model 141 uses the sigma delta conversion technique which makes possible extremely high precision and linearity as well as excellent noise rejection. The 141 can resolve 10 microvolts over a +/- 5 volt range. It will filter out all frequencies above the cut-off frequency. Be aware that the filtering causes the converter to need extra time to respond to a step change at the input.

SECTION 1. Installation

NOTE: Always handle circuit cards by the edges.

There are seven DIP switches located near the bottom edge of the Model 141. These switches determine the base port address of the card. The base address can be placed virtually anywhere in the available I/O space, including places reserved by the operating system. We recommend addresses between 544 (220 Hexadecimal) and 624 (270 Hex). The switch positions for base address 560 are 1,4,5 and 6 ON; 2,3 and 7 OFF. If there are other special purpose cards in your computer you should check their documentation to make sure the port addresses do not conflict. Although the Model 141 base address is a multiple of 8, only the first 4 addresses are used. The upper 4 of the 8 are still available to other boards. Possible base addresses range from 256 (100 Hex) to 998 (3E6 Hex).

FIGURE 1. Recommended Base Address DIP Switch Selection Chart

Base address	Hex	1= ON				0= OFF		
		7	6	5	4	3	2	1
544	220	0	1	1	1	0	1	1
552	228	0	1	1	1	0	1	0
560 (standard)	230	0	1	1	1	0	0	1
568	238	0	1	1	1	0	0	0
576	240	0	1	1	0	1	1	1
584	248	0	1	1	0	1	1	0
592	250	0	1	1	0	1	0	1
600	258	0	1	1	0	1	0	0
608	260	0	1	1	0	0	1	1
616	268	0	1	1	0	0	1	0
624	270	0	1	1	0	0	0	1

To obtain the base address from the DIP switches, use 0 for ON and 1 for OFF in the following formula: $SW7 * 64 + SW6 * 32 + SW5 * 16 + SW4 * 8 + SW3 * 4 + SW2 * 2 + SW1$. Multiply the above by 8 to obtain the base address. The default switch settings select board address 560 (230 Hex).

In addition to the board address switches there is a 3x2 jumper block area located in the upper left hand corner of the board. The jumper settings select the input clock frequency for the converter. The clock frequency also affects the update rate, filter cutoff frequency and settling time.

FIGURE 2. Clock and Timing Jumper Selections

Jumper:	1 2 3 * * * * * *	1 2 3 * * * * * *	1 2 3 * * * * * *
Clock:	224 KHz	895 KHz	3.58 MHz
Filter Cutoff:	0.55 Hz	2.2 Hz	8.7 Hz
Output Update:	218 Hz	874 Hz	3.50 KHz

Settling
Time: 2.27 sec 568 msec 142 msec

In general, a higher clock frequency allows faster response while a lower frequency provides lower noise levels. The clock is factory-set at 895 KHz, a rate satisfactory for most applications.

Static electricity can damage computer circuitry so care should be taken to control static discharge. Turn off the computer but do not unplug it. Remove the cover.

First remove the screw which secures the bracket behind a vacant slot. Then remove the bracket. While holding the Model 141 in one hand touch the computer's chassis with the other. This procedure will harmlessly drain any static charge that may be present. Now insert the card into the connector. Press down firmly to insure that the card is seated and replace the screw in the bracket. Make certain to double-check the DIP switch and jumper settings before replacing the cover of the computer.

Attach a pair of wires to pins 6 and 13 of a mating DB15 connector. The negative input is pin 13 and the positive input is pin 6. The other end of the wires should connect to the voltage being measured. A 1.5 volt battery is a convenient voltage source for test purposes. For a battery or other floating voltage source, a connection must be made between the negative input and ground. The computer's chassis is the preferred ground for most purposes.

NOTE: Strain-relief is recommended for all permanent wiring on the connector. Otherwise, physical stress may cause the failure of an electrical connection. DB15 hoods are available, from Lawson Labs and elsewhere, with a built-in strain-relief clamp.

