Troubleshooting Guide

THEORY OF OPERATION AND TESTS FOR THE CORE16

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2. Version History of This Guide

Revision	Description	Author	Date
A	First draft	Andy Geppert	2024-08-10

The project homepage for this product is at www.Core16.io, which may still point to www.Core64.io.
The latest version of documentation is at https://github.com/ageppert/Core16-Interactive-Core-Memory.
The latest version of firmware is shared with Core64 and Core64c at https://github.com/ageppert/Core64/releases.
Concept and design by Andy Geppert at www.MachineIdeas.com.

3. Important Cautions and Warnings

These caution symbols point out important things to help ensure your assembly goes smoothly!

Beware the ESD monster!

Pico refers the Raspberry Pi Pico or Pico W which is should have all 40 castellated vias solder to the Core16 Logic Board.

Logic Board refers to the Core16 Logic Board.

Oscilloscope voltages are generally not accurate and have a surprising amount of error tolerance compared to a good multimeter. Oscilloscope voltages are more for reference and looking at signal shapes. Don't be thrown off if a normal voltage is listed in the documentation here, and your scope is off by several tenths of a volt. Similarly, how much do you trust your multimeter? Just keep this general advice in mind and don't get too hung up on voltage level accuracy.

Continuity checks should be done with a good multimeter. Press the probe tips into the solder joint to get through the cruft.

Use flux for soldering, but also, clean it off when you are done soldering.

4. Introduction

This guide steps through the functionality of the Logic Board for Core16. Each functional section is reviewed, in sequence form power on through full operation of all cores and associated LEDs.

You do not need to proceed through the guide in sequence. Use your intuition to jump in where you think it makes sense. For instance, if you are confident you have power and the correct firmware installed, and the LEDs always on but unresponsive to the magnetic stylus, jump to the section "Core Matrix Row and Column Drivers."

Since each of the Core16 Logic Boards go through a complete functional test before shipping to customers, the most likely problem areas are where the customer completes final assembly steps. In order of most frequent to least frequent:

- Core Matrix solder joints
- Core Sense Wire solder joints
- Core weaving pattern
- Solder connections between the Pico castellated vias and the Logic Board
- Battery and power switch connections
- Stylus magnetism weak due to excessive soldering heat

Carefully check all of those items to make sure they are all done well, and all connections that you made have good continuity.

Still, it could be that something has been damaged elsewhere on the Logic Board. Perhaps by mishandling, or damaging components adjacent to the outer edges of the Logic Board, or around the perimeter of the Core Matrix area. Visually inspect those areas carefully.

When installing the Core16 into the plastic carrier frame, insert the left edge of the board by sliding it into the plastic clips on the left. Then carefully snap the right edge plastic clips up around the right edge of the board. The reasoning is that the components on the back-side of the left edge/corners of the board are more fragile than the ones on the right edge/corners.

When removing the Core16 from the plastic carrier frame, carefully un-snap the right edge first. Then slide the left edge out of the plastic clips.

The following sections are organized in the functional sequence of the Core16 system. That is:

- Power Supply
- Microcontroller – the Pico W
- Serial Port
- I2C Bus Interface
- EEPROM for Board ID
- Info Query
- Core Matrix Wiring – the part you complete, which is the most likely source of issues
- Core Matrix Enable
- Core Matrix Row and Column Drivers
- Core Signal Sense
- Core Signal Output Latch
- Magnetic Stylus
- RGB LEDs
- Hall Sensors
- SAO OLED (optional)
- SAO and QWIIC ports (optional accessories)

5. Theory of Operation

All modes of operation with the Cores, LEDs and Magnetic Stylus are similar. Each Core in the matrix is written to with a pulsed electromagnetic field created along the length of the row and column wires. Where the two address wires intersect the core, the combined (aka coincident) magnetic field is strong enough to magnetize the wire in a clockwise or counter-clockwise orientation. Each orientation is defined as 1 or 0. If the orientation has been changed by the magnetic field created in the address wires, a small voltage will be induced into the sense wire. That voltage is detected by differential op-amps in the sense circuit, and latched into simple dual-NOR gate latch. If this occurs, the firmware detects that the core state was

changed, the core will then be reset to the opposite state, and the firmware reports the value of that core bit. This information is used to illuminate the corresponding LED when the core is set to 1, or extinguish the LED if the core is 0.

