EconoPET 40/8096

Open Hardware Commodore PET/CBM Mainboard

Hardware Rev. A

"Daddy, can we make a computer?"
—Milo, age 8

Please Don’t Sue Me

⚠️ Disclaimer

This project is provided "**as is**," without warranty of any kind, express or implied. Use of this project is at your own risk. The authors and contributors are **not liable for any damages, injuries, including serious injury or death, or losses resulting from its use.**

⚠️ Safety Warning

Please use caution when working inside Commodore PET/CBM machines. Always **unplug the system before opening it** and be aware that **the CRT can retain a deadly high-voltage charge even when unplugged**. If you are not experienced with high-voltage electronics, seek guidance or supervision before proceeding.

Commodore PET/CBM machines may contain **sharp metal edges**. The **CRT is under vacuum and may implode** if physically damaged. **PCBs can contain hazardous materials**, including lead-based solder. Please use appropriate personal protective equipment (PPE). **Do not eat, drink, or smoke while handling PCBs.**

Soldering involves **very high temperatures, molten metal and potentially harmful fumes.** Always work in a well-ventilated area and wear safety glasses. Handle the soldering iron carefully to avoid burns, keep flammable materials away, and unplug the iron when not in use.

⚠️ Handling and Care Guidelines

To protect both the EconoPET and your original PET/CBM mainboard, **handle all boards using proper ESD precautions**. Always work on an ESD-safe surface or wear a grounded wrist strap. Avoid touching circuitry directly and store boards in anti-static bags when not in use.

When installing or servicing, hold the board by its edges and **avoid flexing or bending**, as mechanical stress can damage traces and solder joints. **Keep boards away from moisture, dust, direct sunlight, and extreme temperatures** to ensure long-term reliability.

⚠️ Not for Mission Critical Applications

The EconoPET is an amateur/hobbyist project that seemed worth sharing. It is not certified by any standards or regulatory authority for any purpose. Please set your expectations accordingly.

Introduction

The EconoPET 40/8096 is an open hardware recreation of the Commodore PET/CBM mainboard. It can be used to repair or upgrade a 2001, 30xx, 40xx or 80xx series machine. The EconoPET can also be used independently with an HDMI display and USB keyboard.

EconoPET as mainboard replacement

EconoPET as stand-alone computer

Features

Functionally, the EconoPET 40/8096 hardware is most similar to the Universal Dynamic PET v2 mainboard with a 64KB Expansion Memory Board installed.

- 96KB RAM (32KB base + 64KB banked expansion)
- Compatible I/O:
    - IEEE-488 port
    - User port (with optional 5V supply on pin 2)
    - Two Cassette ports (with configurable device #s)
- Native PET video generator:
    - Supports both 40 and 80 columns
    - Supports 9” (15 kHz) and 12” (20 kHz) monitors
    - Programmable CRTC (when using 12” monitor only)
- Support for both US graphics and business keyboard layouts

- Small internal speaker

The EconoPET also adds some modern conveniences. These include:

- Selectable ROM set with 40/80 column switching from menu:
  - 2001 original ROMs (BASIC 1, 40 columns, 60 Hz)
  - 2001 upgrade ROMs (BASIC 2, 40 columns, 60 Hz)
  - 40xx (BASIC 4, 40 columns, 50 or 60 Hz)
  - 80xx (BASIC 4, 80 columns, 50 or 60 Hz)
- A menu / reset button (short press = reset, long press = menu)
- 3.5mm Audio Jack (requires amplified speakers)
- USB-C port for use with an ANSI/ISO keyboard
- HDMI port for use with modern displays (720x480p 60Hz)
- Updateable firmware via microSD card

For troubleshooting (and hackers), the EconoPET breaks out most board signals on pin headers. (For more details, refer to the schematics in *Appendix A*.)

Limitations

Limitations of the EconoPET mainboard replacement include:

- The EconoPET is **not compatible with expansion boards that connect to IC sockets** (RAM/ROM boards, SuperPET boards, etc.)
- **The CRTC is only programmable when using a 12" monitor**. When using a 9" monitor, the CRTC registers are not writable to prevent accidental damage.
- **ROMs have been patched** to fix bugs and support hardware combinations not originally produced by Commodore.
- **USB keyboard support is limited**. Only the United States symbolic layouts are supported.
- **Max total current for the USB-C port is 900ma @ 5V** (USB 1.1 standard).

The EconoPET CPU operates at 3V3 instead of 5V logic levels, making the EconoPET incompatible with any original accessories that connect to the CPU socket.

There are also no ROM ICs. ROMs are loaded from the microSD card to SRAM on power on. Hackers will have little difficulty figuring out how to load custom ROMs on the EconoPET, but this is not currently documented as the schema of 'config.yaml' is subject to change.

Setup and Installation

This section describes the process of getting the EconoPET board up and running. There are three main steps to follow:

1. **Initializing the microSD card** describes the process of downloading the board firmware and copying it to a formatted microSD card.
2. **Board Configuration** involves setting various switches and jumpers to configure the EconoPET for your CBM/PET model.
3. **Board Installation** gives instructions for opening the CBM/PET case, removing the original mainboard, and installing the EconoPET board.

Initializing the microSD Card

The EconoPET uses a microSD card to configure the system at power on and reset. To prepare a microSD card for the EconoPET or upgrade the firmware in the future:

- Download and unzip the latest firmware from the EconoPET site: https://dlehenbauer.github.io/econopet/40-8096-A.html
- Format the microSD card with the **FAT32** or **exFAT** filesystem
- Copy the unzipped contents of the firmware archive to the root of the microSD card

If you have trouble trouble formatting the microSD card, try the SD Memory Card Formatter tool from the SD Association: https://www.sdcard.org/downloads/

⚠️ **Note** – The microSD card reader uses a *push-to-eject* mechanism for card removal. Do not remove the card by yanking. Please be gentle with PCB mounted connectors.

⚠️ **Note** – "Hot insertion" is not recommended. Please ensure the CBM/PET is powered off when removing/inserting the microSD card.

⚠️ **Note** – Formatting permanently erases the contents of the drive. Please be sure you have the intended drive selected before starting the format.

Board Configuration

First read the **Safety Warnings** and **Handling and Care Guidelines** at the beginning of this manual before proceeding. *If you are not experienced with high-voltage electronics, seek guidance or supervision before proceeding.*

Before installing the EconoPET replacement board, there are several important configurations that need to be completed:

- You must assign device numbers to the cassette ports
- You must select the appropriate video configuration for your monitor
- You must select the appropriate layout for your keyboard
- You must choose whether user port pin 2 will provide a video signal or 5V

Each of these options is described in the following sections.

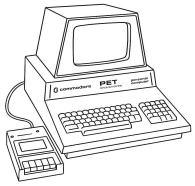
Cassette Port Device Number

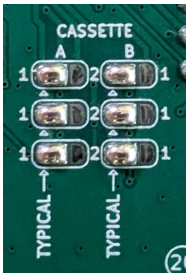
For most CBM/PET models, the cassette port on the back of the machine is assigned to device #1, while the other cassette port is assigned to device #2. The exception is the original PET model with a built-in Datassette. These machines make the built-in Datassette the primary device by assigning it device #1.

On the EconoPET the cassette ports are assigned to device #1 and #2 using solder jumpers on the back of the PCB.

Typical – Bridge all left and middle solder pads.

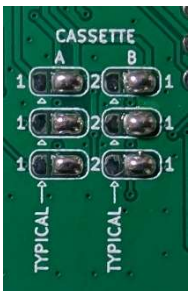
External Datassette is device #1





Built-in Datassette – Bridge all right and middle solder pads.

Built-in Datassette is device #1

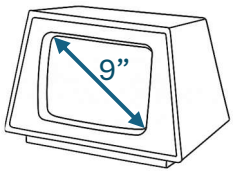


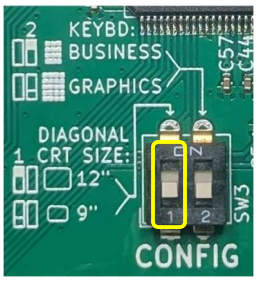
After bridging the solder pads, it is recommended to use a multimeter to verify that the unused left or right pads are disconnected.

Monitor Type

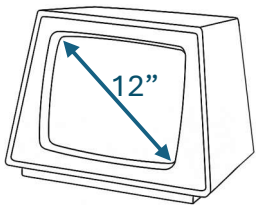
CBM/PET machines with 9" and 12" monitors use different and incompatible video signals. To select the correct video signal for your setup, use the DIP switch #1 located on the top of the EconoPET PCB.

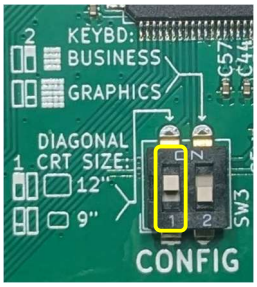
9” Monitor – Put DIP switch 1 in the down/off position.





12” Monitor – Put DIP switch 1 in the up/on position.





⚠️ **Important** - If when powering on the CBM/PET you see a “bright spot” or “line” or hear a ticking sound, **turn the machine off immediately to prevent damage**.

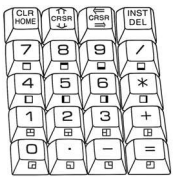
Keyboard Type

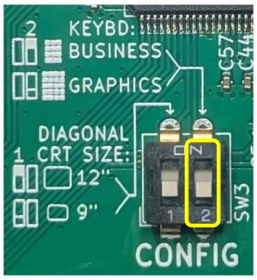
The CBM/PET series machines shipped with two different keyboard layouts: the “graphics” keyboard layout and the “business” keyboard layout.

The graphics keyboard layout can be identified by the PETSCII graphics symbols and 16-key numeric keypad. The business keyboard layout can be identified by number keys in the top row and 11-key numeric keypad.

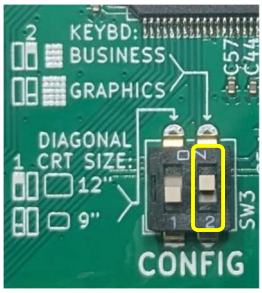
The keyboard matrices of the graphics and business keyboards are incompatible with each other. To select the correct keyboard layout for your setup, use DIP switch #2 located on the top of the EconoPET PCB.

Graphics – Put DIP switch 2 in the down/off position.





Business – Put DIP switch 2 in the up/on position.



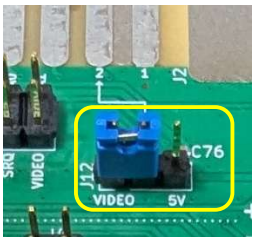
User Port Pin 2

The CBM/PET series machines did not provide a 5V supply at the user port. As a result, many user port peripherals require an adapter that pulls 5V from the cassette port, or a separate power supply.

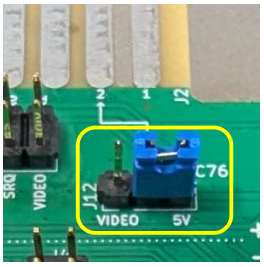
Later Commodore machines, like the VIC-20 and C64, use pin 2 of the user port to supply 5V. Some peripherals designed to work with both the CBM/PET and later machines can optionally receive 5V through pin 2. (Notably, the TexElec SNES adapter does this.)

For convenience, the EconoPET allows you to convert Pin 2 to a 5V supply using a jumper, allowing you to power peripherals directly from the user port.

Normal – Use the jumper shunt to bridge the left and middle pins. This connects pin 2 of the user port to the CBM/PET video signal.



5V – Use the jumper shunt to bridge the right and middle pins. This connects pin 2 of the user port to the +5V supply.



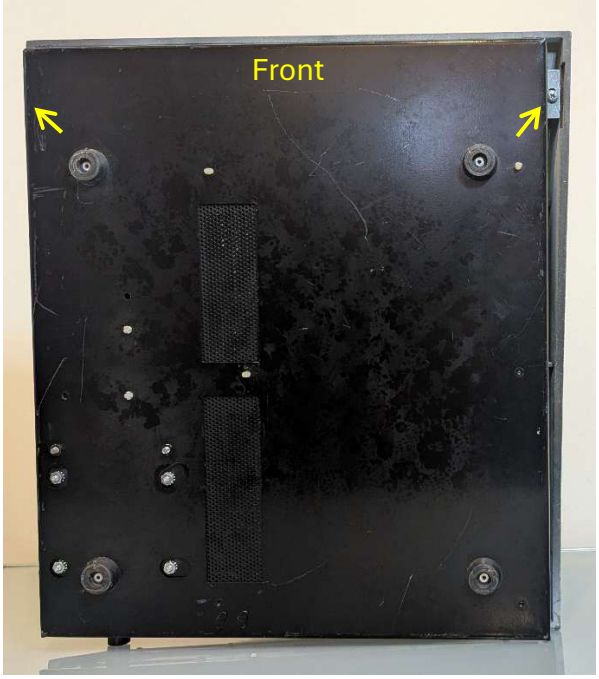
Board Installation

First read the **Safety Warnings** and **Handling and Care Guidelines** at the beginning of this manual before proceeding. *If you are not experienced with high-voltage electronics, seek guidance or supervision before proceeding.*

Step 1 – Make sure the machine is turned off and unplugged, then disconnect all external peripherals.

