

LittleGP-30

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This document describes the newer “wide panel” version of the LittleGP-30.

If you have the original “pocket calculator” version, please see www.e-basteln.de/lgp30 for documentation.



1 Contents

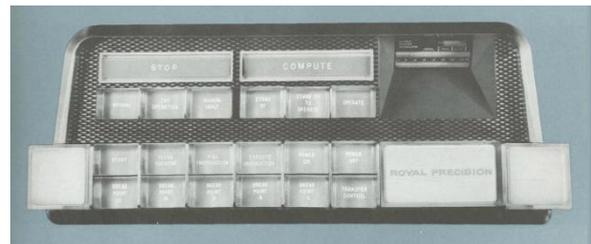
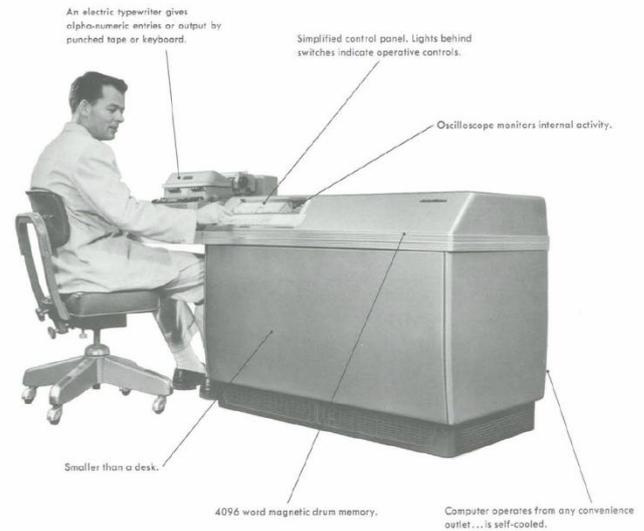
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2 What's this?

The LGP-30 was a commercial computer, released in 1956. Due to its simple design and relatively low cost, it may be seen as the first “personal computer” – to be used by a single user as their “desk computer”. (It could sit by your desk, and happened to be the size of a desk.) Designed in the age of vacuum tubes, it needed only 113 tubes in total, of which only 24 were used in the CPU itself! This simplicity was achieved by a bit-serial CPU design, which was tightly integrated with the magnetic drum storage unit. The magnetic drum contained not only the main memory, but also the CPU’s three 32-bit registers, and several tracks with timing signals to control the instruction decoding and execution.

This document describes a replica that is true to the bit-serial implementation and its timing, but uses modern components. The CPU and the magnetic drum storage are recreated in an FPGA – by implementing the complete logic equations published by the LGP-30’s inventor (in a scientific paper and in the computer’s service manual). The magnetic drum, while implemented in on-board memory inside the FPGA, is made tangible via an optional video display of its contents.

This way, one can play with all the quirks of the LGP-30, including the timing behavior of programs, which depends critically on the position of instructions and data on the magnetic drum. For those who want to really dive into the details of the bit-serial design, the clock rate can be slowed down (all the way to single step, bit-by-bit clocking), and the contents of the CPU’s tube-based flip-flops can be inspected on an LCD (all 15 bits of them!).



*LGP-30 overview and front panel;
from a contemporary brochure*

3 Building the LittleGP-30

Soldering the LittleGP-30 circuit board is quite straightforward. I recommend following the sequence in this chapter. If you are in a rush, please be sure to observe the following hints:

- Components are installed on both, the top and bottom side of the PCB. The component outlines on the silkscreen print will tell you where they go.
- For most resistors and capacitors that are installed on the bottom, the **leads must be clipped flush with the PCB to allow installation of other components on the top**. The same is true for the HDMI socket and for pin header P4. I recommend clipping the leads with a side cutter *before* soldering.
- If you want to use the front panel, **the LCD and the MAX202 should *not* be socketed**, to keep their profile lower than the switches.
- Before installing the LCD, make sure all components below it have been installed (placed on the bottom side). Please **test the correct function of the HDMI output before installing the LCD**, since soldering errors will be very hard to fix afterwards!

3.1 What you will need

- Numato “Mimas” Spartan 6 FPGA board.
- Custom PCB and electronic components, see the bill of materials in the appendix
- Cables:
 - Serial connection: 9-pin Sub-D male to female connection, wired straight through (when connecting to a standard PC RS-232 port, with 9 pin male output)
 - USB connection (to configure the FPGA) and power supply: Mini-USB type B, straight connector, to regular USB type A.
 - HDMI, length < 1.5m recommended
- Hand soldering tools
 - Soldering iron (pen or chisel tip), solder (resin core, 0.5mm diameter or less), wire cutters, tweezers etc.
- A PC running Windows is required (temporarily) to download the FPGA configuration. For later operation, any PC running a serial terminal program, or of course a real serial terminal operating at 19200 Baud, can be used.

3.2 Builder’s choices

Before buying parts and building the replica, there are two choices to be made: Which kind of switches do you want to install, and do you want to build this kit for installation in an enclosure or for use as a bare board?

3.2.1 Switches – OMRON or Diptronics

The PCB is suitable for use with two different switch models. Both are back-illuminated, with 10*10 mm² square key caps which allow the insertion of printed labels to indicate button function. Both are

momentary action switches; the latching action of the LGP-30 switches is recreated in software and indicated using the LED backlights. Which ones you prefer is a matter of taste:

- The OMRON B3W-9000 series switches provide a nice even illumination of the key cap, due to a built-in diffuser. On the other hand, the key tops show an octagonal outline inside the caps, which does not look quite right for the LGP-30. Also, I found that white-on-grey lettering, as used in the original LGP-30, is hard to read on the transparent film needed for the labels. The switches are more expensive, at approx. \$2.50 each (17 switches are required).
- As a lower cost option, Diptronics TLL-6 switches and KTL-SAI key caps can be used. About \$1.00 per pair, but the illumination is not as nice and shows a bright spot in the center. The key cap inserts are square, instead of the octagon shape of the OMRONs. White-on-grey lettering can be used on the paper labels, although it becomes a bit difficult to read when a button is illuminated.



LittleGP-30 with enclosure (Hammond 515-0930) and OMRON switches, and as a bare-board version with Diptronics switches.

The bill of materials in the appendix gives the exact type numbers for the recommended switches. The OMRON switches are more widely available, but come in many different configurations – be sure to get models with a single LED and 10mm clear key caps. Diptronics switches are only available from selected distributors, often in large quantities only. I am looking into sourcing options; Rapid Electronics in the UK is the only supplier of small quantities I have identified so far.

Several Chinese relatives of the TLL-6 switches are available at even lower cost. Also, remaining stock of an obsolete OMRON switch (B3E-1100), which has the same footprint as the Diptronics switches, is available from Jameco. The catch is that the clips for holding the key-cap are shaped slightly different

in these switches, and that I have not found any matching transparent caps for either of them. If you come across a good low-cost option, please let me know!

3.2.2 Enclosure or bare board?

The LittleGP-30 can be built as an open “single board computer” – well, a stack of two boards actually –, optionally adding the front panel for cosmetics. Or you can install the LittleGP-30 in an enclosure of your choice, using the front panel board to cover the cutout in the enclosure.

The only choice you need to make early on is whether to install the on-board Sub-D connector X1 for RS-232, or the 10-pin header P5 instead. The latter allows for a slightly more compact installation of an insulation displacement connector and ribbon cable, to connect to an enclosure-mounted Sub-D jack. If in doubt, I recommend installing the on-board Sub-D connector.

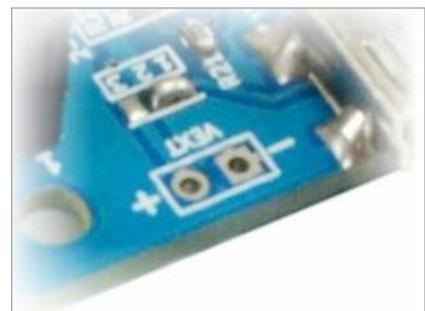
3.3 Preparing the Numato Mimas board

3.3.1 Power supply connection

The Mimas board and front-end PCB require a +5V regulated supply, with a current rating of 500 mA or more. (Up to 350 mA current consumption with an HDMI monitor connected, depending on the number of LEDs that are on. Up to 100 mA extra current can be required for an external relay.) Any regular USB port or small USB-style power supply should be adequate.

The Mimas board can be powered through its USB programming connector, and generates the 3.1V supply for the FPGA and most components on the LittleGP-30 front end. But a few components on the LittleGP-30 board require a +5V supply, which is not present on the Mimas headers P1 and P2. The required connection will be prepared in this step:

- Populate the “VEXT” connector on the Numato Mimas board with a 2-pin female header. This will mate with the single +5V pin P4 on the LittleGP-30 board. The ground connection will be established via the two large headers P1 and P2.
- On the power selection solder jumper, located right behind the VEXT connector, connect all three pins with a fat solder bridge. Power can now be supplied either via USB (for testing and FPGA programming) or through an external power jack connected via the LittleGP-30 piggyback board and the VEXT connector.



Attention: Do *not* supply power via USB and the VEXT connector at the same time! This would result in the two power supplies fighting over the definition of “+5V”, and could damage a power supply. If you plan to install the LittleGP-30 in an enclosure with an external power jack, it’s easy to forget about this restriction if you want to connect USB for reprogramming at some point. To prevent future problems, you can change the power selection jumper later to connect pins 2 and 3 only: This will disconnect the USB power, so +5V will always have to be supplied via the LittleGP-30 board, and

no conflicts can occur. But for initial configuration and testing, it is more convenient to be able to use USB power.

