

TULIP4041 – The Ultimate Intelligent Peripheral for the 41

Introduction

In the mid 00's I had finished the MLDL2000 project, and started to consider a follow-up project that would be named the MLDL3000. Most important addition would be a microcontroller to perform more complex tasks, such as interfacing to a PC, printer emulation and saving and storing user programs and ROM images. This resulted in a working prototype, but real life and family interfered. And with the introduction of Diego's Clonix and NoVRAM modules and finally Monte's HP41CL I thought that the MLDL2000 or -3000 would simply be superfluous.

After starting to reduce my working hours I picked up some activities again in 2018, and late 2022 I decided to give it a go again, now with a slightly different platform. But still using an FPGA for the HP41 bus interfacing, and a microcontroller for the high-level stuff. In the spring of 2023 Andrew Menahue posted a message and video on the HP Museum forum, and that did it. A new approach using the RP2040 microcontroller that did all the work, including the low-level bus interfacing. Not entirely new, as Diego's modules also used a microcontroller to interface with the HP41 bus. The RP2040 however has so much more performance that it could run more complex tasks. After studying the datasheets I made a decision to go for it and in the summer of 2023 a first breadboard version was working. My initial goal was to use the PIO in the RP2040 for the HP41 bus interfacing, and to create emulation of the HP-IL module. After that steps were taken to create a product that is useable for the community.

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1. Credits

Many thanks to Andrew Menahue for inspiring this project and his cooperation, Thomas Fänge for his contributions, cooperation and testing. HP-IL emulation is based on V41 and EMU41 by Christoph Giesselink and Jean-Francois Garnier, PILBox emulation is based on the PILBox from Jean Francois Garnier.

2. Version info

The TULIP4041 is a project that is in constant change. This documentation may not always match the current available version, which is VERSION 00.01.02, the first public BETA.

VERSION 00.01.02 supports the following functionality:

- Basic Command Line Interface (CLI) with functions to reset and boot into BOOTSEL mode, control HP-IL emulation and control of the Tracer functionality
- HP41 bus Tracer
- HP-IL and HP-IL printer emulation and PILBox emulation
- HP-IL scope
- HP82143 Printer emulation

IMPORTANT

The decision has been made to make the move to the RP2350, and the Pico2 board for the Development Board. This document applies to the RP2040 version, the functionality and code is not much different and the assembly and test instructions still apply (Chapter 14). This document will be updated in due time.

3. Conventions

- 00FF Hexadecimal numbers are used to indicate addresses, leading zeroes are typically used to indicate the total possible range, e.g. 00FFFF. The 'x' character is used for a "don't care" situation
- 0x040 The 0x sequence is used to indicate hexadecimal values when context is not clear
- 0b1010 Binary values are preceded with the 0b sequence, the 'x' character is used for don't care bits
- HP41 HP41 indicates all versions of the HP41 calculator, including HP41C, CV, CX, CL, DM41X
- 41CL Is used when specifically referring to the HP41CL system, also 41CL is used
- TEXT** in **blue** is actually typed as input in the examples, when quotes are used this means that the text is typed in ALPHA mode. When used in the text it refers to an actual HP41 command
- [ALPHA]** when in a bracket this is an HP41 key
- 0.0000** is the result of an operation, what is in the display in **green**

4. Copyrights and Disclaimer

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6. TULIP4041 overview

The TULIP4041 firmware is specifically designed for the RP2040 microcontroller. This controller is designed by Raspberry Pi. The device is very low cost (typically under € 1) and offers the following main features:

- Dual-core Arm Cortex-M0+ processor, flexible clock running up to 133 MHz (overclocking possible)
- 264kB on-chip SRAM
- 2 × UART, 2 × SPI controllers, 2 × I2C controllers, 16 × PWM channels
- 1 × USB 1.1 controller and PHY, with host and device support
- 8 × Programmable I/O (PIO) state machines for custom peripheral support
- Operating temperature -40°C to +85°C
- Drag-and-drop programming using mass storage over USB
- Low-power sleep and dormant modes
- Temperature sensor
- Accelerated integer and floating-point libraries on-chip
- Excellent support for multi-platform development tools and many (open source) libraries

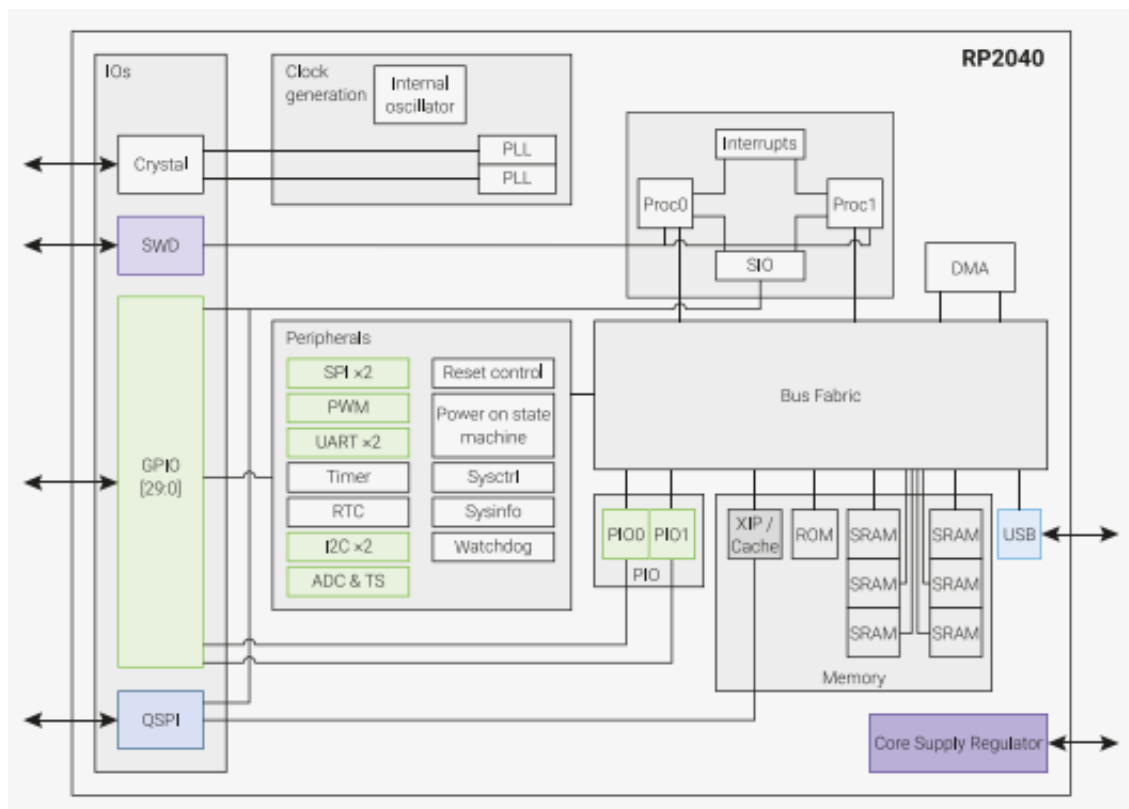


FIGURE 1 RP2040 BLOCK DIAGRAM (FROM THE RP2040 DATASHEET)

The TULIP4041 uses some additional hardware:

- FLASH memory (2 - 16 MByte), part of the RP2040 structure, code actually runs from the flash (XIP) and most of the ROM images are stored in flash and directly accessed there
- FRAM memory to emulate QROM and user memory and for saving system settings
- Micro SD card holder
- Infrared LED for IR printer operation
- Level shifters to interface with the HP41 bus

RP2040 development boards are available from several vendors, including the Raspberry Pico which is used in the prototyping phase of this project.

In this project both ARM cores are used, and the PIO is used to almost its full capacity for the HP41 bus interfacing.

The TULIP4041 comes in two different versions:

- TULIP DevBoard (orderable): a hand solderable board with all interfaces available on headers for development and debugging. This version is mainly intended for my own development to replace the fragile breadboard. It uses a standard Pico board (or 100% pin compatible) and comes with a connectorboard for plugging in the HP41
- TULIP Module (in development): a long module sized PCB with all smd components assembled. This unit has the size of an HP-IL module and is housed in a custom 3D printed module housing

IMPORTANT: the HP41 module connector is NOT included with either product!

[7. TUP4041 Architecture](#)

The TULIP4041 has three main parts:

- PIO state machines running the low-level HP41 bus interfacing, timing and synchronization
- Core1, running the HP41 emulation layer in sync with the HP41 bus interface
- Core0, running the initialization, user interface, communication, and other non-critical tasks

[7.1. PIO State Machines](#)

The RP2040 microcontroller has 2 PIO (Programmable I/O) blocks that are used for low level HP41 bus interfacing, synchronization and timing. Each PIO block has up to four state machines, and a code space of 32 instructions. Data with the other cores is exchanged using fifo's (with the queue functions). The TULIP4041 implementation uses both PIO blocks to almost their full capacity.

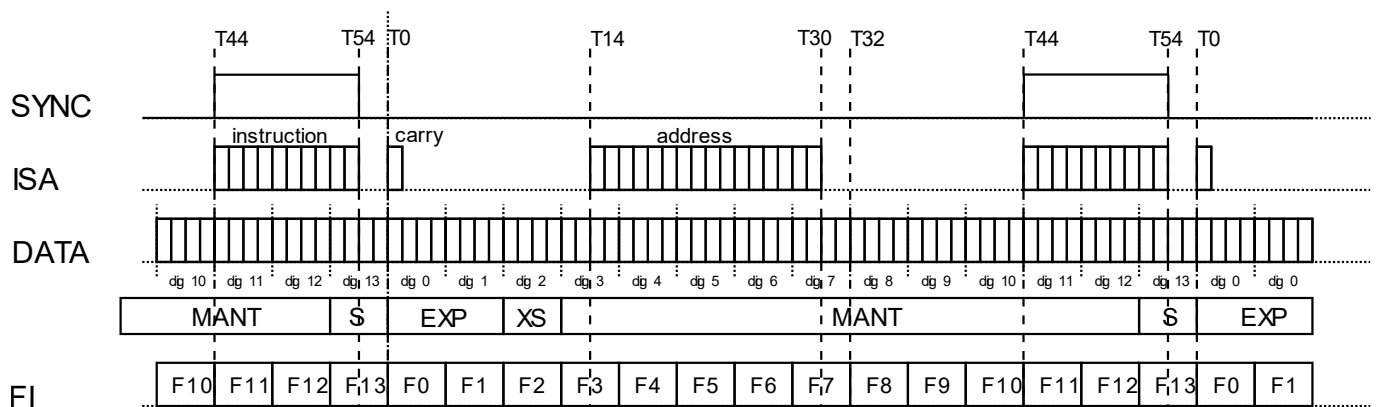
In the description of the state machines the HP41 bit timing starts at T0, the time that data bit 0 appears on the HP41 bus. The counting is a bit different from most MLDL-type hardware that starts counting at the end of the SYNC pulse.

For synchronization between the state machines two GPIO signals are used: SYNC_TIME and T0_TIME. The nature of the HP41 timing and the requirements of the other state machines made the use of GPIO signals necessary, as interrupts in the PIO blocks have some limitations.

7.1.1. SYNC State Machine

After initialization the SYNC state machine waits for the first rising edge of SYNC and then enters its main loop. This is the main state machine that ensures correct synchronization, CLK counting and control of the external signals to synchronize the other state machines. This state machine is also used for ISA input.

- The external synchronization GPIO signal SYNC_TIME becomes active during each SYNC cycle, even when no SYNC appears on the HP41 bus (in case of a non-instruction fetch or the second word of an instruction (XQ/GO, LDI or a peripheral instruction)
- 10 HP41 bit times are counted, and at each rising edge of CLK01 a bit from ISA is pushed in the state machines ISR (Input Shift Register)
- After the 10th bit ISA is sampled again together with SYNC, in order to give the emulation layer access to the SYNC status during the instruction fetch.
- The ISR is then pushed to the state machine RX FIFO, to be read by the emulation layer in core1. This happens during T54, briefly before the end of the SYNC cycle.
- SYNC_TIME is driven low
- The state machine waits two CLK02 cycles before the start of T0
- At the start of T0 (rising edge of CLK02) the external GPIO T0_TIME is driven low (it is an active low signal)
- At the end of T0 (next rising edge of CLK02) the T0_TIME signal is de-asserted (driven high)
- From T1 the state machines starts counting (with a counter initialized during PIO initialization) and samples data from ISA. At the end of the ISA address the address is autopushed to the RX FIFO
- The state machine continues counting until the counter reaches 0 at exactly the start of SYNC



Upon a PWO event (falling or rising edge) the SYNC state machine is reset by a forced jump to the first instruction to wait for the first rising edge of SYNC. This is done by an interrupt handler.

