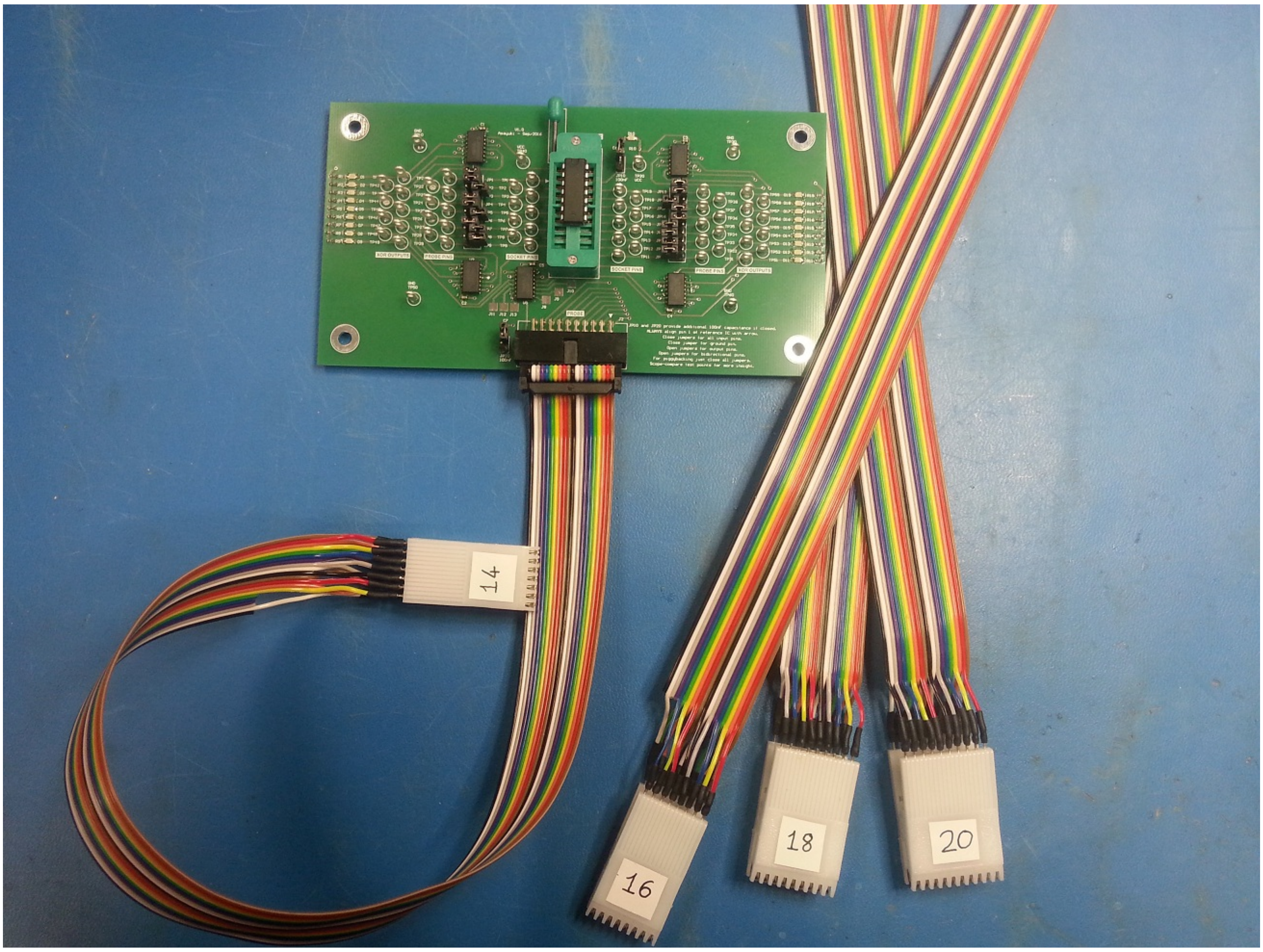
Asayuki's Logic Comparator

Manual rev. A, about SCH from Sep/2016 and PCB vers. 1.0

A logic comparator is a real helping hand in diagnosing faults in TTL logic and occasionally other ICs on arcade boards and other obsolete hardware like home computers and gaming consoles from the 80's. I always wanted one, but didn't want to fork out the 350 euros people typically ask for the real deal (the HP10529A, complete of several reference IC cards, test board, manual, box, etc.). However, in order to shrink costs to the smallest amount possible, I accepted a couple of compromises in my design which make this tool quite different from the HP one. These compromises are explained in detail later.