3.3.2 Configuring the FPGA

To configure the FPGA with an available .BIN binary file, it is *not* necessary to install the Xilinx development environment. (See section 3.6 for details on that package.)

- Obtain the .BIN file for this project : <http://www.e-basteln.de/lgp30>.
- Download the FPGA Configuration Tool, mimasConfig.exe, from Numato:
<http://productdata.numato.com/assets/downloads/fpga/mimas/mimasConfig.exe>
- Download the USB Driver from Numato. Unpack the ZIP file, but don't install it yet:
http://productdata.numato.com/assets/downloads/common/numato_lab_usb_cdc_driver.zip
- Connect the Numato board to the PC via a USB cable.
- When prompted on the PC, install the USB driver.
- Run mimasConfig.exe, which does not require installation. Select the correct COM port (check in the device manager if unsure) and .BIN binary file, and click "Program".
- Documentation from Numato can be found at <https://docs.numato.com/doc/mimas-spartan-6-fpga-development-board/>

3.3.3 Preliminary function test

After programming is complete, the FPGA will automatically start up. The LGP-30 replica is already running, but you can't see much of it as the custom control panel is not there yet.

But you can check the correct function of the on-board switches on the Mimas board (which serve as option switches for a few user interface options): Each of the four buttons should toggle the LED next to it on and off.

If you don't get the expected behavior, please verify that you had selected the correct .BIN file and repeat the download steps above.

3.4 Populating the LittleGP-30 circuit board

Soldering on this board is straightforward. All components have leads for through-hole mounting; no SMD (surface mount) parts are used. I recommend populating the board in the order of the following sections.

3.4.1 Bottom: Discrete components

Start with the discrete components (Rs, Cs, diodes, transistor) mounted on the bottom side. For the components that are installed below the switches and below the LCD, it is important to clip the leads very short, flush with the PCB. I recommend that you

- insert the components,
- turn the board over and place it on a flat surface,
- clip all leads level with the PCB, using side cutters,
- then solder.

Since the through-holes all have plated sides, there will be ample surface for the solder to securely connect and hold the parts to the PCB.

The above applies to all capacitors and nearly all resistors that are installed on the bottom side, as well as diode D1. It can't hurt to clip the leads of the few other components short as well.

3.4.2 Bottom: HDMI connector

The PCB is designed for a through-hole HDMI jack which arranges the 19 pins in three rows, in a 1.5mm pitch. This makes it reasonably straightforward to solder. The connector you buy may have a screw terminal for chassis mounting, which is not needed. You can clip it off if you prefer.

Install the HDMI connector. As it is mounted below the LCD, its leads must also be clipped short, including the two mounting tabs. Clip before soldering, as outlined above. Inspect your soldering carefully, preferably under a magnifier, to catch any missing connections or solder bridges.

3.4.3 Bottom: RS-232 connector and pin headers

Install the pin headers P1 to P4. To ensure that those headers which mate with the Numato Mimas board (P1, P2, P4) are nicely aligned, it is recommended to insert all of them into the corresponding Mimas sockets, place the LittleGP-30 PCB on top, and solder.

The single pin at P4 is located below a switch. If you use the OMRON switches, which have a larger footprint, **clip off P4, flush with the PCB's top side, before soldering.**

Sub-D RS-232 connectors come in two slightly different mechanical packages. This PCB layout is meant for the more compact U.S. flavor, with a distance of 7.2mm between the connector's front edge (PCB edge) and the first row of pins. The pin numbering is for a female Sub-D 9 pin connector. This can be connected 1:1 to the male connector found in PCs, for use with a PC-based terminal emulator program.

Alternatively, if you want to install the LittleGP-30 in an enclosure, you can install the 10-pin header P5 instead of the Sub-D connector. A straight ribbon cable with 10-pin insulation displacement connector can then be used for a space-saving connection to an enclosure-mounted RS-232 jack. (These are also available with insulation displacement connector for easy, solder-free assembly). If in doubt, I recommend installing the on-board Sub-D jack; you can still make a short extension cable for that one if you want to add an enclosure later.

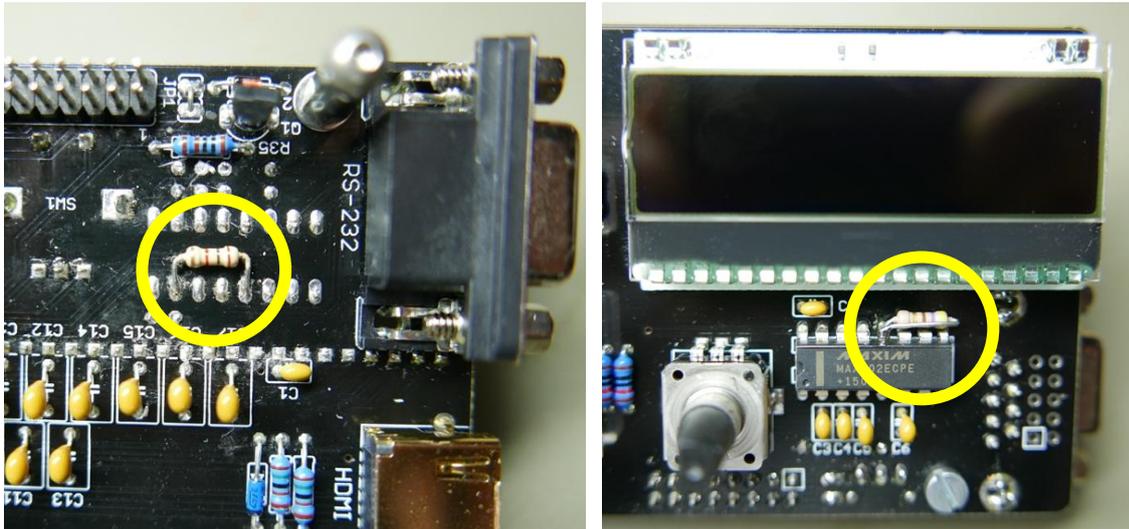
3.4.4 Top: MAX202 and capacitors

Install the MAX202 IC and its capacitors C2 to C6. The IC should typically *not* be placed in a socket, to keep its profile well below the height of the switches.

For the first prototype batch of the "landscape" LittleGP-30, it is necessary to patch in a voltage divider from two resistors, which brings the output level from the MAX202 RX line down to the 3V level expected by the FPGA:

- Before installing the MAX202, clip its pins 9 and 12. For pin 12, leave a little metal tab on the IC body which you can solder to in the following step.
- On the top side, install a 1 kOhm resistor in series between the MAX202's pin 12 and the corresponding solder pad on the PCB. See the picture below.

- On the bottom side, install a 2.2 kOhm resistor between pin 12 and pin 15 (Gnd) of the MAX202. See the picture below.

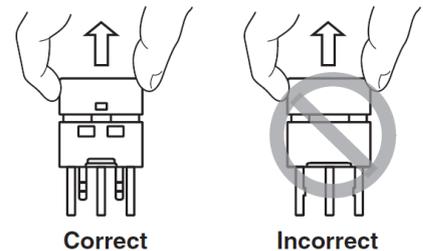


Patch resistors for voltage divider. Use 2.2 kOhm on the bottom (left), 1 kOhm on top (right).

3.4.5 Top: Switches

OMRON switches

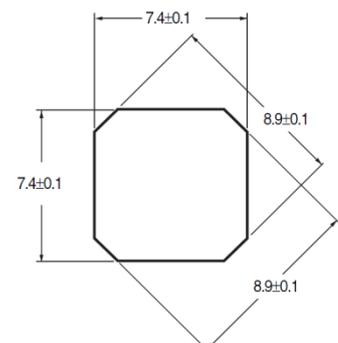
Before installing the OMRON switches, remove their key-caps. OMRON advises against pulling off the caps once the switches have been soldered, to avoid putting stress on the pins. Grab the caps on the side away from their mating latches, as illustrated.



The “Compute” and “Stop” indicators (S16, S17) are not switches in the original LGP-30, but only indicator lamps. The LittleGP-30 replica does use them as switches to select user interface options – see the use instructions below. In the bill of materials, I have suggested switches with red LEDs and higher actuation force for these two. Don’t get them mixed up with the regular switches after you have removed the caps. An abbreviated model number is also printed on the side of the switch body.

The pinout of the OMRON switches is not symmetrical. They can only be inserted in one orientation, so no need to worry about LED polarity. Before soldering the switches, **please double-check that they sit nice and flat on the PCB, and are not tilted due to a resistor pin which is not clipped short enough.**

Before putting the key caps back on, print and insert labels. For the OMRON switches, these look best when printed on clear transparent film or translucent paper. OMRON’s official dimension drawing is shown on the right; these labels fit into a recessed area inside the key caps. I have found that, unless they are printed on very thick film, the small labels can move around inside the caps. Larger labels which fill the full width of the caps stay in place better. A Powerpoint template with labels in both sizes is available for download on the LittleGP-30 page.



If you get a label wrong, it is feasible to carefully pry the key caps back off (violating OMRON's advice).

Diptronics switches

These ship with the caps packaged separately. I recommend soldering the switches first and installing the caps later. Again, the two switches with red LEDs are meant for S16 and S17 ("Stop" and "Compute" indicators).

