

MODEL 140  
15-BIT A/D CONVERTER

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**INTRODUCTION**

The Lawson Labs Model 140 Analog Interface card enables an IBM PC 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 140 uses only four memory locations out of the 32 designated for a "prototype card." These four addresses can be changed by altering the switch settings on the Analog Interface. This arrangement minimizes the chance that there will be a conflict between the Model 140 and any other peripheral card.

**SECTION 1. INSTALLATION**

NOTE: Always handle circuit cards by the edges.

There are four small switches in the upper left corner of the Model 140. Make certain that switch 4 is in the "ON" position and that the other three switches are in the "OFF" position. This will map your Analog Interface into input locations 772 through 775. If you have another special function card in your computer which uses these locations, see Section 2 for alternate mapping.

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 140 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.

Attach a pair of wires to pins 6 and 13 of a mating 15-pin 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 best 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. Hoods are available, from Lawson Labs and elsewhere, with a built-in strain-relief clamp.

**FIGURE 1. CONNECTOR PINOUT**

PIN 8...CHANNEL 1+	PIN 15...CHANNEL 1-
PIN 7...CHANNEL 2+	PIN 14...CHANNEL 2-
PIN 6...CHANNEL 0+	PIN 13...CHANNEL 0-
PIN 5...CHANNEL 3+	PIN 12...CHANNEL 3-
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 is in the +/- 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. For that ground connection, use a ground pin on the Model 140's connector or, preferably, chassis ground at the computer. If the computer chassis is not accessible, use the ground pin of a grounded wall outlet. Remember that the negative input on the Analog Interface should both stay reasonably close to ground potential. See FIGURE 4.

NOTE: For maximum reliability, connect all unused inputs to ground.

## SECTION 2. PERFORMING A/D CONVERSIONS

In the absence of other instructions, the Analog Interface 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 140 uses four port addresses. Two are for input only and two are for both input and output. If your computer contains other special-purpose cards, the possibility of conflict arises. Compare FIGURE 2 with the documentation of other special-purpose cards present and select switch settings that avoid port conflicts. Only one switch should be on at a time.

### FIGURE 2. DIP SWITCH SETTINGS

SWITCH 4 ON, OTHERS OFF	INPUT: PORTS 772-775 OUTPUT: PORTS 772 & 773	ADC = 772
SWITCH 3 ON, OTHERS OFF	INPUT: PORTS 780-783 OUTPUT: PORTS 780 & 781	ADC = 780
SWITCH 2 ON, OTHERS OFF	INPUT: PORTS 788-791 OUTPUT: PORTS 788 & 789	ADC = 788
SWITCH 1 ON, OTHERS OFF	INPUT: PORTS 796-799 OUTPUT: PORTS 796 & 797	ADC = 796

Substitute the ADC (Analog to Digital Converter) number from FIGURE 2 in line #10 of the following BASIC program if an alternate switch setting is used.

```
10 ADC = 772: START = ADC + 1
20 OUT START, 0: REM START CONVERSION
30 GOSUB 1000: REM READ ANSWER
40 LOCATE 1,1: PRINT COUNT/4000: REM SCALE IN VOLTS
50 GOTO 20
1000 WAIT ADC, 128, 128: X = INP(ADC)
1010 COUNT = X MOD 16 + (INP (ADC + 1) MOD 16) * 10 +
      (INP (ADC + 2) MOD 16) * 100 + (INP (ADC + 3) MOD 16)
```

```

* 1000
1030 IF X AND 32 THEN COUNT = COUNT + 10000
1040 IF X AND 64 THEN COUNT = -COUNT
1050 RETURN

```

Line 10 assigns variable names to the port addresses. Line 20 begins the conversion. Line 1000 waits for the conversion to finish then sets the temporary variable X equal to INP (ADC). INP (ADC) MOD 16 is the least significant digit of the answer, INP (ADC + 1) MOD 16 is the tens place of the answer, etc. In line 1010 the four least significant digits are weighted and added to equal COUNT. In line 1030 a flag bit is tested. If bit 5 is a one, then the most significant digit of the answer is a one. The most significant digit has a weight of 10000 so 10000 is added to the COUNT. Line 1040 tests a flag at bit 6. If bit 6 is a one then the answer is negative. Line 40 displays the result in volts. The count will be between -19999 and +19999. Each count represents a quarter of a millivolt. Line 50 repeats the process.

