

DIY KIT 93. PC DATA ACQUISITION UNIT

INTRODUCTION

This kit connects to the standard PC parallel printer port and provides a 'real world' interface for your computer. It enables the PC to both monitor and control external events and devices. The world is a mixed analog & digital world. With the appropriate sensors the PC can monitor physical variables such as pressure, temperature, light intensity, weight, switch state, movement, relays etc, process the information and then use the result to control physical devices such as motors, sirens, other relays, servo motors & up to two stepper motors. It is the recent availability of cheap yet powerful A/D (analog to digital) and D/A (digital to analog) IC's which has made this kit possible.

On the input side the kit has sixteen digital & eleven analog inputs; for output it has eight digital & one analog output. It is supplied with a small plastic case complete with screen-printed front and rear panels. The kit requires a 9-to-12V DC power supply. A standard plug pack, centre positive, can be used. Current consumption (unloaded) is less than 50mA.

Connection to the PC is via a 25 way straight-through cable. Interfacing to the kit is made using standard 10, 16 & 20 pin IDC sockets & a PCB-mounted RCA connector. Connectors & cables are not supplied. An adaptor board (optional) with screw terminals is available for easier connecting.

A set of simple DOS utilities (with source code) and code samples are provided to read the inputs or set the outputs.

The kit is constructed on a double-sided, through-hole-plated printed circuit board (PCB). Protel Autotrax & Schematic were used to design the board.

SPECIFICATIONS

Digital outputs (8)

Output sink current 500mA max (open collector)
Output voltage 33V max
Output protection 33V clamped to ground

Digital inputs (16)

Input voltage 20V max (TTL inputs)
Input protection 1K series resistor with 5V zener to ground

Analog inputs (11)

Voltage range 0 - 5V
Resolution 10 bits (5mV/step)
Conversion time 21uS
Total access time 21uS + 10 I/O clock periods
Input resistance typically >100M
Input protection +/- 20mA max input current.
+/- 30mA max total input current.

Analog outputs (1)

Voltage range 0 - 2.5V or 0 - 10V
Resolution 8 bits (20mV/step)
Output current Depends on power supply voltage.
(See description)

ASSEMBLY INSTRUCTIONS

It is generally best to add components with the lowest height first (like resistors and diodes) for ease of soldering. Follow the component overlay on the PCB for placement of components. The 5V regulator does not need a heatsink. Fix the regulator to the PCB using the nut and bolt provided. There are several points to note during assembly:

- keep the power jack faced square to the front of the PCB when soldering. Do not let it go in skew.
- keep the box headers flat on the PCB when soldering.
- the RCA connector holes need a little filing to fit in.
- the power-on LED requires a 6mm hole to be drilled in the front panel in the top righthand corner. Use a suitable length of wire to connect back to the PCB.
- the PCB uses only six of the eight mounting posts on the bottom of the plastic case. Remove the two posts that are not needed. These can easily be 'snipped' off using wire cutters.

Before mounting the assembled PCB into the case please note the position of pins 1, 2, 3, etc. on the Analog In, Digital In & Digital Out box headers. Pin 1 is marked on the front panel for each. All odd-numbered pins are on one row and all even-numbered pins on the other. Follow the schematic to see which pins are earth or tied high. Finally, apply power to the board and leave it on. Check that none of the ICs get warm. If an IC does get hot check for solder shorts and that the ICs are in their sockets correctly.

To mount into the case, fit the front and rear panels to the PCB and hold them together. Slowly position the PCB into place, making sure that the front and rear panels slide into the slots provided at the front and rear of the case. Note that you must do the calibration (next section) before you screw down the lid. Also note the jumper setting for the analog output range.

CALIBRATION & TESTING

The analog-to digital converter chip (IC5) requires an external reference voltage for accurate data conversion. This is provided by IC6, a precision reference diode. Using a multimeter, measure the voltage at pin 14 of IC5 and adjust trimpot RV1 until it reads exactly 5.00V. For convenience, pin 14 has been brought to a pad marked 'adjust for 5V here'.