Step 2 – Unscrew and remove the expansion cover on the right side of the machine.

Step 3 – With the machine resting on its back, remove the two screws at the front that connect the bottom to the front.



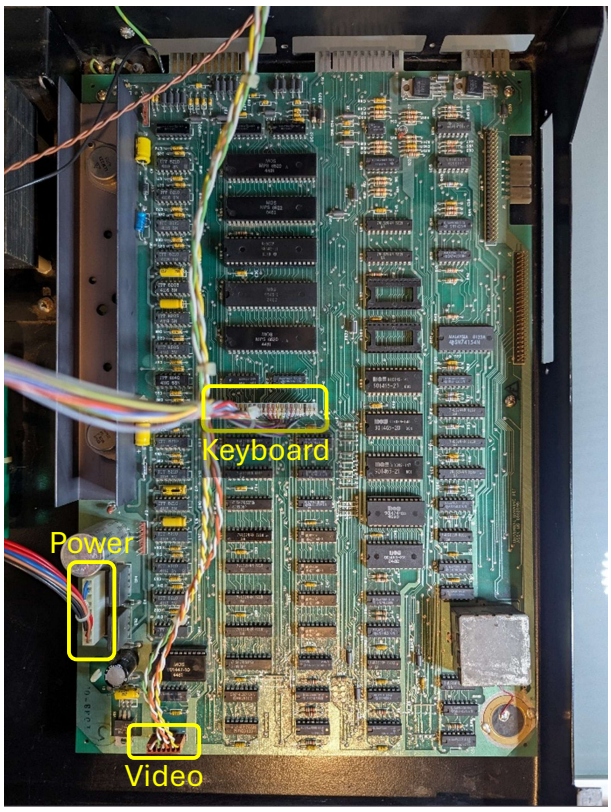
Step 4 – Setting the machine upright, the case should now open like a clamshell.

⚠️ **High Voltage Warning**
Never insert fingers, tools, or any objects through the hole accessing the monitor compartment. **CRTs (Cathode Ray Tubes) can retain a deadly high-voltage charge even when unplugged.**

If you are not experienced with high-voltage electronics, seek guidance or supervision before proceeding.

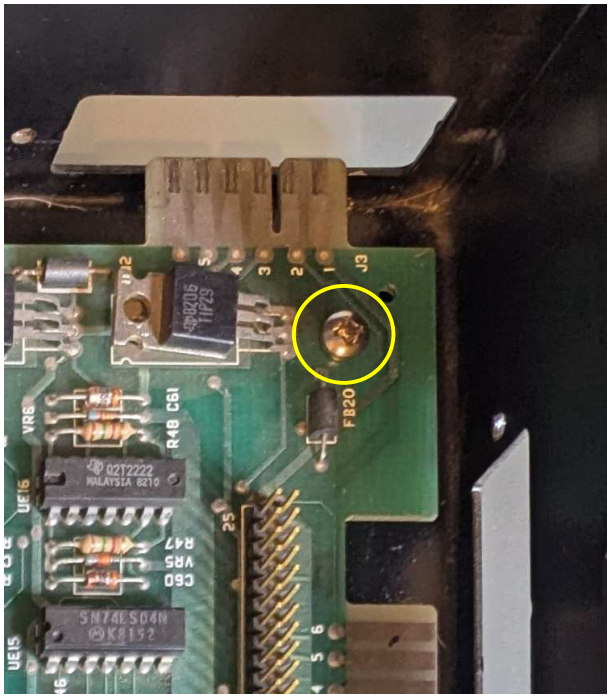
Step 5 – Disconnect the power, keyboard, and video connectors.

Note: The placement of the power, keyboard, and video connections varies between CBM/PET models.



Step 6 – Remove the screws that secure the mainboard to the case. (Save the screws, you'll need them later).

Note: The location and type of mounting hardware varies between CBM/PET models.



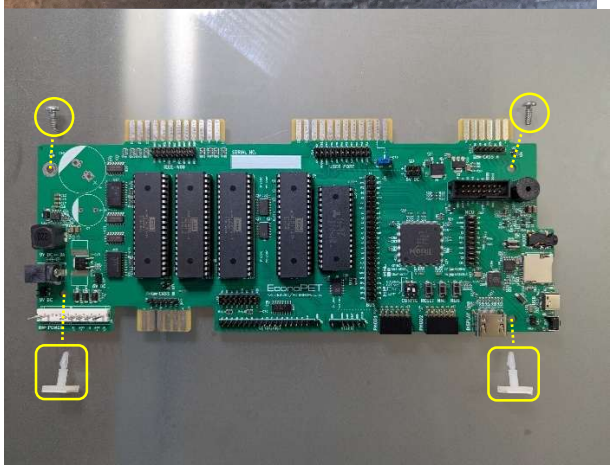
Step 7 – In addition to screws, the mainboard may be connected to the case by the tabs of plastics spacers.

Carefully pinch the tab flat with a pair of pliers while gently working the PCB free one hole at a time.

Step 8 – Prepare to install EconoPET

Before installing the EconoPET **check that you have completed the configuration steps** from the *Board Configuration* section.

To secure the EconoPET to the case, you will need two of the mounting screws from the original PCB as well as two 11mm nylon spacers to support the front of PCB.



Step 9 – Mount the EconoPET PCB at the back of the case.

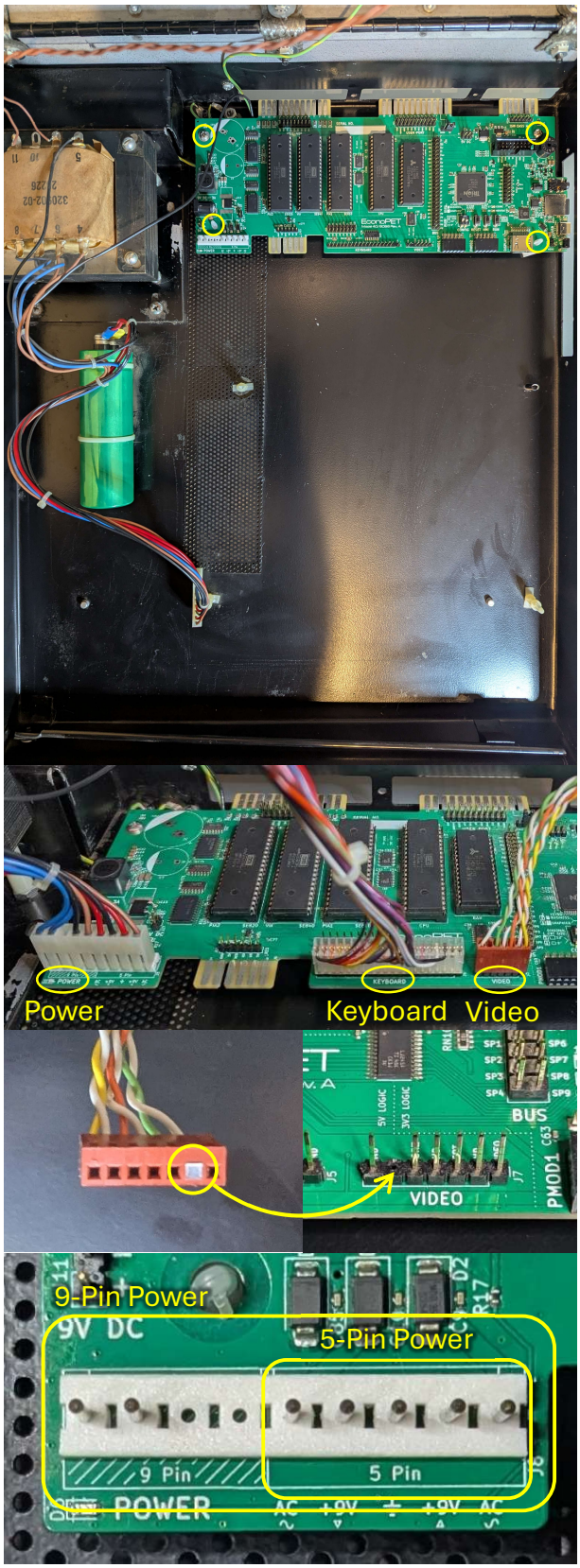
- Place the nylon spacers through the mounting holes near the power and HDMI connectors.
- Insert the top left screw through the PCB into the mounting hole, but do not tighten it.
- Rotate the board until the top right screw hole aligns with the mounting hole and insert screw.
- Tighten the two mounting screws until *just* snug. Be gentle and do not overtighten.

Step 10 – Reconnect the Power, Keyboard and Video cables.

The keyboard, video, and 9-pin power connectors are keyed and can only be connected one way.

If your CBM/PET's power connector has only 5-pins, use the right-most 5-pins on the EconoPET. (The 5-pin connector is symmetrical, so the orientation does not matter.)

Note: To avoid flexing the PCB when pressing down to insert connectors, gently support the underside of the PCB.



Step 11 – Close the CBM/PET case and reconnect power, leaving other peripherals disconnected for the time being.

Turn the CBM/PET power on. If all goes well, you should see the EconoPET menu.

⚠️ **Important** - If when powering on the CBM/PET you see a "bright spot" or "line" or hear a ticking sound, **turn the machine off immediately to prevent damage**.

Troubleshooting

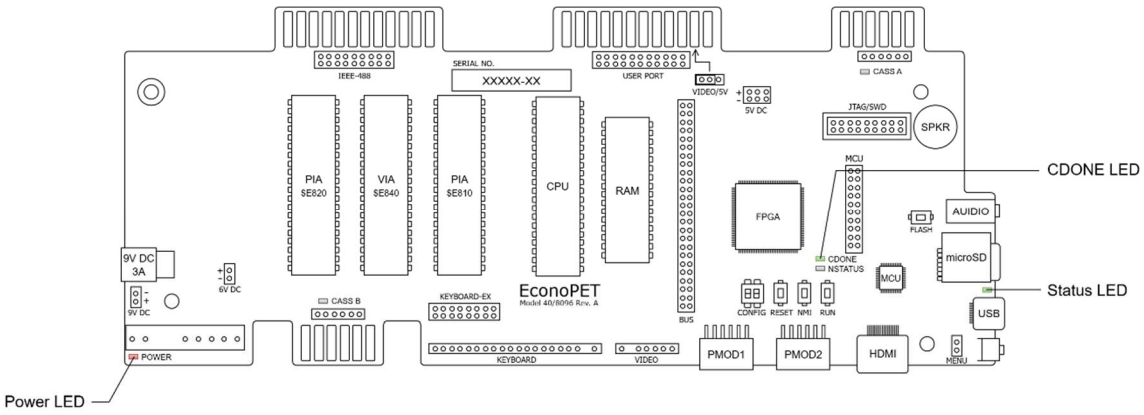
First read the **Safety Warnings** and **Handling and Care Guidelines** at the beginning of this manual before proceeding. *If you are not experienced with high-voltage electronics, seek guidance or supervision before proceeding.*

If you encounter issues with the EconoPET, the first step in troubleshooting is to **disconnect all peripherals**. This includes anything connected to the IEEE-488 port, User port, Cassette ports, USB-C port, and audio jack. By removing these connections, you can isolate the problem and determine if the issue lies with the EconoPET board or with one of the connected devices.

Diagnosing Boot Failures

If the EconoPET does not successfully boot to the Power-On Menu, the next step in troubleshooting is to open the CBM/PET case. With the case open, you will be able to observe the system's internal LED indicators, which provide information about how far the boot sequence progresses and help identify where the startup process may be failing.

The three main indicators are the Power LED, the Status LED, and the CDONE LED. The location of these LEDs is shown in the following diagram.