The Diptronics switches have a symmetrical pinout, and you must install them the right way round to get the LED polarity right. One leg of the LED is painted either red or yellow. This indicates the LED color, and also marks the cathode (negative terminal). **The colored LED leg must be connected to ground. It must be oriented away from the series resistor corresponding to the switch, and away from the LCD display.**

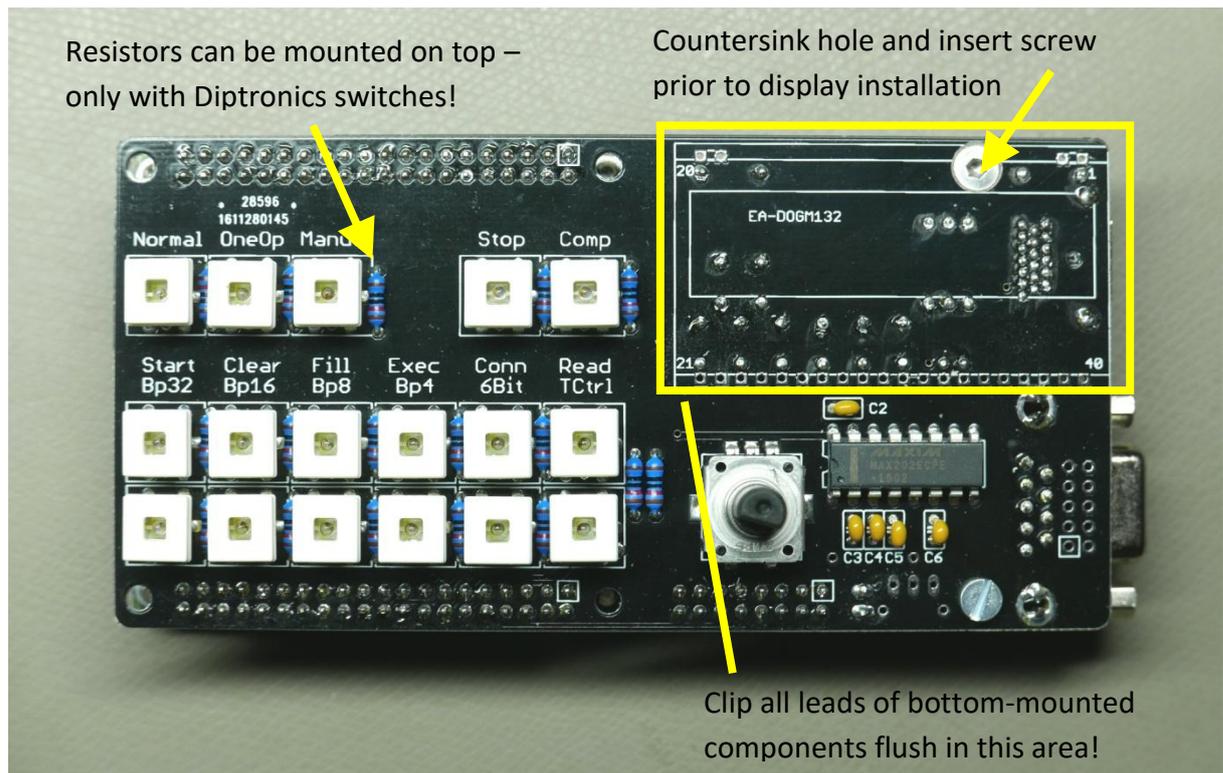
For the Diptronics switches, print the labels on white paper (needed as a diffuser). Be careful when installing the key caps:

- Pry the ivory insert and transparent cap apart before installing them on the switches. I used a small screwdriver blade, inserted into the slits in the insert, to pull the insert out.
- Push the ivory inserts onto the switches first. Observe the correct orientation of the little plastic latches. **This step is not reversible**; the latches will probably break if you try to pull the inserts back up!
- Position the label and push on the transparent cap. This step can be reversed with care if needed, but try to get it right first time to avoid damage to the switch.

3.4.6 Top: Encoder

The encoder can only be installed in one orientation. Do solder its mounting tabs too, for good mechanical support.

A small knob will help in handling the encoder. The one on the parts list (see appendix) is cheap and unobtrusive, but needs to be drilled out with a 7mm drill if you don't want it to sit very high. The required depth of drilling depends on the height at which the front panel is installed – please check and drill after the final assembly. Do not drill too deep; the knob should sit at least 0.5mm above the front panel to allow the pushbutton to be actuated! Before clamping the knob in a vise for drilling, wrap it with a few turns of masking tape – the plastic is quite soft.



PCB before installation of the display. Please note the highlighted hints. The screw in the display area is only needed if you want to use your LittleGP-30 as a freestanding stack of boards, not for enclosed versions. For OMRON switches, resistors must be mounted on the bottom.

3.4.7 Visual inspection and functional test

Congratulations – your LittleGP-30 replica is nearly complete! Before you move on to install the LCD, I recommend a check of your work so far. Start with a careful visual inspection:

- Have all discrete components been populated, and with the right values?
- Pay particular attention to the components located below the LCD (C1, C10-C17, D1, R31-R34). These will be difficult to fix once the LCD has been installed. Check values, diode polarity, and solder joints.
- Any solder bridges? Inspect the HDMI connector in particular. The headers P1, P2 and P3 also deserve a closer look.
- Have all pins actually been soldered? It is easy to miss some of the push-buttons' pins, or some of the pins on the large headers. In addition to malfunctions right from the start, this can lead to annoying problems with intermittent connections later on.

Now plug the LittleGP-30 board onto the Numato Mimas for a first function test. This assumes that you have prepared the Mimas with FPGA firmware and VEXT power connector, as described above.

- Orient the LittleGP-30 such that its one-pin connector P4 meets the VEXT +5V connector on the Mimas. Push down firmly to seat the P1, P2 and P4 connections.
- Connect power via the Mimas USB port.
- You should see several LEDs lighting up: Manual, Stop, Start, Clear, Fill, Conn(ect) and Read.
- Pressing the buttons in the bottom row should each toggle the respective LED on and off. The mode buttons – Normal, OneOp and Manual – should act as “radio buttons”: Pressing one of them will light its LED and disable the LEDs in the other two. Various combinations of

buttons in the middle row will also be lighted depending on the mode selected, showing whether they are enabled.

- Connect a monitor to the HDMI output. An image in XGA format (1024*768 pixels) should come up, displaying the contents of the LGP-30's magnetic drum.
- Try rotating the encoder (but don't push the encoder button). The display contents should move left and right.

The HDMI function test is the most important one, as you cannot access the HDMI connector once the LCD has been installed.

3.4.8 Top: LC display

Before you install the LC display, please perform the visual inspection and function test outlined above. Soldering errors on the components located below the LCD, and specifically on the HDMI connector, are hard to fix afterwards!

The LC Display should normally be installed *without sockets*. The LCD and backlight are 5.5mm high; if you add a 4mm low-profile socket and the 1.2mm front panel thickness, the complete assembly will be nearly as high as the OMRON switches. Unless you like your switches nearly flush with the front panel, there is not enough room for a socket. (If you use the lower profile Diptronics switches, there is definitely not enough room.)

There is one M3 mounting hole below the LCD. This is not used when installing the LittleGP-30 in an enclosure, but you probably need it to attach a foot or spacer if you want to build a bare-board stack. **If you intend to use your LittleGP-30 without an enclosure, be sure to insert an M3 screw through the hole below the LCD before populating the LCD!** I recommend countersinking the hole from the top side and using a countersunk screw.

The DOGM-132 displays (132*32 pixel graphical LCDs) come in different versions. The recommended EA DOGM132S-5 is optimized for inverted operation, with bright pixels on black background, and meant to be used with a backlight. EA LED55X31-G is a yellow/green backlight, which results in a color scheme similar to the original LGP-30 oscilloscope. Other models of the DOGM-132 series, including transfective versions without a backlight, can be used alternatively.

When using a display with backlight:

- Remove the protective foils from the display back and backlight front.
- Insert all display pins into the backlight's corresponding holes.
- Insert the LCD+backlight package into the PCB through-holes.
- Adjust the height of the display above the PCB:
 - For minimum height: Insert a strip of cardboard between the LCD and the PCB. This can be removed after soldering, and will ensure a safety distance of 0.5mm or so to avoid mechanical damage to the LCD backlight.
 - For custom height: Mount your front panel at the desired height (using the spacers and enclosure wall thickness you are planning for). Turn the PCB stack over, let the LCD rest against the front panel, and make sure that it sits level.
- Solder the 20+2+2 pins of the LCD from the bottom side.
- Solder the 2+2 LED supply pins from the top, to electrically connect the backlight board to these pins.

3.5 Expansion port options

The 16-pin expansion connector P3 provides optional connections for

- power supply (5V DC),
- a relay – just for “vintage” clicks,
- eight digital I/O lines – FPGA pins, which are configured as 3.3V CMOS by default. See the oscilloscope section below for information on their function in the standard FPGA setup.

Pin	Function	Function	Pin
1	Relay driver, negative terminal	Relay driver, positive supply	2
3	+5V in/out	+5V in/out	4
5	GND	GND	6
7	TEST6 I/O	TEST7 I/O	8
9	TEST4 I/O	TEST5 I/O	10
11	TEST2 I/O	TEST3 I/O	12
13	TEST0 I/O	TEST1 I/O	14
15	+3.1V out	+3.1V out	16

Pinout of the expansion port connector, looking at the solder side of the connector (i.e. the top of the PCB).

3.5.1 Power supply

Pins 3/4 and 5/6 can be used to connect an external power supply. For LittleGP-30 systems installed in an enclosure, this may be more convenient than supplying power via the USB port on the Mimas board. See section 3.3 for details on the Mimas power selection jumper.

