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Controlling The Real World With Computers

Hardware Description

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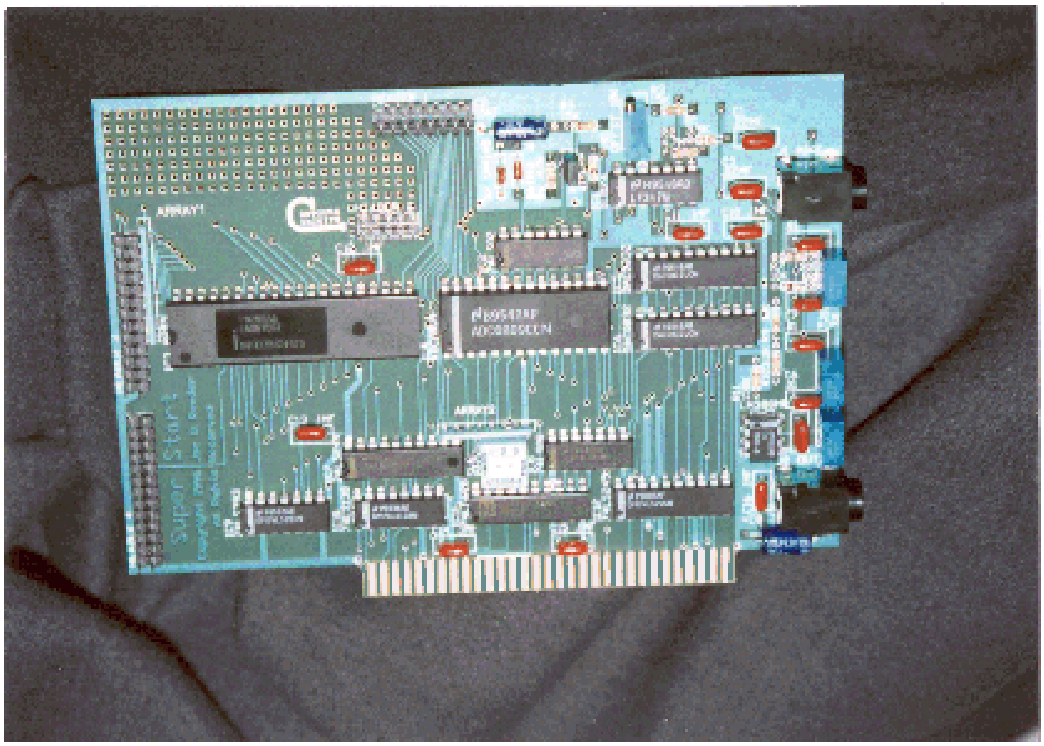


The hardware is shown in the picture (might take a little while to load). Don't be the least bit concerned if you don't understand everything in the first few paragraphs below. Their purpose is to provide a brief description of the hardware to those who understand the terminology. The terms will be second-nature by the time you finish the tutorial. Just skim the information, make a note of the ordering information and Super Start, then move on to the circuit description below. Larger Picture -- 388K

The hardware is a tinned, masked PC-based ISA data acquisition and control board that

- can accept up to 8 analog inputs through its 8 channel, 8-bit analog to digital converter (one has a mike preamp)
- can produce analog output through 2 digital to analog converters (one is connected to an amplifier complete with volume, bass and treble controls that will drive a speaker)
- has 27 digital I/O lines, 24 of which are programmable as inputs or outputs
- offers the opportunity for expansion by providing buffered address, data and control lines, along with three spare select lines
- makes available a spare AND gate, two spare NOR gates and a small breadboarding area
- has everything brought out to headers on the board, except the mike input and speaker output, which are available through miniature phone jacks

Note that the board does not have DMA or interrupt capability. I plan on showing how to add interrupt capability when the Analog to Digital converter section is discussed.

With so much capability, the board can provide almost infinite possibilities for experimentation, and can serve as a base to protype control and embedded systems. See the technology education sites for inspiration. You can order bare boards, kits and assembled boards here. A bare board is only $20, with quantity discounts available for volume users such as technology education classes. You can also get a kit of a board with parts as well as assembled boards. The boards are easy to build with the step-by-step instructions. They even include a soldering tutorial. Download buildit.doc to take a look. It's in Word 97 format. If you don't have Word 97, you can download a free reader from Microsoft's web site by clicking on the following icon.

The board was originally designed for The Super Start Project as well as the hands-on portion of a tutorial and as a development tool. Read the Super Start article to find out about this very important use of the hardware. There are many, many more uses, especially in education. You can also download the free software there. There are several programs that use the board, including some tests which might come in handy. All will provide some insight into using the hardware. There are also some handy routines for placing information on the screen.

More importantly, I hope you will do more than just download the free stuff. I hope you will read the article and pass the information on to others. I figure people who read this site have the knowledge and experience to help others set up Super Start Projects. You can make a huge difference for our kids. I hope you do. It can turn out to be the toughest job you'll ever love, and a lot of kids will thank you someday.