The main emulation loop in core1 can do a blocking wait for data from the RX FIFO. The first data it receives is the ISA instruction, these are 12 bits in the following format:

SYNC status		ISA instruction (10 bits)									
SYNC	bit 9	bit 9	bit 8	bit 7	bit 2	bit 2	bit 2	bit 2	bit 2	bit 1	bit 0

The operation of the SYNC state machine captures the instruction bit 9 a second time, plus the status of SYNC.

After processing the software does a second blocking wait for receiving the ISA address. The 16 least significant bits of the captured data is the 16 bit address.

7.1.2. [DATAIN State Machine](#)

For sampling the DATA line a separate state machines uses the T0_TIME signal to synchronize. The state machine does a constant sampling of DATA on the rising edge of CLK01 and uses the AUTOPUSH feature so it does not have to count the bits. This state machine runs at 12.5 MHz to prevent waiting for both CLK01 edges. By using a slower clock it can skip the wait for the falling edge of CLK01 by using a delay of 15 clocks after the IN instruction.

- The state machine starts with a blocking wait for the rising edge of SYNC_TIME, this will usually be the first SYNC after a PWO event
- The state machine starts sampling DATA on the rising edge of CLK01 until it sees T0_TIME low
- When T0_TIME is low the data in the ISR is pushed and the main loop of the state machine is entered again

The state machine relies on AUTOPUSH with a count of 32. This means that at T32 the first 32 bits of data appear in the RX FIFO, and at T0 the remaining 24 bits.

The main software loop must empty the RX FIFO at each cycle to prevent the state machine to block.

Upon a PWO event (rising or falling edge) the state machine gets a forced jump to the start, waiting again for a new SYNC cycle.

7.1.3. [DEBUGOUT State Machine](#)

This is a very simple state machine, simply sending the TX FIFO contents to a debug output. This can be used by the main loop to indicate its position by putting a code or number of bits in the TX FIFO. This state machine uses AUTOPULL at 16 bits and consists of only one OUT instruction.

The debug output is used together with the T0_TIME and SYNC_TIME outputs for tracing the inner workings of the TULIP4041, and these signals are available on separate pins.

7.1.4. [ISAOUT State Machine](#)

The ISAOUT state machine has three functions:

- Driving ISA output (and ISA output enable) when is has to provide data during the instruction time (SYNC_TIME high)
- Driving ISA for one bit-time during T0 to transmit a carry status after an instruction has requested a status (typically a peripheral status, in practice used only by the HP82134A printer)
- Drive ISA when the calculator is idle (light or deep sleep) to wake up the calculator for an I/O event

The state machine is normally stalled at a blocking pull. When data arrives in the TX FIFO it will then wait for the start of T0_TIME to output one but for the carry status transmission. At the end of T0 it will return to the blocking pull from the TX FIFO.

To transmit an ISA instruction, the main software loop must do a forced jump to the label isa_inst_out. Here is a blocking pull from the TX FIFO, and upon receiving data it will wait for the start of SYNC_TIME and then transmit the 10 instruction bits at each rising edge of CLK01. When done it will return to the blocking wait for the carry status. This setup has been chosen to allow the shortest possible time for transmitting the carry bit, since we have only two clocks after receiving the instruction and sending the carry at T0_TIME.

A wake-up of the calculator is done outside the state machine. Since the calculator is not running (PWO is low) it does not make sense to run the state machine as it depends on CLK02. Instead a C routine will do the following:

- Do a forced jump to the label isa_inst_out, where a blocking pull is from the TX FIFO
- Put a single '1' bit in the TX FIFO, this will pull the bit from the TX FIFO and advance the state machine to a blocking wait for SYNC_TIME (which does not happen)
- Do a forced jump to the label isa_out with a sideset of 0, here is the out instruction to output one bit to ISA and waits for CLK02 rising edge (which does not happen). This drives ISA and the output enable
- Software then waits for about 20 usecs (about the time needed for the calculator to pick up the ISA and start to wake up
- Do a forced jump back to the start of the ISAOUT state machine to the blocking pull to wait for the carry bit

Like the DATAIN state machine, this state machine also runs at 12.5 MHz.

7.1.5. [FIIN State Machine](#)

The FIIN state machine is used to capture the state of the FI signal. It is identical to the DATAIN state machine and actually used the same code, but with its own context. The FI input is used for tracing the HP41 bus only and is not available on the TULIP Module. The FI input requires an additional level shifter for which there is no space on the module.

7.1.6. [DATAOUT State Machine](#)

The DATAOUT state machine drives the DATA output signals and the DATA output enable signal. Input is the 56 bit pattern to be output on the DATA line. The state machine only drives the DATA output enable when data is present in the TX FIFO. It is possible to only put one byte or word in the TX FIFO, this word will be shifted out to DATA with the LSB first, and the rest of bits on DATA will be zero. The first bits will then end up in the S&X of the C register. This state machine runs at 12.5 MHz.

7.1.7. [FIOUT State Machine](#)

The FIOUT state machine is almost identical to the DATAOUT state machine to drive the FI output enable signal. Since the FI signal on the HP41 bus is an active low signal, we only drive the output enable of the output driver IC, the input of the driver is tied to GND. The OE signal is active high. The input to the FIOUT state machine is a 56 bit word, with the first 3 bits of a set flag high, the 4th bit is low to allow the bus to settle. The original specs of the HP41 demand pre-charging this signal to high after being driven, but tests have shown that this is not necessary.

7.1.8. [IROUT State Machine](#)

The IROUT state machine drives the IR LED with the correct Redeye protocol and timing. The state machine is designed to send half bits to the IR led. This is a trade-off between available code space in the PIO block and required functionality. To meet the IR timing requirements the state machine needs to run at the double IR carrier frequency of 32768 kHz.

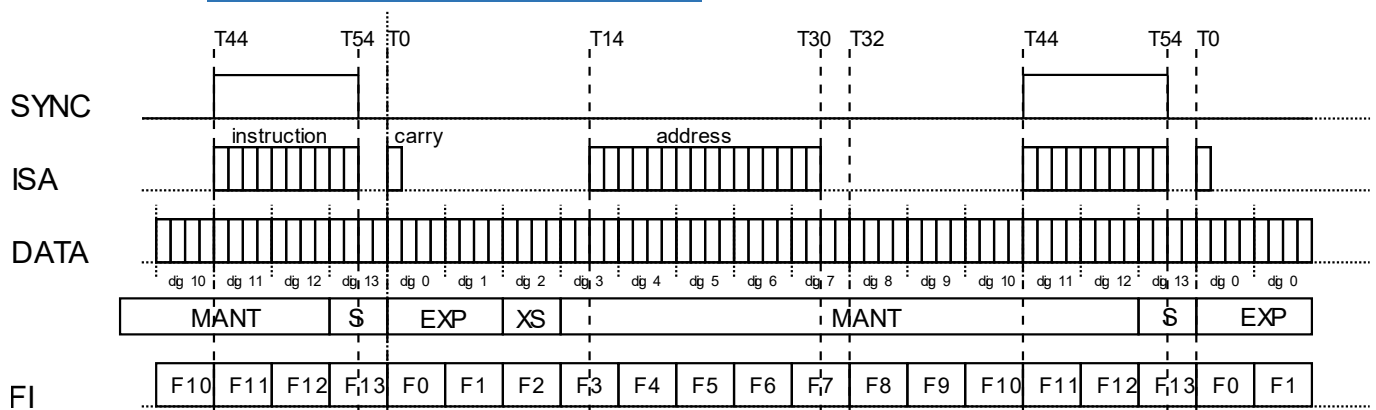
To output a frame the C level software needs to prepare a specific pattern (with checksum) of half bits as follows:

- start frame : 3 hi-lo transitions
- 0-bit : 1 hi-lo, 1 lo-lo
- 1-bit : 1 lo-lo, 1 hi-lo
- the irout state machine sends the following:
 - input 0-bit : send lo-lo frame. put 01 in the output frame (lsb sent first)
 - input 1-bit : send hi-lo frame, put 10 in the output frame (lsb sent first)

Summarizing, for sending an 'A' character, the frame to send to the state machine is the following:

- 0000.0111.1010.0110.0110.0101.0101.0110
- ^^^ start bits
- ^^^ ^^ payload 24 bits

7.2. [Principle of Operation, core1](#)



The RP2040 core1 runs the time critical software that does the actual emulation of HP41 peripherals and interaction with the HP41 bus. It runs in sync with the HP41 bus and is driven by the data it receives from the PIO State Machines. These provide data at specific HP41 bus events. To keep up with the timing of the bus the response must be in time for the next critical event. The core1 main loop runs from SRAM to prevent cache misses when run from FLASH.

The core1 software is started by core0, and core0 runs the main TULIP application program, controlling the Command Line Interface and all communication (USB, SD Card) and non-time critical peripheral operation. The DEBUGOUT is typically driven just before all the Tx events

7.2.1. [Initialization](#)

All state machines are initialized to wait for one of the synchronization signals, or to wait until valid data appears in the TX FIFO. The SYNC state machine waits for the first SYNC appearance. When PWO goes high (calculator switched on and going to RUN mode) most state machines are forced to their waiting state.

The main core1 loop starts with a blocking wait for data to appear from the first SYNC after power on and returns to this waiting state when the calculators is switched off or goes into STANDBY mode (PWO low).

7.2.2. [T54, Start of core1 loop](#)

The after startup and initialization of the system and the PIO's the core1 software is idle and waiting for the first data to arrive from the SYNC state machine, this will always be the ISA INSTRUCTION. The SYNC state

machine is triggered by the PWO interrupt handler to wait for the first SYNC after power on, and when that appears it will capture the ISA bits during SYNC time, and present the data during T54. At this event the main loop in core1 gets the data and can start the HP41 emulation.

At T54 the software receives 12 bits of the instruction (or data) as presented on ISA. The lower bits are the actual instruction bits, the highest bit (bit 11) represents the status of SYNC during the instruction.

The main challenge immediately after T54 is to ensure that the deadline at T0 is met. At T0 the software must have presented the first 32 bits for the DATA line in case any instruction came by that requires driving the DATA line. These are all variations of the READ instruction and peripheral instructions to read registers. In addition, some peripheral instructions require to drive the carry (during T0_TIME) on the bus. These instructions must be handled first and within 2 HP41 CLK cycles.

The FIOUT state machine also requires that any flags to be driven on the FI line are presented to the state machine before T0_TIME.

Before T0 the data must be sent to the DATAOUT state machine, and if any flags are to be driven these must be sent to the FIOUT state machine. Driving the carry during T0 is done by the ISAOUT state machine by writing a single '1' bit to its TX FIFO.

7.2.3. T0, DATA complete

After the critical work is done to be ready for T0, the main loop does a busy wait for data arriving from the DATAIN state machine and as long as PWO is high. These are the remaining 28 high bits of DATA. When the calculator is going into light or deep sleep, PWO will be low and there may not be any more data coming as the clocks will stop and the DATAIN state machine may stall.

Important now is to do a check if PWO is indeed high. If it is low the RX FIFO of the SYNC state machine is emptied, and also the PWO interrupt handler will ensure that all state machines are in a known and stable state. This can also be used to put the RP2040 in a low power mode.

When PWO is still high after T0 the core1 loop can continue to process any instructions that did not have high priority. Before that the information for the HP41 bus tracing is completed by reading the FIIN RX FIFO. That runs in sync with the DATAIN state machine and its data is now also available. The complete trace information is pushed (non-blocking) into the trace queue. If the trace queue was full the trace sample is discarded, and an overflow will be noticed by the tracer software in core0 reading the queue.

Emulation actions that should be done now are the following:

- Pending write that was waiting for the DATA to be completed
- Pending read (completion of read that was handled between T54 and T0) of the higher data bits, these must be provided to the DATAOUT state machine before T32
- RAMSLCT instruction, this is used to write any cached data back to FRAM due to the FRAM speed. We must wait until T32 when data becomes available to know the new selected register
- HP-IL (receive frame handling), Wand (handling of incoming data)
- Bankswitching
- HEPAX instructions (not implemented yet)
- All other supported instructions that do not need any DATA

The software has time for all this until T30, which is the next deadline, although this is not critical. After all activities are done the next step is to get into a blocking read of the SYNC state machine.

7.2.4. [T30, ADDRESS complete](#)

The ISA address is complete at T30. The start of the address is fully handled by the SYNC state machine, all we have to do is wait for data to be ready. It is also not so relevant if the activities before have taken a bit longer, as long as the next activities are completed before the next deadline, which is at T54.

When the ISA address is complete this can be used to get data from any of the active emulated ROM images (and taking bank switching into account). In the case of FRAM this may take a bit of time due to the speed of the SPI interface that controls the FRAM. Since the ISAOUT state machine is normally waiting for a carry to be sent (which must be done with priority between T54 and T0) this state machine must receive a forced jump to the correct offset in the PIO code with a `pio_sm_exec()` function. After that instruction has been issued the data from the ROM image can be pushed in the ISAOUT TX FIFO. The deadline for providing the instruction word is at T44.

