Single Board Relay Computer

Build Instructions

Version: 0.2 (please keep checking for updates, it will take a few more days to complete this document)

Joseph Allen, 2017

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1 Recommended Tools

1.1 Soldering Station

These Hakko 936 clones from Yihua are available at low cost and work fine:

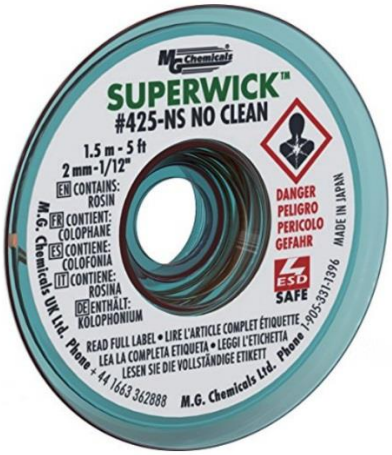
But I recommend a small chisel-tip for it, “0.8D or 1.2D”:

1.2 Solder

You will need rosin flux core 0.8 mm / .032 inch diameter solder. Lead or lead-free is fine:

1.3 Solder Wick and Solder Sucker

Some solder wick and a solder sucker are good to have for fixing mistakes:



1.4 Flux cleaner

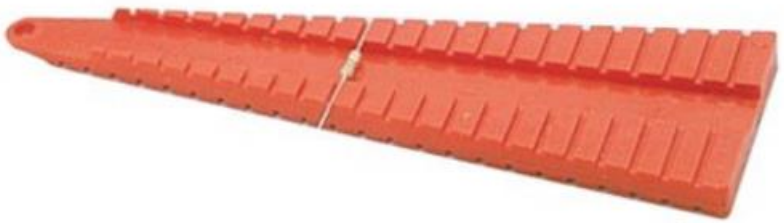
Use this when the entire project is done to clean flux from the solder off the board.

1.5 Diagonal Cutters

You will need these to trim leads from LEDs, resistors, capacitors and diodes.

1.6 Axial part lead forming tool

There are many axial components in the relay computer, so I recommend one of these to save time bending the leads:



You can buy one here:

https://www.jameco.com/z/801-Lead-Forming-Tool-for-Resistors-and-Capacitors_106884.html

1.7 IC lead straightening tool

The pins on new DIP ICs are spread too far apart for easy inserting into IC sockets, so I recommend one of these to save time adjusting the IC leads:

You can buy one here:

https://www.jameco.com/z/ICS-01-R-IC-Pin-Straightener-Tool_99363.html

1.8 Small flat screwdriver

Use to pry ICs out of sockets.

1.9 Multimeter

Use to verify voltages (particularly output of 5V regulator), check continuity during debugging, and verify resistor values. Get one that beeps to indicate continuity.

1.10 Microchip PIC programmer

This is a good idea in case you would like to hack the firmware or to install firmware updates if they are ever necessary. It is very useful for many other projects.

You can buy one here:
http://www.microchip.com/Developmenttools/ProductDetails.aspx?PartNO=PG164130

2 Components

Order the components as shown on the BOM (Bill of Materials). The BOM is located here:

https://sourceforge.net/projects/relaysbc/files

The BOM lists the components I used when I had the contract manufacture produce fully assembled boards.

The components can be ordered from these popular distributers:

http://www.mouser.com/

https://www.digikey.com/

A great resource for checking multiple distributors at once is this:

https://www.findchips.com/

2.1 Substitutions

Many of the parts may be substituted to save money or to customize your relay computer. Here are some guidelines:

2.1.1 LEDs

Any T 1-3/4 LED may be used, but each LED's associated ballast resistor was chosen to provide ~10 mA for orange LEDs. Some of the LEDs are powered from 12 V while others are powered from 5V. I suggest these ballast resistor values for various colors so that the 12V and 5V powered ones have approximately the same brightness:

LED Color	Voltage	Ballast resistor for 12V	Ballast resistor for 5V
Yellow	2.2V	1K	220
Green	2.1V	1K	270
Orange	1.8V	1K	270
Red	1.6V	1K	330
Blue	3.4V	820	120

5V LED current is: (5V - .33V – 1.8V) / 270 ohms = 10.6 mA

1.8V for the LED, .33V for the 74HC595 driver.

12V LED current is: (12V – .8V - 1.8V) / 1000 ohms = 9.4 mA

1.8V for the LED, .8V for the ULN2803A driver.

2.1.2 7-Segment LED display

Any common cathode LED display with the same 18-pin .6" wide DIP pinout as the green LTD-6440G may be used except for blue. I doubt there is enough voltage to drive blue LED displays.

2.1.3 Tactile buttons

Standard 12mm tactile buttons are used and there are many substitutes. There are several styles: the round buttons are made for use without keycaps. Low profile round buttons may use a sticker-paper cover over the entire keypad if you would like to make nice labels. Buttons with square pegs may use keycaps- I recommend small keycaps (6mm) so that you can still read the labels on the PCB silkscreen. Large keycaps may be used, but then you need to screen-print or make labels for them since they obscure the silkscreen.

2.1.4 Relays

There are many 12 V DPDT non-latching DIP relays which will work. However, the 13 relays used as flip-flop bits need to have matching holding resistors. If you select different relays than the ones in the BOM for these, you will have to experiment with different holding resistors.

The holding resistors for the flip flops are these two resistor arrays: R204 and R205. They are 2K ohms for the V23105A5003A201 relays.

The flip flop relays which must match the holding resistors are these: K1, K2, K4, K5, K7, K8, K10, K11, K70, K78, K79, K81, and K82.

2.1.5 Resistors

None of them are critical except the three resistors used to set the 5V regulator voltage: R194, R195 and R196. These should be 1% resistors.

2.1.6 Capacitors

They may be substituted, but these must be low ESR types (ceramic or tantalum electrolytic):

C8, C37, C38, C39, C40

Pay attention to the lead spacing and voltage when you find substitutes. It's always a good idea to derate capacitors (use higher voltage ones than necessary).

2.1.7 ICs

These common ones may be substituted (the manufacture doesn't matter):

ULN2803A

74HC595

74HC597

SN754410E: you may use L293 instead.

74HC4017

The microcontrollers may not be substituted, except that both the commercial and industrial temperature range versions will both work:

PIC24FV32KA301-I/P or PIC24FV32KA301-E/P

PIC16F720-I/P or PIC16F720-E/P

There are two DC-DC converter ICs which may be used:

NR111D or NR887D

NR887D has same pinout and reference voltage as NR111D, but is limited to 2A instead of 4A (5V requires 1.3A max). NR887D costs more because it has the diode built-in.

SI-8105QL might also work. It has same pinout, is 3.5A but has a 0.5V internal reference instead of 0.8V. The feedback resistors would have to be changed for sure to use this chip.

2.1.8 Transistors

Any manufacturer's 2N4401 / 2N4403 in TO-92 packages will work fine. The parts selected have pre-formed pins for .1" spaced holes.

2.1.9 Diodes

D92 must be a fast recovery Schottky diode. The others may use any low cost silicon diode.

2.1.10 TVS (Transient Voltage Suppression) Diodes

They may be substituted with any bidirectional TVS with reverse standoff voltage in the range 13V – 16V.

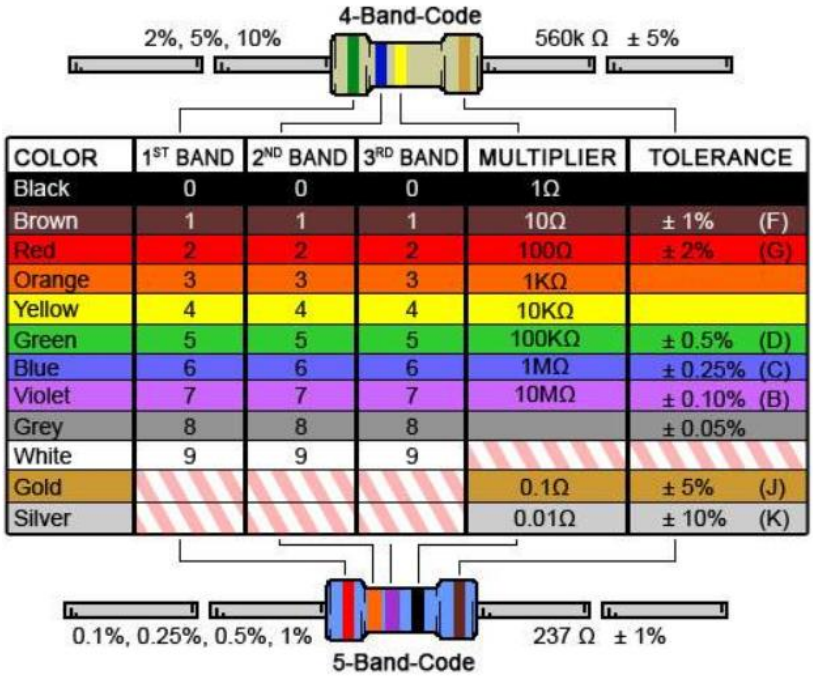
3 Build steps

Assemble the computer in the order below. We are assembling from shortest component to tallest component.

3.1 Resistors

Use the lead forming tool. All of the resistors use .4” lead spacing.

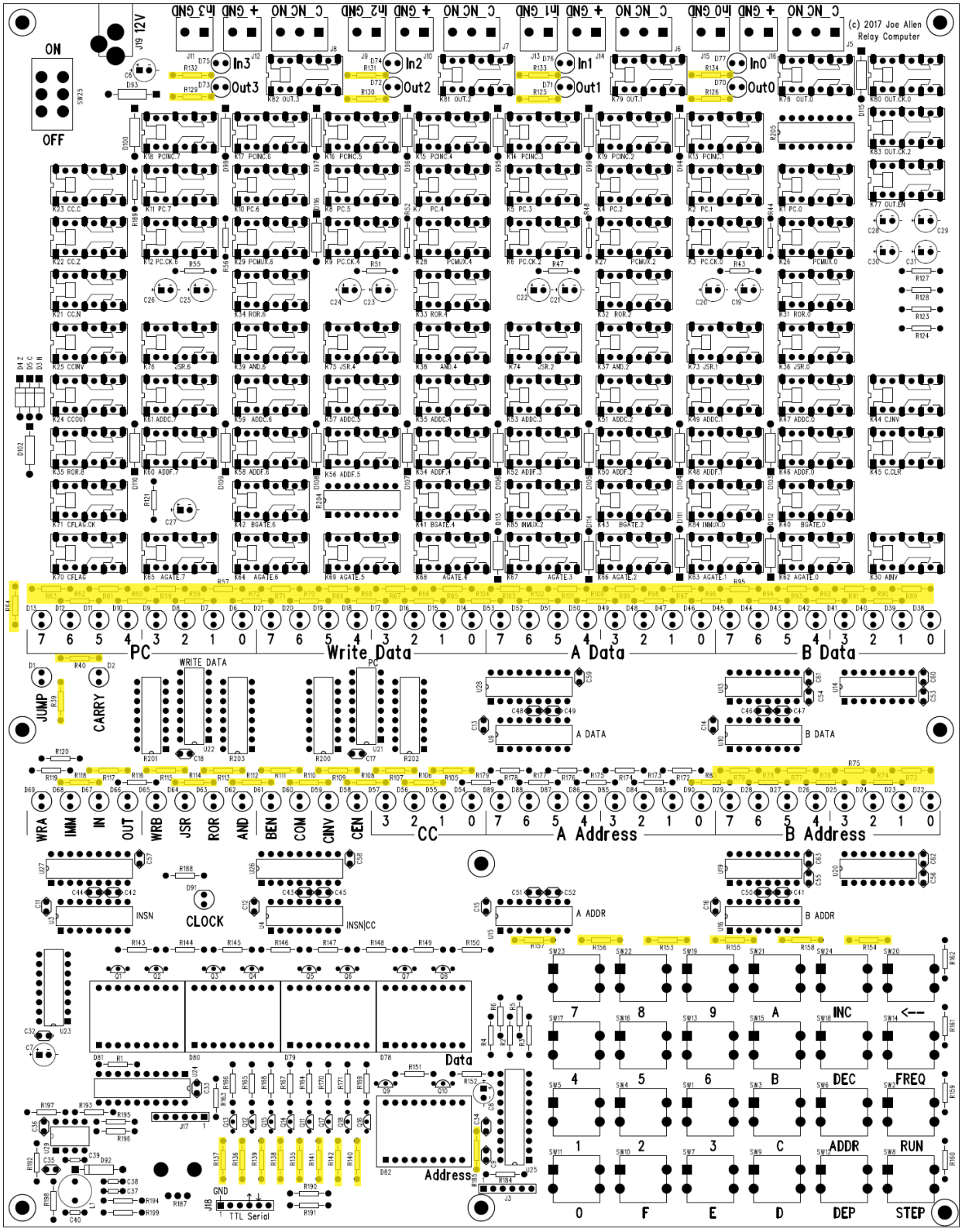
Here is a color code chart for reference (from Digikey.com):



COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8		± 0.05%
White	9	9	9		
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

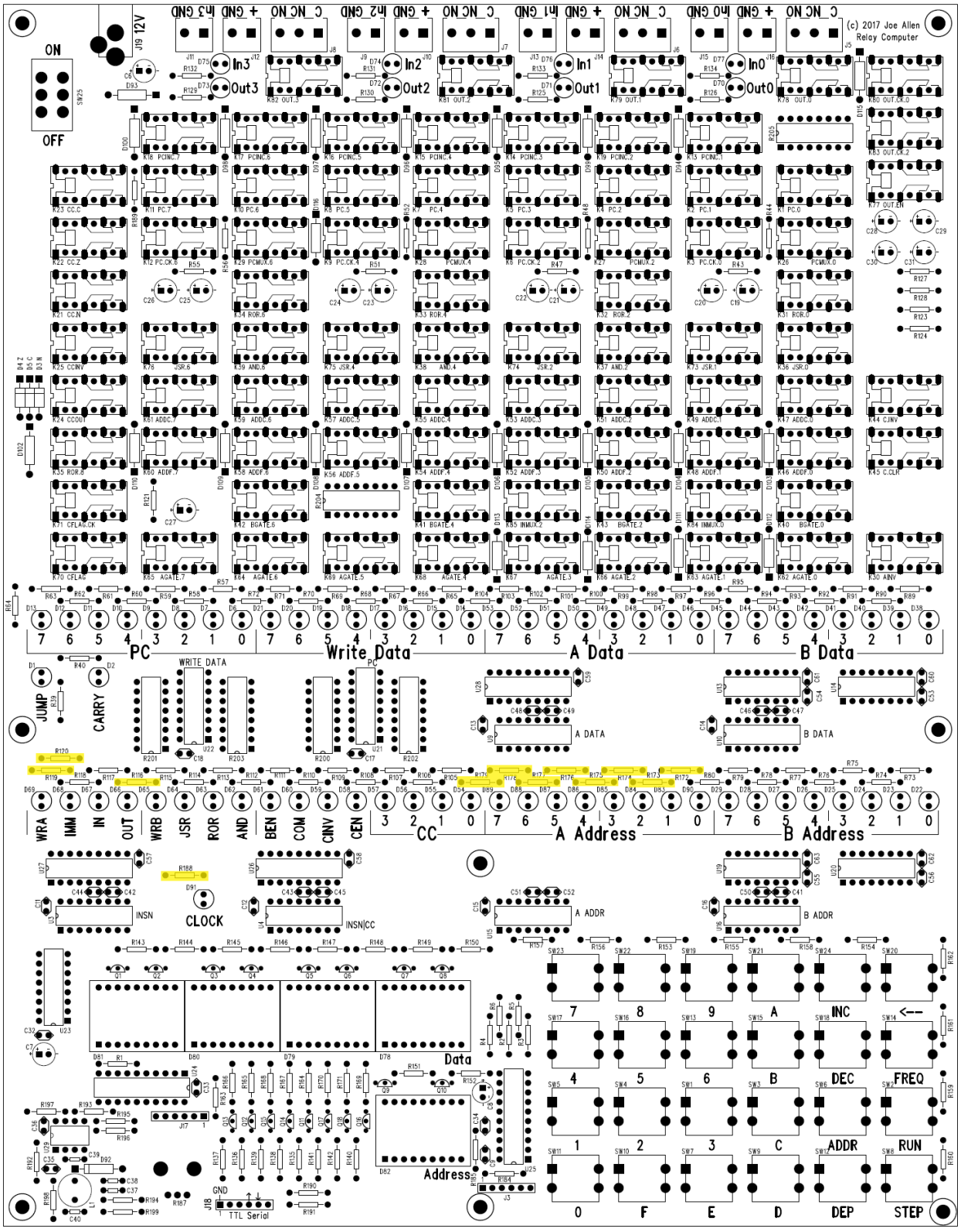
3.1.1 Resistors, 1K

R39, R40, R57, R58, R59, R60, R61, R62, R63, R64, R65, R66, R67, R68, R69, R70, R71, R72, R73, R74, R75, R76, R77, R78, R79, R80, R89, R90, R91, R92, R93, R94, R95, R96, R97, R98, R99, R100, R101, R102, R103, R104, R105, R106, R107, R108, R109, R110, R111, R112, R113, R114, R115, R117, R118, R125, R126, R129, R130, R131, R132, R133, R134, R135, R136, R137, R138, R139, R140, R141, R142, R153, R154, R155, R156, R157, R158, R185


(c) 2017 Joe Allen
Relay Computer
ON
OFF
J19 12V
In3
In2
In1
In0
Out3
Out2
Out1
Out0
PC
Write Data
A Data
B Data
WRITE DATA
JUMP
CARRY
A DATA
B DATA
WRA
IMM
IN
OUT
WRB
JSR
ROR
AND
BEN
COM
CINV
CEN
CC
A Address
B Address
INSN
CLOCK
INSN|CC
A ADDR
B ADDR
Data
Address
GND
TTL Serial
7
8
9
A
INC
<--
4
5
6
B
DEC
FREQ
1
2
3
C
ADDR
RUN
0
F
E
D
DEP
STEP