The first thing to check is that the unit works. A set of software utilities are supplied which can quickly check all four functional blocks. These checks assume you are using LPT1. (Refer to "Software Utilities" section)

ANOUT 10 6.7 will set 6.7V on the analog out jack if the range jumper is set to 10V. Remember that the minimum resolution (variation) is 20mV.

DIN x returns the level of the selected digital input. According to the specifications for HCT series logic, the minimum input high level voltage is 2.0V; the maximum input low level voltage is 0.8V. Voltages between these two levels can be read either as high or low.

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ANIN x reads the voltage input level of the selected analog input & prints it to the screen. Try connecting the analog output to one of the analog inputs. Use the software to set the output voltage then read it back on the analog input. The maximum input that the analog inputs can read is 5 volts and the minimum resolution (input variation) is 5mV.

DOUT xx switches the open collector outputs for the 8-bit hex byte xx. Connecting an LED (with series current-limiting resistor) between each output and a positive power supply will verify that each output is on. Remember to common the power supply 0V terminal to the ground pin(s) on the DAQU.

CIRCUIT DESCRIPTION

The circuit of the Data Acquisition Unit (DAQU) can be divided into four functional blocks:-

Digital outputs are based around IC1, an octal D-type flip-flop. Data is written to the flip-flop via the 8 data outputs of the printer port and then latched by the 'STROBE' signal. The latched outputs feed into IC2, a high current open collector driver. Writing a high (logic 1) to an input of IC1 causes the corresponding IC2 output to switch on.

Output protection of IC2 is provided by internal diodes connected to each output pin and commoned together at pin 10. This pin has a 33V zener connected to ground. This limits the voltage at the output to the zener voltage plus the diode forward drop (approx. 33.7V).

Digital inputs are provided by IC3 and IC4. These are 8-bit parallel-in, serial-out shift registers. They take an 8-bit data byte and convert it to a serial bit stream which can be shifted out under control of the clock inputs. The shift registers also have a serial input so that multiple devices can be cascaded to provide more parallel inputs.

The shift register inputs are only TTL compatible and need to be protected from over-voltage. A 1K series resistor limits the input current while the 5.1V zener diode to ground prevents the input to the IC rising above 5 volts. Inputs of up to 20 volts can be handled quite safely.

Analog inputs are provided by IC5, a 10-bit analog-to-digital converter from Texas Instruments. It has 14 addressable analog inputs and a serial digital interface. The 4-bit address of the analog input is entered serially, after which the ADC performs a conversion. The analog input voltage is converted to a 10-bit digital number. An End-Of-Conversion signal (EOC) indicates that conversion is complete. The 10-bit number is available as serial data. The digital output, N, is given by:

$$N = V_{in} / V_{ref} \times 1024$$

The conversion resolution (minimum step) is

$$\text{Resolution} = V_{ref} / 2^{\text{bits}} = V_{ref} / 1024$$

If $V_{ref} = 5.00\text{V}$ then the resolution is 4.8828mV.

Therefore,

$$V_{in} = N \times 4.8828\text{mV}$$

Only 11 of the 14 analog inputs are available external to the chip. The other 3 are connected internally to self-test voltages. Internal clamping protects the analog inputs from voltages greater than 5V. These clamps can withstand currents of up to +/- 20mA. An external 1K series resistor allows the input voltage to reach +25V or -20V without damage to the chip.

Analog output is provided by IC7, an 8-bit digital-to-analog converter from Analog Devices. It features an internal reference voltage and has a choice of two output voltage ranges, 0-2.56 or 0-10 volts. The range is selected with jumper J1. Note that to use the 10V range, the power supply voltage needs to be at least 12 volts.

The output voltage is given by the equation:

$$V_{out} = N \times \text{RANGE} / 256$$

where

$$N = \text{digital input value (0 - 255)}$$

$$\text{RANGE} = \text{setting of jumper J1 (2.56 or 10)}$$

For the 2.56V range, $V_{out} = N \times 10\text{mV}$.

For the 10V range, $V_{out} = N \times 39.06\text{mV}$.

The maximum supply voltage that IC7 can handle is 18V. This needs to be considered when using DC plug packs or AC adapters. These are usually unregulated, with the actual output being much higher than the 'nominal' rating.