7.2.5. [T32, DATA first 32 bits complete](#)

After T30 the main core1 loop waits for the data bits 00..31 from the DATAIN state machine at T32. This is close to T30, but not critical. At this time any operations needing any of the lower data bits can be executed. Examples of these instructions are:

- WROM, write word to QROM
- Peripheral instructions using data from the C register
- RAMSLCT, mark address and prefetch if the selected register is in our FRAM
- PRPHSLCT, mark active peripheral
- All WRIT instructions, cache data bits and mark a pending write for use after T0 (when remaining data bits are available)
- Write to HP-IL registers. When a write is done to the HP-IL output register the frame should be sent to the HP-IL out queue to trigger the actual sending of the data (by core0)

In essence, all needed work is now done. The ISA address is complete at T30. The start of the address is fully handled by the SYNC state machine, all we have to do is wait for data to be ready. It is also not so relevant if the activities before have taken a bit longer, as long as the next activities are completed before the next deadline, which is at T54.

At this point also the HP-IL status register is used to check if any flags need to be driven to set the flag output register that is used to drive the FIOUT state machine. This must be done before T0 to ensure driving the FI line in time.

7.2.6. [PWO interrupt handler](#)

Critical in the operation of TUP4041 is the handling of the PWO signal. An interrupt handler is used on both the rising and falling edge of PWO. This allows the state machines to be brought into a known state and to enable proper synchronization to the HP41 signals.

It should be noted that after the initial SYNC the state machines fully rely on counting the CLK01 edges in the SYNC state machine. There is no possibility to resync if a clock has been missed.

7.3. Core0 firmware

The core0 firmware runs the tasks that are not time critical, and does the initialization of the IO, TinyUSB stack, SD card, buffers, PIO, starting the core1 firmware and other housekeeping. It then enters an endless loop with the following calls:

- PowerMode_task: checks the HP14 powermode and logs this. Puts the TULIP4041 in low power mode if needed (not in the bETA software)
- tud_task: call to the TinyUSB stack to process any data requests pending for USB communication
- runCLI: call to the Command Line Interface to process incoming commands
- trace_task: to process HP41 bus trace information data coming from the core1
- print_task: process any data to be printed (both HP82143 and IR printing) coming from core1
- HPIL_task: process HPIL data request (incoming and outgoing) and control the HP-IL scope output
- TULIP_IF_task: process any requests from the emulation layer for the TULIP ROM (commands, files, etc)
- Any other tasks used for handling traffic to and from peripherals

The tasks above all deal with the communication between TULIP4041 and the USB connection and/or the file system on the SD card. The tasks in core0 should prevent blocking as much as possible. The USB interface and the CLI rely on polling in the main loop to handle all communication, and when another task is blocking the USB communication is also halted.

8. [TULIP4041 interfaces](#)

The TULIP4041 has a number of interfaces to the outside world:

- HP41 module interface, using level shifters to convert the 6V HP41 signals to the 3.3 V RP2040 compatible levels, and vice versa.
- RP2040 debug interface
- RP2040 USB interface
 - In BOOTSEL mode it offers the possibility to upload a new firmware image and to program FLASH memory
 - In normal running mode (TULIP4041 firmware) offers the following virtual serial ports
 - Command Line Interface (CLI)
 - HP41 mcode/bus trace output
 - HP-IL communication
 - HP-IL scope output
 - Printer data (output from TULIP4041 only)
- Micro SD card (working but not used in version 00.01.xx)
- Serial interface (3.3V level only)
- RP2040 GPIO pins
- IR led
- On-board LED
- Auxiliary signals for multi-core communication, debugging en future additional functions

The TULIP4041 interfaces with the HP41 using level shifters. These are needed to convert the 6V HP41 signals to the 3.3 V RP2040 compatible levels, and vice versa. All other signals are strictly 3.3V only.

8.1. [TULIP4041 PICO/RP2040 pinout](#)

The TULIP4041 has a number of interfaces to the outside world. This paragraph handles the I/O as seen from the RP2040 microcontroller, the Pico board (for use with the TULIP DevBoard) and the final products (DevBoard and Module).

RP2040 GPIO	Development board function (Pico board pinout)		Module version (RP2040 pinout)	
GP0	UART TX/I2C0 SDA	probe/debug	UART TX/I2C0 SDA	debug/aux serial port
GP1	UART RX/I2C0 SCL	probe/debug	UART RX/I2C0 SCL	debug/aux serial port
GP2	FI input	FI input	I2CSDA	display/aux I2C
GP3	IR output/PWO out	IR output/PWO out	I2C1 SCL	display/aux I2C
GP4	SPI0 RX	FRAM SO	FRAM SO	FRAM SO
GP5	SPI0 CSn	FRAM CS	FRAM CS	FRAM CS
GP6	SPI0 SCK	FRAM SCK	FRAM SCK	FRAM SCK
GP7	SPI0 TX	FRAM SI	FRAM SI	FRAM SI
GP8	SPI1 RX	uSD card DO	uSD card DO	uSD card DO
GP9	SPI1 CSn	uSD card CS	uSD card CS	uSD card CS
GP10	SPI1 SCK	uSD card SCK	uSD card SCK	uSD card SCK
GP11	SPI1 TX	uSD card SI	uSD card SI	uSD card SI
GP12	CLK01	HP41 CLK01 bus input	CLK01	HP41 CLK01 bus input
GP13	CLK02	HP41 CLK02 bus input	CLK02	HP41 CLK02 bus input
GP14	ISA_in	HP41 ISA bus input	ISA_in	HP41 ISA bus input
GP15	SYNC_in	HP41 SYNC bus input	SYNC_in	HP41 SYNC bus input
GP16	DATA_in	HP41 DATA bus input	DATA_in	HP41 DATA bus input
GP17	PWO_in	HP41 PWO bus input	PWO_in	HP41 PWO bus input
GP18	ISA_out	HP41 ISA bus output	ISA_out	HP41 ISA bus output
GP19	ISA_OE	HP41 ISA output enable	ISA_OE	HP41 ISA output enable
GP20	DATA_out	HP41 DATA bus output	DATA_out	HP41 DATA bus output
GP21	DATA_OE	HP41 DATA output enable	DATA_OE	HP41 DATA output enable
GP22	FI_OE	HP41 FI output enable	FI_OE	HP41 FI output enable
GP23	(NA on Pico pins)	not used	SPARE1	HP41 PWO output (optional)
GP24	(NA on Pico pins)	VBUS present	VBUS present	USB power connected
GP25	(NA on Pico pins)	on-board LED	on-board LED	activity/diagnostics LED
GP26	TO_TIME	PIO synchronization	TO_TIME	PIO synchronization
GP27	SYNC_TIME	PIO synchronization	SYNC_TIME	PIO synchronization
GP28	P_DEBUG	debug output	P_DEBUG	debug output
GP29	(NA on Pico pins)	not used	IR output	IR output

The differences between the DevBoard and Module version are the following:

- The module version does not have an FI input, and can therefore not trace this signal. Tracing of FI on the Module version is only for the FI signal driven by the TULIP
- The DevBoard has a shared output for the IR led and PWO out, and only one of these can be used. This is selectable with a jumper
- On the DevBoard GPIO2 and GPIO3 can be used for I2C when FI input and PWO/IR output are disabled with an open jumper

8.2. [TULIP4041 memory layout](#)

The TULIP4041 has a number of different memory types

- 264 KByte on-chip SRAM, used by the RP2040 for its own data and execution of critical parts of the program. This memory is dual ported for fast access by both cores. When used, the TraceBuffer typically takes up most of the available SRAM.
- 2 MByte FLASH memory (on the Pico board), used for program storage (and program execution) and storage of ROM images. The first 1 MByte is reserved for code storage, the rest is available for ROM images
- 256 KByte FRAM, used for QROM images, Extended/Expanded/User memory emulation and persistent storage of settings
- Micro SD card, storage used for ROM images, user programs (RAW files) and LIF container for HP-IL drive simulation.

All storage is managed by the firmware under control of the User Interface (CLI). The SD card must be formatted by the user in a host system with the FAT file system, and the subdirectories with ROM images and RAW files must be created in that system as well.

8.3. [FLASH memory layout](#)

The first 1 MByte of FLASH memory is used for storing the firmware image. This is handed automatically by the RP2040 development tools and bootloader. This means that a software image (including any data it contains) can not be larger than approx. 1 MByte. Current image size is about 200 KByte. Software is executed directly from the FLASH memory, unless a part is marked as critical, in that case it will run from SRAM. The TULIP4041 core1 critical loop runs from SRAM for example. FLASH code is cached, and a cache miss may lead to unacceptable delay in software execution.

The start address of the software in FLASH memory is 0x10000000 (XIP_BASE), the start address of the ROM images (offset in FLASH) is at 0x80000 (allowing 1 MByte for code). ROM images may be stored in FLASH in ROM, MOD1 or MOD2 format. The contents are accessed directly by the emulation layer for ROM access, no images need to be copied to SRAM when plugging into the HP41 ROM map. To keep track of the ROM images in FLASH (and FRAM as well) rudimentary filesystem is maintained.

The BETA software does not yet support the storage of ROM images in FLASH.

The RP2040 supports FLASH sizes from 2 to 16 MByte, and this limits the number of ROM images that can be in FLASH at any time. The standard Pico board has a total of 2 MByte FLASH.

It must be noted that FLASH memory requires a special sequence to write (and erase before writing), while reading can be at very high speed. Any operations to write to FLASH are time consuming and can only be done when the HP41 emulation core is idle (calculator OFF) and no USB communication is happening. Typically all interrupts are switched off during a FLASH erase cycle. FLASH memory can be erased only in blocks of 4 Kbyte and written to in blocks of 256 bytes.

8.4. [FRAM memory layout](#)

FRAM is used for persistent storage that requires byte based read and write access. This is the case for QROM images (MLDL pages or HEPRAM pages). FRAM also contains the TULIP4041 configuration settings and (emulated) User, Extended and Expanded memory. ROM images are stored in the same format as in FLASH.

The BETA software does not support the use of (Q)ROM images in FRAM.

8.5. [Micro SD card storage](#)

The micro SD card is provided by the user and can have any reasonable size larger than 2 GByte. It should be formatted with the FAT file system and contains the following information:

- Root directory with the LIF container files (for use with a virtual HP-IL drive) and configuration backup files
- MOD directory containing your own repository of .MOD files (MOD1 and MOD2)
- ROM directory containing your own repository of .ROM files
- RAW directory containing your collection of .RAW files (HP41 user programs). These files can be accessed only by the special TULIP ROM

The BETA software supports the uSD card for testing, but not for any other functionality yet.

8.6. [Storage of ROM images](#)

ROM images can be stored in 3 formats: MOD1, MOD2 and ROM. Most common and easy to use is the MOD1 format. MOD2 is not very common, but can be used without any special action just like MOD1 files. Both have the .MOD file extension. The only difference between the two is that a MOD1 ROM image is somewhat compressed and contains only the 10-bit words, while the MOD2 image contains the 16-bit words of the image, for example for use with the HP41CL. ROM files require a bit more care when using. The full 16-bit word is NOT used in the TULIP4041, only the 10-bit word is used.

The advantage of a MOD file is that it can contain multiple ROM images and has meta information such as the preferred page to be plugged in and many other attributes. The TULIP4041 uses this information, and especially the information about the hardware, to enable the hardware features for an HP-IL module for example. When plugging a .ROM file the user must manually choose the page and enable any hardware specific features.

The place for offline storage for ROM images is on the SD card. There are 2 directories, one for MOD files, and one for ROM files. In order to be used by the TULIP4041 with your HP41 a ROM image must be in either FLASH memory or in FRAM. With the user interface you can copy your desired ROM images to FLASH or FRAM. Only images in FLASH or FRAM can be 'plugged' in a (virtual) slot of your HP41. ROM images in FLASH are organized in a basic file system. This file system and its support routines is currently in development.

8.7. [TULIP4041 power usage](#)

The HP41 system is generally a very low power system. The RP2040 however is a very performant and somewhat power hungry processor. Care should be taken to properly manage power consumption in combination with the HP41.

When running the TULIP4041 consumes up to 30 mA, and the processor is running constantly when the HP41 is running. When not powered by USB the TULIP4041 enters low power mode after about 10 seconds when the HP41 goes into STANDBY (also referred to as LIGHT SLEEP) or OFF (DEEP SLEEP) mode. The power consumption is then still around 2.7 – 3 mA, and this will drain the HP41 battery quickly. The TULIP4041 is powered by the HP41 at all times when not powered by USB. Power is sourced by the HP41 battery directly and not by the HP41 regulator.

When powered by USB the calculator is still always powered by its own battery.

Advice 1: Connect the TULIP4041 to a USB power source whenever possible and practical

Advice 2: Remove the TULIP4041 from your calculator when not in use and when it is not connected to a USB power source.

When powering down the TULIP4041 will save all relevant settings and memory contents to non-volatile storage. These contents are then safe when the TULIP4041 is removed from the calculator.