6. Schematic and PCB Layout

Reference: https://github.com/ageppert/Core16-Interactive-Core-Memory/tree/master/Electronic%20Design/Core16_LB_V0.2%20Schematic%20and%20Renders

Schematic

The schematic is organized into functional sections which correspond to the sections of this guide.

PCB Layout

The PCB layout is fairly tight, and doesn't follow the schematic blocks perfectly, but it attempts to lump functional elements together in the same area.

TO DO: Block diagram sections of schematic connected to rendering of the back of the board to make navigation easier.

7. Symptoms and Test Table

Failure Symptoms and likely causes

If all of the LEDs are on, there is a problem common to the whole matrix.
The sense wire and circuit are common to the whole matrix.
The core memory enable CM_EN signal is common to the whole matrix.

Overview

After power on, the 4x4 matrix of LEDs should show three symbols in a row, in RED: C, 16, and the hysteresis flux symbol.
Then it will move to scrolling text "I [heart] CORE16".
After that that, several more multicolor symbols will be displayed and it will return to scrolling text.

During scrolling text, the cores are actually being used as screen RAM. Interaction with the magnetic stylus should alter the state of the LEDs in the scrolling text mode.

In the other mode, displaying symbols, the cores are NOT being used, and just the LEDs are being controlled.

Beginning with the power sources. The Core16 may be powered from a battery pack or micro USB cable. To

SYMPTOM	TEST STARTING POINT	ASSUMPTIONS
Nothing happens when I connect the USB Cable.	Power Supply	No power.
All I see is an Green LED blinking on the Pico W.		No firmware.
The serial port responds, but nothing shows on the RGB LEDs		
Some symbols displayed correctly, but instead of scrolling text, all LEDs are on, fading through a rainbow of colors. None of the cores/LEDs respond to the magnetic stylus in any mode.	Info Query, and subsequent sections.	Power from USB is good. Firmware is installed. Serial connection established

8. Power Supply

Quick Test

With only USB power, switch in OFF (USB) position, ground at SAO port GND, verify

- 5.0V at VB pin 40 on Pico W (aka 5V_USB, PICO_VBUS)
- 4.9V at VS pin 39 on Pico W (aka PICO_VSYS)
- 3.3V at SAO port 3V3 pin
- 3.3V at U9 LM393 Dual Op-amp pin 8
- 3.3V at U10 74HC02 Quad NOR pin 14

Overview

Beginning with the power sources. The Core16 may be powered from a battery pack or micro USB cable. To simplify troubleshooting, use just the USB cable and leave the battery pack disconnected or remove the batteries. This will provide enough current to the Core16 Logic Board for troubleshooting, and enables serial communications for testing and diagnostics. Additionally, the computer USB ports are current limited.

For consistent troubleshooting, keep the USB cable connected, and enter mode 30 "`SPECIAL/CORE TEST ONE.`" The measurements included in the subsections below are made with the Core16 in this mode. Similar results are expected with the battery, but since you are troubleshooting the operation of the cores, you are unlikely to be able to navigate the menu with the cores/stylus. Thus, all testing is done with USB power.

Ground Reference for Measurements

Use the GND pin of the SAO port as your ground reference.

Battery Power on Back of Logic Board

The default configuration supports three "AAA" alkaline cells. Nominally, they supply 4.5V. Absolutely do not exceed 5.5V by trying something like a 2S LiPo. This will destroy the 3.3V Regulator.

If you suspect a short-circuit in the system, limit the current with a current limited power supply or resistor in series with the battery pack to the positive terminal of the Logic Board.

USB Power into Pico on Front of Logic Board

Connect the Pico to your computer with the MicroUSB cable. This supplies a clean 5V and it is conveniently current limited by the computer USB power manager. Unless there is something completely short-circuited on the Core16 Logic Board, the current limiting can be considered a nice feature.

The quality of USB cables varies significantly. The cable included in the kit has been tested to work well. Other cables may have excessive resistance, or by power only, without data signals. Make sure you are using a good USB cable with power AND data. Measure the voltage at the Pico connection to the Logic Board at Pin 40 labeled VB for VBUS. A range of 4.5 to 5.0V is normal.

It can be helpful to have a switched USB Hub between the computer and the Core16 so you can press a button to turn off the Core16 (to reset it) instead of unplugging the fragile Mico USB connection to the Core16. For example:

https://www.amazon.com/Aceele-Splitter-Individual-Switches-Portable/dp/B0CBTN686G/

Some USB hubs keep the serial connection (USB Data) connected and only interrupt the USB 5V power line.