WARNING

A logic comparator is just a tool, like a multimeter or a screwdriver. It is not a push-button solution that will magically tell you which component to replace. You still need to possess advanced repairing skills and be knowledgeable in electronics in order to make use of it.

Manual, schematic, board and part list by Asayuki. Get in contact with me through the Arcade Otaku forum or the Arcade Projects forum.

How does a comparator work

Logic comparators are based on a very simple yet effective principle: let's compare the outputs of a suspect IC with the outputs of a known good IC. If the two behave even slightly different from one another then obviously the suspect IC is broken. This idea allows testing logic ICs without removing them from the circuit and thereby saving lots of soldering work. On the other end, this approach also has several limitations. For example, it traditionally does not allow testing bidirectional pins because connecting a pin under test with a reference pin short-circuits the two outputs when the pin is configured as an output; by converse, separating the pin under test from the reference pin prevents the required input data to reach the reference IC and therefore its outputs will not reflect the state they should. The logic comparator approach also does not highlight corner cases like an input pin which is killing the signal that drives it because of a fault causing a low impedance path to either of the power rails.

A	B	Out
0	0	0
0	1	1
1	0	1
1	1	0

The schematic for this comparator is absurdly simple: the inputs of the two ICs are connected together via jumpers. The outputs are instead left separated and brought to a XOR gate. The XOR gate will generate an high logic level if the output of the reference IC and the output of the IC under test differ. This high logic level ends up lighting the corresponding LED. Dead easy, isn't it? However, relying on the LEDs is definitely a bad idea because differences might be so tiny that the LED will emit too few light for human eyes to see. Also, the XOR gate does not check if the voltage level generated by the IC under test is good. As soon as it is “somewhat” high, like 2V or something, it will accept the signal as high therefore masking out this problem. In other words, LEDs don't tell the full story. And this is just as true for this comparator as well as for the HP10529A. That's the reason why there are so many test points on the board: this way it's possible to ignore the still very useful LED and see in detail with an oscilloscope what exactly is happening to make a much more precise judgement. The last thing one wants during a repair effort is to mistakenly judge an IC as good and firmly believe the problem to be somewhere else.

To complete the design I have thrown in a few no-frills add-ons that do not impact the overall cost but can be very useful:

- There is a power LED on board. If that lights up, then the comparator's on-board components are getting power and are therefore able to make comparisons. This does not protect from misconfiguration cases or loose joints cases but sure is a help.
- There are VCC and GND test points that allow connection of the oscilloscope's ground terminals, allow easily monitoring of the VCC voltage and spikes on the power supply rail and also allow to relate power to the error signals output from the XOR gates, to check if the problem might be power related.
- Two 100nF capacitors can be enabled with jumpers to try and better filter the power supply at the other end of the probe cable and at the reference IC. They can help in debugging power-glitch-related issues.

How to operate the comparator

As you can see on the picture, there is a ZIF socket in the middle, two columns full of jumpers and two columns full of miniature surface mount LEDs. There are also tons of test points and a connector for the probe. The tool itself requires no battery (it takes its power from the system under test) and works in the following way.

Step 1: A known working, better yet brand new, reference IC is inserted in the ZIF socket, exactly the same model and family as the IC to test, making sure that pin 1 is correctly aligned.

Step 2: The jumpers are reconfigured based on the type of reference IC loaded into the ZIF, according to the on-board instructions.

Step 3: The appropriate probe is chosen based on the number of pins the IC has, and connected to the rectangular black socket visible on the bottom of the photo.

Step 4: The probe is attached to the system under test, onto the IC to test, ensuring that the polarity of the probe is correct and all pins are correctly mating.