When powered by a USB power source the TULIP4041 will also enter low power mode when the calculator goes into LIGHT or DEEP SLEEP, or when the user issues a command to power down the processor. In any case, power down means that the RP2040 processor goes into dormant mode and consumes 2.5 – 3 mA. The processor will NOT power down when one of the virtual serial ports is active or during file operations or FLASH/FRAM programming. When a USB power bank is connected, no serial ports are active and the power bank will power the TULIP4041 in low power mode. Please be aware that many USB power banks require a minimum current to prevent them from being shut down.

The BETA software does not support the low power modes. Remove the TULIP from the calculator when not in use.

9. [HP41 device emulation on the TULIP4041](#)

The main function of the TULIP4041 is emulating devices plugged on the HP41 bus. There may be a debate about the term emulation versus simulation. My take on the matter is that the HP41 sees a real device on its bus and has no idea if it is a genuine device or something that behaves like it. I think the term emulation is correct here.

The TULIP device may be plugged in any convenient port, the port address signals B3 and B4 are not connected.

TULIP4041 interacts with the HP41 system in various ways, and this chapter gives an overview of the ways of interaction. Very basically, the device captures all events on the HP41 system bus and responds to address and instructions. The main functions are:

1. Bus tracing: passive catching of all bus traffic and presenting in an understandable way
2. ROM emulation: watching the address on the bus, and responding with a data word whenever the address is in the range of the emulated ROM
3. QROM/MLDL emulation: catching the WROM (0x040) instruction and the information on the DATA line to write a word to QROM if the address matches the correct address range
4. Peripheral emulation: catching the SELP n instruction for the emulated device and executing the special device instructions (mainly for the HP82143 printer and HP-IL)
5. Peripheral emulation: catching the PRPHSLCT instruction for the emulated device and use the READ and WRIT instructions to transfer data
6. User memory emulation: catching the RAMSCLT and READ/WRIT instructions and take appropriate action to emulate memory modules and Extended or Expanded Memory
7. Special instruction emulation: monitor special instructions like bank switching, HEPAX special instructions, HP41CL instructions
8. HP41 carry control: drive the carry flag during T0 when requested
9. HP41 FI control: drive the FI line at the relevant bit time to indicate an emulated device requests servicing
10. HP41 power control: drive the ISA line to wake up the calculator
11. HP41 reset control: drive the PWO line to interrupt and reset the calculator

9.1. [ROM / QROM emulation](#)

The ROM emulation is relatively simple. The TULIP maintains a table with the mapping of virtual ROMs that are plugged and compares the received address on ISA with this table and presents the result (if any) on ISA during the instruction time. Banks switching is not supported in the first BETA version but will be in a future version. The ROM mapping is kept in FRAM and will remain valid after the next power cycle or reset.

Please be aware of possible port or XROM conflicts since the TULIP firmware does not know of any physical modules plugged in the calculator, and that also applies to the calculator type (HP41C, CV or CX). Also be careful when using an HP41CL with possible virtual ROMs plugged.

ROM images are placed in both FLASH or FRAM, and are embedded in the firmware in the BETA version (HP-IL, IL Printer and the HP82143A printer). ROM images can be programmed (imported) in FLASH or FRAM from the micro SD card using the Command Line Interface. In the first BETA versions only the ROM format is supported, support for MOD images will be added in a later version.

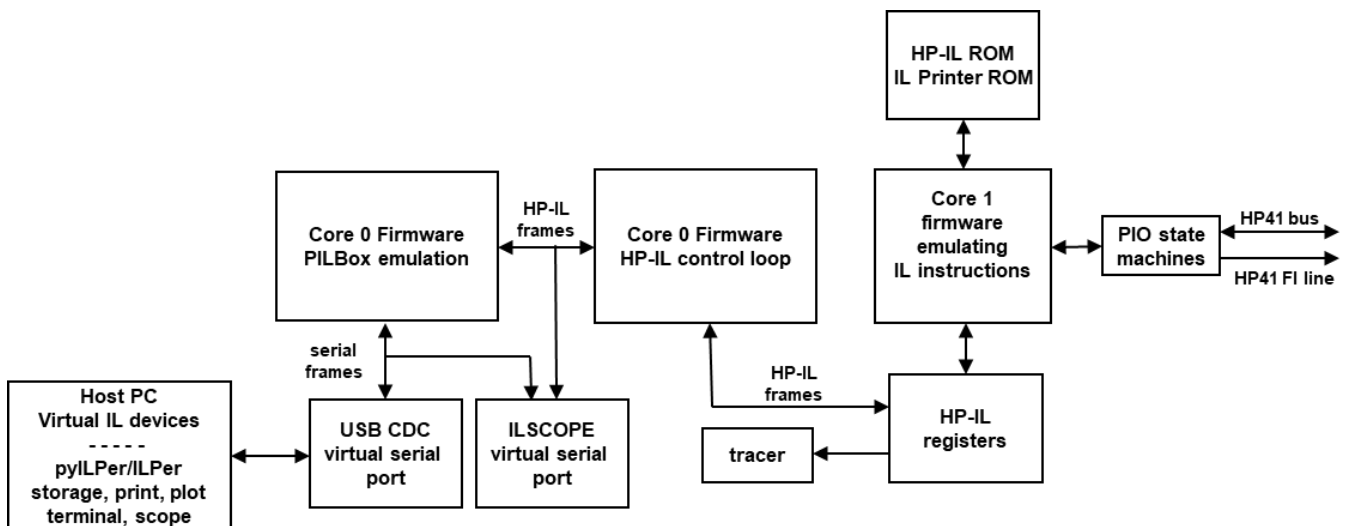
The TULIP can emulate QROM (or MLDL RAM) as part of the ROM mapping. QROM must always be mapped in FRAM, because only FRAM is writeable with the WROM instruction. FRAM storage is persistent and will withstand a power cycle or reset.

Any ROMs needing support of specific instructions (HEPAX, HP-IL, printer etc) must have the specific instruction support enabled. In the BETA version this is automatic, and this will be automatic as well when MOD files are supported.

9.2. [HP-IL emulation](#)

The TULIP HP-IL emulates a virtual IL loop. This means that it connects with a host computer via a USB virtual serial port to virtual HP-IL devices running on the computer. There are provisions to expand the possibilities in future firmware versions. TULIP emulates the registers of the 82160A HP-IL module and the instructions to communicate with these registers and in addition uses the FI signals towards the HP41 system bus. The emulation is based on the V41 sources by Christoph Giesselink and EMU41 by Jean-Francois Garnier.

A (virtual) serial link is used for the connection with the host computer, and the translation of HP-IL frames to serial is that of the PIL Box (by Jean Francois Garnier), which is emulated by the TULIP4041. The host software for virtual HP-IL will see a PIL Box connected.



When no Host PC or virtual serial port is connected the HP-IL virtual loop is always closed internally. For more advanced functionality other ROMs can be plugged (not in the BETA version, unless real modules or an additional device like MLDL or Clonix/NovRAM is used). The Plotter ROM is tested for example.

In the BETA firmware version there are a few limitations:

- It is not yet possible to put the TULIP system in device mode (with the IL Development ROM for example)
- RFC/CMD frame handling as in the original PILBox is not implemented. As a result multiple RFC frames may be sent to the Virtual IL devices.
- AUTOIDY mode is not implemented

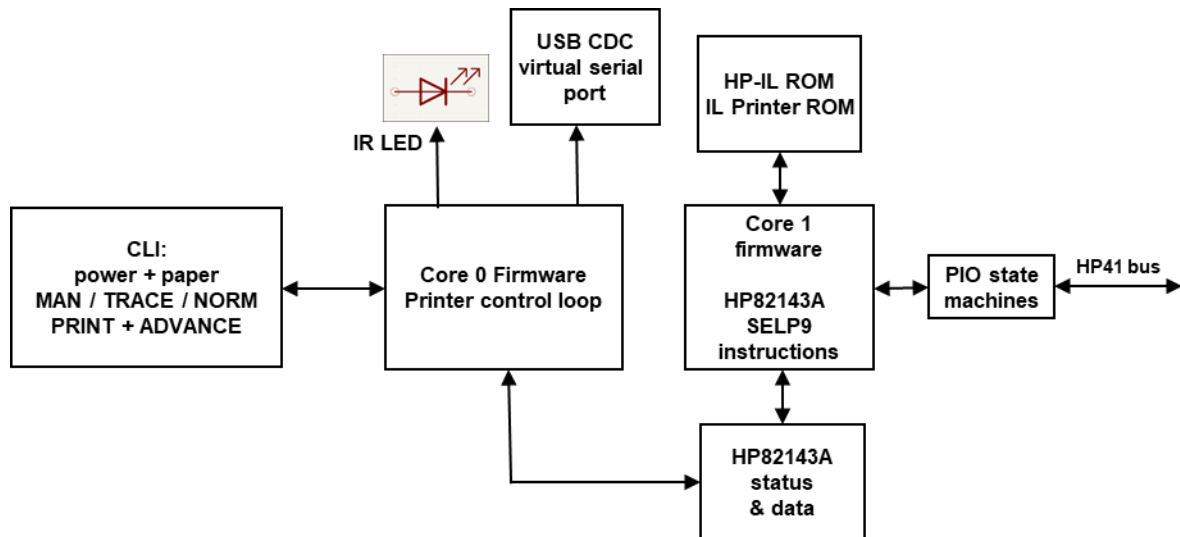
For debug and study purposes the HP-IL registers are sent every cycle to the tracer queue and can be visualized in the tracer (using the tracer virtual serial port and a terminal emulator). With the CLI this can be enabled or disabled. The tracer supports the HP-IL instructions in the disassembler.

HP-IL frames and PILBox serial traffic are sent to the ILSCOPE virtual serial port for analyzing or debugging your HP-IL applications. This can be controlled by the CLI.

The HP-IL printer can be disabled (like the little switch on the HP-IL module) by simply not plugging it or unplugging it. The IL Printer ROM will be completely disabled and not parked in Page 4, so Page 4 is available for other fun stuff. The HP82143 Printer ROM can be plugged instead and can co-exist with the HP-IL module.

9.3. [HP82143A printer emulation](#)

The HP82134A printer emulation is based on earlier experiences with the printer emulation for the HP41CL and the USB Printer module by Diego Diaz. Main source of knowledge is the document “HP82134A Printer Study” by Doug Wilder.



The printer emulation is based on the implementation of the printer status register and the SELP 9 instructions. The HP82143A printer is (as far as I know) the only device that uses the HP41 capability to transfer the carry status by driving ISA at T0 when requested (with a SELP 9 instruction), and that feature is implemented in the ISA output state machine.

The CLI is used to control the keys and switches that are normally on the printer itself. Be aware that (like in real life) the printer is default without paper, so before use paper must be loaded using the CLI.

Printer output is sent to one of the virtual serial ports for use by the HP82240 simulator (from Christoph Giesselink). This simulator must be put in the proper mode for the HP82143A printer. Graphics printing is supported. The printer output is also sent (if enabled with a jumper) to the infrared LED. The bytes printed to the IR port are *not* compatible with the real HP82240 IR printer and are intended to be used with an IR receiver (serial or USB) connected to a host computer and the HP82240 simulator in HP82143A mode.

There are a few implementation limitations:

- The internal printbuffer (the queue between core1 and core0 firmware) is 100 bytes. In addition there is a large buffer (about 1 KByte) for the USB virtual serial port. Normally the printing to the USB serial port is much faster than the HP41 can keep up with, in theory this could lead to a PRINTER BUSY message if the core0 software cannot empty the queue fast enough. This has been tested by throttling the output bytes, currently there is no throttling and bytes are sent as fast as they come in
- When no virtual serial port is connected the printer emulation will work, but the printed data is simply discarded internally
- When printing to the infrared LED there is currently no throttling implemented

- When printing the IR LED is always used, it cannot (yet) be disabled in the current firmware. **When using the printer emulator jumper 3 must be open!** JP3 enables PWO output and will reset the calculator!
- When using IR printing, jumper 1 must be closed to enable the IR led

9.4. [Extended Memory emulation](#)

The TULIP4041 can emulate User Memory. This is the memory used for the HP41 status registers, program memory and Extended Memory. In the BETA version only emulation of Extended Memory is possible. This is valid only for the Extended Memory modules that can be plugged. The TULIP currently does not support the Extended Functions module or its built-in memory. Using the CLI the user may plug and unplug 0, 1 or 2 Extended Memory modules. When 0 is used all plugged modules are unplugged, with a value 1 only the first Extended Memory module is plugged (and module 2 unplugged if it was plugged).