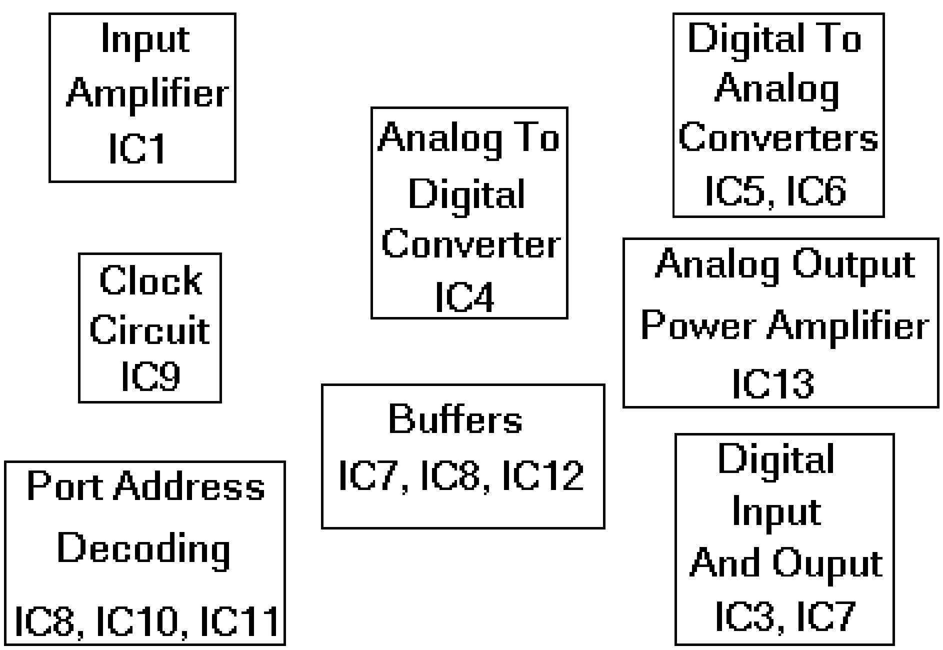
That's my sermon for today.

NOTE: Please be sure to read the Warranty And Disclaimer before ordering!

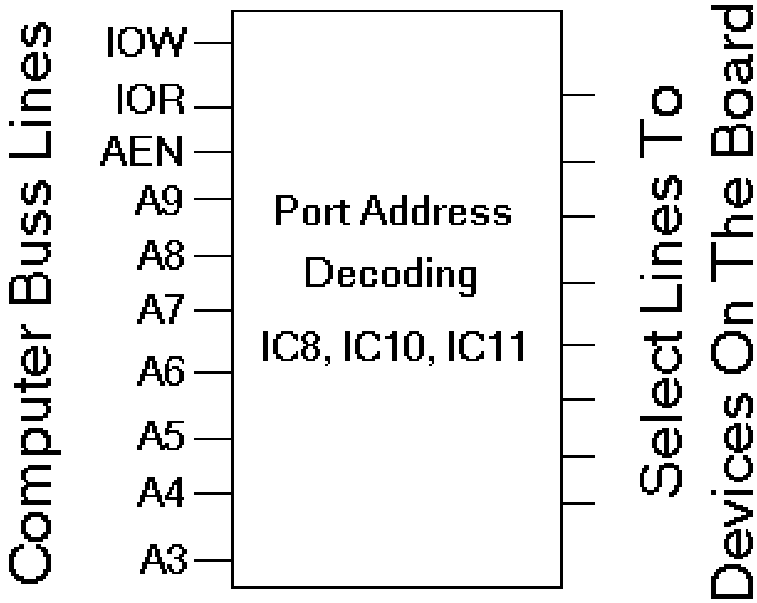
THE CIRCUIT

You will see references to PDF data sheets in the following descriptions. The data sheets might show parts with variations on the part number, but they will have the same functionality. You can download a PDF reader here.

This section will cover parts of the circuit not covered in other parts of the tutorial. The board can be blocked into a few simplified sections. Again, don't be concerned if you don't understand everything in the blocks. All will become clear as you progress through the tutorial:

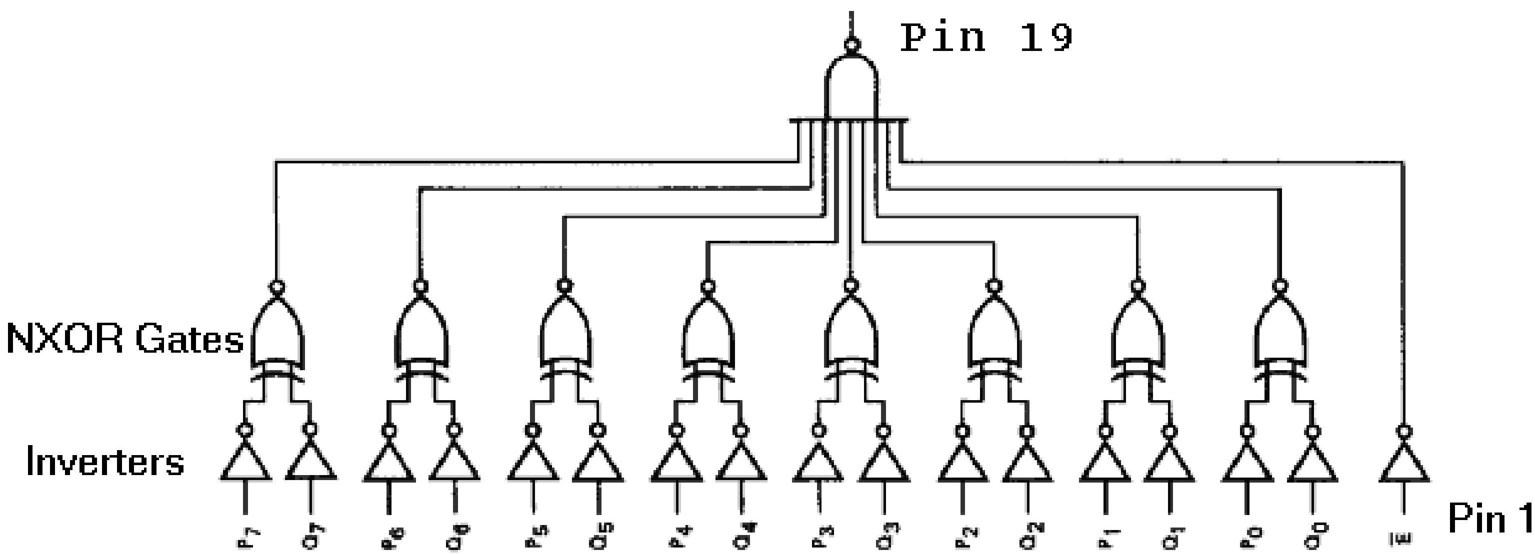


The section that selects the board's port address is outlined below. It is the only part that will not be covered in other parts of the tutorial:



Port addresses on a typical PC Industry Standard Architecture (ISA) bus are derived from the ten address lines A0 through A9, with A9 always high. Note that all buffered lines in the schematics are prefixed with the letter B. Half of IC7, a 74LS244 buffer, is used to buffer the first three address lines and the RESET line. [74LS244.PDF](74LS244.PDF)

Base address selection is made by three DIP switch (see How To Read A Schematic) sections connected to IC11, a 74LS688 8-bit magnitude comparator:



The main logic elements in the 74LS688 are the NXOR gates. Recall from the Boolean Logic section that an XOR gate will produce a high output if the inputs are different. The NXOR does the same thing but inverts the output. The output of one of the NXOR gates above will be low if its inputs are different. Its output will be high if its inputs are the same. The logic is not changed even though pairs of inputs go through inverting buffers. The 9-input NAND gate output will go low when all of the NXOR outputs go high along with the enable input on pin 1. 74LS688.PDF

When a switch is closed, its input to the 74LS688 is taken low. When the switch is open, the input is pulled up by a resistor in an array. Corresponding inputs to the comparator are connected to address lines A6 through A8. If a switch is open, its corresponding address line must be high to make the output of its NXOR high. If a switch is closed, its corresponding address line must be low. A9 is also connected, with its corresponding input taken high. Similarly, the AEN (address enable) line is connected to the comparator with its corresponding input connected to ground since AEN is low with a valid port address. The three other pairs are taken high. Finally, either the I/O Read (IOR) or the I/O Write (IOW) line must be low for there to be a valid port address. The bars over IOR and IOW in the schematic mean they are active low. IOR and IOW are first buffered by using two AND gates with one side tied high in IC8, a 74LS08, then ANDed using a third. The result is a signal that will go low if either IOW or IOR goes low. This is tied to the pin 1 enable input of the 74LS688. When all conditions are satisfied, pin 19 of the 74LS688 will go low. 74LS08.PDF

Following are the HEX addresses that can be selected by setting the DIP switches on (1) and off (0), and the possible conflicts that might arise (~ means "through"):

SWITCH		
1 2 3	ADDRESS	POSSIBLE CONFLICTS
1 1 1	200 ~ 23F	200 ~ 20F = game port
0 1 1	240 ~ 27F	278 ~ 27F = LPT2 (OK with no spares used -- see below)
1 0 1	280 ~ 2BF	2B0 ~ 2DF = Alternate EGA
0 0 1	2C0 ~ 2FF	2B0 ~ 2DF = Alternate EGA
1 1 0	300 ~ 33F	300 ~ 31F = Some Sound Cards and The Prototype Card
0 1 0	340 ~ 37F	378 ~ 37F = LPT1 (OK with no spares used)
1 0 0	380 ~ 3BF	380 ~ 38F = bisynchronous 2
		390 ~ 393 = cluster
		3A0 ~ 3AF = bisynchronous 1
		3B0 ~ 3BF = mono adapter and printer adapter
0 0 0	3C0 ~ 3FF	3C0 ~ 3CF = EGA

The best choices would probably be HEX 200 or 300. If the board is used on a dedicated computer however, any conflicting devices not used could be removed from the computer.