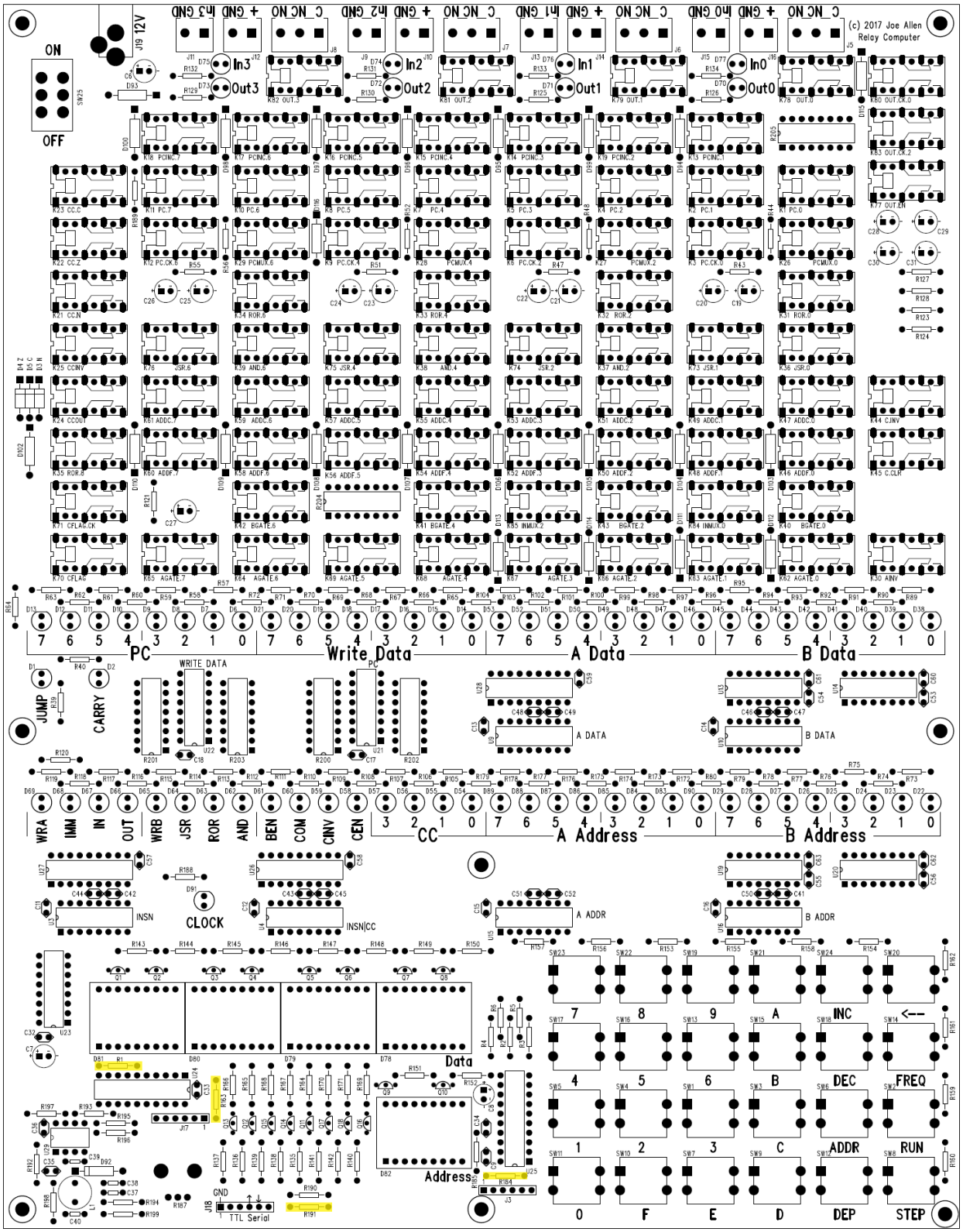
3.1.2 Resistors, 270

R116, R119, R120, R172, R173, R174, R175, R176, R177, R178, R179, R188



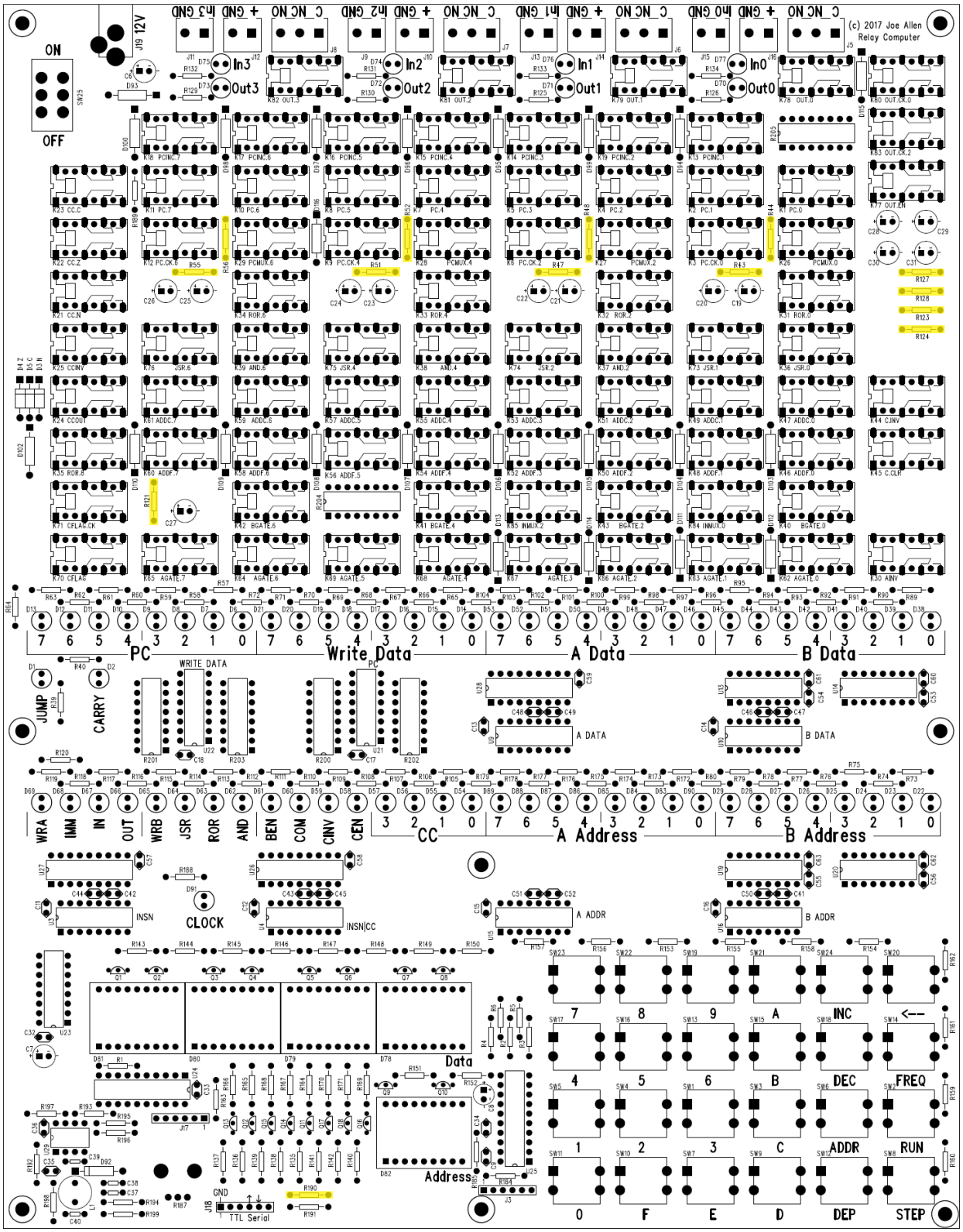
3.1.3 Resistors, 4.7K

R1, R163, R184, R191



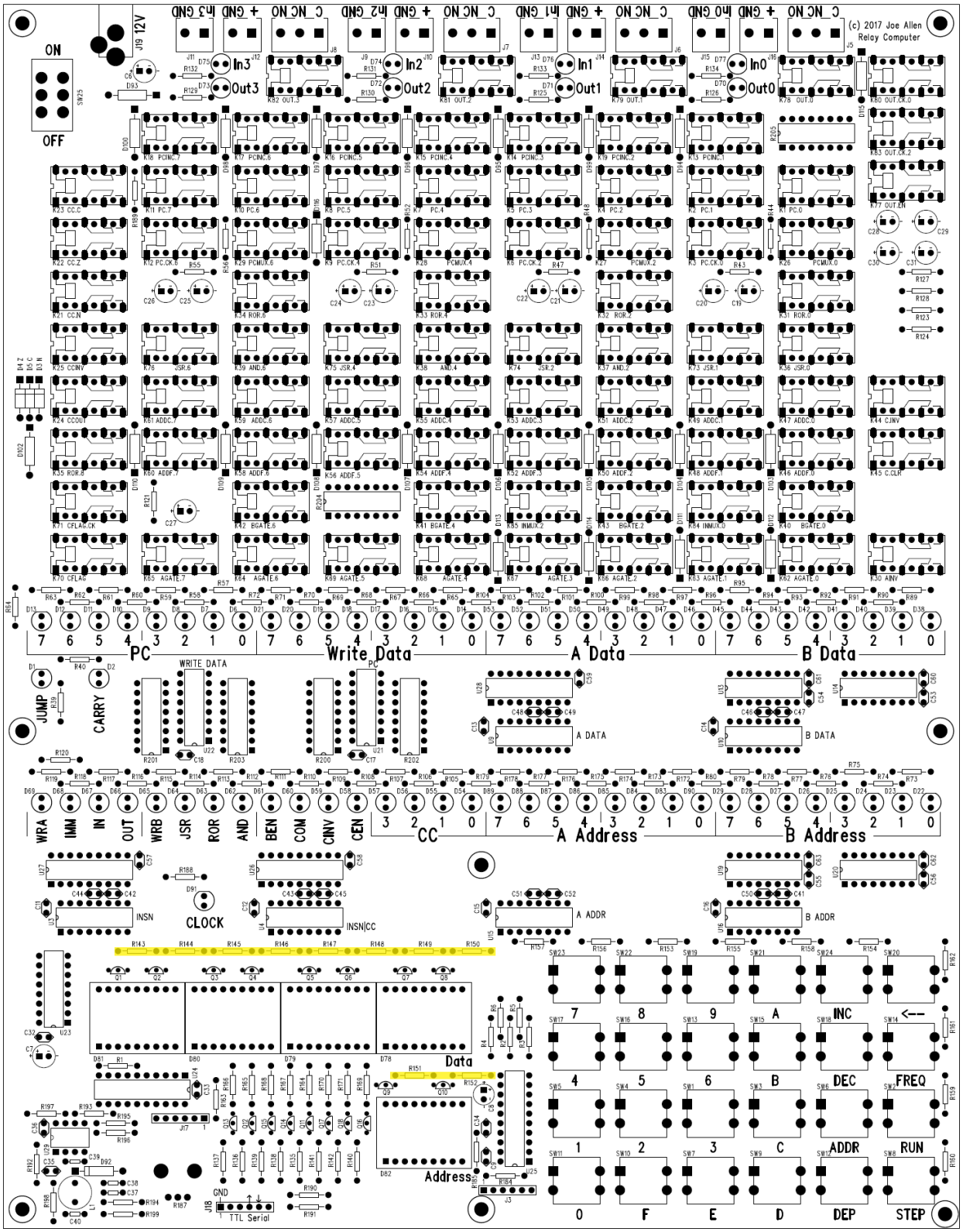
3.1.4 Resistors, 100

R43, R44, R47, R48, R51, R52, R55, R56, R121, R123, R124, R127, R128, R190



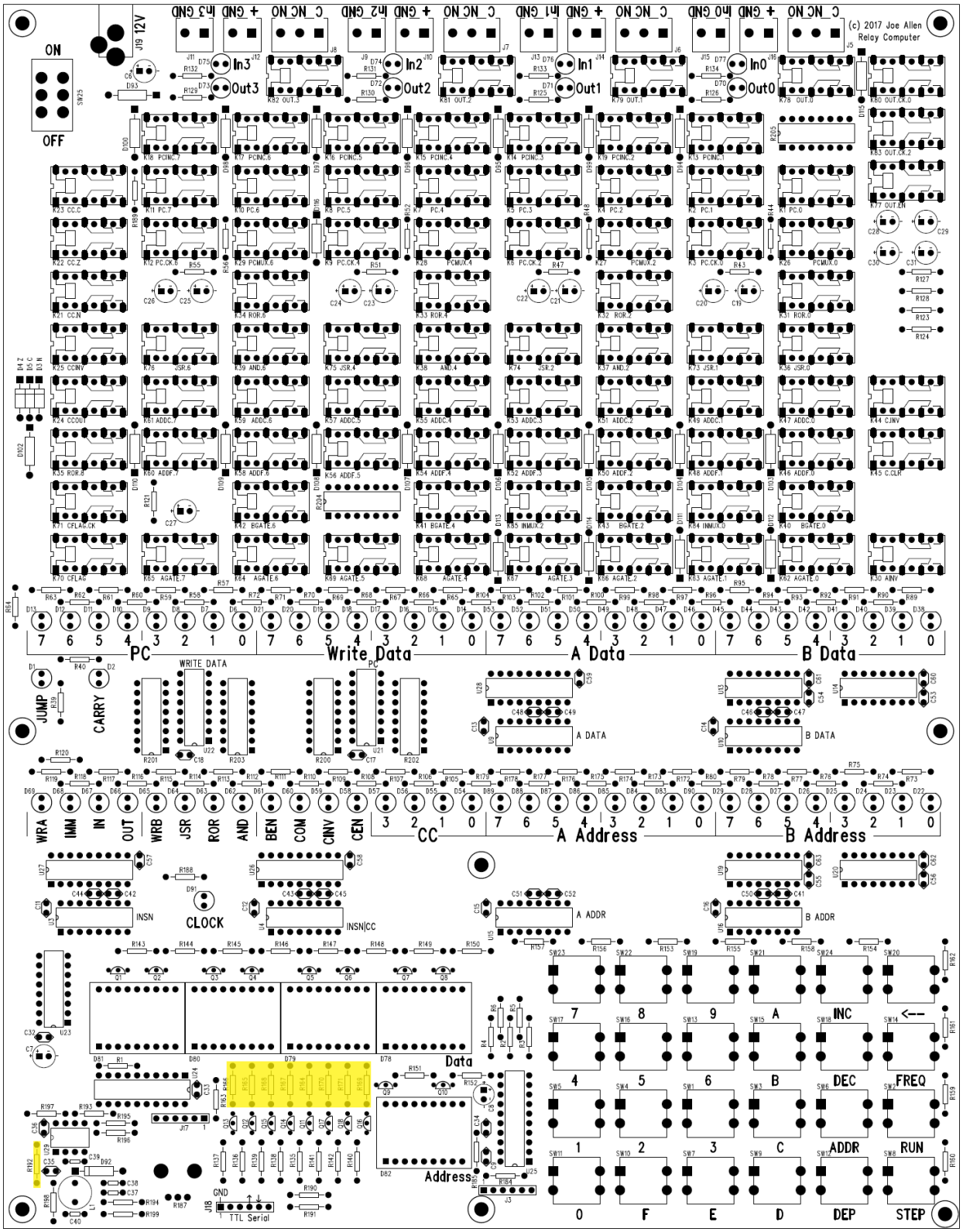
3.1.5 Resistors, 220

R143, R144, R145, R146, R147, R148, R149, R150, R151, R152



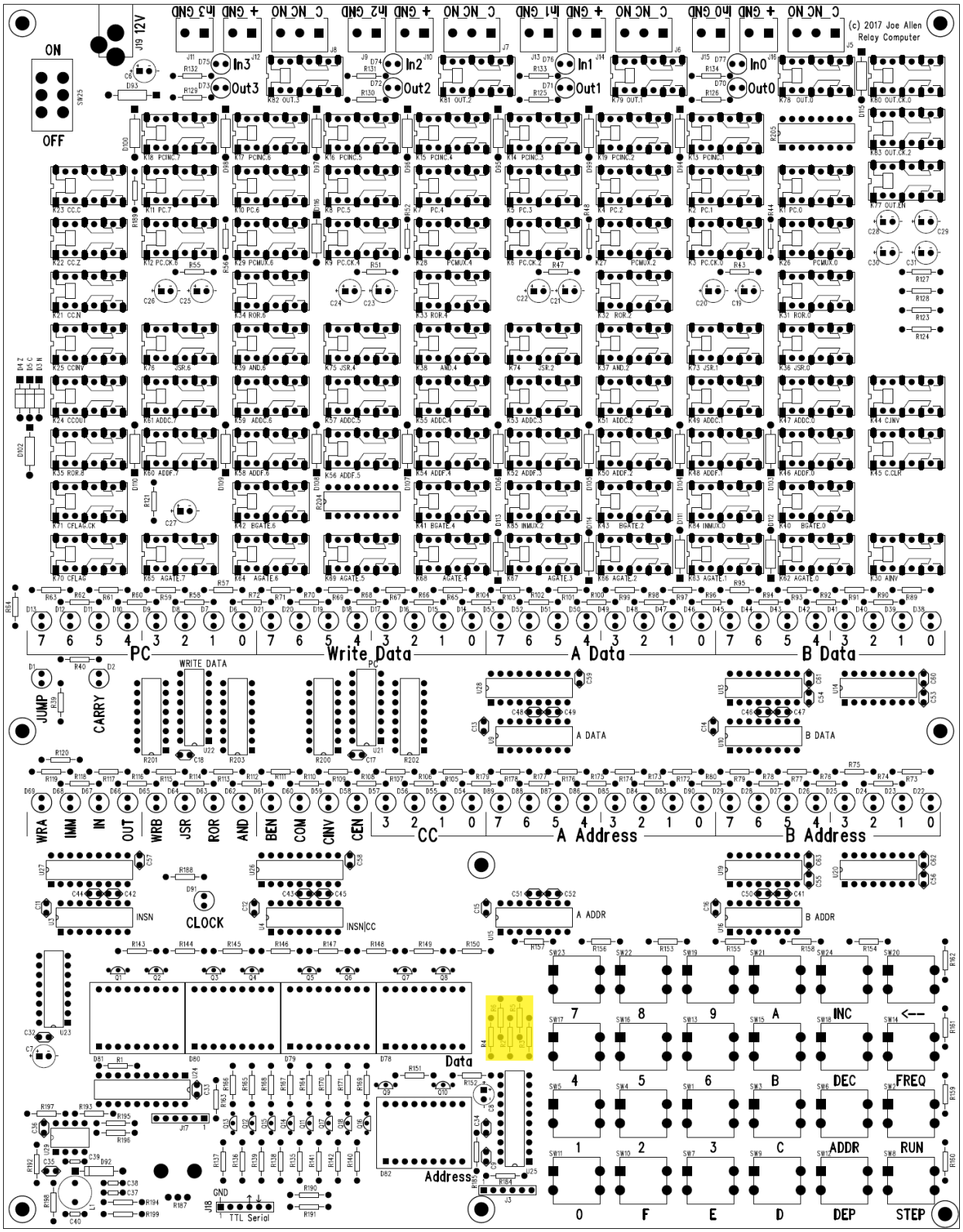
3.1.6 Resistors, 22

R164, R165, R166, R167, R168, R169, R170, R171, R192



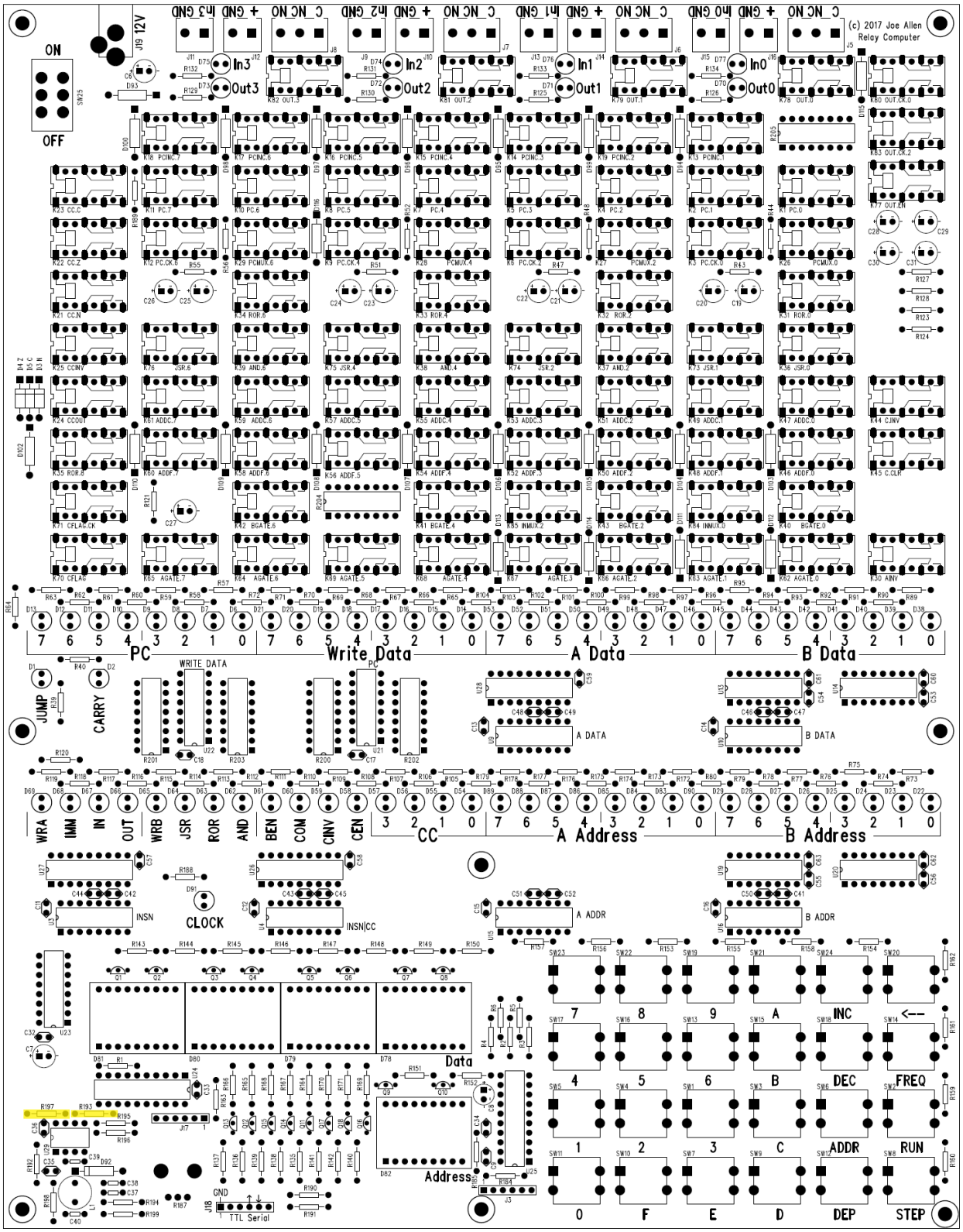
3.1.7 Resistors, 33

R2, R3, R4, R5, R6



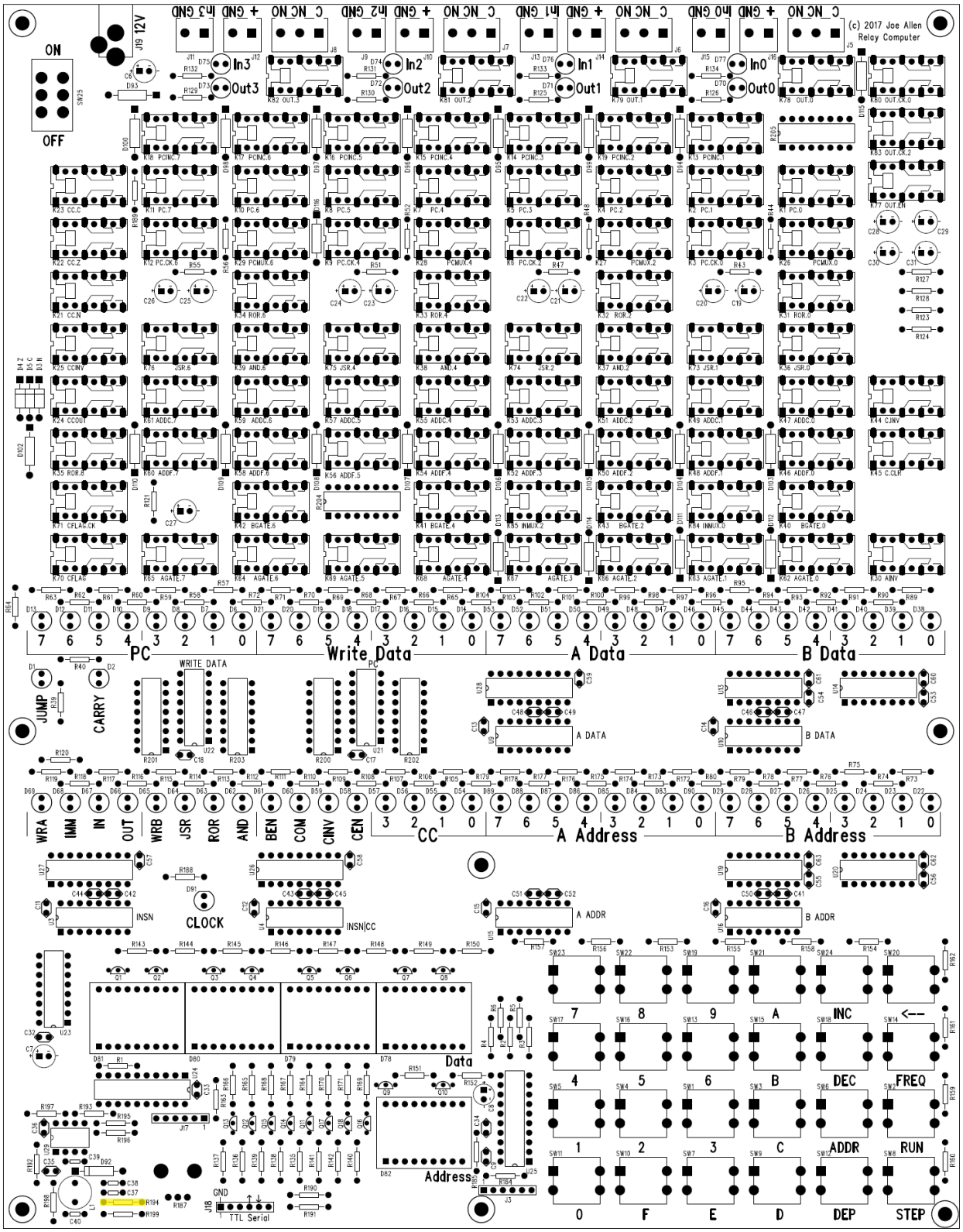
3.1.8 Resistors, 220K

R193, R197



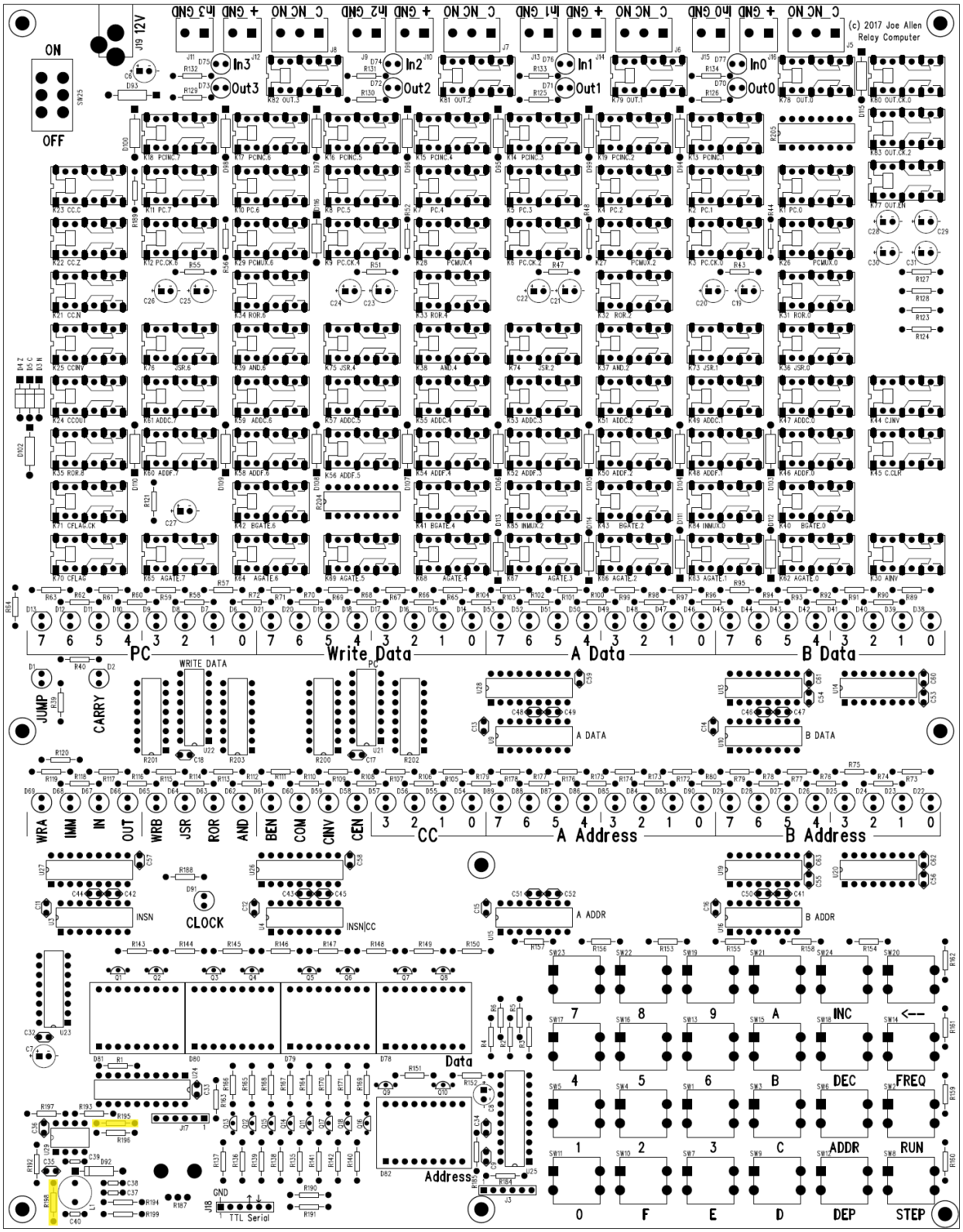
3.1.9 Resistors, 2.7K

R194



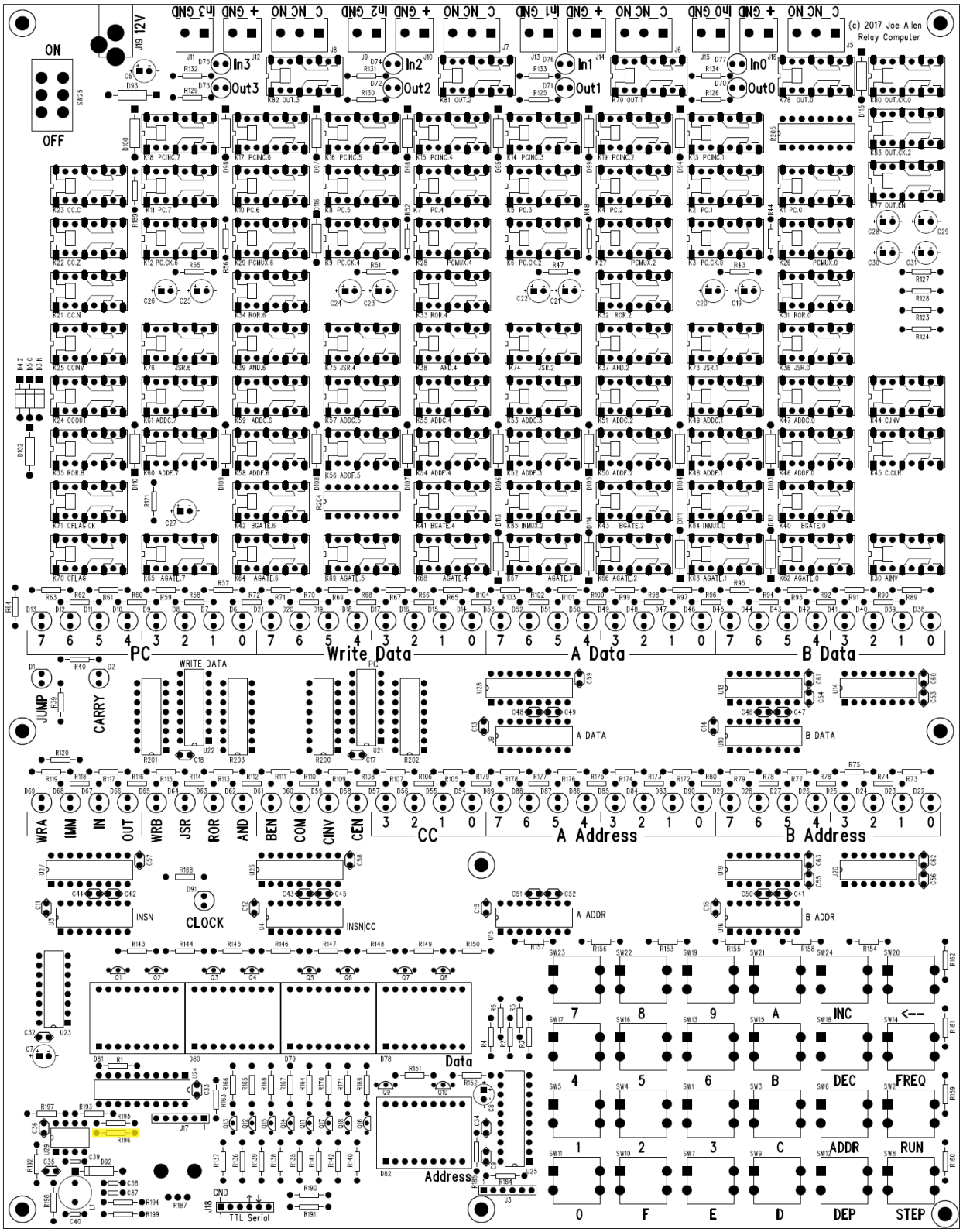
3.1.10 Resistors, 18K

R195, R198



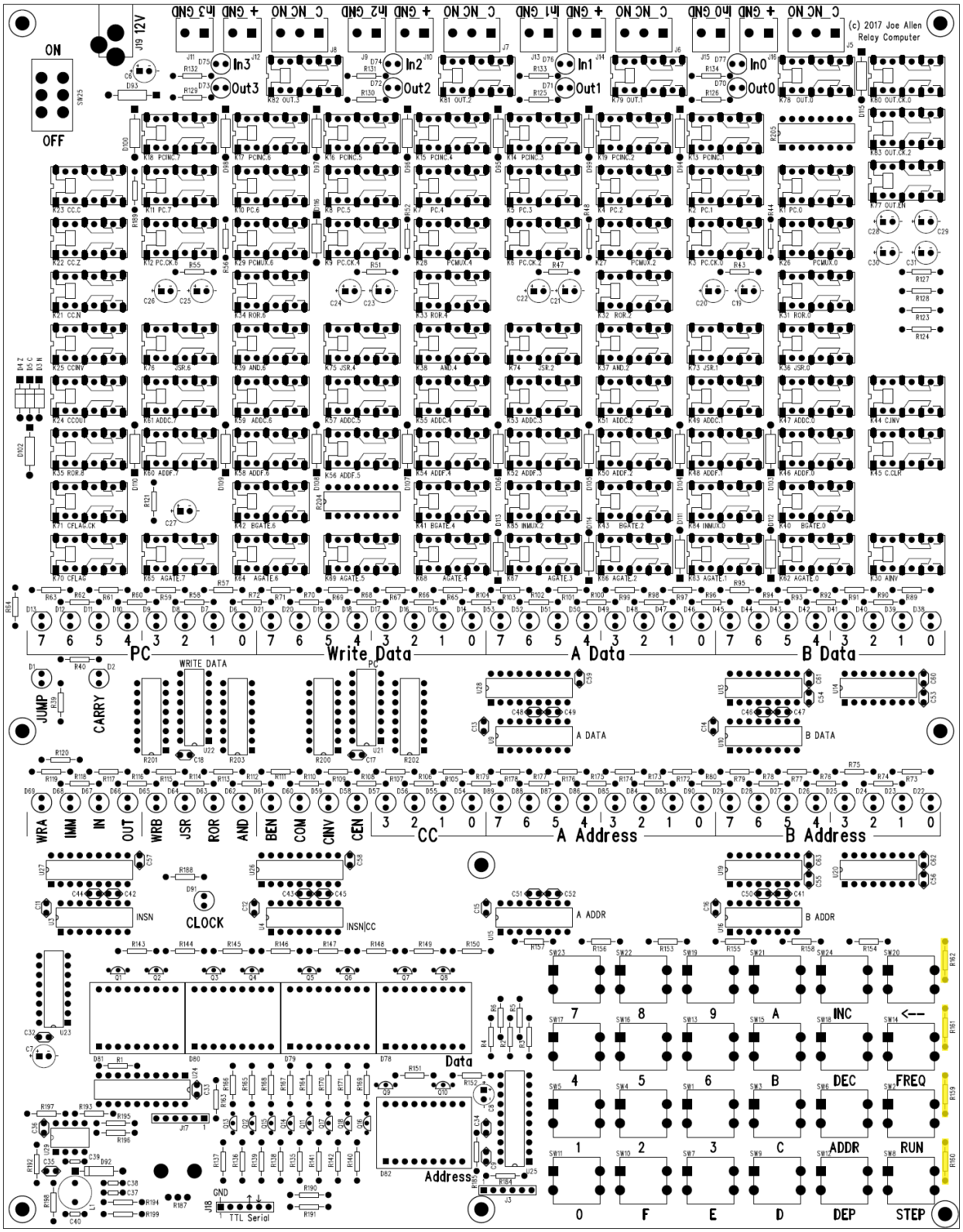