Data is written to the DAC via the data outputs of the printer port and latched in using the 'AUTOFD' signal. The analog output voltage appears at pin 16. Transistor Q1 is used as an output current booster. Resistor R55 provides some short circuit protection for the transistor. The chip monitors the output voltage via pin 15, an output voltage sense input. It detects any voltage variations and adjusts the drive current to Q1 to compensate.

Without a heatsink, transistor Q1 can dissipate a maximum of 1.25W at an ambient (air) temperature of 25°C. It is less than that above 25°C (-10mW/°C). This needs to be considered when using the analog output. The power dissipated by the transistor depends on the power supply voltage, the output voltage and output current. The equation is:

$$\text{Power dissipated in Q1} = (V_{\text{supply}} - V_{\text{out}}) \times I_{\text{out}}$$

Most 12V plug packs are unregulated and actually supply about 14 volts with a 100-200mA load. If we want a 1V output at 100mA, the power dissipated by the transistor is 1.2W (0.1W is dissipated by R55). This is just on the limit of the transistor specification. The transistor gets quite hot

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and may be damaged with continuous use over a long period of time.

The power rating of the transistor needs to be considered when using the analog output. As we can see from the above equation, it is possible to draw more current, provided that the output voltage is also higher. Limiting the power dissipation to 1W maximum should avoid any problems.

PRINTER PORT INTERFACE

Printer cables tend to act as antennas and can pick up interference, especially if the cable is unshielded or running close to other electrical equipment. This noise is usually made up of short duration voltage spikes, which can interfere with the operation of the DAQU.

Series resistors R1-11 and capacitors C1-11 are used to suppress these spikes. They form a low-pass filter which eliminates short duration signals. However, the problem is that signals generated by the computer need to be slowed down to get through the filter circuit. For the values used, this sets the minimum signal pulse width at approximately 1.25uS. This may not be a problem with high-level languages such as BASIC, C or PASCAL. However, it has been found that when using fast computers such as Pentiums, suitable program delays are needed to ensure this minimum pulse width. When talking to the port signals should remain stable for at least 5 to 10 microseconds. One millisecond delays have used in the utilities which come with this kit. You may experiment with shorter delays.

Some of the ICs used in this unit are CMOS devices and cannot be directly driven (reliably) from TTL outputs, such as found on some printer cards. A TTL logic 1 is usually a lower voltage than that required by CMOS devices. Resistors R12-22 have been added to 'pull up' any signals that don't quite meet the CMOS specification.

THE PC PARALLEL PORT

The PC I/O address space reserves three ranges for parallel interfaces.

Port	Interface
3BCH - 3BFH	Parallel interface on MDA card
378H - 37FH	Parallel interface 1
278H - 27FH	Parallel interface 2

Table 1

The standard PC parallel port consists of three registers, each referred to by their functional name. These registers occupy the first three addresses in the range. The first address in the range is referred to as the *base address*.

Data register	Base address	Read/Write
Status register	Base address + 1	Read only
Control register	Base address + 2	Read/Write

For example, for parallel interface 1, the data register would be at address 378H, status register at address 379H and control register at address 37AH.

Note that the data and control registers can be written to and read from. This does not mean that they are bidirectional. It means that the outputs of these registers can be read back to check their status.

During the system boot-up sequence, the BIOS tests for the presence of parallel ports in order, according Table 1. The first port found becomes LPT1, the second LPT2, and so on. The BIOS stores the base address of each port found in a table in the BIOS variable segment of memory, as follows:

Address	Contents
0040:0008H	Base address of LPT1
0040:000AH	Base address of LPT2
0040:000CH	Base address of LPT3
0040:000EH	Base address of LPT4

(If address=0 then there is no port for that LPT number.)

Every signal line on the port, whether it is used for read/input or write/output, is allocated one particular bit at one of the three addresses Base, Base+1 or Base+2. The logic state of the bit indicates the state of the wire (0V or 5V.) The following table shows each printer port signal used by the DAQU and the register, address and bit position associated with it. The last three signal names are preceded by a minus sign. This means that the signal is active low. Writing a high to the bit causes the signal to go low.