A regulated +5V supply, with a current rating of 500 mA or more, is required. I have measured up to 350 mA current consumption with an HDMI monitor connected, depending on the number of LEDs that are on. Up to 100 mA extra current can be required for an external relay (see below), and ~40 mA less if operating without an HDMI monitor. Any regular USB port or small USB-style power supply should be adequate.

3.5.2 Relay clicker

Pins 1 and 2 allow connection of a small external relay. It is intended just for the “vintage” clicking sound. In the FPGA’s default configuration, it will click for each character that is printed on the Flexowriter. Yes, that is a bit corny, but a nice reminder that the original LGP-30 was a very mechanical device... The clicks can be disabled at any time via an option key on the LittleGP-30.

For the simplest connection (recommended):

- Use a relay designed for 5V or 6V coil voltage and $\leq 100\text{mA}$ coil current.
- Close jumper JP1 to connect the relay driver to the internal +5V supply. Soldering in a wire bridge will do, since you will not need to change this often.
- Connect the relay coil to pins 1 and 2. A protection diode is already on board.

Alternatively, if you need to drive a relay designed for a higher coil voltage (and have another power supply available for that voltage):

- Use a relay for up to 30V coil voltage. The 100mA current limit still applies.
- Leave jumper JP1 open. (**Important!** Otherwise you will fry your Mimas and LittleGP-30 boards by connecting their supply to the higher relay drive voltage!)
- Connect your external power supply to pin 2 (up to +30V DC) and pin 5/6 (GND).
- Connect the relay coil to pins 1 and 2. A protection diode is already on board.

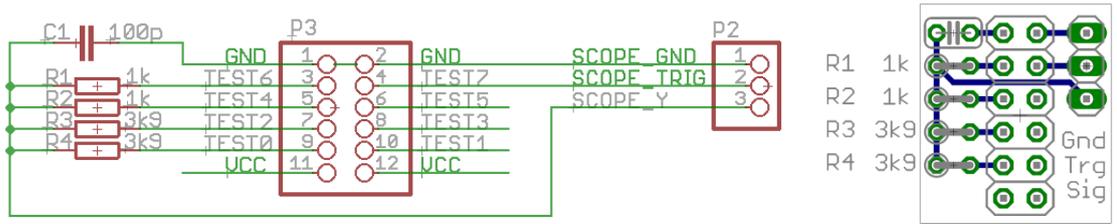
Experiment with the “sound design” a bit. The volume and timbre of the clicks will vary significantly depending on where the relay is positioned in the enclosure, how it is attached, and even which side of the relay is in contact with the enclosure.

3.5.3 Oscilloscope connection

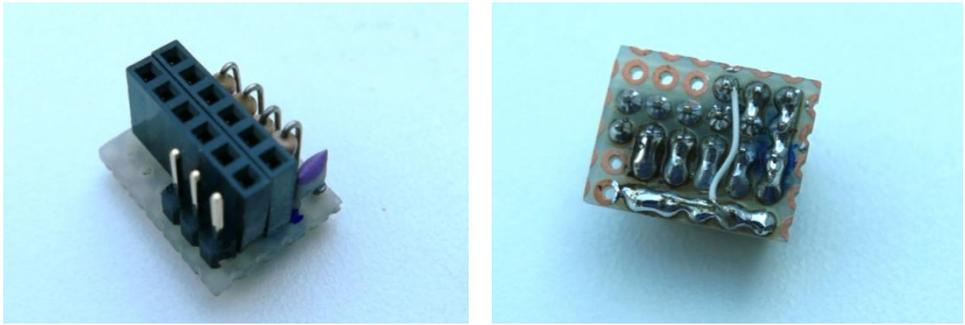
The original LGP-30 used an oscilloscope to display the register contents – accumulator, instruction register, and program counter. This type of display was needed since, due to the bit-serial architecture, the bits only showed up one at a time, at 120 kHz clock rate.

The LittleGP-30 replica has an LCD to display the same graphical information, so the oscilloscope is not needed. If you want to connect one just for kicks, here’s how. (The oscilloscope is actually a better display than the LCD, since it follows changes quite a bit faster!)

Connector P3 provides the required signals: A register output, which alternates between bitstreams of the A, R, and C registers, and two offset outputs, which create the vertical offsets . All signals need to be added via a simple resistor network – please see the circuit diagram and layout suggestion below. A trigger signal, which occurs at the beginning of each register word, is also provided.



Schematic and layout for an oscilloscope adapter for the expansion port.
Easily hand-wired on perfboard, as shown below.



In the only image of a working LGP-30 display that I know of, the traces have a large vertical width (but are quite crisp in the horizontal direction). I don't know what causes the vertical width and whether the LGP-30 scope was supposed to look like this, but find that it makes the display easier to read. Hence, a "fat trace" component (5 MHz signal) is output on the connector and added to the Y signal via R4 to make the trace appear wider. To reduce the width of the trace, increase the value of R4, or vice versa.



LGP-30 Display.
Image from http://computermuseum.informatik.uni-stuttgart.de/dev/lgp30/lgp30_3.html

The polarity of the provided signals is such that the traces will appear in the same order as in the LGP-30: Counter on top, instruction register in the middle, accumulator below. However, the bit order will be the wrong way round: The LGP-30 drum always outputs the low bit first (needed for ripple carry during addition and subtraction), and its oscilloscope scanned *from right to left* to show the bits in the conventional order, with the low bit on the right. Your oscilloscope is probably fixed to scanning from left to right; and unfortunately the FPGA cannot easily output a ramp signal for use with an X/Y scope.

There is an easy solution to this problem: Turn your scope upside down! ;-)
You will also need to invert the scope's Y input to correct the orientation.



This scope scans from right to left, showing low bits on the right ;-)

3.6 Enclosures

Use of an enclosure is optional. Personally, I like the “bare board stack”, positioned at an angle by using taller feet in the back. If you prefer an enclosure, these two fit nicely – there are many others of course:

- Hammond 515-0930, steel/aluminum. Available e.g. from tube-town.net, 21.80€.
<https://www.tube-town.net/ttstore/Gehaeuse/Hammond-Gehaeuse/Hammond-515-Serie/Hammond-Chassis-515-0930::3444.html>
- Combiplast CP-18-34, grey ABS. Available e.g. from tme.eu, 5.95€.
www.tme.eu/de/katalog/#search=cp-18-34

Suggested dimensions for the front panel cut-out are provided in appendix 5.3.

Be careful when using metal hardware to mount the boards. The GND and +3V layers come quite close to the mounting holes; if the solder mask layer gets damaged, metal screw heads or nuts will connect to the supply layers and may cause shorts. The use of Nylon screws or washers is recommended.

RS-232 and power connections can be made via connectors P3 and P5, see section 3.4.3 above. If you want a panel-mounted HDMI connector, you will need to obtain a short HDMI cable for the internal wiring. Cables with a jack suitable for panel mounting are available (but only with a straight plug on the other end, it appears). If space is tight and you need to use an angled HDMI plug on the PCB side, use a cable with plugs on both ends, and a separate HDMI panel connector (with jacks on both sides).



A “bare bones” build of the LittleGP-30. This version simply uses PCB spacers for feet, with longer feet in the back to tilt the whole unit.

3.7 FPGA development

If you want to dive into modifying the FPGA code, free development tools for the Spartan-6 FPGA family are available from Xilinx. They are a bit unwieldy, however.

These are *not* needed if you just want to download the .BIN file provided for the LittleGP-30! For that, see the section on “Preparing the Numato Mimas board” above.

- A Xilinx Account is needed to download the tools. Free registration under <https://secure.xilinx.com/webreg/createUser.do>
- Download Xilinx ISE Webpack (a 6 GByte download!)
https://secure.xilinx.com/webreg/register.do?group=dlc&htmlfile=&emailFile=&cancellink=&eFrom=&eSubject=&version=14.7&akdm=1&filename=Xilinx_ISE_DS_Win_14.7_1015_1.tar
- Xilinx ISE is no longer maintained and is not fully compatible with Win8 and Win10. The License Manager and Project Navigator both just close when you try to open a file. This can be fixed as follows, quoted from <http://www.eevblog.com/forum/microcontrollers/guide-getting-xilinx-ise-to-work-with-windows-8-64-bit/>:
 - Fixing Project Navigator, iMPACT and License Manager.
Note: I am assuming you are using ISE 14.7 and have installed it to the default location
 - Open the following directory: C:\Xilinx\14.7\ISE_DS\ISE\lib\nt64
 - Find and rename libPortability.dll to libPortability.dll.orig
 - Make a copy of libPortabilityNOSH.dll (copy and paste it to the same directory) and rename it libPortability.dll
 - Copy libPortabilityNOSH.dll again, but this time navigate to C:\Xilinx\14.7\ISE_DS\common\lib\nt64 and paste it there
 - In C:\Xilinx\14.7\ISE_DS\common\lib\nt64 Find and rename libPortability.dll to libPortability.dll.orig
 - Rename libPortabilityNOSH.dll to libPortability.dll
- A brief tutorial for first steps with Xilinx ISE: <http://langster1980.blogspot.de/2014/10/elbert-v2-fpga-tutorial.html>

4 Using the LittleGP-30

4.1 The real LGP-30

If you have decided to build this kit, you have probably familiarized yourself with the design and operation of the original LGP-30 to some extent. Several nice web pages with LGP-30 descriptions, technical documentation, and reminiscences of the early days of programming are easily found online.

The University of Stuttgart hosts the most comprehensive site, with technical documentation, a software collection on ASCII-converted paper tapes, and a description of their own, working LGP-30. Please see the Appendix for links.