3.1.11 Resistors, 3.9K

R196



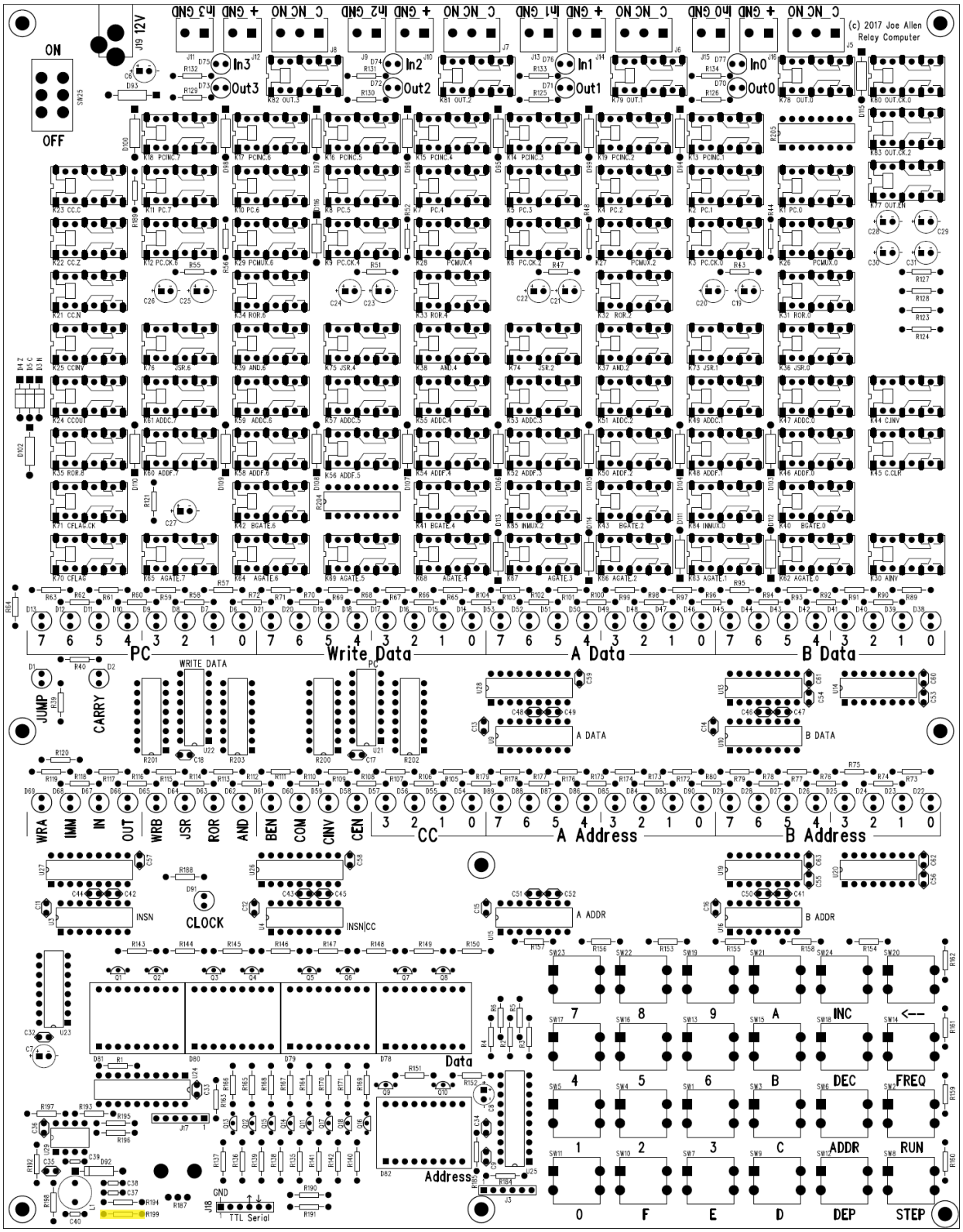
3.1.12 Resistors, 33K

R159, R160, R161, R162



3.1.13 Resistors, 0

R199

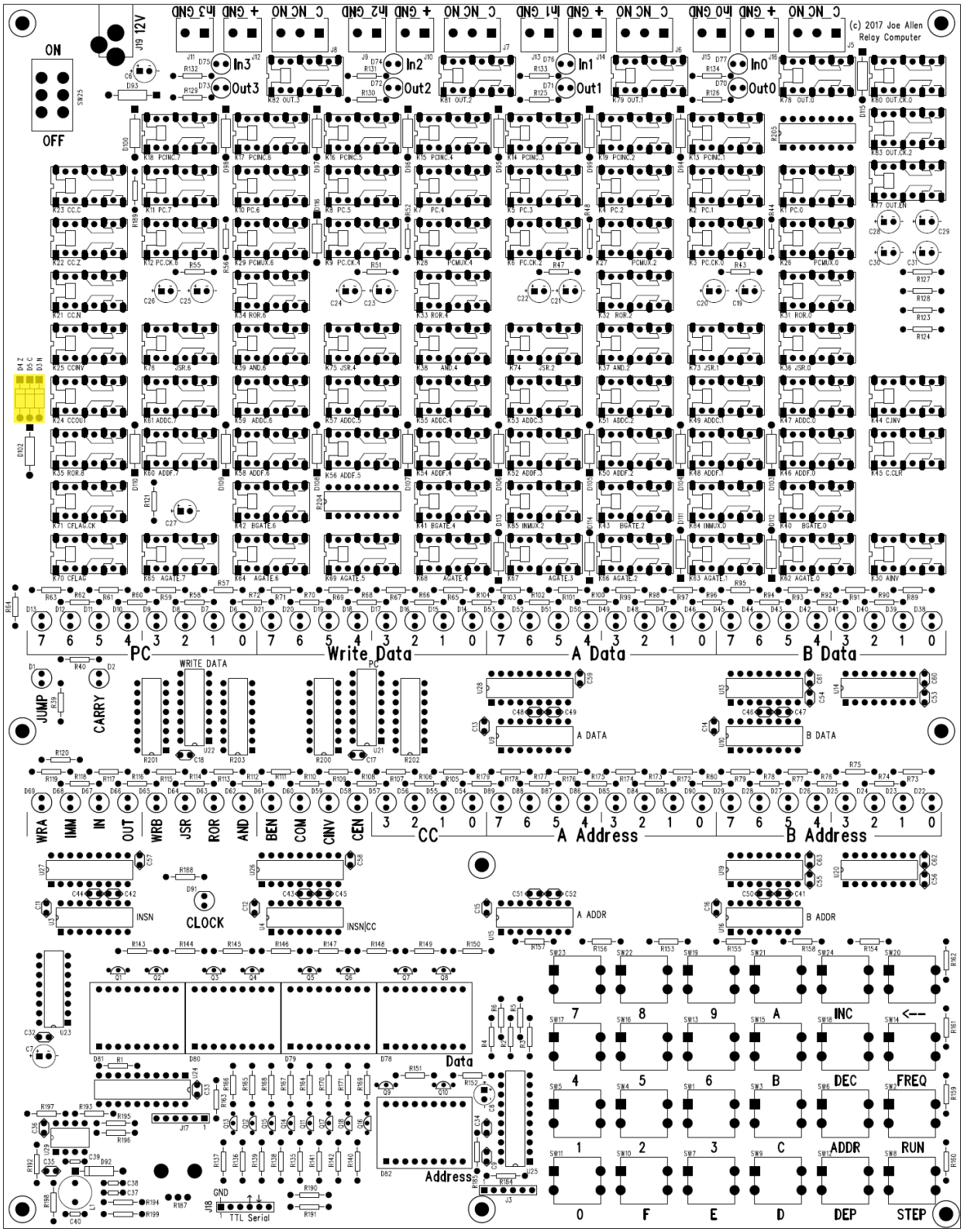


3.2 Diodes

Diodes are polarized- they must be inserted in the proper orientation.

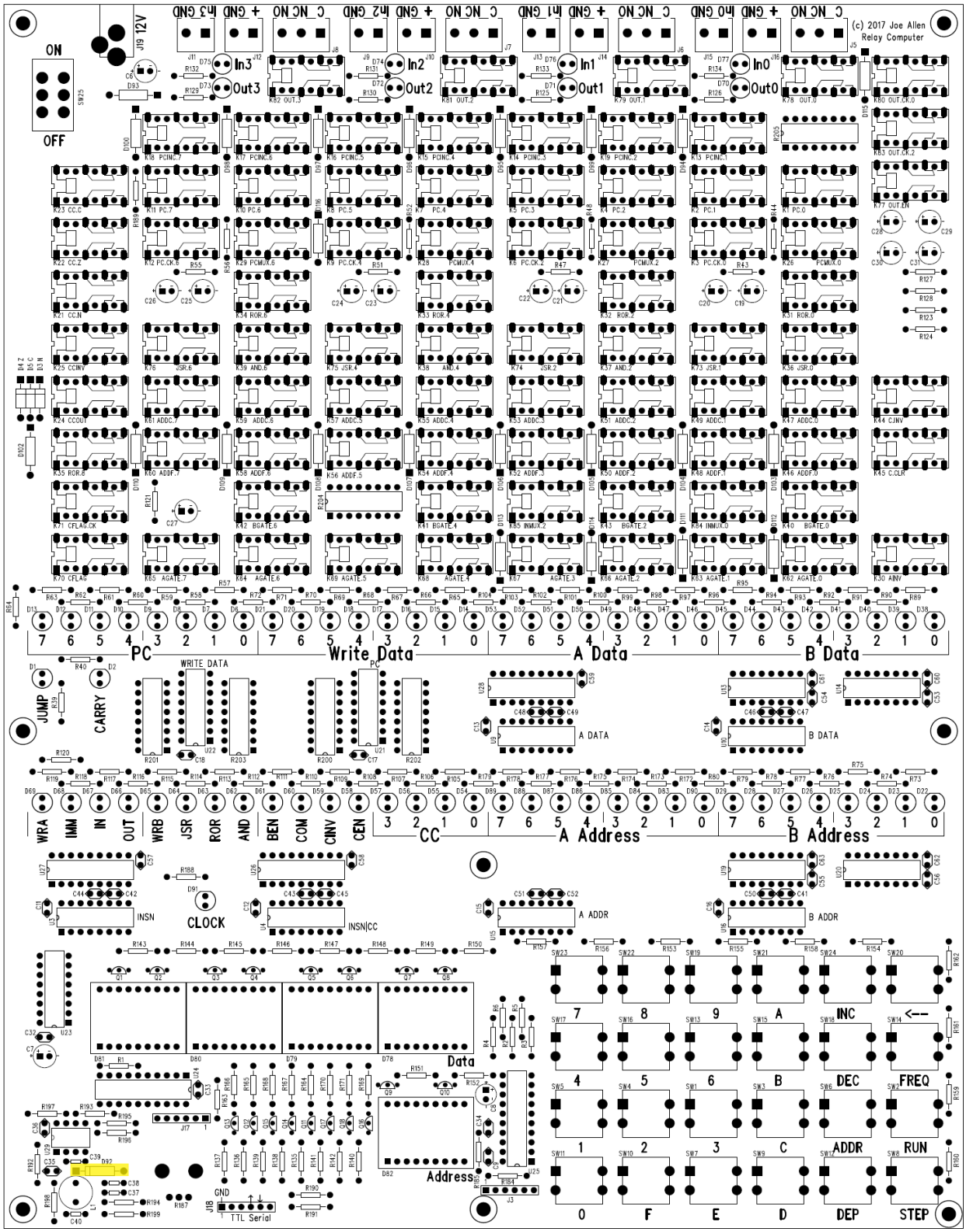
3.2.1 Diodes, 1N4002

D3, D4, D5



3.2.2 Diodes, SB230TA

D92

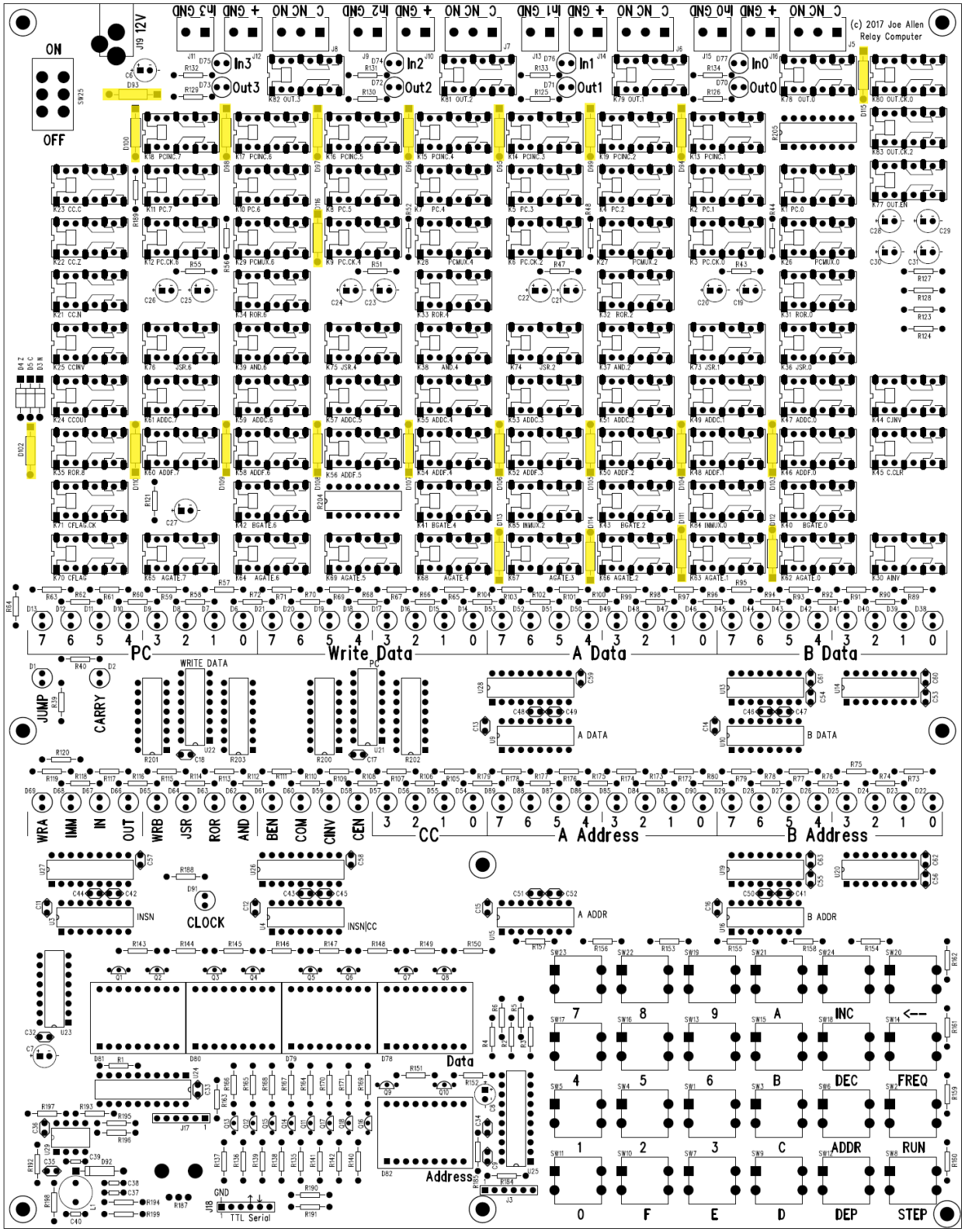


3.3 TVS, Transient Voltage Suppressors

TVS diodes are not polarized, their orientation does not matter.

3.3.1 TVS, SA13CA

D93, D94, D95, D96, D97, D98, D99, D100, D102, D103, D104, D105, D106, D107, D108, D109, D110, D111, D112, D113, D114, D115, D116

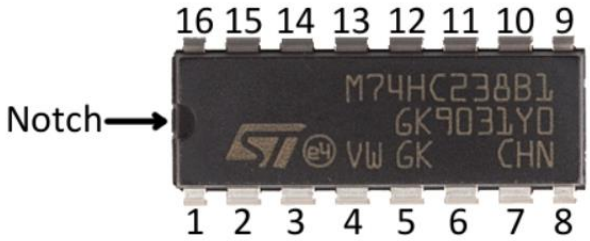

(c) 2017 Joe Allen
Relay Computer
ON
OFF
J19 12V
In3
In2
In1
In0
Out3
Out2
Out1
Out0
PC
Write Data
A Data
B Data
WRITE DATA
JUMP
CARRY
A DATA
B DATA
WRA
IMM
IN
OUT
WRB
JSR
ROR
AND
BEN
COM
CINV
CEN
CC
A Address
B Address
INSN
CLOCK
INSN|CC
A ADDR
B ADDR