Step 5: Power is applied to the system under test.

Step 6: The LEDs on the comparator will signal any logic level discrepancy found between the IC under test and the reference IC; if any of them lights up, even if dim, then the IC under test is broken.

Step 7: Optionally an oscilloscope is connected to the LED test points. If the scope shows anything else than a steady zero volts level or sporadic insignificant glitches then the IC under test is failing to meet the timing requirements it has been specified for (in other words... it's broken).

Step 8: Optionally a two or more channels oscilloscope is connected to the other test points to compare directly the output levels of the IC under test and the reference IC. This might highlight weakened output drivers in the IC under test, which means it might be failing soon and it had better been replaced to be on the safe side.

If the IC under test manages to pass step 8 then it's very likely good.

Differences with the HP comparator

But what are the advantages and the drawbacks with respect to the HP10529A?

PROS

- Way cheaper than the HP one.
- Brand new parts, which means it will last potentially much more than a used HP comparator.
- ZIF socket and jumpers for the reference IC instead of reference cards:
  - no more soldering,
  - no more drilling pads,
  - no more “oh no, I'm out of reference cards and I need to buy more, don't know where”,
  - even more money can be spared using a standard DIL socket instead of a ZIF one
  - creative uses are possible to a certain extent (more on this in the next chapter)
- 18 channels enable testing of 20 pin devices like the 74LS244 and the 74LS373 (impossible with the HP one)
- Not limited to TTL ICs: as long as the suspect IC works on 5V and has VCC and GND in the right places, it can be tested. PROMs and CMOS 4xxx ICs come to mind.
- Probes are easily repairable and replaceable.
- Test points allow to see the tiniest glitches LEDs can't show (requires oscilloscope).
- Test points allow to spot ill input signals and ill output pins that are bound to fail soon (at least multimeter required, but oscilloscope is better).
- Selectable 100nF power decoupling capacitors.

CONS

- Jumpers are needed to configure the tool: they need to be fiddled with any time the reference IC is changed. A cheat sheet can be prepared to quickly search for the needed configuration based on the IC model, but that's just as much as one can do.
- At least two different probes are needed to test the vast majority of TTL ICs: 14 pin and 16 pin. One more probe is needed to test 20 pin ICs and one might want yet another probe for 18 pin ICs just in case (2114 RAMs for example). The good news is that probes can be very easily built as needed.
- There is no enclosure, and there will never be one as it would prevent the use of the tool: being careful that no metal part touches the PCB of the comparator on either side is mandatory. Screw holes allow the bottom side to be protected by an isolator, but that's just as much as one can do.
- Does not employ the pulse enlargement circuitry used by HP to make LEDs always fully light up (this would have added a lot of parts and made the comparator much more expensive). The good news is that this comparator can make use of modern very bright LEDs, therefore a faint LED is easily seen anyway; and an oscilloscope can still be used to confirm uncertain cases.
- Home-made cabling makes for higher parasitic capacitance, parasitic inductance and cross-talk. This tool does not perform as good as the professionally built one.
- Does not employ 10k pull-ups at the reference IC socket as the HP10529A does. This means that the few logic ICs with open-collector outputs are not supposed to work correctly when used as references unless you manually solder pull-ups on the reference IC itself. This in turn allows other “creative” uses (more on these below).

Use of the comparator in a “creative” way

Please understand that these are just corner case uses that go beyond the scope of the comparator itself. The comparator has not been designed with these functions in mind! They might or might not work on a case by case basis, but the comparator will definitely be happy if it can do something more to serve the cause through a creative mean that wasn't supposed to work in the first place.