The LGP-30 Operating Manual is specifically recommended as a starting point for your exploration of the LGP-30: ftp://bitsavers.informatik.uni-stuttgart.de/pdf/royalPrecision/LGP-30/LGP-30_Operations_Manual.pdf

4.2 Getting started

4.2.1 Connecting peripherals

Only two connections to the LGP-30 replica are required:

- Power supply: +5V either via the USB port on the Mimas board which you have already used to configure the FPGA, or via expansion connector P3 on the LittleGP-30 board.
- Serial port: An external ASCII terminal is required to simulate the Flexowriter. See the “Serial terminal” section below.

Further optional connections (HDMI monitor for drum display, oscilloscope for old-style register display) are discussed in the respective sections.

4.2.2 Loading programs

There are three ways to load programs into the LGP-30 replica:

- Reading “paper tapes”:
 - Text files are uploaded via your terminal program to simulate paper tapes.
 - The 10.4 loader program is already preinstalled on the replica’s drum.
 - Press the following control panel buttons to start the loader:
Manual Input – Clear Counter – Normal – Start
 - Tell your terminal program to send the paper tape text file.
 - Most paper tapes will end with a command that sets the program counter to the start address, so you simply have to press Start once more to start the newly loaded program.
- Loading previously stored drums:
 - Complete drum contents can be stored and re-loaded if you use a terminal program that supports the old XModem file transfer mode. (1970’s data communications meets 1950’s computer!)

- See the “XModem” section below for details.
- Manual bootstrap from an empty drum:
 - The hard way, for “real programmers” ;-)
The papertape for the 10.4 loader begins with an interesting self-extending bootstrap sequence. This is entered in a semi-manual way; then the boot loader can read the main program from the remainder of the tape. It’s worthwhile trying this once. (But then it gets old quite fast...)
 - To start from scratch and remove the pre-installed 10.4 loader, first load an empty drum image via XModem.
 - The bootstrap process is described in the 1963 edition of the Programming Manual. German version available here – see page 27:
ftp://ftp.informatik.uni-stuttgart.de/pub/cm/lgp30/docs/EC13-022_Programmierungsanleitung_Apr1963.pdf

General hint: Paper tape files should *not* have a carriage return (or other characters) after their final “conditional stop” character! When reading a paper tape, this character will remain in the RS232 input buffer and may get in the way of subsequent operations, e.g. an XModem download. Many of the Stuttgart paper tape files do have a final carriage return; I recommend removing it. To flush the buffer of pending characters, switch the LGP-30 to Manual mode and activate “Read” – possibly several times, until no further input is received.

4.3 Control panel

4.3.1 LGP-30 Control Panel

All relevant buttons and indicators from the LGP-30 control panel are present. See the LGP-30 operation manual for a detailed explanation of their function.

- Top row: Mode switches (Normal, One Operation, Manual Input). Pushing one button selects its mode and releases any other mode. The LEDs indicate the active mode. “Stop” and “Compute” are pure status indicator lights in the original LGP-30. Switches are used in the replica; they control user interface options (see section 4.3.4 below).
- Middle row: Operation buttons (Start, Clear Counter, Fill Instruction, Execute Instruction). Pushing a button triggers an operation. Depending on the Mode selection, only some of these buttons are active. The LEDs indicate which buttons are active.
- Bottom row: Toggle switches (Breakpoints, 4/6 bit input, Transfer Control). Each push toggles their state, and the LEDs show the current state.

The LGP-30’s power-up, standby and shutdown functionality is not replicated.

4.3.2 Flexowriter controls

The keypad include two buttons normally located on the Flexowriter:

- “Connect” switch (toggle): Controls whether the “Start” button on the Flexowriter or a “conditional stop” character read by the Flexowriter are passed to the LGP-30. This should be enabled most of the time, but will need to be disabled e.g. for a semi-manual bootstrap

procedure. (The bootstrap involves reading word for word from the tape, each followed by manual fill/execute instruction commands).

- “Read” toggle: Combines the functions of the Flexowriter’s “Start Read” and “Stop Read” controls. It will start and stop the paper tape reader – in case of the replica by setting or clearing the “CTS” signal on the RS-232 port.

4.3.3 Encoder

The Encoder is not present in the original LGP-30, but is a feature of the replica only. It operates in two modes; you can toggle between them by pushing down on the encoder knob. The active mode is indicated in the LCD clock rate display:

- Normal mode (active after startup): Shift the HDMI drum display left and right.
- Clock mode (clock rate display in the LCD is inverted): Control the LGP-30 CPU clock rate, i.e. the rotation speed of the simulated drum, in bits/second.

The standard bit clock is 125 kHz. It can be increased up to 1.25 MHz and decreased down to 1.25 Hz in three steps per decade.

At speeds of 250 Hz and below, the HDMI drum display will switch to animated mode, showing the drum rotation and the position of the read/write heads. Turning the encoder further left (slower) below 1.25 Hz enters single step mode: The drum will stop, and each further encoder step to the left will move the drum by one bit. Note that this is much slower than the LGP-30 “One Operation” mode, which executes one complete instruction per step.

4.3.4 Option switches

Four switches on the front edge of the Numato Mimas board may be used to control options of the replica. Two options can also be toggled via the switches in the “Compute” and “Stop” status lights, so they are accessible in enclosed systems. In the standard FPGA configuration, the following are supported:

- SW2: Disable the relay click which simulates the Flexowriter print sound. This function can also be controlled via the switch in the “Stop” status light.
- SW3: In the RS-232 output, disable the VT-100 ESC sequence for black/red color shifting. This may be useful when using a non VT-100 terminal, or when capturing LGP-30 output in a text file (“punching a tape”).
- SW4: Disable the extended information in the LC display. True to the original LGP-30, only the CPU register contents will be displayed; flip-flop and clock rate display will be disabled. This function can also be controlled via the switch in the “Compute” status light.

4.4 LCD display

The LCD’s main task is to replicate the functionality of the oscilloscope display in the LGP-30: It shows the CPU registers – from top to bottom: Program counter C, instruction register R, accumulator A. 32 bits are displayed, including the spacer bit in the rightmost position. The most significant bit (sign bit) is on the left.

In addition, the LCD displays the status of the LGP-30's 15 electronic flip-flops, as well as the current CPU clock rate. These displays were not present on the original LGP-30's user control panel, although the flip-flop circuit boards had neon bulb indicators for troubleshooting. The additional display items are on by default, but can be toggled off via option switch SW4 on the Mimas board or the switch in the "Compute" status light.

4.5 Serial terminal

4.5.1 Settings

An ASCII terminal with serial (RS-232) connection is required to use the LGP-30 replica. It replaces the Flexowriter and its paper tape reader and punch. If a terminal program with XModem capability is used, it can also be employed to store and recall the contents of the magnetic drum memory. (See the separate section below.)

Set the RS-232 parameters to

- 19200 Baud
- 8 data bits
- 1 stop bit
- No parity
- Hardware handshake (RTS/CTS)
- No local echo

The replica translates the Flexowriter 6-bit code to ASCII. Plain ASCII text is used, with one exception: The Flexowriter's "color shift" code, which switches between black or red typewriter ribbon, is translated into VT-100 escape sequences to toggle between normal and boldface characters. Use of these escape sequence can be disabled by option switch SW3 (on the Mimas FPGA board); it is enabled by default.

The physical data rate is chosen quite high, to enable XModem transfers of complete drum contents at reasonable speed. (19200 Baud is the fastest rate handled by real VT-100 terminals, in case you want to connect one.) But the effective transfer speed in regular LGP-30 operation will be much slower: Approx. 200 cps (characters per second) when reading, and 10 cps when printing. This matches the speeds of the high speed tape reader and the Flexowriter, respectively. The slower speeds are required because the CPU timing during input and output operations needs to match the I/O timing. When running the CPU at lower or higher clock rates, I/O speed is adjusted accordingly.

4.5.2 Special characters and control buttons

The ESC key has a special function: It simulates the "Start" key on the Flexowriter, which is identical in function to the "Start" button on the control panel.

Reading a " " (conditional stop) character from the keyboard or from a text file also triggers a "Start" signal. In addition, it stops further input by clearing the CTS flow control signal. Input will be re-enabled by the next Input instruction executed the LGP-30.

Two buttons on the replica's control panel provide controls which were originally located on the Flexowriter:

- The “Read” button, located on the replica’s control panel, is a toggle switch. It replaces the “Stop Read” and “Start Read” switches on the original Flexowriter. It can be used to manually start and stop input from the serial terminal by changing the state of the CTS handshake signal. Note that, different from the real Flexowriter, the replica will not accept input from the keyboard while the “paper tape” is stopped. (Since the CTS signal will of course stop all RS-232 input.)
- The “Connect” button, also on the control panel, represents the “Connect” lever on the Flexowriter. The “Start” signals triggered by the ESC key or the “ ‘ ” conditional stop character will only be sent to the logic unit when the Connect switch is on. The Connect switch should always be on in regular operation, but needs to be switched off e.g. for a manual, tape-assisted bootstrap. (See the “Getting started” section.)
- There is no “Conditional Stop” control on the replica. On the real Flexowriter, this can be used to suppress the “stop the tape reader” function of the “ ‘ ” character. I have not found any use for this in the replica and assume that it was only needed if one wanted to copy a tape on the Flexowriter. So, the “conditional stop” character is actually an “unconditional stop” on this replica... If you run into the need to disable the stop function, please let me know!