Data
Address
TTL Serial
INC
DEC
FREQ
ADDR
RUN
DEP
STEP

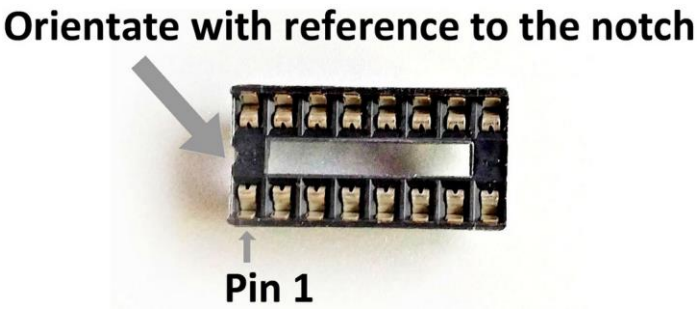
3.4 IC Sockets

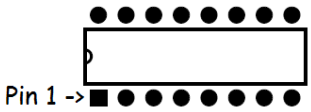
Install all IC sockets using the following procedure:

- Insert them (or some fraction of them).
- Flip the board over while holding them in place with a piece of cardboard.
- Solder just two opposite corners of each socket.
- Verify that each socket is properly seated by re-melting the solder on the two corners while simultaneously applying force to the socket from the front.
- Now that the sockets are properly seated, solder the rest of the pins in place.

Note the location of pin 1 of each IC. It's always the square pad. IC pins are always numbered counter-clockwise starting with pin 1.







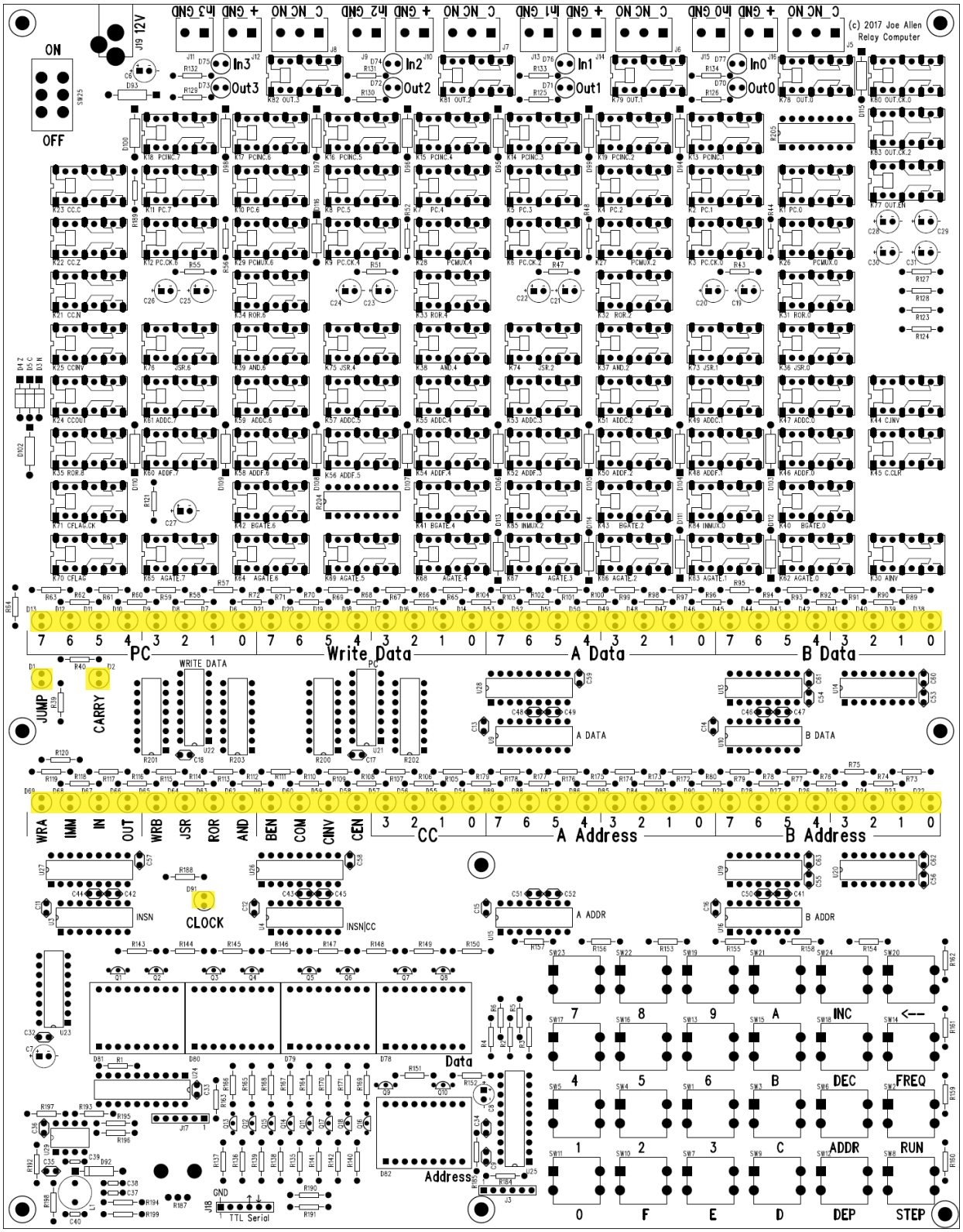
3.5 LEDs

Install all the T 1-3/4 LEDs. Note that these are polarized. The silkscreen indicates the proper orientation.

Make sure that the LEDs are flush with the PCB.