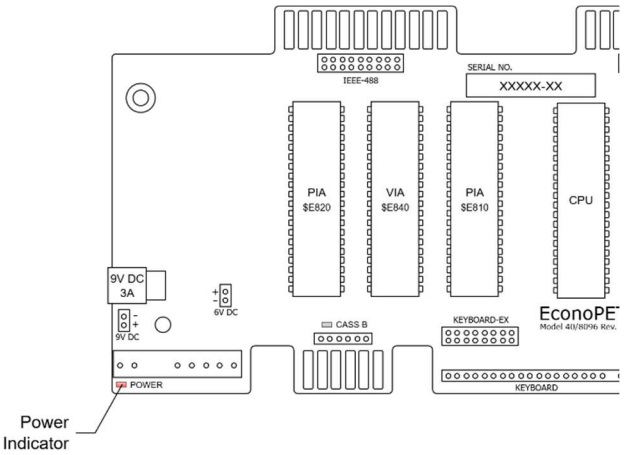
Under normal circumstances, the Power LED will be lit and the Status and CDONE LEDs will progress through the following states during power on:

Status LED	**CDONE LED**	**Meaning**
One short blink	Off	Bootloader has completed / Firmware starting
On (solid)	Off	Firmware is initializing EconoPET hardware
Off	On	EconoPET initialized

At this point you would normally hear a happy 4-note beep and the Power-On menu will appear on both the CBM/PET monitor and the HDMI display. If that is not the case, consult the following sections.

Power LED Does Not Light

The first LED to light is the red power indicator in the lower left corner, just below the CBM/PET power connector.



If the Power Indicator LED fails to illuminate when the system is switched on, check the following:

- With the power off and machine unplugged, **disconnect all peripherals** as described at the beginning of the Troubleshooting section.

- **Verify that the machine is plugged in** and that the outlet is working outlet. Try eliminating any extension coords or power strips.

- **Check that the internal power connector is correctly connected** to the EconoPET (see Board Installation section).

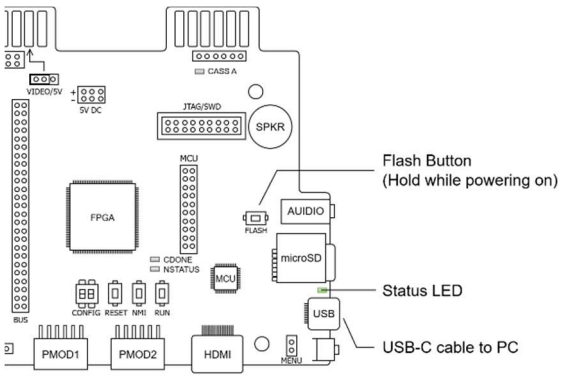
- **Ensure that the CBM/PET power switch is in the *ON* position**. Note that the ON / OFF orientation of the CBM/PET power switch may be counter intuitive.

If the issue is still not identified, the problem is likely to be the CBM/PET power supply. At this point, you will want to refer to online troubleshooting guides.

Green Status LED Inactive

Under normal circumstances, the green Status LED located next to the microSD card will show activity shortly after power on. If the Status LED remains unlit, this indicates that the EconoPET firmware is missing or corrupted.

Because the EconoPET firmware includes the bootloader that enables microSD card updates, you must first use the USB-C port to install the bootloader before firmware updates from the microSD card will succeed.



To do this, first **prepare a microSD card as described in the *Initializing the microSD Card* section**. (Once the EconoPET bootloader is restored, the microSD card will be used to finish the firmware update.)

To restore the EconoPET bootloader, do the following:

1. **Power off the CBM/PET.**
2. **Connect a USB cable** from the EconoPET's USB-C port to your computer.
3. **Enter flash mode:**
    - Press and hold the **FLASH** button on the EconoPET.
    - **While holding FLASH**, power on the CBM/PET.
    - After a couple of seconds, you can release the FLASH button.
4. The EconoPET will appear on your PC as a **USB mass storage device** named RPI-RP2.
5. **Copy the bootloader file:** Drag and drop the bootloader.uf2 file into the RPI-RP2 drive. (bootloader.uf2 is contained in the same .zip used to initialize the microSD card.)
6. After the file is copied, the EconoPET will automatically reboot and finish the firmware update from the microSD card. (Green LED will blink rapidly during this process.)

7. Disconnect the USB cable and proceed with troubleshooting (if necessary).

Status LED Error Indications

Under normal operation, the green **Status LED** next to the microSD card reader will:

- **Blink once** at power-on.
- **Turn on solid** while the EconoPET hardware is initializing.
- **Turn off** once initialization is complete.

If instead the Status LED blinks in a **continuous repeating pattern**, this indicates that the EconoPET has halted due to a critical error.

CDONE LED	Status LED	Description
Off	— ▪	The EconoPET bootloader could find the file 'firmware.uf2' at the root of the microSD card. 1. Turn off the machine 2. Prepare the microSD card as described in the *Initializing the microSD Card* section 3. Reinsert the microSD card into the EconoPET 4. Turn on the machine.

Beep with No Video / Bad Video

If you hear the startup beep but do not see the boot menu on the CRT, verify that the CBM/PET video cable is securely connected and that **DIP switch #1** is set for the correct monitor type (see the *Monitor Type* section for more details).

⚠️ **Important** - If when powering on the CBM/PET you see a "bright spot" or "line" or hear a ticking sound, **turn the machine off immediately to prevent damage**.

Error Message at Power On

If an error message appears at power-on, it usually indicates a problem with the contents of the microSD card. To resolve this, reformat and reinitialize the card as described in the *Initializing the microSD Card* section.

Keyboard Issues

If you have successfully booted to BASIC, but find that typing on the CBM/PET keyboard produces the wrong characters, you probably have misconfigured the keyboard type. Power off the machine and toggle DIP switch #2 and see if this corrects the problem.

Also note that some CBM/PET programs that read the keyboard state directly from the PIA are only compatible with a specific keyboard layout (generally, it is games that assume the graphics keyboard layout). There is no good solution, but one workaround is to select the "wrong" keyboard layout with DIP switch #2 and use a USB-C keyboard.

Cassette Ports Issues

If the cassette ports do not function as expected, verify that the device numbers are correctly assigned. The device number for each cassette port is set using the solder pads on the back of the EconoPET board. Refer to the *Cassette Port Device Number* section for instructions on selecting the correct configuration.

User Port Video Output Issues

If you are using a device that generates video from the User Port (such as a composite video adapter) and the output appears blank or incorrect, confirm that video output has been enabled on **User Port Pin 2**. Refer to the *User Port Pin 2* section for details on selecting and configuring this output.

Other Issues

If you've reached this section of the manual, I'm sorry. :-(

If the problem is with the EconoPET replacement board, please create an issue on GitHub and let me know what went wrong:

https://github.com/DLehenbauer/econopet/issues

The EconoPET is an open hardware / public domain hobbyist project. For those with a background in electronics, schematics for the EconoPET board are provided in *Appendix A*. The firmware source code and KiCad hardware project files are available on GitHub.

Help is always warmly appreciated.

For **general troubleshooting and repair of Commodore PET/CBM machines** (such as power supply or video display issues), I highly recommend the **Commodore PET / CBM Enthusiasts** group on Facebook:

https://www.facebook.com/groups/214556078753960

Acknowledgements

This project would not have been possible without the advice and encouragement of the Commodore PET / CBM Enthusiasts community on Facebook. I am particularly grateful to the following members, who were generous in sharing their time and expertise:

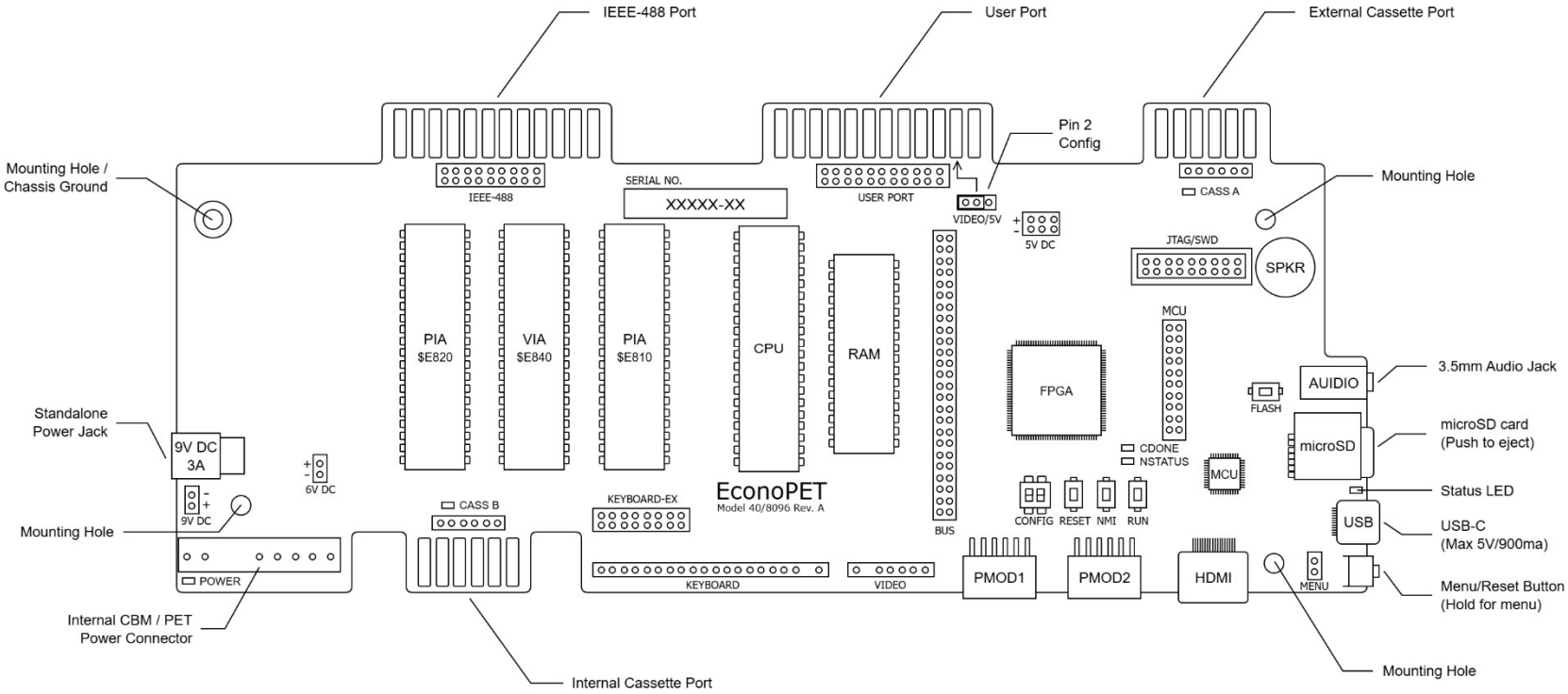
Gavin Andrews
Ethan Dicks
Steve Gray
Chuck Hutchins
Mia Magnusson
Sven Petersen
Jannie Van Zyl

These individuals patiently guided me through schematics, took the time to probe their own machines with oscilloscopes and multimeters, and demonstrated an uncanny ability to remotely debug my mistakes from just a few lines in a forum post.