Signal	Reg.	Addr.	Bit	Direction
D0	Data	Base	0	Output
D1	Data	Base	1	Output
D2	Data	Base	2	Output
D3	Data	Base	3	Output
D4	Data	Base	4	Output
D5	Data	Base	5	Output
D6	Data	Base	6	Output
D7	Data	Base	7	Output
SLCT	Status	Base+1	4	Input
PE	Status	Base+1	5	Input
ACK	Status	Base+1	6	Input
-STROBE	Control	Base+2	0	Output
-AUTOFD	Control	Base+2	1	Output
-SLCTIN	Control	Base+2	3	Output

SOFTWARE PROGRAMMING

A combination of parallel and serial data transfer is used between the computer and the DAQU. The standard PC printer port is generally an output only port, with only 4 inputs available for reading data into the port. When writing to the DAQU, parallel data transfer is used. When reading from the DAQU, serial data transfer is used.

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Digital and analog outputs:

The procedure for setting each of these outputs is almost identical. The 8-bit output data is written to the printer port data register. This data appears at the inputs of both IC1 and IC7. (Look at the schematic.) To set the digital outputs, pulse the 'STROBE' signal low. To set the analog output, pulse the 'AUTOFD' signal low. Both 'STROBE' and 'AUTOFD' are active low signals so the corresponding register bit needs to be set high for the signal to go low.

The following QBASIC example switches on digital outputs 0, 1, 2 and 3.

```
PORT = &H378
OUT PORT, &H0F
OUT PORT+2, &H01
OUT PORT+2, &H00
```

The first line defines the base address of the printer port, 378H. The second line writes 0FH (binary 00001111) to the data register. Remember that writing a logic 1 switches on the output. The third line sets the 'STROBE' signal low (bit 0 of control register). The last line sets 'STROBE' high again.

The same code can be used to set up the analog output. Just change the second last line to use the 'AUTOFD' bit (&H02) instead of the 'STROBE' bit.

The printer port output data is stored in latches so the commands do not have to be repeated to keep any wire in a particular state.

Digital inputs:

Before reading the digital inputs, they must be loaded into the shift registers IC3 & IC4. A series of 15 clock pulses is then used to shift out each data bit ready for reading. The data is shifted out most significant bit first.

When the PL input (pin 15) is low, data is loaded into the registers on the next rising edge of CLK (pins 6 & 7). When PL is high, the data loaded from each input pin is shifted to the output pin with each rising edge of CLK. Note that the P7 input data automatically appears on the D7 output (pin 13) after the registers are loaded - no CLK pulse is necessary. Each data bit is read in using the 'PE' printer port status line. After seven CLK pulses the remaining data bits from IC3 have been shifted out.

The SER input (pin 1) of IC3 is connected to the D7 output of IC4. A further eight CLK pulses will now shift out the data bits loaded into IC4.

Fifteen CLK pulses are needed to read all 16 digital inputs. If you only want inputs 1-8 then only seven CLK pulses are required. If you only want to read in input number 8 (P7 of IC3) then you don't need any.

The following printer port lines are used to communicate with the digital input shift registers:

D0..... PL input

D1 CLK inputs
PE..... Data (Q7) output

The following QBASIC program reads in the first eight digital inputs (1-8). It is included on the distribution disk (DIN.BAS). **Note:** Line numbers are for reference only.

```
1. PORT = &H378
2. PE = 32
3. OUT PORT, &H00
4. OUT PORT, &H02
5. OUT PORT, &H00
6. OUT PORT, &H01
7. BITS = 0
8. X = INP (PORT+1) AND PE
9. IF X = PE THEN BITS = 128
10. FOR I% = 6 TO 0 STEP -1
11.  OUT BASE, &H03
12.  OUT BASE, &H01
13.  X = INP (PORT+1) AND PE
14.  IF X = PE THEN BITS = BITS + (2 ^ I%)
15. NEXT I%
16. PRINT BITS
```

Line 1 defines the printer port base address.

Line 2 defines the 'PE' input mask value ($2^5 = 32$).

Lines 3 to 7 load the input data into the shift registers.

Line 7 initializes the result to zero.

Line 8 reads the printer port 'Status' register and masks off all bits except the 'PE' input. This is the data bit read from the shift registers.

Line 9 tests 'PE' and, if set, adds in the "value" of this bit.