D1, D2, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D16, D17, D18, D19, D20, D21, D22, D23, D24, D25, D26, D27, D28, D29, D38, D39, D40, D41, D42, D43, D44, D45, D46, D47, D48, D49, D50, D51, D52,

D53, D54, D55, D56, D57, D58, D59, D60, D61, D62, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72, D73, D74, D75, D76, D77, D83, D84, D85, D86, D87, D88, D89, D90, D91

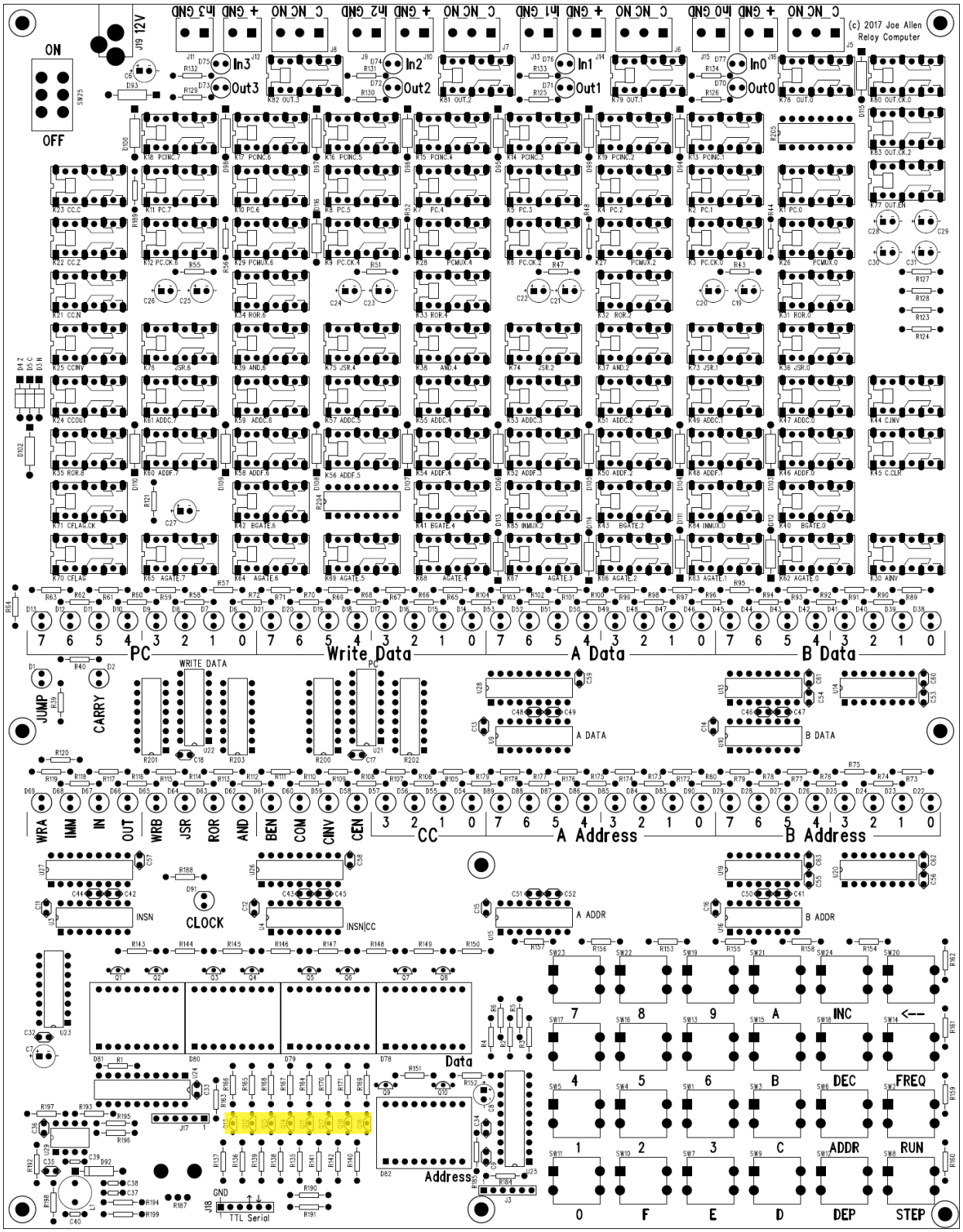


3.6 Transistors

Install all the transistors. Note that these are polarized. The silkscreen indicates the proper orientation.

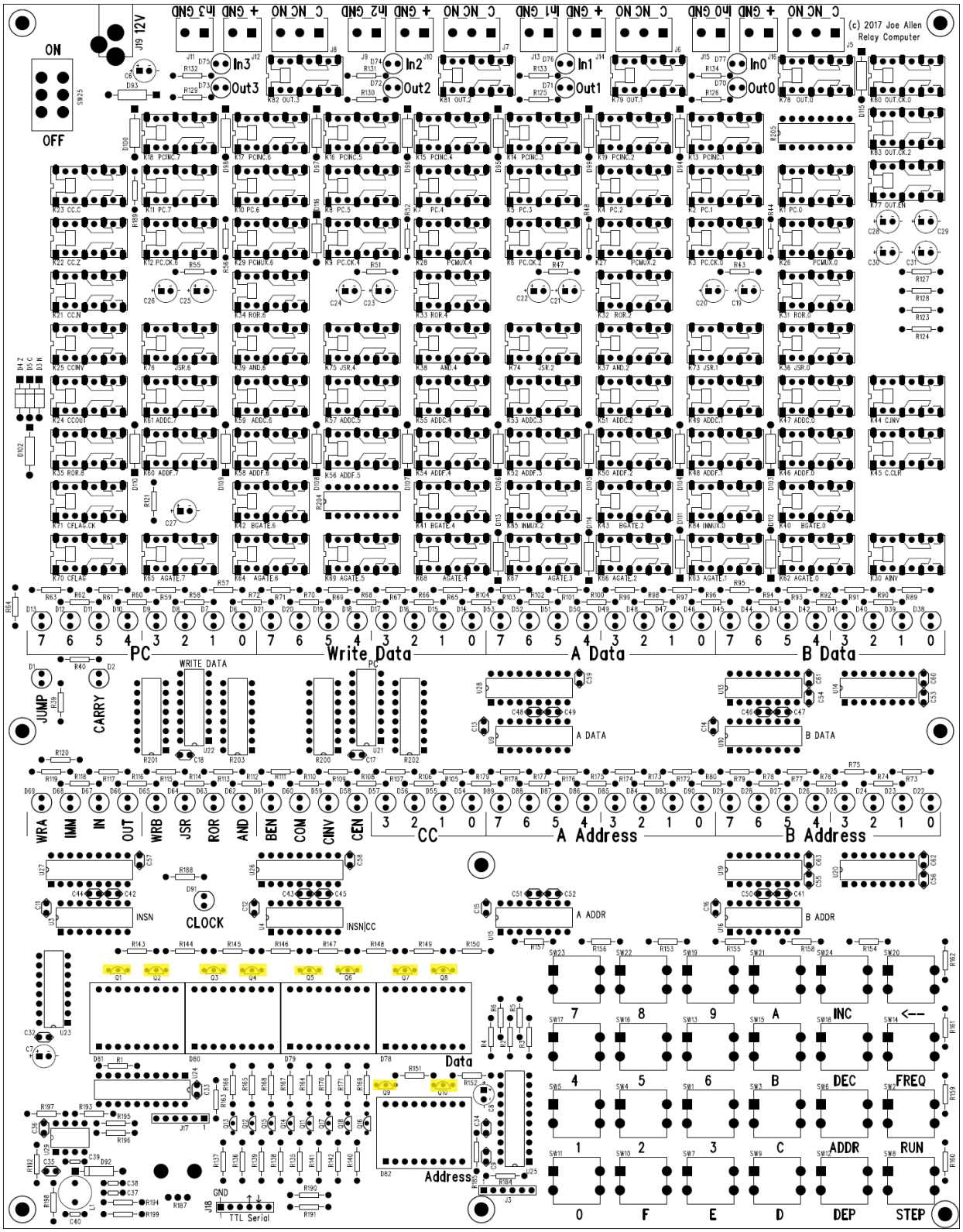
3.6.1 2N4403

Q11, Q12, Q13, Q14, Q15, Q16, Q17, Q18



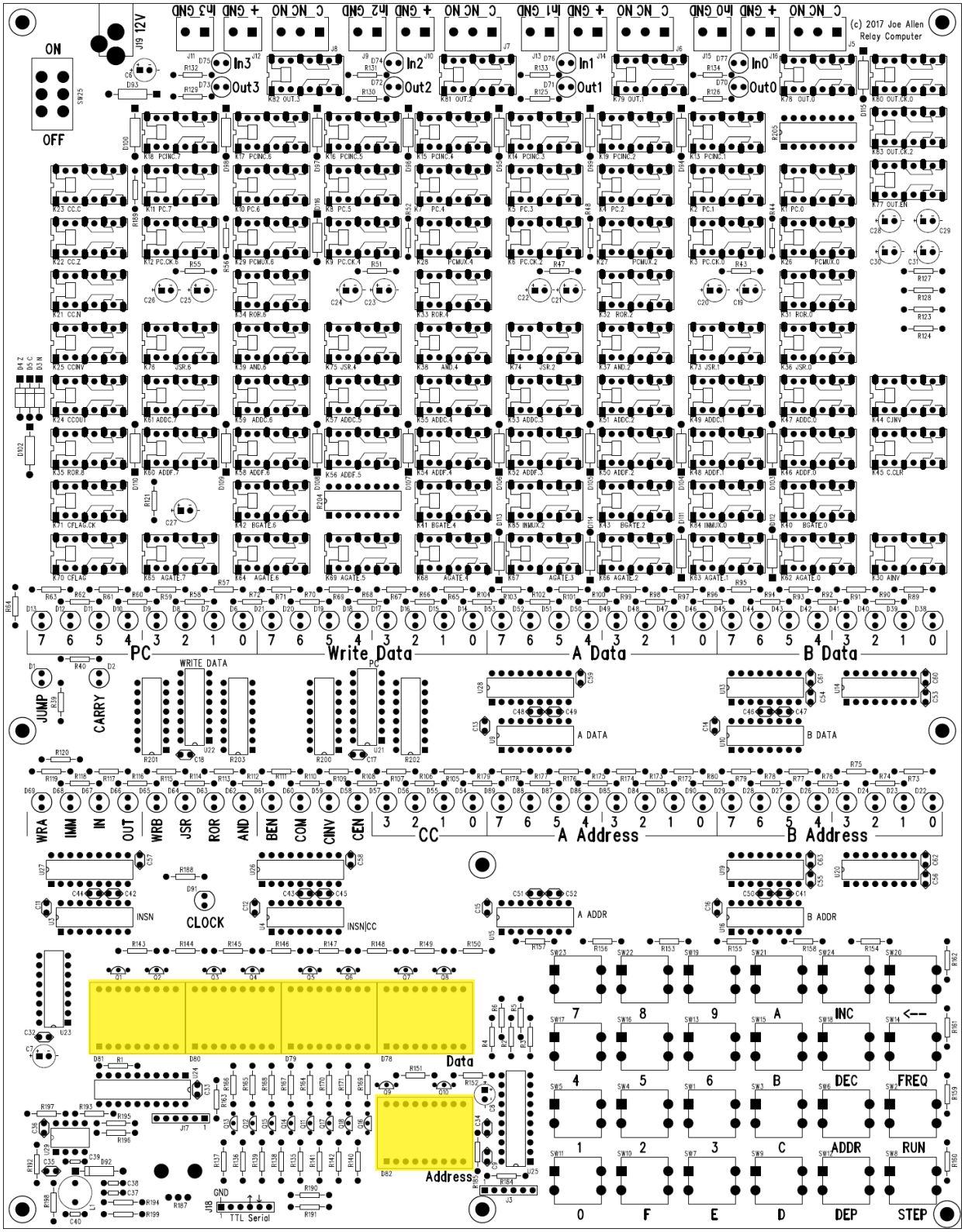
3.6.2 2N4401

Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10



3.7 LED Displays

D78, D79, D80, D81, D82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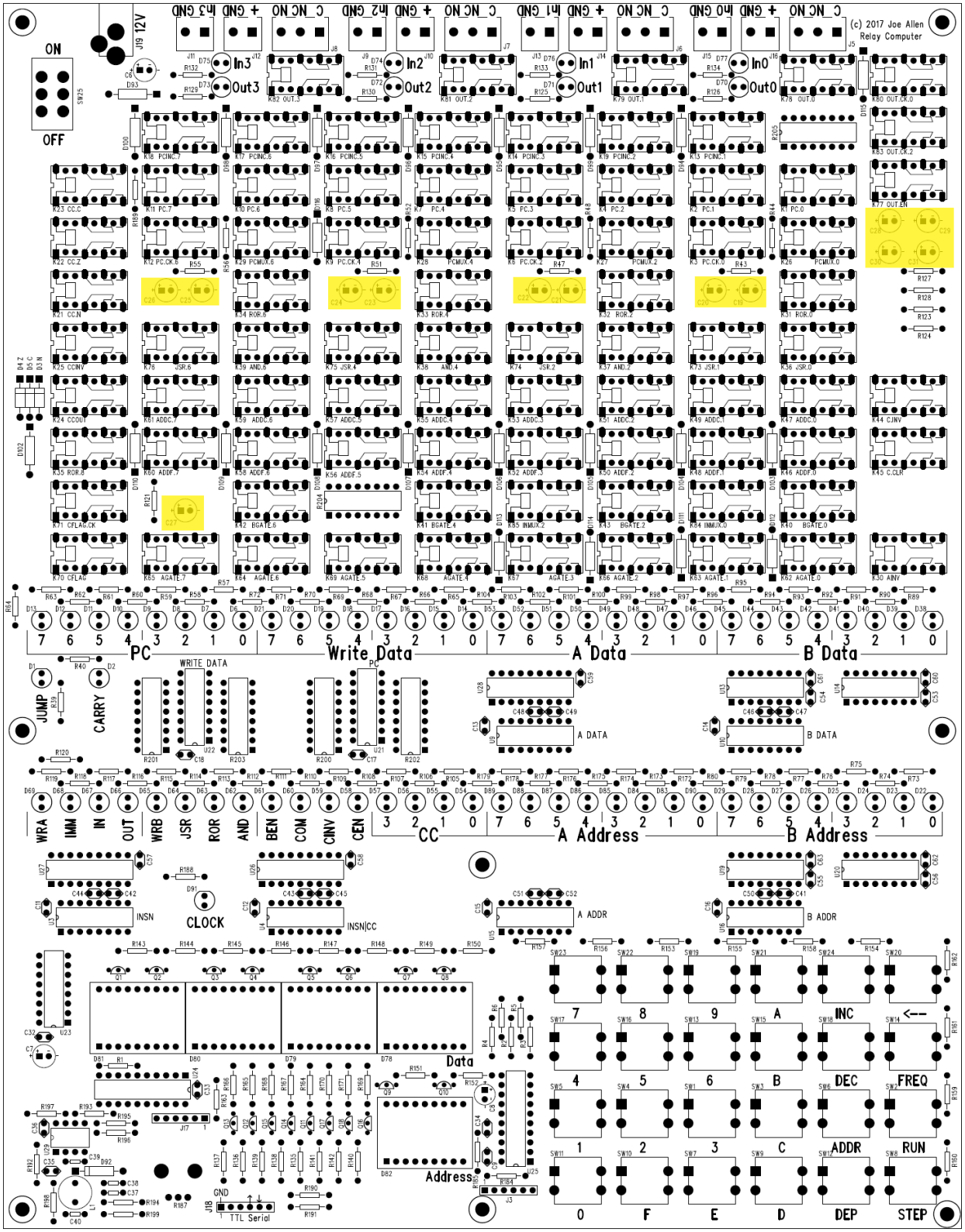
Relay Computer
ON
OFF
J19 12V
In3
In2
In1
In0
Out3
Out2
Out1
Out0
PC
Write Data
A Data
B Data
WRITE DATA
JUMP
CARRY
A DATA
B DATA
WRA
IMM
IN
OUT
WRB
JSR
ROR
AND
BEN
COM
CNV
CEN
CC
A Address
B Address
INSN
CLOCK
INSN|CC
A ADDR
B ADDR
Data
Address
GND
TTL Serial
7
8
9
A
INC
<--
4
5
6
B
DEC
FREQ
1
2
3
C
ADDR
RUN
0
F
E
D
DEP
STEP

3.8 Capacitors

3.8.1 33uF Electrolytic

These are polarized, install them in the correct orientation.

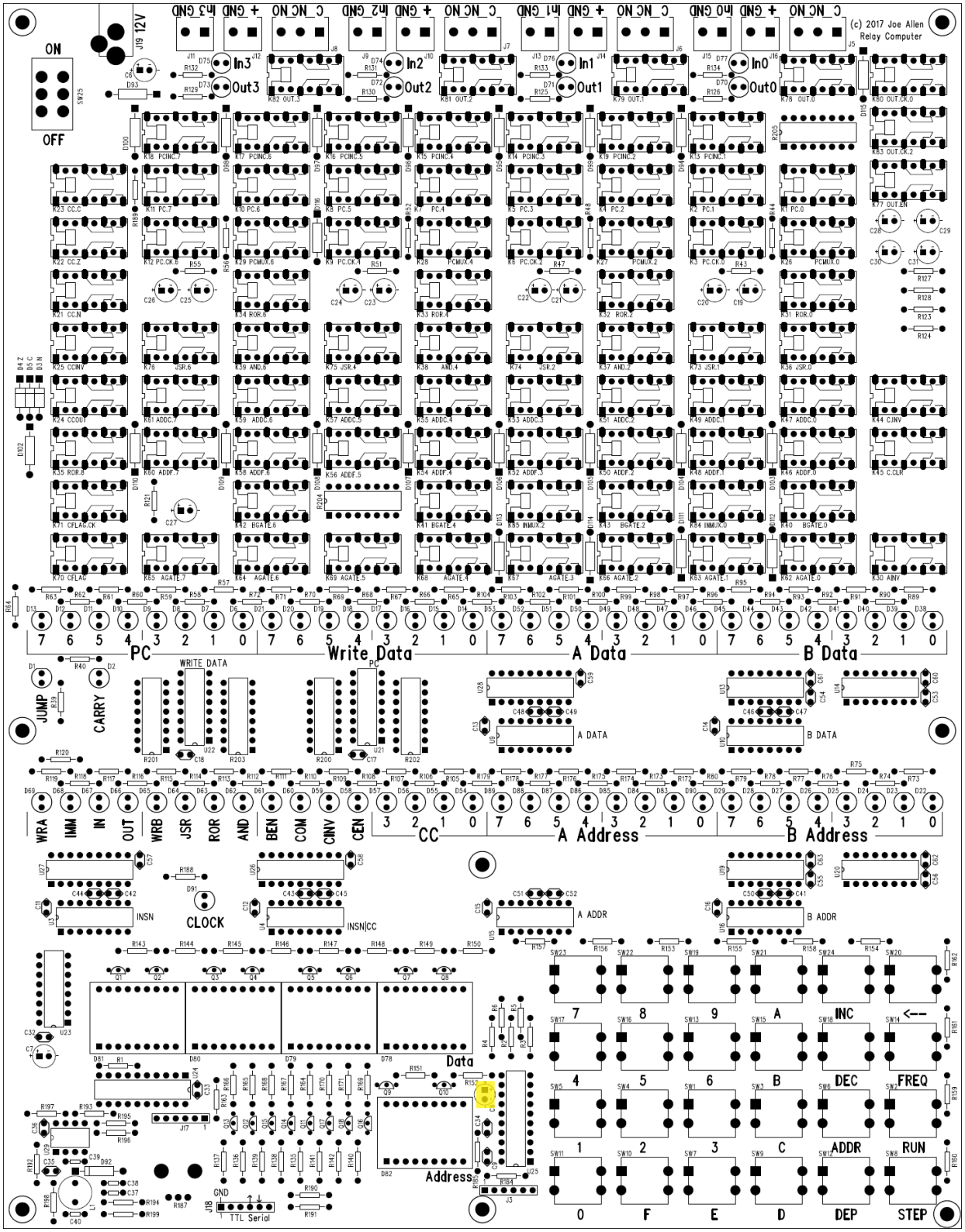
C19, C20, C21, C22, C23, C24, C25, C26, C27, C28, C29, C30, C31


(c) 2017 Joe Allen
Relay Computer
ON
OFF
In3
In2
In1
In0
Out3
Out2
Out1
Out0
PC
Write Data
A Data
B Data
WRITE DATA
JUMP
CARRY
A DATA
B DATA
WRA
IMM
IN
OUT
WRB
JSR
ROR
AND
BEN
COM
CNV
CEN
CC
A Address
B Address
INSN
CLOCK
INSN|CC
A ADDR
B ADDR
Data
Address
TTL Serial
INC
DEC
ADDR
RUN
FREQ
DEP
STEP

3.8.2 10uF Tantalum

These are polarized, install them in the correct orientation.