Pin 19 on the 74LS688 enables IC12, a 74LS138 3-to-8 line decoder/multiplexer. It uses address lines A3 through A5 to break the above up into eight-byte chunks used by devices on the board. Providing it is enabled, the 138's select lines are activated in the following manner:

A5	A4	A3	Output Pin Active Low
0	0	0	15
0	0	1	14
0	1	0	13
0	1	1	12
1	0	0	11
1	0	1	10
1	1	0	9
1	1	1	7

There is a reason for eight-byte chunks. The ADC0809 has eight channels and uses the first 8 bytes of a port address location to select them. That's also why it uses A0 through A2. Since the '138 selects 8 devices and each is 8 bytes wide, the board needs a total of 64 bytes port address space. 74LS138.PDF

The device selections for all possible switch settings are shown below. The first entry for each corresponds to the base address in the table above. Don't be concerned if you don't know what some of the items in the tables mean. They will be covered in the experiments. Notice that each of the 8 devices on the board is 8 bytes from a device next to it:

200 ~ 207	Eight Channel Analog to Digital Converter
208 ~ 20F	Digital to Analog Converter 1
210 ~ 217	Digital to Analog Converter 2
218 ~ 21F	Analog to Digital Converter Ready Line And 3 Digital Inputs
220 ~ 227	Programmable Peripheral Interface
228 ~ 22F	Spare Select Line
230 ~ 237	Spare Select Line
238 ~ 23F	Spare Select Line

240 ~ 247	Eight Channel Analog to Digital Converter
248 ~ 24F	Digital to Analog Converter 1
250 ~ 257	Digital to Analog Converter 2 (optional)
258 ~ 25F	Analog to Digital Converter Ready Line And 3 Digital Inputs
260 ~ 267	Programmable Peripheral Interface
268 ~ 26F	Spare Select Line
270 ~ 277	Spare Select Line
278 ~ 27F	Spare Select Line

280 ~ 287	Eight Channel Analog to Digital Converter
288 ~ 28F	Digital to Analog Converter 1
290 ~ 297	Digital to Analog Converter 2 (optional)
298 ~ 29F	Analog to Digital Converter Ready Line And 3 Digital Inputs
2A0 ~ 2A7	Programmable Peripheral Interface
2A8 ~ 2AF	Spare Select Line
2B0 ~ 2B7	Spare Select Line
2B8 ~ 2BF	Spare Select Line

2C0 ~ 2C7	Eight Channel Analog to Digital Converter
2C8 ~ 2CF	Digital to Analog Converter 1
2D0 ~ 2D7	Digital to Analog Converter 2 (optional)
2D8 ~ 2DF	Analog to Digital Converter Ready Line And 3 Digital Inputs
2E0 ~ 2E7	Programmable Peripheral Interface
2E8 ~ 2EF	Spare Select Line
2F0 ~ 2F7	Spare Select Line
2F8 ~ 2FF	Spare Select Line

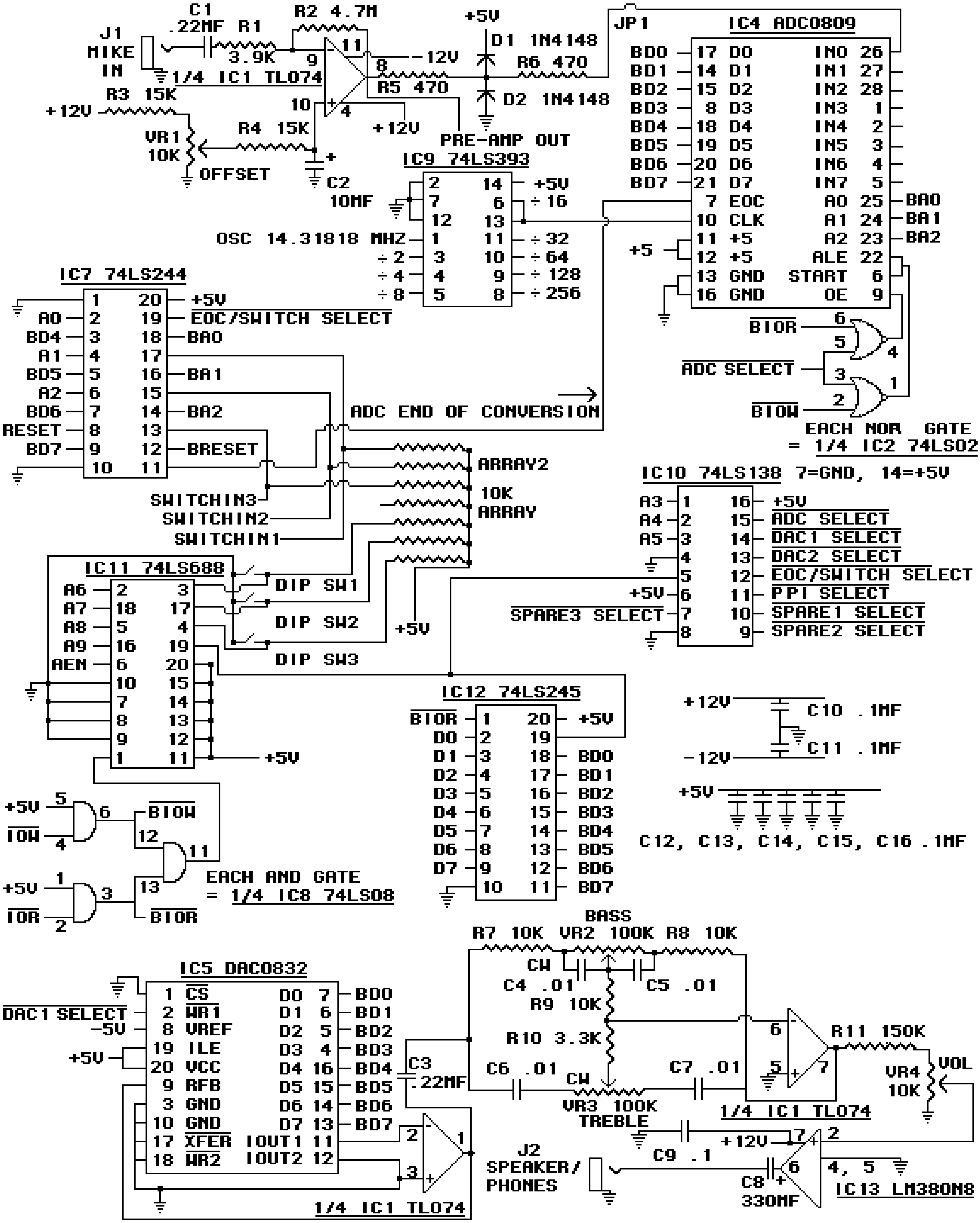
300 ~ 307	Eight Channel Analog to Digital Converter
308 ~ 30F	Digital to Analog Converter 1