In this case it is bit 7 so its value is 128 (2^7)

Line 10 sets up a loop to read in the remaining bits.

Line 11 & 12 shift out the next data bit to be read. The shift register CLK input is set high then low.

Line 13 determines the setting of 'PE' (0 or 1)

Line 14 checks if the bit just read is set (=1). If so, it adds in the "value" of that bit ($2^{\text{bit number}}$).

Line 15 repeats the loop until all bits have been read.

Line 16 prints the result (in decimal).

Analog Inputs:

A 4-bit serial address selects the analog input to be converted. This address is shifted in on the rising edge of the I/O clock. At the same time, data from the previous conversion is available on the falling edge of the clock. This data can be ignored if not required.

The device is selected by taking the CS input (pin 15) low. The MSB bit (bit 9) of the previous conversion is available on DOUT (pin 16). The MSB of the address of the next input to be converted is sent to the ADDR input (pin 17). The CLK input (pin 18) is taken high which shifts in this address bit. The CLK input is then taken low, which shifts out the next bit of the previous conversion data. This process repeats for another three CLK cycles to shift in the remaining address bits. A further six CLK cycles are necessary before the conversion cycle can start (and also to shift out the remaining data from the previous conversion).

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After the tenth CLK pulse, the conversion cycles begins. The EOC output (pin 19) goes low to indicate that a conversion is in progress. The CLK input should remain low during the conversion time. The EOC output goes high at the end of the conversion cycle. The printer port ACK input is used to monitor the EOC output. The digital data is shifted out on the next ten falling edges of the CLK input.

The following printer port lines are used to communicate with the A/D chip, IC5:

D0..... ADDR input
D1..... CLK input
SLCTIN..... CS input
SLCT DOUT output
ACK EOC output

The following QBASIC program reads analog input 0 (A0) and prints the result to the screen. Previous conversion data is ignored. It is included on the distribution disk (ANIN.BAS). **Note:** Line numbers are for reference only.

```
1. PORT = &H378
2. ACK = 64
3. SLCT = 16
4. OUT PORT+2, &H08
5. OUT PORT, &H00
6. FOR I% = 1 TO 10
7.   OUT PORT, &H02
8.   OUT PORT, &H00
9. NEXT I%
10. DO
11.  X = INP (PORT+1) AND ACK
12. LOOP UNTIL X = ACK
13. N = 0
14. FOR I% = 9 TO 0 STEP -1
15.  X = INP (PORT+1) AND SLCT
16.  IF X = SLCT THEN N = N + (2 ^ I%)
17.  OUT PORT, &H02
18.  OUT PORT, &H00
19. NEXT I%
20. OUT PORT+2, &H00
21. VIN = N * 0.0048828
22. PRINT VIN
```

Line 1 defines the printer port base address.

Lines 2 & 3 define the input mask values for 'ACK' and 'SLCT'

Line 4 selects the A/D chip (CS low)

Line 5 sets the address bit

Line 6-9 shifts in the 4-bit address (all zeros in this case) plus 6 more CLK cycles to start the conversion process.

Lines 10-12 wait for the EOC signal to go high.

Line 13 initializes the result to zero

Lines 14-19 clock the serial data out of the A/D chip. If a bit is set (=1) its binary value ($2^{\text{bit number}}$) is added to the result.

Line 20 deselects the A/D chip (CS high)

Line 21 converts the digital data to an analog voltage value in the range 0-5 volts.

Line 22 prints the result (in decimal).

SOFTWARE UTILITIES

A set of four DOS utilities are provided with this kit. The utilities are used to set analog and digital outputs and read the analog and digital inputs. The programs are written in Turbo C and the source code is supplied. In each case, entering the program name without any parameters displays a help message.

DOUT.EXE - switches open collector digital output port.

Syntax: DOUT</port> HEX_BYTE

</port>Optional LPT port number - defaults to LPT1

HEX_BYTE8-bit hex value to write to output port

On exit: ERRORLEVEL = 0 if all OK

ERRORLEVEL = 1 if parameter error or invalid LPT port

DIN.EXE - returns the level on one of the digital inputs.