FIGURE 3:

CONNECTOR PINOUT

PIN 8...CHANNEL 1+	PIN 15...CHANNEL 1-
PIN 7...UNUSED	PIN 14...UNUSED
PIN 6...CHANNEL 0+	PIN 13...CHANNEL 0-
PIN 5...UNUSED	PIN 12...UNUSED
PIN 4...GROUND	PIN 11...DIGITAL INPUT
PIN 3...GUARD	PIN 10...OUTPUT C
PIN 2...OUTPUT D	PIN 9...OUTPUT B
PIN 1...OUTPUT A	

Attach the connector and tighten the small screws that hold the halves together. Replace the cover. Turn on the power to the computer. If the power-on self-test (POST) does not

behave normally, turn off the computer and refer to the troubleshooting section of this manual.

Connect the plus and minus wires to the voltage being measured. Make certain that the voltage at both input terminals is within +/- 6 volts of ground and that the difference between the input terminals is in the +5 to -5 volt range. If the voltage source is floating in relation to ground, e.g. a battery, also connect the minus side of the voltage being measured to ground. You may use the ground pin on the Model 141's connector for that ground connection, but we recommend chassis ground at the computer.

NOTE: For maximum reliability, connect any unused inputs to Pin 4 (ground).

SECTION 2. Performing A/D conversions

In the absence of other instructions, the Model 141 card will measure the voltage at input channel #0. Because the wires that you attached are connected to input #0, we need not concern ourselves with the channel selection process at this time.

The Model 141 requires four port addresses which are used for both input and output. When used as inputs, three ports are needed for reading the result of the conversion and one provides status information. As outputs, only two of the four ports are active. They are used for calibration, channel selection and control of the digital output bits.

Refer back to FIGURE 1 above and set the variable ADC% in line number 120 in the BASIC program to the base address of the Model 141 board as selected by the DIP switch settings.

This program is included on the accompanying support disk and is titled DEMO_141.BAS. Be sure to make a backup copy of your support disk before proceeding.

```
90 KEY OFF: CLS
100 BP%= 128           ' BIPOLAR MODE (0 for unipolar)
110 CH% = 0           ' input channel, 0 or 1
120 ADC% = &H230      ' default port address
130 GOSUB 250         ' calibration
140 IF INP(ADC%+3) > 127 THEN GOTO 140 'wait until done *
150 OUT ADC% + 1, 1   ' assert freeze
160 H = (INP(ADC% + 2) AND &HF) ' get the 4 high bits
170 M = INP(ADC% + 1) ' get middle byte
180 L = INP(ADC%)     ' get low byte
190 OUT ADC% + 1, 0   ' unfreeze
200 COUNT! = L + M * 256 + H * 65536! ' combine counts
210 PRINT USING "#####"; COUNT!, ' print count
220 VOLTS = COUNT! * 9.536743E-06 - 5 ' convert to volts
230 PRINT USING "#####.#####"; VOLTS ' print volts
240 IF INKEY$="" THEN GOTO 140 ELSE END ' press key to stop
250 PRINT "Calibrating" ' begin cal routines
260 OUT ADC% + 1, 1     ' freeze
270 OUT ADC%, 48 + BP% ' offset calibration
280 OUT ADC%, 48 + 64 + BP% ' set calibration bit
290 OUT ADC%, 48 + BP% ' clear calibration bit
300 OUT ADC% + 1, 0     ' unfreeze
310 IF INP(ADC%+3) > 127 THEN GOTO 310 'wait until done
```

```

320 OUT ADC% + 1, 1           ' freeze
330 OUT ADC%, 32 + BP%       ' fullscale calibration
340 OUT ADC%, 32 + 64 + BP%  ' set calibration bit
350 OUT ADC%, 32 + BP%       ' clear calibration bit
360 OUT ADC% + 1, 0         ' unfreeze
370 IF INP(ADC%+3) > 127 THEN GOTO 370 'wait until done
380 OUT ADC%, CH% * 16 + BP%  ' select channel
390 RETURN                   ' end of calibration

```

* This line may be omitted for slower PCs and/or interpreted BASIC.

Lines 100-120 assign variable names to the desired mode, channel number and board base address. Line 130 calls a subroutine which performs offset and full scale calibration of the converter. Line 140 waits for new data. Next the FREEZE bit is raised to prevent newer data from overwriting the current data before all three bytes have been read. In line 190, the FREEZE bit is lowered allowing new data to be latched. Note that in line 160 the high 4 bits of the most significant byte must be masked out. In line 200 the three bytes are weighted and added to equal COUNT! Line 210 displays the result in counts and lines 220-230 convert the count to volts and display it. Line 240 repeats the process.