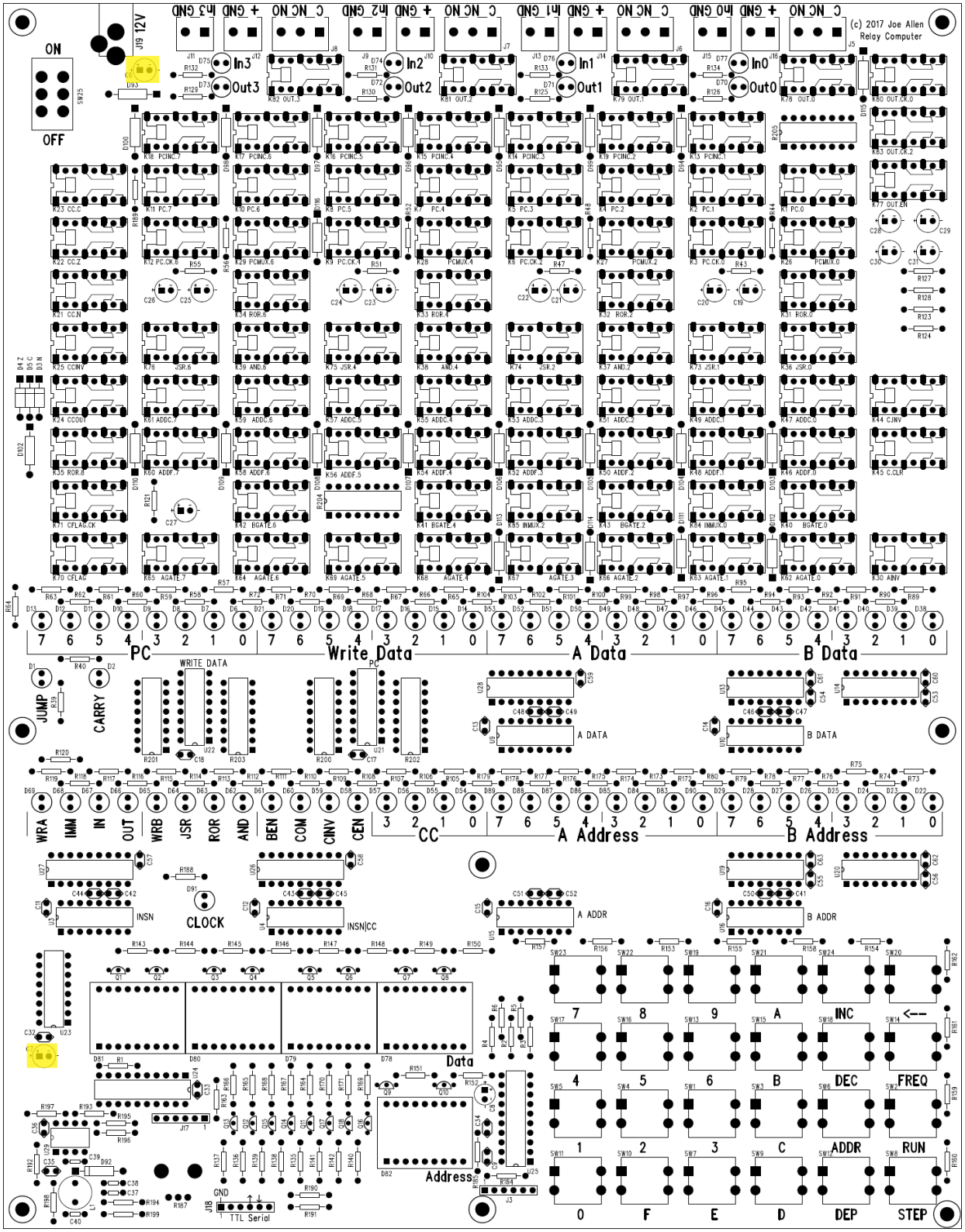
C8


(c) 2017 Joe Allen
Relay Computer
ON
OFF
J19 12V
In3
In2
In1
In0
Out3
Out2
Out1
Out0
PC
Write Data
A Data
B Data
WRITE DATA
JUMP
CARRY
A DATA
B DATA
WRA
IMM
IN
OUT
WRB
JSR
ROR
AND
BEN
COM
CNV
CEN
CC
A Address
B Address
INSN
CLOCK
INSN|CC
A ADDR
B ADDR
Data
Address
GND
TTL Serial
7
8
9
A
INC
<--
4
5
6
B
DEC
FREQ
1
2
3
C
ADDR
RUN
0
F
E
D
DEP
STEP

3.8.3 100uF Electrolytic

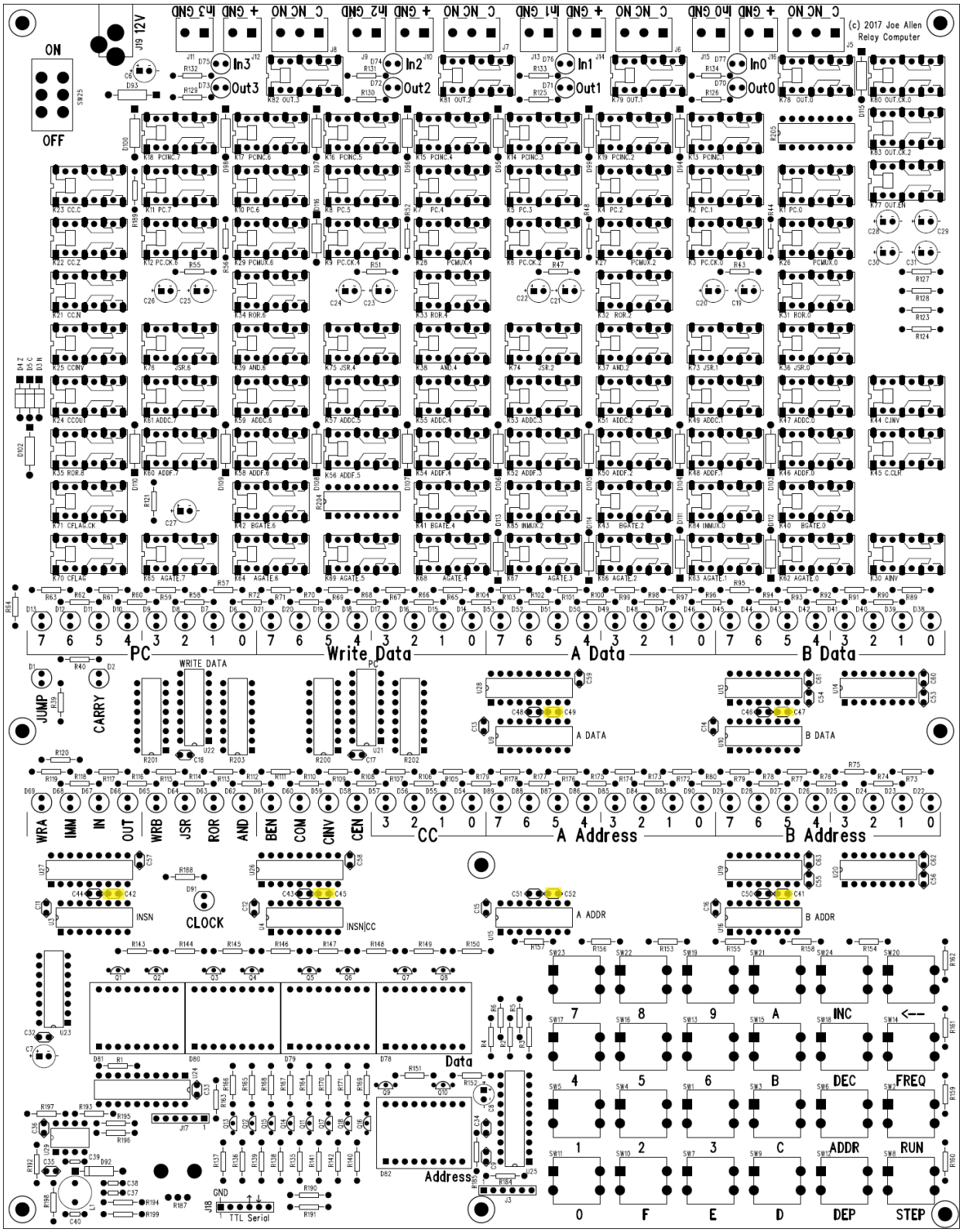
These are polarized, install them in the correct orientation.

C6, C7


(c) 2017 Joe Allen
Relay Computer
ON
OFF
PC
Write Data
A Data
B Data
JUMP
CARRY
WRITE DATA
A DATA
B DATA
WRA
IMM
IN
OUT
WRB
JSR
ROR
AND
BEN
COM
CNV
CEN
CC
A Address
B Address
INSN
CLOCK
INSN|CC
A ADDR
B ADDR
Data
Address
GND
TTL Serial
INC
DEC
FREQ
ADDR
RUN
DEP
STEP