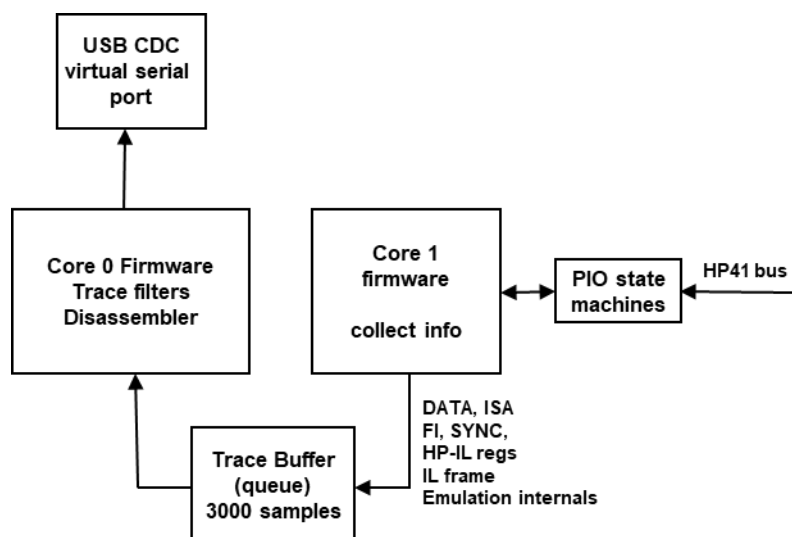
- 0 modules: no Extended Memory
- 1 module: 0x201..0x2EF Extended Memory Module 1
- 2 modules: 0x201..0x2EF and 0x301..0x3EF Extended Memory Module 1 + 2

The contents of the Extended Memory modules are saved in FRAM and will survive a power cycle. The memory contents are not erased when a module is unplugged.

Reading a full HP41 register (8 bytes) from FRAM is relatively slow and not fast enough to support a READ instruction. Therefore a single HP41 register (if it exists) is cached from FRAM in the RP2040 RAM when a RAMSLCT (DADD=C) occurs. This register is then ready for actual reading when a READDATA (C=DATA) instruction happens. This works fine for the existing Extended Functions ROM, but none of the READ n (C=REGN) are supported. For practical purposes also the WRIT n (REGN=C) instructions are currently not supported, only WRITDATA (DATA=C, 0x2F0) is implemented.

10. [HP41 Bus tracing](#)

HP41 bus tracing is extremely useful when testing and debugging mcode programs, and to discover how the HP41 software or existing peripherals work. It can also be used to mimic some HP41 peripherals, such as using the data to drive an additional display to mirror the existing HP41 display (not yet supported in the TULIP).



The Bus Tracing unit in the TULIP catches the following information during each HP41 cycle in the critical core1 loop:

- Instruction counter (reset after each PWO event)
- ISA address (16 bits)
- ISA instruction (10 bits)
- SYNC state during the ISA instruction (1 bit)
- DATA (56 bits)
- FI line (56 bits, at each bit time) (only on the TULIP DevBoard). On the TULIP Module FI tracing is limited to the flags that are driven by the TULIP. Flags driven by physical devices on the HP41 bus (like the TIME module in an HP41CX) are not visible to the TULIP module
- Carry status (ISA state at T0) when output by the TULIP
- RAMSLCT selected register (only captured when a RAMSCLT instruction was executed)
- (optional) HP-IL registers (9* 8 bit register) and HP-IL frame in and frame out

Briefly after T0 the information above is sent to the TraceBuffer, but only under the following conditions:

- Bus tracing is enabled
- The TraceBuffer is not full. If the buffer was full, the sample is discarded. This is an overflow condition which will be recognized by the core0 firmware because the sample counters are not consecutive

The TraceBuffer is a queue structure, the core1 part will never do a blocking wait and checks if the queue is not full before writing a sample, otherwise the sample will be discarded. The size of the TraceBuffer is 3000 samples. This is currently a fixed number, a future version of the software allows more flexible sizing of the buffer.

The TraceBuffer is read by the core0 non-critical loop and before reading will check if there is any data in the buffer to prevent that it blocks the application.

A single trace line consists of the data captured during a single T0-T0 cycle. Remember that this cycle presents the DATA (usually the C-register), the address (in ISA) and the instruction (also on ISA) fetched at this address. The instruction is then executed in the next cycle, but the C-register is not updated yet. The effect of the instruction on the C-register is shown in the cycle after that on the DATA line.

20	0208	1	046	0.0000000000.0.00	...	R2FD	C0	FI-----	C=0 S&X
21	0209	1	3F0	0.0000000000.0.00	...	R2FD	C0	FI-----	PRPHSLCT
22	020A	1	270	0.0000000000.0.00	3F0	R2FD	C0	FI-----	RAMSLCT
23	020B	1	130	0.0000000000.0.00	270	R000	C0	FI-----	LDI
24	020C	0	169	0.0000000000.0.00	...	R000	C0	FI-----	169
25	020D	1	106	0.0000000000.0.00	...	R000	C0	FI-----	A=C S&X
26	020E	1	378	0.0000000000.1.69	...	R000	C0	FI-----	READ 13 (c)
27	020F	1	17C	1.A70016919C.1.9A	...	R000	C0	FI-----	RCR 6

In the example above the first LDI 169 instruction is fetched in sample 23 and 24 (note that SYNC is low in cycle 24, 0 in the 3rd column, indicating the fetch of a literal). While the CPU executes this during sample 25, this is not shown on DATA yet. But the next instruction is already fetched. Sample 26 shows the result on DATA from the LDI 169. This is confusing, but please understand that the cycles are shown as they appear on the bus for T0 to the next T0.

When showing all sampled data by the tracer the stream to the serial port will generally limit the performance, and after 5000 or 6000 samples (depending on the host showing the trace) the TraceBuffer will overflow. This will never block the operation of the TULIP4041, you will simply miss samples (indicated by an O for overflow in the trace display). With clever filtering (for example to filter out some of the standard loops in the system ROM for keyboard checking and debounce) the performance will be much better, or even when you filter out the complete

mainframe ROM (0x0000-0x5FFF) for example, depending on your ROM configuration and what information you are looking for. This allows you to do near real-time tracing of your HP41 system on mcode level.

Using the Tracer is a significant load on the TULIP4041 firmware in core0, due to the high data density especially to the USB serial port. In some cases characters or part of a traceline can be skipped. This can best be resolved by being smart about the filtering, while this also prevents overflows. This has been seen specifically on Windows systems, Linux systems seem to behave better.

Due to the behavior of the Tracer during PWO events the first and last traces may show incorrect information.

To be able to save a trace log use the features of your terminal emulator. First thing to do is set the terminal buffer depth. In Teraterm this is set with Setup->Window->Scroll Buffer. When a trace is finished it is then very easy to select the samples of interest and copy/paste into a text editor. Alternatively you can activate a logging function if available.

Using the CLI the Tracer functionality can be managed and trace filters and triggers can be set.

The output of the Tracer is streamed to one of the USB Serial Ports, connect to it with you favorite terminal emulator. When the virtual serial port is not connected all trace samples will be discarded. The output has the following columns (subject to change):

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
O	0	0193	1	201	0.000002C048.0.FD	...	R010	C0	FI01234-----	...
	1	0001	0	006	0.000052C048.0.FD	...	R010	C0	FI-----	?NC GO 0180
	2	0002	1	2B5	0.000052C048.0.FD	...	R010	C0	FI-----	...
	3	0003	0	006	0.000052C048.0.FD	...	R010	C0	FI-----	?NC GO 01AD
	4	01AD	1	001	0.000052C048.0.FD	...	R010	C0	FI-----	...
	5	01AE	0	100	0.000052C048.0.FD	...	R010	C0	FI-----	?NC XQ 4000
	6	4000	1	000	0.000052C048.0.FD	...	R010	C0	FI-----	NOP
	7	01AF	1	2E0	0.000052C048.0.FD	...	R010	C0	FI-----	DSPOFF

[11]	[12]	[13]
?FI 8 ?FRAV	IL> 023 DAB	Reg E0 A0* 40 40 01 03 01 00 00

- [1] Tracer status, one character with the following meaning
 - [space] normal traceline
 - = tracelines before this line are skipped due to a filter
 - O an overflow occurred in the TraceBuffer
 - T Trigger occurred on this address (not in the BETA software)
- [2] Traceline sample counter, counts all traces to identify how many lines are skipped. Counter is reset upon a PWO event. The counter is generated by the core1 emulation layer, and will be non-consecutive in case of a filter or overflow, and can be used as an indication of the number of samples lost or skipped.
- [3] Address (+ active bank in future version)
- [4] SYNC status during ISA Instruction, 1 when this is an instruction fetch, 0 for data fetch or under peripheral control
- [5] Data or instruction (instruction when SYNC is 1, otherwise it is a data fetch, peripheral instruction or second word of an instruction)
- [6] Contents of DATA line, formatted like a register with sign, mantissa, exponent sign and exponent. Most of the time the C register is output to DATA, except during a peripheral or memory read
- [7] 16 bit indicator of the instruction (including the SYNC status as read from the state machine), appears only when the firmware has a potential instruction match, is zero otherwise. Used for firmware debugging
- [8] Current valid RAMSLCT memory address

- [9] Carry output during T0 (C0 when not set, C1 when set), only used by the HP82143 printer emulation
- [10] FI line status, 14 flag positions, will show hex flag number in the correct position. The TULIP module version will shown only the flags that are driven by the TULIP, it has no access to flags from other devices. The Development Board actually traces the FI line and shows all flags from other peripherals in the calculator (TIME for example in an HP41CX). The very first traceline may show incorrect FI information
- [11] Disassembled instruction. Currently only JDA type mnemonics supported, peripheral instructions are not decoded except HP-IL instructions
- [12] HP-IL frame, > indicates output, < is input, only shown when enabled and when the HP-IL module is (virtually) plugged. The frame is decoded
- [13] HP-IL registers (when enabled) show all registers of the HP-IL module, only when there is a change. A changed register is indicated with *

Tracing of HP-IL frames and registers can be enabled or disabled in the CLI and is only available when the HP-IL module is plugged. The tracer shows 9 registers, R1R is only the read part of Register 1, R1W is the Write part of R1 since HP-IL register 1 has different functions for read and write (as implemented in EMU41 and V41).

[11]	[12]	[13 R1R R2 R3 R4 R5 R6 R7 R8 R1W]	
?FI 8 ?FRAV	IL> 023 DAB Reg E0 A0* 40 40 01 03 01 00 00		

The disassembler is a very simple lookup table and therefore very fast, but with limitations. A data fetch (SYNC low during ISA instruction time) is shown as hexadecimal literals. Only 2-word XG/GO's are not handled by the lookup table but constructed in core0, and the first word of such an instruction is shown with 3 dots. 3-word relative GOTO/GOSUB are not decoded. Mainframe labels are also not decoded (this may be implemented in a next version). Peripheral instructions for HP-IL are disassembled.

Possible future features of the HP41 bus tracer are:

- Advanced pass or block filter by user provided address range
- Trigger on the Nth occurrence of a trigger
- Trigger on a data or instruction fetch (instead of an address)
- Trigger inside a specified Bank
- Add labels to the disassembler
- Disassembly of peripheral instructions
- Support for other mnemonic types
- Dynamic sizing of the TraceBuffer (this is limited by available memory)
- Customizable columns in the trace presentation
- Decoding 3-word relative GOTO/GOSUB
- Set a trigger to enable a trigger pulse to an external output to allow tracing with an external logic analyzer or oscilloscope

The Tracer has the feature to pass or block samples, and to set or clear a trigger condition. It is not possible yet to apply the filters or triggers to a specific bank.

- Pass: simply pass all samples. Default is to pass all samples. When a range is active to pass samples, this effectively blocks all other addresses.
- Block: samples that match a specified address or address range will be blocked, and not shown in the trace listing

- Trigger: samples that match a trigger address are marked in the listing, and traces are listed starting at this address. An option can filter out specific ranges (apply blocked addresses), and an option can block all samples until the Trigger condition is met. There is currently no pre-trigger buffer (yet)
- Trigger End: after a Trigger, the listing of samples stops when there is a Trigger Address match. As an option, sampling can stop after a given number of samples

The BETA software only supports a limited number of pre-defined filters and Page ranges.

A number of system loops to block is pre-programmed and can be enabled using the CLI:

0x0098 - 0x00A1	RSTKB and RST05
0x0177 - 0x0178	delay for debounce
0x089C - 0x089D	BLINK01
0x0E9A - 0x0E9E	NLT10 wait for key to NULL
0x0EC9 - 0x0ECE	NULTST NULL timer

11. [Using the TULIP4041](#)

The primary interface for the TULIP4041 is the USB interface. This offers a number of virtual serial ports (VCP) to the host system and a USB storage medium. On a Windows system these will be visible as COM ports. The next section assumes a Windows host computer. Due to the handling of these ports on a host system it can sometimes be tricky to identify a port, and this can change as well. The assignment of the COM port numbers appears to be somewhat arbitrary. On a Windows system, use the Device Manager -> Communication Ports to get a list of which COM ports are used. The storage medium is the micro SD card and a drive letter will be assigned by the host computer, even when no micro SD card is plugged on the TULIP.

When the TULIP4041 is connected (via USB) to a host computer the first action is typically to connect to the CLI with a terminal program.