Line 250 begins the calibration routines. These routines should be used as is. Changes here can cause unusual results.

RUN the program. (Press any key to exit.) Successive pairs of counts and voltage should appear at the left side of the screen. Note that the readings do not stabilize until the settling time has elapsed. The Model 141 resolves 10 microvolts. A typical D cell should read about 1.5 volts (681600 counts in bipolar mode, 314600 in unipolar). Connecting the input wires directly together will cause a potential of zero volts. The reading with the input shorted should be typically +/- 50 microvolts or less. An open circuit or overvoltage will read unpredictably. The input channels are protected against overvoltages of up to 120 volts. Reverse the wires and note the polarity change. Note that the plus sign is implicit and does not appear.

The conversion of counts to volts is different for unipolar and bipolar modes. To select unipolar mode (0 to 5 volt range), set BP% to 0 in line 100. Then change line 220 to:

```
220 VOLTS = COUNT! * 4.768372E-06
```

NOTE: Calibration must be repeated after changing BP%.

The conversion process itself in a sigma delta converter is essentially continuous. However since the value available from the digital filter at the converter output is only updated periodically, it is necessary to watch the CONVERTING bit to be certain of reading freshly-converted data instead of a previously-read value. The CONVERTING bit is set by raising the FREEZE bit and is reset by new data from the converter. New data will not be available until after the FREEZE bit has been lowered. Refer to FIGURE 2 for update rates.

The digital filter section of the Model 141 has a 6-pole Gaussian response which sharply attenuates any frequency above the programmed cut-off frequency. At the

same time it will pass, with virtually no attenuation, frequencies below that cut-off. For example with a cut-off frequency of 10 Hz, 60 Hz rejection is 55 dB. With a .5 Hz cut-off frequency, 60 Hz rejection is better than 160 dB.

Calibration of the Model 141 board must be performed after powering up and before attempting to make any measurements. This is the only time calibration is absolutely required. Temperature changes have a small effect upon the calibration. Temperature effects are typically less than .6 millivolts but may be as much as 2 millivolts. For maximum accuracy it is advisable to calibrate the board again once it has reached operating temperature. Additional calibrations may be done periodically to minimize any temperature effects and maximize precision.

On the diskette included with the Model 141 is a driver program for the A/D board written in BASIC and titled DRIVR141.BAS. It serves as a programming example and may be included, wholly or in part, in user programs. The header portion contains timing and address information. The main body of the program contains code that allows the user to set up the Model 141, calibrate offset and full scale, select a channel, measure voltages and average and display them.

An assembly routine for averaging a number of readings (that number being a power of 2) is available on request from Lawson Labs.

SECTION 3. Selecting Other Input Channels

First connect the other voltage to be measured to the unused pair of input pins on the Model 141's connector. See Figure 3. The two available channels are numbered 0 and 1. To select channel 1, set CH% = 1 in line 110. The channel selection is sent to the card in line 380.

```
380 OUT ADC%, CH% * 16 + BP%
```

Because of the nature of the sigma delta conversion process, a settling time, specified in FIGURE 2, is required after changing input channels before the reading at the second channel will be accurate. This delay applies both to the A/D card's channels and to any external multiplexing device. This delay allows data from the previous channel contained in the digital filter stage of the converter to be flushed out and replaced by data from the newly-selected channel.

We recommend that the TIME function be used to insert delays where needed rather than using machine speed dependent delay loops.

SECTION 4. Using the Control Outputs & Digital Input

There are four optically isolated output lines on the Model 141 card. These are intended primarily for expanding the number of input channels using external multiplexers or multiplexed amplifiers. The four lines can be decoded to yield 16 different input channels. The external control code is a 4-bit word written to the lower 4 bits of the control register. Configurations of up to 32 analog inputs are possible with two Model 17B Multiplexers.

A number from 0 to 15 sent to port ADC% will appear on

the output lines, coded in binary. The instruction `OUT ADC%, 3` will cause outputs A and B to become active. Below is a list of codes and the corresponding active outputs. Note that the sequence is that of counting in binary. 1=active.