4.5.3 Terminal programs

A real VT-100 terminal should be usable, but I recommend a terminal emulation program on a PC. These can also send and receive text files, to replace the Flexowriter’s paper tape reader and punch. The papertape files available on the internet are directly usable, specifically those from the Stuttgart computer museum: <ftp://ftp.informatik.uni-stuttgart.de/pub/cm/lgp30/papertapes/>

If the terminal program supports the XModem file transfer protocol, this can be used to load and store complete images of the magnetic drum – see the chapter on XModem below.

Under Windows, I like Tera Term, a free program which is still actively maintained: <https://tssh2.osdn.jp/index.html.en>. If you use Tera Term, insert or edit the following entries in teraterm.ini:

```
; XMODEM receive command
XModemRcvCommand=\

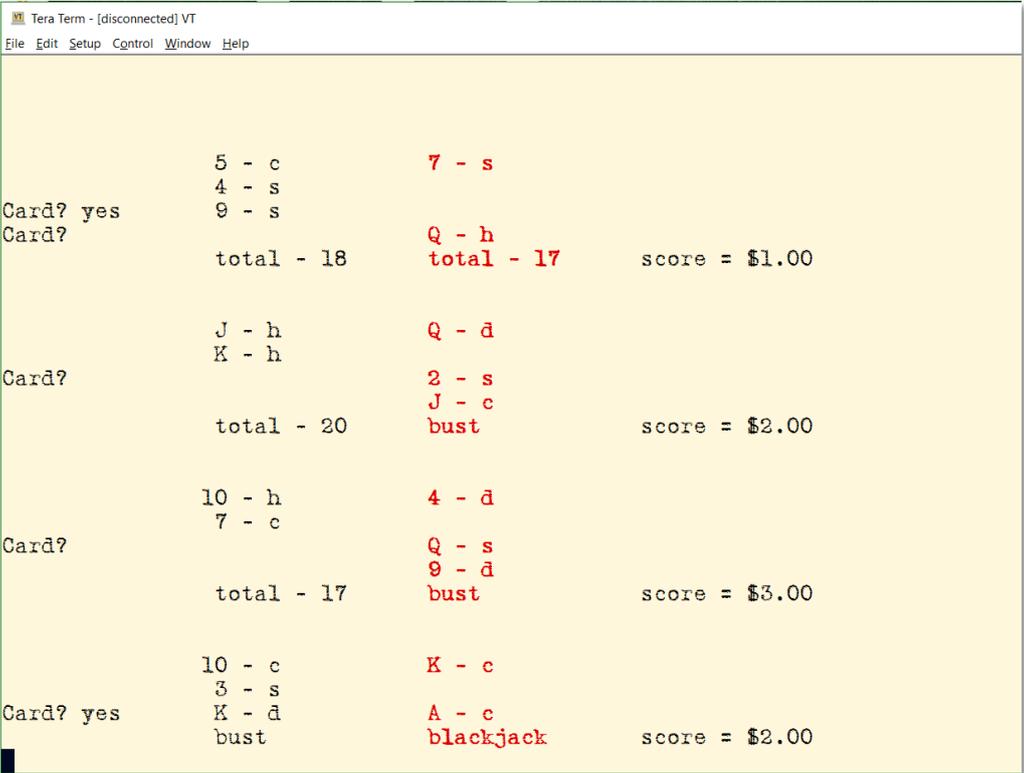
; Black text and yellowish background colors
; for normal characters
VTColor=0,0,0,255,255,229

; Set "bold" typeface to red, to match LGP-30 color shift
EnableBoldAttrColor=on
VTBoldColor=222,0,0,255,255,230
```

The Flexowriter – at least some models – had tabulator stops that were easily adjustable depending on the current application. The complete set of tab stops was arranged on a removable tabulator rack (<http://homepage.cs.uiowa.edu/~jones/flexo/tour.shtml>). While I am not sure whether this was the case for the Flexowriter model shipped with the LGP-30, it appears that tab settings different from the 8-character increments common today were indeed used. The output from the well-known Blackjack program is correctly aligned for a tabulator spacing of 12 or larger.

The VT-100 terminal has user-adjustable tab stops as well: The “ESC [3g” sequence tells the terminal to clear all pre-defined tab stops; “ESC H” sets a tab stop at the current cursor position. If your

terminal program correctly emulates the VT-100, you can prepare text files to set the tabs at various positions. This will allow you to emulate the Flexowriter's quickly exchangeable tab racks by replaying the desired tab-setting file. Tera Term has a command line option to replay a file upon startup: "ttermpro.exe /R=tab12.tty" will start a terminal with tabs set every 12 characters, if that's how you have set up the tab12.tty file.



With the right color scheme, font, and tab setting, the terminal does a credible job at conveying the Flexowriter look.

4.6 Drum memory display (HDMI) – optional

Use of the drum memory display is entirely optional. The real LGP-30 did not have such a display, and the replica can be fully used without it. But when you really want to follow the operation of the LGP-30 on a bit level, the display may be useful.

A monitor with an HDMI input is required. DVI inputs can also be used, with a cheap adapter. (HDMI and DVI video signals are electrically the same, so only a passive adapter plug is required.) The video output has XGA resolution, 1024*768 pixels. Hence older 4:3 monitors should work nicely, but the picture should also look fine when scaled to higher resolution or at 16:9 format.

The display always shows all 64 tracks of the LGP-30 main memory. Register contents and control signal tracks are also shown in the bottom. Track numbers are indicated on the left and right side of the screen, sector numbers on top. Note that the display shows the sectors in their physical order on the drum; therefore the logical sector numbers follow the 7-step interleave pattern used by the LGP-30.

The display shows a 10-word segment of each track. Low bits are shown on the right. Word boundaries and word structure are delineated by blue bands, with track, sector and opcode fields highlighted in brighter shades.

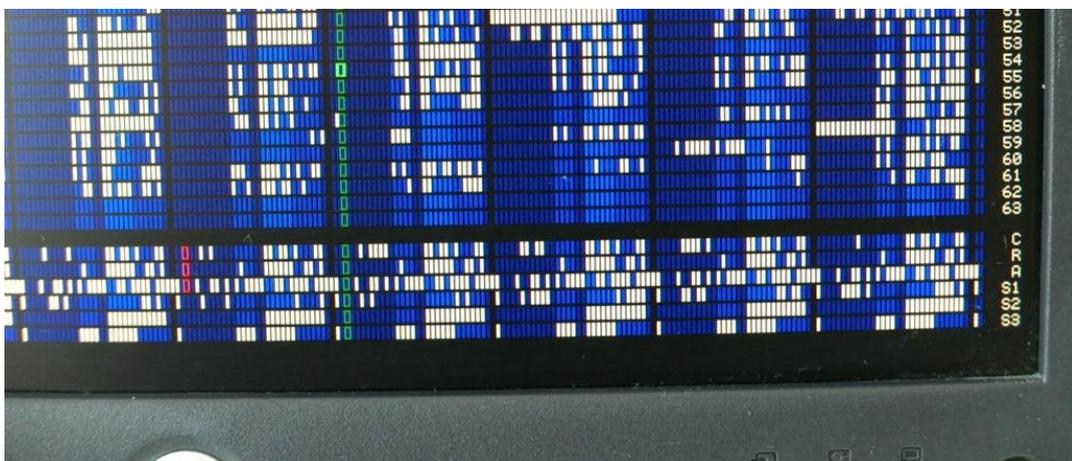
In normal operation, the display is static and can be scrolled left and right with the encoder knob. (Encoder must be in normal mode, clock rate in the LCD not highlighted.)

At slow CPU clock rates (250 Hz and below), the display will switch to scrolling mode. A stationary column of 64 read/write heads is shown in green, and the drum's bit pattern scrolls across it from left to right. The active read head is indicated by a highlighted frame; during write operations this frame switches to red color.

The three dedicated write heads for the re-circulating registers are shown in red, upstream from the read heads. When register contents change, you can observe how the write head refreshes the whole track content with the same repeating pattern, by continuously re-writing what the read head sees 32 bits downstream. The additional read head for the accumulator, used during multiplication, is not shown – the drum does not “know” when the logic unit reads this head anyway.



The drum display shows all 64 tracks as well as the CPU register and sync tracks, but only 10 sectors at a time. Rotate left or right with the encoder knob.



When the logic unit's clock is slowed down to 250 Hz and below, the read/write heads will be displayed, and the drum will move across the heads in real time.

4.7 Drum memory storage (XModem) – optional

The magnetic drum of the real LGP-30 retains its contents – main memory and registers – when the LGP-30 is stopped and shut down. After restarting the computer, a program can be resumed at the exact point it had been stopped.

In contrast, this replica stores the drum content in RAM memory; data are lost when the FPGA is powered off. To make the use of complex programs easier – e.g the ACT compiler and libraries, which have to be read from multiple tapes – drum contents can be stored and retrieved via XModem file transfers. To use this feature, you must use a terminal program that supports the classic XModem protocol:

4.7.1 Operation

- The classic XModem protocol is used, with 128 Byte blocks and 1-byte checksums (not CRC).
- Main memory (64*64 words) and register tracks (A, R, C) are stored.
- Download of the drum contents from the FPGA is started via the terminal program. The simulator will recognize the NACK control character sent by the terminal program and will automatically start the transfer. This is part of the standard XModem protocol and should work for all terminal programs that implement XModem.
- Upload of drum contents to the FPGA is also started from the terminal program. It requires sending the reserved “\” character to signal a transfer to the replica, which will then enter reception mode and send a NACK. This function of the “\” character is *not* an XModem standard feature, but a convention adopted for the LGP-30 replica only.