Normally the TULIP4041 is plugged in an HP41 calculator for use. It is very well possible to connect a unit to USB without being plugged in an HP41.

The virtual devices will be visible only when valid firmware is loaded on the TULIP4041. Please refer to the section in one of the next paragraphs on instructions to load the TULIP firmware.

11.1. [Virtual serial ports](#)

The primary interface for the TULIP4041 is the USB interface. This offers a number of virtual serial ports (VCP) to the host system. On a Windows system these will be visible as COM ports. This section assumes a Windows host computer. The COM port numbers used here are indicative. Details of each port use is described in detail in later paragraphs.

All COM ports use 8 bits, 1 stop bit, no parity, and should be set to the highest possible baud rate, generally the highest baud rate will be used automatically.

- **COM(1)** : used for the Command Line Interface (CLI). Use a terminal program (for Windows I use Teraterm, but most of these tools will work just fine). This is the main tool to manage ROM images, plug/unplug modules and manage all aspects of the TULIP4041.
With the TULIP ROM most CLI commands can be issued as well, for the initial setup the CLI is recommended.
- **COM(2)** : used for HP41 mcode/bus tracer output. Another instance of a terminal program should be connected to this COM(2) port to present the results. The TULIP4041 constantly monitors the HP41 system bus (where the modules are physically plugged) and provides an almost realtime stream of information with details about bus activity. CLI commands are used to control if and how the data is presented and filtered. Default is no tracing active at all. Tracing can have impact on the performance of the TULIP4041. Tracing uses memory based buffers with limited capacity and filtering should be used to prevent overflows of these buffers. Overflows are visualized in the trace results and do not impact the operation of the TULIP4041.
- **COM(3)** : used for printer output from the HP82143A printer ROM (PRINTER 1E). When this ROM is plugged the output is sent to this port and the HP82240 simulator (for Windows) can be used for presenting the results. The HP82240 simulator should be set to HP82143A mode for correct results, including graphics. With the CLI the printer characteristics can be changed, such as printing to a terminal window. Other settings include TRACE/MAN/NORM mode. This can be done only with the CLI (or functions in the TULIP ROM). In addition it is possible to direct the HP82143A output to the Infrared LED.

- **COM(4)** : used for HP-IL communication. The TULIP4041 can emulate the HP-IL ROM (with printer) and virtual HP-IL devices on a host computer (ILPer or PyILPer) can be connected to COM(4) to offer a large number of virtual devices. Internally the TULIP4041 emulates a PILBox, the host computer will see a PILBox connected. When a host computer is not connected the firmware will automatically simulate a closed HP-IL loop. Using the CLI a virtual drive can be enabled in a container file on the SD card.
- **COM(5)** : used for HP-IL frame tracing, much like an HP-IL scope. A terminal program should be connected to this port to present the results. In addition to HP-IL frames the serial communication to and from the emulated PILBox is shown.
- **COM(6)** : used for HP41 simulated WAND input (in development).

Another serial port is available on GPIO 0 and 1, UART Tx and UART Rx. These can be used to connect to a Pico Probe (or a USB to UART interface, connect only 3.3V equipment to the GPIO's!) and offer a very low level CLI that was used for development. In some cases low-level error messages are shown here. Use only when really needed in case of support. Do NOT use the offered FLASH programming functions!

11.2. [Disk drive: micro SD card](#)

The micro SD card will be assigned a drive number by the host computer, even when no micro SD card is plugged in the TULIP4041. When a micro SD card is plugged it will show in the host computer, and the SD card is accessible for the host after enabling this in the CLI.

11.3. [BOOTSEL mode and firmware upgrade](#)

The RP2040 processor uses BOOTSEL mode for a number of internal functions such as firmware update, FLASH programming and other settings. Also the update of the TULIP4041 firmware requires entering BOOTSEL mode. In this mode the processor enables a special USB interface (for FLASH programming for example). Please refer to the RP2040 documentation and tools for a complete description.

In BOOTSEL mode the RP2040 presents a USB disk drive to the connected host system. To upgrade or change the firmware, simply copy a valid firmware file with .UF2 extension to this drive. When the copy operation is complete the RP2040 processor will automatically reboot into the new firmware.

To enter BOOTSEL mode use one of the following methods:

- Use the CLI to issue the *system BOOTSEL* command, this is the preferred method. This will work only if there was already a TULIP firmware running
- On the TULIP-DevBoard disconnect the USB cable, push the button on the Pico board, and while pushing the button connect the USB cable again and then release the button. The RP2040 should now be in BOOTSEL mode. This is also the preferred method for a new Pico board or a Pico board that had other software loaded
- On the TULIP-Module create a short between the USB-BOOT and GND while disconnecting and reconnecting USB (this is the same as pushing the button in the Pico board).
- With a development system and Pico Probe connected through the debug interface new firmware can be downloaded using the development tool (VS Code or OpenOCD)

IMPORTANT: due to the use of multiple virtual serial ports it is not possible to enter BOOTSEL mode under control of the PICOTOOL utility on the host computer when the TULIP4041 firmware is running. Once in BOOTSEL mode the various functions of PICOTOOL can be used.

11.4. [Reset of the TULIP4041](#)

A reset of the TULIP4041 can be achieved by removing all power and applying power again. Alternatively, connect the RUN pin on the Pico board to GND for a reset. The RUN pin is also exposed on the TULIP-Module, and shorting this pad to GND will also reset the unit.

The CLI can be used to reset the TULIP4041 using the *system REBOOT* command.

11.5. [TULIP4041 power](#)

Please re-read section 8.7 : TULIP4041 power usage on the power characteristics of the TULIP4041.

11.6. [Micro SD card](#)

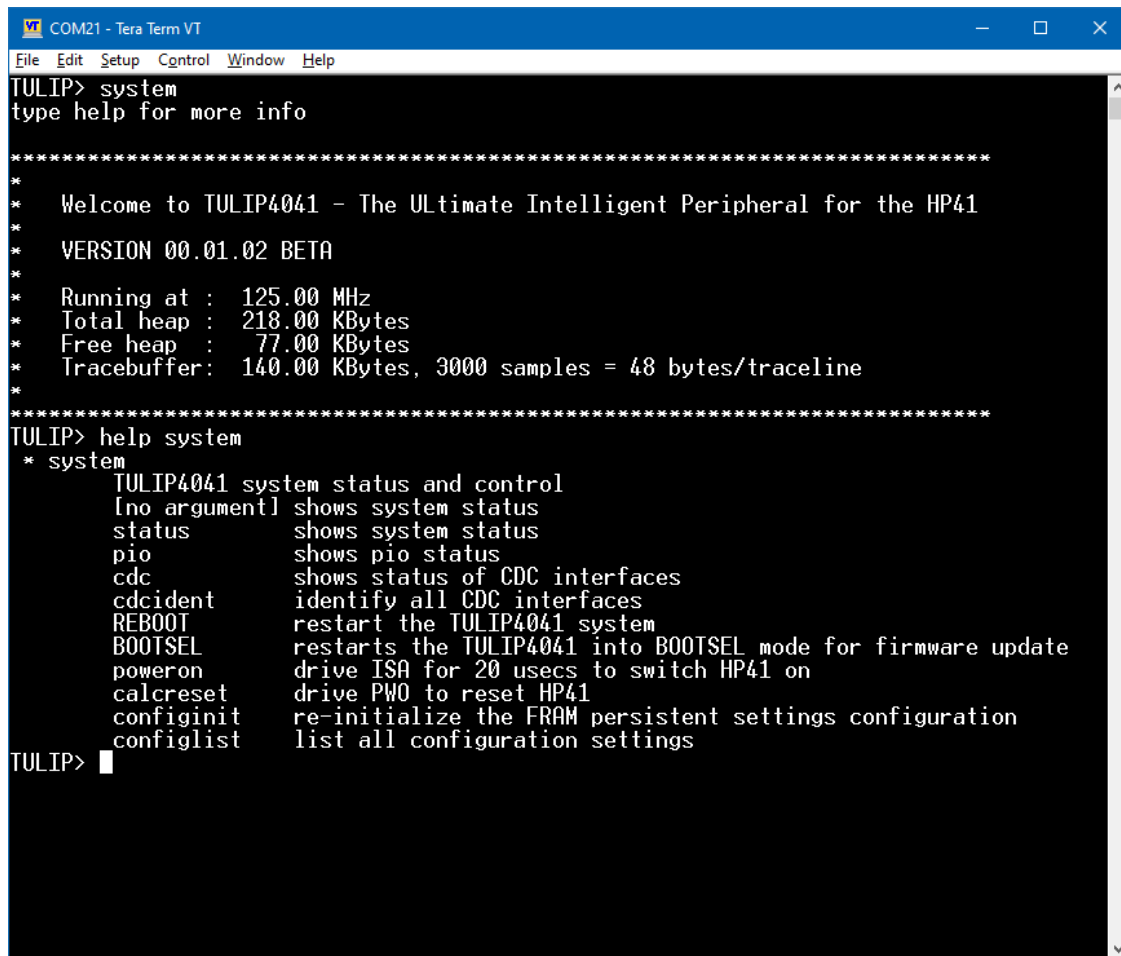
The TULIP4041 has slot for a micro SD card. This is used for central off-line storage of ROM images and it is necessary to use a card to program ROM images in FLASH and/or FRAM to be able to use the TULIP4041. Please understand the following:

- Best plug or unplug a micro SD card only when the TULIP4041 is not powered. The unit should NOT be connected to USB or the HP41 calculator while plugging or unplugging the card
- Format the card on a host computer according to the FAT file system. The TULIP4041 firmware uses the FatFS software to manage the files on the card, and only the FAT file system is supported. This may limit the amount of useable disk space.
- After formatting create a MOD and ROM subdirectory in the root directory. A RAW subdirectory or a LIF container is optional.
- Any MOD images that you plan to use should be put in the MOD subdirectory
- Any ROM images that you plan to use should be put in the ROM subdirectory
- Put the micro SD card in the slot on the TULIP device and power the device
- Use the *sdcard mount* in the CLI to activate the card
- Use the *dir* command, followed by the directory to list the contents of the card
- The micro SD card is connected using a single channel SPI connection which is not very fast
- The micro SD card is exposed as a removable USB drive on your host computer. Use the command *sdcard connect* to make the card visible, and *sdcard eject* to remove the card from the host PC

The micro SD card is not used in the first BETA version, but will be in subsequent versions.

12. [TULIP4041 Command Line interface reference](#)

The TULIP4041 Command Line Interface (CLI) is accessible using the first (usually lowest numbered) virtual serial port. Upon a reboot or reconnect of the unit the CLI will show a welcome message with system information and a prompt. Commands can be issued at the prompt. The CLI buffers the commands given which can be recalled and edited. This paragraph gives an overview of the available commands. Details on plugging and unplugging ROM images and other features relevant to HP41 device emulation and tracing are given in the next paragraphs. Many commands have parameters, these are explained with the command. Commands are case sensitive, most commands can be entered in lower case, some critical commands or parameters have to be given in uppercase.



```

COM21 - Tera Term VT
File Edit Setup Control Window Help
TULIP> system
type help for more info

*****
*
* Welcome to TULIP4041 - The ULtimate Intelligent Peripheral for the HP41
*
* VERSION 00.01.02 BETA
*
* Running at : 125.00 MHz
* Total heap : 218.00 KBytes
* Free heap : 77.00 KBytes
* Tracebuffer: 140.00 KBytes, 3000 samples = 48 bytes/traceline
*
*****
TULIP> help system
* system
  TULIP4041 system status and control
  [no argument] shows system status
  status       shows system status
  pio          shows pio status
  cdc          shows status of CDC interfaces
  cdcident     identify all CDC interfaces
  REBOOT       restart the TULIP4041 system
  BOOTSEL      restarts the TULIP4041 into BOOTSEL mode for firmware update
  poweron      drive ISA for 20 usecs to switch HP41 on
  calcreset    drive PWO to reset HP41
  configinit   re-initialize the FRAM persistent settings configuration
  configlist   list all configuration settings
TULIP>
  
```

The description below applies to TULIP4041 firmware version 0.01.02, the first public beta. Functions indicated with a * are planned to be implemented in a later version. It may be possible to type the command, but no action will be taken.

Parameters in <> are optional, parameters in (square brackets) must be given.

help <command>

Shows all available commands with a short explanation. Shows the help for a specific command when a parameter is typed, for example *help system*

system <argument>**<no argument>**

Shows the welcome message with the system status, including memory usage

status

Shows the welcome message (same as the command system without a parameter).

pio

Shows the results of the PIO state machine initialization

cdc

Shows the status of the virtual serial ports connected to the USB port

cdcident

Sends a message to each connected virtual serial port to facilitate identification of the connected serial ports. Use only when a terminal emulator is connected to the ports. When a virtual IL device is connected this command may confuse the virtual device.