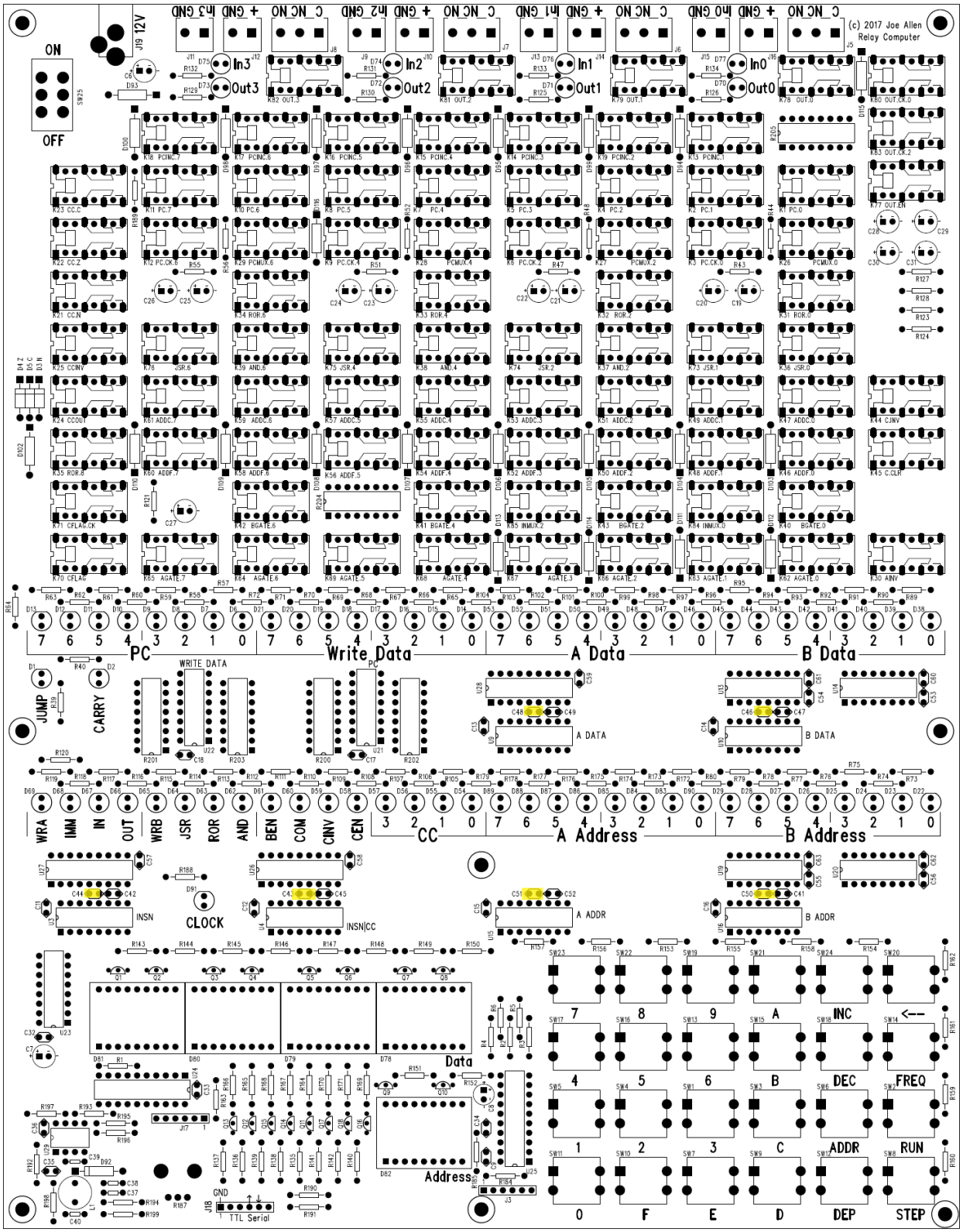
3.8.4 22pF

C41, C42, C45, C47, C49, C52



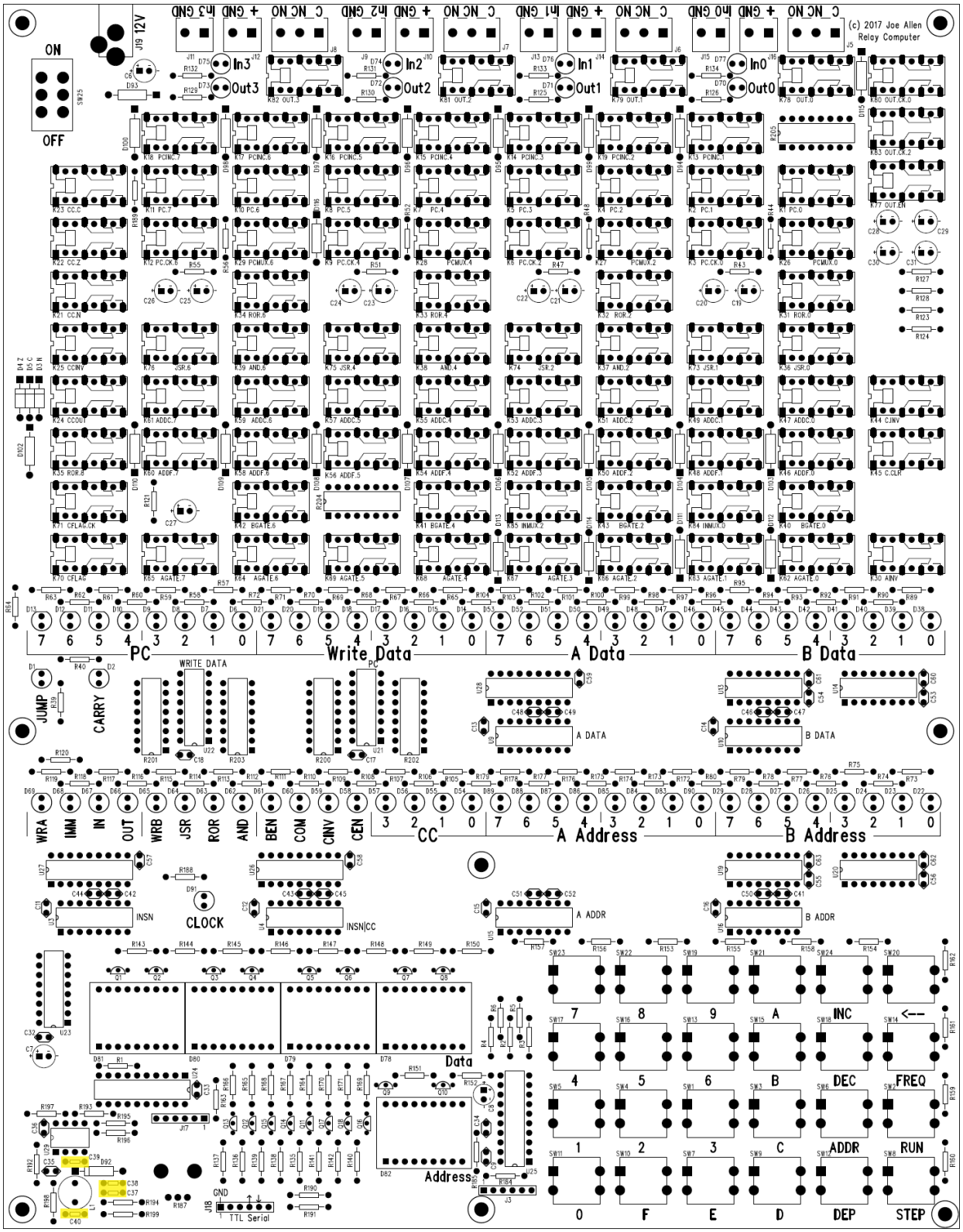
3.8.5 470pF

C43, C44, C46, C48, C50, C51



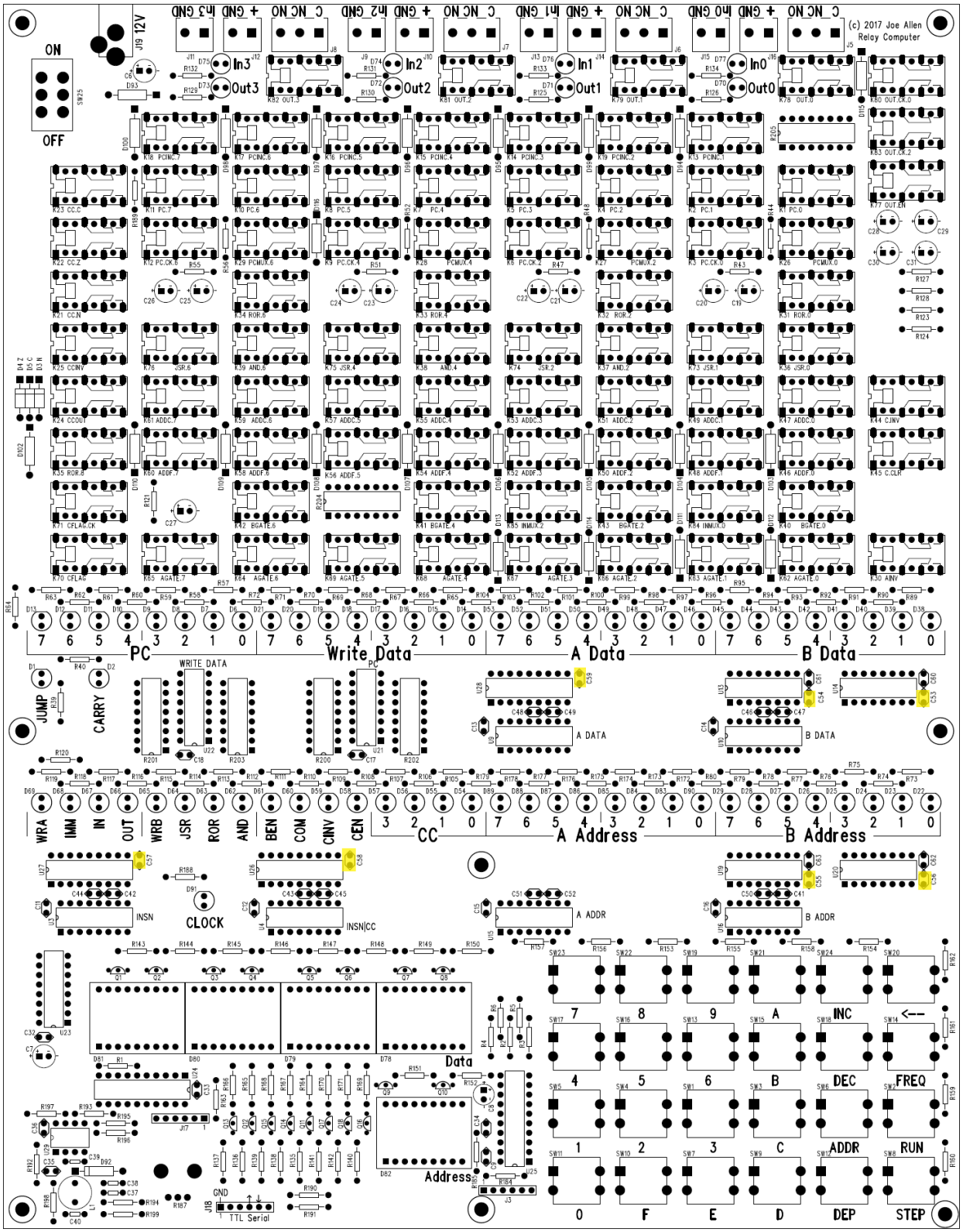
3.8.6 22uF

C37, C38, C39, C40



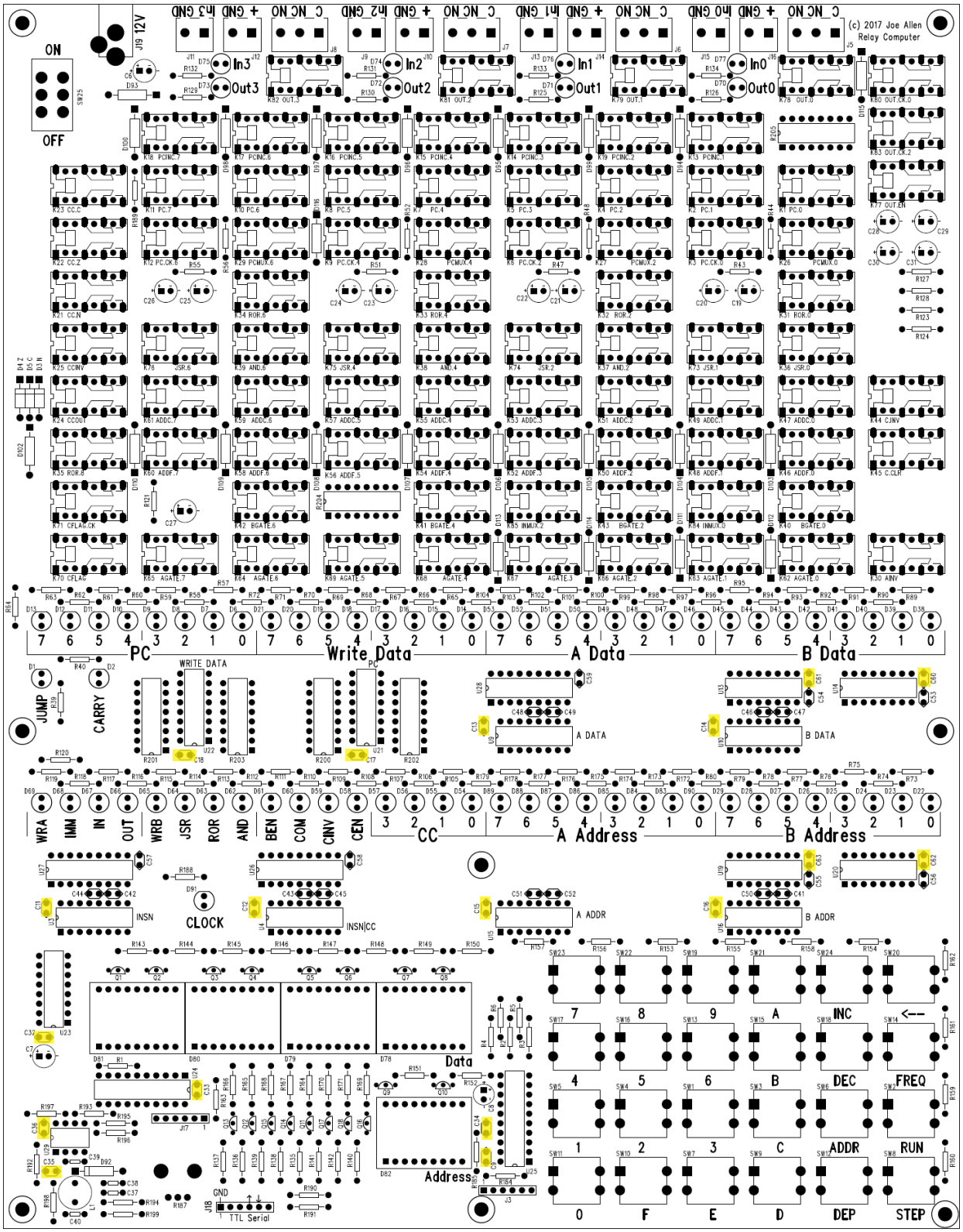
3.8.7 1uF

C53, C54, C55, C56, C57, C58, C59



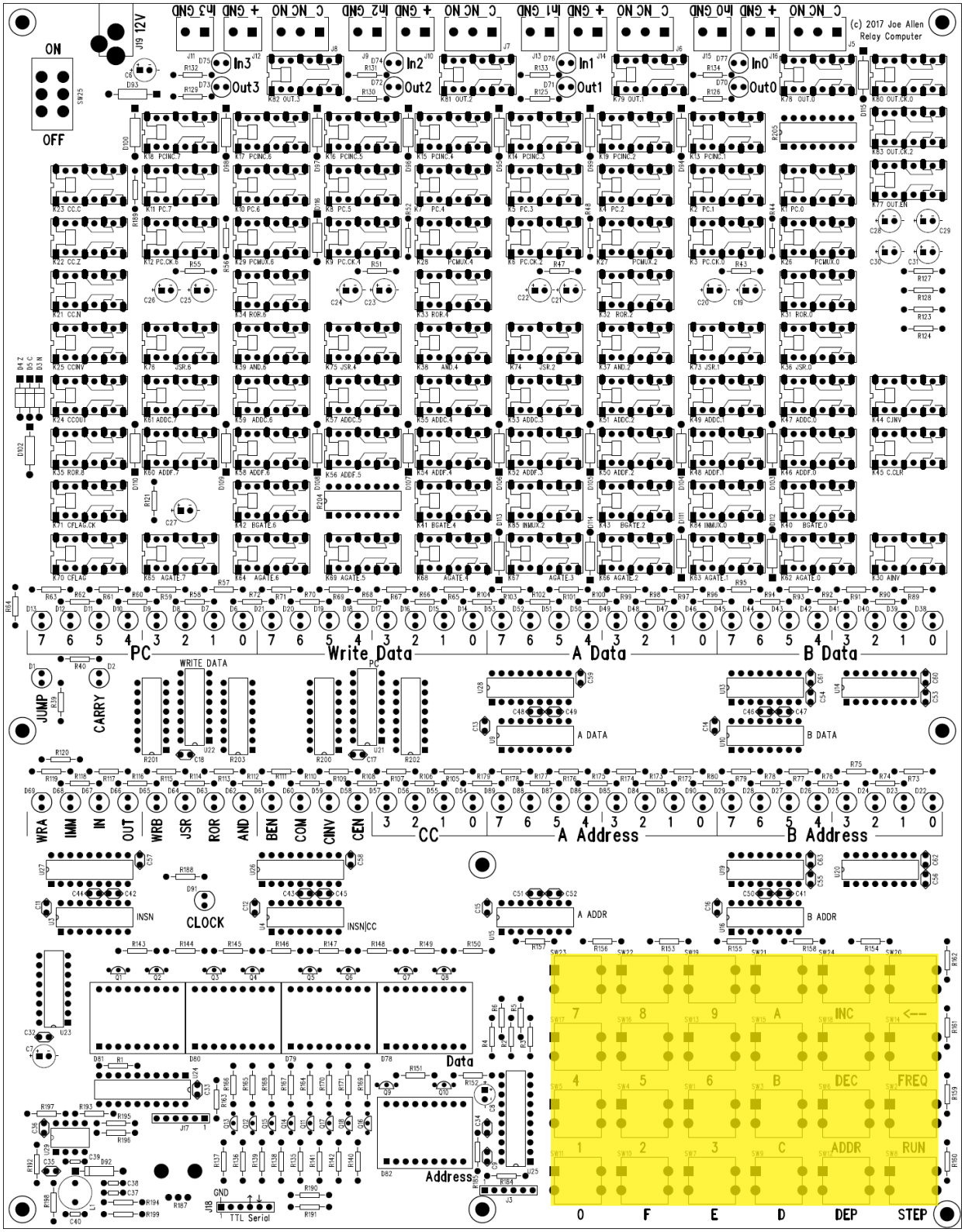
3.8.8 .1uF

C9, C11, C12, C13, C14, C15, C16, C17, C18, C32, C33, C34, C35, C36, C60, C61, C62, C63



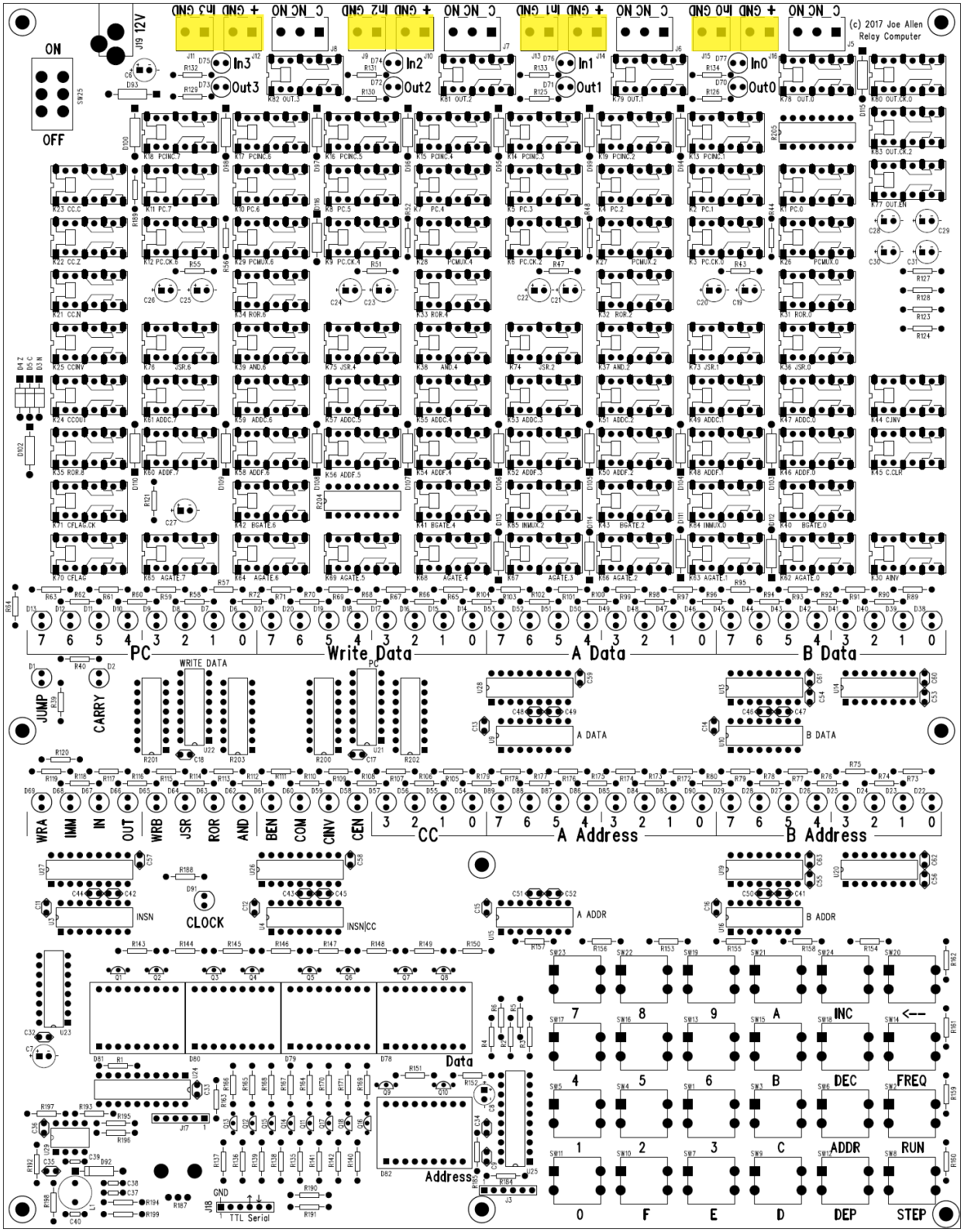
3.9 Tactile Switches (Buttons)

SW1, SW2, SW3, SW4, SW5, SW6, SW7, SW8, SW9, SW10, SW11, SW12, SW13, SW14, SW15, SW16, SW17, SW18, SW19, SW20, SW21, SW22, SW23, SW24


(c) 2017 Joe Allen
Relay Computer
ON
OFF
J19 12V
In3
In2
In1
In0
Out3
Out2
Out1
Out0
PC
Write Data
A Data
B Data
WRITE DATA
JUMP
CARRY
A DATA
B DATA
WRA
IMM
IN
OUT
WRB
JSR
ROR
AND
BEN
COM
CNV
CEN
CC
A Address
B Address
INSN
CLOCK
INSN|CC
A ADDR
B ADDR
Data
Address
GND
TTL Serial
INC
DEC
FREQ
ADDR
RUN
DEP
STEP