The “\” can either be sent manually from the terminal program; in this case the upload must be started max. 100 seconds afterwards. Alternatively, some terminal programs are configurable to send an XModem upload command automatically. See the “Serial Terminal” section above for an example configuration for the Tera Term program.

4.7.2 Data format

As long as you just store and retrieve drum files, you don’t need to care about the data file format. Here it is anyway. Note that for technical reasons, the file format is *not* compatible with the format used by Christian Corti’s LGP30SIM.EXE!

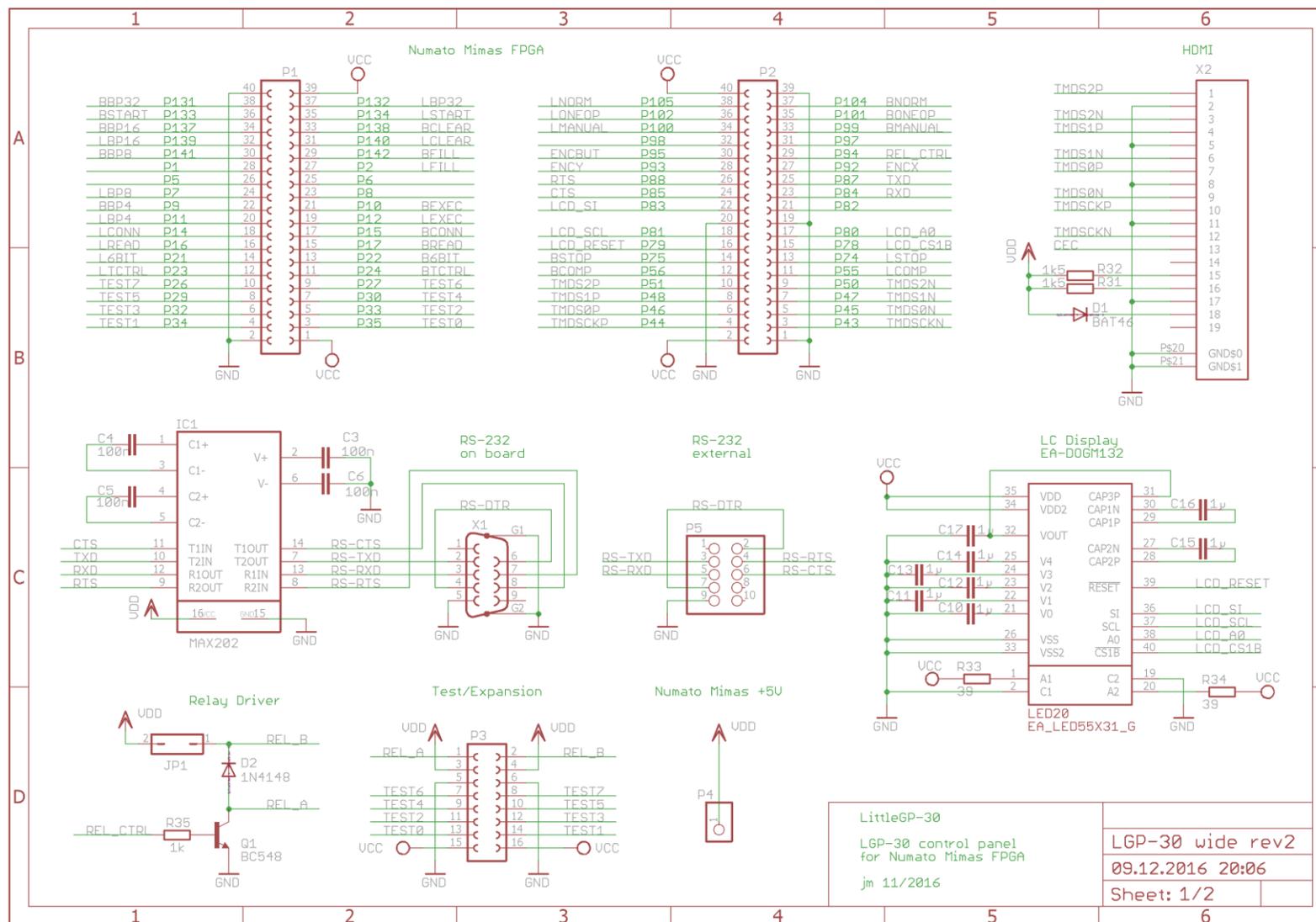
- Data files are 18,432 byte binary files.
- First 16,384 bytes are the main memory data:
Track 0..63 in ascending order; each starting with logical sector 00, followed by sectors in physical order (i.e. logical sectors 00, 57, 50, ...); low byte first.
- Following 2,048 bytes are the register data:
Each stored byte contains one bit each from the A, R, C register tracks, with the following structure: “0 0 0 0 0 A R C” (five padding zeros in the high bits, register data in the low bits). Bytes are stored in the order in which they appear on the physical tracks, starting with drum position 0 (logical sector 0 on the data tracks).

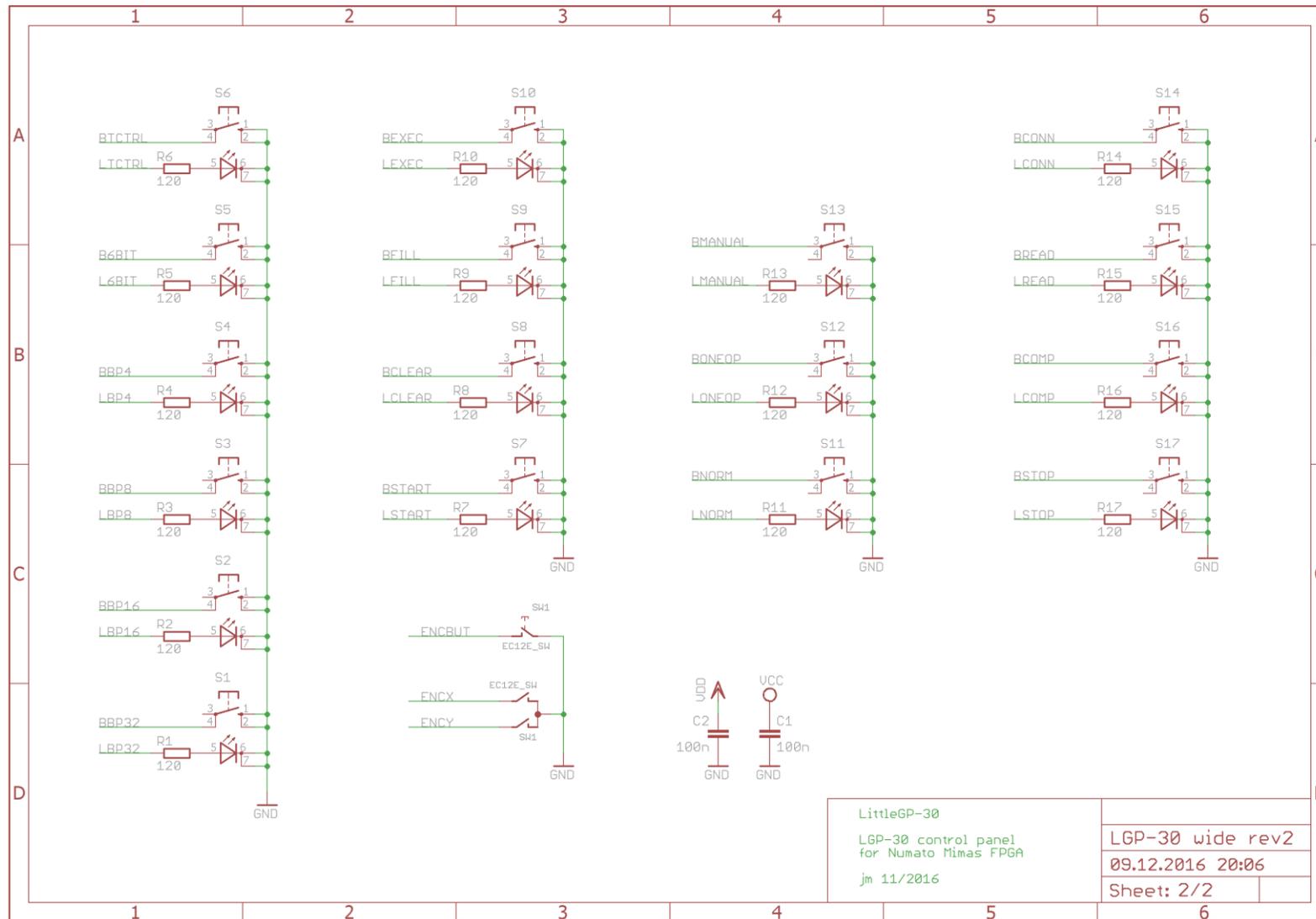
5 Appendix

5.1 Download links

- All my project files (FPGA source code and binary, and the latest version of this document) can be downloaded from www.e-basteln.de/lgp30.
- Tools and documentation for the Numato Mimas Spartan 6 development board are available from <http://numato.com/mimas-spartan-6-fpga-development-board/>.
- For download links to the Xilinx development tools, see the section on FPGA development.
- The University of Stuttgart's computer museum has a great collection of LGP-30 information:
 - Program documentation and ASCII-converted paper tapes:
<ftp://ftp.informatik.uni-stuttgart.de/pub/cm/lgp30/>.
 - Manuals and more program documentation:
<ftp://bitsavers.informatik.uni-stuttgart.de/pdf/royalPrecision/LGP-30/>
 - History and repair of their original, working LGP-30:
http://computermuseum.informatik.uni-stuttgart.de/dev_en/lgp30/lgp30.html.
- The Operation Manual and Programming Manual are specifically recommended as starting points for exploring the LGP-30:
 - Operation Manual ftp://bitsavers.informatik.uni-stuttgart.de/pdf/royalPrecision/LGP-30/LGP-30_Operations_Manual.pdf
 - Programming Manual ftp://bitsavers.informatik.uni-stuttgart.de/pdf/royalPrecision/LGP-30/LGP-30_Programming_Manual_Apr57.pdf