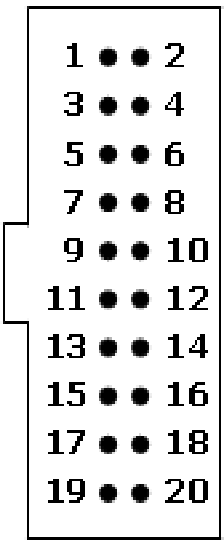
1) **Piggybacking mode**. How many times does a repairer piggy-back an IC to check if its inputs are flaky? With a logic comparator there should be no need for piggy-backing in the first place, but since jumpers are used for configuration then one might just as well close all of them. In this case the probe is completely connected 1-to-1 to the refernce IC, thereby piggy-backing one IC onto the other without the nuisance of loose contacts or the risk of inadvertent short circuits. Please note that this will not work everywhere. The cable will get in the way of the faster signals and tighter logic edges.
2) **Insertion side effects**. Sometimes the mere connection of the probe alone to the target system makes the target system misbehave. This happens because the parasitic inductance, parasitic capacitance and cross-talk of the probe are impacting the system under test negatively. On relatively slow circuits, like arcade boards are, this is only a concern in high speed areas. On all other areas it might indicate issues in the signal that is driving the IC under test.
3) **Compare bidirectional pins**. Wouldn't it be great if logic comparators could compare bidirectional pins as well? With the HP10529A this is definitively impossible. This comparator however has test points and jumpers which can be creatively taken advantage of. To test input-output pins (like the data pins of a 2114 RAM for example) it is sufficient to use a resistive jumper instead of a normal one. This allows input data to reach the reference IC when it operates as an input but prevents the reference IC to actively influence the output of the IC under test, at the cost of a small current flowing through the resistive jumper when the two ICs output different values. Please note that this will not work everywhere. It depends on the speed of the involved signals, slope of the signal edge and impedance of the inputs the signals are directed to. The amount of resistance required depends on the situation, typically 1kΩ to 10kΩ. 4.7kΩ is a safe starting value.
4) **Two spare XOR gates** are located on the comparator's board. They have been brought out to easily soldered pads just in case a future creative use might require an additional XOR gate, a NOT gate (a XOR gate with one input tied to VCC becomes a NOT gate) or a buffer (a XOR gate with an input tied to GND becomes a non-tristate buffer).

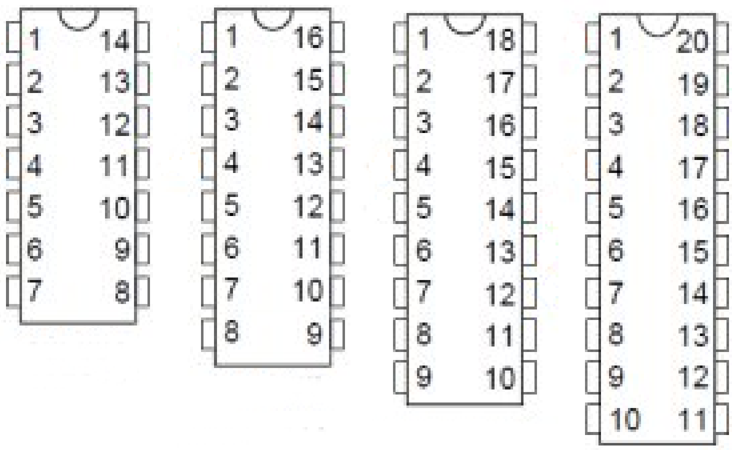
Pro tips

1) The parasitic inductance and capacitance of the probe, as well as its cross-talk, must always be taken into account! They will slow down the signals and can make the system under test behave funny, crash etc.
2) Signals take time to travel back and forth on the probe cable, while the reference IC is much closer to the test points. This makes glitches appear on the LED output test points, which are to be considered normal up until a certain width. This “certain width” depends on the driving strength of the signal, the physical cable itself as well as the speed of the logic circuit.
3) Loose joints can always be part of the picture, because the comparator is based on connectors, jumpers, a socket and an IC clip. It must be kept in mind that any of those might not be touching correctly.
4) As with every new tool, using this logic comparator is a lot like trying to get along with another person: the more one spends time together, the more one learns on how the other person typically behaves and reacts. Trying the comparator on surely working circuits allows getting familiar with glitches and issues typically shown on different kinds of signals. Experience makes more and more proficient.
5) To use the tool with ICs having open-collector outputs one needs, for each and every output, a 10k axial resistor. These can be physically soldered to the reference IC between the output pins and the VCC pin.