Power Switch

The ON (BAT) position selects the battery as the source of power. It does NOT disconnect USB power if a USB cable is connected to the Pico because power is supplied downstream directly to the 5V0 rail of the Logic Board. The USB power bypasses the switch and reverse polarity protection circuit.

The OFF (USB) position selects the USB port as the source of power. It disconnects the battery power. If a USB cable is not connected, it effectively cuts all power to the Logic Board.

RPP - Reverse Polarity Protection

The protection is for the battery pack wires, which are soldered in near the power switch. If the wires are soldered into the wrong positions, or the battery cells are reversed, it prevents the Logic Board from receiving reverse polarity and protects it from damage.

+V Switched = 5V0

USED FOR:

- RGB LEDS
- 3V3 REGULATOR

This is a carry over from the Core64/c kits, which allow battery pack voltages greater than 5V, and include a 5V0 Regulator. In Core16, the voltage at this +VSW and 5V0 are equal, and will by 5V or less. Three capacitors are provided as bulk storage to smooth out power draw fluctuations from the RGB LEDs and the demands of the 3V3 Regulator. Despite the label of 5V0, the voltage will be between 3.5V and 5.0V normally.

3V3 Regulator

USED FOR:

- SYSTEM LOGIC
- CORE MATRIX DRIVER
- CORE MATRIX SENSE
- HALL SENSORS
- SAO AND QWIIC PORTS

The 3V3 Regulator creates a stable 3.3V source for all of the logic in the system, and the core memory.

Core Matrix Power

Three capacitors provide bulk storage to help hold up the 3V3 rail during the current surges used to write to the cores. Each row and column wire used to access a core is around 200-250 mA. When combined, this is a substantial 400-500mA draw on the 3V3 rail.

Core Matrix Enable

The Core Memory Enable CM_EN signal activates the Core Matrix FET which connects the entire Core Driver circuit GMEM to ground. This is used as a sort of a safety mechanism. During experimentation with firmware and control algorithms, you might inadvertently create a situation where the Core Matrix Drive Transistors are shorting the 3V3 to ground. By only activating CM_EN for a brief moment after the transistors are configured, this limits potential damage to the drive circuit. Generally, the 3V3 regulator save the components by kicking in a current limiting feature which will cause the 3V3 rail to fade to zero volts.

9. Microcontroller – Pico W Board

Overview

The Pico W can be operated independently from the Core16 Logic Board through the Micro USB port.

Factory fresh Pico's and Pico W's have pre-loaded firmware which blinks the built-in LED on the Pico at a 1 second interval. There will be no serial communication active with the default pre-loaded firmware.

If the Pico is programmed with the Core64/c/16 firmware (the same firmware is common to all three models) the built-in LED will blink in a heart beat pattern, and the serial port will periodically report the mode and respond to serial queries like "info" or "mode".

At the time of this writing (Firmware Version 0.8.10), the Core16 Pico W uses the same firmware, but does NOT blink the built-in LED… because I haven't gotten it working yet. It's on the TO DO list.

Overview of Core16 operation with a magnetic stylus: https://www.youtube.com/watch?v=5HAyPMMNyDc

For more extensive information about the firmware operation, please refer to:
https://github.com/ageppert/Core64/blob/master/Documentation
TO DO: Complete the User Guide and a video of the firmware walk-through.

PICO W Board Soldering

There are 40 castellated vias to solder to the Core16 Logic Board. Carefully inspect and verify continuity between the top of the Pico W thru-hole and the bottom of the Core16 Logic Board thru-hole.

Ensure firmware is installed

See the "Core64 Firmware Update Guide.pdf" to install firmware on the Core16. The firmware is common between Core64, Core64c, and Core16.

10. Microcontroller – Serial Port

Overview

The Pico W has a serial port, accessible through the Micro USB connection on the end of the Pico W. This used for diagnostics, changing modes, and changing settings.

Establish a serial connection

With the Micro USB cable connected to the Pico W, and the Pico W soldered down to the Logic Board, use your serial terminal of choice to establish a [115,200 8 bits, No Parity, 1 stop bit, no flow control] connection to the Pico W.

Ensure you are using a known good USB power AND DATA cable. Test it with another device to be sure.

Once the serial connection is established, send a RETURN from you keyboard to see the `Core>` command prompt.

Type "`info`" to capture information about your particular Core16. Don't type the quotes. This is a helpful bit of information if you contact me about troubleshooting.