Syntax: DIN</port> CHANNEL

</port>Optional LPT port number - defaults to LPT1

CHANNELDigital input channel number (0 - 15)

On exit: ERRORLEVEL = 0 if input is low

ERRORLEVEL = 1 if input is high

ERRORLEVEL = 2 if error

ANOUT.EXE - sets the output voltage of the analog port. The output voltage is passed as a parameter on the calling line. For example 'anout 10 5.7' sets 5.7V when the range is selected to 10V by the jumper & LPT1 is used.

Syntax: ANOUT</port> RANGE OUTPUT

</port>Optional LPT port number - defaults to LPT1

RANGEVoltage range setting of jumper 'J1' - 2.5 or 10

OUTPUTOutput voltage setting - must be less than RANGE

On exit: ERRORLEVEL = 0 if all OK

ERRORLEVEL = 1 if parameter error

ERRORLEVEL = 2 if End-Of-Conversion time out

ANIN.EXE - reads the voltage level on one of the A/D inputs. The voltage level is printed to the screen.

Syntax: ANIN</port> CHANNEL

</port>Optional LPT port number - defaults to LPT1

CHANNELAnalog input channel number (0 - 13)

Note:

Channels 11-13 are internal test channels. Channel 12 returns zero, channel 11 returns $V_{\text{ref}}/2$ (01FFh) and channel 13 returns V_{ref} (03FFh).

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REFERENCES

The Internet is the place to get references and any sort of technical support.

Data sheets for the TLC1543 are available from the Texas Instruments web site at <http://www.ti.com>.

Data sheets for the AD558 are available from the Analog Devices web site at <http://www.analog.com>.

Data for the 74HCT166 and 74HCT374 can be found in any TTL data book. Functionally, they are identical to the LS series of parts.

A good place to start looking for technical data on the PC printer port is on Jan Axelson's web site at <http://www.lvr.com>. Many links are included for further information. (See her article Using the New Parallel Ports in *MicroComputer Journal*, July-August, 1996, pages 14-19.)

Nuts & Volts Magazine had some up-to-date introductory articles on the latest A/D and D/A in their 4/96 & 5/96 issues.

A similar but less powerful DAQU was described in *Electronics Australia*, June 1996, pages 54-59. (It has no digital inputs nor a box.)

SOFTWARE UPDATES & PROBLEMS

If you have any problems or requests please contact us. We are now working on an **improved software interface** for this kit. Register your name with us for notification when this software is available. Software may be downloaded from our web site.

DIY Electronics

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PARTS LIST - KIT 93

Resistors (0.25W, 5%)

10R	R55	1
22R	R23-25	3
1K	R1-11, R26-52, R54.....	39
4K7	R53	1
10K	R12-22	11
10K 10 turn trimpot	RV1	1

Capacitors

220pF ceramic	C1-11	11
100nF monoblock	C12-16, C18, C20.....	7
10uF 16V electro	C19	1
1000uF 35V electro	C17	1

Semiconductors

1N4004	D1	1
1N4752, 33V 1W zener	ZD1	1
IN751A	ZD2-17	16
5.1V 400mW zener		
74HCT374	IC1	1
Octal d-type flip flop		
74HCT166	IC3,4	2
8-bit shift register		
ULN2803A	IC2	1
Octal open collector driver		
TLC1543	IC5	1
Texas Instruments, 10-bit A/D converter		
LM336Z-5	IC6	1
5V reference diode		
AD558	IC7	1
Analog Devices, 8-bit D/A converter		
7805 regulator, TO-220	IC8	1
BD139 transistor	Q1	1
LED, 5mm red	L1	1