Probe wiring diagram

In order to build or repair a probe, the following table can be used. The grey column lists the pin numbers of the IDC connector on the comparator's board. Pin 1 is marked on the board itself as visible on the photo. Once the ribbon cable is crimped to the connector, pin 1 will be the outermost wire oriented toward the pin 1 marking of the IDC connector. The other pins follow sequentially wire by wire. A coloured ribbon cable helps with identifying the wires.
The other columns of the table list the IC clip pin numbers the wires have to be connected to. As you sure know, DIL ICs have their pin 1 on the top left corner when the IC key is oriented upwards. Pins follow sequentially on the left side down to the bottom left corner and then on the right side from the bottom right corner up to the top right corner. If this sounds all too confusing, look at the picture below. The photo of the comparator will also be helpful.



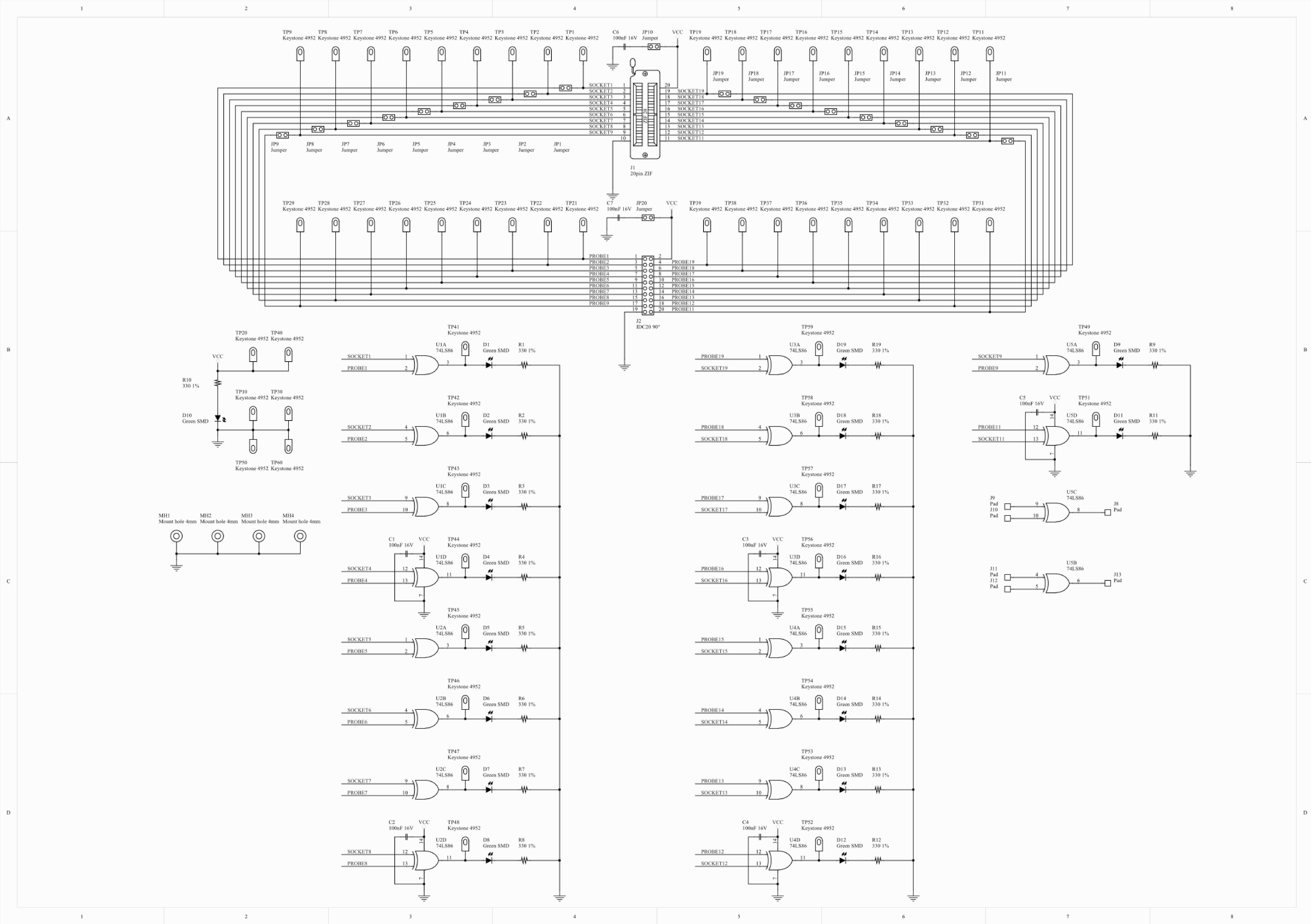


IDC	20 pin	18 pin	16 pin	14 pin	IDC	20 pin	18 pin	16 pin	14 pin
1	1	1	1	1	**11**	2	2	2	2
2	3	3	3	3	**12**	4	4	4	4
3	5	5	5	5	**13**	6	6	6	6
4	7	7	7	7	**14**	8	8	8	8
5	9	9	9	9	**15**	10	10	10	10
6	11	11	11	11	**16**	12	12	12	12
7	13	13	13	13 + 19	**17**	14	14	14	14
8	15	15	15 + 19	-	**18**	16	16	16	-
9	17	17 + 19	-	-	**19**	18	18	-	-
10	19	-	-	-	**20**	20	-	-	-

Schematics and part list