310 ~ 317	Digital to Analog Converter 2 (optional)
318 ~ 31F	Analog to Digital Converter Ready Line And 3 Digital Inputs
320 ~ 327	Programmable Peripheral Interface
328 ~ 32F	Spare Select Line
330 ~ 337	Spare Select Line
338 ~ 33F	Spare Select Line

340 ~ 347	Eight Channel Analog to Digital Converter
348 ~ 34F	Digital to Analog Converter 1
350 ~ 357	Digital to Analog Converter 2 (optional)
358 ~ 35F	Analog to Digital Converter Ready Line And 3 Digital Inputs
360 ~ 367	Programmable Peripheral Interface
368 ~ 36F	Spare Select Line
370 ~ 377	Spare Select Line
378 ~ 37F	Spare Select Line

380 ~ 387	Eight Channel Analog to Digital Converter
388 ~ 38F	Digital to Analog Converter 1
390 ~ 397	Digital to Analog Converter 2 (optional)
398 ~ 39F	Analog to Digital Converter Ready Line And 3 Digital Inputs
3A0 ~ 3A7	Programmable Peripheral Interface
3A8 ~ 3AF	Spare Select Line
3B0 ~ 3B7	Spare Select Line
3B8 ~ 3BF	Spare Select Line

3C0 ~ 3C7	Eight Channel Analog to Digital Converter
3C8 ~ 3CF	Digital to Analog Converter 1
3D0 ~ 3D7	Digital to Analog Converter 2 (optional)
3D8 ~ 3DF	Analog to Digital Converter Ready Line And 3 Digital Inputs
3E0 ~ 3E7	Programmable Peripheral Interface
3E8 ~ 3EF	Spare Select Line
3F0 ~ 3F7	Spare Select Line
3F8 ~ 3FF	Spare Select Line