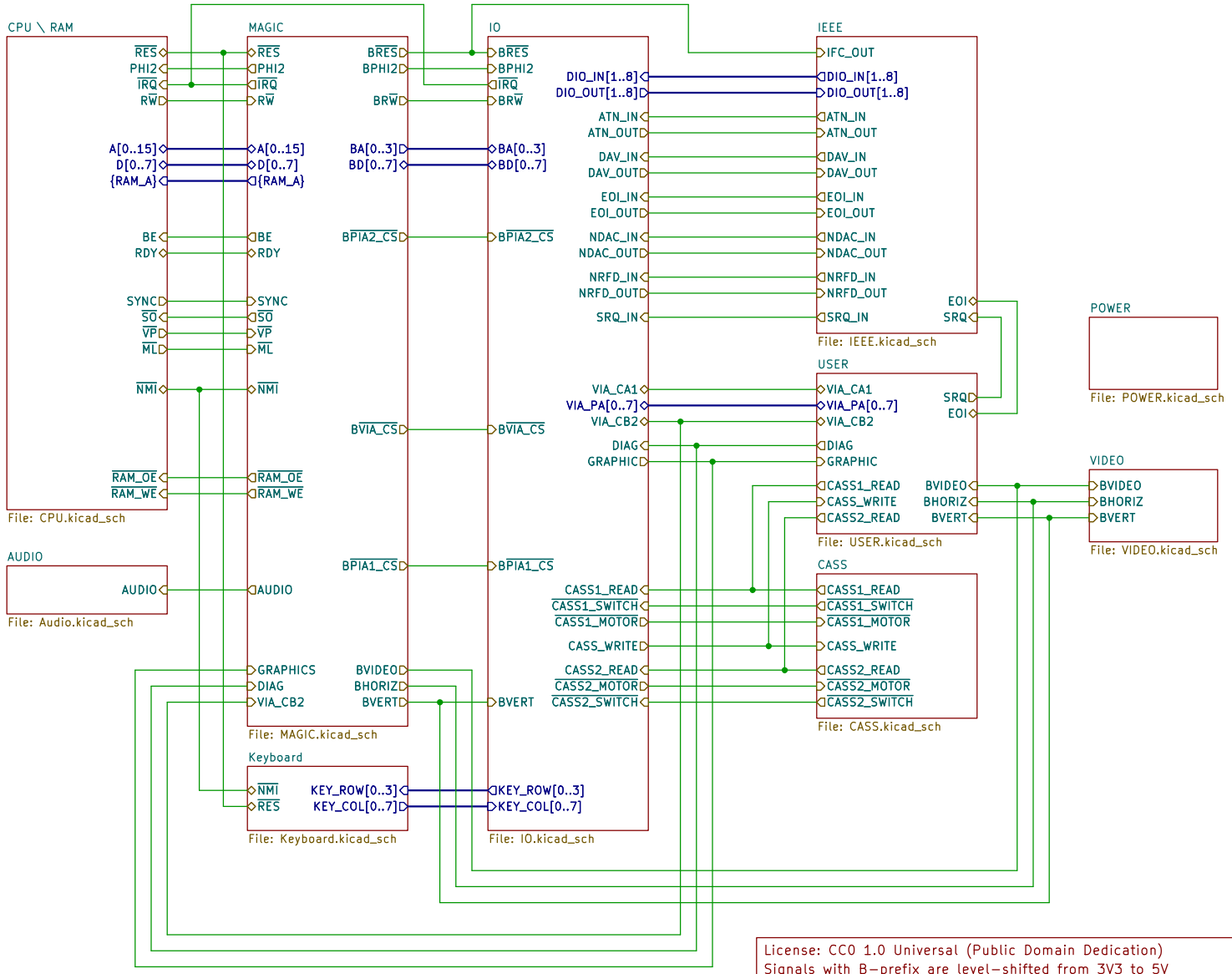
I would like to thank my family for their patience and support. The project started with a simple question from my son and became much more ambitious when he discovered ORB's *No Pet's Allowed* demo. I am also grateful to my wife, Bonnie, who — together with her brother and sister-in-law — helped acquire the CBM 8032 shown in the photos, allowing me to test the EconoPET as a mainboard replacement in a real machine.

Appendix A

Board Layout and Schematics



System Block Diagram



"If you don't use a current limiting resistor the LED will light up orange! Because of the fire! Because sometimes Daddy makes mistakes."

– Milo, Age 4.5

License: CC0 1.0 Universal (Public Domain Dedication)
Signals with B–prefix are level–shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher
https://is.gd/6hpvh6

Sheet: /
File: Mainboard.kicad_sch

Title: EconoPET 40/8096

Size: A	Date: 2023–10–01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 1/17

CPU and RAM operate at 3V3 so that the system bus and CPU control signals can be directly shared with the FPGA.

Level shifters are used for connections to the 5V I/O section. This design avoids needing level shifters for A[5..16].

The FPGA deasserts BE (Bus Enable) to transition the CPU's Address, Data, and RW buffers to high-Z when the FPGA drives the bus.

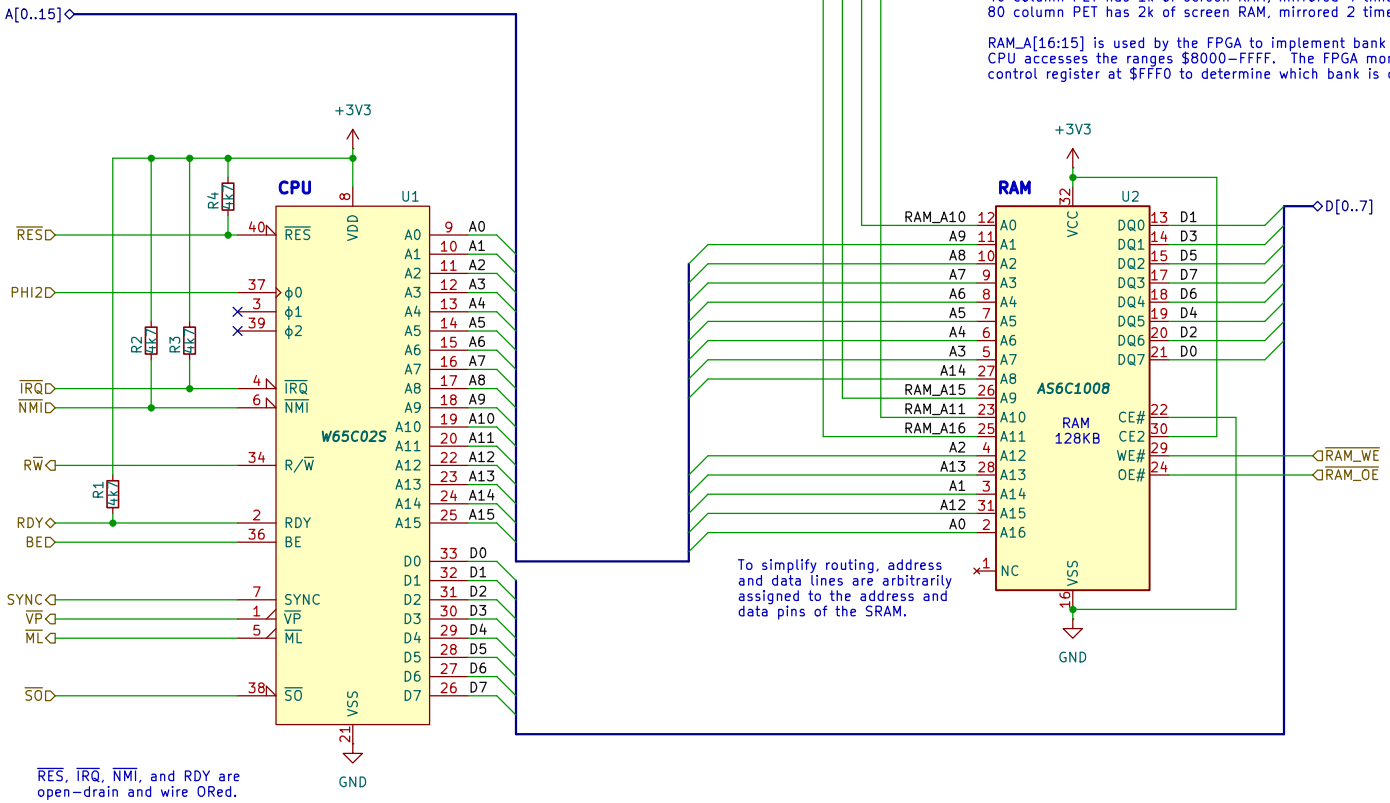
A single 128KB SRAM chip is used for the 32K main RAM, 64K expansion RAM, 2K display RAM, 2K character ROM and 26K system ROM. ROMs are initialized by the MCU on POR (via SPI -> bus bridge provided by the FPGA).

A[15:0] are the address of the shared system bus, which is connected to the CPU, IO, FPGA and most RAM address pins. The exceptions are RAM_A[16:15,11:10], which are driven exclusively by the FPGA.

RAM_A[11:10] is used by the FPGA to mirror display RAM when the CPU accesses the range $8000-8FFF.

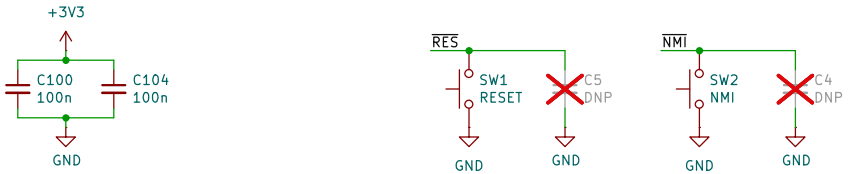
40 column PET has 1k of screen RAM, mirrored 4 times.
80 column PET has 2k of screen RAM, mirrored 2 times.

RAM_A[16:15] is used by the FPGA to implement bank switching when the CPU accesses the ranges $8000-FFFF. The FPGA monitors writes to the control register at $FFF0 to determine which bank is currently selected.



$\overline{RES}$, $\overline{IRQ}$, $\overline{NMI}$, and RDY are open-drain and wire ORed.

$\overline{SO}$ is driven high by the FPGA.

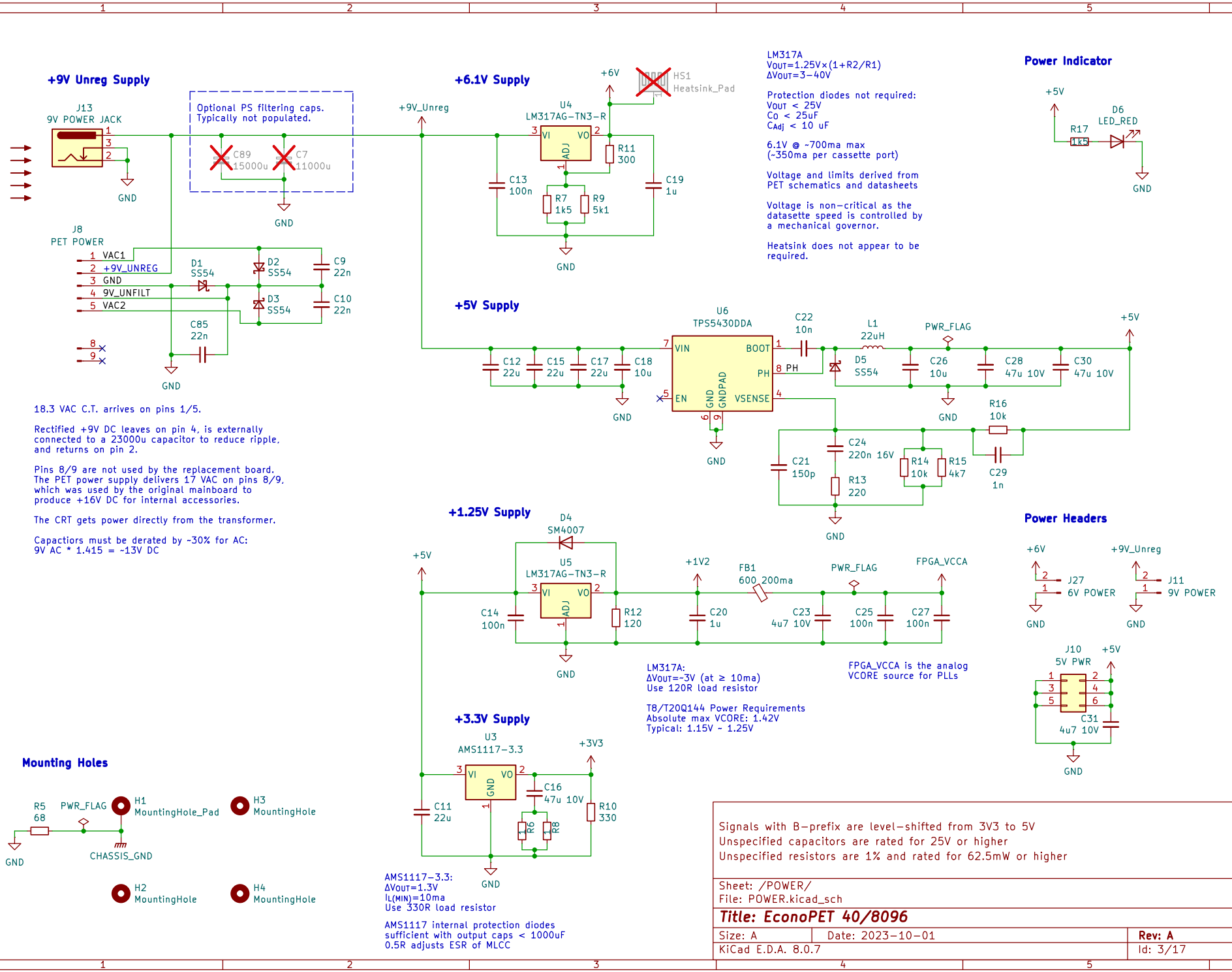


Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

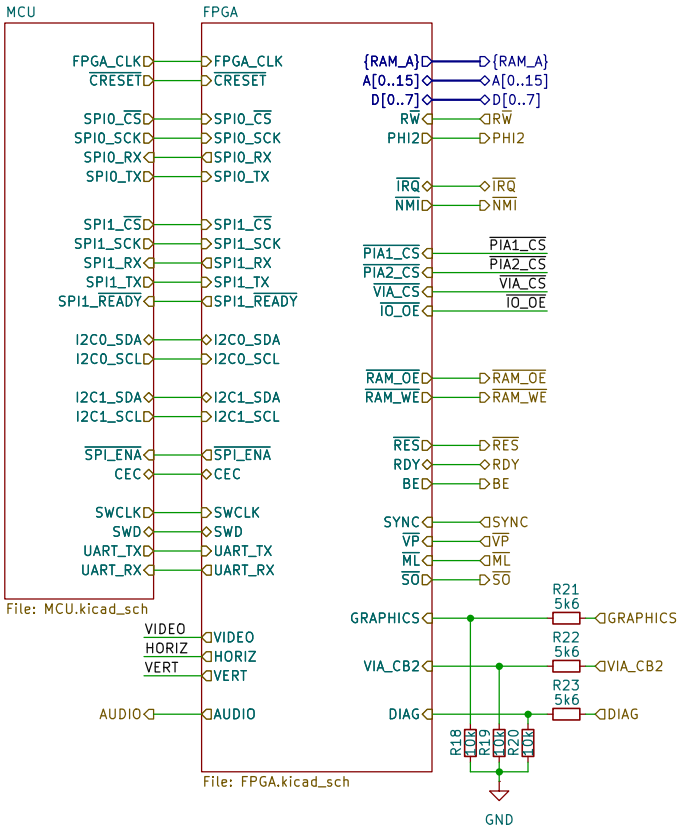
Sheet: /CPU \ RAM/
File: CPU.kicad_sch

Title: EconoPET 40/8096

Size: A	Date: 2023-10-01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 2/17