The part list below allows very quick purchase and delivery of all required components. The prices are however quite high. The full schematic diagram can be found on the next page.

Description	Designator	Manuf.	Manuf. order code	QTY	Supplier	Supplier order code
Ceramic capacitor, 100nF 10% 16V X7R 0603	C1 to C7	AVX	0603YC104KAT2A	7	Digikey	478-1239-1-ND
Chip led diode, 50mcd 20mA 2.1V green 0805	D1 to D19	Kingbright	APT2012CGCK	19	Digikey	754-1127-1-ND
20pin ZIF connector for 300mil DIP integrated circuits	J1	3M	220-3342-00-0602J	1	Digikey	3M2002-ND
20pin IDC connector 90° through hole	J2	CNC tech	3020-20-0200-00	1	Digikey	1175-1618-ND
Through hole jumper strip, 100mil	JP1 to JP20	Sullins	PREC010DAAN-RC	2	Digikey	S2012EC-10-ND
Chip resistor, 330ohm 1% 0.1W 50ppm 0603	R1 to R19	Vishay	MCT06030C3300FP500	19	Digikey	MCT0603-330-CFCT-ND
Through-hole test terminal for scope clip	TP1 to TP60	Keystone	4952	60	Digikey	4952K-ND
Quad, 2 input, XOR gate	U1 to U5	Texas Instr.	SN74LS86ADR	5	Digikey	296-14901-1-ND
Jumper cap, 100mil	Off-board	3M	969102-0000-DA	20	Digikey	3M9580-ND
IDC20 female crimp	Off-board	CNC tech	3030-20-0103-00	4	Digikey	1175-1422-ND
Ribbon cable, 20 w ires, 0.5m	Off-board	Assmann	AWG28-20/F/300	4	Digikey	AE20M-5-ND
DIP14 probe clip	Off-board	3M	923698	1	Digikey	923698-ND
DIP16 probe clip	Off-board	3M	923700	1	Digikey	923700-ND
DIP18 probe clip	Off-board	3M	923703	1	Digikey	923703-ND
DIP20 probe clip	Off-board	3M	923704	1	Digikey	923704-ND