C1 .22MF
R1 3.9K
R2 4.7M
J1 MIKE IN
1/4 IC1 TL074
R3 15K
+12V
VR1 10K
OFFSET
R4 15K
C2 10MF
+5V
D1 1N4148
D2 1N4148
R5 470
R6 470
-12V
PRE-AMP OUT
JP1
IC4 ADC0809
BD0 17 D0
BD1 14 D1
BD2 15 D2
BD3 8 D3
BD4 18 D4
BD5 19 D5
BD6 20 D6
BD7 21 D7
7 EOC
10 CLK
+5 11 +5
12 +5
13 GND
16 GND
IN0 26
IN1 27
IN2 28
IN3 1
IN4 2
IN5 3
IN6 4
IN7 5
A0 25 BA0
A1 24 BA1
A2 23 BA2
ALE 22
START 6
OE 9
IC9 74LS393
OSC 14.31818 MHZ
÷2 ÷4 ÷8
÷16 ÷32 ÷64 ÷128 ÷256
BIOR
ADC SELECT
BIOW
EACH NOR GATE = 1/4 IC2 74LS02
IC7 74LS244
A0 BD4 A1 BD5 A2 BD6 RESET BD7
EOC/SWITCH SELECT
BA0 BA1 BA2 BRESET
ADC END OF CONVERSION
ARRAY2
10K ARRAY
SWITCHIN3
SWITCHIN2
SWITCHIN1
IC10 74LS138 7=GND, 14=+5V
A3 A4 A5
ADC SELECT
DAC1 SELECT
DAC2 SELECT
EOC/SWITCH SELECT
PPI SELECT
SPARE1 SELECT
SPARE2 SELECT
SPARE3 SELECT
IC11 74LS688
A6 A7 A8 A9 AEN
DIP SW1
DIP SW2
DIP SW3
IC12 74LS245
BIOR
D0 D1 D2 D3 D4 D5 D6 D7
BD0 BD1 BD2 BD3 BD4 BD5 BD6 BD7
+12V C10 .1MF
-12V C11 .1MF
C12, C13, C14, C15, C16 .1MF
+5V IOW BIOW
+5V IOR BIOR
EACH AND GATE = 1/4 IC8 74LS08
IC5 DAC0832
DAC1 SELECT
-5V
1 CS
2 WR1
8 VREF
19 ILE
20 VCC
9 RFB
3 GND
10 GND
17 XFER
18 WR2
D0 7 BD0
D1 6 BD1
D2 5 BD2
D3 4 BD3
D4 16 BD4
D5 15 BD5
D6 14 BD6
D7 13 BD7
IOUT1 11
IOUT2 12
C3 .22MF
1/4 IC1 TL074
BASS
R7 10K VR2 100K R8 10K
CW
C4 .01
C5 .01
R9 10K
R10 3.3K
C6 .01
C7 .01
VR3 100K
TREBLE
R11 150K
VR4 10K
VOL
1/4 IC1 TL074
J2 SPEAKER/ PHONES
C9 .1
C8 330MF
IC13 LM380N8