+9V Unreg Supply
J13
9V POWER JACK
Optional PS filtering caps.
Typically not populated.
C89
15000u
C7
11000u
GND
J8
PET POWER
1 VAC1
2 +9V_UNREG
3 GND
4 9V_UNFILT
5 VAC2
D1
SS54
D2
SS54
D3
SS54
C9
22n
C10
22n
C85
22n
18.3 VAC C.T. arrives on pins 1/5.
Rectified +9V DC leaves on pin 4, is externally connected to a 23000u capacitor to reduce ripple, and returns on pin 2.
Pins 8/9 are not used by the replacement board. The PET power supply delivers 17 VAC on pins 8/9, which was used by the original mainboard to produce +16V DC for internal accessories.
The CRT gets power directly from the transformer.
Capactiors must be derated by ~30% for AC:
9V AC * 1.415 = ~13V DC
+9V_Unreg
+6.1V Supply
U4
LM317AG-TN3-R
VI
VO
ADJ
R11
300
R7
1k5
R9
5k1
C13
100n
C19
1u
+6V
HS1
Heatsink_Pad
LM317A
VOUT=1.25V×(1+R2/R1)
ΔVOUT=3–40V
Protection diodes not required:
VOUT < 25V
CO < 25uF
CAdj < 10 uF
6.1V @ ~700ma max
(~350ma per cassette port)
Voltage and limits derived from PET schematics and datasheets
Voltage is non-critical as the datasette speed is controlled by a mechanical governor.
Heatsink does not appear to be required.
Power Indicator
+5V
D6
LED_RED
R17
1k5
GND
+5V Supply
U6
TPS5430DDA
VIN
BOOT
PH
EN
VSENSE
GND
GNDPAD
C12
22u
C15
22u
C17
22u
C18
10u
C22
10n
L1
22uH
D5
SS54
PWR_FLAG
C26
10u
C28
47u 10V
C30
47u 10V
R16
10k
C29
1n
C24
220n 16V
R13
220
C21
150p
R14
10k
R15
4k7
+1.25V Supply
D4
SM4007
U5
LM317AG-TN3-R
C14
100n
R12
120
C20
1u
+1V2
FB1
600_200ma
C23
4u7 10V
C25
100n
C27
100n
FPGA_VCCA
LM317A:
ΔVOUT=~3V (at ≥ 10ma)
Use 120R load resistor
T8/T20Q144 Power Requirements
Absolute max VCORE: 1.42V
Typical: 1.15V ~ 1.25V
FPGA_VCCA is the analog VCORE source for PLLs
Power Headers
J27
6V POWER
J11
9V POWER
J10
5V PWR
C31
4u7 10V
+3.3V Supply
U3
AMS1117-3.3
C11
22u
C16
47u 10V
R10
330
R6
R8
+3V3
AMS1117-3.3:
ΔVOUT=1.3V
IL(MIN)=10ma
Use 330R load resistor
AMS1117 internal protection diodes sufficient with output caps < 1000uF
0.5R adjusts ESR of MLCC
Mounting Holes
H1
MountingHole_Pad
H2
MountingHole
H3
MountingHole
H4
MountingHole
R5
68
PWR_FLAG
CHASSIS_GND
Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher
Sheet: /POWER/
File: POWER.kicad_sch
Title: EconoPET 40/8096
Size: A
Date: 2023-10-01
Rev: A
KiCad E.D.A. 8.0.7
Id: 3/17

Magic



MCU responsibilities:
- Generate FPGA_CLK
- Configure FPGA at POR
- Initialize SRAM with ROM images
- Read back video RAM and output to HDMI (bit-banged DVI)
- Report USB keyboard matrix to FPGA

FPGA responsibilities:
- Timing / address decoding
- Native PET video generation / CRTC
- Expose sysem bus to MCU (via SPI)
- Intercept PIA1 to inject USB keyboard

SRAM is shared between the 6502 and the FPGA by using an effective bus speed of 8 MHz taking turns in round-robin fashion.

From the CPU and I/O chip's perspective, PHI2 is "stretched" with a 1/8th duty cycle. From the FPGA's perspective, there is an 8 MHz clock and 8 clock enable signals, which are used as follows:

0: Read/write to SRAM to service SPI request from MCU
1: Read even character from VRAM
2: Read even character bitmat from "ROM"
3: Read odd character from VRAM
4: Read odd character from "ROM"
5: Read/write to SRAM to service SPI request from MCU
6: Setup for next CPU cycle
7: Pulse PHI2

(Note: Above subject to change with firmware updates.)

Shift 5V -> 3V3:

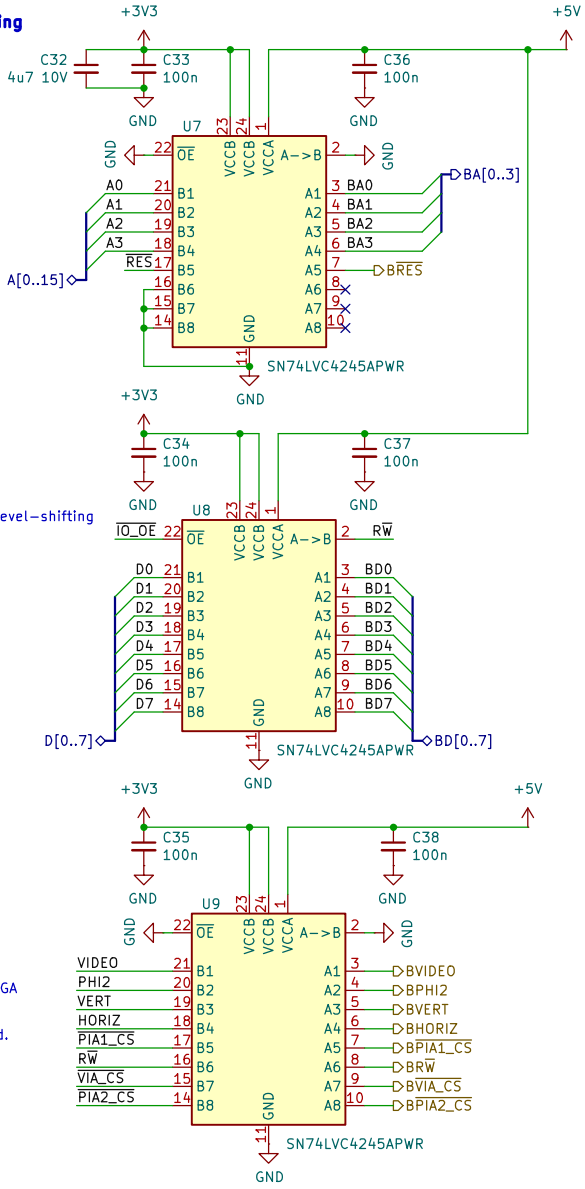
VOUT = VIN * (R2 / (R1 + R2)
VIN = 5.1V
R1 = 5.6k - 1%
R2 = 10k + 1%
VOUT = 3.29V

PIAs and VIA operate at 5V logic levels for compatible I/O.

CPU and RAM operate at the same 3V3 logic levels as the FPGA and MCU to reduce the amount of level shifting required.

D[0..7] are the only bidirectional lines that need to be shifted. The direction of D[0..7] is controlled by RW.

Level Shifting



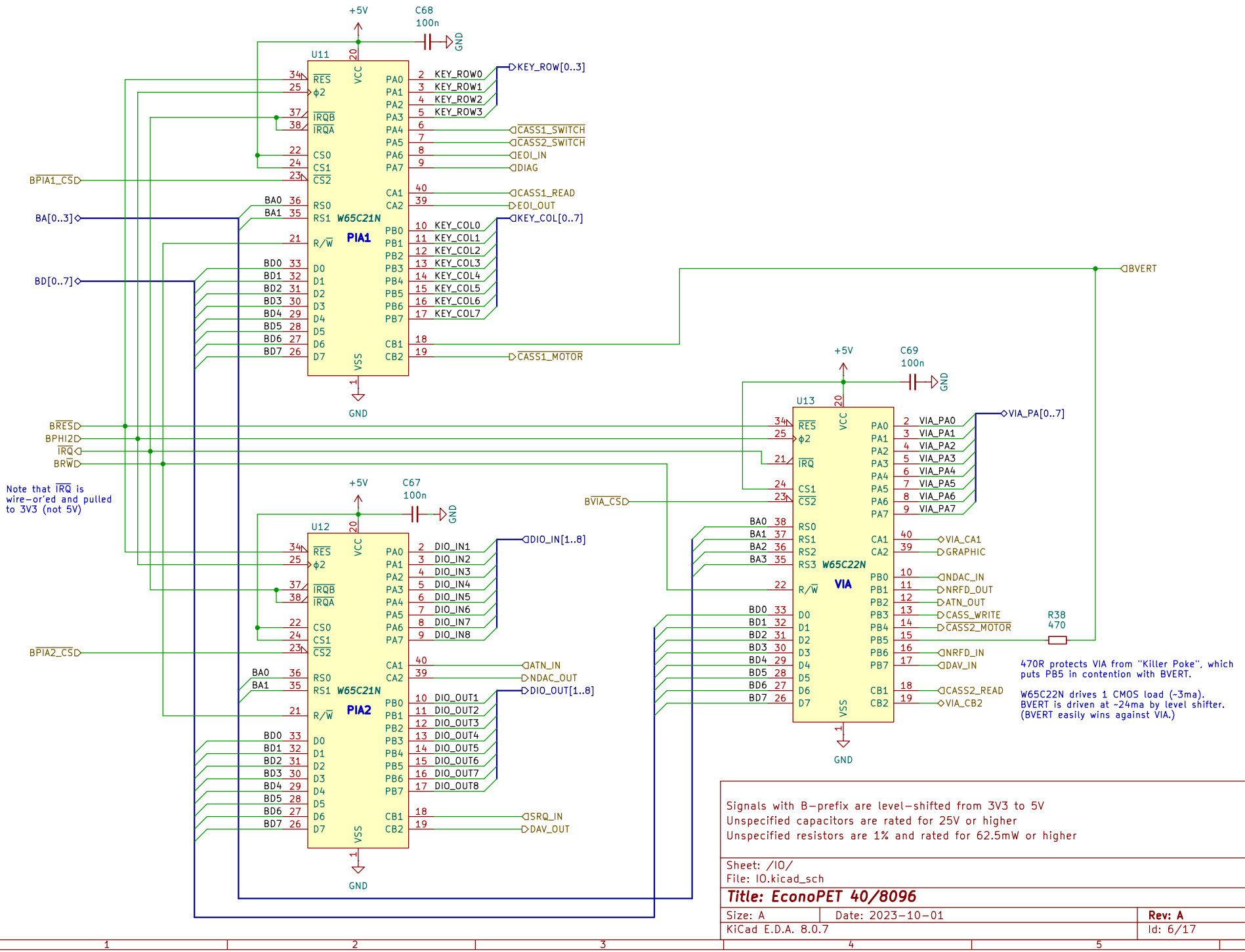
IO_OE does not require level-shifting (high @ 2V)

Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

Sheet: /MAGIC/
File: MAGIC.kicad_sch

Title: EconoPET 40/8096

Size: A	Date: 2023-10-01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 4/17


U11
W65C21N
PIA1
U12
W65C21N
PIA2
U13
W65C22N
VIA
+5V
GND
C68
100n
C67
100n
C69
100n
BPIA1_CS
BPIA2_CS
BVIA_CS
BA[0..3]
BD[0..7]
BRES
BPHI2
IRQ
BRW
BVERT
KEY_ROW[0..3]
KEY_COL[0..7]
CASS1_SWITCH
CASS2_SWITCH
EOI_IN
DIAG
CASS1_READ
EOI_OUT
CASS1_MOTOR
DIO_IN[1..8]
DIO_OUT[1..8]
ATN_IN
NDAC_OUT
SRQ_IN
DAV_OUT
VIA_PA[0..7]
VIA_CA1
GRAPHIC
NDAC_IN
NRFD_OUT
ATN_OUT
CASS_WRITE
CASS2_MOTOR
NRFD_IN
DAV_IN
CASS2_READ
VIA_CB2
R38
470
Note that IRQ is wire-or'ed and pulled to 3V3 (not 5V)
470R protects VIA from "Killer Poke", which puts PB5 in contention with BVERT.
W65C22N drives 1 CMOS load (~3ma).
BVERT is driven at ~24ma by level shifter.
(BVERT easily wins against VIA.)
Signals with B-prefix are level-shifted from 3V3 to 5V
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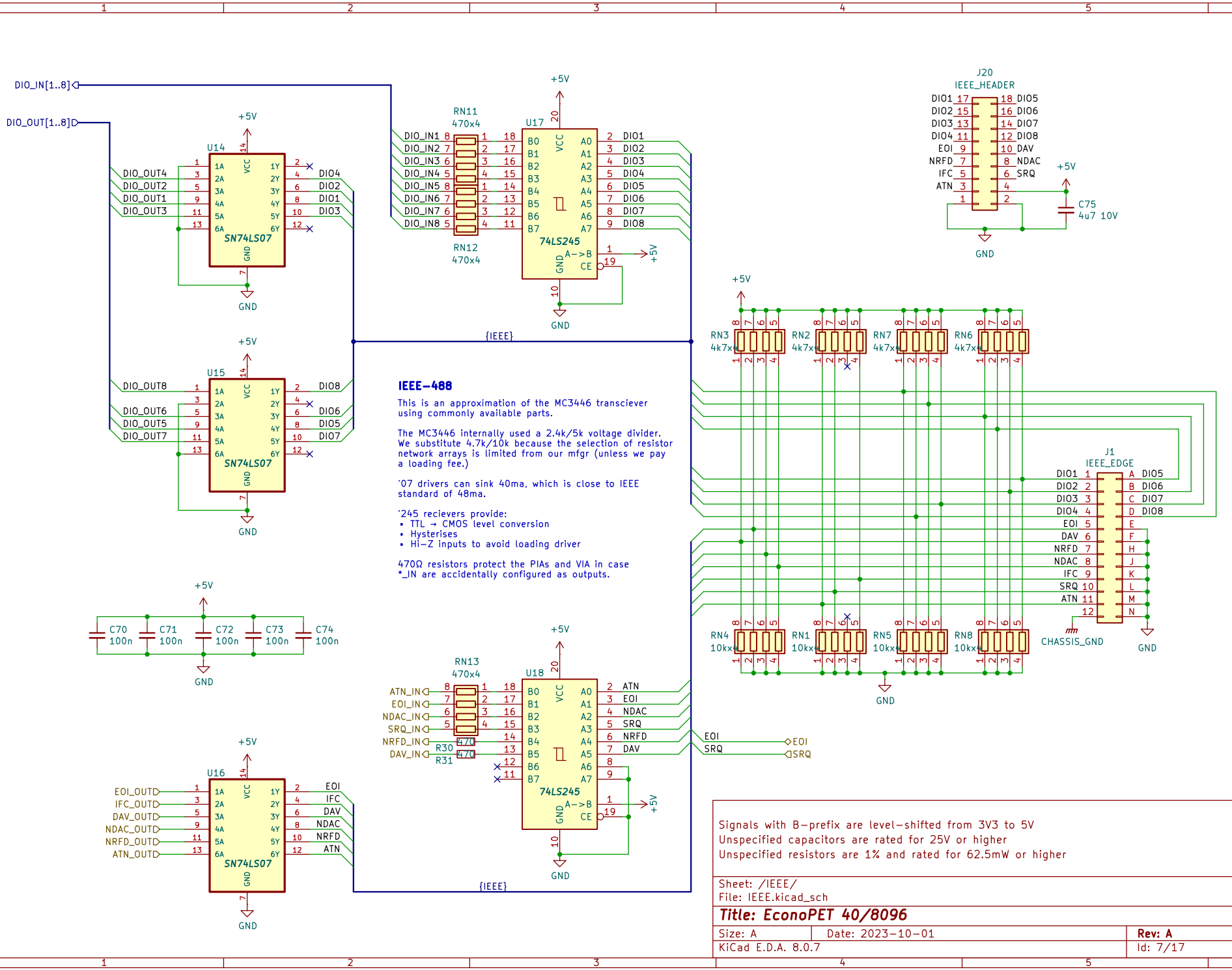
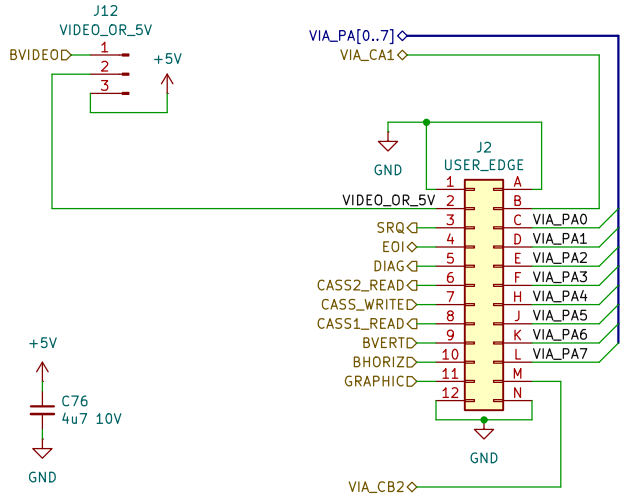
Unspecified resistors are 1% and rated for 62.5mW or higher
Sheet: /IO/
File: IO.kicad_sch
Title: EconoPET 40/8096
Size: A
Date: 2023-10-01
Rev: A
KiCad E.D.A. 8.0.7
Id: 6/17

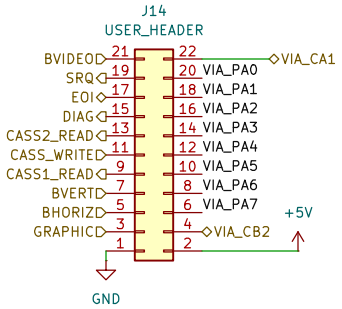

DIO_IN[1..8]
DIO_OUT[1..8]
U14
SN74LS07
DIO_OUT4
DIO_OUT2
DIO_OUT1
DIO_OUT3
DIO4
DIO2
DIO1
DIO3
U15
DIO_OUT8
DIO_OUT6
DIO_OUT5
DIO_OUT7
DIO8
DIO6
DIO5
DIO7
U16
EOI_OUT
IFC_OUT
DAV_OUT
NDAC_OUT
NRFD_OUT
ATN_OUT
EOI
IFC
DAV
NDAC
NRFD
ATN
RN11
470x4
RN12
470x4
U17
74LS245
DIO_IN1
DIO_IN2
DIO_IN3
DIO_IN4
DIO_IN5
DIO_IN6
DIO_IN7
DIO_IN8
DIO1
DIO2
DIO3
DIO4
DIO5
DIO6
DIO7
DIO8
{IEEE}
RN13
470x4
U18
74LS245
ATN_IN
EOI_IN
NDAC_IN
SRQ_IN
NRFD_IN
DAV_IN
R30
R31
470
ATN
EOI
NDAC
SRQ
NRFD
DAV
{IEEE}
C70
C71
C72
C73
C74
100n
RN3
RN2
RN7
RN6
RN4
RN1
RN5
RN8
4k7x4
10kx4
J20
IEEE_HEADER
DIO1
DIO2
DIO3
DIO4
EOI
NRFD
IFC
ATN
DIO5
DIO6
DIO7
DIO8
DAV
NDAC
SRQ
C75
4u7 10V
J1
IEEE_EDGE
CHASSIS_GND
GND
+5V
IEEE-488
This is an approximation of the MC3446 transciever using commonly available parts.
The MC3446 internally used a 2.4k/5k voltage divider. We substitute 4.7k/10k because the selection of resistor network arrays is limited from our mfgr (unless we pay a loading fee.)
'07 drivers can sink 40ma, which is close to IEEE standard of 48ma.
'245 recievers provide:
• TTL → CMOS level conversion
• Hysterises
• Hi-Z inputs to avoid loading driver
470Ω resistors protect the PIAs and VIA in case *_IN are accidentally configured as outputs.
Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher
Sheet: /IEEE/
File: IEEE.kicad_sch
Title: EconoPET 40/8096
Size: A
Date: 2023-10-01
Rev: A
KiCad E.D.A. 8.0.7
Id: 7/17

USER PORT

The VIDEO_OR_5V jumper allows partial compatibility
with VIC-20 and C64 user port peripherals by delivering
+5V on PIN_2 instead of PET video.

(Example: TexElec SNES adapter)





Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

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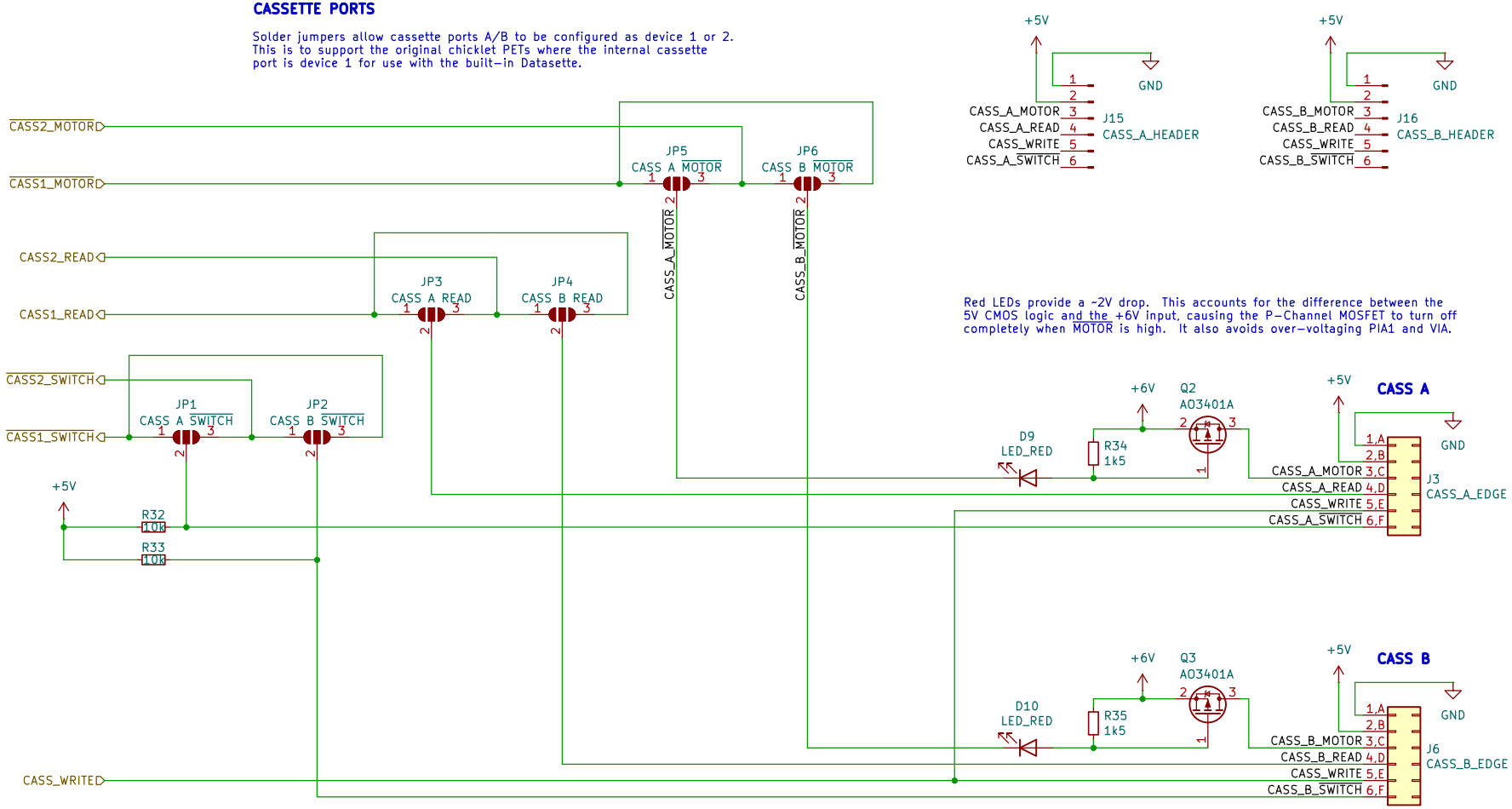
File: USER.kicad_sch		
Title: EconoPET 40/8096		
Size: A	Date: 2023-10-01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 8/17

CASSETTE PORTS

Solder jumpers allow cassette ports A/B to be configured as device 1 or 2.
This is to support the original chicklet PETs where the internal cassette
port is device 1 for use with the built-in Datasette.