RUN the program. (Use Ctrl Break to exit.) The voltage should appear in the upper right-hand corner of the screen. The Model 140 Analog Interface resolves 1/4 of a millivolt. To scale the answer in millivolts, the COUNT should be divided by 4. To scale in volts, the COUNT should be divided by 4000. A fresh D cell should read about 1.5 volts (6000 counts). Connecting the input wires directly together will cause a potential of zero volts. The reading with the input shorted should be within 0.75 millivolts (3 counts) of zero. An open circuit or overvoltage will read unpredictably. Be aware that an overvoltage can give a reading of 2500.0 millivolts. The input channels are protected against overvoltages of up to 200 volts. Reverse the wires and note the polarity change. Note that the plus sign is implicit and does not appear.

The conversion itself takes 134 milliseconds (approximately 1/7 of a second). If the WAIT immediately follows the START instruction the computer will mark time until the 134 milliseconds are over. The computer can use that time to do other things if those appear between the START and WAIT instructions in the program. If the conversion is already over when the WAIT instruction is encountered, then no delay will result. To obtain a higher sampling rate add this line to the above listing:

```

1020 OUT START, 0

```

Also change line 50 to GOTO 30. Now the next conversion will be in progress while the last one is being processed and printed.

### **SECTION 3. SELECTING OTHER INPUT CHANNELS**

First connect the other voltage to be measured to an unused pair of input pins on the Model 140's connector. See Figure 1. The four available channels are numbered 0 through 3. To select a channel, substitute the channel number to be selected for the "x" in this instruction.

```

OUT ADC, 16 * x

```

Channel 3 could be selected using the instruction OUT ADC, 48 or OUT ADC, 16 \* 3.

Here is a sample routine which will measure the voltage at each channel and print the data:

```
10 ADC = 772: START = ADC + 1
15 FOR N = 0 TO 3
20 OUT ADC, 16 * N: REM SELECT CHANNEL N
25 OUT START, 0: REM START CONVERSION
30 GOSUB 1000: REM READ ANSWER
40 PRINT COUNT/4000: REM SCALE IN VOLTS
50 NEXT N
60 END
1000 WAIT ADC, 128, 128: X = INP(ADC)
1010 COUNT = X MOD 16 + (INP (ADC + 1) MOD 16) * 10 +
      (INP (ADC + 2) MOD 16) * 100 + (INP (ADC + 3) MOD 16)
      * 1000
1030 IF X AND 32 THEN COUNT = COUNT + 10000
1040 IF X AND 64 THEN COUNT = -COUNT
1050 RETURN
```

Running this program with no connections made on channels 1 through 3 will do no harm. However, the data from those channels will be meaningless. Notice that after the program has run, channel 3 is still selected. An OUT START, 0 instruction would measure the voltage at channel 3. Turning the power off and on or OUT ADC, 0 will reselect input zero.

To speed up the sampling, the same principle can be applied. Add the following line to the above listing to create an all-purpose subroutine:

```
1020 OUT ADC, NEXTCHANNEL: OUT START, 0
```

Set NEXTCHANNEL equal to the selection code for the channel to be sampled next and GOSUB 1000. The routine will return, as before, with COUNT equal to the result of the last conversion and with the next conversion in progress.

#### **SECTION 4. USING THE CONTROL OUTPUTS & DIGITAL INPUT**

There are four optically isolated output lines on the Analog Interface card. These are intended primarily for expanding the number of input channels using an external multiplexer. Any channel can be expanded to 16 channels with an external multiplexer. The optically isolated control lines prevent ground loops from being formed. Configurations of up to 64 analog inputs are possible with four Model 17 Multiplexers. The outputs can also be used for digital control. Think of each one as a contact closure to guard.

The output port has the same address as the input channel selector. The lower four bits appear, optically isolated, at the connector. 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.

#### **FIGURE 3. OUTPUT CODES**

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 it is necessary to alter the output code without affecting the input channel selection, the input selection code should be added to the output code. For example, to select input channel 1 with output code 15 use OUT ADC, 16 + 15 or OUT ADC, 31.

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.