Figure 1: Circuit, Part 1

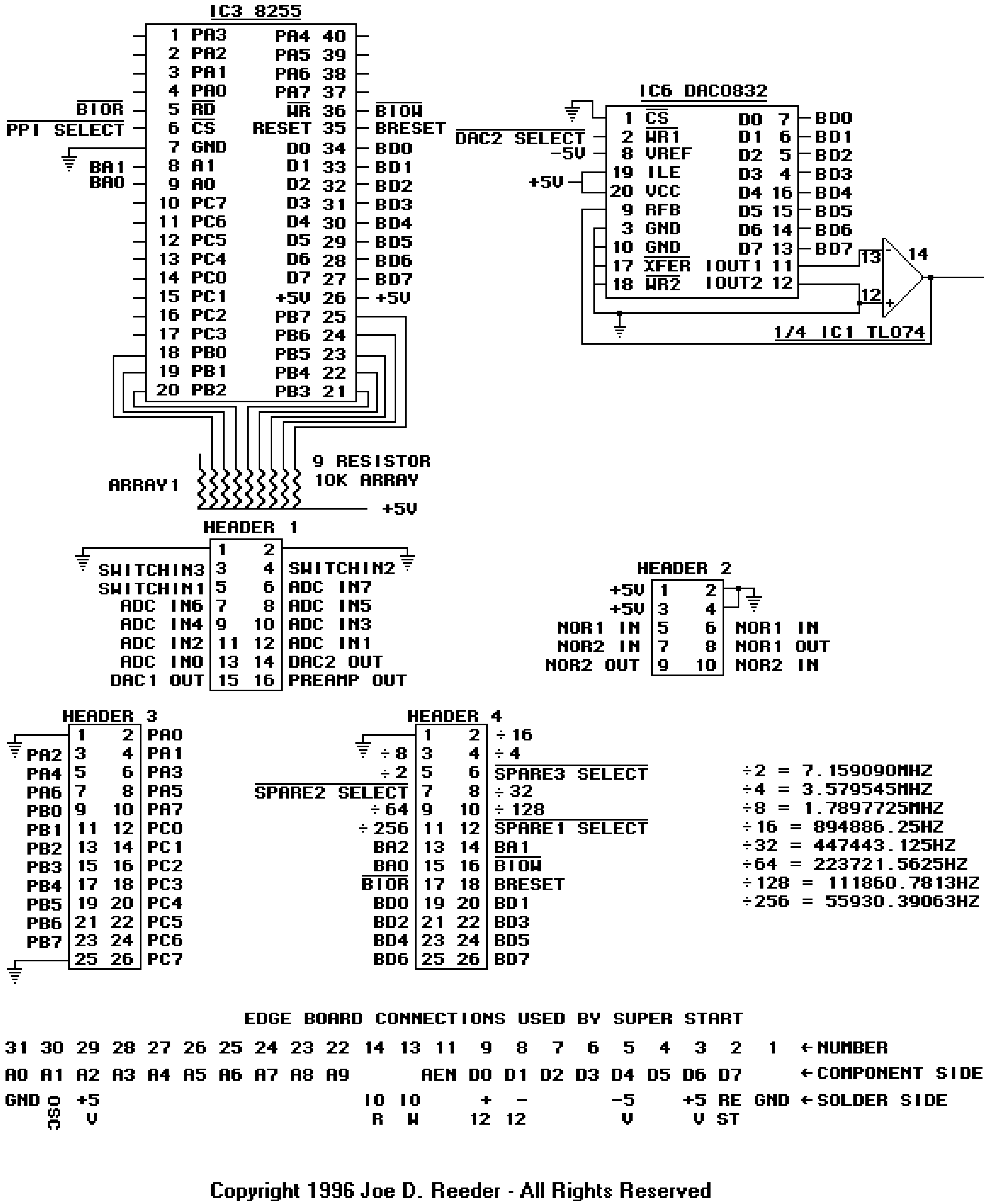


Figure 2: Circuit, Part 2

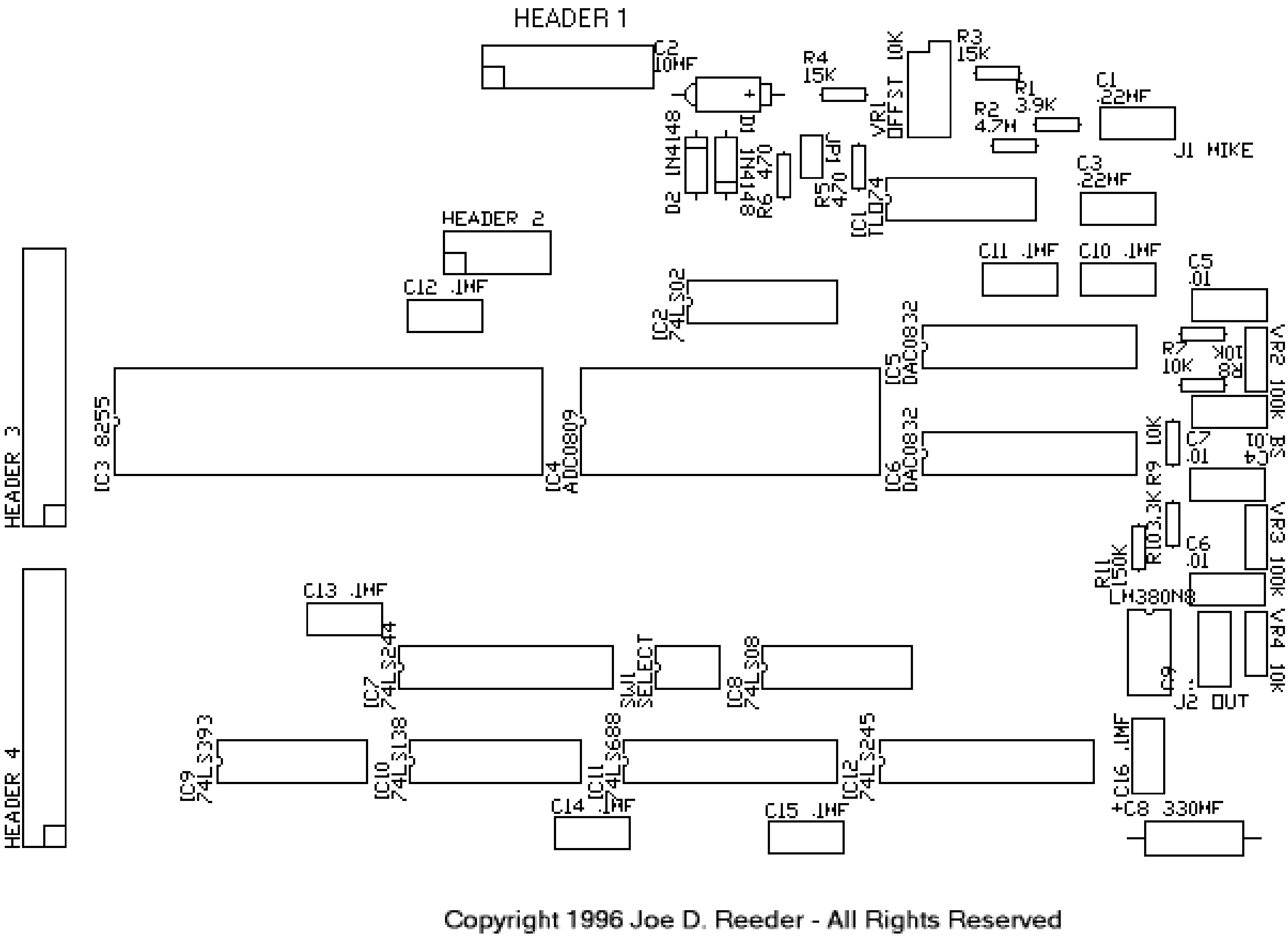


Figure 3: Board Layout Silk Screen Print

The following are provided on the headers:

Header 1:
A. 3 basic switch inputs
B. 8 8-bit Analog To Digital inputs (0 through 5 volts)
C. 2 8-bit Digital To Analog outputs (0 through 5 volts)
D. Pre-amp Output
E. 2 grounds

Header 2:
A. 2 Spare NOR gates (the spare AND is brought out to pads)
B. 2 +5V and 2 grounds

Header 3:
A. 24 PPI I/O lines
B. 2 grounds

Header 4:
A. 1 ground
B. The 14.31818 MHz oscillator divided by 2, 4, 8, 16, 32, 64, 128 and 256
C. 3 Spare Select Lines
D. Buffered address lines BA0 through BA2
E. Buffered data lines BD0 through BD7
F. Buffered read, write and reset lines

Notice the inclusion of spare select lines and buffered data and address lines. They can be used to expand the capabilities. For example, you could add more PPIs to give you more digital I/O lines, or another digital to analog converter or two. There is also a small bread board area.