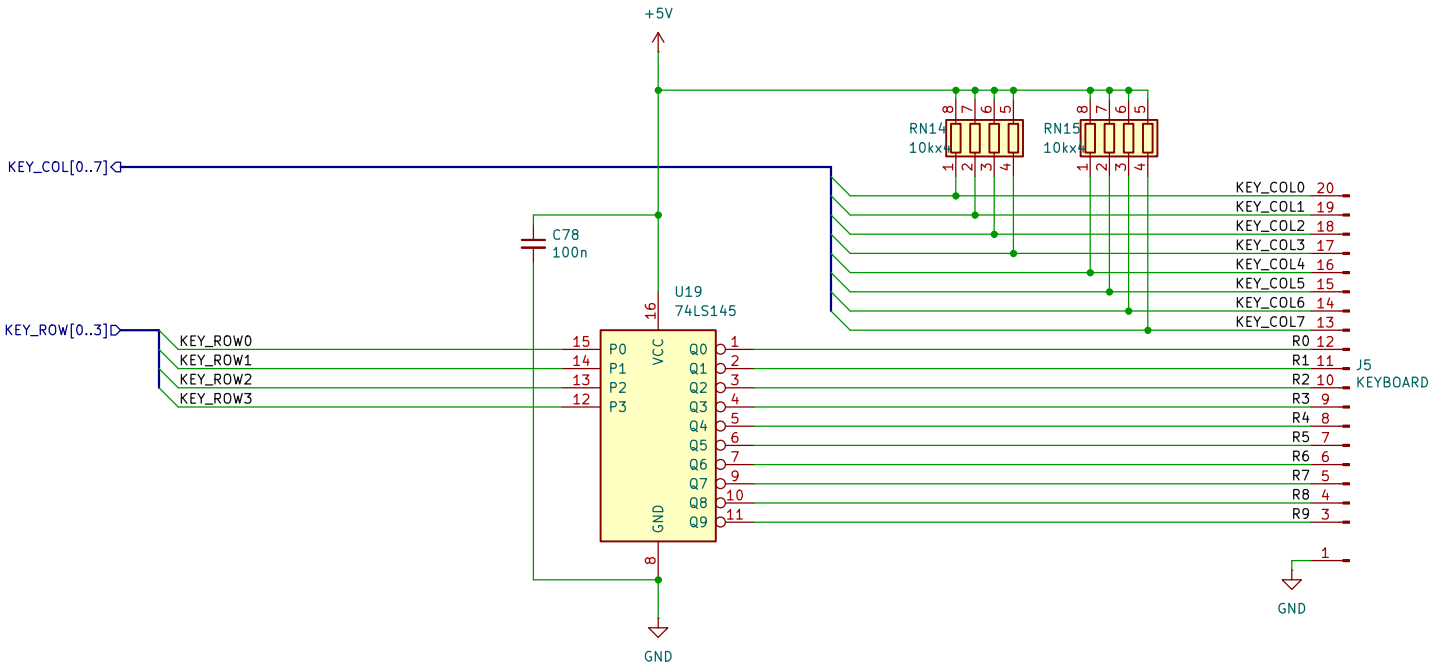
Place decoupling cap near CASS_B connector.
CASS_A has sufficient decoupling nearby.

Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

Sheet: /CASS/
File: CASS.kicad_sch

Title: EconoPET 40/8096

Size: A	Date: 2023-10-01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 9/17



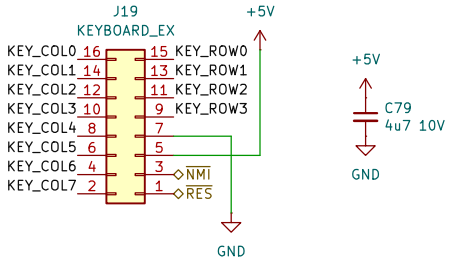
KEYBOARD

The PET uses a 74LS145 BCD-to-decimal to sink the active row of an 8x10 keyboard matrix. When a key in the selected row is pressed, it sinks the 10k pullup of the corresponding column.

The '145 is active low / open collector, capable of sinking an excessive 80ma for driving lamps in the pre-LED era. This is more than enough to sink all eight of the 10k pullups if the user pushes all keys for currently select row.

The KEYBOARD_EX header conveniently exposes the PA[3:0] and PB[7:0] lines for users interested in building adapters to support non-PET keyboards. It also exposes NMI for RESTORE and RES for reset.

http://www.6502.org/users/sjgray/projects/petexpkbd/index.html



Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

Sheet: /Keyboard/
File: Keyboard.kicad_sch

Title: EconoPET 40/8096

Size: A	Date: 2023-10-01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 10/17

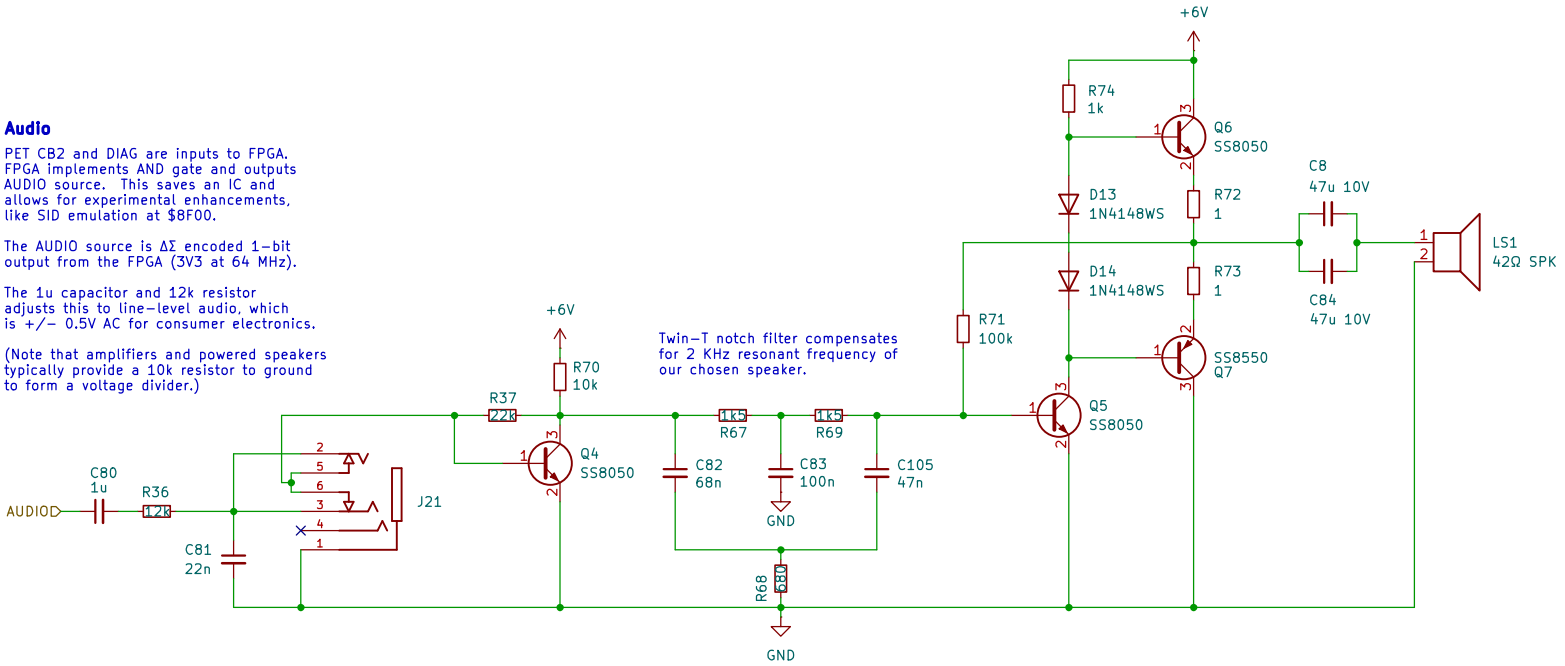
Audio

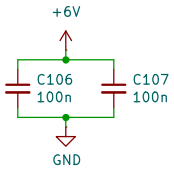
PET CB2 and DIAG are inputs to FPGA.
FPGA implements AND gate and outputs
AUDIO source. This saves an IC and
allows for experimental enhancements,
like SID emulation at $8F00.

The AUDIO source is ΔΣ encoded 1-bit
output from the FPGA (3V3 at 64 MHz).

The 1u capacitor and 12k resistor
adjusts this to line-level audio, which
is +/- 0.5V AC for consumer electronics.

(Note that amplifiers and powered speakers
typically provide a 10k resistor to ground
to form a voltage divider.)





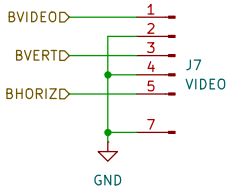
Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

Sheet: /AUDIO/
File: Audio.kicad_sch

Title: EconoPET 40/8096

Size: A	Date: 2023-10-01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 11/17

VIDEO HEADER



Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

Sheet: /VIDEO/
File: VIDEO.kicad_sch

Title: EconoPET 40/8096

Size: A	Date: 2023-10-01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 12/17

MCU

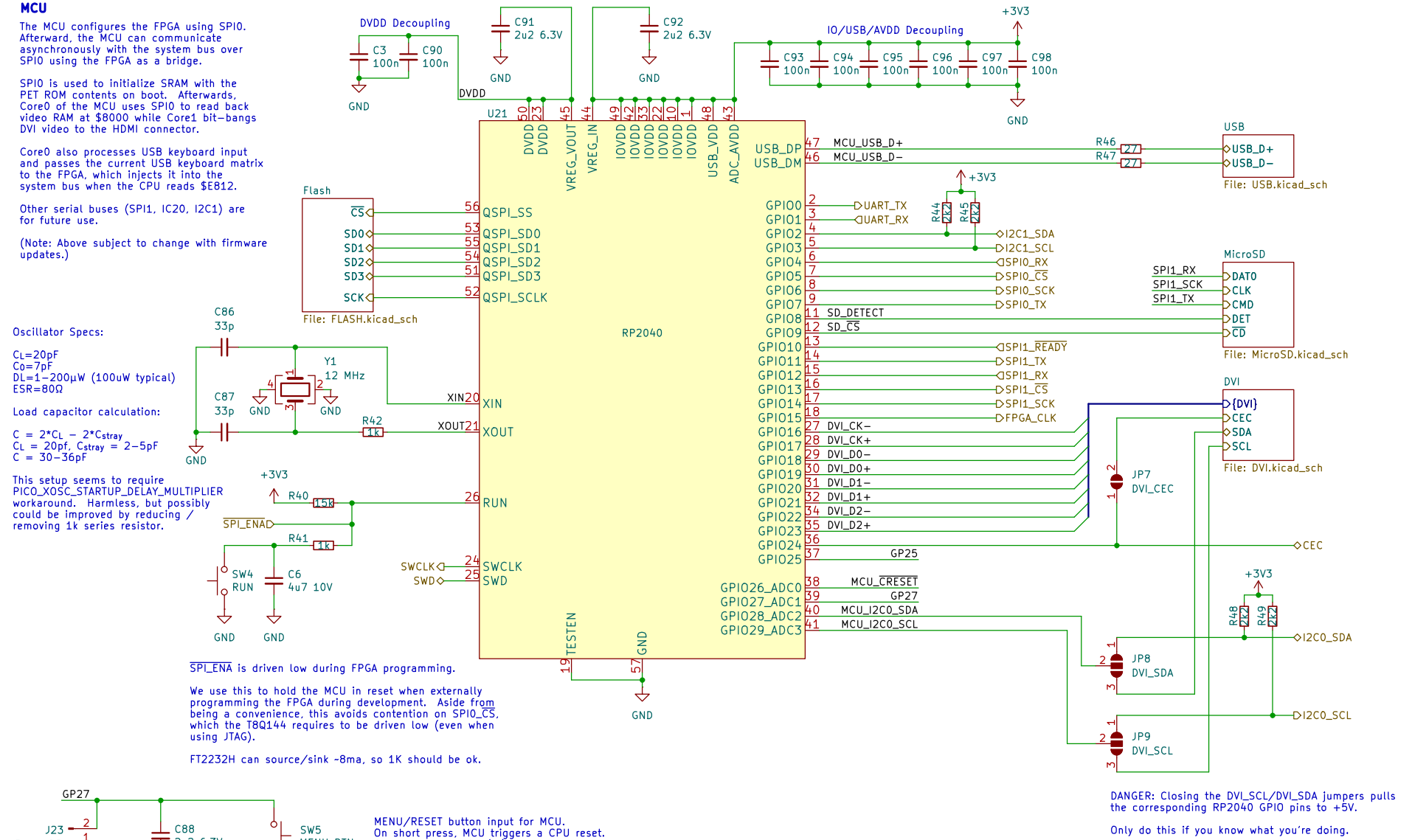
The MCU configures the FPGA using SPI0. Afterward, the MCU can communicate asynchronously with the system bus over SPI0 using the FPGA as a bridge.