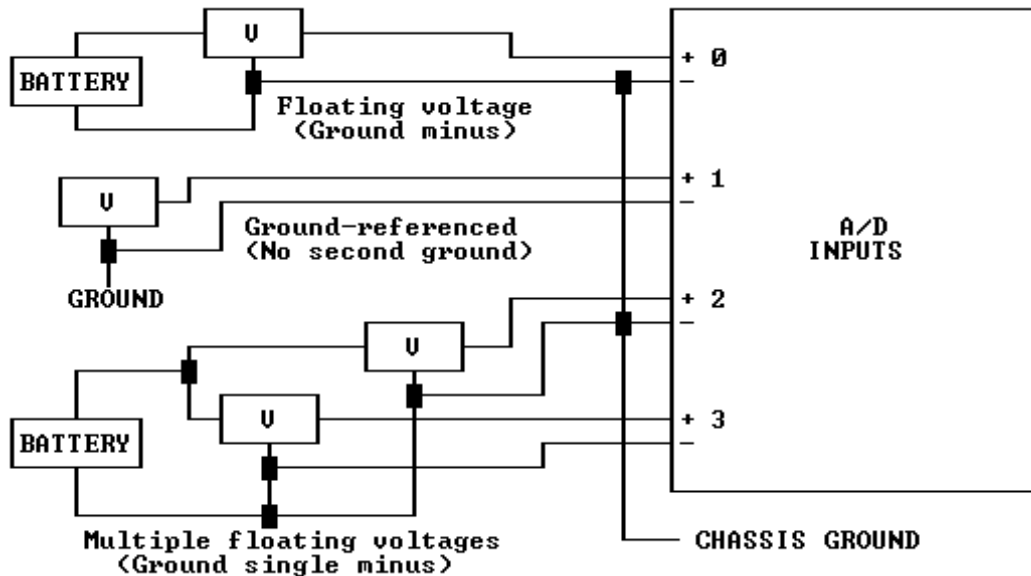
```
IF (INP(ADC) AND 16) THEN PRINT "off" ELSE PRINT "on"
```

## SECTION 5. OPERATING SUGGESTIONS

The Analog Interface 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 Analog Interface card requires a vanishingly small input current so the error caused by even very long wires is negligible. For proper operation of the Analog Interface it is necessary that the negative input be reasonably close to 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 wire, but the resulting voltage drop will not cause a measurement error. 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.

**FIGURE 4. TYPICAL INPUT CONNECTIONS**



The Model 140 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 connected at one end to ground. Sometimes twisting together the plus and minus wires on an input to form a twisted pair will eliminate pick-up. If noise problems persist, try to locate the source of the interference and shield it. Electric motors, electric heaters and flickering fluorescent lights are potential sources of interference.

Programmers should note that the lower 4 bits at the input ports are the conversion result in binary coded decimal (BCD). The least significant digit is at address ADC, the next digit at ADC+1, etc. The upper 4 bits are always the same. The most significant bit, bit 7, is a "converting" bit, bit 6 is the sign bit, bit 5 is the 10 thousands count (0 or 1), and bit 4 is the digital input.

Note: When programming in C, assembly or other fast languages, you will need to add a 1 millisecond delay after the status check and before reading the registers.

## **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 140. 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 0.75 millivolts of zero, 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.

The ADC port address is wrong or in conflict with another card. The computer is WAITing indefinitely for the conversion to finish.

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 reading the voltage is certainly unsteady. The Analog Interface will filter out high frequency noise. However, any oscillation below 50 cycles per second can cause increased scatter.

## **SECTION 7. INTERNAL ADJUSTMENTS**

The only adjustment on the Analog Interface card is a gain control. This adjustment 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 Analog Interface Card at the rear. A clockwise rotation will reduce the reading. It is best to make any adjustment with the card at its normal operating temperature.

## **SECTION 8. SPECIFICATIONS**



TYPE: Dual slope A/D with automatic zero  
and automatic polarity control

INPUT  
RANGE: +4.75 to -5 volts guaranteed  
+/-5 volts typical

RESOLUTION: 0.25 millivolts

LINEARITY: 0.005% of full scale

ACCURACY: 0.025% of full scale  
at normal operating temperatures

INPUT  
IMPEDANCE: 1000 megohms typical

CONVERSION  
TIME: 134 milliseconds

ANALOG  
INPUTS: 4 channels fully differential  
protected to 200 volts

DIGITAL  
INPUT: Contact closure to ground  
or TTL or 5 volt CMOS logic level

OUTPUTS: 4 latched optically isolated channels  
protected to 200 volts  
Each output will drive two low-power TTL  
loads or many CMOS loads

TYPICAL POWER  
CONSUMPTION: +5v....160 milliamps  
+12v...17 milliamps  
-12v...15 milliamps

SIZE: 3.9 x 6.75 inches  
0.625 inches maximum height

#### **LIMITED WARRANTY**

The Lawson Labs, Inc. Model 140 Analog Interface 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.