Figure 4 shows where the controls, mike input and speaker/headphone output are on the board.

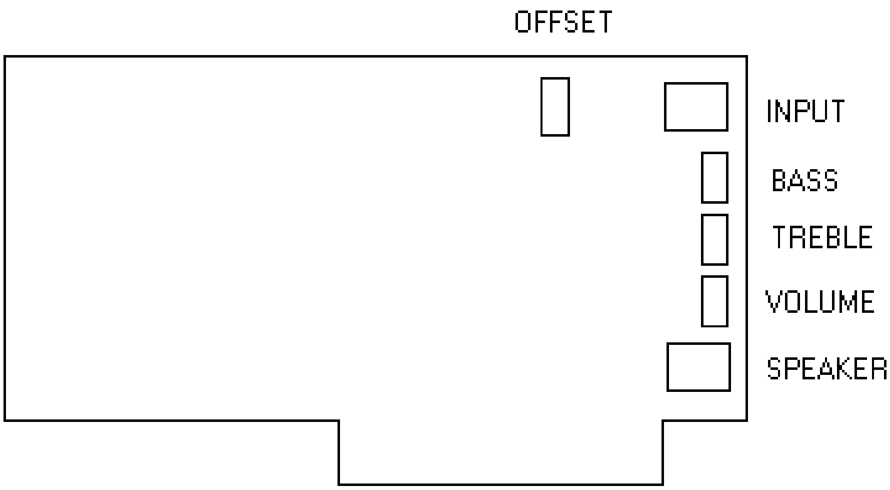


Figure 4: Controls, IN and OUT

Parts List

Parts Needed For Digital Experiments
(These will get you started. I priced them at $18.65, mostly from Jameco .)

Capacitors	
C9, C10, C11, C12, C13, C14, C15, C16	.1MF .2", or 5mm spacing, anything above 5 volts OK, ceramic OK

Resistor Arrays or Networks	
ARRAY1	9 resistor, 10 pin 10K SIP with one end of each resistor commoned to pin 1
ARRAY2	7 resistor, 8 pin 10K SIP with one end of each resistor commoned to pin 1

DIP Switch	
SW1	Three Position DIP Switch

Headers -- All have two rows .1" apart with pins .1" apart	
HEADER 1	2 X 8 pin header
HEADER 2	2 X 5 pin header
HEADER 3 and 4	2 X 13 pin headers

Integrated Circuits -- 74, 74HCT, 74AHC, etc. prefixes may be substituted for 74LS		
IC2	74LS02 quad NOR gate	74LS02.PDF
IC3	8C255 Programmable Peripheral Interface	8255.PDF
IC7	74LS244 octal buffer	74LS244.PDF
IC8	74LS08 quad AND gate	74LS08.PDF
IC9	74LS393 counter	74LS393.PDF
IC10	74LS138 1 of 8 decoder	74LS138.PDF
IC11	74LS688 digital comparator	74LS688.PDF
IC12	74LS245 octal transceiver	74LS245.PDF

Additional Parts Needed For Remaining Experiments
(I priced these parts at about $24.00, mostly from Jameco .)

Variable Resistors	
VR1	10K TRIMMER (25 turn) used for offset -- equal to Bourns type 3296X
VR2 and VR3	100K TRIMMERS used for bass and treble -- equal to Bourns type 3386C
VR4	10K TRIMMER used for volume -- equal to Bourns type 3386C

Capacitors	
C1, C3	.22MF .2" or 5mm spacing film similar to Panasonic ECQ-V1H224JL
C2	10MF 25v axial electrolytic similar to Panasonic ECE-B1EU100S
C4, C5, C6, C7	.01MF .2" or 5mm spacing film similar to Panasonic ECQ-V1H103JL
C8	At least 220MF, at least 6.3v axial electrolytic similar to Panasonic ECE-B0JU331

Jumper	
JP1	.1" Header Type Jumper 

Integrated Circuits		
IC1	TL074 or LF347A quad op amp	TL074.PDF
IC4	ADC0809 8 input, 8-bit AD converter	ADC0809.PDF
IC5, IC6	DAC0832 8-bit DA converter	DAC0832.PDF

IC13	LM380N-8 power amp (8 pin DIP version)	LM380N-8.PDF

Diodes	
D1, D2	1N4148 switching diode

IN/OUT CONNECTORS	
J1, J2	Switchraft 1/8" phone jack -- Mouser Electronics # 16PJ528

Resistors -- All Are 1/8 Watt	
R1	3.9K
R2	4.7M
R3, R4	15K
R5,R6	470
R7,R8,R9	10K
R10	3.3K
R11	150K

See the electronic parts links for parts to build a board.

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