5.2 Schematics





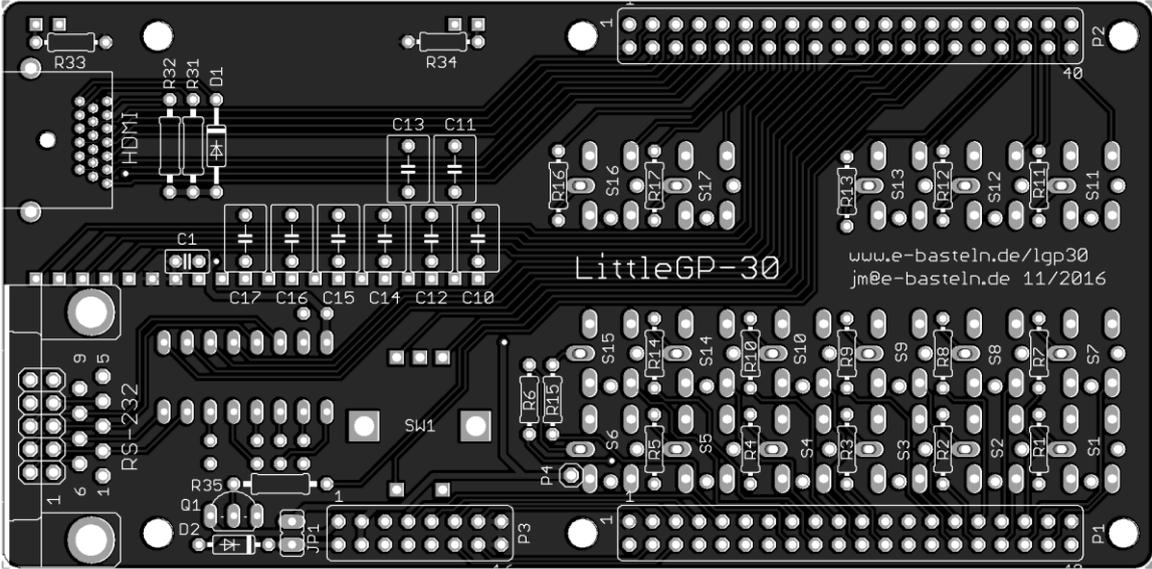
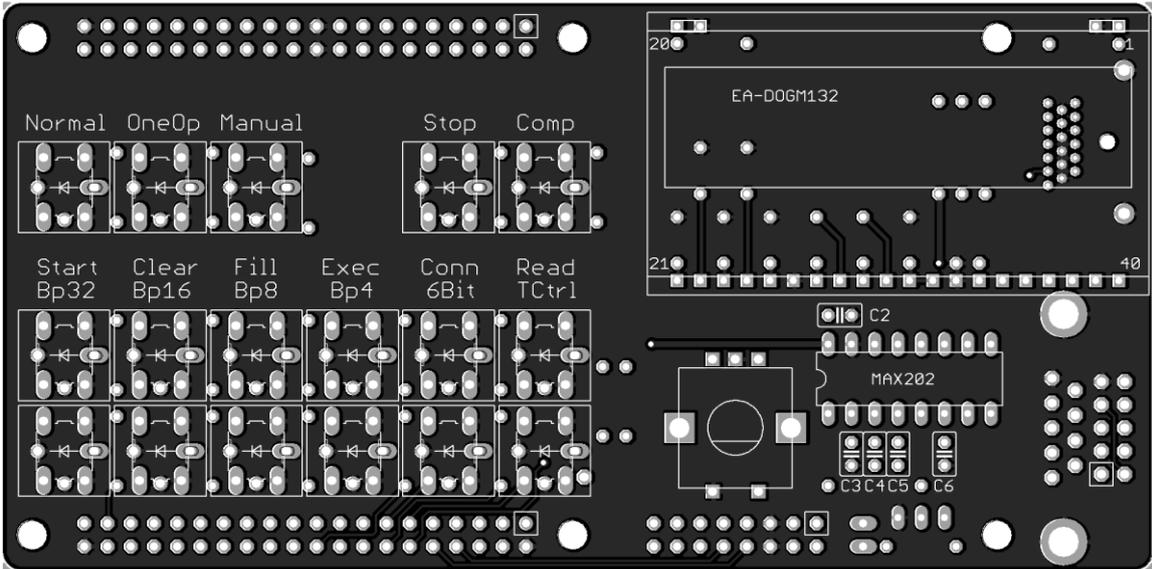
5.3 Front panel cutout

Suggested mounting holes and cutout for an enclosure-mounted board.

This should be at 1:1 scale, hence can be printed and used as an overlay to transfer dimensions to an enclosure.



5.4 PCB layout



5.5 Bill of materials

Part numbers refer to www.reichelt.de, and are for reference only. Their online catalog has further details and data sheets if any designation is ambiguous. (Catalog can be switched to English.)

Ref	Quant	Item	Reichelt No.	Comment
C1 - C6	6	Capacitor 100nF, 2.5mm spacing	Z5U-2,5 100N	multilayer ceramic capacitor
C10 - C17	8	Capacitor 1µF, 5mm spacing	Z5U-5 1,0µ	multilayer ceramic capacitor
R1 - R17	17	Resistor 120 Ohm, 0.6W	METALL 120	series resistors for LEDs, ~9mA
R31, R32	2	Resistor 1k5, 0.6W	METALL 1,50K	I ² C termination HDMI
R33, R34	2	Resistor 39 Ohm, 0.6W	METALL 39,0	series resistors LCD backlight
R35	1	Resistor 1k0, 0.6W	METALL 1,00K	
D1	1	Schottky diode BAT46, DO35	BAT 46	UF = 0,25V, 150 mA
D2	1	Diode 1N4148, DO35	1N 4148	UF = 1V, 200 mA
Q1	1	BC 548B, TO92	BC 548B	Uce = 30V, Ic = 100 mA
(none)	1	Resistor 1k0, 0.6W	METALL 1,00K	patch: see section 3.4.4
(none)	1	Resistor 2k2, 0.6W	METALL 2,20K	patch: see section 3.4.4
U1	1	LCD, Electronic Assembly DOGM132-5	EA DOGM132S-5	transmissive, inverse, FSTN
LED20	1	LED backlight for EA DOGM	EA LED55X31-G	green
IC1	1	MAX202 ECPE, DIL16	MAX 202 ECPE	RS-232 level converter, 100nF C's
S1 - S15	15	Illum. tactile button, 10*10mm	B3W-9000 Y1C	OMRON - 1 yellow LED, clear cap, low force
S16, S17	2	Illum. tactile button, 10*10mm	B3W-9002 R1R	ORMON - 1 red LED, red cap, high force
SW1	1	Rotary enoder with push-button	STEC12E08	ALPS EC12E24244
(none)	1	Knob for 6mm flattened axis	KNOPE 10-150E	for encoder, optional
X2	1	HDMI connector	HDMI 090P	through-hole, 7+6+6 pins, 1.5mm pitch
P1, P2	1	Pin header 2*40, 2.54mm pitch	SL 2X40G 2,54	split into 2 headers, 2*20 each
P3	1	Pin header 2*8, 2.54mm pitch	SL 2X10G 2,54	optional. Part is 2*10, shorten to 2*8
X1	1	D-Sub jack, 9 pins, angled, 7.2mm	D-SUB BU 09US	short US type! 7.2mm front edge > pins
P4	1	Pin header, 1 pin	MPE 087-1-002	Mates with Mimas +5V socket. Use 1 pin.
(none)	1	Pin socket, 2 pins (Mimas +5V)	BL 1X05G7 2,54	on Mimas board! Use 2 pins for +5V, GND.
JP1	1	(solder a jumper wire)		
<i>optional, for enclosure-mounted RS-232, replaces X1</i>				
P5	1	Pin header 2*5, 2.54mm	SL 2X10G 2,54	Replaces X1. Part is 2*10, shorten to 2*5
(none)	1	Connector 2*5 pin, flat cable	HAN 510 6803	connect to P5
(none)	1	D-Sub 9 pin female, for flat cable	D-SUB BU 09FB	
(none)	0.25m	flat cable 10-pin	AWG 28-10G 3M	
<i>optional, for enclosure-mounted power jack and/or clicking relay</i>				
(none)	1	Connector 2*8 pin, flat cable	HAN 516 6803	connect to P3
(none)	1	DC power jack, 2.1mm pin	HEBLM 21	example - use any DC jack
(none)	0.25m	flat cable 16-pin	AWG 28-16G 3M	can use less strands
(none)	1	relay, 5V/166 Ohm coil	M4 05H	example - use any relay with 5V, >50 Ohm
<i>alternative switches (replacing the OMRON switches above)</i>				
S1 - S15	15	tactile button, yellow LED	TLL-63BY-S-V-B	Diptronics, available from rapidonline.com
S16, S17	2	tactile button, red LED	TLL-63BR-S-V-B	Diptronics, available from rapidonline.com
	17	key cap (clear cap, ivory insert)	KTL-SAI	Diptronics, available from rapidonline.com