Type "`mode 30`" to enter the "`Special/Core Test One`" mode. This is the primary mode used for the tests in this guide. By default, the upper left core will be the single core to test. It is Pixel #0, and in this mode, is referenced as Core #0. To test other cores, type "`cs [#]`" where [#] is the Core # from 0 to 15.

Type "`help`" to see a list of commands.

Expected behavior

All LEDs in the matrix should be off.

When the magnetic stylus is placed over the upper left core, the LED should illuminate only when the stylus is present. Similar functionality for each individual core/LED, provided you use the "`cs [#]`" command to change the core under test.

11. I2C Bus Interface

Overview

An I2C Bus is fundamental to correct operation of the system. It is connected to:

- An EEPROM on the Logic Board with Board Specific Information on it, required for proper function of the firmware.
- Four magnetic hall sensors, under the M, -, +, and S symbols. These are "soft keys" used to select modes and change settings.
- Optionally, provide diagnostic information to a small 128x64 OLED I2C Display through the SAO port. I have these available on www.Core64.io and you can make your own with information at https://github.com/ageppert/SAO_OLED
- Furthermore… connect to whatever other I2C devices you'd like through the SAO port.

Normal Operation

The data and clock lines idle high, at 3.3V.
During bus activity, those lines rapidly pulse between 0 and 3.3V.

12. EEPROM for Board ID

Overview

The EEPROM stores information such as:

- Board Version and Serial Number
- Core configuration
- Custom settings

If the EEPROM is not accessible, the firmware does not know how to configure itself to use all of the available features. Substantial parts of the normal functionality of Core16 won't work.

13. INFO Query

Overview

The "`info`" command returns valuable troubleshooting information.

Normal Operation

Establish a serial connection through the Micro USB cable.

Type "`info`" to display information about your particular Core16. Don't type the quotes. Here's an example of the output with useful details highlighted in yellow:

```
  ----------------
  |     INFO     |
  ----------------
  EEPROM S/N indicates Logic Board Type: 3 (eLBT_CORE16_PICO)
  Core16 Logic Board with Raspberry Pi Pico RP2040 MCU. Hardware configuration in HardwareIOMap.h
  Hardware Version: 0.1.0     Serial Number: 300003     Born on: 2023-10-4
  Voltages: Input (Battery): 5.05, 5V0 Rail: 5.00, 3V3 Rail: 3.29
  Firmware Version: 0.8.11     (Compiled on Apr 13 2024 at 09:35:51)
  Firmware Description: All ICM (Interactive Core Memory) Kits, add option to drive Color OLED
1.5 inch from https://www.adafruit.com/product/1431
  For more details see https://www.github.com/ageppert/Core64
      HardwareConnectedCheckButtonHallSensors = true
```

From this information I see that the EEPROM can be accessed and is providing a valid serial number and hardware version. The Hall Sensors are also being detected correctly. The firmware version and 5V0/3V3 rail voltages are a function of the native firmware.

14. Core Matrix Wiring

Overview

Problems with some of the rows and columns could be caused by lack of continuity in corresponding wires. All four columns each have their own dedicated wire/driver. The 1st and 3rd rows share a drive circuit, as do the 2nd and 4th rows. It could also be one of the diodes or transistors in the drive circuit, especially near the top and bottom edges where they are more exposed and prone to handling damage.

Problems with all of the cores point to the elements that are common to all cores: core enable, sense, Pico W connections.

All of the Logic Board functionality is tested for each board that is shipped. Having a wide variety of customers with different levels of technical skill means that weaving the core matrix is the most likely place to introduce problems, or end up incomplete. Thus, this is the most likely place to look for problems. The following list of watch-out areas starts with the most frequent occurrences.

> ? Perform the matrix wiring tests with the power disconnected from the Core16 Logic Board!

PICO W Soldering

It's worth mentioning this again: Carefully inspect and verify continuity between the top of the Pico W thru-hole and the bottom of the Core16 Logic Board thru-hole. It's easy to be fooled by just looking at the solder joint!