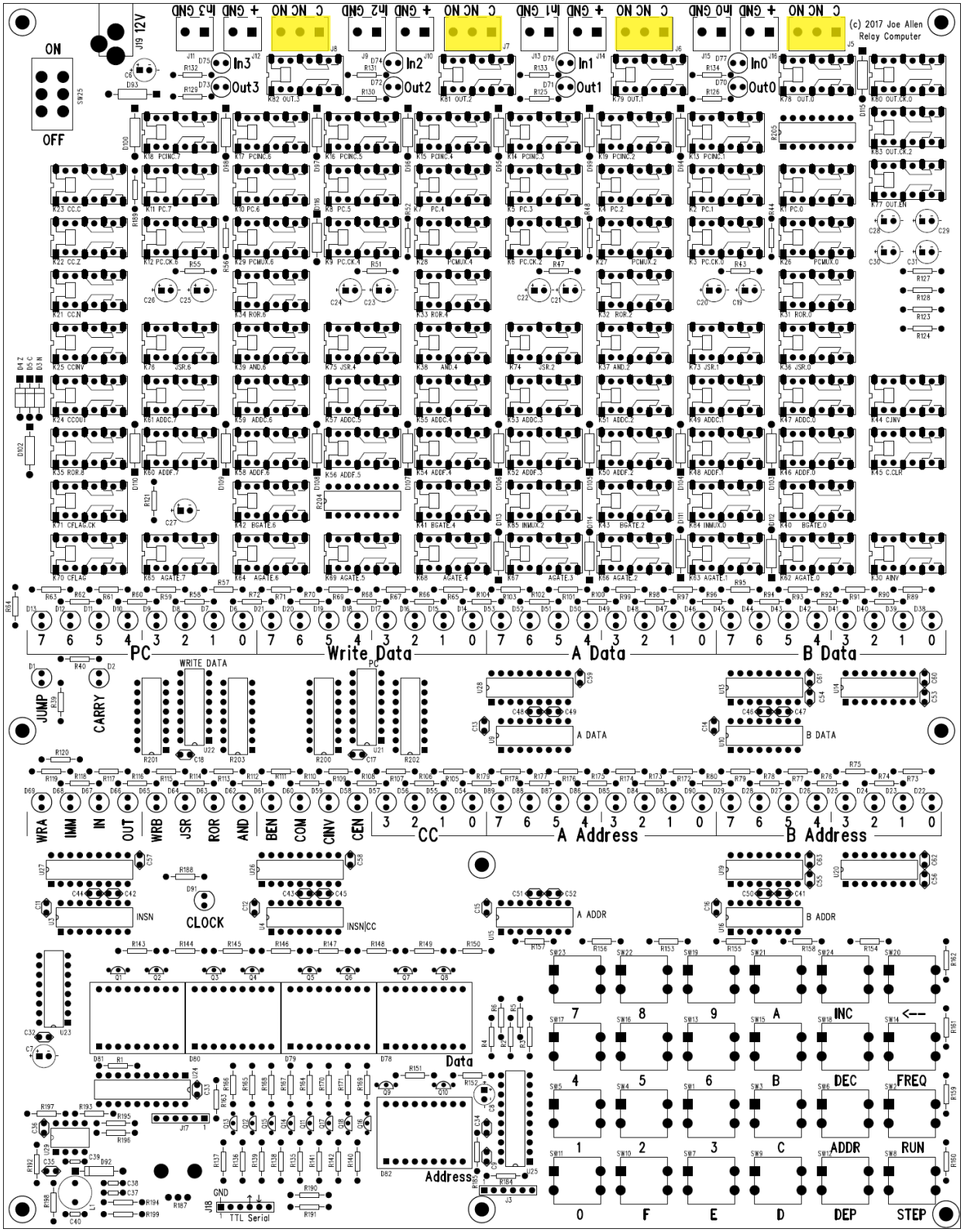
3.10 Two position terminal blocks

J9, J10, J11, J12, J13, J14, J15, J16



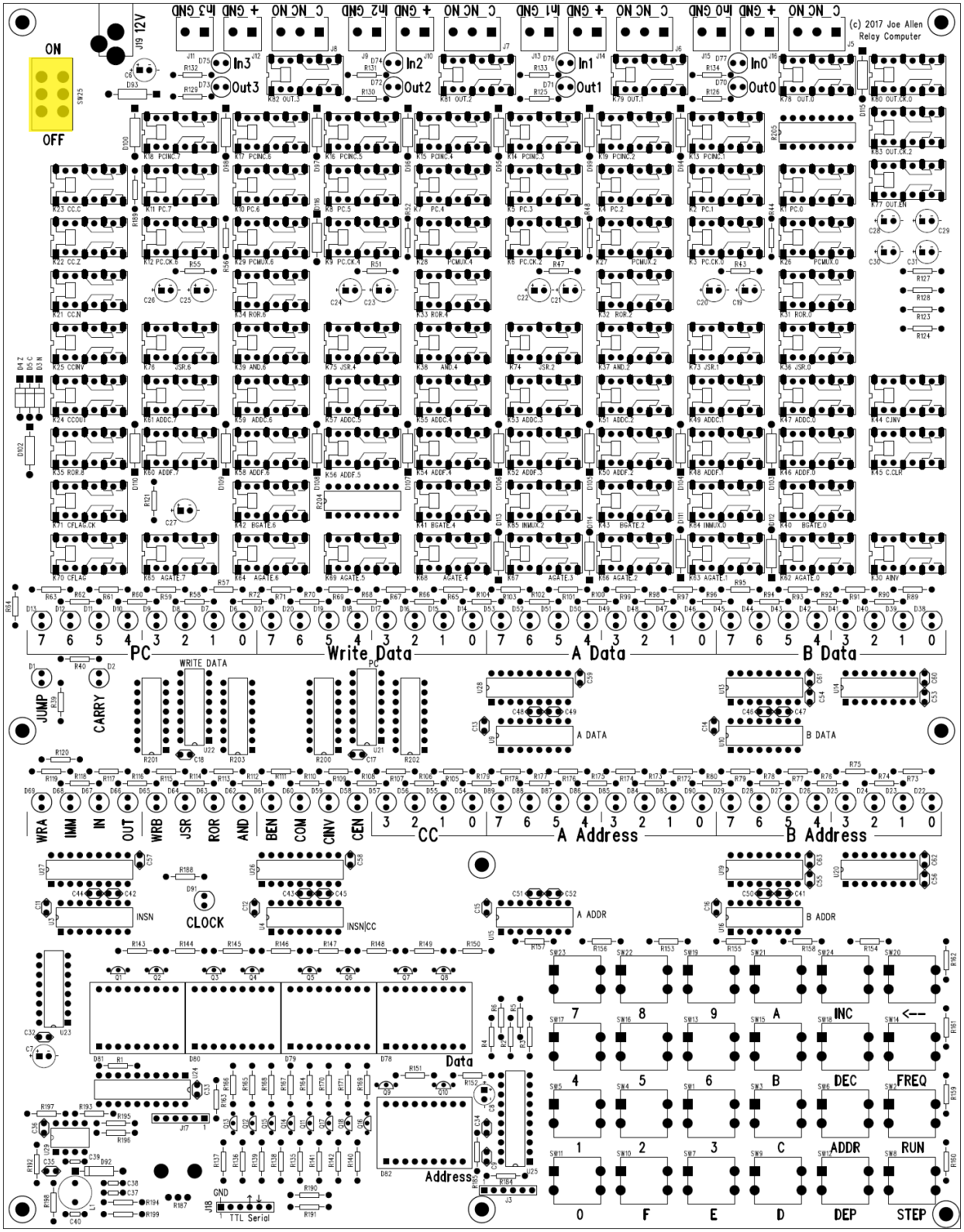
3.11 Three position terminal blocks

J5, J6, J7, J8



3.12 Slide Switch

SW25

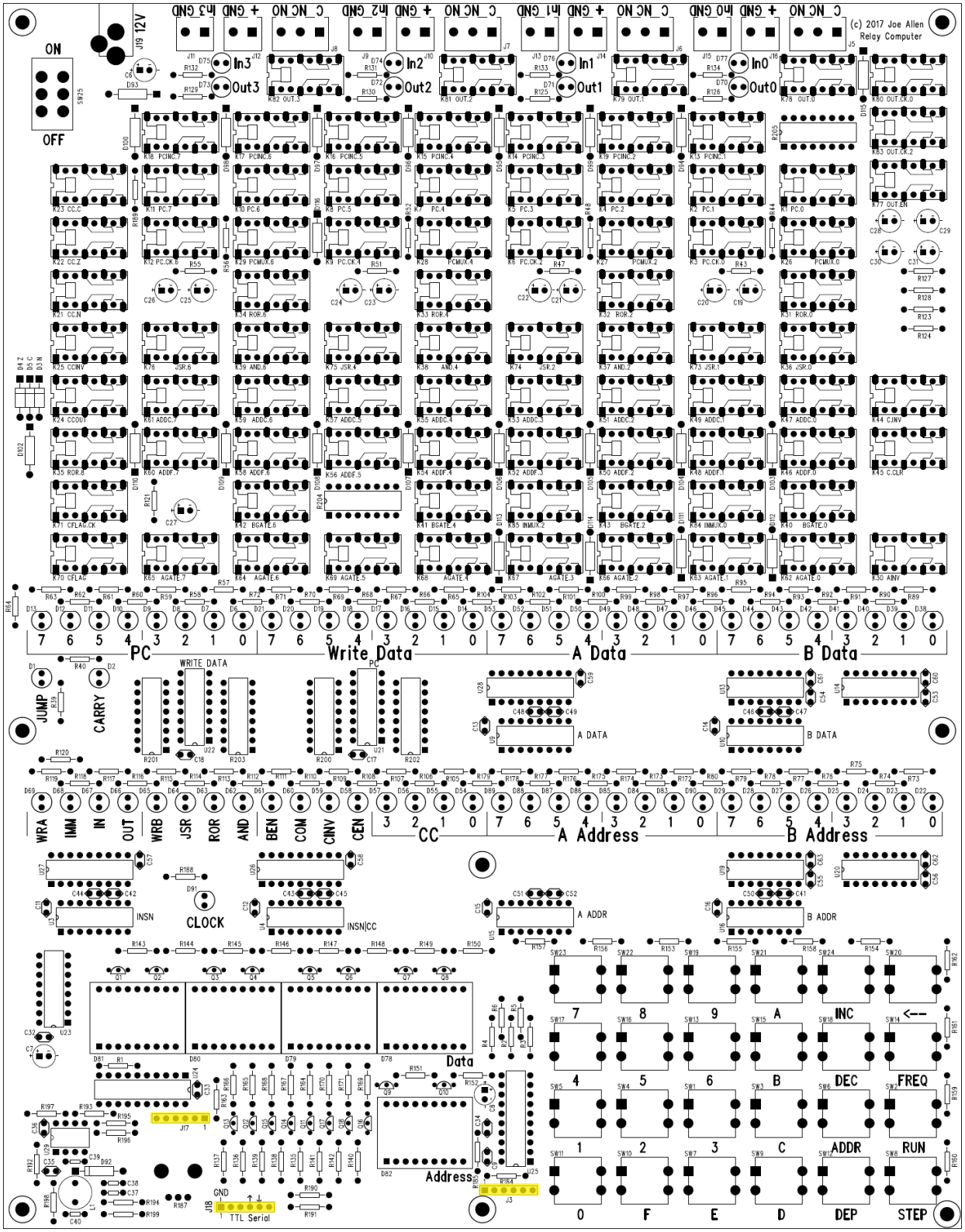


3.13 Headers

To install these, follow this procedure:

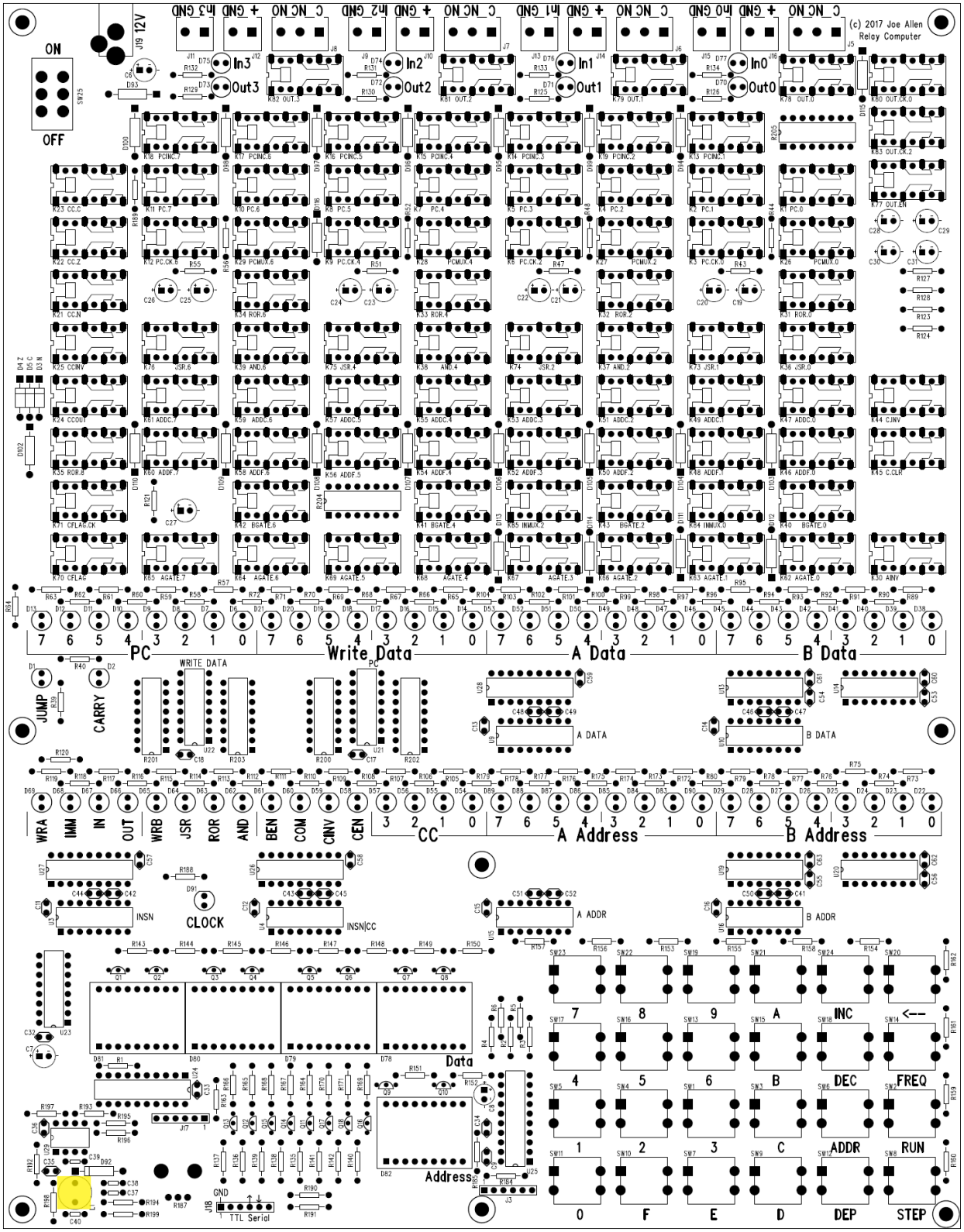
- Solder just a single pin
- Verify that the header is flush and straight (re-melt the single pin to fix it)
- Now that the header is in straight and flush, solder the remaining pins

J3, J17, J18


(c) 2017 Joe Allen
Relay Computer
ON
OFF
J19 12V
In3
In2
In1
In0
Out3
Out2
Out1
Out0
PC
Write Data
A Data
B Data
WRITE DATA
JUMP
CARRY
A DATA
B DATA
WRA
IMM
IN
OUT
WRB
JSR
ROR
AND
BEN
COM
CNV
CEN
CC
A Address
B Address
INSN
CLOCK
INSN|CC
A ADDR
B ADDR
Data
Address
GND
TTL Serial
7
8
9
A
INC
<--
4
5
6
B
DEC
FREQ
1
2
3
C
ADDR
RUN
0
F
E
D
DEP
STEP

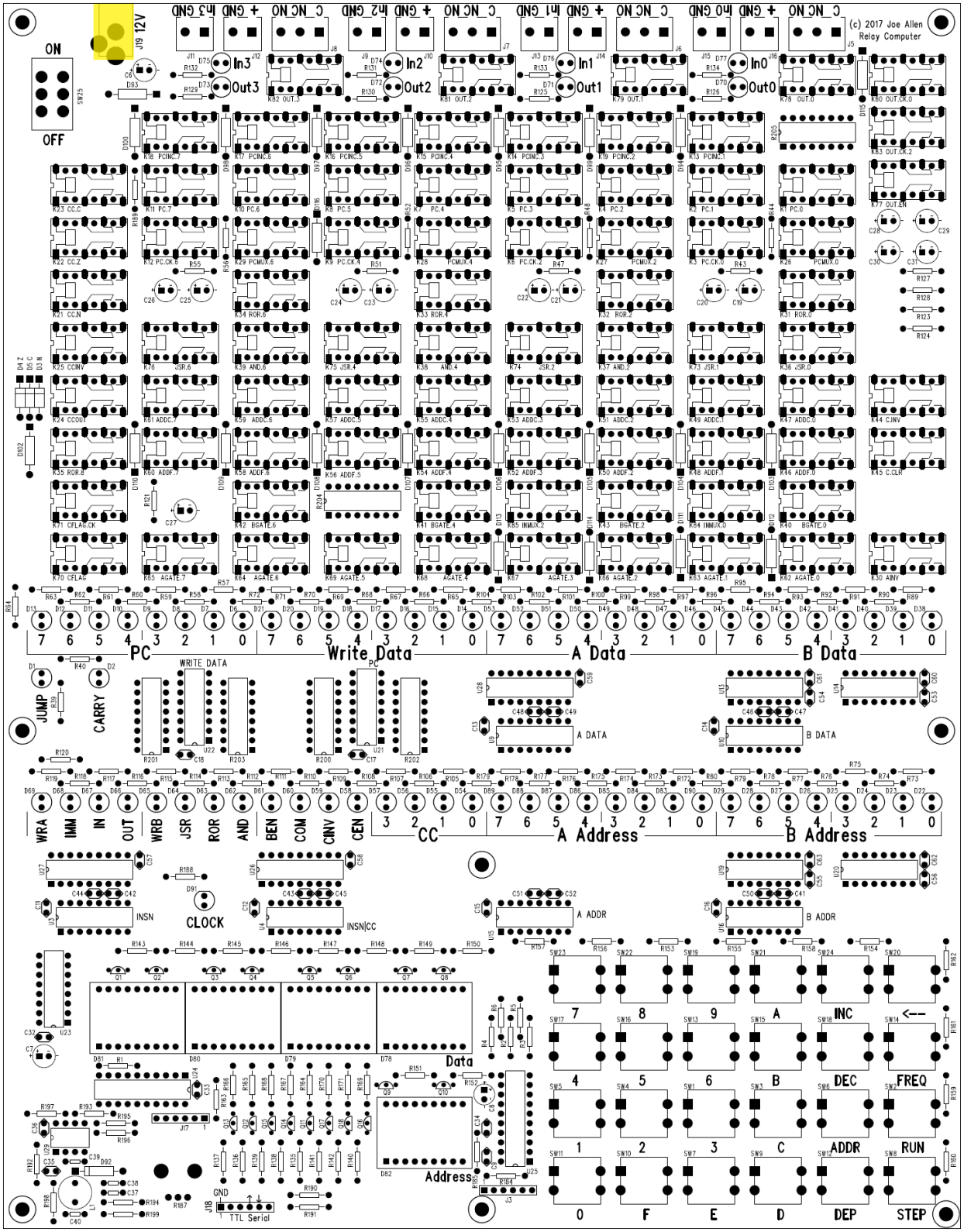
3.14 Inductor

L1



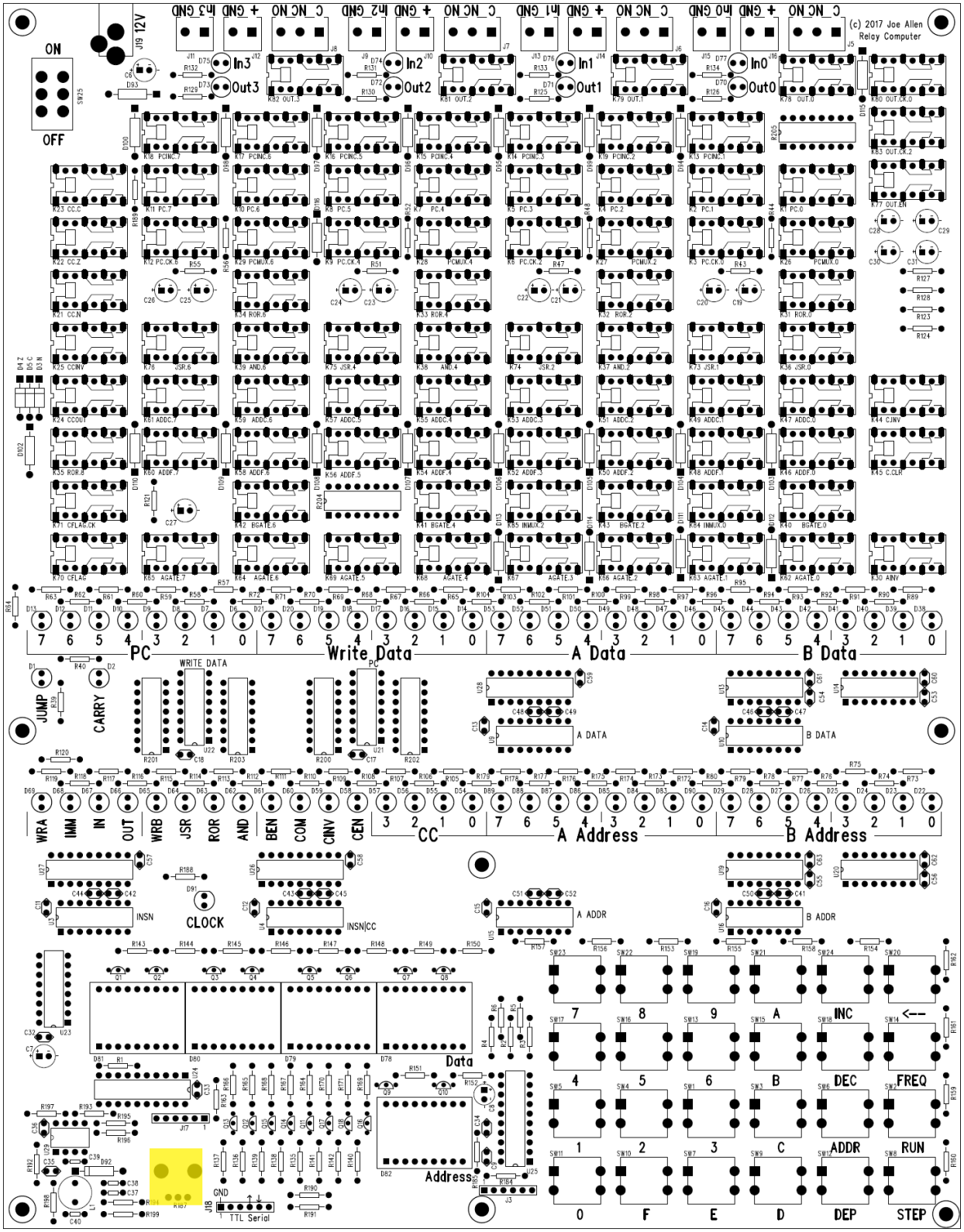
3.15 Power connector

J19



3.16 Potentiometer

R187



4 Bring up

4.1 Verify 5V supply

Install the voltage regulator IC: NR111D, U29.

Plug in the 12V adapter and turn on the computer. Use a multimeter to verify that the voltage between U23 pins 8 and 16 is between 4.9 V and 5.1 V. If it is outside of this range, check that the correct resistors are installed in R194, R195 and R196. Fix any other issues until the 5V supply is working.

Unplug the 12V.

4.2 Verify microcontrollers

Install remaining ICs and resistor arrays (R200 – R205).

Plug in the 12V adapter and turn on the computer. The LED display should be working. Try all keypad keys.

Unplug the 12V.

4.3 Install relays

Install all relays.

Plug in the 12V adapter and turn on the computer.

Verify that you can set and clear all PC bits by entering FF then <step>. All PC LEDs should be on. Now enter 00 then <step>. All PC LEDs should be off. If some appear to be stuck on or off, check that the holding resistors are installed properly: R204 and R205.

If some relays are still stuck, try swapping the PC bit which is stuck with some other relay on the board. You should be able to find one that works with the holding resistor.

4.4 Try demo program

Enter 1 0 <RUN>. The built-in demo program should run.