TABLE 2.

CODE	OUTPUT	D	C	B	A
0		0	0	0	0
1		0	0	0	1
2		0	0	1	0
3		0	0	1	1
4		0	1	0	0
5		0	1	0	1
6		0	1	1	0
7		0	1	1	1
8		1	0	0	0
9		1	0	0	1
10		1	0	1	0
11		1	0	1	1
12		1	1	0	0
13		1	1	0	1
14		1	1	1	0
15		1	1	1	1

If an external multiplexer is used, the channel selection code is the sum of the external control code and the A/D channel number times 16.

$$\text{CHANNELCODE\%} = \text{CH\%} * 16 + \text{EXTCODE\%}$$

Codes 0-31 can select valid channels on the Model 141 (with external multiplexers). Remember that the variable `BP%` should always be added to the channel selection code before outputting to the card.

Electrically, each output line is the collector of an optically coupled NPN transistor whose emitter is connected to guard. Each output line can drive two low-power TTL loads or many CMOS loads. An external pull-up resistor (from the collector to the external positive supply) must be used. Typically, 20 K ohms for low-power TTL or 47 K ohms for CMOS is appropriate. When the output code is 0 all four phototransistors are off and no current is drawn through the transistors. If the input to an inverting buffer is connected to output line A (with the appropriate pull-up resistor), the input level is forced high by the resistor so the buffer output would be 0. If the output code is 1, the A transistor will turn on and pull the buffer input to a logic level 0. The buffer output will then be a logic level 1.

The digital input can be a contact closure to ground or a TTL or 5 volt CMOS logic level, active low. This line reads the digital input.

```
IF (INP(ADC% + 3) AND 16) THEN PRINT "off" ELSE PRINT "on"
```

SECTION 5. Operating suggestions

The Model 141 features fully differential inputs. A basic

understanding of differential measurements will help you to use your card to best advantage. The plus and minus input pins should be wired directly to the voltage being measured. In this way, it is assured that the only current flowing in the wires will be the input current of the A/D converter. Because the wires have finite resistance, any current flowing will cause a voltage drop and a corresponding error. The card requires a vanishingly small input current so the error caused by even very long wires is negligible. For proper operation of the Model 141 it is necessary that both the positive and negative inputs be within 6 volts of ground potential. For a floating voltage source, this is generally accomplished by connecting a third wire between the computer chassis and a ground terminal at the source of the measured voltage. Ground currents may flow in this third wire, but the resulting voltage drops will not cause measurement errors. If the source of the voltage being measured is a line-connected device with a three-pronged plug, its output voltage is likely to be referenced to ground. In that case, no ground connection should be made or a ground loop will be formed. Ground loops can cause unpredictable behavior.

The Model 141 has excellent intrinsic noise rejection. Still, accuracy is sometimes limited by electrical noise that travels through the air and is picked up by interconnecting wires. The first defense against noise is shielding. If you suspect noise problems, use shielded wire with the shield's drain wire connected at one end to chassis ground. Sometimes twisting together the plus and minus wires on an input to form a twisted pair will minimize pick-up. If noise problems persist, try to locate the sources of the interference and isolate them. Electric motors, electric heaters and flickering fluorescent lights are potential sources of interference.

SECTION 6. Troubleshooting

GENERAL:

If the A/D converter appears not to be working, first check all external wiring and all port addresses. Double check the switch settings on the Model 141. Be sure that all input voltages are within range. If another special function card is present, check for conflicting port addresses. Also, try adding a wire from the negative input to ground.

1. Results seem to be meaningless numbers

The most likely culprit is a loose wire or an input with nothing attached. Try connecting the + and - inputs to ground. If the voltage does not read within approximately 50 microvolts of 0, the problem is in the wires themselves or in the channel selection. Check that the program has been correctly entered.

2. The computer hangs up and requires a Ctrl Break to resume operation after trying to read a voltage.

Maybe the ADC% port address is wrong or in conflict with

another card. The computer is waiting indefinitely for the conversion to finish. Also, check that the programming jumper for the clock is in place.

3. Readings show excessive scatter.

First check for proper grounding. If there is no connection between the negative input and ground, try one. If there is such a connection, try removing it.