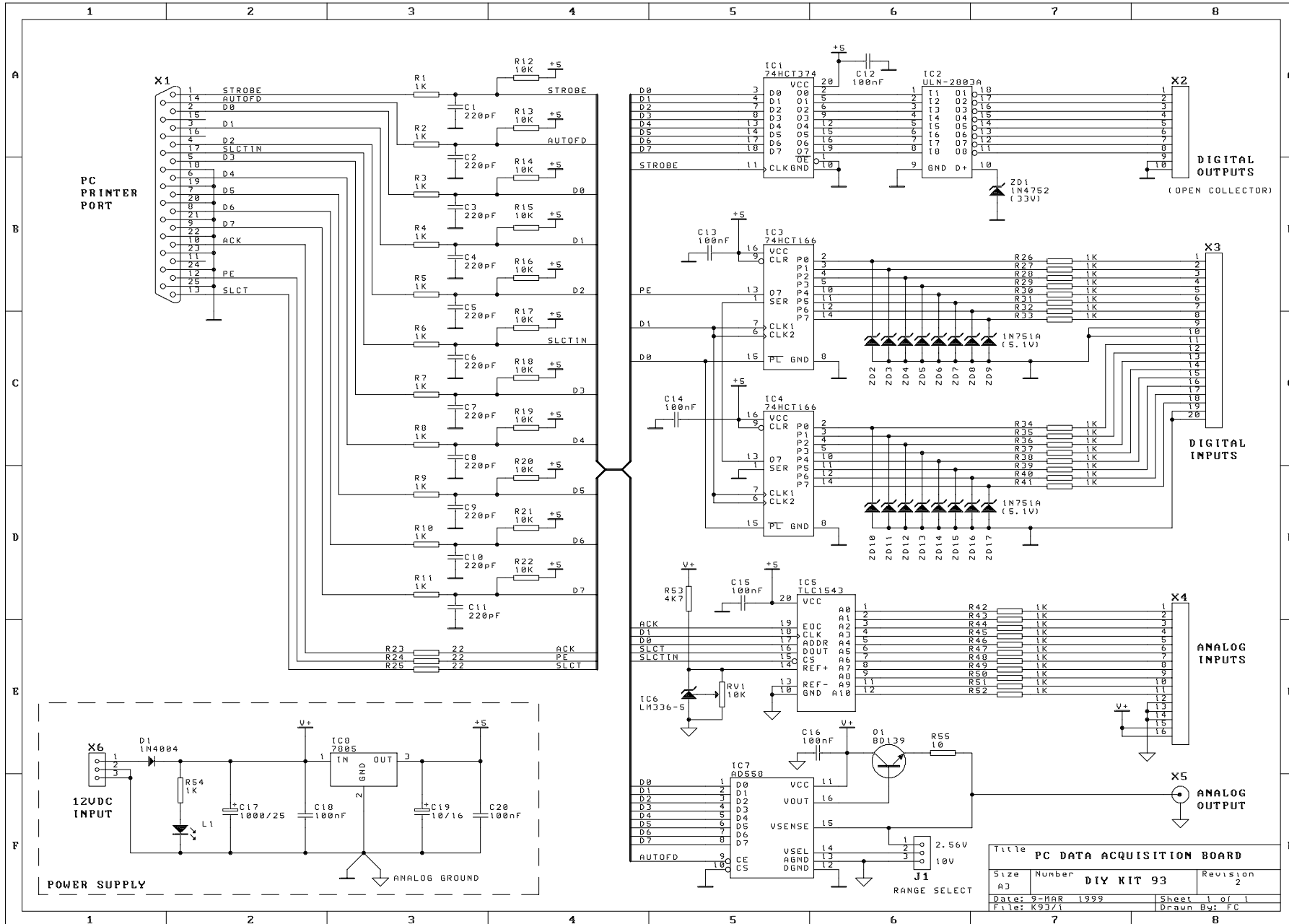
Miscellaneous

D25 connector	X1	1
PCB mounting, male		
10 pin R/A box header	X2	1
16 pin R/A box header	X4	1
20 pin R/A box header	X3	1
RCA connector	X5	1
R/A, PCB mounting		
2.5mm DC jack	X6	1
3 pin SIL header	J1	1
and jumper plug		
16-pin IC socket	IC3,4,7	3
18-pin IC socket	IC2	1
20 pin IC socket	IC1,5	2
Plastic case G738 (with 8 screws included)		1
Set of front & rear panels		1
3 x 10mm screw & nut		1
Kit 93 PCB		1
Floppy disk		1

You may contact Frank Crivelli, the designer of this kit directly at

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Title			PC DATA ACQUISITION BOARD		
Size	Number	DIY KIT 93		Revision	2
A3					
Date:	9-MAR 1999	Sheet	1 of 1	Drawn By:	PC
File:	K93/1				

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