REBOOT

Resets the TULIP4041 unit. Note that a reboot can take a few seconds before the TULIP4041 is able to respond to the HP41 and before the CLI can be accessed. All virtual serial ports are disconnected, automatic reconnect depends on the host computer and the terminal emulator used. Only works when the HP41 is not running (HP41 PWO line is low) or no calculator is connected

BOOTSEL

Stops the TULIP4041 firmware and enters RP2040 BOOTSEL mode for example for a firmware upgrade. Only works when the HP41 is not running (HP41 PWO line is low) or no calculator is connected

poweron

Drives ISA for 20 microseconds to switch on the calculator. Works only when PWO is low. Driving ISA causes the HP41 to wakeup and execute the IO Service requests. If there is no active request the calculator will go to STANDBY mode again, this is typically not visible in the calculators' display. The tracer will show the instructions executed. This command is equivalent to pushing the button on a Wand for example, except there is no interrupt routine executed

calcreset

Drives PWO for 10 microseconds to halt the calculator. Works only when PWO is high. This will immediately halt all running code in the calculator, and can be used to recover from a mcode loop or other kind of lock-up. Test this by starting a CAT 3 for example and then type *system calcreset* in the CLI. The CAT listing will immediately halt. Back in the good old days this function was implemented in a small module device or as an addition to an MLDL. Very useful to recover from experimental mcode programming, it was therefore also known as a crash killer. Executing this command may upset the tracer as the synchronization may be lost.

configinit

Initialized the persistent system configuration in FRAM to its default values. Use only in case the configuration seems to be corrupted.

configlist

Shows the persistent system configuration. A bit cryptical, use only for support purposes.

clear

Clears the CLI console window, typically does not clear the complete scroll buffer. Use a command in your terminal emulator to do that.

**blink **

Blinks the LED on the Pico board. Blinks b times, when no value is given will blink 5 times. B must be between 1 and 9.

dir <subdir>

Shows a directory listing of the microSD card root directory or subdirectory (when given).

sdcard <parameter>

<without parameter>

Shows the uSD card status report and will mount the card

status

Shows the uSD card status report and will mount the card

mount

Mounts the uSD card and prepares for use. The uSD card is automatically mounted upon start of the TULIP. Use only when plugging a card in a powered system.

unmount

unmounts the uSD card and disables the use of it.

connect

enables use of the uSD card as a USB drive on the host computer when it has a valid USB connection to a host PC.

eject

disables the use of the uSD card as a USB drive from the host PC. The card is still available to the TULIP until unmounted. Use only after ejecting the TULIP drive on the host computer to prevent corruption of the card's filesystem.

plug <argument>

Plug a ROM image (virtually) in the HP41

<no argument>

Shows the ROM images plugged (only the images plugged by the TULIP).

status

Shows the ROM images plugged (only the images plugged by the TULIP).

hpil

plugs the HP-IL module in Page 7

ilprinter

plugs the HP-IL printer module in Page 6. Works only when the HP-IL module is plugged. The hP82143A printer module will be unplugged if it was plugged before.

printer

plugs the HP82134A printer module in Page 6, unplugs the HP-IL printer if it was plugged.

In the BETA software the ROM images are embedded in the firmware. No other virtual ROM images can be plugged in this version.

unplug <argument>

Removes a ROM image from the HP41 (only images plugged in the TULIP4041)

<no argument>

Shows the ROM images plugged

status

Shows the ROM images plugged (only the images plugged by the TULIP).

hpil

unplugs the HP-IL module, also unplugs the HP-IL Printer if it was plugged

ilprinter

unplugs the HP-IL printer module. Unlike the real HP-IL module, the HP-IL Printer ROM is not parked in Page 4 but is really unplugged, leaving Page 4 available for other fancy stuff

printer

unplugs the HP82134A printer module

printer <argument>

Controls the HP82143A printer emulation. When this ROM is not (virtually) plugged, most actions will be stored and become effective when the ROM is plugged. Most status settings (power, printmode and paper) are saved on powerdown.

<no argument>

Shows the printer status including the print mode and details of the status/control register

status

shows the printer status including the print mode and details of the status/control register

power

toggles the printer power mode. The printer must be ON for any printing operations. By default the printer is OFF (like the real one). Once switched on the printer will stay on

trace

puts the printer into TRACE mode, like moving the slider on the real printer

norm

puts the printer into NORMAL mode, like moving the slider on the real printer

man

puts the printer into MANUAL mode, like moving the slider on the real printer

paper

toggles the printer Out Of Paper status. Default is no paper, like in real life you must put paper in for the printer to work.

print

does a virtual push of the PRINT button. Prints X or ALPHA depending on the calculator mode, or enters PRINT (or PRA) in a program when in program mode.

adv

does a virtual push of the ADV button. Virtually advances paper in the connected simulator or enters ADV in a program when in program mode

xmem <argument>

Controls Extended Memory emulation. Without argument will show the current status(number of modules plugged). The Extended Functions (and its built in Memory) is not emulated. This must be physically plugged or available in the HP41CX. Do not use with an HP41CL, as it has its own Extended Memory emulation. Ensure to set the number of modules to 0 when using the HP41CL in combination with the TULIP4041.

<no argument>

shows the number of modules plugged (0, 1 or 2)

status

shows the number of modules plugged (0, 1 or 2)

dump

creates a listing of the Extended Memory contents. Only non-zero registers are shown. Use for your own interest and to verify the pattern for testing FRAM. The expected pattern for the FRAM test is below:

```
REG 200 = 0x4142414241424142
REG 201 = 0x4243424342434243
REG 202 = 0x4344434443444344
REG 203 = 0x4445444544454445
REG 204 = 0x4546454645464546
REG 205 = 0x4647464746474647
REG 206 = 0x4748474847484748
REG 207 = 0x4849484948494849
REG 208 = 0x494A494A494A494A
REG 209 = 0x4A4B4A4B4A4B4A4B
REG 20A = 0x4B4C4B4C4B4C4B4C
REG 20B = 0x4C4D4C4D4C4D4C4D
REG 20C = 0x4D4E4D4E4D4E4D4E
REG 20D = 0x4E4F4E4F4E4F4E4F
REG 20E = 0x4F504F504F504F50
```

0, 1 or 2

plugs the given number of Extended Memory modules. 0 will unplug any modules

PATTERN

fills the Extended Memory with a test pattern for testing the FRAM. Will overwrite any existing information, verify with *xmem dump*

ERASE

clears all emulated Extended Memory to 0's

tracer <argument>

Controls the HP41 bus tracer. Without argument will toggle tracer on/off. Commands may be given while the tracer is running. For more detailed information see the chapter about the HP41 Tracer. Pressing a key in the tracer window will toggle the tracer activity. Note that that will most likely lead to an overflow when resuming tracing again. Note that the tracer settings are not automatically saved, this must be done with the *tracer save* command. This is done to allow control of the tracer while the calculator is running, and a running calculator prevents access to FRAM, where the settings are saved.

<no argument>

shows tracer status

status

shows the tracer status

trace

toggle trace enable/disable

sysloop

toggle tracing of system loops:

0x0098 - 0x00A1	RSTKB and RST05
0x0177 - 0x0178	delay for debounce
0x089C - 0x089D	BLINK01
0x0E9A - 0x0E9E	NLT10 wait for key to NULL
0x0EC9 - 0x0ECE	NULTST NULL timer

These loops are regularly called for a delay or when waiting for a key time-out. When system loop tracing is disabled, the above address will be skipped in the trace output and will usually allow much longer traces without overflow

sysrom

toggle tracing of system ROMs in Pages 0 to 5. Useful when you are interested only in tracing your own ROM images

ilrom

toggle tracing of the HP-IL and Printer ROM in pages 6 and 7

hpil

toggle tracing of the HP-IL frames to the ILSCOPE virtual serial port

pilbox

toggle tracing of the PILBox serial frames to the ILSCOPE virtual serial port

ilregs

toggle tracing of the HP-IL frames and registers to the trace window. Disabling (if you are not interested in this) reduced the load on the tracer software

save

save the tracer settings in the FRAM persistent storage. This is done to allow control of the tracer while the calculator is running, and a running calculator prevents access to FRAM, where the settings are saved.

13. [Limitations](#)

The current version of the TULIP4041 firmware is VERSION 00.01.02

- HP-IL and HP-IL printer emulation with PILBox emulation
 - RFC and CMD frames are not processed in the same way as in the hardware PILBox. This has no functional impact, the ILSCOPE window in the virtual HP-IL device on the host will be slightly different with too many RFC frames

14. TULIP4041 Hardware: Development Board

The initial hardware for TULIP4041 is the TULIP-DevBoard, a development board for a commercial Pico module. On this board all signals are available on pins for testing and measurement. A separate module connector board is used for the physical interface to the HP41. There are some minor functional differences between the DevBoard and the module version. The DevBoard is intended to be assembled by the user. The DevBoard is designed for the original Raspberry Pico board. Please do not use the Pico-W board. Any other 100% pin-compatible alternative to the Pico (Pimorini for example) should work just fine but may require recompilation of the firmware to adjust for additional features (such as extra memory).

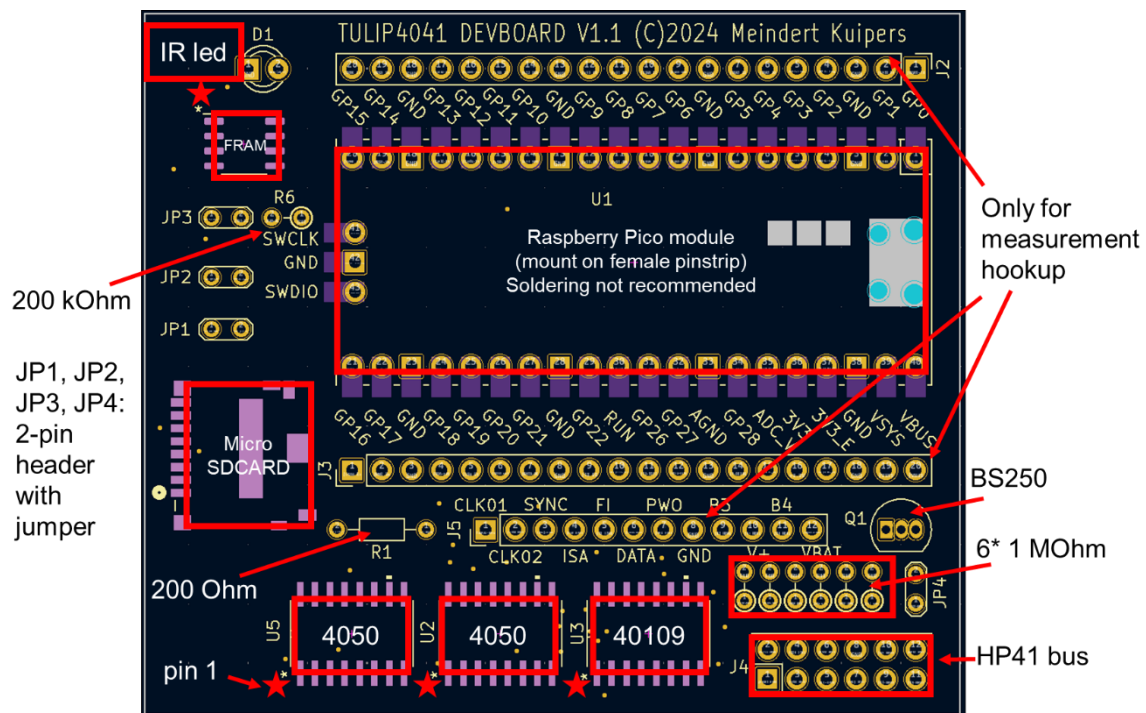
It is very well possible to solder the Pico board on the DevBoard, but this is not recommended. It is very hard to unsolder in case of a hardware failure or possible upgrade to another model. When ordering the female headers for the Pico board, ensure that the receptacles are large enough for the Pico pins. Typically turned receptacles may be too small.

The complete Bill Of Material (BOM) is available on the TULIP github pages.

Please follow the steps below in the given order. Do not connect with your precious calculator until instructed.

14.1. Assembling the DevBoard

The DevBoard requires some precise soldering. The figure below shows the position and orientation of the components, pin one is indicated with a red *. Best is to start with the smd components. The headers for probe or analyzer attachment are optional depending on your own preferences. Some of the connections here may be used for future expansions.



U5 is optional. This is a 4050 input level shifter and used only for the FI input tracing. If you do not want to trace FI this component can be left out, but it is highly recommended to keep this in.

To solder an SMD component, the way I do it (using a magnifier lamp):

- Apply a bit of solder on one of the edge pads
- Apply some flux on all pads
- Take the component and verify the value and orientation of pin 1
- Use tweezers to position the component, and solder the edge pad where you applied a bit of solder earlier. Correct the position where needed, such that all pins align with the respective pads
- Solder the pin on the opposite edge, verify the positioning and then solder all other pins
- Check the soldering of all pins with the magnifier

The IR led should be soldered with plenty of pin length above the PCB (about 10mm) and bent in a 90 degree angle away from the board.