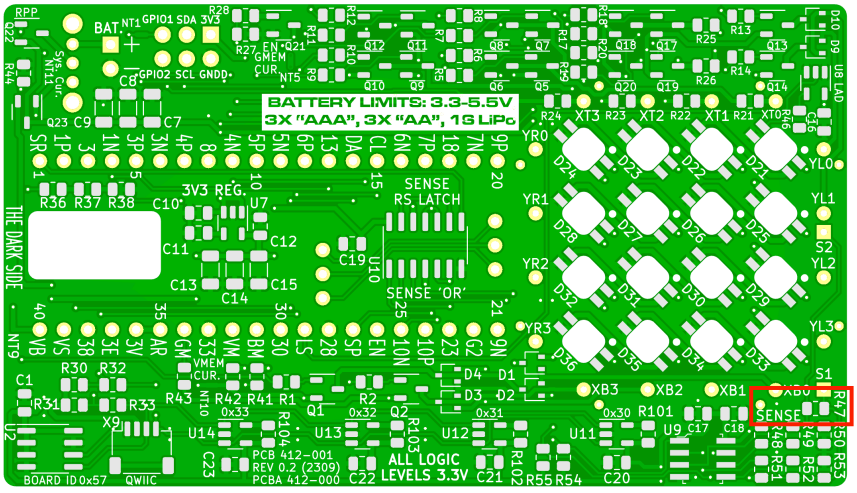
Row and Column continuity

Verify continuity from the top to bottom solder pads around the Core Matrix, and the left to right solder pads, on the top side of the board. Resistance should be between: 0.0 and 0.2 Ohms.

If there isn't continuity, the solder joint needs to be gently reworked from the bottom side to break down the enamel coating of the wire. Use a slightly higher temperature than normal solder, add flux, and rub the sides of the wire enamel while gently maintaining tension on the wire with a tweezers. Maintain the tension until the solder joint solidifies to avoid creating "cold" colder joints.

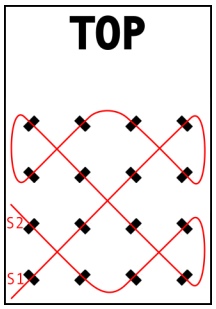
Sense Wire continuity

Verify continuity of each end of the sense wire S1 to S2 solder pads, on the top side.
Resistance should be 0.0 to 0.4 Ohms.
Verify the same continuity/resistance reading across the pads of R47 (which is not populated).



Core Orientation

The cores must be installed in this alternating configuration shown by the diagonal black rectangles:



Screen Protector Wiring

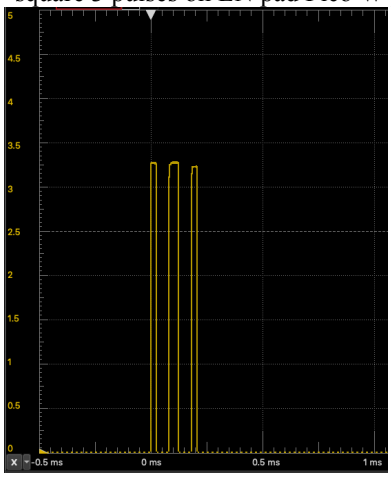
If you have installed the diagonal wires to hold the screen protector in place, verify they are in the correct hole positions, without any solder blobs carrying over to adjacent pads.

15. Core Matrix Enable

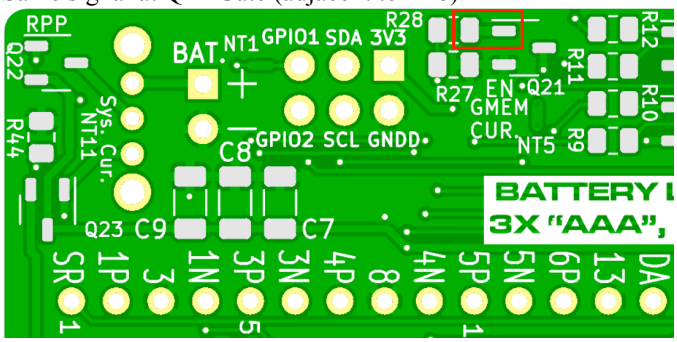
Quick Test

In mode 30… with only USB power, switch in OFF (USB) position, ground at SAO port GND, verify:

- 3.3V square 3 pulses on EN pad Pico W pin 26, bottom side of Logic Board



- Same signal at Q21 Gate (adjacent to R28)



Overview

Core Matrix Enable connects the entire drive matrix to ground, and enables it. Failure of this section will render all cores inoperable.

16. Core Matrix Row and Column Drivers

Quick Test

Finish this

TO DO:

- Core Matrix Row and Column Drivers
- Core Signal Sense
- Core Signal Output Latch
- Magnetic Stylus
- RGB LEDs
- Hall Sensors
- SAO OLED (optional)
- SAO and QWIIC ports (optional accessories)