If the card reads zero volts properly but still returns widely varying numbers when measuring a voltage, the voltage could be oscillating or noisy. If you check the voltage with another voltage-measuring device remember that some meters will average out oscillations or noise to produce a steady reading. Try switching to an alternating current scale. If you get a large reading the voltage is certainly unsteady. The Model 141 will filter out high frequency noise. However, any oscillation below the cut-off frequency can cause increased scatter.

4. External multiplexer or multiplexed amplifier always reads channel 0.

Make sure the ground on any external multiplexer or multiplexed amplifier is connected to the guard terminal on the Model 141's connector.

5. Power On Self Test does not run.

If ADC% is not 560, check the DIP switch address settings to make sure there is no conflict with the operating system. Look for any mechanical problems such as the A/D card physically touching an adjacent card. Is the card fully inserted in its slot? Be sure that no interconnecting cables were loosened during the installation process.

SECTION 7. Internal Adjustments

The only adjustments on the Model 141 card are a common mode rejection adjust and an overall gain adjust. The latter varies the reference voltage used during the A/D conversion.

The long-term stability of the initial calibration is excellent. If you decide to alter the original gain setting, be sure your voltage reference or test meter is sufficiently accurate and has been calibrated recently. Remember that if you change the gain setting you may not be able to restore the converter to its original accuracy.

The gain adjustment potentiometer is at the top edge of the Model 141 card and is the one farthest from the rear panel connector. A clockwise rotation will increase the magnitude of the reading. It is best to make any adjustment with the card at its normal operating temperature. For best results, adjust the gain using a low noise DC voltage source of between 2 and 4 volts.

The common mode rejection adjustment does not require an external voltage reference, though you will probably want to recheck the gain after setting the common mode. The common mode potentiometer is located nearest the rear panel of the computer. To adjust for maximum common mode rejection (106 dB), first connect both inputs of the selected channel together and to ground with the converter in bipolar mode. Note the voltage or count reading displayed. Now connect both inputs of the selected channel to the plus terminal of a 1.5 volt battery and connect the minus terminal of the battery to ground. Adjust the potentiometer so the displayed voltage or count is the same as before. Always do a software calibration after adjusting the trimpots.

SECTION 8. Model 141 Specifications

TYPE:	20-bit sigma delta
DIFFERENTIAL INPUT RANGE:	+/- 5 volts or 0 to 5 volts
COMMON MODE RANGE:	+/- 6 volts
COMMON MODE REJECTION:	100 dB minimum
RESOLUTION:	10 microvolts
LINEARITY:	0.005% of full scale *
ACCURACY:	0.01% of full scale typical at normal operating temperature *
REPRODUCIBILITY:	+/- 4 counts or better in bipolar mode
INPUT IMPEDANCE:	100,000 megohms typical
CLOCK RATE:	224 KHz / 895 KHz / 3.58 MHz
CUT-OFF FREQUENCY:	0.55 Hz / 2.2 Hz / 8.7 Hz
UPDATE RATE:	218 Hz / 874 Hz / 3.50 KHz
SETTLING TIME:	2.27 sec / 568 msec / 142 msec
ANALOG INPUTS:	2, fully differential protected up to 120 volts
DIGITAL INPUT:	Single bit, contact closure or 5-volt logic compatible
DIGITAL OUTPUTS:	4 optically isolated lines protected to 200 volts
TYPICAL POWER CONSUMPTION:	+5v 15 milliamps with all digital outputs inactive +12v. . . . 15 milliamps -12v. . . . 15 milliamps
SIZE:	3.9 x 5.25 inches (half card size)

.6 inches maximum height

* Premium versions available from the factory at extra cost

LIMITED WARRANTY

The Lawson Labs, Inc. Model 141 is guaranteed against defects in materials and workmanship for a period of one year from the date of delivery. Products must be returned to Lawson Labs for warranty service. Contact Lawson Labs at 800 321-5355 for return authorization before returning anything for service.

The above warranty is in lieu of all warranties express or implied. Lawson Labs will not be liable for indirect or consequential damages caused by any defect in this product. Some states do not allow the limitation of consequential damages, so the above exclusion may not apply to you.