SPI0 is used to initialize SRAM with the PET ROM contents on boot. Afterwards, Core0 of the MCU uses SPI0 to read back video RAM at $8000 while Core1 bit-bangs DVI video to the HDMI connector.

Core0 also processes USB keyboard input and passes the current USB keyboard matrix to the FPGA, which injects it into the system bus when the CPU reads $E812.

Other serial buses (SPI1, IC20, I2C1) are for future use.

(Note: Above subject to change with firmware updates.)



Oscillator Specs:

C_L=20pF
C_0=7pF
DL=1-200µW (100uW typical)
ESR=80Ω

Load capacitor calculation:

$C = 2*C_L - 2*C_{stray}$
C_L = 20pf, C_{stray} = 2-5pF
C = 30-36pF

This setup seems to require PICO_XOSC_STARTUP_DELAY_MULTIPLIER workaround. Harmless, but possibly could be improved by reducing / removing 1k series resistor.

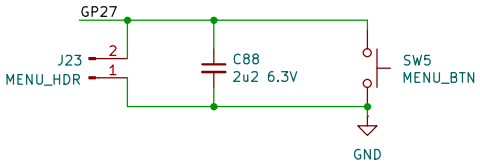
$\overline{SPI\_ENA}$ is driven low during FPGA programming.

We use this to hold the MCU in reset when externally programming the FPGA during development. Aside from being a convenience, this avoids contention on SPI0_$\overline{CS}$, which the T8Q144 requires to be driven low (even when using JTAG).

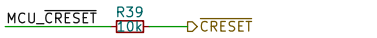
FT2232H can source/sink ~8ma, so 1K should be ok.

DANGER: Closing the DVI_SCL/DVI_SDA jumpers pulls the corresponding RP2040 GPIO pins to +5V.

Only do this if you know what you're doing.

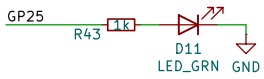


MENU/RESET button input for MCU.
On short press, MCU triggers a CPU reset.
On long press, MCU (re)enters boot menu.



10k resistor on $\overline{CRESET}$ enables programmer to override MCU during development.

MCU status LED visible when looking into the PET expansion slot. (Other LEDs are only visible when the PET case is open.)



Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

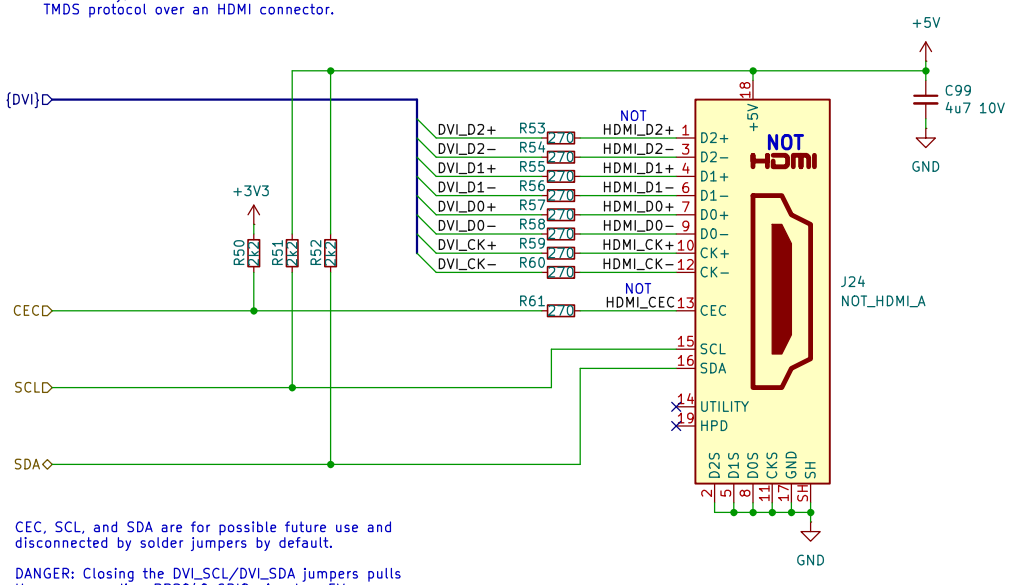
Sheet: /MAGIC/MCU/
File: MCU.kicad_sch

Title: EconoPET 40/8096

Size: A	Date: 2023-10-01	Rev: A
KiCad E.D.A. 8.0.7		Id: 13/17

DVI VIDEO

Technically, not true HDMI. This is the DVI TMDS protocol over an HDMI connector.



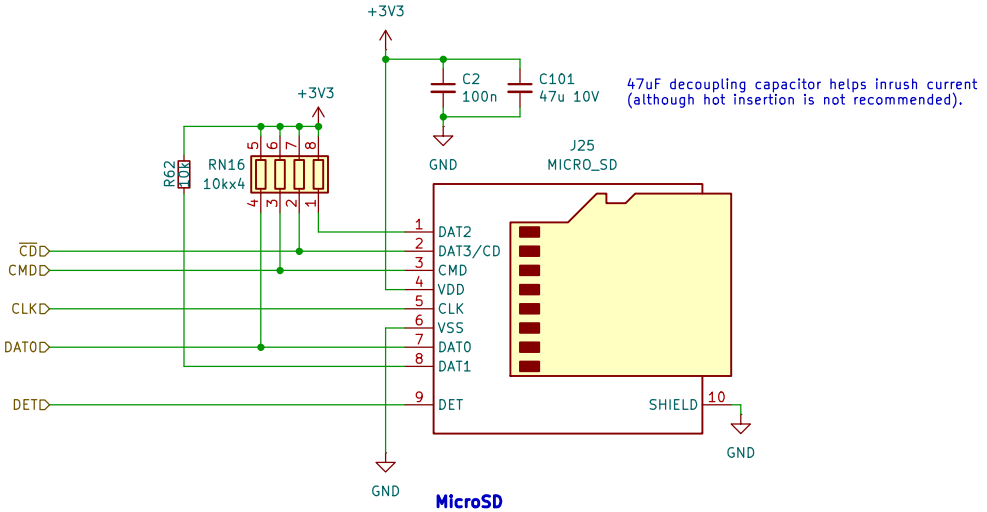
CEC, SCL, and SDA are for possible future use and disconnected by solder jumpers by default.

DANGER: Closing the DVI_SCL/DVI_SDA jumpers pulls the corresponding RP2040 GPIO pins to +5V.

Only do this if you know what you're doing.

Signals with B−prefix are level−shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

Sheet: /MAGIC/MCU/DVI/		
File: DVI.kicad_sch		
Title: EconoPET 40/8096		
Size: A	Date: 2023−10−01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 14/17



MicroSD

DAT[0] : (POCI) is open-drain output that requires pullup.
DAT[2:1] : Unused inputs in SPI mode. Pullups recommended to avoid current draw due to metastablitiy.
DAT[3] : (CS) has built-in 22-50k pullup to ensure card is deselected by default.
CMD : (PICO) input in SPI mode.
CLK : (SCK) always an input. Never gets pullup.

For reference, CM1624 uses:
25k pullup for DAT[0:3] and CMD
40 Ohm termination for DAT[0:3], CMD, and CLK

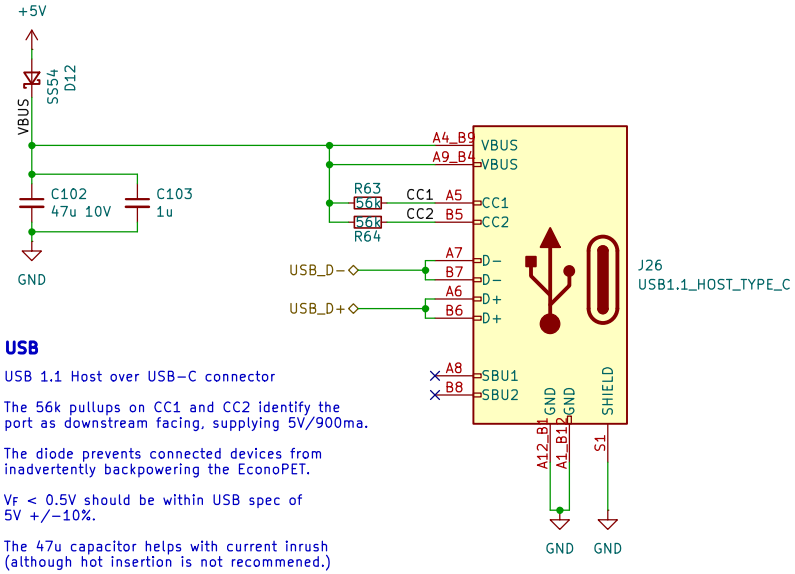
10k pullups common (e.g., ExpressIf documentation).

Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

Sheet: /MAGIC/MCU/MicroSD/
File: MicroSD.kicad_sch

Title: EconoPET 40/8096

Size: A	Date: 2023-10-01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 15/17



USB

USB 1.1 Host over USB−C connector

The 56k pullups on CC1 and CC2 identify the port as downstream facing, supplying 5V/900ma.

The diode prevents connected devices from inadvertently backpowering the EconoPET.

V_F < 0.5V should be within USB spec of 5V +/−10%.

The 47u capacitor helps with current inrush (although hot insertion is not recommened.)

Consider using an independently powered USB hub as an extra layer of protection.

Signals with B−prefix are level−shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

Sheet: /MAGIC/MCU/USB/
File: USB.kicad_sch

Title: EconoPET 40/8096

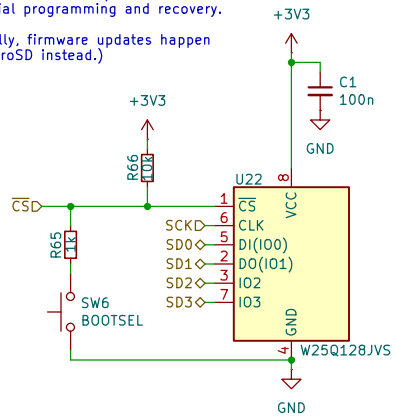
Size: A	Date: 2023−10−01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 16/17

Flash

16MiB Quad SPI flash memory for MCU.

Holding BOOTSEL at power on puts the MCU into programming mode, allowing new firmware to be uploaded via USB for initial programming and recovery.

(Typically, firmware updates happen via microSD instead.)



Signals with B-prefix are level-shifted from 3V3 to 5V
Unspecified capacitors are rated for 25V or higher
Unspecified resistors are 1% and rated for 62.5mW or higher

Sheet: /MAGIC/MCU/Flash/		
File: FLASH.kicad_sch		
Title: EconoPET 40/8096		
Size: A	Date: 2023-10-01	**Rev: A**
KiCad E.D.A. 8.0.7		Id: 17/17