Q1 is optional. Mount this if you want the DevBoard to be powered from the HP41. When USB is connected the Devboard is always powered from USB.

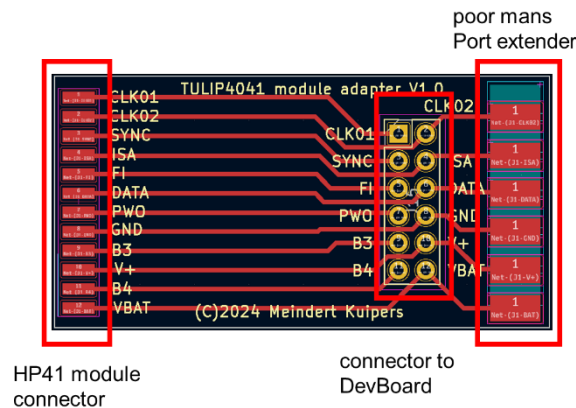
After soldering all components take some time to visually inspect all solder joints and verify the correct orientation before applying power.

Devboard connections:

J1	micro SD card holder
J2/J3	2* 20 pin header (optional) connections to all Pico pins for analyzer hookup or additional (future) expansions.
J4	2* 6 pin header, connection to the HP41 connector board (use a 12-pin flatcable or solder wires). Do not exaggerate the length of the cable, typically 20 cm will work just fine
J5	12 pin header (optional) connections to all HP41 signals for analyzer hookup
JP1	jumper to enable IR led output. When closed JP3 must be open and correct firmware settings must be observed
JP2	jumper to enable FI tracing (when U5 is mounted)
JP3	jumper to enable PWO output. When closed JP1 must be open and correct firmware settings must be observed. MUST BE OPEN WHEN USING THE HP82143 PRINTER EMULATION
JP4	jumper to enable powering the DevBoard from the HP41 BAT line. Only works if Q1 is fitted. Please re-read the section on power consumption
R2..R8	6* 1 MOhm weak pulldowns for stabilizing the HP41 input signals when no HP41 is connected
R1	is the current limiting resistor for the IR led. A value of 200-400 Ohm is just fine and will give you quite a range to reach your printer or IR receiver at a distance up to 50 cm. Use a low value for more range, but this consumes more power

HP41 ConnectorBoard connections:

- J1 2* 6 pin header, connection to the HP41 connector board (use a 12-pin flatcable or solder wires). The PCB has pads on both sides of the board and can be soldered on top of the connector as well, although this is not recommended.
- J2 HP41 module connector. Please be careful when positioning the connector to ensure proper connection with the HP41. Best is to place the PCB in bottom module case and then position and solder the connector. Keep the PCB with soldered connector in a module case to ensure proper alignment when plugging in the HP41 port.



The connector board has pads on the other end of the PCB to plug a physical module as a kind of poor mans port extender. These are not plated and not suited for a large number of cycles.

Connection between the ConnectorBoard and DevBoard can be done with individual soldered or plugged cables, or a flatcable with IDC headers. Cable length should be around 20 cm, longer may work but do not exaggerate.

14.2. [Prepare the micro SD card](#)

The BETA firmware version of the TULIP4041 does not use the SD card, but it will be in a next version of the firmware. There are functions to test the functionality and soldering of the SD card which are necessary.

Prepare a micro SD card formatted with the FAT file system on your host computer. Any size larger than 2 GByte will normally work fine. Create the following subdirectories in the root directory of the micro SD card (although it is not relevant yet)

- ROM, and put some .ROM files in here
- MOD, and add some .MOD files
- RAW, with some .RAW files
- And put some files in the root directory

Remove (in a safe way) the micro SD card from the host computer and plug it in the slot of the DevBoard.

14.3. [Getting the DevBoard up and running](#)

After visual inspection remove any jumpers, these will be used later. Do NOT connect with your calculator yet. First carefully seat the Pico board and verify if it is properly connected.

You may now connect the Pico board with your host computer using a USB cable. If the Pico board is new it does not have any firmware and will go straight into BOOTSEL mode. Otherwise disconnect from USB and put it into BOOTSEL mode by pushing the button on the Pico board while plugging the USB cable. It is also possible to use Picotool to enter BOOTSEL mode, please refer to the Pico documentation for more information.

With the USB cable plugged it makes sense to watch out for smoke or overheated components, although that is unlikely, but may depend on your soldering skills. If you have one it might be useful to use a USB power meter to check for excessive power consumption. Expected current should be under 40-50 mA.

Prepare your host computer with a terminal emulator and have the firmware file (with .uf2 extension) at hand. Keep the Pico connected with USB to your host PC. Do not connect your calculator yet.

Once the TULIP4041 firmware is loaded it is not possible to use Picotool for this. When the Pico is in BOOTSEL mode a USB disk drive is exposed to your host PC. Simply copy the firmware file (with extension .uf2) to this drive. The Pico will reset and start to run the TULIP4041 firmware. Your host PC may respond (if enabled) with sounds that new USB devices are connected.

Now verify if your system registers 5 new COM ports and a USB disk drive. The system may complain about a USB drive not being ready, that is fine.

Start the terminal emulator and connect with the TULIP4041 Command Line Interface (CLI). This is available on one of the new COM or ttyACM ports. Typically the CLI is on the lowest numbered (new) port, but this may differ between systems. The baud rate does not matter. When connected with the correct port the CLI will respond with a welcome message. Try multiple ports to find the CLI, and verify in the system settings of the host PC if all 5 COM ports are visible. When the CLI first connects it will immediately show the welcome message and prompt. You are now ready for the next steps to test the DevBoard and make it operational. The tests are intended to verify the soldering joints.

- **Initial situation**

The TULIP is connected with USB and the latest TULIP4041 firmware is loaded. The TULIP welcome message is shown in the terminal emulator connected to the CLI virtual serial port. The HP41 is NOT connected and NO jumpers are placed. Have a multimeter at hand. Your HP41 is near the test setup and has no modules plugged. The calculator may be an HP41C, -CV or -CX. It is possible to use an HP41CL if it is set to the lowest (original) speed and no (virtual) ROMs are plugged.

- **Find the USB Serial Ports**

To verify the COM port numbers of all serial ports open an instance of your favorite terminal emulator and connect to each USB virtual serial port you find. Do not worry about the baud rate. In the terminal with the CLI (the one with the TULIP welcome message) type the command: *system cdcident*. This will send an identification string to each port. Best make a note of the COM port number and function for later use.

- **SD card test**

Put the SD card in the slot on the DevBoard and type *sdcard status* in the CLI. This will give the SD characteristics and mount the card. Then type *dir* to get a listing of the files in the root directory, and *dir rom* to list the files in the ROM subdirectory.

Type *sdcard connect* to expose the uSD card filesystem to the host computer, and check if that is indeed the case.

- **FRAM test**

FRAM is tested with the functions for Extended Memory. No plugging of a virtual module is needed. The emulated Extended Memory will be erased with this operation! First type the command *xmem dump* in the CLI. This will produce a listing of the emulated Extended Memory contents. Only non-zero registers will be listed. Then type the command *xmem PATTERN*. This will program a test pattern in FRAM. Then type *xmem dump* again. If the registers show the test pattern then the FRAM is functioning correctly. The test pattern is a counting byte value in the bytes of FRAM, and will show as Extended Memory registers as follows:

```
REG 200 = 0x4142414241424142
REG 201 = 0x4243424342434243
REG 202 = 0x4344434443444344
REG 203 = 0x4445444544454445
REG 204 = 0x4546454645464546
REG 205 = 0x4647464746474647
REG 206 = 0x4748474847484748
REG 207 = 0x4849484948494849
REG 208 = 0x494A494A494A494A
REG 209 = 0x4A4B4A4B4A4B4A4B
REG 20A = 0x4B4C4B4C4B4C4B4C
REG 20B = 0x4C4D4C4D4C4D4C4D
REG 20C = 0x4D4E4D4E4D4E4D4E
REG 20D = 0x4E4F4E4F4E4F4E4F
REG 20E = 0x4F504F504F504F50
```

Now type *xmem ERASE* and then *xmem dump*. You should see no registers (the dump function only shows non-zero registers).

- **Configuration test**

FRAM contains the persistent configuration settings and these should now be initialized. Type the command *system configlist*. Item #92 must contain the value 4041 (Global settings initialized). The other values are the default settings

This concludes the first part of the test. In case of problems do the following:

- Visually inspect the DevBoard if all components are placed correctly, on the right place and with the correct orientation. Pin 1 is indicated with a * on the PCB silkscreen, and with a dot on the component itself
- Visually inspect all soldering joints (with magnifiers) of the FRAM and micro SD card holder for good soldering contacts and make certain that there are no shorts between component pins
- Check if the Pico board is properly seated and if all solder joints of the Pico connector are good. The TULIP firmware will run even when it is not plugged on the DevBoard.

You may now connect your calculator. Unpower the DevBoard (disconnect USB) and remove all physical modules from the calculator. Connect the DevBoard and ConnectorBoard with a 1-1 cable or individual wires. The B3 and B4 signals are not used and it does not matter which port is used. The calculator should have its own power source. Put the ConnectorBoard in an empty module shell for proper alignment with the HP41 module port.

Best practice is to first connect the DevBoard with USB, and then insert the module in the calculator.

- **Power test and initial connection**

Apart from the terminal emulator with the CLI also start an instance of the terminal emulator and connect it with the tracer virtual serial port (verify that with the *system cdcident* command).

Switch your calculator on and verify if it is still working correctly with the TULIP4041 connected. When the HP41 is running the LED on the Pico board will be briefly on. The window with the tracer connected should now show the activity from the calculator. Tracing should be enabled by default, otherwise enable the tracer with the *tracer trace* command. Pressing a key in the tracer windows also toggles the operation of the tracer.

Switch the calculator off.

Use a multimeter to verify the voltages on the HP41 BAT and V+ on the pins or pads at J5. These should both be around 6V, when the calculator is off V+ will be a bit lower.

- **HP41 interface test**

Switch the calculator on again and verify that there is activity in the tracer. This means that the input to the tracer from the HP41 is working. With the calculator off you can now close the jumper JP2, but only if you have U5 (the additional 4050 level shifter) mounted. This will allow you to trace the FI signal. If you U5 is not mounted then leave JP2 open. You will only see activity on the FI line when a relevant peripheral is connected, the FI signal should normally show only dashes.

In the CLI type the command *plug hpil*. This will plug the HP-IL module (but not yet the HP-IL printer ROM). Now switch the calculator on. In the trace windows you should see activity, and occasionally the FI lines in use. Do a CAT 2 on the calculator to verify that the HP-IL module is now plugged.

In the HP41 you can now key in the DIR command. This should return with the message NO DRIVE. If this does not happen first do a reboot of the TULIP system by typing the command **system REBOOT**, and try again. In this case you can skip plugging the HP-IL module, as this will remain plugged.

When successful you have now verified the connections of the level shifters. There are now 2 more tests for the connections.

First we will test the ISA power on feature. Make certain that your calculator is not running. It may be powered off or in standby mode. Also have the tracer windows standby and keep an eye on it. In the CLI give the command *system poweron*, and you should see activity in the tracer (but no activity on the calculator).

Now close jumper JP3 and open jumper JP1. We will now drive PWO low while the calculator is running, and this act like a hard emergency stop for the HP41. Enter a program with an endless loop and start it, or start a CAT 3 on the HP41. While the calculator is running give the CLI command *system calcreset*, and verify that the calculators halts and the tracer also stops (after the trace buffer is emptied).

- **IR Led test**

Final test is for the infrared LED. For this you will need an IR to USB serial receiver and align with the IR LED on the DevBoard. Connect this to your host computer and start the HP82240 simulator in HP82134 mode (Windows only). On a no-Windows system best is to connect a terminal emulator. Ensure that jumper 1 is closed and jumper 3 is open.

The TULIP IR printing currently does not work with a real HP82240 printer.

In the CLI type *plug printer* to plug the HP82143 Rom image and enable the emulation. Then do the following:

- Type *printer*, verify the status
- Type *printer power* if the printer was powered off
- Type *printer paper* if it was out of paper
- On the calculator key CAT 2 to verify of the printer ROM is plugged
- In the TULIP CLI key *printer trace* and run a CAT 2 again. You should see the catalog listing in the printer simulator, or a catalog listing with some control characters in a terminal emulator
- If you do not have the IR receiver, start a long printing operation, like PRP PRPLOT. Point your mobile phone camera straight into the IR LED and you should see a faint blue glow that stops when the printing is done

You have now tested all functions and soldering of the DevBoard. Congratulations!

15. [References](#)

References to follow.

All firmware files, documentation and schematics are available at my GitHub pages:

<https://github.com/mjakuipers/TULIP-DevBoard>

Reference	URL	Description

16. [Change log](#)

Version

00.01.01	June 2024	Initial version for beta release
00.01.02	September 2024	Edited and expanded for first public release
00.01.03	September 2024	Preparing for change to RP2350/Pico2 and first public PCB's