TP9 Keystone 4952
TP8 Keystone 4952
TP7 Keystone 4952
TP6 Keystone 4952
TP5 Keystone 4952
TP4 Keystone 4952
TP3 Keystone 4952
TP2 Keystone 4952
TP1 Keystone 4952
C6 100nF 16V
JP10 Jumper
VCC
TP19 Keystone 4952
TP18 Keystone 4952
TP17 Keystone 4952
TP16 Keystone 4952
TP15 Keystone 4952
TP14 Keystone 4952
TP13 Keystone 4952
TP12 Keystone 4952
TP11 Keystone 4952
JP19 Jumper
JP18 Jumper
JP17 Jumper
JP16 Jumper
JP15 Jumper
JP14 Jumper
JP13 Jumper
JP12 Jumper
JP11 Jumper
SOCKET1
SOCKET2
SOCKET3
SOCKET4
SOCKET5
SOCKET6
SOCKET7
SOCKET8
SOCKET9
SOCKET19
SOCKET18
SOCKET17
SOCKET16
SOCKET15
SOCKET14
SOCKET13
SOCKET12
SOCKET11
JP9 Jumper
JP8 Jumper
JP7 Jumper
JP6 Jumper
JP5 Jumper
JP4 Jumper
JP3 Jumper
JP2 Jumper
JP1 Jumper
J1 20pin ZIF
TP29 Keystone 4952
TP28 Keystone 4952
TP27 Keystone 4952
TP26 Keystone 4952
TP25 Keystone 4952
TP24 Keystone 4952
TP23 Keystone 4952
TP22 Keystone 4952
TP21 Keystone 4952
C7 100nF 16V
JP20 Jumper
TP39 Keystone 4952
TP38 Keystone 4952
TP37 Keystone 4952
TP36 Keystone 4952
TP35 Keystone 4952
TP34 Keystone 4952
TP33 Keystone 4952
TP32 Keystone 4952
TP31 Keystone 4952
PROBE1
PROBE2
PROBE3
PROBE4
PROBE5
PROBE6
PROBE7
PROBE8
PROBE9
PROBE19
PROBE18
PROBE17
PROBE16
PROBE15
PROBE14
PROBE13
PROBE12
PROBE11
J2 IDC20 90°
TP20 Keystone 4952
TP40 Keystone 4952
R10 330 1%
D10 Green SMD
TP10 Keystone 4952
TP30 Keystone 4952
TP50 Keystone 4952
TP60 Keystone 4952
MH1 Mount hole 4mm
MH2 Mount hole 4mm
MH3 Mount hole 4mm
MH4 Mount hole 4mm
TP41 Keystone 4952
U1A 74LS86
D1 Green SMD
R1 330 1%
TP42 Keystone 4952
U1B 74LS86
D2 Green SMD
R2 330 1%
TP43 Keystone 4952
U1C 74LS86
D3 Green SMD
R3 330 1%
C1 100nF 16V
TP44 Keystone 4952
U1D 74LS86
D4 Green SMD
R4 330 1%
TP45 Keystone 4952
U2A 74LS86
D5 Green SMD
R5 330 1%
TP46 Keystone 4952
U2B 74LS86
D6 Green SMD
R6 330 1%
TP47 Keystone 4952
U2C 74LS86
D7 Green SMD
R7 330 1%
C2 100nF 16V
TP48 Keystone 4952
U2D 74LS86
D8 Green SMD
R8 330 1%
TP59 Keystone 4952
U3A 74LS86
D19 Green SMD
R19 330 1%
TP58 Keystone 4952
U3B 74LS86
D18 Green SMD
R18 330 1%
TP57 Keystone 4952
U3C 74LS86
D17 Green SMD
R17 330 1%
C3 100nF 16V
TP56 Keystone 4952
U3D 74LS86
D16 Green SMD
R16 330 1%
TP55 Keystone 4952
U4A 74LS86
D15 Green SMD
R15 330 1%
TP54 Keystone 4952
U4B 74LS86
D14 Green SMD
R14 330 1%
TP53 Keystone 4952
U4C 74LS86
D13 Green SMD
R13 330 1%
C4 100nF 16V
TP52 Keystone 4952
U4D 74LS86
D12 Green SMD
R12 330 1%
TP49 Keystone 4952
U5A 74LS86
D9 Green SMD
R9 330 1%
C5 100nF 16V
TP51 Keystone 4952
U5D 74LS86
D11 Green SMD
R11 330 1%
J9 Pad
J10 Pad
U5C 74LS86
J8 Pad
J11 Pad
J12 Pad
U5B 74LS86
J13 Pad